Water Use of Crops and Nutritional Water Productivity for Food Production, Nutrition and Health in Rural Communities in KwaZulu-Natal

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Supplementary information related to this report has been included in a separate document.

EXECUTIVE SUMMARY

The role of water in achieving food and nutrition security for improved nutrition and human health cannot be understated. Water is essential for food and nutrition security through its linkages with all aspects related to economic access to food. Any discussion on food and nutrition security is incomplete without first establishing the linkages with water. Thus, there is a need to link the concept of 'more crop per drop' with aspects of nutritional value. This could provide a holistic approach to linking water, agriculture and nutrition with improving human health. This report builds on previous research aimed at highlighting and strengthening the linkages between water, agriculture, nutrition and human health, with a particular focus on poor rural households. This is done by placing emphasis on the use of nutritional water productivity as a suitable index for assessing the contribution of water use and agriculture to food and nutrition security. The focus on underutilised crops, as an alternative to major, mainstream crops, is meant to address the need for dietary diversity in poor rural communities.

At inception, a global review of the literature was undertaken to establish the linkages between agriculture (a proxy for food), water, nutrition and human health, with focus on poor rural households. The review took a global approach as it sought to establish the global relevance of the study and establish opportunities for the project outcomes to also inform a wider audience. The review noted that, while there had been some progress in addressing food security driven by increased crop productivity, these gains were not linked to nutrition security. There was a disjoint between improving crop productivity, the choice of crops and addressing gaps in nutrition. As a result, most of the poor rural households still suffered high levels of nutrition insecurity and malnutrition. This was associated with, in part, a chronic lack of dietary diversity and access to nutrient dense foods. Such increasing malnutrition, if left unchecked, could reinforce a vicious cycle of poverty among poor rural communities. Importantly, the review confirmed the project hypothesis that there was a need for a paradigm shift in how agriculture interventions were designed and implemented, such that the interventions were more closely linked to water, nutrition and human health outcomes. However, achieving this calls for more transdisciplinary type approaches which focus on the broader food system rather than just specific food value chains, which tend to be linear.

Following from the global review, we undertook a qualitative systematic approach to conduct an environmental scan and review of the literature of studies conducted in South Africa, specifically within the study population of KwaZulu-Natal. This complemented the initial review, but with greater focus on the study population. The systematic analysis confirmed that the major constraints to achieving food and nutrition security as well as human health and well-being within poor rural households of KwaZulu-Natal was a very limited availability and access to nutritious, diverse and balanced diets. Consequently, both under- and over-nutrition, in particular, stunting, continued to affect children under 5 years of age. In addition, there was a high prevalence of over-nutrition, both overweight and obesity, among black African females. Low incomes limit poor rural households' access to a healthy diet. However, given that most of these households have access to farming land, agriculture could be used to improve both availability and access to diverse and nutritious foods, leading to improved human health and well-being of the poor rural households. Such interventions should pay attention to the fact that water remains scarce in these rural areas. As such, the adoption and wider use of traditional vegetable crops and pulses could improve availability and access to healthy and locally available alternative food sources. The promotion of household and community food gardens, and the use of nutrient dense crops with low levels of water use, i.e. high nutritional water productivity, were then identified as options for addressing food and nutrition insecurity in poor rural areas.

From the review of the relevant literature, it emerged that detailed studies of dietary intake of defined population groups living in specific areas of KZN had not been conducted. To address this shortcoming, a follow-up study aimed at assessing the nutritional status of four selected rural communities in KZN, using selected anthropometric indices and dietary assessment methods was conducted. The results of the study confirmed that under- and over-nutrition co-existed in the studied black African rural communities of KZN. Stunting was prevalent among children under 5 years, whilst obesity also affected children under 5 years and adults, especially females aged 16-35 years. There was frequent consumption of food items high in carbohydrates (mainly the cereal grain foods), and low in micronutrients and fibre. The findings indicated that a nutrition transition had influenced the nutritional status of the rural KZN population groups investigated. Similar to the findings of the literature review described above, the trends of gaps and weak designs of past agriculture interventions observed during the investigation were observed. Based on the literature reviews, the project team undertook to focus on grain legumes as alternative crops. The choice of these crops was informed by review of previous studies documented in the literature as well as awareness of ongoing research, which focussed on cereal and leafy vegetable crops. Thus, in order to not duplicate what was being done elsewhere, the project focussed on legumes and selected provitamin A (PVA)-biofortified crops, such as orange-fleshed sweet potato and PVA-biofortified maize.

With regard to the measurement of water use and water productivity (WP) of the selected crops, it was hypothesised that nutrient content and nutritional water productivity (NWP) of crops would vary with varying water availability and across environments. The use of multiple environments was meant to assess the suitability of various bioclimatic regions of KZN for growing the different study crops. The aim of the study was, therefore, to determine water use, WP and NWP of selected alternative indigenous grain legumes [bambara groundnut (*Vigna subterranea*) and cowpea (*Vigna unguiculata*)] and conventional grain legumes [groundnut (*Arachis hypogaea*) and dry bean (*Phaseolus vulgaris*)], in response to production environment. The specific objectives were to determine water use, WP and NWP of selected African indigenous (bambara groundnut and cowpea) and major grain legumes (groundnut and dry bean) in response to (i) water regimes and (ii) environments. Results highlighted the role of legumes in increasing dietary diversity as they can complement cereals and vegetables in diets to meet the nutrient requirements for a healthy life. Water regimes did not have a significant effect on NWP, implying that there is scope for legumes to contribute to food and nutrition security under rainfed conditions.

Following from the field studies, a major part of the project was to model the water use and WP of the selected crops. The AquaCrop model, which has been widely used for such studies, as well as for alternative crops, was selected for this study. The modelling stage of the study focused on the groundnut and dry beans as bambara groundnut has been previously modelled in another project, while cowpea was the subject of a separate ongoing study. Therefore, the aim of the study was to calibrate and test the performance of the AquaCrop model for groundnut and dry bean under varying water regimes and sub-environments within the larger semi- and arid environments, respectively. The specific objectives were to (i) calibrate AquaCrop for groundnut and dry bean, (ii) evaluate its ability to simulate canopy cover (CC), biomass, yield and evapotranspiration (ET) of groundnut and dry bean for varying soils and climates. Overall, the model showed potential for simulating yield and ET of groundnut and dry bean under semi-arid conditions.

A major value advantage of developing models is their importance in addressing hypothetical "*what if, when, where and how*" type of questions. This can save both time and costs associated with conducting lengthy multilocational field studies. The AquaCrop model was therefore applied to evaluate the effect of management practices on yield (*Y)* and water productivity (WP_{ET}) for groundnut and bambara groundnut. This would aid in developing best management practices for increased *Y* and WP of groundnut and bambara groundnut under different environments. Management scenarios focused on practices such as (i) planting dates, (ii) irrigation, and (iii) soil water conservation as being key for improving productivity of smallholder farmers. Based on this, a total of 6 scenarios were evaluated using AquaCrop to develop best management practices. Notably, this exercise confirmed that crop diversification remains a viable option as the study showed that bambara groundnut had a lower risk of crop failure, compared to groundnut, under the various scenarios considered.

The second phase of the project focused mainly on linking the crops to the plate, i.e. addressing food intake. Previous studies and the review of the literature confirmed that vitamin A deficiency (VAD) remained problematic in KZN, and South Africa as a whole. The orange-fleshed sweet potato (OFSP) and PVA-biofortified maize were, therefore, identified as suitable crop-based alternatives for addressing VAD. Pursuant to that, a study was then conducted to determine the effect of replacing non-biofortified white maize and cream-fleshed sweet potato (CFSP) with PVA-biofortified maize and OFSP on the nutritional composition of popular traditional foods consumed locally in KZN. The food products studied were *phutu*[1] prepared with white maize meal and PVA-biofortified maize meal, served with curried[2] chicken, cabbage or bambara groundnut and boiled sweet potato[3] (CFSP and OFSP). The *phutu* combinations were selected based on a survey conducted in four selected rural study sites in KZN to determine popular dishes in which maize was combined with other food items. The results of the study showed that PVA-biofortified *phutu*, when combined with other foods, such as curried cabbage, chicken or bambara groundnut as well as OFSP, have the potential to improve nutrient intake and dietary diversity of rural population groups in KZN and other rural areas of South Africa. This confirmed the recommendations from the initial reviews conducted.

Subsequent to that, and having established the positive benefits of PVA-biofortified maize and OFSP, a separate study then investigated the effect of replacing white maize and CFSP with PVA-biofortified maize and OFSP, respectively, on consumer acceptability and perceptions of traditional dishes among selected rural communities in KZN. The results of the study were encouraging as the foods investigated were acceptable to and positively perceived by the majority of the study participants.

Malnutrition, in all its forms, in the communities used in this study, was mainly associated with a lack of dietary diversity and limited access to and non-availability of nutrient dense foods. Under these circumstances, agriculture offers an opportunity to address the availability and accessibility of diverse nutrient-dense foods in poor rural communities. Alternative crops have the potential to provide nutrient dense options; however, they still lack improvement and often produce yields that are lower than those of conventional crops, making them unattractive. This study was a first to benchmark NP and NWP of conventional grain legumes to alternative

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[1] Maize meal cooked into a crumbly porridge.
[2] A curry was selected as the preparation method as it was reported by study participants as the most common way in which the food items were prepared.
[3] Prepared using the boiling method.

grain legumes under similar conditions. Crop improvement should target improving the yield and sensory attributes of these crops.

Despite several interventions targeted at alleviating household food and nutritional insecurity, poor rural households still suffer unacceptable levels of malnutrition. This is mostly associated with a lack of dietary diversity and limited access to and non-availability of nutrient-dense foods. Also, the lack of clear linkages between food, nutrition and health outcomes limits the impact of interventions. Therefore, future research should focus on: (i) adopting a food systems approach, which links agriculture, the environment and health, (ii) investigating the potential of promoting underutilised crops as nutrient dense alternatives, (iii) the role of indigenous fruit trees in agroecology and income generation initiatives should be considered, (iv) developing metrics such as the NWP that help the assessment of the water-food-nutrition-health nexus, and (v) building education and awareness among consumers on healthy dietary habits. Finally, transdisciplinary approaches that straddle the science-policy interface should be promoted in such research in order to inform policy and decision makers.

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- The students at MSc and PhD levels registered at the University of KwaZulu-Natal who worked on various aspects of the project (***cf***. Appendix 1).
- The administration, technical and field support staff at the University of KwaZulu-Natal who supported the project.

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LIST OF ACRONYMS AND ABBREVIATIONS

AI	Adequate Intake
ALASA	Agricultural Laboratory Association of Southern Africa
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
BMI	Body Mass Index
CC	Canopy cover
CCI	Chlorophyll content index
CFSP	Cream-fleshed sweet potato
CIP	International Potato Centre
CVD	Cardiovascular disease
DAP	Days after Planting
DAFF	Department of Agriculture, Forestry and Fisheries
DoH	Department of Health
EAR	Estimated Average Requirement
FAO	Food and Agriculture Organisation
FGDs	Focus group discussions
FHE	Fountain Hill Estate
GDD	Growing degree-days
HCLC	Hierarchical clustering linear combination
HFA	Height-for-age
HI	Harvest index
HIV	Human Immunodeficiency Virus
HPLC	High-performance liquid chromatography
HST	Health Systems Trust
IMAM	Integrated Management of Acute Malnutrition
KZN	KwaZulu-Natal
LAI	Leaf Area Index
LSD	Least significant difference
MAM	Moderate Acute Malnutrition
MRC	Medical Research Council
MUAC	Mid-upper arm circumference
NAM	Not at risk of Malnutrition
NAMC	National Agricultural Marketing Council

NDF	Neutral detergent fibre
nDoH	National Department of Health
NFCS	National Food Consumption Survey
NFCS-FB	National Food Consumption Survey: Fortification Baseline
OFSP	Orange-fleshed sweet potato
PEM	Protein energy malnutrition
PVA	Provitamin A
RAE	Retinol activity equivalents
RDA	Recommended Dietary Allowance
rDNA	Recombinant deoxyribonucleic acid technology
RMSE	Root mean square error
RSA	Republic of South Africa
RUE	Radiation use efficiency
SA	South Africa
SADHS	South African Demographic and Health Survey
SAM	Severe Acute Malnutrition
SAMRC	South African Medical Research Council
SAVACG	South African Vitamin A Consultative Group
SC	Stomatal Conductance
SD	Standard deviation
SPSS	Statistical Package for Social Sciences
SSA	Sub-Saharan Africa
StatsSA	Statistics South Africa
SWC	Soil water content
UKZN	University of KwaZulu-Natal
UL	Tolerable Upper Intake Level
UNICEF	United Nations Children's Fund
UPLC	Ultra performance liquid chromatography
VAD	Vitamin A deficiency
WAP	Weeks after Planting
WFA	Weight-for-age
WFH	Weight-for-height
WFP	World Food Programme
WHO	World Health Organisation
WRC	Water Research Commission

LIST OF SYMBOLS

Roman (upper)

B	Final biomass (kg)
BD	Bulk density (g cm^{-3})
D	Drainage below the bottom of the root zone (mm)
Es	Soil evaporation (mm)
ET	Actual evapotranspiration or total evaporation (mm or m^{-3})
ET_a	Actual evapotranspiration (mm)
ET_c	Crop water requirement (mm)
ET_o	Reference crop evaporation (mm d^{-1} or mm h^{-1})
FC	Field capacity (m m^{-1} or vol %)
HI	Harvest index
I	Irrigation (mm)
K_c	Crop coefficient for standard (i.e. non-stressed) conditions
K_{c_adj}	Adjusted crop coefficient for stressed conditions
K_{sat}	Saturated hydraulic conductivity (mm h^{-1} or mm day^{-1})
P	Precipitation or rainfall (mm)
PWP	Permanent wilting point (m m^{-1} or vol %)
R	Runoff (mm)
RH	Relative humidity (%)
R_n	Net irradiance (W m^{-2} or MJ m^{-2} d^{-1})
SAT	Saturation (m m^{-1} (or vol %)
TAW	Total available water (m m^{-1} or vol %)
T	Air temperature (°C)
T_{ave}	Daily averaged air temperature (°C)
T_{bse}	Base temperature (°C)
T_{max}	Daily maximum air temperature (°C)
T_{min}	Daily minimum air temperature (°C)
T_{upp}	Cut-off temperature (°C)
WUE	Water use efficiency (kg mm^{-1} or kg m^{-3})
WP	Water productivity (kg m^{-3})
Y	Crop yield (kg or t ha^{-1} or kg ha^{-1})

Greek

ΔSWC	Change in soil water storage (mm)
θ_g	Gravimetric water content (g g^{-1} or %)
θ_v	Volumetric water content (cm^3 cm^{-3} or m^3 m^{-3} or m m^{-1})

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CHAPTER 1

WATER USE OF CROPS AND NUTRITIONAL WATER PRODUCTIVITY FOR FOOD PRODUCTION, NUTRITION AND HEALTH IN RURAL COMMUNITIES IN KWAZULU-NATAL: AN OVERVIEW

T Mabhaudhi and AT Modi

1.1 Background and Conceptualisation

"Food and nutrition security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Over the past decades, issues of food and nutrition security have taken centre stage in defining the development agenda in sub-Saharan Africa (SSA) and other developing regions. Significant funding has been channelled towards fighting food and nutrition insecurity. Although considerable progress has been made towards combating food and nutrition insecurity on a global scale (FAO-IFAD-WFP, 2013), the same cannot be said for much of SSA. The region still has the highest prevalence of undernutrition (FAO-IFAD-WFP, 2013). Recent reports have pegged the prevalence of undernutrition in SSA at 23.8% (FAO-IFAD-WFP, 2014). In addition, most SSA countries are still characterised as food and nutrition insecure (FAO-IFAD-WFP, 2014). Therefore, despite achievements realised over the period under review, food and nutrition security remain elusive (Chivenge et al., 2015).

The roles that water and agriculture have to play in delivering food and nutrition security goals cannot be overstated. This realisation has stimulated discussions around the water-food nexus. Within the context of SSA it is important to note that 70% of the population relies on agriculture (Livingston et al., 2011), either directly or indirectly, and that 95% of this agriculture is primarily rainfed (Singh et al., 2011). Poor rural households rely on rainfed agriculture as the primary source of their food and nutrition. This highlights the linkage between water use in agriculture and food and nutrition security and explains why agriculture remains the main vehicle for addressing food and nutrition security in poor rural households. Approaches used in the past have mainly focused on increasing food production and water productivity. This has resulted in nutrition security playing second fiddle to food production. Given that nutrition security is the basis upon which human health and well-being are built (IFPRI, 2014), it would be grossly unwise and not prudent to continue paying lip service to nutrition, especially as we move into the post-2015 era of Sustainable Development Goals (SDGs) replacing the Millennium Development Goals (MDGs) (Sachs, 2012).

Although South Africa is food secure at the national level, it experiences household food insecurity (De Klerk et al., 2004). Earlier reports suggested that rural and peri-urban South African households faced food and nutrition insecurity, with about 14 million people residing in these areas facing malnutrition (De Klerk et al., 2004). A decade later, recent reports (Oxfam, 2014) have also confirmed these observations. This highlights that while several government programmes have been implemented over the past decade, food and nutrition security still remain a poignant challenge. There is a need to improve agriculture in rural areas so that people are empowered to produce enough food, broaden their existing food basket and improve supply and access to nutritious foods; a concept that has been linked to food sovereignty.

There is a need for a paradigm shift in order to effectively deliver on the twin challenges of food and nutrition security. Part of this means re-thinking the indices that have been used by researchers and development agencies in assessing food and nutrition goals and assessing their impacts on human health. Previous studies have focussed separately on either crop production (food availability) or food access or nutrition (Sachs, 2012). Thus, food production, nutrition and human health have been addressed separately using different indices, with the balance tilting in favour of food production. In order to meaningfully address food and nutrition security, there is a need for indices that combine aspects of production, access and nutrition. This could also encourage multidisciplinary research between agricultural scientists, nutritionists and dieticians, considering available agribusiness data. In doing so, recommendations can be generated that empower rural farmers so that they get the most (biomass and nutrition) per unit drop of water used – nutritional water productivity (NWP) (Renault and Wallender, 2000). The potential for such approaches was highlighted by Wenhold et al. (2012) in their report on water use and nutrient content. The scoping study by Wenhold et al. (2012) made significant progress in establishing a baseline for future studies on NWP of crops.

This review builds on previous work (Wenhold et al., 2012) and aims to highlight the linkages between water, agriculture, nutrition and human health. This is done by placing emphasis on the use of NWP as a suitable index for assessing the contribution of water use and agriculture to food and nutrition security. The focus on crops alternative to major crops, is meant to address the need for dietary diversity in poor rural communities. The review introduces the water-food-nutrition-health nexus as a way of planning agriculture-based strategies for improving human nutrition and health in poor rural households.

1.2 Objectives

The contractually specified objectives of the project were:

1.2.1 General objective

To determine water use and nutritional water productivity for improved production, nutrition and health in poor rural communities.

1.2.2 Specific objectives

i. To review and update available knowledge on water use and nutritional water productivity, food intake, food sources and nutrition of food consumed in poor rural communities;

ii. To identify food intake and sources of food in poor rural households;

iii. To identify the reasons behind choices of food intake in poor rural households and nutritional evaluation of food intake;

iv. To determine nutrient content (nutritional value) of currently used crops and alternative crops;

v. To measure water use and nutritional water productivity of currently used crops as well as new crops to be introduced;

vi. To perform crop yield modelling and nutritional water productivity of the range of crops; and

vii. To formulate best management practices for maximising water use and nutritional value for current crop choices and new crops.

1.3 Scope of the Report

For the purposes of the current project, we have defined conventional and alternative crops as follows:

- Conventional crops: these are commonly referred to as major or staple crops and generally include those crops that have been the subject of significant research, development and innovation and now occupy larger production areas. Examples include maize, wheat, rice, dry beans, groundnuts, spinach, etc.

- Alternative crops: these are commonly referred to as underutilised crops and are crops that have not been previously classified as major crops, have previously been under-researched, currently occupy low levels of utilisation and are mainly confined to smallholder farming areas. Such crops may have the potential to contribute to food and nutrition security of poor rural households and may be suited to the marginal production environments that typify most rural areas. Examples of such crops include, but are not limited to, cereals (sorghum, teff and millets), legumes (bambara groundnut, cowpea, lablab), root and tuber crops (taro, orange-fleshed sweet potatoes) and traditional leafy vegetables (amaranth, wild mustard, cleome).

For the current study, the focus has been on conventional (dry beans and groundnuts) and alternative legumes (bambara groundnut and cowpeas), with some limited focus on sorghum, which derives from WRC K5/2274//4, and orange-fleshed sweet potatoes for VAD. The focus on traditional leafy vegetables has been covered in a separate and recently completed WRC project WRC K5/2171/1/16. The studies were conducted in KwaZulu-Natal Province, uMgungundlovu District Municipality in Swayimane which is located in Ward 8 of uMshwati Local Municipality (Figure 1.1)

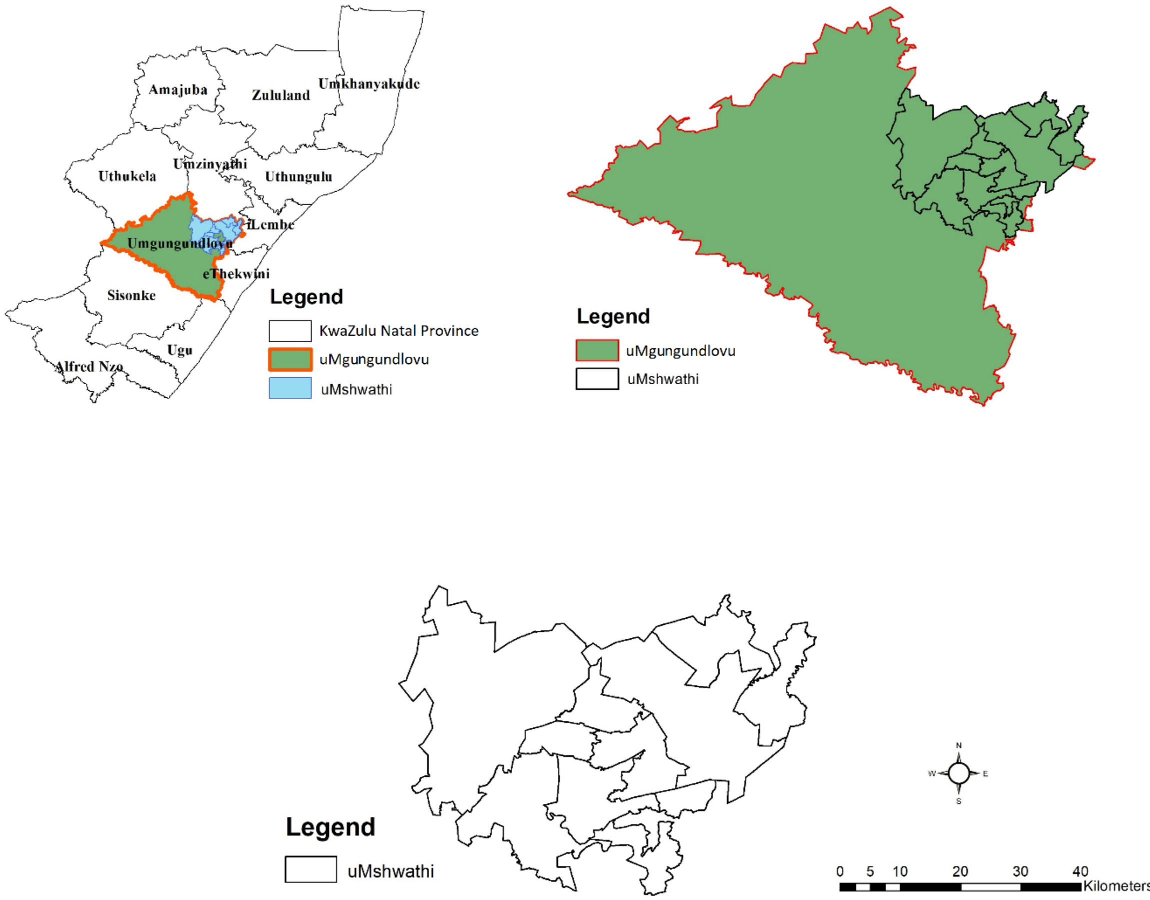

Figure 1.1: Maps of the study area in relation to where it is located within the Province, District Municipality and Local Municipality

The report is written in a series of self-contained chapters, with different authors. Each Chapter addresses at least one of the specific objectives of the project, as set out in the terms of reference. Due to the paper format that has been used, the report does not have a general methodology section; each Chapter has its own specific methodology. In some cases, this may have inadvertently created cases of minor repetition, especially in the methodology section.

The report is structured to address the project objectives of the study in a logical framework. Chapters 1-3 address the first objective related to conducting literature reviews. Chapters 4-7 report on field trials conducted to quantify water use of indigenous cereal and legume food crops as sole crops and intercrops; these address the second objective of the study. Chapters 8 and 9 address the third objective related to modelling water use of indigenous cereal and legume food crops. Lastly, Chapters 10 and 11 address both objective three and four on agronomic management and developing best practice recommendations. A general overview of the report is provided below:

Chapter 1: provides a general introduction, background and conceptualisation of the entire study. It provides a motivation for the broad study as set out in the terms of reference. It also sets out the project's aims and specific objects as defined in the contract.

Chapter 2: provides a literature review on food sources, reasons for food choices and linking water to nutrition and human health. The chapter takes a broader and more holistic view to give a global perspective to the problem, highlighting commonalities with South Africa. The chapter addresses specific objective 1 of the project. It also addresses specific objectives 2 and 3 related to food intake and sources of food in poor rural households, and reasons behind choices of food intake in poor rural households and nutritional evaluation of food intake

Chapter 3: provides a more in-depth analysis of food and nutrition security within the study population, which is KwaZulu-Natal, again, showing similarities to the national, regional and global perspectives. It also addresses specific objectives 2 and 3 related to food intake and sources of food in poor rural households, and reasons behind choices of food intake in poor rural households and nutritional evaluation of food intake.

Chapter 4: reports on results of an analyses of food intake and nutritional status of the identified population groups within the selected study populations of KwaZulu-Natal. It also addresses specific objective 2 on food intake and sources of food in poor rural households.

Chapter 5: this follows from the gaps identified in Chapters 2, 3 and 4, and the proposals contained therein. The preceding chapters highlighted the need for a crop-based approach or intervention, where the choice of crop is linked to addressing identified gaps in nutrition. This chapter reports on results of water use and nutritional water productivity of the range of identified crops and addresses specific objectives 4 and 5 of the project.

Chapter 6: reports on results of modelling yield and water use for the range of crops identified and addresses specific objective 6 of the study related to modelling yield and water use of the range of identified crops.

Chapter 7: based on crop model application, report on the development of best management practices for the range of identified crops. This chapter addresses specific objective 7 of the study.

Chapter 8: reports on the use of composite dishes featuring PVA-biofortified maize and orange-fleshed sweet potato as well as bambara groundnut as alternative food sources for addressing identified gaps in nutrition.

Chapter 9: explores further the consumer perceptions and acceptability of food products prepared using the identified alternative crops.

Chapter 10: provides a holistic discussion of the entire project and links all the separate studies to achieving the project objectives. The chapter also provides the conclusion and recommendations for future studies.

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CHAPTER 2

WATER-FOOD-NUTRITION-HEALTH NEXUS: LINKING WATER TO IMPROVING FOOD, NUTRITION AND HEALTH IN SUB-SAHARAN AFRICA

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2.1 Introduction

"Food and nutrition security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Over the past decades, issues of food and nutrition security have taken centre stage in defining the development agenda in sub-Saharan Africa (SSA) and other developing regions. Significant funding has been channelled towards fighting food and nutrition insecurity. Although considerable progress has been made towards combating food and nutrition insecurity on a global scale (FAO et al., 2013), the same cannot be said for SSA. At 23.8% (FAO et al., 2018), the region still has the highest prevalence of undernutrition in its population (FAO et al., 2018). Most countries in SSA are still characterised as food and nutrition insecure (FAO et al., 2013). Therefore, despite achievements realised over the period under review, food and nutrition security remain a major challenge (Chivenge et al., 2015).

Water for agriculture and crop productivity play a significant role in delivering food and nutrition security goals (Chivenge et al., 2015) This realisation has stimulated discussions around the water-food nexus. Within the context of SSA, it is important to note that 70% of the population relies on agriculture (Livingston et al., 2011a), either directly or indirectly, and that 95% of this agriculture is primarily rainfed (Singh et al., 2011). This highlights the linkage between water use in agriculture and food and nutrition security and explains why agriculture remains the main vehicle for addressing food and nutrition security in poor rural households. Approaches to dealing with poverty and hunger in SSA have hitherto mainly focused on food production under water scarce conditions (Singh et al., 2011). While this approach indirectly allowed for nutrition security to be addressed, it was not adequate, because agriculture and nutrition research was conducted in isolation. Given that nutrition security is the basis upon which human health and well-being are built (Rosegrant et al., 2014), it is important to design a transdisciplinary approach with scientific and social credibility, especially as we move into the post-2015 era of Sustainable Development Goals (SDGs) (Sachs, 2012). Such multifunctional agricultural systems have been reported to have had more success in delivering on nutrition, health and income goals (Leakey, 2012).

There is a need for a paradigm shift in order to effectively deliver on the twin challenges of food and nutrition security. Part of this means re-thinking the indices that have been used by researchers and development agencies in assessing food and nutrition goals and assessing their impacts on human health. Previous studies have focussed separately on either crop production (food availability) or food access or nutrition (Sachs, 2012). Thus, food production, nutrition and human health have been addressed separately using different indices, with the balance tilting in favour of food production. In order to meaningfully address food and nutrition security, there is a need for indices that combine aspects of production, access and nutrition. This could also encourage transdisciplinary research between agricultural scientists, nutritionists and dieticians. In doing so, recommendations can be generated that empower rural farmers so that they get the most (biomass and nutrition) per unit drop of water used – nutritional water productivity (NWP) (Renault and Wallender, 2000). According to Renault and Wallender (2000), NWP, defined as nutritional value per unit of water, offers more meaning in linking crop water productivity, and food production to malnutrition and poverty. The potential for application for NWP was highlighted by Wenhold et al. (2012) and Nyathi et al. (2016) in their report on water use and nutrient content. These WRC studies (Project No. 2171/1/16 and report No. TT 537/12, respectively) made significant progress in establishing a baseline for future studies on NWP of crops (Wenhold et al., 2012).

The review introduces the water-food-nutrition-health nexus as a way of planning agriculture based strategies for improving human nutrition and health in poor rural households. It hypothesizes that water, agriculture, nutrition and human health are intricately linked to each other – a nexus. In addition, it suggests that such linkages should be made explicit in planning agricultural interventions aimed at improving food and nutrition security and human health among the poor. Furthermore, recognition of these linkages entails transdisciplinary research. Such transdisciplinary research needs to be supported by the development of appropriate metrics that can articulate components of the linkage. In this regard, the review suggests the use of NWP as a suitable index for assessing the contribution of water use and agriculture to food and nutrition security as a starting point. The focus on neglected and underutilised crop species (NUCS), as an alternative to major crops, is meant to address the need for dietary diversity in poor rural communities. Within the scope of this review, NUCS are defined as those crops that have not been previously categorized as major crops, are currently under-researched or have not been the subject of major research projects, have low levels of utilisation and are mainly confined to niche agroecological areas (Chivenge et al., 2015).

2.2 Water

The role of water in achieving food and nutrition security for improved nutrition and human health cannot be understated. Water is essential to food and nutrition security through its linkages with all aspects related to economic access to food (HLPE, 2015). While the role of water in the provision of food and nutrition transcends many sectors, this review focusses primarily on the linkages between water and agriculture. Sufficient and quality water is critical for agricultural production (HLPE, 2015) and achieving food and nutrition security. Options for increasing agricultural production to meet the growing food demand include increasing (i) land area under production; (ii) yield, through crop improvement, plant biotechnology or other alternative methods; and (iii) output per unit input (productivity) on existing land area (Edgerton, 2009). Agricultural productivity in SSA is currently low and remains far below yield potentials (Chauvin et al., 2012), suggesting that there is need to improve current levels of productivity on existing land area.

Reports also suggest that poor rural farmers in SSA cannot afford inputs such as fertilizers, chemicals and herbicides to improve their productivity (Druilhe and Barreiro-Hurlé, 2012). This may, in part, explain current low levels of productivity. In such instances, it may be more effective to develop agroecological approaches to crop husbandry and income generation opportunities so that farmers can afford inputs to achieving more sustainable systems (Wezel and Soldat, 2009; Wezel et al., 2011; Druilhe and Barreiro-Hurlé, 2012). This review focuses on the third option with a particular emphasis on water as an integral input in agriculture. Global reports indicate that agriculture is the biggest water user, accounting for 60-90% of fresh water withdrawals (Water, 2006). Water will be a major constraint for agriculture especially in SSA, where rainfall is generally low and the population is increasing rapidly (Rijsberman, 2006). Recent reports on climate change have confirmed this with indications that climate change impacts in SSA will mainly be felt through changes in rainfall and water availability (IPCC, 2014). This has placed agriculture in a situation where any increases in agricultural production cannot be met with corresponding increases in water use. This has brought about the slogan “more crop per drop” (FAO, 2003; Molden et al., 2003;

SIWI-IWMI, 2004). Increasing agricultural production without increasing water use will contribute to sustainability by ensuring food and nutrition security now and in the future without further threatening scarce and limited water resources.

2.3 Agriculture

In crop production, water use is often equated to evapotranspiration (ET) which is the combined loss of water from the soil surface by evaporation (E) and from the plant by transpiration (T) (Allen, 1998). Evaporation and transpiration are the two processes where water is actually depleted from the soil; other outflows such as runoff and drainage are not considered as depletion as water is captured in other sinks such as ground water, saline water bodies and oceans (Molden et al., 2010). Globally, rainfall contributes about 80% of water that is lost through evapotranspiration while 20% is drawn from water bodies for irrigation purposes [Comprehensive Assessment of Water Management in Agriculture (CA), 2007]. Climate change and variability are expected to significantly alter this situation through changes in rainfall patterns with significant impacts on agriculture. This threatens the role of agriculture in providing food and nutrition security, especially in water scarce areas. Ali and Talukder (2008) suggested that improving productivity under rainfed conditions would decrease irrigation withdrawals and ultimately decrease pressure on fresh water resources. This would include adopting crops that thrive under rainfed conditions reducing the need for irrigation and adopting strategies that reduce the amount of water used by crops during production. It is important to note that these strategies are at the crop interphase and do not consider nutritional value, which is key to nutrition security.

2.3.1 Crop Water Use

Crop water use refers to the amount of water lost by the crop through evaporation and transpiration (evapotranspiration) in exchange for biomass accumulation. Due to the combination of the processes of evaporation and transpiration, some authors refer to crop water use as crop ET (Soppe and Ayars, 2003; Candogan et al., 2013). Both processes are driven by point weather conditions, with some meteorological variables having a direct influence (wind, radiation, temperature and humidity) (Allen et al., 1998). There are various methods of determining ET, which can be grouped into hydrological (e.g. soil water balance and lysimetric measurements) and micrometeorological techniques (e.g. eddy covariance, the Bowen ratio-energy balance and the temperature difference method). Hydrological approaches are often the most practical approach to determine ET under field conditions and consider incoming and outgoing water fluxes (Allen et al., 1998):

$$ET = Irrigation + Rainfall - Runoff - Deep\ percolation + Capillary\ rise \pm changes\ in\ subsurface\ flow \pm changes\ in\ soil\ water\ content$$

Equation 2.1

Fluxes such as runoff, deep percolation, capillary rise and changes in subsurface flow are challenging to determine accurately under field conditions (Allen et al., 1998). The published water use values of some crops suggest that vegetables such as carrots (*Daucus carota*) and garden beans (*Phaseolus vulgaris*) use the least amount of water (200 and 320 mm, respectively) while groundnut (*Arachis hypogaea*), soybean (*Glycine max*) and maize (*Zea mays*) are among the crops with high water use (700-1000 mm) (Wenhold et al., 2012). It is important to note that these values were obtained at a specific location and may not be applicable across various locations due to differences in weather conditions.

Water use values also differ with crop management and genotype. Efforts to determine water use of crops have been linked to relating it to biomass production and ultimately crop yield. Notably, these efforts have not focussed much on relating crop biomass and yield to the provision of nutrition for improved human health. They have assumed that more biomass and yield translate to more nutrition.

2.3.2 Improving Crop Water Productivity

There is a need to improve WP under rainfed production (Ali and Talukder, 2008). This will benefit the majority of the sub-Saharan African population (>70%) that relies on rainfed agriculture as the primary source of livelihood (Livingston et al., 2011). Despite the limitations in resources suffered by farmers across SSA, there is high confidence that productivity levels can be improved (Nin-Pratt et al., 2011). Currently, yields in the USA and Europe are approximately 200-300% higher than yields achieved in SSA (AGRA, 2013). The huge yield gap is partly due to poor agronomic practices and limited use of improved crop varieties in SSA. The USA and Europe also have higher water productivity (~2 $kg \cdot m^{-3}$) compared to SSA (~0.2 $kg \cdot m^{-3}$). The disparity between these yield and water productivity values creates an opportunity for interventions to narrow the gap. The approaches taken so far have included adopting better agronomic practices, promoting use of improved varieties and improved water productivity. These strategies are not linked to increasing production of nutrient dense crops. Strategies to improve yield and water productivity should also consider increasing production of several nutrient dense crops in order to address malnutrition.

There are possible crops that could be recommended in SSA where food and nutritional insecurity are currently high (Wenhold et al., 2012). Among the vegetable crops, black nightshade (*Solanum nigrum*) and cleome (*Cleome gynandra*) have low water use and high water use efficiency (37-300 mm and 60 $kg{\cdot}ha^{-1}.mm^{-1}$) (Wenhold et al., 2012). Among the legumes, groundnuts (*Arachis hypogea*) yield the most (2-4.8 $t{\cdot}ha^{-1}$) but require more water (800 mm) compared to cowpea (*Vigna unguiculata*), which yields 2.6-3.9 $t{\cdot}ha^{-1}$ and uses about 600 mm of water during the growing season. The same difference was observed for maize (*Zea maize*) and grain sorghum (*Sorghum bicolor*). Water use of grain sorghum was shown to be lower than that of maize, but they shared the same range of WUE (6-10 $kg{\cdot}ha^{-1}.mm^{-1}$) due to sorghum's lower grain yields (Wenhold et al., 2012). Most of the crops reported to 0have lower water requirements in the different categories are alternative crops of African origin or African traditional varieties. They thrive well under SSA conditions and with improved agronomic practices and improved varieties there is potential that these crops could contribute to future food security, especially under rainfed conditions (Mabhaudhi and Modi, 2013). While it is acknowledged that increasing yields and reducing crop water use is of great importance, there is a need to link crop water productivity with nutrition.

2.3.3 Relating Water Use to Dry Matter Production in Crops

While the focus has been on increasing dry matter production in crops, it is the amount of water required that agricultural scientists are concerned about. This is because water is a finite resource and its efficient use in crop production is of primary concern (Heydari, 2014). It also addresses the "more crop per drop" slogan that is being promoted by agricultural and water practitioners. The history of efficient use of water dates back to the 1950s (Sinclair et al., 2009). Then, since irrigation was considered responsible for the highest water withdrawals, irrigation scientists attempted to control and manage irrigation water by introducing an irrigation efficiency (IE) ratio defined as water consumed by crops of an irrigated farm to the water diverted from the source (Nin-Pratt et al., 2011):

$$\mathbf{IE} = \frac{\text{water consumed}}{\text{water diverted}} \qquad \text{Equation 2.2}$$

where, IE is irrigation efficiency, water consumed is the volume of water consumed by crops on an irrigated farm and water diverted is the volume of water diverted from the source for that purpose (Sinclair et al., 1984; Perry, 2007; Heydari and Heydari, 2014). The IE ratio was from an engineering perspective and facilitated better water allocation from water sources to farms. It did not account for crop yield and water used to produce the crop, failing to describe the relationship between yield output per unit of water.

The relationship between yield output per unit of water started being investigated before the 19th century as a measure of drought tolerance (Heydari, 2014). It was termed efficiency of transpiration,

defined as dry matter produced per unit water transpired:

$$TE = \frac{\mathrm{B}}{\mathrm{T}} \qquad \text{Equation 2.3}$$

where, TE is efficiency of transpiration ($g \cdot kg^{-1}$ water), B is the total dry matter produced (g) and T is mass of water transpired (kg) (Maximov, 1929). From a strictly engineering perspective, this was more of an efficiency index as it produced a unitless ratio. In the late 1950s, the term employed to describe the relationship between yield output per unit of water was water use efficiency (WUE) (Viets, 1962). It was defined as mass of dry matter produced per unit volume of water evapotranspired:

$$\mathrm{WUE} = \frac{\mathrm{B}}{\mathrm{ET}} \qquad \text{Equation 2.4}$$

where, WUE ($g \cdot mm^{-1}$) is water use efficiency, B is total dry matter produced (g) and ET is amount of water evapotranspired (mm). Viets (1962) justified the term WUE as being more appropriate since it emphasises water, whose efficient use was the subject of interest. Water use efficiency was then widely used under field conditions to describe the ratio between yield/biomass per unit water used. However, depending on scope and scale of studies, WUE was understood, interpreted and calculated differently (Anyia and Herzog, 2004; Siahpoosh and Dehghanian, 2012; Candogan et al., 2013; Li et al., 2013). Molden et al. (2010) introduced the term water productivity (WP) to describe the ratio between yield output per unit of water. Productivity of water emerged during a System-Wide Initiative on Water Management (SWIM), to develop standardised water accounting procedures (Molden, 1997). Since then the terms WUE and WP have been used interchangeably, creating much confusion for researchers, practitioners and policy makers.

2.3.4 Water Use Efficiency and Water Productivity

While the terms WUE and WP seek to address the notion of "more crop per drop", they are now being used interchangeably and seemingly lack common definition. The efforts in distinguishing

WP and WUE sparked debate, with several papers being written on the subject, where irrigation engineers, crop physiologists and water managers hold different perspectives. Molden et al. (2010) proposed a common conceptual framework for communicating water productivity. They highlighted the importance of water accounting at various scales of interest. WUE calculated as:

$$\frac{\text{B/Y}}{\text{water applied}} \qquad \text{Equation 2. 5}$$

where B/Y is biomass (B) or yield (Y) (g) and water applied is water into the system as precipitation and/or irrigation (mm) or:

$$\frac{\text{B/Y}}{\text{ET}} \qquad \text{Equation 2.6}$$

where B/Y is biomass or yield (g) and ET in mm (calculated as the residual of precipitation + rainfall ± changes in soil water content) are efficiency ratios to describe the ability of crops to utilize water made available to them (Van Halsema and Vincent, 2012).

The denominator in Equations (5) and (6) (water applied and ET) assume that water entering the field through irrigation and precipitation is all taken up via crop evapotranspiration. These do not account for other water movements in and out of the system such as runoff, deep percolation, capillary rise and changes in subsurface flow. This may be attributed to the fact raised by Allen et al. (1998) that water fluxes were challenging to quantify; hence, in many cases, authors assume the effect of other water fluxes to be negligible. While this approach may be justified, it posed difficulties in its application as a comparative measure of efficacy (Van Halsema and Vincent, 2012). This was reflected in the scoping study where WUE values derived from various studies showed a wide range. A classic example was for carrots where an experiment conducted in South Africa reported WUE values of 131-148 $kg \cdot ha^{-1}.mm^{-1}$ and experiments conducted in Chile reported WUE of 19.4-28.3 $kg \cdot ha^{-1}.mm^{-1}$ for the same crop (Wenhold et al., 2012).

On the other hand, WP[4] calculated as

$$WP = \frac{Ya}{ETa} \qquad \text{Equation 2.7}$$

where WP is water productivity ($kg \cdot m^{-3}$), Ya is the actual yield (kg) and ETa is the actual evapotranspiration ($mm \cdot ha^{-1}$ or m^3) or water consumed [48,49] (Zwart and Bastiaanssen, 2004;

[4] In this project we adopted the use of Water Productivity (WP). See chapters 5, 6 and 7

Perry et al., 2009) is a true efficacy parameter of the crop production process. In this case, the denominator only considers water consumed by the crop for biomass production (Van Halsema and Vincent, 2012). When calculating WP only, the water consumed by the crop through evaporation and transpiration is considered. Complex water flows in and out of the system are accounted for in order to determine the actual volume of water consumed by the crop. One advantage of WP is that unlike WUE, its values are more conservative, hence, comparable across temporal and spatial scales (Zwart and Bastiaanssen, 2004; Steduto et al., 2007). However, these arguments, while valid, tend to narrow the scope of WP.

Molden et al. (2010) simplified WP by defining it as the benefits derived from a unit of water, thus, from a holistic point of view, WP can be used to analyse water management. More recently, the High Level Panel of Experts (HLPE) on Food and Nutrition also weighed in on the subject in their report on linking water to food and nutrition (HLPE, 2015). While concurring with Molden et al. (2010), they reasoned that owing to its origins in agronomic and economic sciences, water productivity was more an output-centred concept. In this way, the output could vary from crop yield, monetary value, or nutritional value per unit of water (HLPE, 2015), making WP a more useful parameter for water management. For the purposes of this review, the reasoning of the HLPE is followed, because it provides a basis for linking water use in agriculture to nutrition.

2.3.5 Linking Water Productivity to Nutrition – Nutritional Water Productivity

The progress made over the last few decades by agricultural scientists towards water saving strategies is laudable (Edgerton, 2009; Wezel and Soldat, 2009; Wezel et al., 2011; Altieri et al., 2012; Chauvin et al., 2012; Druilhe and Barreiro-Hurlé, 2012; Wenhold et al., 2012; HLPE, 2015). Irrigation scientists have designed more efficient irrigation systems, breeders have identified and bred high water use efficient crops and crop scientists have identified more water productive cropping and field management systems. While these efforts towards improving water productivity remain commendable, the question remains – "is this enough?"

Water scarcity is not the only global challenge that needs to be addressed. Between 30% and 40% of the world population is malnourished; they experience some form of undernutrition, are overweight or obese, or have some type of micronutrient deficiency (Rosegrant et al., 2014). As such, malnutrition is a problem that is currently affecting nearly every country in the world, although it is more prevalent in SSA. Addressing malnutrition should focus on nutritional value and quality of agricultural produce and diets, as most nutrients come from crops (Gupta and Gupta, 2014). Looking at the United Nations' (United Nations et al., 2014) proposed SDG 2 (End hunger, achieve food security and improved nutrition and ensure sustainable food production by 2030), it is clear that while the "more crop per drop" approach addresses ending hunger and achieving food security, it is silent on issues of nutrition. It is directly linked with increasing food availability and access, while silent on utilisation, hence, ultimately failing to achieve sustainable food production. Sustainable food production describes the capability of agriculture over time to provide sufficient and nutritious food at all times in ways that are economically efficient, socially responsible, and environmentally sound (UNCSD, 2011). The water productivity approach focusses on dry matter production but does not account for nutritional content of the biomass produced. As such, efforts towards increasing food and nutrition security will possibly improve physical and economic access to sufficient food, from the production perspective. This will be in addition to efficient utilisation of water resources by agriculture. However, the WP approach falls short of addressing aspects related to provision of "nutritious food capable of meeting their dietary requirements and food preferences for an active and healthy life". Therefore, there is a need to link the concept of "more crop per drop" with aspects of nutritional value. This could provide a holistic approach to linking water, agriculture and nutrition with improving human health.

In this regard, achieving sustainable food production should also focus on dietary requirements and their relation to scarce water resources (Renault and Wallender, 2000). This is especially true for the rural poor, where the link between water and food is a crucial link for nutrition and livelihood security (SIWI-IWMI, 2004). Within these communities, improved nutrition will lead to improved health, development and productivity (Fanzo, 2014). This was proposed by the SIWI-IWMI (2004) under the notion of "more nutrition per drop". Renault and Wallender (2000) had earlier identified this relationship and termed it nutritional water productivity (NWP).

By definition, NWP is nutritional content per volume of water consumed (Renault and Wallender, 2000). Hence,

$$NWP = \left(\frac{Y_a}{ET_a}\right) \times NP \qquad \text{Equation 2.8}$$

where NWP is the nutritional water productivity (nutrition m^{-3} of water evapotranspired), Ya the actual harvested yield ($kg \cdot ha^{-1}$), ETa the actual evapotranspiration ($m^3 \cdot ha^{-1}$), and NP is the nutritional content per kg of product (nutrition unit$\cdot kg^{-1}$). A closer look at Equation (8) shows Ya/ETa = WP as described in Equation (7).

When determining nutritional value, there is need to consider many other nutritional components of food (Renault and Wallender, 2000). There is a dearth of empirical information describing NWP for a range of crops. Where available, values of NWP are calculated using WP and NP values obtained from separate studies. For example, in the scoping study by Wenhold et al. (2012), published international benchmarks for energy, protein and fat values of selected crops from Canada, Ghana and the USA together with WUE values obtained separately, were used to calculate NWP (Table 2.1). Another concern is the values that Wenhold et al. (2012) refer to as WP. Were they actually WP values or were they a combination of WP and WUE values, but for the sake of consistency were all referred to as WP? As mentioned earlier WUE values are less conservative and when used to determine NWP, can increase inaccuracy. In addition, nutritional composition values were obtained from crops grown under different conditions and at different water contents. This casts doubt on the conservativeness of NWP values. However, the importance of the study was not in calculating NWP, but rather in highlighting the linkages between water, agriculture and nutrition (Table 2.1; Wenhold et al., 2012; Nyathi et al., 2016).

Based on South African benchmarked values of macronutrient water productivities, among the vegetable crops, sweet potatoes (*Ipomoea batatas*), carrots, pumpkin leaves (*Cucurbita pepo*) and amaranth (*Amaranthus* sp.) showed high efficiency in terms of water consumed per energy and carbohydrates produced (>20 $MJ \cdot m^{-3}$ and >300 $g \cdot m^{-3}$). Amaranth and pumpkin leaves were efficient in terms of water consumed per protein produced (>500 $g \cdot m^{-3}$). Legumes generally did not show a wide range in energy and protein water productivities, but soybeans, lentils (*Lens culinaris*), groundnuts and dry beans (*Phaseolus vulgaris*) were the most efficient (>100 $g \cdot m^{-3}$) with respect to protein water productivity. Among cereal crops, only maize NWP values were estimated. Maize was not as efficient as sweet potatoes, carrots, pumpkin leaves and amaranth with respect to energy and protein water productivity (17 $MJ \cdot m^{-3}$ and 132 $g \cdot m^{-3}$, respectively). Maize was, however, an efficient synthesiser of carbohydrates (672 $g \cdot m^{-3}$). Wenhold et al. (2012) also calculated NWP for minerals and vitamins for selected crops. It was apparent that vegetable crops were the most efficient. Their results highlighted the potential of amaranth and pumpkin leaves with respect to their high NWP. Coincidentally, these crops are currently underutilised.

Table 2.1: Nutrient content and nutritional water productivity (NWP) (macronutrients) (Adapted from Wenhold et al., 2012).

Food Group	Product	Nutrient			NWP			Source *
		xE	yP	zF	xE	yP	zF	
		kcal·kg-1	g·kg-1		kcal·m-3	g·m-3		
Vegetables	Tomatoes	184	8	1	1416	650	11	(Renault and Wallender, 2000)
	Carrots	25	10		2174	87		(Grauenhorst et al., 2007)
	Cabbage	250	14		3289	89		(Grauenhorst et al., 2007)
	Pepper	200	12		38	2		(Grauenhorst et al., 2007)
	Onions	331	12		880	31		(Mdemu et al., 2009)
Legumes	Groundnut	6067	283	426	2382	111	206	(Renault and Wallender, 2000)
	Peas	2720	229		8889	748		(Grauenhorst et al., 2007)
	Green beans	330	24		935	68		(Grauenhorst et al., 2007)
	Soybean	3470			2828	304		(Grauenhorst et al., 2007)
		4160		200	956.8	83.95	46	(Mdemu et al., 2009)
Grain	Maize	2738	55	12	3856	77	17	(Renault and Wallender, 2000)
		3270	85		8583	223		(Grauenhorst et al., 2007)
		2738	55	12	547.7	11	2	(Mdemu et al., 2009)

xE = Energy; yP = Protein; zF = Fats; * (Renault and Wallender, 2000) (USA); (Grauenhorst et al., 2007) (Canada); (Mdemu et al., 2009) (Ghana).

Unlike WP, which only focuses on increasing food availability and access, NWP addresses availability, access and utilisation components of food security. It also provides a linkage for water, agriculture and nutrition, making NWP a more useful index for evaluating impacts of agriculture on food and nutrition security. There is a need to promote the use of NWP in studies using agriculture to address nutrition and health aspects (Nyathi et al., 2016). Concurrently, there is also a need for transdisciplinary dialogue and studies to develop more such appropriate metrics that can be useful to operationalise transdisciplinary efforts to link water, agriculture and nutrition.

2.4 Water-Food-Nutrition-Health Nexus

In developing countries, the goal of the water, agriculture, nutrition and health sectors is to improve the standard of living of people, especially historically disadvantaged poor rural communities. Despite this shared goal, agriculture has seldom been openly set out to address nutrition and health challenges (IFPRI, 2011). This is because the linkages between agriculture and nutrition have not always been explicit in planning. There is a need for a paradigm shift in terms of how we continue to deal with food and nutrition insecurity. In the past decades, the "green revolution" made huge strides in boosting food production in much of SSA (Welch, 2001); however, an unforeseen problem emerged in the form of inadequate nutrition. While investments in agriculture increased crop production, mainly for cereal crops, this was accompanied by declining crop diversification, production and utilisation of traditional food crops (e.g. legumes and leafy vegetables) with high nutrient density (Welch, 2001). Although unintended, this reduced dietary diversity and nutrition, especially for poor rural households. The goals that drove the "green revolution" did not explicitly include adequate nutrition as an output from agriculture. If the endpoint to agriculture is improved human health anchored on good nutrition, it follows that the role of agriculture in providing adequate nutrition must be explicit in planning. Shifting agriculture to focus on "food for nutrition" would establish the crucial linkages between food and its role as the primary source of nutrition in human diets. In addition, given the water-food nexus, such agriculture should also be water-smart (Nicol et al., 2015).

The lack of explicit linkages between water, agriculture, nutrition and health is not isolated to agricultural planning alone. A paradigm shift is also required with regards to how we deal with nutritional challenges. In the past, the response from human nutritionists was rather medical in that it viewed malnutrition as a "disease" that needed to be "treated" (Welch, 2001). Consequently, intervention programs spearheaded the use of supplements or food fortification programs to "treat" malnutrition (Welch, 2001). In cases where crops were short-listed to combat malnutrition, only a few were singled out for their ability to deal with specific nutrient deficiencies (e.g. orange-fleshed sweet potato to tackle VAD). Although these nutritional interventions have registered successes in the short-term, they have failed in the long-term due to various social, policy and technical problems which affected their sustainability (Beaton et al., 1994; Welch et al., 1997; Yip, 1997). Most importantly, these approaches did not fully embrace the opportunities that exist along the agricultural value chain to improve human nutrition and health. Including nutrition in the agricultural value chain would ensure that nutritious foods are more available and affordable for poor rural households; this would also improve utilisation wherein nutrition lies. The need to consider the interlinked value of agriculture and nutrition has been recognised for many years. For example, a 1992 global conference on nutrition concluded that "most nutrition programs directed at eliminating malnutrition do not consider using agriculture as a primary weapon in their arsenal against this public health crisis" (FAO and WHO, 1992). In many agrarian countries and rural communities in particular, agriculture remains best placed to effectively deliver nutritional outcomes and improve the health status of the rural poor. In order to achieve this, the linkages between water, agriculture, nutrition and health must be made explicit in planning agriculture-based interventions for improving nutrition and health of the rural poor.

While the linkages between water, agriculture, nutrition and health have always existed, it is only recently that they have become more recognised. The agriculture-nutrition-health nexus which highlights these linkages only came to prominence in 2011 (IFPRI, 2011). It called for coordinated action in agriculture, nutrition and health planning and implementation. Proponents suggested that, if fully adopted and implemented, it could have significant positive impacts for food and nutrition security and development, as well as improving the health status of the rural poor and women (Fanzo, 2014). Some progress has been made in this regard. Since 2011, several multilateral agencies have started to realign their programs in line with the agriculture-nutrition-health nexus (IFPRI, 2011). In Africa, the New Partnership for Africa's Development (NEPAD) is currently exploring opportunities to fully integrate the agriculture-nutrition-health nexus into Africa's agriculture roadmap – the Comprehensive Africa Agriculture Development Program (CAADP) framework (IFPRI, 2011). While this process is on-going, some individual member states have also started to apply the agriculture-nutrition-health nexus to national planning. Uganda launched a Nutrition Action Plan (2011-2016), while Malawi has brought together policymakers and planners in the agriculture, nutrition, and health sectors to coordinate and integrate their activities on the basis of the agriculture-nutrition-health nexus (IFPRI, 2011). Although the agriculture-nutrition-health nexus is now being recognised, there is currently scant empirical evidence on how these linkages work (IFPRI, 2011; Ruel and Alderman, 2013; Webb and Kennedy, 2014)

There are, however, limitations to the agriculture-nutrition-health nexus in that the role of water is not made explicit. Some might contend that water already features in all three, hence, there is no need to explicitly mention it. However, it is also for that very reason that water should be included in the nexus. This review has so far established the water-food nexus, highlighting that food production is inextricably linked to water. In addition to the linkages between water and food production, water also plays significant roles in nutrition and hygiene from a water and sanitation perspective. The HLPE (2015) affirmed the crucial linkages between water and food and nutrition security and highlighted the challenges of securing food and nutrition security under increasingly water scarce conditions. Recognising this important linkage is more essential to securing food and nutrition security in SSA, where water scarcity (physical and economic) is the major limitation to crop production. This is especially true under rainfed agriculture which is practiced by more than 70% of SSA's population. The need to include water alongside agriculture, nutrition and health has previously been suggested by several authors (Field, 1987; Hawkes and Ruel, 2006). Furthermore, across SSA, the impacts of climate change and variability on food production will mainly be felt through water. As such, including water in the nexus would ensure that agriculture becomes resilient through water-smart agricultural practices. This review therefore proposes that the agriculture-nutrition-health nexus be renamed the water-food-nutrition-health nexus. Compared to the former, the latter includes the water sector and focuses more on food for nutrition, thus making the roles of water and food for nutrition explicit.

In order to operationalise the water-food-nutrition-health nexus, there is a need for research on the nutritional and health impacts of water use for food production. To achieve this, more nutrition-relevant data need to be generated and collected from agricultural experiments, while nutritional and health indicators should be included in evaluations of agricultural programs (IFPRI, 2011). There is also need to develop common indices that can be used to measure the health outcomes of agricultural interventions. In this regard, the use of NWP, if linked to health indicators, could prove instrumental in operationalising the water-food-nutrition-health nexus. The objective of improving the well-being of poor communities requires a transdisciplinary approach that addresses all aspects of improving the quality of life (Schultz, 1979; Backeberg et al., 2010). Focus on agriculture alone tends to overate the value of land (Schultz, 1979) at the expense of water, nutrition and health.

They all require equal attention in order to transform the quality of life among poor communities. In this regard, adopting the water-food-nutrition-health nexus for planning rural development and food and nutrition security programmes, could prove beneficial to SSA.

2.5 Food for Nutrition

While there has been much effort towards combating food and nutrition insecurity, the balance has been tilted more in favour of food production than nutrition. The concept of "food and nutrition security" in itself may have unintentionally led to the two being treated as separate, with more focus on food production. The fact that agriculture underpins rural livelihoods and is inextricably linked to rural development explains why, over the past decades, large investments have been made in agriculture. In addition, such agricultural production is assessed mostly by metrics of crop yield, economic output (IAASTD, 2009) and resource use efficiency/productivity, which do not address the nutritional value associated with the crop yield (Remans et al., 2011). The evolution of the concept of NWP and the limited literature on its application speaks volumes about the limitations of current agricultural interventions to deliver nutrition outcomes. The IAASTD (2009) highlighted the need for a holistic and multi-functional approach as well as a need for an agro-ecological approach to farming. This, they argued, could assist in transforming agriculture to deliver on issues of food, nutrition and sustainability.

Although there are now growing calls for agriculture to deliver nutritional goals (Haddad, 2013), there has been a lag in integrating issues of nutrition into planning and evaluation of agricultural and food systems and policies (Remans et al., 2011). In order to achieve such integration, there is a need for a paradigm shift with regards to food and nutrition security. Part of this requires revising the notion of "food and nutrition" and focussing rather on "food for nutrition". The latter recognises the crucial link that food, in the context of this review derived from crop production, is the primary source of nutrition in human diets. A draft definition of nutrition security states that "nutrition security exists when all people at all times consume food of sufficient quantity and quality in terms of variety, diversity, nutrient content and safety to meet their dietary needs and food preferences for an active and healthy life style, coupled with a sanitary environment, adequate health, education and care" (FAO/AGN, 2013). This involves obtaining, utilising and absorbing nutrients that are required for normal growth, health and social well-being (Fanzo, 2014). Although there is now emerging interest in addressing nutrition, malnutrition still remains a significant development challenge and a multidimensional problem in infants, young children, and women (Fanzo, 2014).

Malnutrition continues to cause poor health, morbidity and mortality from childhood through to adulthood, affecting social and economic development among the rural poor. About 38% of children in less developed countries suffer stunting due to undernutrition; this could negatively impact on cognitive development during early childhood development (Save the Children et al., 2013). Burchi et al. (2011) emphasised the vital role of nutrition for growth, cognitive development and health, suggesting that there could be significant consequences for children who experienced undernutrition in the first 1000 days of their lives. They were likely to perform poorly in math and science subjects in the future (Save the Children et al., 2013); this in itself would help to perpetuate poverty in poor rural communities. In this regard, it can be hypothesised that breaking the cycle of malnutrition during early childhood development could go some way towards breaking the cycle of intergenerational poverty among the rural poor. This is especially true for SSA, where social inequality is still rife and continues to perpetuate poverty among the rural poor (Tsegay et al., 2014). Poor rural farmers lack the privilege of having access to diverse food sources and choices (Fanzo, 2014). Where food sources are available and accessible, it is their utilisation that limits poor rural communities from deriving the nutritional benefits therein.

Nutrition is inextricably linked to utilisation. Nordhagen (2013) suggested that in order to achieve food and nutrition security, policy makers must look at agriculture as not merely the provider of food, but rather as the provider of nutrition in human diets – food for nutrition. This is because nutrition is seldom about adequate food supply/availability, but rather impeded utilisation, which is often associated with poverty and lack of education (Nordhagen, 2013). As such, efforts aimed at addressing nutrition insecurity should not be merely technological interventions aimed at boosting productivity, but should also consider social anthropogenic issues that influence food utilisation such as sources of food and reasons for the food choices made by poor rural households.

2.5.1 Food Intake, Sources of Food in Poor Rural Households

As previously highlighted, much of the effort directed towards achieving food and nutrition security has been crop-centric and biased towards increasing food availability and accessibility, with less attention paid to nutrition. Food availability and access are some of the factors linked to food and nutrition security of rural households (Wenhold et al., 2012) However, knowledge of food sources consumed by poor rural households is essential for developing appropriate food-based interventions for addressing malnutrition (under- and over-nutrition) in rural households. While it may be difficult to clearly define a food basket of food consumed by rural households, it is clear that diets among this group are mainly starch (cereals and root and tuber crops) based (Wenhold et al., 2012). Other food groups such as legumes, fruit and vegetables do not feature prominently in diets of poor rural households. This apparent lack of dietary diversity could explain some of the underlying reasons for undernutrition amongst the rural poor. Agriculture, because of its potential to produce nutrient-dense foods, can play an important role in addressing dietary diversity (Fanzo, 2014). Diverse cropping systems and inclusion of alternative crops in food for nutrition interventions could address dietary diversity and contribute to nutritional goals. Multicrop systems and alternative crops have historically played a crucial role in the diets of rural people (Modi and Mabhaudhi, 2013a; Mabhaudhi and Modi, 2014). Bezner et al. (2011) reported that intercropping of maize and legumes in Malawi for improved dietary diversity resulted in improved levels of nutrition in children under five years.

In this instance, agricultural interventions were also coupled with nutrition education at the community level. Alternative crops which are mostly affordable and often free, if sourced from the wild, are often nutrient-dense. However, a lack of education on their nutritional value and stigma remain an obstacle to improving their utilisation amongst poor rural households. Therefore, in addition to addressing scientific knowledge gaps on food for nutrition, there are social barriers that need to be addressed to ensure uptake and utilisation by poor rural communities. This emphasises the need to understand reasons for food choices in poor rural households.

2.5.2 Reasons for Food Choices in Poor Rural Households

Reasons for food choices reflect the various causes that, either separately or synergistically, influence why people consume certain foods and not others. Reasons for food choices are more than a simple matter of nutritional value (Sun, 2008). Each time people choose food, they bring their past food choices, events, experiences, thoughts and feelings as well as historical context to the fore (Devine, 2005). This salient observation is important in highlighting why people eat what they eat as a complexity. In addition, reasons for food choices exist at various levels and are influenced by a range of factors such as demographics, health awareness (Sun, 2008), availability, affordability, taste and cultural preferences, among others. Whilst availability and affordability can be dealt with from a technical viewpoint, it is the other variables and often dynamic reasons that present challenges. While noting the shortfalls of previous research in interrelating the variables influencing food choices (Sun, 2008) suggested that research needed to be dynamic and to transcend the boundaries of nutritional value. This would allow researchers to grasp the dynamic nature of the reasons behind food choices. Wenhold et al. (2012) emphasised that understanding the reasons for food choices was important as they were directly linked to the food and nutrition security of rural households. This also included gaining knowledge of why rural households used certain foods more frequently than others (Wenhold et al., 2012); this would be essential for coordinating an effective food for nutrition programme. (Renault and Wallender, 2000) suggested that while macro-, meso- and micro-level factors influenced reasons for food choices, it was the latter that required more in-depth research and case studies in order to make meaningful breakthroughs.

The different issues regarding food for nutrition, food sources and reasons for food choices present a case for a multidisciplinary approach to address nutrition security in poor rural households. Agriculture has a role to play through providing food for nutrition. It also has a role to play through increasing dietary diversity and giving people more choices. In addition, agriculture can improve household income and allow people to afford other nutritious foods. Nutrition education is still needed to allow people to exercise their choices and to utilise the food from agriculture in order to derive the nutrition required for a healthy lifestyle.

2.5.3 Alternative crops: Potential to Contribute to Food and Nutrition Security

As we continue to re-think strategy, focus should also be on diversifying the food basket in order to create dietary diversity in poor rural households. Diets of poor rural households are essentially starch-based and lack protein, vitamins and minerals. The reasons for this include limited food sources and choices (Wenhold et al., 2012; Stein et al., 2014) mainly associated with poverty. Fanzo (2014) stated that dietary diversity was an integral component of a quality diet; both diversity and quality are key to achieving food and nutritional goals. In addition, consumption of a diversified diet ensures adequate provision of essential nutrients and health enhancers (Wenhold et al., 2012; Stein et al., 2014). However, access to a diversified diet is often hampered by a lack of understanding on its effects on human health and affordability.

While the latter is partly true, this thinking fails to recognise the rich tapestry of agro-biodiversity that exists within rural landscapes, which could be a source of sustainable dietary diversity for poor rural households at little to no cost. In addition, a lack of skills and understanding also hampers the effective utilization of such agro-biodiversity (Leakey et al., 2003; Tchoundjeu et al., 2006). This concurs with suggestions by Schultz (1979) and Backeberg et al. (2010) that there was a need for human capacity development to support and sustain agricultural interventions. Such capacity development could be in the form of participatory approaches as exemplified by the work reported by Tchoundjeu et al. (2006) on domestication of indigenous fruit trees. The findings of Wenhold et al. (2012) (Table 1) also justify the need to conduct more research on alternative crops for the purposes of contributing to food and nutrition security. Neglected and alternative crops species (NUCS) have the potential to improve access to and availability of nutritious food for poor rural households. There currently exists no common definition of NUCS with variations in classification due to geography (underutilized/neglected where?), social (underutilized by whom?) and economic (to what extent) concerns. While acknowledging these shortcomings, Chivenge et al. (2015) defined NUCS as "crops that have not been previously classified as major crops, have previously been under-researched, currently occupy low levels of utilisation and are mainly confined to smallholder farming areas". Such crops may have the potential to contribute to food and nutrition security of poor rural households and may be suited to the marginal production environments that typify most rural areas in SSA (Chivenge et al., 2015). However, NUCS currently occupy low levels of utilization. Limitations in utilisation have been linked to limited research addressing basic aspects of their production, water use, nutritional value and seed systems (Modi and Mabhaudhi, 2013b). There is a gap in agronomic information on the range of crops that could be utilised as food security crops (Wenhold et al., 2012). This highlights the need for more research targeted at NUCS with a view to tapping into their potential to contribute to food and nutrition security in rural areas.

Indigenous fruit trees also form an important aspect of agro-biodiversity that is currently underutilised within SSA. A recent review by Chivenge et al. (2015) noted that indigenous fruit which were often consumed by poor rural communities, were highly nutritious. Indigenous fruit were reported to be rich sources of sugars, essential vitamins, minerals and essential oils (Saka and Msonthi, 1994; Kwesiga et al., 2000). However, their potential to contribute to food for nutrition and health has not been fully explored. Unlocking the value of NUCS requires multidisciplinary initiatives which can recognize the diverse roles that NUCS often play within the communities that have preserved them. Reports of work done in Cameroon to promote utilization of indigenous fruit provides some evidence of the transformation that can be achieved through multifunctional approaches (Leakey et al., 2009; Leakey, 2012). Inclusion of NUCS will broaden the food basket, hence influencing food choices, especially in rural communities where access to nutritious food is a major limitation. Within these communities, inclusion of NUCS would not only increase dietary diversity, but would also increase dietary quality, hence contributing to improved human nutrition and health.

2.5.4 Competing Needs in Poor Rural Household

When considering food for nutrition, reasons for food choices and crop diversification in poor rural households and competing economic interests within poor rural households, also require consideration. For example, farmers may grow a nutrient-dense crop and opt to sell the crop as opposed to consuming it within the household. Other related competing interests in poor rural households include the need for energy production on the farm (manure for cooking, fuel wood needs, or commercial biofuel crops), which have an impact on competing water uses and on soil quality, all of which are interlinked This adds to the general complexity of understanding reasons for food choices in poor rural households and partly explains why technical interventions, alone, may not be successful. The occurrence of such competing needs also emphasises the need for multidisciplinary approaches that not only address biophysical constraints, but also socio-economic constraints.

2.6 Human Health and Well-Being

According to the World Health Organisation (1946), "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"; this definition has not been amended since 1948. The Global Food Report emphasised good nutrition as being the basis of human health. This underscored the importance of nutrition to human health and well-being. In addition to nutrition, several other factors are known to influence human health and these include background, culture/lifestyle, and economic and social conditions. Interestingly, these factors can be linked to factors that influence reasons for food choices and nutrition, thus reaffirming the critical role of nutrition to human health. It is for this reason that we are interested in nutrition (Stein, 2014), hence, human health and well-being are the primary end goal for food for nutrition.

Nutrition has always been a key development indicator. The consequences of inadequate nutrition include poor human health, well-being, productivity, livelihood and consequently a stagnation in national development (Welch, 2001). For developing regions such as SSA, this can have huge negative impacts on economic development and poverty alleviation efforts. This justifies the need for governments within SSA to invest in food for nutrition as a strategy for improving human health and well-being among the rural poor. The economic justifications for investments in nutrition have long been established. Behrman (1993) reviewed the economic justification for developing countries to invest in nutrition and found that improved nutrition resulted in improved health, labour productivity and general upliftment of the poor. Investments in food for nutrition which targeted the rural poor were a cost effective use of national resources and led to reduced social and financial losses associated with poor health resulting from malnutrition (Behrman, 1993).

The consequences of malnutrition are even more severe on the health and well-being of vulnerable groups, which include children under five years and breastfeeding women. For children under five years, inadequate nutrition is a major contributing factor to child mortality; undernutrition accounts for more than 33% of child mortality in low-income countries (Horton and Hoddinot, 2014). Adequate nutrition is essential for cognitive development during early childhood development, and hence educational success, both of which are important determinants of labour productivity and economic growth (Save the Children et al., 2013; Horton and Hoddinot, 2014) Globally, an estimated 162 million children remain moderately or severely stunted, an indication of chronic undernutrition (Black et al., 2013; Unicef, 2013), with most of these children from the developing world.

In pregnant women, malnutrition has been associated with low birth weight and varying levels of mental retardation in offspring. Intelligent quotients (IQs) of infants with low birth weight have been reported to be about five points lower than for normal weight infants (Welch, 2001); thus, setting in motion an unfortunate cycle which can perpetuate poverty (Seery and Caistor Arendar, 2014). The effects of malnutrition on pregnant and breastfeeding women as well as on infants and children, further justify the need for robust food for nutrition programmes targeted at poor rural communities. Lack of adequate nutrition and the consequences thereof on human health can perpetuate poverty, making it difficult for generations of poor rural people to ever escape poverty. In order to achieve food for nutrition programmes that can effectively improve human health and well-being among the rural poor, there is a need to fully recognise the various linkages that contribute to this end goal. In this regard, realising the crucial linkages between water, agriculture, nutrition and human health is essential for achieving the endpoint of a healthy nation. Hawkes and Ruel (2006) described these linkages as mutual in that while water and agriculture affected nutrition and health, the latter two also affected agriculture. However, the linkages between water, agriculture, nutrition and health are still not well-understood. This may be because these sectors have traditionally used, and still continue to use, distinct indices to assess their impacts on human well-being. The use of an index such as NWP offers the possibility of linking water to agriculture and nutrition via the food for nutrition paradigm.

2.7 Conclusions

While progress has been made towards improving food security through improvements in crop production, the same cannot be said of nutrition security. Little attention has been paid to nutrition goals and linking them to agriculture programmes as well as the endpoint of improved human health and well-being in poor rural households. Consequently, poor rural households still suffer unacceptable levels of malnutrition despite the various interventions that have been made to improve their status. Inadequate nutrition in poor rural communities is partly associated with a lack of dietary diversity and limited access to and non-availability of nutrient-dense foods. Improving the utilisation of several NUCS could increase dietary diversity and increase access to nutrient-dense foods in poor rural communities. The role of indigenous fruit trees, which also qualify as NUCS, in agroecology and income generation initiatives should be considered. Malnutrition, if left unchecked, could perpetuate poverty in poor rural communities. Programmes aimed at addressing food and nutrition security for improved human health have had limited success. This is because of failure to clearly recognise the crucial linkages between water, agriculture, nutrition and health outcomes. There is a need for a paradigm shift which includes adopting the water-food-nutrition-health nexus approach. This would ensure that nutrition is made an explicit output in agricultural interventions. Developing appropriate metrics, such as NWP, which can be used to evaluate water, crop productivity, and nutrition and health impacts would also go some way in achieving this. In order to operationalise the water-food-nutrition-health nexus, there is a need for interdisciplinary studies that can address the knowledge gap which is critical for formulating policy.

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CHAPTER 3

FOOD AND NUTRITION INSECURITY IN SELECTED RURAL COMMUNITIES OF KWAZULU-NATAL, SOUTH AFRICA – LINKING HUMAN NUTRITION AND AGRICULTURE

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3.1 Introduction

Worldwide, many forms of malnutrition co-exist. Malnutrition presents as either undernutrition (underweight, wasting, stunting and micronutrient deficiencies) or over-nutrition (overweight, obesity and chronic diseases of lifestyle) [Food and Agriculture Organisation of the United Nations (FAO)], International Fund for Agricultural Development (IFAD), United Nations Children's Fund (UNICEF), World Food Programme (WFP) and World Health Organisation (WHO), 2017]. Globally, in 2016, 815 million people had chronic undernutrition. Stunting affected 155 million children under five years and wasting affected 52 million children between the ages of one and 12 years. Over-nutrition is as much of a problem as undernutrition. The 2016 statistics indicated that 41 million children under the age of five years were overweight (FAO et al., 2017). Both under- and over-nutrition are not only on the rise globally, but is also a major concern in sub-Saharan African countries, including South Africa (SA) (Faber and Wenhold, 2007).

In SA, all forms of malnutrition could be attributed to, in part, the shift from traditional diets, which were high in carbohydrates and fibre, to western diets which are high in fat. The shift in dietary habits seems to be contributing significantly to the increased risk of chronic diseases of lifestyle such as obesity, hypertension, coronary heart disease and hyperlipidaemia (Van Zyl et al., 2012; Lutter et al., 2011; Schönfeldt et al., 2010; Faber and Wenhold, 2007; Bourne et al., 2002). The dietary shift has had varying impacts on the nutritional and health status of different demographic groups in SA. A high prevalence of over-nutrition has been reported among South African women, whereas children and infants are mostly affected by undernutrition (Shisana et al., 2013). Similar to other countries in sub-Saharan Africa (SSA), there are several underlying causes of malnutrition in SA, including poverty, food insecurity, inadequate infrastructure and access to health care facilities, lack of education and inadequate food intake (Bain et al., 2010; Chopra et al.,2009; Manary and Sandige, 2008; Smuts et al.,2008). These causes are largely inter-linked (UNICEF 1998), with poverty being the leading cause, including in SA (Bain et al., 2013).

Poverty can be defined as the lack of or limited access to necessities, such as safe clean water, health care, shelter, sanitation, nutritious food and basic education due to economic constraints (WHO, 2016; Woolard, 2012). The 2015 statistics indicated that one in every two South Africans is poor, which equates to approximately 30.4 million South Africans [Statistics South Africa (StatsSA), 2017]. In SA, black Africans are particularly affected by poverty (47-53%) (Argent et al., 2009). The KwaZulu-Natal (KZN) province has the largest proportion of poor households in SA and has been one of the poorest provinces in SA since 2011 (StatsSA, 2017; Argent et al., 2009). Poor households are at a high risk of malnutrition, as they cannot afford a diverse diet (Mabhaudhi et al., 2016a; Wenhold et al., 2012). Within KZN, 37.2% of poor households receive a child support grant (StatsSA, 2017), which is currently R430/month [Republic of South Africa (RSA) 2019]. In some instances, households depend solely on grants for purchasing food in SA. A basic food basket costs approximately R883.16/month in SA, which may be unaffordable to many impoverished people [National Agricultural Marketing Council (NAMC), 2019]. Several strategies have been proposed to address dietary diversity in poor rural households. These include biofortification and the promotion of alternative crops that are nutrient-dense (Mabhaudhi et al., 2016a).

Food and nutrition insecurity can be defined as the inability to access adequate quantities of nutritious foods required for optimal growth and development (Napoli et al., 2011). There is a direct relationship between food and nutrition insecurity and poverty (Kimani-Murage et al., 2010). In SA, at the national level, food insecurity affects one in five households (Labadarios, Moodie and Van Rensburg, 2007). Most rural communities consume diets that have very limited variety and are typically inadequate in fruits and vegetables (WHO, 2013). Micronutrient deficiencies are common in developing countries such as SA. These micronutrient deficiencies include iron, iodine, zinc and vitamin A (Bailey et al., 2015).

Various national studies have been conducted to assess the nutritional status of South Africans. The South African Vitamin A Consultative Group (SAVACG) conducted a survey in 1994 on children aged 0-71 months (Labadarios and Van Middelkoop, 1995), while the National Food Consumption Survey (NFCS 1999) surveyed children aged 1-9 years of age (Labadarios et al., 2000). The 2005 National Food Consumption Survey-Fortification Baseline (NFCS-FB) was conducted on children aged 1-9 years and women of childbearing age (Labadarios et al., 2007).

The most recent national study, the South African National Health and Nutrition Examination Survey (SANHANES-1), was conducted in 2012 (Shisana et al., 2013). These studies have given an overall view of the nutritional status of the South African population and have drawn conclusions on the nutritional status of South Africans living in different provinces. The sampling method used when conducting the national studies was disproportionate stratification by province. This means that only a certain fraction of the province was sampled. Therefore, the data obtained from these studies are arguably not a true reflection of the nutritional status of different population groups found in specific localities within the province, including district and sub-district levels (Shisana et al., 2013; Labadarios and Van Middelkoop, 1995).

The aim of this literature review is to determine the nutritional status of people living in KZN, especially those living in poor rural areas, by evaluating available data and information on the nutritional status of population groups residing in KZN. This study focussed on poor rural communities because most of the national studies indicated that poor rural populations are the worst affected and are most vulnerable to both under- and over-nutrition (Shisana et al., 2013; Labadarios et al., 2007; Labadarios et al., 2000).

3.2 Nutritional status of South African children and adults with a focus on KwaZulu-Natal

3.2.1 Undernutrition

Undernutrition is a serious nutritional problem as it leads to poor quality of life due to the loss of body cell mass. It is associated with various health issues such as anaemia, hepatic mass losses, infection, emphysema, gastrointestinal tract (GIT) atrophy and intestinal bacterial overgrowth (Escott-Stump, 2015). Undernutrition, more specifically stunting, is common in South African children, affecting approximately 27% of children under the age of five years [National Department of Health (nDoH), StatsSA, South African Medical Research Council (SAMRC) and ICF, 2017]. There are a number of measurements used to classify undernutrition in children using the WHO classification. These include a weight-for-age (WFA), height-for-age (HFA) and weight-for-height (WFH). This classification indicates if a child is underweight, stunted or wasted. The WFH can further classify a child as having severe acute malnutrition (SAM) or moderate acute malnutrition (MAM), being not acutely malnourished (NAM) or overweight (WHO, 2017). For persons under 18 years of age, the mid-upper arm circumference (MUAC) is another common anthropometric measurement used in addition to weight and height, to identify malnutrition. Tables 3.1, 3.2 and

3.3 provide a detailed classification of malnutrition using anthropometric indicators (WHO, 2014). These indicators were formulated using the WHO guidelines (WHO, 2017; WHO, 2014).

Table 3.1: Weight-for-age and weight-for-height classification for children under five years of age (WHO, 2017)

WFA	WFH[5]	Z score
Severely underweight	Severely wasted	Below -3 SD[6]
Moderately underweight	Moderately wasted	Between -2 and -3 SD
Normal weight	Not wasted	Above -2 and below +2 SD
Overweight	Overweight	Above +2 SD

Table 3.2: Height-for-age classification for children under five years of age (WHO, 2008)

HFA	Z score
Severely stunted	Below -3 SD
Moderately stunted	Between -2 and -3 SD
Normal height	Above -2 SD and below +3SD
Tall	Above + 3SD

Table 3.3: Mid-upper arm circumference classification in children under five years of age (WHO, 2014)

MUAC	Classification
Below 11.5 cm	SAM
11.5-12.5 cm	MAM
Above 12.5 cm	NAM

3.2.1.1 Stunting

Although the global rates of stunting decreased by 6.6% from 2015 to 2016, 155 million children under five years are still affected by stunting (FAO et al., 2017). According to the 2005 NFCS-FB study, one in five children in SA were stunted, with those living in rural areas most affected by stunting (Labadarios et al., 2008). Moreover, the prevalence of stunting was high in KZN, with 24% and 26% in the UMkhanyakude and Zululand districts, respectively (Schoeman et al., 2010). These results are similar to the results reported in a more recent study, the 2012 SANHANES-1 study (Shisana et al., 2013). Between 2005 and 2012, stunting in South African children aged 1-3 years worsened as the rates increased from 23.4 to 26.5% (Shisana et al., 2013;

[5] The WFH can be used to classify severe acute malnutrition (SAM), moderate acute malnutrition (MAM), not acutely malnourished (NAM) and over-nutrition (WHO and UNICEF, 2009).
[6] SD=Standard deviation.

Labadarios et al., 2007). According to the 2016 South African Demographic and Health Survey (SADHS), stunting affected 27% of children under the age of five years, indicating an increase in stunting in comparison to other studies (nDoH et al., 2017). There are many implications of stunting, especially in children under five years of age [Health Systems Trust (HST), 2016; UNICEF, 2016; Escott-Stump, 2015].

Stunting is a chronic form of malnutrition (UNICEF, 2016) and is diagnosed when HFA is below minus two standard deviations (SD) of the WHO child growth standards median (UNICEF, 2012). Stunting is caused either by inadequate food intake or by the consumption of foods that lack adequate nutrients for an extended period of time (WHO, 2019). It is a serious health problem as it can lead to reduced mental development, poor performance in school, poor social-emotional development and increased risk for chronic diseases of lifestyle, later on in life. It is important to determine the WFA in children under five years of age, as they are most vulnerable to all forms of malnutrition, including stunting (HST, 2016; UNICEF, 2016; Escott-Stump, 2015). From the point of in-utero fetal development up to two years of age, children are at risk of poor development due to inadequate nutrition. After two years, some of these effects become irreversible (HST, 2016). These children perform poorly in school, suffer from food and nutrition insecurity and lack financial stability later on in life. This contributes to an economic loss as these children grow up to become unemployed adults reliant on social grants, thus perpetuating a vicious cycle of poverty and food insecurity (HST, 2016; Escott-Stump, 2015).

3.2.1.2 Underweight

Underweight is diagnosed when WFA is less than the minus two SD of the WHO child growth standards median. It is a serious nutritional problem that may be caused by either weight loss or poor nutritional intake (WHO, 2017). Globally, 16% of children under five years are underweight. This figure is higher in SSA, with 21% of children under five years underweight (UNICEF, 2012). Although these percentages are high, the prevalence of underweight and wasting has reduced in SA. National studies conducted for the period 2005-2012 indicated that the prevalence of underweight and wasting in children aged 1-3 years in SA declined from 11% to 6.1% and 5.1% to 2.2%, respectively (Shisana et al., 2013; Labadarios et al., 2007). In KZN, the highest prevalence (6%) of underweight in children between the ages of 12-23 months was found in the UMkhanyakude district (Schoeman et al., 2010).

As alluded to earlier, poor dietary intake may contribute to malnutrition. The improvement in undernutrition in KZN could be attributed to the Integrated Management of Acute Malnutrition

(IMAM) programme that was implemented by the national Department of Health in 2014 (DoH, 2014) and the new 2018 standard operating procedures on the prevention and management of malnutrition in KZN (DoH, 2018). Although the prevalence of underweight and wasting in children has improved, it remains important to determine the nutritional status of vulnerable children and adults in rural KZN. This is especially because many of those living in poor rural areas with malnutrition may remain undiagnosed, as they live far away from health care facilities (Strasser, 2003).

3.2.1.3 Wasting

Wasting is diagnosed when WFL/WFH is less than minus two SD of the WHO child growth standards median. Wasting is a serious nutritional problem that may be caused by either weight loss or poor nutritional intake (WHO, 2017). It can present as protein-energy malnutrition (PEM), which is the most common form of malnutrition observed in developing countries. It is caused by a lack of one or more macronutrients that are required by body tissue in order to sustain the optimal functioning of the human body (Manary and Sandige, 2008). This form of malnutrition is caused by a protein and glycaemic carbohydrate deficiency (Mahan and Raymond, 2017). Malnutrition can manifest in different ways depending on the symptoms presented, with PEM often manifesting itself as SAM with or without oedema or MAM. Severe acute malnutrition is characterised by the presence of severe wasting or pitting oedema and MAM presents clinically as moderate wasting with no oedema (DoH, 2018). Malnutrition can be classified using anthropometric measurements (Tables 3.1, 3.2 and 3.3).

When an individual is malnourished, the body goes into a state of starvation (Mahan and Raymond, 2017). Glucose is the main energy source for the body, obtained from the consumption of carbohydrate-containing foods. Although free fatty acids are utilised to provide energy when glucose is unavailable in the body, certain organs, such as the kidneys, brain, eyes and red blood cells, are unable to use free fatty acids as a source of fuel and require glucose as an energy source. When the body is in a state of starvation, the brain still requires a constant supply of energy. The liver produces ketone bodies, which are partly used as an energy source by the brain during starvation (Mahan, Escott-Stump and Raymond, 2012). Starvation affects the GIT, cardiac muscle, liver, kidneys and the immune system (Manary and Sandige, 2008). During starvation, appropriate nutrition is required to correct electrolyte imbalance, prevent further organ damage and provide the correct amounts of macronutrients for sustainability. The human body is significantly affected during episodes of starvation (Mahan et al., 2012,).

3.2.1.4 Micronutrient deficiencies, particularly vitamin A deficiency

Although micronutrient deficiencies are also a problem in developing countries, they are not routinely treated. Globally, about two billion people have micronutrient deficiency due to the consumption of poor quality foods that lack diversity. The most common micronutrient deficiencies observed in developing countries are iron, iodine, zinc and vitamin A (Bailey et al., 2015). Micronutrient deficiencies result in several health conditions, including growth retardation and delayed development (Bain et al., 2013). The 1999 NFCS showed that South African children had a low intake of the following micronutrients: vitamin A, calcium, iron, zinc, folate, vitamin B_6, niacin, riboflavin, vitamin C and vitamin E. The study further indicated that, in SA, the highest prevalence of micronutrient deficiencies was noted in rural communities (Labadarios et al., 2000). Similarly, the 2005 NFCS-FB study also found that many micronutrients were consumed at less than 67% of the recommended dietary allowances (RDA). These included calcium, iron, zinc, selenium, vitamin D, vitamin C, vitamin E, riboflavin, niacin, folic acid and vitamin D (Labadarios et al., 2008). On a national level, poor iron status was noted in one in five and one in 10 women and children, respectively. Iron deficiency anaemia affected 5.9% of children aged 1-9 years in KZN (Labadarios et al., 2008). The prevalence of iron deficiency in South African children reduced from 5% in 1994 to 1.9% in 2012 (Shisana et al., 2013; Labadarios et al., 2000; Labadarios and Van Middelkoop, 1995).

Nationally, 43.3% of children in SA have a poor zinc status (Labadarios et al., 2008). A recent longitudinal study conducted on children aged 4-6 years and 6-8 years in rural KZN, found that out of the 103 children in the study, 37.9% of the children were mildly anaemic, 60.2% were moderately anaemic and 1.9% were severely anaemic (Gwetu et al., 2015). These study results were in contrast to the results obtained from the 2012 SANHANES-1 study. A possible reason for the difference in results could be due to the classification used to analyse data. The study conducted by Gwetu et al. (2015), classified anaemia using two target groups, i.e. 0-59 months (mild: 10-10.9 g/dl; moderate: 7-9.9 g/dl; and severe: <7 g/dl) and 5-11 years (mild: 11-11.4 g/dl; moderate: 8-10.9 g/dl; and severe: <8 g/dl) (Gwetu et al., 2015). On the other hand, the 2012 SANHANES-1 study classified anaemia in children under five years as follows: mild (10-10.9 g/dl); moderate (7-9.9 g/dl) and severe (<7 g/dl) (Shisana et al., 2013). The results from Gwetu et al. (2015) are similar to previous national studies (Labadarios et al., 2008; Labadarios and Van Middelkoop, 1994), and local studies (Faber et al., 2001; Oelofse et al., 1999). These studies all indicated that the prevalence of anaemia ranged from 16.5 to 33% between 1994 and 2005 (Labadarios et al., 2008; Faber et al., 2001; Oelofse et al., 1999; Labadarios and Van Middelkoop, 1995). As previously highlighted, the 2012 SANHANES-1 study used disproportionate stratification that did not cover every area of a specific province (Shisana et al., 2013). This may explain, in part, the differences noted.

A separate study conducted on the urban population of Durban, KZN also found high rates of anaemia. The cross-sectional prospective study conducted in a regional hospital found that out of 2000 pregnant patients enrolled in the study, 854 patients (42.7%) were anaemic. From the pregnant women that were anaemic, 81.4% were mildly anaemic, 18% were moderately anaemic and 0.6% were severely anaemic (Tunkyi and Moodley, 2016). Anaemia in pregnancy is a significant problem as it affects the health of both the mother and fetus. Iron is required during pregnancy to assist with fetal growth and improves the Apgar[7] score, which provides an indication of how well the infant is doing outside the womb. A mother suffering from anaemia is at risk of maternal and perinatal mortality due to poor nutritional status (Pasricha et al., 2013; Allen, 2000). Anaemia during pregnancy can result in a low birth weight or premature delivery (Allen, 2000). This is a serious problem, as the vicious cycle of malnutrition continues. These infants may suffer from developmental delays that may affect their academic performance in school, with possible unemployment later in life, hence exposing them to poverty and food insecurity (HST, 2016; Escott-Stump, 2015; Kimani-Murage et al., 2010).

Although there has been an improvement in the iron status of South Africans, it is important to highlight that national studies only sampled a portion of the province and were not district specific. It also indicates that iron deficiency anaemia affects two vulnerable groups in KZN, women of childbearing age and children. It is important to prioritise the nutritional status of these two vulnerable groups as they are at high risk of micronutrient malnutrition (Shisana et al., 2013; Labadarios et al., 2000; Labadarios and Van Middelkoop, 1995). A possible long-term strategy that could be explored to help address micronutrient malnutrition is dietary diversification through the promotion of household and community food gardens, utilisation of indigenous crops and consumption of biofortified foods.

Vitamin A deficiency is a common micronutrient deficiency, observed globally and throughout SSA (Shisana et al., 2013; Bain et al., 2013; Labadarios et al., 2008; Smuts et al., 2005; Labadarios

[7] Apgar (A: appearance, P: pulse, G:grimace, A: activity, R: respiration)

et al., 2000; Labadarios and Van Middelkoop, 1995. A few national studies have documented VAD in SA. In 1994, the SAVACG study (Labadarios and Van Middelkoop, 1995) reported that 33.3% of South African children had VAD, while the 2005 NFCS-FB study (Labadarios et al., 2008) reported that 63.6% had VAD. This showed that the VAD situation had worsened between 1994 and 2005. Furthermore, the 2005 NFCS-FB study reported that two in three women had VAD. In KZN alone, six out of ten women had VAD, which was the highest prevalence in SA. Forty-four percent of children between the ages of 1-9 years living in KZN had VAD. Overall, KZN had the second highest prevalence of VAD (Labadarios et al., 2008; Labadarios et al., 2000; Labadarios and Van Middelkoop, 1995). A more recent study, the 2012 SANHANES-1 study, reported an improvement in the VAD situation in SA (Shisana et al., 2013). Although still significantly high, the SANHANES-1 study reported a decline in the number of children with VAD (43.6%). The SANHANES-1 study also reported that there was an improvement in the vitamin A status of females residing in KZN. Those with the lowest education levels were the most affected by VAD (Shisana et al., 2013).

Although the prevalence of VAD in SA has decreased, it still remains a challenge, especially in KZN (Shisana et al., 2013; Labadarios et al., 2008). It is vital to find ways to reduce VAD as vitamin A is an important micronutrient required by the human body. Vitamin A deficiency affects protein synthesis, vision, growth and development and could result in a child not being able to reach their full potential, both physically and mentally (Mahan and Raymond, 2017). The main reasons for VAD, especially in SA, are poor economic status and limited access to nutritious foods. A possible solution to this problem could be diversifying household food baskets with biofortified crops and underutilised indigenous crops. However, the acceptability of such crops by poor rural communities remains a challenge. It is therefore important to identify the foods consumed by people at risk of VAD in KZN, and analyse these foods to determine their nutritional value.

Improvements in the prevalence of micronutrient deficiencies could be attributed to the success of the nutritional interventions implemented to help alleviate micronutrient deficiencies (DoH, 2018; Swart et al., 2008; DoH and UNICEF, 2007). Although these interventions have shown an improvement in the prevalence of micronutrient deficiencies, progress has been slow. Despite the improvement in the iron status of women and children observed from national studies, it is evident that it remains a problem in some areas of KZN (Shisana et al., 2013). With the high poverty rates and the worsening economy, many poor rural communities remain unable to access basic food items (NAMC, 2019; RSA, 2019). This leads to poor nutritional status as the foods consumed lack variety and many essential nutrients. Assessing the dietary intake of the rural population in KZN could assist in improving dietary intake by modifying current eating patterns or advising on cheaper, more nutritious food options. Current recipes could be documented and assessed for nutritional composition. Items from these recipes could be substituted with options that are more nutritious. For example, substituting unfortified white maize with biofortified maize or sweet potato with OFSP could improve vitamin A intake and address VAD. Adding fruits and vegetables to diets that lack variety by promoting vegetable gardens, utilising wild vegetables and fruit or biofortified foods, could assist in diversifying household food baskets.

3.2.2 Over-nutrition

For many years, undernutrition has been under the spotlight, while over-nutrition has received less attention. However, this has now changed (DoH, 2018; Haslam and James, 2005). Over-nutrition was previously mostly associated with affluence. However, due to the nutritional transition, it is now also prevalent in middle and low-income groups. Over-nutrition is a major risk factor for chronic diseases of lifestyle, especially in women (Devanathan et al., 2013).

3.2.2.1 Overweight and obesity in children

There are several possible causes of childhood obesity. These include increased consumption of poor quality, high-energy foods, children born to mothers who were overweight or obese during pregnancy, overweight or obese parents, low physical activity and metabolic disorders (Escott-Stump, 2015). Overweight and obesity are serious health concerns, especially in children, as it increases the risk of other chronic diseases of lifestyle later, such as cardiovascular disease, hypertension and diabetes mellitus (Escott-Stump, 2015). Stunting in children increases the risk of obesity in adulthood (FAO et al., 2017).

Globally, in 2016, 41 million children under the age of five were overweight. Southern Africa accounts for 12% of the overweight children (FAO et al., 2017). The 2005 NFCS-FB found that 1 in 10 South African children were overweight (Labadarios et al., 2008). A separate study conducted by Armstrong et al. (2006), using random sampling in South African children aged 6-13 years in five selected provinces during the National Health Survey (2001-2004), found that the prevalence of overweight and obesity increased with age among black African girls. However, the opposite trend was observed with white girls. The combined percentage of overweight and obesity increased from 11.9% in black African girls aged 6 years to 21.8% in black girls aged 13 years (Armstrong et al., 2006). Similarly, a national study conducted in 2012 in SA, reported that the prevalence of overweight and obesity was lower in boys (16.5% and 7.1%, respectively) than girls (16.5% and 4.7%, respectively). These results were consistent for all age groups. KwaZulu-Natal was one of the provinces with high rates of obesity among children. The prevalence of obesity in KZN was 6.1% and 8.5% among boys and girls, respectively. Furthermore, this national study reported that black African girls were the most affected by obesity (Shisana et al., 2013).

3.2.2.2 Overweight and obesity in adults

Black African women were reported to be at greatest risk for obesity in SA (nDoH et al., 2019). Another study that reviewed demographic and health surveys to assess the nutritional status in seven African countries found that in Africa, overweight and obesity were on the rise. Furthermore, this review noted that poor women and those that had less than a primary school education, were the most affected by overweight and obesity (Ziraba et al., 2009). A similar trend was observed in SA. The 2012 SANHANES-1 study reported that, on a national level, the prevalence of obesity in women from the rural formal and rural informal populations was 31.8% and 37.6%, respectively. Furthermore, KZN was shown to have the second highest prevalence of obesity. The prevalence of overweight and obesity was higher in women (24.8% and 39.2%, respectively) than men (20.1% and 10.6%, respectively) (Shisana et al., 2013).

A few studies have assessed the nutritional status in the KZN population (Table 3.4) and limited data has been collected from the urban KZN population. Many authors reported that stunting affected young children, whereas overweight and obesity were a major problem among females from both urban and rural areas of KZN (Table 3.4) (Napier and Oldewage-Theron, 2015; Duncan et al., 2014; Devanathan et al., 2013; Grobbelaar et al., 2013; Zhou et al., 2012; Smuts et al., 2008; Jinabhai et al., 2003). It was noted that the prevalence of overweight and obesity increased with age in black African females (Napier and Oldewage-Theron, 2015; Duncan et al., 2014; Devanathan et al., 2013; Grobbelaar et al., 2013; Zhou et al., 2012; Smuts et al., 2008; Jinabhai et al., 2003). As highlighted earlier, the SA rates of stunting in children age 1-3 years worsened from 23.4% in 2005 to 26.5% in 2012 (Table 3.4). A study conducted by Grobbelaar et al. (2013), reported that children consumed foods that were high in energy and carbohydrates and inadequate in micronutrients (vitamin C, calcium and iodine), which are essential for growth and development.

Table 3.4: Studies conducted to assess the nutritional status of the KwaZulu-Natal population

Authors	Study design and methods	Area conducted	Participants	Findings
Napier and Oldewage-Theron (2015)	Three informal settlements, randomly selected. Anthropometric data was collected (weight and height) and a structured 24-hour recall was conducted.	EThekwini Municipal District (Urban area).	Girls in secondary school and women aged 19-28 years of age (n=523).	- Stunting was evident in young girls (7.7%). - Forty-three percent of the girls were at risk of being overweight and 12.8% were overweight. - BMI for age indicated that 5.2% of the women were underweight and that 30.5% and 15% were overweight and obese, respectively. - Half the women had a normal BMI. - The intake of micronutrients was adequate among both the girls and women, however, the energy intakes were inadequate.
Duncan et al. (2014)	Nested cross-sectional study. Anthropometric measurements and blood pressure were measured for all participants. A questionnaire was formulated and participants interviewed.	Manguzi, KwaZulu-Natal (Mahlungulu, Maputa, Mshundu, Thengane and Zama Zama).	Males (n=109) and females (n=391). Patients from 11 primary health care clinics.	- The results of the study indicated that 28% of the participants were overweight, 34% were obese and 4% were underweight. - This study concluded that most of the participants were overweight and obese; however, not many participants perceived that they were overweight.
Devanathan et al. (2013)	A cross-sectional exploratory study. Systematic sampling was used. Anthropometric measurements were taken and interviews were conducted.	Wentworth Hospital, Durban, KZN.	Urban black women (n=328) aged 19-70 years.	- The prevalence of overweight and obesity was 16% and 76%, respectively. - All participants had one or more chronic diseases of lifestyle. - The overweight and obese women who had one or more chronic diseases of lifestyle perceived themselves as thinner than they were.
Grobbelaar et al. (2013)	Anthropometric measurements were taken. A seven-day cycle menu was obtained and analysed.	Three residential care facilities in Durban.	Girls (n=33) and boys (n=110) aged 5-18 years	- Severe stunting was noted in 4.7% and 3.3% of the boys aged 4-8 years and 14-18 years, respectively. - Stunting affected 13.3% and 20% of girls aged 9-13 years and 14-18 years, respectively. - Wasting was noted in 6.7% of girls aged 9-13 years and 3.3% of boys aged 14-18 years. - Approximately 27% of girls aged 14-18 years were overweight and 33.5% of girls aged 9-13 years were at risk of becoming overweight.

Authors	Study design and methods	Area conducted	Participants	Findings
				- This study found that younger boys were more overweight than younger girls, while the opposite was noted for older boys compared to girls.

Table 3.5: Studies conducted to assess the nutritional status of the KwaZulu-Natal population continued.

Authors	Study design and methods	Area conducted	Participants	Findings
Grobbelaar et al. (2013)				- These authors found that the majority of children consumed all the food on their plate. - The energy, protein and carbohydrate intakes met 100% or more of the dietary reference intake (DRI). The children did not meet their calcium and iodine requirements. Further, a low intake of vitamin C was noted in both the older girls and boys. Recommended fibre intakes were not met by any of the groups. - Results from this study showed that fruit and vegetable intake was limited. On average, a single serving of 40 grams of vegetable was given to the children, whereas fruit was only given three times a week. - This study concluded that although large portions were given to the children, the foods were nutritionally inadequate and there was a poor intake of fruits, vegetables, milk and milk products.
Kolahdooz et al. (2013)	A cross-sectional study assessing dietary adequacy from a 24-hour recall. Participants were randomly selected.	Empangeni, KZN.	Rural adults (n=136) (52 males and 84 females).	- The energy content of both male and female diets exceeded the acceptable macronutrient distribution ranges (2200 and 1800 kCal, respectively). - Mean daily energy intake from carbohydrate for both males and females was higher than the estimated average requirements (EAR) (69% and 66%, respectively).

Authors	Study design and methods	Area conducted	Participants	Findings
				- Although the protein intake was adequate, plant sources of protein were consumed by the majority of the subjects. - The male participants consumed inadequate amounts of vitamin A, B_{12}, calcium and zinc. - The sodium intakes in all groups were higher than the EAR. - This study concluded that despite food fortification in South Africa, the majority of the study population consumed diets that contained inadequate amounts of vitamin A, B_{12}, C, D and E, calcium, zinc and pantothenic acid.

Table 3.6: Studies conducted to assess the nutritional status of the KwaZulu-Natal population continued.

Authors	Study design and Methods	Area conducted	Participants	Findings
Tathiah et al. (2013)	Secondary analysis of anthropometric data (weight and height) collected during the Human papillomavirus (HPV) vaccination demonstration project VDP in Zululand, SA during 2011.	Nongoma and Ceza, Zululand.	Girls aged 9-14 years.	- There was a high prevalence of stunting in the 11-12 year age group. - More than 50% of children aged 13-14 years were stunted. - Overall, 9% were overweight, 3.8% obese, 4% underweight and 9.2% stunted. - Both under and over nutrition was noted in girls between 9-14 years residing in two rural areas of KZN.
Spearing et al.(2012)	Random selection of persons living in rondavels of the same socioeconomic status. Data obtained for the recipes were analysed by Nutribase clinical Nutrition Manager, version 9.	A rural village surrounding Empangeni, KZN.	Males (n=34) and females (n=45) that prepared or purchased foods.	- Commonly consumed composite dishes were; fried beef, beef stew, beef soup, fried chicken, chicken soup, chicken stew, fish stew, dumplings, *ujeqe*, *phutu*, potatoes, stiff pap, beans, samp and beans, fried spinach and fried cabbage. - The study found that participants' diets contained good sources of protein, vitamins and minerals; however, it was high in fat.

Authors	Study design and Methods	Area conducted	Participants	Findings
Zhou et al. (2012)	A large population-based survey measuring BMI and blood pressure.	Hlabisa sub-district in rural Umkhanyakude.	BMI (n=2298) and blood pressure (n=2307). Females aged 15-49 years and males aged 15-54 years.	- More than half of the participants were overweight (58.4%). - Females were more likely to be overweight in comparison to their male counterparts.
Schoeman et al. (2010)	A cross-sectional study was conducted. Structured interview questionnaires were used and anthropometric measurements were taken (height and weight).	Umkhanyakude (n=398) (sub-district Jozini), Zululand (n=303) (sub-district Pongola) and OR Tambo (n=364) (sub-district Nyandeni)	Children between 0-59 months from UMkhanyakude, Zululand and OR Tambo.	- Thirty percent of participants in the two KZN districts had food gardens. - Half of the participants from the two KZN districts had experienced a food shortage in the previous 12 months. - Zululand had the lowest coverage of vitamin A supplementation. - Wasting was not a concern in this study. - The highest rates of stunting were seen in UMkhanyakude (6%), in the 12-23-month old group. - Stunting was higher in the second year of life. - The rates of overweight in the 0-23-month group were higher than underweight. - There was a high rate of obesity noted among the caregivers living in Zululand (60%).

Table 3.7: Studies conducted to assess the nutritional status of the KwaZulu-Natal population continued.

Authors	Study design and methods	Area conducted	Participants	Findings
Smuts et al. (2008)	A cross-sectional study was conducted. A questionnaire was used and anthropometric measurements were taken.	OR Tambo and Alfred Nzo district (Eastern Cape, n=1794) and UMkhanyakude and Zululand (n=1988).	Children 0-71 months old and caregivers.	- Between 16-18% of the children in both provinces were overweight. - Childhood malnutrition doubled from the first year of life to the second. Further, the prevalence of stunting was significantly high in the Nongoma district of KZN. - The mean BMI for the caregivers was above 25 kg/m^2 for all areas, except the UMkhanyakude district. - Obesity was higher among females; 45% of female caregivers in KZN were obese. - Only 9% of the caregivers in the UMkhanyakude district were underweight. - This study indicates that maternal over-nutrition and childhood malnutrition co-exist in both the Eastern Cape and KZN.
Jinabhai et al. (2003)	A cross-sectional survey conducted in 1995 on primary school children in KZN. Anthropometric data was collected. WHO and International obesity task force (IOTF) sets were used to measure nutritional status.	Eleven schools from the Vulamehlo district (rural) (n=802).	Grade 3 pupils, aged 8-11 years.	- Females had a higher prevalence of overweight and obesity in comparison to their male counterparts. - Levels of stunting ranged between 31.4-75% in this study. There was no clear link between stunting and obesity in this particular study.

The studies reviewed indicated that overweight and obesity affected females more than males. There are many possible reasons for the increasing prevalence of obesity in older girls of black ethnicity. Some studies have noted that overweight is perceived as being associated with wealth and a negative Human Immunodeficiency Virus (HIV) status (Duncan et al., 2014; Devanathan et al., 2013). Thinness is usually associated with illness and being HIV positive (Devanathan et al., 2013). From the studies reviewed, it was noted that some overweight and obese participants did not perceive themselves as overweight or obese. Furthermore, the participants did not recognise that they had a weight problem (Duncan et al., 2014; Devanathan et al., 2013). These social misconceptions further emphasise the need for education and awareness programmes, especially in poor rural communities (Duncan et al., 2014; Devanathan et al., 2013).

Over-nutrition increases the risk for chronic diseases of lifestyle (Devanathan et al., 2013). Various studies conducted in KZN have noted that although participants consumed large portions of foods, these foods were nutritionally inadequate. These foods were often high in energy, carbohydrates and sodium, but low in micronutrients such as vitamin A, vitamin B_{12}, vitamin C, vitamin D, vitamin E, zinc, pantothenic acid, calcium and iodine. A poor intake of fruits, vegetables, dairy products and fibre was noted (Kolahdooz et al., 2013; Grobbelaar et al., 2013; Spearing et al., 2012). These results indicate that there is a need to improve dietary diversity.

Based on the literature reviewed, it is evident that there is limited data on the nutritional intake of people living in KZN. It is also important to highlight that these studies were conducted in specific districts and sub-districts within KZN, and therefore do not necessarily reflect the nutritional status of the KZN population as a whole. Furthermore, the nutritional status of most of the localised areas within KZN has not been investigated. Each area has a population with a different income, socio-economic status and education level. These factors could possibly affect the nutritional status of the populations living within these districts. Therefore, it would be beneficial to investigate the nutritional status of people living in the districts and sub-districts of KZN, which have not been previously investigated.

3.3 Interventions to combat nutritional problems in KwaZulu-Natal

In response to the nutritional problems discussed thus far in this chapter, there have been a number of interventions employed by the South African DoH in order to combat these problems. These include food fortification, vitamin A supplementation, the prevention and management of malnutrition and dietary diversity (DoH, 2018; DoH, 2013; Swart et al., 2008; DoH and UNICEF, 2007). These are discussed further in this section.

3.3.1 Food fortification

The results of the 1999 NFCS study led to the fortification of foods to improve the nutritional status of South Africans (Labadarios et al., 2000). Food fortification is a cost-effective process that involves the addition of micronutrients to foods that are commonly consumed by vulnerable populations (Pretorius and Schönfeldt, 2012; Gillespie and Mason, 1994). As of October 2003, the South African Department of Health made it mandatory for all maize meal and wheat flour to be fortified with vitamin A, iron, zinc, folic acid, thiamin, niacin, vitamin B_6 and riboflavin (DoH and UNICEF, 2007). The decision to use maize meal and wheat flour were taken because the commonly consumed foods in SA were bread and maize (Labadarios et al., 2000). However, access to fortified foods remains problematic for poor people who rely on social grants to purchase food (NAMC, 2019; StatsSA, 2019; Labadarios et al., 2008). This implies that alternative solutions are needed to reach this vulnerable group.

3.3.2 Vitamin A supplementation

Vitamin A supplementation was another strategy employed by the South African DoH to assist in the alleviation of VAD. The KZN DoH guidelines state that all children over six months of age and under five months should receive a routine dose of vitamin A supplementation (DoH, 2013). A therapeutic dose is issued to all children that present to the hospital or clinic with severe malnutrition or signs of VAD (DoH, 2018; DoH, 2013). Although this programme is currently in place in KZN, not all children benefit from it. Health care facilities are usually far from where people reside and many people do not have money to transport children to health care facilities for supplements. Many children only receive a therapeutic dose of vitamin A on admission to hospital with malnutrition (DoH, 2018; DoH, 2013). Results of a study conducted in KZN indicated that there was poor utilisation of health care facilities. A high percentage of mothers (25%) living in KZN had no access to basic healthcare and many home deliveries were noted (Smuts et al., 2008). Another study conducted in UMkhanyakude and Zululand indicated that not all the children residing in these areas received vitamin A supplementation (Schoeman et al., 2010).

As alluded to earlier, other than financial constraints, poor maternal education is also a contributing factor to poor nutritional intake. Poor utilisation of health care facilities to obtain vitamin A supplementation may be attributed to low levels of education. Caregivers from these communities may be unaware of the importance of vitamin A supplementation (Faber and Benadé, 2007), thus resulting in a poor vitamin A status in children from these areas. Maternal education could play a significant role in reducing malnutrition, as mothers could be educated on the effective utilisation of basic resources as well as family planning. This could result in smaller families and improved nutritional status in children (Bain et al., 2013).

3.3.3 Prevention and management of malnutrition in KwaZulu-Natal

As mentioned earlier, both under- and over-nutrition co-exist (nDoH et al., 2017; Shisana et al., 2013). A possible reason why malnutrition is not detected early is that there is a poor utilisation of health care facilities due to location as well as financial constraints (Bain et al., 2013; Chopra et al., 2009; Smuts et al., 2008). Many caregivers only bring their children to health care facilities when they are ill and, in most cases, the children are severely malnourished. This is because there are a number of family members involved in the decision making on when to bring the child to the hospital (Haskins et al., 2017).

The old policy for treating malnutrition could be a contributing factor in improving the prevalence of wasting and underweight observed in KZN (nDoH et al., 2017; DoH, 2014; Shisana et al., 2013). The problem with the old policy was that the primary focus was on undernutrition in children. In KZN, since March 2018, the DoH has implemented standard operating procedures on the prevention and management of malnutrition in KZN. The new policy now incorporates children and adults, both under- and over-nutrition, as well as food security. Nutritional treatment is based on the diagnosis and either nutritional advice only or nutritional advice and nutritional supplements are issued (DoH, 2018). Table 2.5 indicates the nutritional supplements that are issued to children under five years and pregnant and lactating women. Different supplements are issued depending on the severity of the undernutrition and the age of the individual (DoH, 2018).

Table 3.8: Nutritional supplements issued to children under five years and pregnant and lactating women in KwaZulu-Natal (DoH, 2018)

Age group	Classification	Supplements
6-69 months	SAM	Outpatient treatment: RUTF (Tubs calculated on individuals weight)
6-11 months	MAM/NAM at Risk	Infant cereal and RUTF
12-59 months	MAM/NAM at Risk	EMM, RUTF and LFED
Pregnant	SAM/MAM/NAM	EMM and LFED
Lactating	SAM/ MAM/NAM	EMM, RUTF and LFED

RUTF: Ready to use therapeutic food; EMM: Enriched maize meal; LFED: Lactose free energy drink.

3.3.4 Dietary diversity

Dietary diversity is a long-term strategy used to assist in combating micronutrient deficiencies in SA (Latham et al., 2001). It involves adding a variety of foods to the diet such as fruit and vegetables, legumes, starch and animal products (Faber, 2002). In SA, KZN has the highest energy, protein, fat carbohydrate and fibre intake, however, micronutrient intake is poor (Labadarios et al., 2000). The 1999 NFCS study found that two thirds of South African children, including those residing in KZN, consumed only half of the RDA for calcium, iron, zinc, selenium, vitamin A, vitamin D, vitamin C, vitamin E, riboflavin, niacin, vitamin B_6 and folic acid (Labadarios et al., 2000). Unfortunately, the diets of the majority of people living in tribal and informal urban areas in South Africa, specifically KZN, lack dietary diversity (Bain et al., 2013; Smuts et al., 2005).

The commonly consumed foods in SA are mealie meal, white sugar, tea, brown bread, non-dairy creamer, brick margarine, chicken meat, full cream milk and dark green leafy vegetables (Steyn, 2003; Labadarios et al., 2000). A study conducted in a peri-urban site in Marianhill, Pinetown, KZN by Faberet al. (2013), showed that commonly consumed foods were sugar, maize meal porridge, bread, rice, cordial squash, hard margarine, tea and legumes, similar to other studies. On the other hand, the foods that were consumed by more than half the participants in rural KZN were maize meal and bread (Faber et al., 2015). From this it is evident that many of these diets are low in eggs, legumes, animal products and vitamin A-rich fruit and vegetables, due to the high costs of these foods (Labadarios et al., 2011; Labadarios et al., 2008; Faber et al., 2002).

3.4 Biofortification

The South African government has put various strategies in place to assist in the alleviation of malnutrition, including VAD (DoH, 2018; DoH, 2012; Swart et al., 2008; DoH and UNICEF, 2007). However, there is still a need for a complementary or alternate strategy to assist in the reduction of VAD. An effective and sustainable approach to address VAD could be through biofortification (Singh et al., 2016). Biofortification is a complementary strategy that involves the production of micronutrient-rich crops (Singh et al., 2016). The two methods used for biofortification are genetic modification and conventional breeding (Saltzman et al., 2013; Stevens and Winter-Nelson, 2008).

HarvestPlus has a biofortification programme that uses conventional breeding and has identified seven crops suitable for biofortification namely; beans (*Phaseolus vulgaris*), maize (*Zea mays*), pearl millet (*Pennisetum glaucum*), wheat (*Triticum aestivum*), cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), and rice (*Oryza sativa*). Of the seven crops, three crops (cassava, maize and sweet potato) have been identified for PVA-biofortification (HarvestPlus, 2018; WHO, 2018). White maize and cream-fleshed sweet potato (CFSP) are two commonly grown and consumed crops in SA [Department of Agriculture, Forestry and Fisheries (DAFF), 2017; Low et al., 2017] and are therefore ideal for PVA-biofortification (DAFF, 2017; Low et al., 2017; Mitra, 2012).

Some studies have indicated that there is a low acceptance of biofortified crops (Muzhingi et al., 2008; Stevens and Nelson-Winter, 2008; Pillay et al., 2011). However, there have also been reports of acceptance. Govender et al. (2014), found that caregivers were willing to give their infants porridge made with PVA-biofortified maize if it had a health benefit and was affordable and readily available. Additionally, Amod et al. (2016) reported that biofortified maize was acceptable to caregivers if it was consumed with another food item such as chicken stew. Thus, this strategy could be introduced to assist in improving the nutritional intake of poor rural people. However, before this is implemented, there is a need to determine the acceptability of biofortified foods in KZN.

3.5 Linking agriculture to address malnutrition

The traditional crops grown in KZN are maize, beans, potatoes, pumpkin, amadumbe and groundnuts (Modi et al., 2006). This traditional food basket highlights a lack of dietary diversity due to the lack of nutrient-dense foods. Due to the high cost of food, household and community food gardens are now being promoted as an alternative means of improving availability and access to nutritious foods, in poor rural households. A study conducted by Modi et al. (2006) found that wild vegetables contributed to the nutritional intake of the study participants from Ezigeni, a rural location in KZN. Wild vegetables are found in abundance when other vegetables are scarce (Modi et al., 2006). KwaZulu-Natal province has the second highest consumption of wild vegetables in SA with as many as 24 species of wild vegetables identified in KZN. The authors noted that although these vegetables were available, there has been a decline in their consumption. This could be attributed to the nutrition transition from traditional diets to more westernised diets. Increased consumption of wild vegetables could improve food insecurity by providing variety to a diet that is already nutrient deficient (Bvenura and Afolayan, 2015; Modi et al., 2006).

Although wild vegetables are not routinely consumed and communal gardens are not popular, many people grow foods for their own consumption. A study conducted by Faber et al. (2013), found that cabbage and pumpkin were popular items consumed in KZN. Fifty percent of the participants consumed cabbage and 63% grew their own pumpkin (Faber et al., 2013). Yellow vegetables, which are high in vitamin A were only consumed by a small percentage of children in KZN, which could be the reason for the poor vitamin A status (Faber et al., 2015). A possible intervention to assist in improving the nutritional status of vulnerable groups is to improve the consumption of wild vegetables. There has been a decline in the consumption of these often-free crops due to a lack of education. These crops are most often nutrient-dense and readily available. There are, however, challenges with the acceptability of some of these indigenous leafy vegetables. The acceptability of indigenous crops could be improved if people residing in rural communities were made aware of the health benefits associated with consumption of these crops, and incorporating them into already existing traditional dishes.

3.6 Traditional, indigenous and innovative crops with a potential to alleviate malnutrition in rural areas of South Africa, with a focus on KwaZulu-Natal

3.6.1 Alternative crops

Modi et al. (2006) reported that several indigenous crops in KZN could be utilised as food sources to diversify diets. The utilisation of these crops could provide nutrients that are currently lacking in the diets of poor rural people. For example, amaranth, blackjack and gallant soldier are popular indigenous crops in the Ezigeni area of KZN (Modi et al., 2006). Of these, amaranth contains vitamin C and iron, while blackjack contains vitamin A and vitamin E (Modi et al., 2006). A study conducted by Olumakaiye (2011) found that the vitamin C content of amaranth ranged from 0.79-1.7 mg/100 g and iron content ranged from 35.42-53.58 mg/100g (Olumakaiye, 2011). Amaranth contains non-haem iron, which is less well absorbed. However, amaranth also contains vitamin C, which when consumed together with a non-haem iron containing food, enhances the absorption of iron (Mahan and Raymond, 2017). It is important to note that the amount of nutrients obtained from these nutrient-rich foods depends on the amount eaten as well as preparation methods used. If prepared correctly and eaten in appropriate amounts, they could be used to diversify diets, especially where other vegetables are lacking (Modi et al., 2006). Mabhaudhi et al. (2016a) further emphasised that improved utilisation of alternative crops could contribute to improving dietary diversity and providing nutrient-dense foods to poor rural communities.

3.6.1.1. Sweet potato

There are four main root and tuber crops grown in Africa, namely cassava, yam, potato and sweet potato (Sanginga, 2015). From these crops, sweet potato is a staple food crop with a short cycle of between 3-4 months, thus suitable for double cropping (two or more crops grown on the same land). This is advantageous especially in months where other crops are not harvested (Sanoussi et al., 2015).

Creamed-fleshed sweet potato is the most commonly consumed sweet potato in Africa and contains a number of vitamins and minerals such as potassium, phosphorus, vitamins C, K, E, several B vitamins and dietary fibre. However, it lacks beta-carotene (Low et al., 2017; Mitra, 2012). It is high in carbohydrates, but low in protein and fat (Sanoussi et al., 2016). Orange-fleshed sweet potato is a new crop that could improve nutritional status; it not only contains the vitamins and minerals found in CFSP, but also contains beta-carotene, a good source of vitamin A (Mitra, 2012; Burr, i 2011).

Unlike PVA-biofortified maize, several studies have shown positive responses from participants toward OFSP, despite the orange colour (Pillay et al., 2018; Laurie et al., 2013; Tomlins et al., 2012; Chowdhury et al., 2011; Tomlins et al., 2007). A study conducted by Pillay et al. (2018) on infant caregivers, found that a complementary food made with OFSP was well accepted by the caregivers (Pillay et al., 2018). Additionally, another study that investigated the acceptance of OFSP by caregivers, reported that the OFSP was preferred to the pale-fleshed sweet potato for all sensory attributes investigated (Low and Van Jaarsveld, 2008).

Moreover, a study conducted in Uganda found that the deep orange coloured sweet potato was preferred over yellow or white sweet potato (Chowdhury et al., 2011). Biofortified crops have the potential to improve the nutritional status of individuals. These crops are better accepted if their non-biofortified counterparts are commonly consumed and known to individuals of a particular area. Orange-fleshed sweet potato is a good example of this crop and further research should be conducted on its nutritional composition and consumer acceptability.

3.6.1.2 Bambara groundnut

As mentioned earlier, a basic food basket in SA costs R883.16/month, which is a 3% increase from 2018 (NAMC, 2019). This price rise makes animal food products unaffordable to vulnerable households (NAMC, 2019). Plant-based proteins have also risen in price, however, they are still cheaper than animal sources (NAMC, 2019). Legumes, a widely consumed plant food is considered cheaper than animal sources and is a source of protein as well as carbohydrates, minerals and vitamins (Maphosa and Jideani, 2017).

Bambara groundnut (*Vigna subterranean*) is an indigenous crop in Africa and is well adapted to and thrives in the agronomical marginal regions (Chibarabada et al., 2017), where a significant proportion of vulnerable individuals live in SSA countries, including SA. Although bambara groundnut is grown in various parts of SA, it is an underutilised legume (Chivenge et al., 2015). It is a traditional crop grown by subsistence farmers in Mpumalanga, Limpopo, North-West province, Gauteng and KZN. Within KZN, this crop is grown in Greytown, Msinga, Nkamdla, Nguthuthu, Makhati and Kosibaai (Agriculture, Forestry and Fisheries, 2016).

Unlike other legumes, bambara groundnut contains the essential amino acid methionine (Lichtfouse, 2016; Stone et al., 2011; Mwale et al., 2007). Moreover, bambara groundnut has been found to have high levels of essential fatty acids, minerals and vitamins (Adeleke et al., 2018). The combination of a starch-based food such as maize and a legume such as bambara groundnut, would result in a good quality complementary protein (Lichtfouse, 2016; Mwale et al., 2007; Linnemann and Azam-Ali, 1993).

Unfortunately, despite the fact that bambara groundnut has the potential to form a complementary protein when consumed with a starch-based food item and is nutrient-dense, it is underutilised as a food source in SSA for a number of reasons (Bogart et al., 2012). Bambara groundnut exhibits antinutritional properties and hard-to-mill and hard-to-cook properties (Ndidi et al., 2014; Boye et al., 2010; Uvere et al., 1999). Additionally, the acceptability of bambara groundnut is a challenge, as many South Africans are unaccustomed to this crop (Oyeyinka et al., 2017). Although bambara groundnut is underutilised, a few studies conducted in SA have found that when bambara groundnut was prepared in some food types, it was positively accepted by consumers (Oyeyinka et al., 2018; Oyeyinka et al., 2017; Okafor et al., 2015). Furthermore, roasting, a heat processing method, has been found to improve the protein quality and taste of bambara groundnut (Okafor et al., 2015). Bambara groundnut is grown in various areas of KZN, thus it could possibly be accepted by impoverished communities to improve their nutritional status and dietary diversity. However, consumer acceptability needs to be further investigated in rural communities of KZN.

3.7 The way forward

Despite the implemented nutrition interventions, more work is required in order to improve the nutritional status of poor rural communities in KZN. The sustainable development goals (SDGs) one, two and three speak explicitly to the need to (i) end poverty, (ii) achieve zero hunger, and (iii) ensure good health and well-being (Sachs, 2012). Achieving these goals is important and discussions on how to do that currently dominate the post-2015 debate (Mabhaudhi et al., 2016a; Mabhaudhi et al., 2016b). It is evident that food and nutrition security remains a major problem in developing countries, including SSA (Temple and Steyn, 2016). A multi-disciplinary approach needs to be adopted to help address poor nutrition. Agriculture on its own is insufficient to provide nutritious produce. Poor utilisation of nutritious foods will not change the nutritional status of vulnerable people (Temple and Steyn, 2016).

Malnutrition is a serious public health concern, especially in children. A major contributor to poor nutritional status is poverty. Financial insecurity directly affects the utilisation of foods, which affects the nutritional status of vulnerable groups (Mabhaudhi et al., 2016a). According to Mabhaudhi et al. (2016a), agriculture should be recognised as a provider of nutrition and not as a provider of food. This emphasises the crucial role that agriculture and optimal utilisation of nutritious food play in improving the nutritional status of vulnerable populations. Before one can determine what optimal utilisation is for a specific population, one needs to determine which foods are consumed within that population group. Thus, it is important to assess food intake and identify sources of food among poor rural communities in KZN, in order to strengthen and diversify their food systems.

3.8 Conclusions

The trends in the nutritional status of population groups in the province of KZN are similar to national trends. There is a burden of both under- and over-nutrition. Undernutrition, specifically stunting, remains a problem in children. Over-nutrition, including both overweight and obesity are a problem among black African females. Data on the micronutrient status of both the rural and urban population as well as the nutritional status of the different population groups in KZN are limited. There is a gap in knowledge with regards to the nutritional status of rural population groups in the local municipalities of uMshwathi, Msinga and eThekwini, in uMgungundlovu and uMzinyathi Districts and the eThekwini metropolitan of KZN, which were the focus of the current study. This is attributed to the fact that national studies aimed to determine the nutritional status of the South African population and not specific sub-groups, within the population. Consequently, while such studies are plausible, they have limitations of over-generalising the nutritional status of specific sub-groups. Availability and access to nutritious foods is a major obstacle to improving the diets of poor rural people. The majority of them rely on social grants, which restricts them to a narrow food basket that lacks diversity. Under these circumstances, agriculture offers an opportunity to address the availability and accessibility of diverse nutrient-dense foods in poor rural communities. The promotion of household and community food gardens should be encouraged. Dietary intake, habits and patterns and nutritional status vary across the provinces in SA, as well as across defined population groups within a province. In order to implement targeted nutritional interventions, the nutritional status of specific provinces and defined local areas within a province should be determined. In that regard, this study aimed to assess the nutritional status (using selected anthropometric indices and dietary intake methods), of population groups in four defined rural areas in the local municipalities of uMshwathi, Msinga and eThekwini, in uMgungundlovu and uMzinyathi Districts and the eThekwini metropolitan of the KZN province.

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CHAPTER 4

ASSESSMENT OF THE NUTRITIONAL STATUS OF FOUR SELECTED RURAL COMMUNITIES IN KWAZULU-NATAL

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4.1 Introduction

Malnutrition, including both under- and over-nutrition, remains an ongoing challenge worldwide (Development Initiatives, 2017), especially in children (FAO et al., 2017). The 2018 Global Nutrition Report indicated that stunting and wasting affected 150.8 and 50.5 million children under five years, respectively, while 38.3 million children under the age of five years were overweight (Development Initiatives, 2018). In Africa, the percentage of stunted children under five years of age had increased from 50.6 million in 2000 to 58.7 million in 2017 (Development Initiatives, 2018). Child malnutrition is most prevalent in the sub-Saharan African region and there are inter-and-intra-country variations in malnutrition trends (Development Initiatives, 2017; FAO et al., 2017).

A number of national studies investigated the nutritional status of the South African population. The 2012 SANHANES-1 study, which investigated the nutritional status of all South Africans, found that underweight (5.5%) and wasting (2.5%) rates had improved in children (Shisana et al., 2013). While these results showed an improvement compared to previous national studies, the nutritional status of children and other vulnerable population groups such as women of childbearing age is still a cause for concern. The National Food Consumption Survey-Fortification Baseline (NFCS-FB) of 2005 showed that nationally, one out of five and one out of ten South African children were stunted and underweight, respectively (Labadarios et al., 2007). The prevalence of stunting among children from the 2012 SANHANES-1 and the 2016 South African Demographic and Health Survey (SADHS), which was 21.6% and 27%, respectively, has worsened since the 2005 NFCS-FB study (Shisana et al., 2013; nDoH et al., 2017). Stunting is a form of undernutrition and can result in fever, dehydration due to diarrhoea, compromised immunity and acute respiratory infections, which could lead to morbidity and mortality (Manary and Sandige, 2008; Escott-Stump, 2015; HST, 2016; UNICEF, 2016). This emphasises that stunting is a public health concern (Labadarios et al., 2007; Shisana et al., 2013; nDoH et al., 2017).

National studies conducted in SA between 1994 and 2005 revealed that the prevalence of VAD had doubled amongst children. The 2012 SANHANES-1 study reported that the prevalence of VAD in children was still high, despite a 20% drop since the 2005 NFCS-FB study (Labadarios and Van Middelkoop, 1995; Labadarios et al., 2000; Labadarios et al., 2007; Shisana et al., 2013). The 2005 NFCS-FB study showed that in children, the intakes of energy and several essential micronutrients including, calcium, iron, selenium, vitamins, D, C and E, riboflavin, niacin, vitamin B_6 and folic acid, was less than two-thirds of the recommended dietary allowance (RDA) (Labadarios et al., 2007).

Both under- and over-nutrition remain a concern among South African children (Shisana et al., 2013). Undernutrition leads to several health conditions, including those linked to protein-energy malnutrition (PEM) and micronutrient deficiencies (Faber and Wenhold, 2007; UNICEF, 2016; UNICEF et al., 2017). There are a number of factors responsible for the vicious cycle of child malnutrition as described by the UNICEF conceptual framework (UNICEF, 1998) (Figure 4.1). The main factors include poverty, food and nutrition insecurity, inadequate infrastructure and poor access to healthcare facilities and limited education (Smuts et al., 2008; Manary and Sandige, 2008; Chopra et al., 2009; Kimani-Murage et al., 2010; Bain et al., 2013).

There are several possible causes of childhood obesity. These include increased consumption of poor-quality high-energy foods, children born to mothers who were overweight or obese during pregnancy, overweight or obese parents, poor physical activity and metabolic disorders (Escott-Stump, 2015, p626). Overweight and obesity are serious health concerns, especially in children, as it increases the risk of other chronic diseases of lifestyle later, such as cardiovascular disease, hypertension and diabetes mellitus (Joubert et al., 2007; Escott-Stump, 2015). Stunting in children increases the risk of obesity in adulthood (FAO et al., 2017).

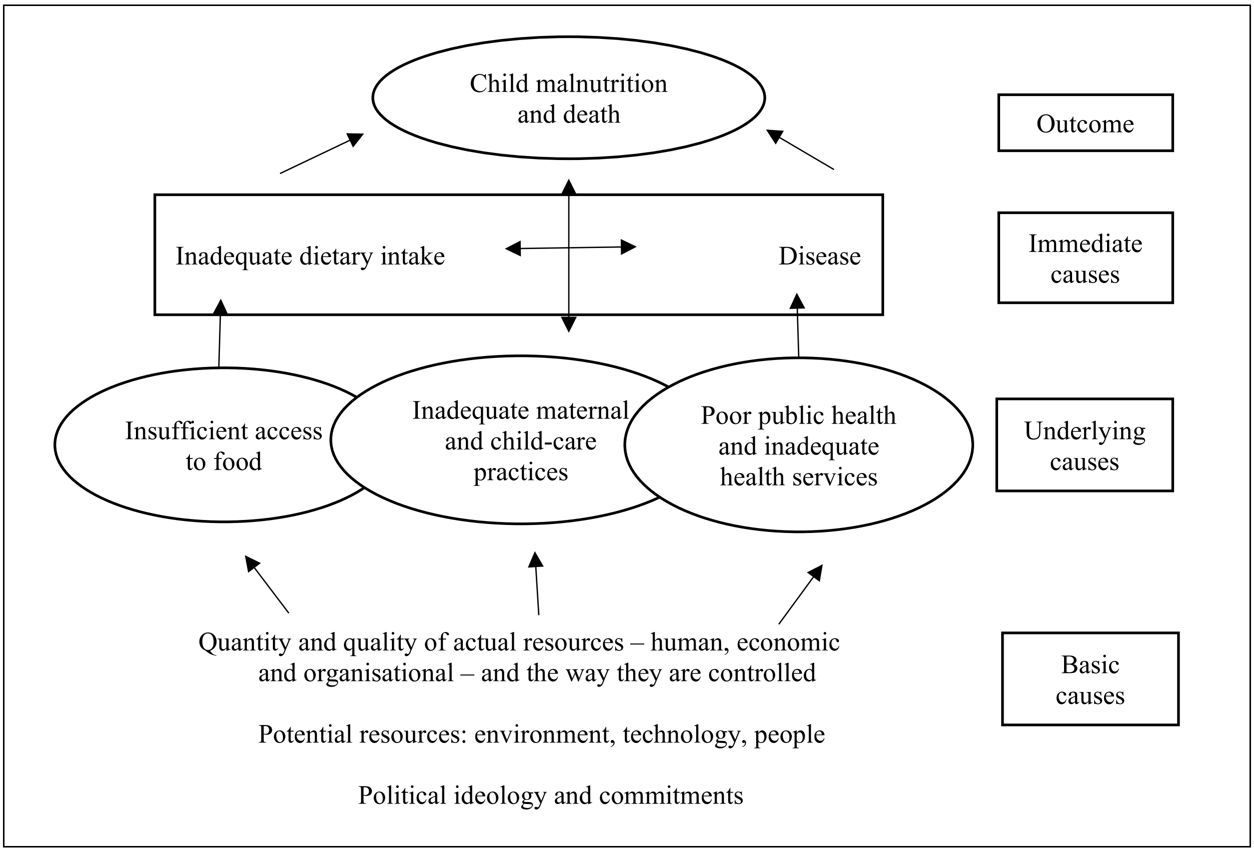

Figure 4.1: The UNICEF conceptual framework illustrating the causes of malnutrition (UNICEF, 1998).

The 2005 NFCS-FB found that one in ten South African children were overweight (Labadarios et al., 2008). A separate study conducted by Armstrong et al. (2006), using random sampling in South African children aged 6-13 years in five selected provinces during the Health of the Nation Study (2001-2004), found that the prevalence of overweight and obesity increased with age among black African girls. However, the opposite trend was observed with white girls. The combined percentage of overweight and obesity increased from 11.9% in black African girls aged six years, to 21.8% in black African girls aged 13 years (Armstrong et al., 2006). Similarly, a national study conducted in 2012 in SA, reported that the prevalence of overweight and obesity was lower in boys (16.5% and 7.1%, respectively) than girls (16.5% and 4.7%, respectively). These results were consistent for all age groups. KwaZulu-Natal was one of the provinces with the highest rates of obesity among children. The prevalence of obesity in KZN was 6.1% and 8.5% among boys and girls, respectively (Shisana et al., 2013). Furthermore, the SADHS study indicated that 13% of children under five years of age were overweight (Shisana et al., 2013; nDoH et al., 2017). These studies reiterate that over-nutrition is a serious health concern in children (Labadarios et al., 2008; Armstrong et al., 2006; Shisana et al., 2013; nDoH et al., 2017).

Over-nutrition is also prevalent among South African adults, especially women. On a national level, the 2016 SADHS indicated that one in five women were severely obese with a BMI > 35kg/m^2 (nDoH et al., 2017). The 2012 SANHANES-1 study revealed that the prevalence of overweight and obesity was higher among women (24.8% and 39.2%, respectively), compared to men (20.1% and 10.6%, respectively). The highest prevalence of overweight in men was found in the Western Cape (26.9%), KZN (23.7%) and Gauteng (21.0%). Furthermore, Gauteng (28.1%), Mpumalanga (26.2%) and KZN (25.2%) provinces had the highest prevalence of overweight, while KZN (44.0%), the Free State (43.0%) and the Eastern Cape (41.8%) provinces had the highest prevalence of obesity in SA (Shisana et al., 2013). There is a high prevalence of overweight and obesity among South African women, which negatively affects their health and nutritional status. Obesity can lead to a number of health-related issues such as arthritis, sleep apnoea, hypertension, diabetes, heart disease, breast cancer, stroke, gall bladder disease, and non-alcoholic fatty liver disease. Additionally, severely obese individuals are at higher risk of mortality due to the health conditions associated with obesity (Sizer and Whitney, 2017). A possible reason for the high rates of obesity seen among the South African population could be as a result of the nutrition transition, whereby refined diets high in sugar, fat and salt have replaced traditional diets, high in fibre (Faber and Wenhold, 2007; Schönfeldt et al., 2010; Lutter et al., 2011).

In most sub-Saharan African countries, including SA, the majority of rural communities consume diets that are limited in variety and inadequate in fruit and vegetables (WHO, 2013). As mentioned earlier, poverty is a major contributing factor to inadequate food intake, which leads to malnutrition. The 2015 statistics indicated that one in every two South Africans is living in poverty, which equates to approximately 30.4 million South Africans (StatsSA, 2017). Furthermore, South Africans from the black African ethnic group are particularly affected by poverty (47-53%) (Argent et al., 2009). The largest proportion of poor households are found in the KZN province in SA (StatsSA, 2019). Moreover, the KZN province has been one of the poorest provinces in SA since 2011 (Argent et al., 2009; StatsSA, 2017). Poor households are at a high risk of malnutrition, as they cannot afford a diverse diet (Wenhold et al., 2012; Mabhaudhi et al., 2016). Within KZN, 37.2% of poor households receive a child support grant (StatsSA, 2017), which is currently R430/month (RSA, 2019). In some instances, households depend solely on grants for purchasing food. A basic food basket in SA costs approximately R883.16/month and may be unaffordable to many impoverished people (NAMC, 2019). Several strategies have been proposed to address dietary diversity in poor rural households.

These include biofortification and the promotion of alternative crops that are nutrient-dense (Mabhaudhi et al., 2016).

It is evident that under- and over-nutrition co-exist in SA. Children are affected by stunting and over-nutrition, whereas adults, especially females, are affected by obesity. The diets consumed, especially by the black African rural communities lack dietary diversity. The studies described earlier aimed to determine the nutritional status of the South African population. However, dietary intake and nutritional status vary across the South African provinces, as well as across defined population groups within a province. Nutrition data from specific provinces and defined areas (or population groups) within a province are required, in order to implement targeted nutritional interventions. From the available literature, it seems that detailed studies of the dietary intake of defined population groups living in specific areas of KZN have not been conducted. To address this shortcoming, the current study aimed to assess the nutritional status of four selected rural communities in KZN, using selected anthropometric indices and dietary assessment methods.

4.2 Methodology

This study aimed to determine the nutritional status of black African individuals residing in four rural locations in KZN, using selected anthropometric[8] indices and dietary assessment[9] methods. These rural locations included Ward 8 of Swayimane, Umbumbulu (Ezigeni and Ogagwini villages), Tugela Ferry (irrigation scheme and dryland farmers), and Fountain Hill Estate (farm workers). Systematic randomised sampling was used to generate a sample of 50 households at Swayimane, Umbumbulu and Tugela Ferry and 21 households at Fountain Hill Estate. Purposive sampling was used to select households from Swayimane, Umbumbulu and Tugela Ferry in order to avoid collecting data from extended families and neighbouring households.

All members of the household were invited to participate in the study. However, the following inclusion criteria were used to recruit study participants for different parts of the study. For the food frequency questionnaire and the survey questions, a head of the household or the person responsible for purchasing food items was selected to provide information pertaining to food frequency and consumption. Anthropometric measurements and diet histories were taken from all participants. However, the anthropometric results were separated

[8] Weight, height and MUAC measurements were collected from children, while weight, height and waist circumference measurements were collected from adults.
[9] 24-hour repeated recall and a food frequency questionnaire.

into three categories; children (≥ 1 and ≤ 5 years), adults and women of childbearing age (16-35 years).

Pilot study participants and individuals who were not at home on the first day of data collection were excluded from the study. Specific households were targeted for the pilot study. These households were known to all research assistants and were not visited during data collection for the main study. Participants, who were not home on both non-consecutive days of data collection, were excluded as a diet history for two non-consecutive days could not be collected. Children who were at day-care, crèche or on a school feeding programme were excluded from the study because caregivers would not know the quantities and types of foods consumed by their children while away from home. As a result, the mothers or caregivers would not have been able to give an accurate 24-hour recall and accurately answer the food frequency questionnaire. Children who were not at a day-care or crèche on the day of data collection or had not attended a school feeding programme the day before, were included in the study. Written consent was obtained from all adult participants and caregivers of the children before data collection commenced.

4.2.1 Anthropometry

Anthropometric measurements, which involves measuring the physical attributes of an individual, are one of the easiest, most non-invasive and cost-effective methods to obtain data for assessing the nutritional status of both children and adults. Anthropometric measurements can indicate both under- and over-nutrition in both adults and children. Weight, height, MUAC waist circumference and BMI are common measurements used to assess the nutritional status of both adults and children (Shisana et al., 2013; DoH, 2018).

The fieldworkers were responsible for taking the anthropometric measurements. The fieldworkers were extensively trained on how to take anthropometric measurements and how to record it on the data collection sheets. A training manual (Supplementary Information 1) was developed and given to each fieldworker to use as a reference during data collection. This was done to ensure that the data was collected correctly. Furthermore, to ensure that data was collected accurately, trained postgraduate students from the University of KwaZulu-Natal (UKZN) supervised the community-recruited field workers. The UKZN postgraduate students were trained on how to correctly take anthropometric measurements and how to correctly record it on the data collection sheet. Furthermore, they were also trained to check data collection sheets for accuracy and missing data.

4.2.1.1 Children

Weight, height and MUAC measurements were collected from children ≥ 1 and ≤ 5 years.

Weight

Children in the study were weighed using a Seca 813 scale (GmbH and Co. KG., Hamburg, Germany). The scale was calibrated using a 1 kg packet of porridge at the start of the day, before taking any weight measurements and at the end of the day, after all measurements were taken. The scale read zero before and after each child was weighed. All children were weighed with minimal clothing, including diapers. Children wearing diapers had their diapers changed by their caregivers before the weight measurement was taken. All fieldworkers followed this standardised procedure and obtained weight measurements to the nearest 100 g. All measurements were taken in triplicate. The World Health Organisation (WHO) cut-offs in Table 4.1 were used to classify WFA and WFH in this study (WHO, 2017).

Table 4.1: Weight-for-age and weight-for-height classification for children under five years of age (WHO, 2017)

WFA	WFH[10]	Z score
Severely underweight	Severely wasted	Below the -3 SD[11]
Moderately underweight	Moderately wasted	Between -2 and -3 SD
Normal weight	Not wasted	Above -2 and below +2 SD
Overweight	Overweight	Above +2 SD

Length/Height

The length was measured using a Seca 210 (GmbH and Co. KG., Hamburg, Germany) mobile measuring mat for babies and toddlers (< 2 years old) and the height was measured using a Seca 213 (GmbH and Co. KG., Hamburg, Germany) portable stadiometer for children (> 2 years old). The mobile measuring mat was placed on a level sturdy surface before the measurement was taken. The caregiver was asked to remove the child's socks, shoes and any hair ornaments, before the child was placed on the mobile measuring mat. The caregiver placed the child on the mat with the child's head held in a straight position. The fieldworker ensured that the child's head was placed against the board. The fieldworker then used one hand to hold the child's legs

[10] The WFH can be used to classify severe acute malnutrition (SAM), moderate acute malnutrition (MAM), not acutely malnourished (NAM) and over-nutrition (WHO & UNICEF 2009).
[11] SD=Standard deviation.

down and the other hand to move the footboard towards the child's heels. The fieldworker ensured that the child's knees were not bent during this procedure. If assistance was needed, the fieldworker asked the caregiver to help. Trained fieldworkers measured length in triplicate and measurements were recorded to the nearest 0.1 cm.

When the fieldworker measured the standing height, the child stood with his/her feet slightly apart and his/her body in an upright position. The fieldworker ensured that the child was relaxed, with their arms at their side. The back of the child's head, shoulders and buttocks were against the board and knees were straight with the child looking straight ahead. The fieldworkers ensured that the head was in the Frankfort Plane (a horizontal line from the ear canal to the lower border of the eye socket that runs parallel to the board), before the measurement was taken (Lee and Nieman, 2010). The child took in a deep breath and the headboard was moved down until it rested firmly on the child's head. For children who could not follow commands, the fieldworker pressed the child's tummy gently and moved the headboard down. The height measurement was taken in triplicate to the nearest 0.1cm. The HFA was determined using the height or length measurements. Table 4.2 indicates the WHO classification for HFA using Z-scores (WHO, 2008a).

Table 4.2: Height-for-age classification for children under five years of age (WHO, 2008a)

HFA	Z score
Severely stunted	Below -3 SD
Moderately stunted	Between -2 and -3 SD
Normal height	Above -2 SD and below +3SD
Tall	Above + 3SD

Mid-upper arm circumference (MUAC)

The mid-upper arm circumference was taken by fieldworkers for all children ≥ 1 and ≤ 5 years. A Seca 201 fibreglass non-stretch measuring tape (GmbH and Co. KG., Hamburg, Germany) was used to measure the MUAC. The measurement was taken halfway between the acromion process and the tip of the olecranon process of the left arm. Fieldworkers ensured that the measuring tape was not too tight or loose when the measurement was taken. All measurements were taken in triplicate to the nearest 0.1 cm. Table 4.3 indicates the classification used to assess the MUAC (WHO, 2014).

Table 4.3: Mid-upper arm circumference classification in children under five years of age (WHO, 2014)

MUAC	Classification
Below 11.5 cm	SAM
11.5-12.5 cm	MAM
Above 12.5 cm	NAM

4.2.1.2 Adults

Weight

Weight in adults was measured using a Seca 813 scale (GmbH and Co. KG., Hamburg, Germany). The scale was calibrated using a 1 kg packet of porridge at the start of the day before taking any weight measurements and at the end of the day, after all, measurements were taken. The scale read zero before the participant was weighed. The participant was required to stand in the middle of the scale with his/her feet slightly apart and as still as possible. Similarly, to children, all heavy objects in pockets, excess clothing and shoes were removed before the participant was weighed.

Height

Height was measured in metres (m) using the Seca 213 portable stadiometer (GmbH and Co. KG., Hamburg, Germany). The participant was required to remove hats, hair ornaments and shoes before height was measured. The participant stood in an upright position with his/her feet slightly apart. The participant kept their arms at their side and looked straight ahead. The fieldworkers ensured that the head was in the Frankfort Plane (a horizontal line from the ear canal to the lower border of the eye socket that runs parallel to the board) before the measurement was taken (Lee and Nieman, 2010). The fieldworker ensured that the head, shoulders and buttocks were against the board and knees were straight, before the measurement was taken. The participant took in a deep breath and the fieldworker moved the headboard down until it rested firmly on the participant's head. All measurements were taken in triplicate to the nearest 0.1 cm.

Body mass index (BMI)

Weight and height measurements were used to determine body mass index (BMI) for individuals above the age of 18 years. The BMI was calculated by dividing the weight by the height in metres squared. The BMI helps to determine the nutritional status of an individual and risk for obesity-related conditions (Gibson, 2005; Shisana et al., 2013). Table 4.4 indicates the BMI classification for adults ≥ 18 years and Table 4.5 indicates the BMI classification used for individuals >16 and <18 years of age.

Table 4.4: Body mass index classification for adults ≥18 years (DoH, 2018)

Classification	BMI (kg/m^2)	Risk for co-morbidities
Underweight	< 18.5	Low
Normal	18.5-4.9	Average
Pre-obese	25.0-29.9	Increased
Obese class I	30.0-34.9	Moderate
Obese class II	35.0-39.9	Severe
Obese class III	≥ 40.0	Very severe

Table 4.5: Interpretation of body mass index cut-offs for individuals >16 and <18 years of age (WHO, 2017).

Classification	Standard Deviation (SD)
Severely underweight	< -3SD
Moderately underweight	< -2SD
Normal	Above -2SD below +1SD
Overweight	>+ 1SD
Obese	>+ 2SD

Waist circumference

Waist circumference measurements were taken at the umbilicus level (at the navel) for all participants. A Seca 201 fibreglass non-stretch measuring tape (GmbH and Co. KG., Hamburg, Germany) was placed in a horizontal plane over the navel of the participants, who wore a light layer of clothing when the measurements were taken. Waist circumference measurements were taken to the nearest 0.1 cm, in triplicate. A waist circumference greater than 88 cm in females and greater than 102 cm in males indicate risk for co-morbidities, including obesity (Gibson, 2005; WHO, 2008b). This classification was used to determine the risk for co-morbidities in this study.

4.2.2 Dietary intake

4.2.2.1 24-hour repeated recall method

In this study, a 24-hour repeated recall method was used to assess the dietary intake of the target group at a nutrient level. Trained fieldworkers interviewed the selected household members to obtain information about the types of foods consumed by individuals over the age of one year, over a 24-hour period for two non-consecutive days. This data set was collected randomly[12] on all days of the week, including weekends. The primary caregiver was interviewed in the case of children under four years of age. Children between 4-8 years of age were interviewed together with their primary caregiver. The information obtained from the 24-hour recall included portion sizes, preparation methods and ingredients used. Portion sizes were determined using measuring cups, plates of different sizes, cups, mugs, glasses, measuring spoons, dishing spoons and rulers. The first step of the 24-hour recall was to determine the time of day and place that the food was consumed. The participants were then asked to list the foods that they consumed at the times documented. Thereafter, participations were asked to give a description of the preparation methods used to prepare the meals. Participants then provided the research assistants with household measures used to serve the meals, so that portion sizes could be determined. Participants indicated to the research assistant whether this was the usual diet followed. Lastly, participants were asked if they took any vitamins or mineral supplements. This was done because the vitamins or mineral supplements would need to be included in the analysis of dietary intake. The 24-hour recall was conducted using standardised methods, similar to previous studies (Faber and Kruger, 2005; Spearing et al., 2012; Faber et al., 2013; Sheehy et al., 2013; Fagúndez et al., 2015).

4.2.2.2 Qualitative food frequency questionnaire[13]

A food frequency questionnaire is used to assess the frequency with which foods are consumed (Rodrigo et al., 2015). In the current study, a qualitative food frequency questionnaire was used to collect data to validate the 24-hour recall data (Faber and Kruger, 2005; Faber et al., 2013; Fagúndez et al., 2015). The food frequency questionnaire comprised of a list of 94 food items, subdivided into the following groups; cereals and grains, bread, biscuits and snacks, starchy vegetables, starchy foods prepared with fats, fruit, milk and milk products, vegetables, meat and meat substitutes, fats and other carbohydrates. The frequency was indicated next to each

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[12] There was no specific day allocated for each fieldworker to collect data. Data was collected on any day of the week as long as it was two non-consecutive days.

[13] Dietary intake was assessed on a food level (no nutritional analysis was conducted on the food items obtained from the food frequency).

food item listed. The frequency options were; never or less than once a month, 1-3 times a month, 2-4 times a week, 5-6 times a week, once a day, 2-3 times a day, 4-5 times a day or more than 6 times a day. The food frequency questionnaire that was developed was similar to those used in other studies (Coulston et al., 2013; Rodrigo et al., 2015). The trained fieldworkers recorded the responses of the study participants in the food frequency questionnaire.

4.2.3 Pilot study

A sample of 18 households was used for the pilot study. The pilot study was conducted to test the feasibility of the study design and the appropriateness of the questionnaires. This allowed for appropriate changes to be made before the main study was conducted. Anthropometric measurements (weight, height and MUAC for children and weight, height and waist circumference for adults) and dietary intake data (24-hour recall and food frequency) were collected at two selected sites (Swayimane and Tugela Ferry). The researcher supervised the fieldworkers on a one-on-one basis during the pilot study to ensure that the correct techniques for collecting anthropometric measurements and dietary intake were being followed. A post-pilot training session was conducted to revise the correct procedures to be followed during data collection. Each fieldworker received a training manual at the start of the training session (Supplementary Information 1).

4.2.3.1 Findings of the pilot study and consequent changes made to the methods

Several problems were encountered during the pilot study. Areas and households from Swayimane and Tugela Ferry were a far distance away from each other. More time was spent travelling to research sites and less time on data collection. For the main study, local members of the community were employed to assist with data collection. These members were extensively trained to collect data accurately. This saved on travelling time and more households were reached in a shorter space of time. The recruited fieldworkers resided in different areas within the study sites, which allowed for more households to be reached. Another problem encountered was that there were only one or two people available in some households, as the members of the households were working or had gone out. To overcome this, more field workers were recruited to assist with data collection, which resulted in more members of the household being interviewed at a given time. To ensure that data was collected accurately the trained fieldworkers from UKZN supervised the community-recruited field workers. The last problem encountered was that the large volume of paperwork involved was confusing to the fieldworkers. The loose pieces of paper could easily be misplaced. For the main study, data collection sheets were printed in a booklet for each household. This minimised confusion with regard to the information that needed to be collected. A training manual (Supplementary

Information 1) was developed and given to each field worker to use as a reference during data collection.

4.2.4 Data analysis

4.2.4.1 Anthropometry

Trained fieldworkers[14] captured the data onto Microsoft Excel spreadsheets. The data were cross-checked for accuracy by the researcher. The means and standard deviations for weight, height, MUAC and waist circumference were calculated using Microsoft Excel. The BMI was calculated using the equation, BMI = weight (kg)/height (m)^2. The BMI value obtained was coded and interpreted using the BMI classification (Table 4.4 and Table 4.5) (WHO, 2017; DoH, 2018).

4.2.4.2 Dietary intake data

The repeated 24-hour recall data was captured onto the Food Finder version 3 software programme of the Medical Research Council (MRC), SA, to determine the nutrients consumed over the two non-consecutive days. Nutrient values for fortified maize and bread were obtained from Food Finder. Data from Food Finder was exported to Microsoft Excel and mean daily nutrient intakes and standard deviations were calculated. Of the four Dietary Reference Intakes (DRIs), the Estimated Average Requirement (EAR) and Adequate Intake (AI) were used to assess the nutrient intake. The EAR was selected as it is the recommended DRI for assessing the nutritional status of population groups, defined by demographic profiles, including age, gender and lifecycle stage (Institute of Medicine, 2006). The EAR is the amount of a nutrient that is estimated to meet the needs of 50% of people in a defined population group and can be used to estimate the prevalence of inadequate nutrient intakes (EAR cut-point method). The EAR cut-point method can be used for most nutrients, except energy, as energy intake and expenditure are highly related (Institute of Medicine, 2001a; Murphy et al., 2006). The AI values were used for nutrients without an EAR. The AI is based on observed or experimentally determined estimates of the average nutrient intake of an apparently healthy population group. It is assumed that if the nutrient intake is above the AI, there is a low risk for inadequate intake (Institute of Medicine, 2001a; Murphy et al., 2006; Institute of Medicine, 2006).

4.2.4.3 Statistical analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS) version 25 (SPSS Inc., Chicago, IL, USA). Descriptive statistics, including means, standard deviations and

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[14] The researcher trained fieldworkers on how to enter data onto Excel spreadsheets and how to interpret the coded data.

frequencies, were computed where applicable. The Chi-square test was used to analyse for relationships among anthropometric data: BMI, WFH, BMI-for-age and MUAC. The Chi-square test was used to determine whether there were significant associations among the categorical variable responses selected. The binomial test was used to test whether a significant proportion of respondents selected one of two possible responses. When conditions were not met, the Fisher's exact test was used. The Chi-square test was also used to analyse for associations between anthropometric data and gender and age. The Fisher's exact test was used for MUAC and gender, MUAC and WFH and BMI and waist circumference. A p-value of <0.05 was considered statistically significant.

4.2.5 Ethical considerations

Ethical approval was obtained from the UKZN, Humanities and Social Science Ethics Committee (HSS/0256/016D) (Supplementary Information 2). Gatekeeper's permission was obtained from Swayimane, Tugela Ferry, Umbumbulu and Fountain Hill Estate (FHE). Each participant was required to sign a consent form before participating in the study (English version: Supplementary Information 3; isiZulu version: Supplementary Information 4). In the case of minors, the caregiver gave consent for the minor[15] to participate in the study. The consent form was read to the participants in isiZulu so that illiterate participants could understand the contents of the consent form. Thereafter, they were shown where to sign or initial on the consent form if they had understood what had been explained. If the study participants did not understand what had been explained, the explanation was repeated. The participants signed the form only after they had understood its contents.

[15] For the purpose of this study, a minor is any person under the age of 18 years.

4.3 Results

4.3.1 Demographic characteristics

The demographic characteristics of the study participants are presented in Table 4.6. Of the 466 participants (both adults and children) who participated, 63.7% (n=297) were female and 42.9% (n=200) were from Umbumbulu. Most of the participants were between 19-30 years (23.6%; n=110) and 31-50 years (20.2%; n=94), and the least number of participants were over 70 years old (3.2%; n=15). One hundred and sixty-five households participated in the study (Table 4.7).

Table 4.6: Demographic characteristics of study participants (n=466)

Characteristics	n	%*
Gender		
Male	169	36.3
Female	297	63.7
Participant distribution by study site		
Swayimane	139	29.8
Umbumbulu	200	42.9
Tugela Ferry	114	24.5
Fountain Hill Estate	13	2.8
Age (years)		
1-3	16	3.4
4-8	59	12.7
9-13	51	10.9
14-18	50	10.7
19-30	110	23.6
31-50	94	20.2
51-70	71	15.2
70+	15	3.2

* Percentage of sample (n=466)

Table 4.7: Household distribution by study site (n=165)

Study sites	n	%*
Swayimane	50	30.3
Umbumbulu	53	32.1
Tugela Ferry	49	29.7
Fountain Hill Estate	13	7.9

* Percentage of sample (n=165)

4.3.2 Anthropometry

4.3.2.1 Children

Weight, height and MUAC were measured in triplicate and the mean was calculated. The weight and height were used to classify WFA, HFA and WFL/WFH in children above one year and under five years of age. The WFL/WFH was used to determine the WHO Z-scores. The WHO classification was used to classify the degree of malnutrition in children. Results obtained are presented in Figure 4.2 (weight-for-age classification), Figure 4.3 (height-for-age classification), Figure 4.4 (weight-for-length classification), and Figure 4.5 (MUAC classification). Although not statistically significant, 30.8% (n=12) of children under five years were stunted (Figure 4.3) and 15.4% (n=6) of children under five years were overweight (Figure 4.4).

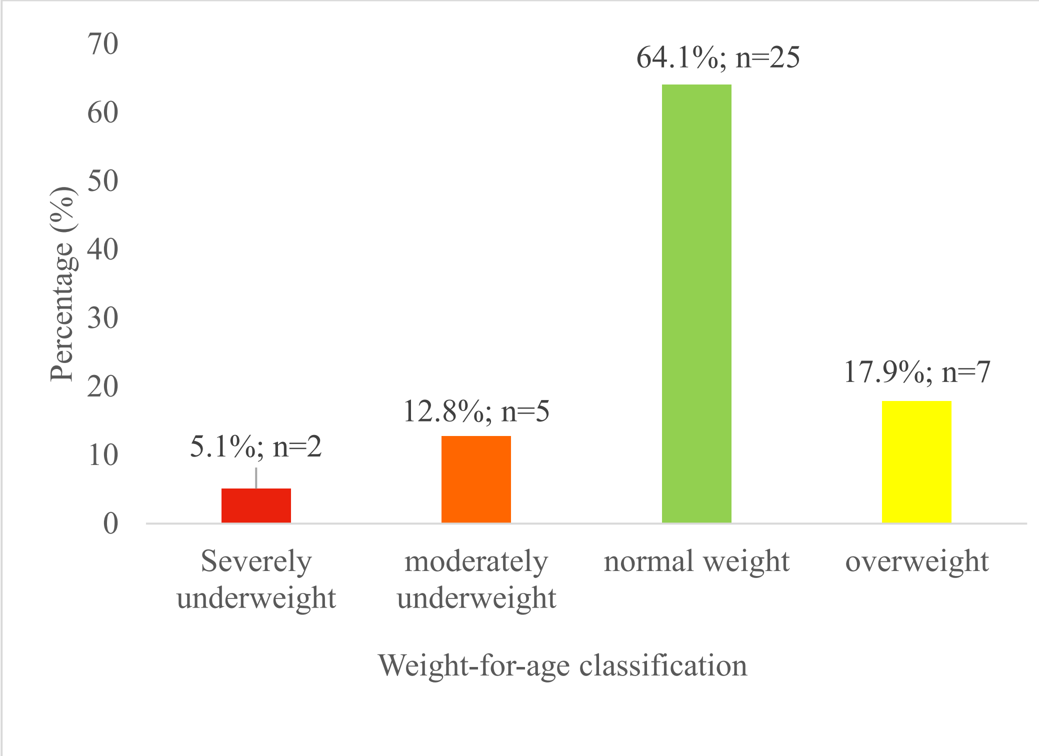

Figure 4.2: Weight-for-age classification for children under five years (n=39)

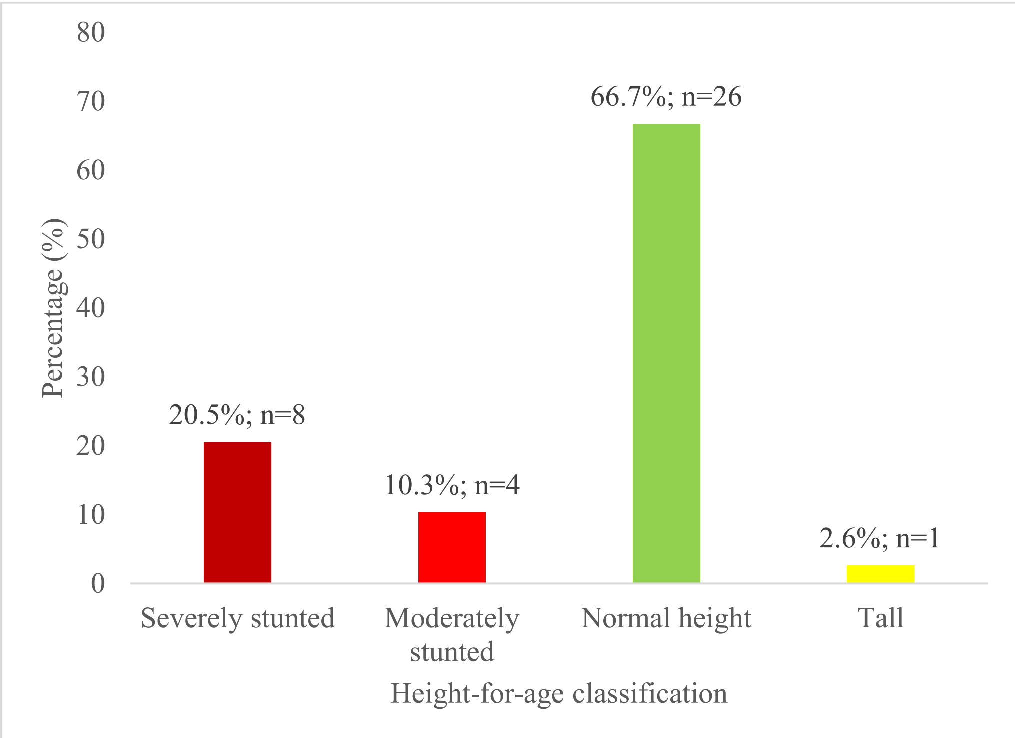

Figure 4.3: Height-for-age classification for children under five years[16] (n=39)

[16] Children under five years with a HFA greater than the +3SD were classified as tall.

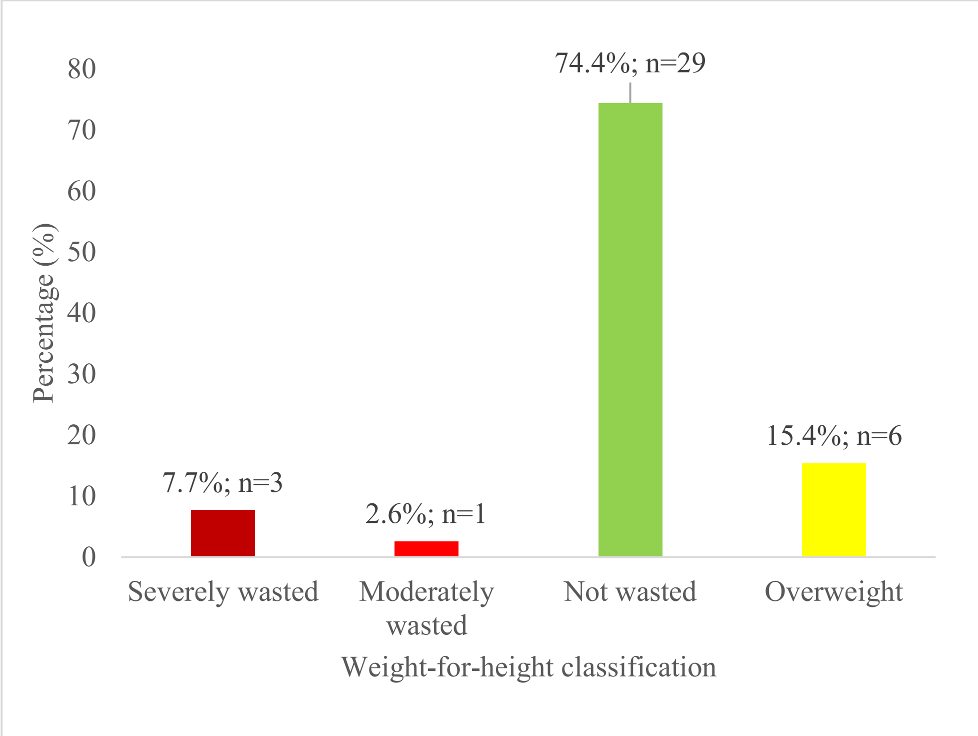

Figure 4.4: Weight-for-height classification in children under five years (n=39)

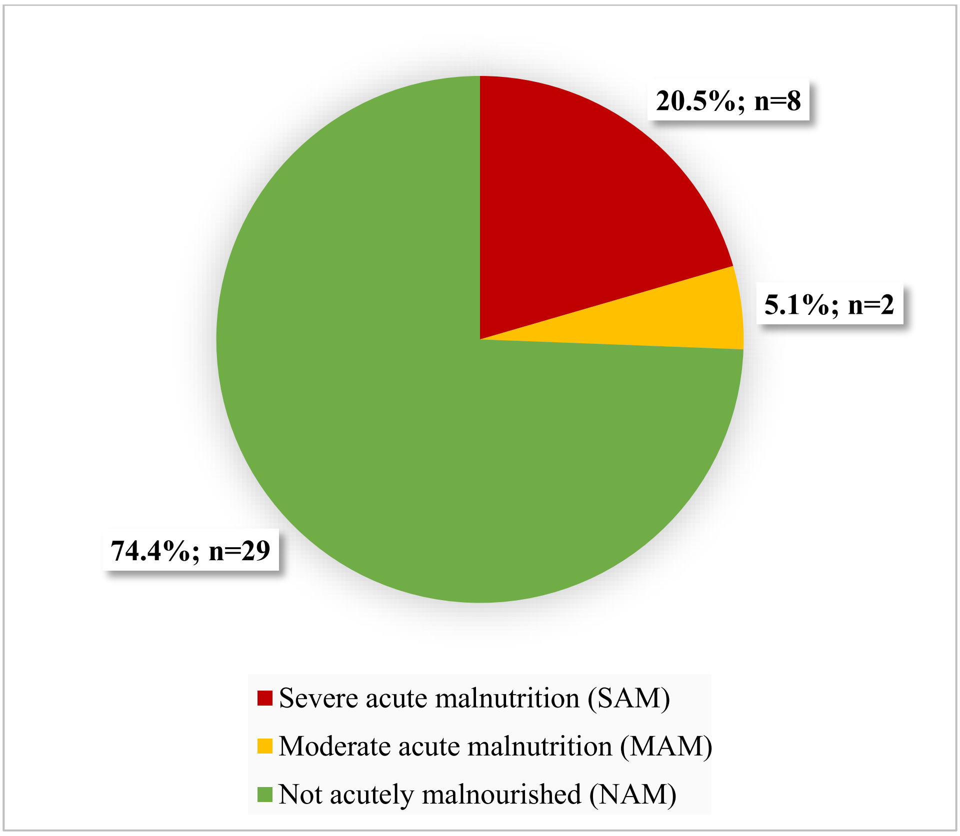

Figure 4.5: Classification of degree of malnutrition using mid-upper arm circumference in children under five years (n=39)

According to the Fisher's exact test, there was a significant relationship ($p<0.05$) between the MUAC and WFH classification for children aged 1-5 years. A significant number (37.5%; n=3) of those with a MUAC below 11.5 cm had a WFH Z-score below -3SD, indicating severe acute malnutrition ($p=0.046$).

4.3.2.2 Adults

BMI

Mean weight and height measurements were used to calculate BMI for adults. BMI distribution for all adults (Figure 4.6) and BMI classification by gender were determined (Table 4.8). Although not significantly different, it is important to note that there was a higher prevalence of over-nutrition than undernutrition at all four research sites (Figure 4.6). The majority of the study participants were either overweight (23.6%; n=76) or obese (29.4%; n=95), with a higher prevalence of overweight and obesity among females than males. However, the prevalence of underweight was higher in males (12.2%) than females (7.2%). A significant number ($p<0.05$) were found to be either normal (n=122; 37.9%) or overweight (n=76; 23.6%).

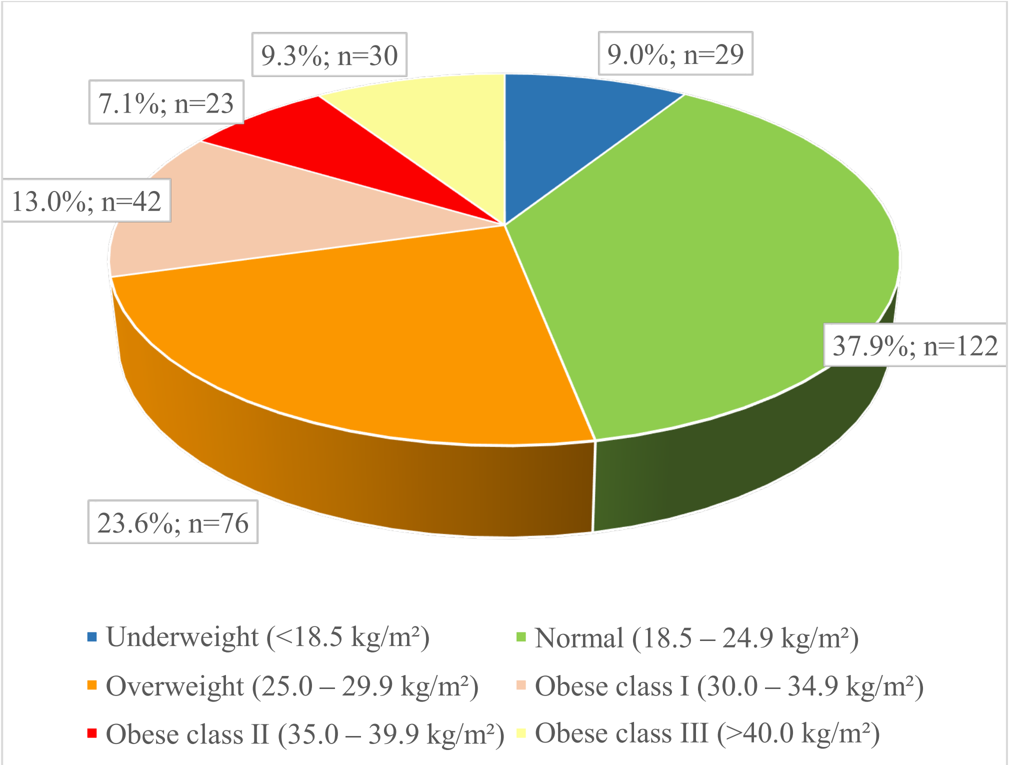

Figure 4.6: Distribution of body mass index for adults from four rural areas of KwaZulu-Natal (n=322)

Table 4.8: Body mass index classification for adults by gender (n=322)

	BMI classification (n=322)					
Gender	**Underweight (<18.5 kg/m^2)**	**Normal (18.5-24.9 kg/m^2)**	**Overweight (25.0-29.9 kg/m^2)**	**Obese class I (30.0-34.9 kg/m^2)**	**Obese class II (35.0-39.9 kg/m^2)**	**Obese class III (≥40.0 kg/m^2)**
Male (n=115)	14[a] (12.2%)[b]	65 (56.5%)	22 (19.1%)	9 (7.8%)	3 (2.6%)	2 (1.7%)
Female (n=207)	15[c] (7.2%)[d]	57 (27.5%)	54 (26.1%)	33 (15.9%)	20 (9.7%)	28 (13.5%)

BMI=Body mass index; [a] Number of males; [b] Percentage of males; [c]Number of females; [d] Percentage of females

Waist circumference

Figure 4.7 indicates waist circumference classification for adults by gender. The total number of weight circumference measurements obtained was lower than the total number of BMI measurements obtained, as the waist circumference measurements were either missing or not taken correctly. The measurements that were not taken correctly were discarded. According to the binomial test, a significant number (67.0%; n=213) had waist circumference measurements below 88 cm and 102 cm for females and males, respectively ($p<0.05$). The chi-square test of independence indicated that there was a significant relationship between gender and waist circumference ($p<0.05$). A significant proportion of males (92.9%; n=105) had a normal waist circumference and were not at risk for obesity-related diseases, while 47.3% of females (n=97) were ($p<0.05$).

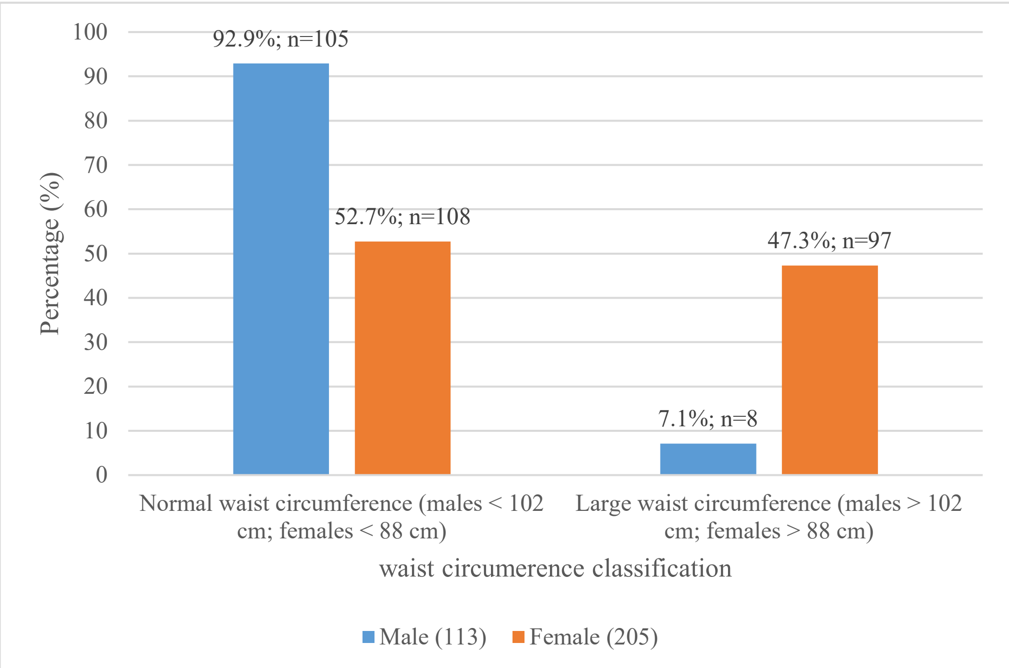

Figure 4.7: Waist circumference classification by gender (n=318)

Overweight and obesity

There was a significant relationship between BMI and risk for co-morbidities associated with waist circumference ($p<0.05$). Underweight and normal BMI was not associated with risk for co-morbidities and obesity, while individuals that were classified as obese class I, II and III had high risk for co-morbidities.

4.3.2.3 Women of child-bearing age (16-35 years)

Body mass index (Figure 4.8) and waist circumference (Figure 4.9) were determined for women aged 16-35 years to classify their nutritional status. Although not statistically significant, there was a higher prevalence of over-nutrition compared to undernutrition at all four research sites for females aged 16-35 years old (Figure 4.8).

Overweight and obesity

There was a significant relationship between BMI and risk associated with waist circumference ($p<0.05$). Individuals that were classified as obese class I, II and III were at high risk for co-morbidities according to waist circumference measurements.

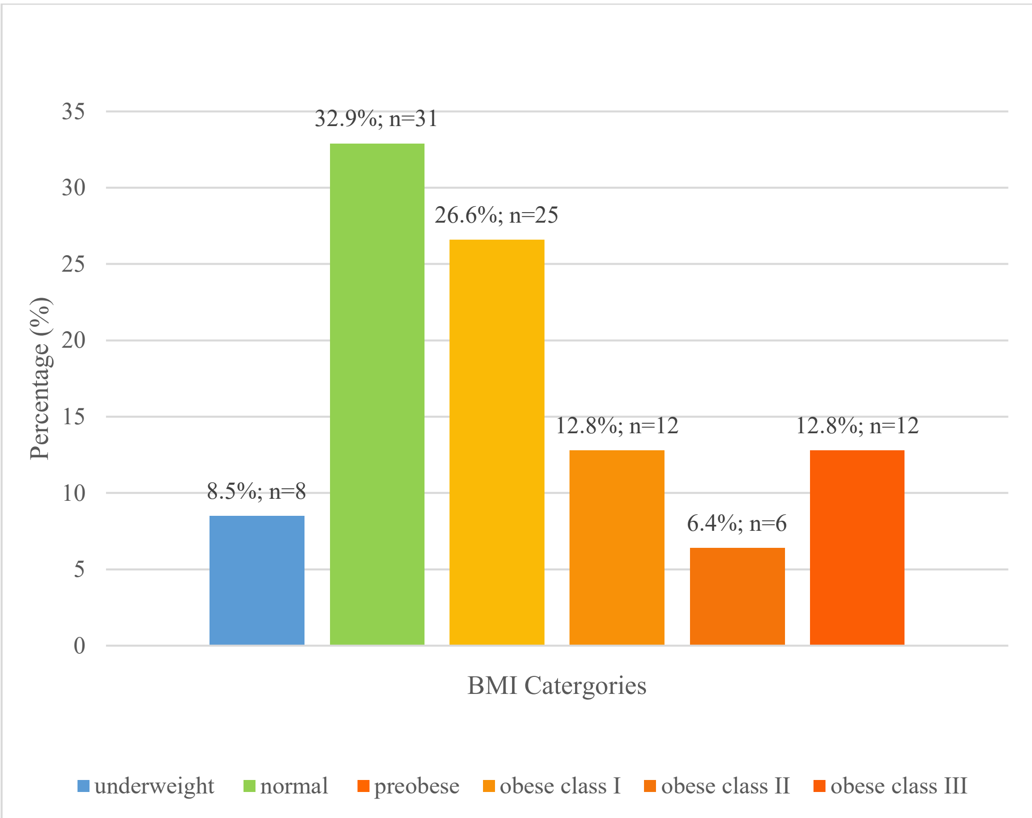

Figure 4.8: Distribution of body mass index for females aged 16-35 years (n=94)

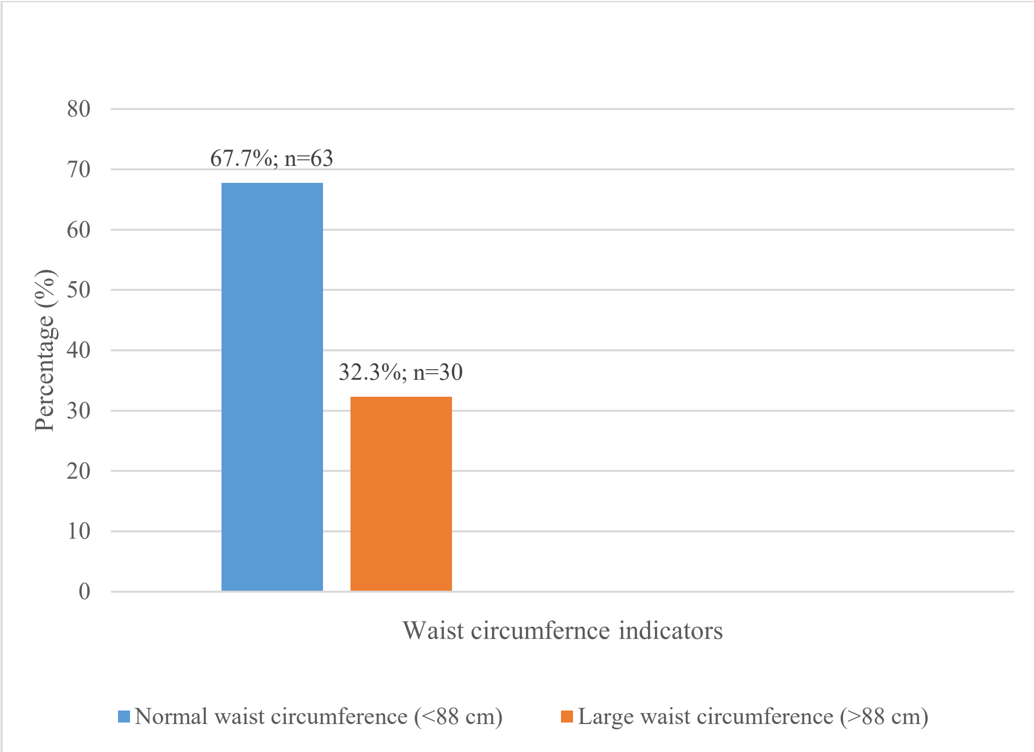

Figure 4.9: Waist circumference classification for females aged 16-35 years (n=93)

4.3.3 Dietary assessment

4.3.3.1 24-hour repeated recall

The 24-hour repeated recalls were analysed using the MRC Food Finder software and the mean nutrient intakes were compared with the EAR and AI, where relevant. The participants were divided into different age categories to determine the prevalence of inadequacy using the EAR cut-point method. The prevalence of inadequacy was considered high if the percentage of inadequacy was above 50%. The mean calcium and vitamin D values were compared against the AI value as there was no EAR value available for these nutrients. Assumptions were not made about the prevalence of inadequacy for calcium and vitamin D when the mean values were below the AI value. Results from the 24-hour repeated recall are presented in Appendix D (Supplementary Information). Table 4.9 indicates the prevalence of inadequate intake for each age group. The prevalence of inadequate intake of calcium and vitamin D could not be determined for all groups as the mean values for these nutrients were below the AI value, except for the 9-13-year-old males. From the results, it can be assumed that the males, 9-13 years old, consumed adequate amounts of vitamin D.

Table 4.9: The prevalence of inadequate nutrient intake for each age and gender group

Age group (years)	n	Gender	Nutrients with inadequate intake
1-3	16	Male and female	Dietary fibre, riboflavin, niacin, folate, vitamins A, E and K.
4-8	59	Male and female	Dietary fibre, zinc, riboflavin, folate, vitamins B_{12}, vitamin C, A, E and K.
9-13	37	Female	Dietary fibre, magnesium, phosphorous, zinc, riboflavin, folate, vitamins C, A, E and K.
9-13	14	Male	Dietary fibre, phosphorus, zinc, riboflavin, niacin, folate, vitamins C, A, E and K.
14-18	32	Female	Dietary fibre, magnesium, phosphorous, iron, zinc, thiamine, riboflavin, niacin, folate, vitamins C, A, E and K.
14-18	18	Male	Total protein, dietary fibre, magnesium, phosphorous, iron, zinc, thiamine, riboflavin, niacin, folate, vitamins B_6, B_{12}, C, A, E and K.
19-30	67	Female	Dietary fibre, magnesium, iron, zinc, thiamine, riboflavin, folate, vitamins B_6, B_{12}, C, A, E and K.
19-30	43	Male	Dietary fibre, magnesium, zinc, thiamine, riboflavin, niacin, folate, vitamins B_6, B_{12}, C, A, E and K.
31-50	62	Female	Dietary fibre, magnesium, iron, riboflavin, folate, vitamins B_6, B_{12}, C, A, E and K.
31-50	32	Male	Dietary fibre, magnesium, phosphorus, zinc, thiamine, riboflavin, folate, vitamins B_6, B_{12}, C, A, E and K.
51-70	51	Female	Dietary fibre, magnesium, iron, zinc, thiamine, riboflavin, niacin, folate, vitamins B_6, B_{12}, C, A, E and K.
51-70	20	Male	Dietary fibre, magnesium, iron, zinc, thiamine, riboflavin, folate, vitamins B_6, B_{12}, C, A, E and K.
Above 70	10	Male	Dietary fibre, magnesium, iron, zinc, thiamine, riboflavin, niacin, folate, vitamins B_6, B_{12}, C, A and E.
Above 70	5	Female	Total protein, dietary fibre, magnesium, iron, zinc, thiamine, riboflavin, folate, vitamins B_6, B_{12}, C, A, E and K.

Table 4.10: The mean frequency scores for commonly consumed food items

Food items	n[17]	Mean[18]	Food items	n	Mean	Food items	n	Mean
Oil	156	3.37	*Mageu*[19]	159	1.82	Beef, sausage	160	1.39
Onions	159	3.31	Orange	156	1.79	Samp and beans	160	1.37
Phutu[20]	158	2.63	*Maas*[21]	156	1.74	Steamed bread (*Ujeqe*)	99	1.34
Sweets	151	2.35	Fruit juice	159	1.73	Peanut butter	161	1.30
Brown bread/roll	145	2.33	Chicken, feet	159	1.70	Avocado, medium	157	1.30
Tomato	157	2.29	Cabbage	161	1.68	Grapes, small	157	1.27
Mayonnaise	159	2.28	Potato crisps	156	1.65	Organ meat (liver, kidney, heart)	161	1.23
Rice, white	156	2.15	Mealie/corn (on cob)	156	1.63	*Isijingi*[22]	24	1.21
Apple, unpeeled medium	159	2.13	Baked beans	160	1.61	Margarine, tub	159	1.21
Eggs	158	2.12	Sweet potato	157	1.62	Instant noodles	158	1.19
Chicken, stewed	159	2.11	Squash, butternut, pumpkin, winter squash	159	1.59	Scone	159	1.18
Chicken, cooked	161	2.06	*Amadumbe*[23]	159	1.58	Green leafy vegetable	23	1.17
Pepper	159	2.01	Beef, cuts	161	1.58	Cake, plain	160	1.16
White bread/roll	157	1.99	Margarine, brick	160	1.57	Biscuit	160	1.14
Maize meal porridge	158	1.93	Cornflakes	160	1.56	Ice cream	158	1.09
Full cream milk	160	1.91	Weetbix	155	1.54	Custard Ultra Mel	159	1.09
Potato, pumpkin	159	1.90	Fried chips	158	1.50	Pear	156	1.09
Mixed vegetable	160	1.88	Vetkoek (*amagwinya*)[24]	144	1.47	Low fat milk	160	1.07
Polony	159	1.87	Pilchards, canned	161	1.43	Beetroot	156	1.06
Banana, small	158	1.84	Cheese, cheddar	160	1.42	Canned fruit	159	1.03
Spinach	155	1.82	Maize meal porridge	157	1.41	Biscuit, filling	150	1.01

[17] n: Indicates the number of households that consumed that particular food item.
[18] The mean is expressed as an average score.
[19] *Mageu*: fermented maize meal.
[20] *Phutu*: maize meal cooked into a crumbly porridge.
[21] *Maas*: Fermented milk product.
[22] *Isijingi*: Soft porridge made with pumpkin.
[23] *Amadumbe*: A tuber that grows underground.
[24] *Amagwinya*: Traditional fried bread made with flour, yeast, sugar and salt.

Table 4.11: The mean frequency scores for commonly consumed food items continued.

Food items	n	Mean	Food items	n	Mean	Food items	n	Mean
Viennas	159	1.00	Beans, green	158	0.77	Future life	143	0.55
Rice, brown	158	0.99	Fish, hake	158	0.73	Guava	11	0.55
Pasta	160	0.98	Cupcake	159	0.72	Pork, ham	158	0.53
Yoghurt, flavoured	157	0.94	Popcorn with oil	158	0.72	Yoghurt low fat	158	0.46
Fruit salad, fresh	159	0.94	Holsum	159	0.71	Pork sausage	161	0.44
Chocolate	160	0.93	Custard, sweetened full cream	157	0.68	Morvite	12	0.42
Beef, patty	158	0.89	Cucumber	160	0.65	Oats	157	0.38
Lettuce	160	0.88	Maltabella	157	0.64	Pronutro	156	0.37
Beans, lentils and peas (cooked)	160	0.88	Fish, tuna	156	0.63	Cauliflower	160	0.36
Beef mince	159	0.87	Pork, bacon	160	0.63	Yoghurt plain	158	0.35
Peas, green	157	0.86	Mushroom	158	0.61	Lentils	159	0.31
Bean salad, no oil	159	0.85	Cream crackers	160	0.61			
Cake, with icing	161	0.83	Broccoli	159	0.58			

4.3.3.2 Food frequency questionnaire results

The food frequency questionnaire data was collected from either the head of the household or the person responsible for purchasing the groceries for the household. Appendix K (Supplementary Information) indicates the food items consumed by households and the frequency of consumption. Table 4.10 indicates the average frequency score using an ordinal scale. The mean value was determined using the average frequency scores. These scores were used to identify which food items were consumed the most and the least.

4.4 Discussion

The purpose of this study was to assess the nutritional status of communities residing in four rural areas of KZN using selected anthropometric indices and dietary assessment methods.

4.4.1 Anthropometry

4.4.1.1 Children

The results indicate that under- and over-nutrition co-existed in children. In comparison to other South African studies, the prevalence of stunting in children (30.8%) in the current study was higher than the 2016 SADHS, which found that 27% of children under five years were stunted (nDoH et al., 2017). The prevalence of stunting in children in the current study was also higher than that reported by earlier national studies. The 2005 NFCS-FB study indicated that one in five children in SA was stunted, and the SANHANES-1 study indicated that 26.5% of South African children aged 1-3 years were stunted (Labadarios et al., 2008; Shisana et al., 2013). This study also found a higher prevalence of stunting in children compared to a study conducted in the uMkhanyakude and Zululand districts of KZN, which found that 24% and 26% of children were stunted, respectively (Schoeman et al., 2010). However, the results of the current study should be interpreted with caution because a small sample was taken from the population of children under five years of age. Another limitation was that anthropometric data were collected only from children who were present at the time of the study. It is recommended that these limitations be addressed in future studies.

Stunting is a chronic form of undernutrition which is classified by a HFA < -2SD and results from a lack of adequate energy or nutrient intake for a prolonged period (WHO, 2008a). There are many negative consequences to stunting and it can be detrimental. It can lead to poor performance in school and poor social and mental development, resulting in a poor quality of life (Escott-Stump, 2015; HST, 2016; UNICEF, 2016). Furthermore, stunting could lead to obesity in adulthood, which increases the risk for health-related conditions (Escott-Stump, 2015; HST, 2016; UNICEF, 2016). The effects of stunting become irreversible after two years of age (HST, 2016).

Although undernutrition is a serious problem in SA, over-nutrition is also of concern. This study found that 15.5% (n=6) of children under five years were overweight. This result was expected as Southern Africa accounts for 12% of overweight children in Africa (FAO et al., 2017). The current study results for overweight in children under five years was higher than other national studies (Labadarios et al., 2008; Shisana et al., 2013; nDoH et al., 2017). The 2005 NFCS-FB found that one in ten South African children were overweight (Labadarios et al., 2008), whereas the 2016 SADHS found that 13% of children under five years old were overweight (nDoH et al., 2017). The percentage of overweight children increased between 2005 and 2016 (Labadarios et al., 2008; Shisana et al., 2013). Furthermore, the 2012 SANHANES-1 study indicated that KZN was one of the provinces with the highest rates of obesity among children (Shisana et al., 2013). As mentioned earlier, in the current study, measurements were obtained from a small sample and results should be interpreted with caution. However, obesity in childhood is still an issue and is on the rise in SA, especially in KZN. Childhood obesity has been linked to a number of chronic diseases in adulthood such as cardiovascular disease, hypertension and diabetes mellitus (Escott-Stump, 2015).

It is important to remember that caregivers are responsible for the types of food and portion sizes given to children (Omidire et al., 2015). Food choice is influenced by many factors such as affordability, seasonality, cultural practices and personal preferences (Kearney, 2010; Wenhold et al., 2012; Kamphuis et al., 2015; Emily et al., 2017). Caregivers are more likely to give their child a food item that is affordable and positively affects their child's health (Govender et al., 2014). Thus, if caregivers are educated on nutritious foods, they would be able to make more informed choices, leading to an improved nutritional status for their children. A good nutritional status can be achieved not only by having access to nutritious foods but also by correct utilisation of these foods. Many rural communities cannot afford a variety of foods. However, if healthier cheaper food types were provided such as underutilised and biofortified crops and caregivers were educated on the correct processing and preparation methods of these crops, the nutritional status of vulnerable children could be improved.

4.4.1.2 Adults

The prevalence of obesity among females (39.1%) in the current study is similar to the 2016 SADHS, which found that one in five women were severely obese and the SANHANES-1 study, which found that 31.8% of females living in rural areas were obese (Shisana et al., 2013;

nDoH et al., 2017). Black African women have been previously reported to be most at risk of obesity (Puoane et al., 2002; Senekal et al., 2003), similar to the current study. The prevalence of overweight and obesity was higher in females than males in the current study, which was similar to the 2016 SADHS and 2012 SANHANES-1 study (Shisana et al., 2013; nDoH et al., 2017). The prevalence of overweight and obesity is on the rise in all provinces of SA, with the KZN province having the second highest prevalence (Ziraba et al., 2009; Shisana et al., 2013). This is a major concern as overweight and obesity increases the risk of non-communicable diseases such as cardiovascular disease (CVD), certain cancers, type 2 diabetes and musculoskeletal disorders (WHO, 2011a; Nyberg et al., 2018).

Waist circumference measurements and BMI confirmed that females were more at risk for chronic diseases of lifestyle than males. This is a problem as obesity affects women at every stage of the life cycle (Hawkins et al., 2018). It can have economic, biological and psychosocial implications. A child born to a pregnant, obese mother is at increased risk of chronic diseases, thus negatively affecting the health of future generations (Hawkins et al., 2018). This study indicated that individuals with a higher BMI also had a higher waist circumference, indicating an increased risk for obesity-related diseases. A study by Zhu et al. (2004), conducted on 8712 white men and women indicated that a combination of both a high BMI and waist circumference could increase the risk for CVD (Zhu et al., 2004). Another study by Gierach et al. (2014), found a direct relationship between waist circumference and BMI. High amounts of abdominal fat were noted in overweight males and normal females (Gierach et al., 2014). The risk for comorbidities due to a large waist circumference can be independent of BMI (Jansen et al., 2002; Wildman et al., 2005).

The study findings indicate that there is an urgent need for interventions to address the high prevalence of overweight and obesity. A possible strategy to address this problem could be to increase the nutrient density of foods consumed by vulnerable individuals through the introduction of food types that are more accessible and affordable, such as biofortified foods and alternative crops. However, the acceptance of alternative food types would need to be investigated. The prevalence of obesity could be reduced by educating the affected population groups on optimum methods of food preparation and processing, and emphasising healthier cheaper food types and control of portion sizes.

4.4.1.3 Women of childbearing age (16-35 years)

As mentioned earlier, black African women were reported to be at greatest risk for obesity in SA (Puoane et al., 2002; Senekal et al., 2003). This study found that among the females aged

16-35 years, there was a higher prevalence of overweight and obesity (n=55; 58.5%) than underweight (n=8; 8.5%). This was an expected result for rural areas of KZN as the 2012 SANHANES-1 study reported that, on a national level, the prevalence of obesity in women from the rural formal and rural informal populations was 31.8% and 37.6%, respectively (Shisana et al., 2013). Furthermore, the SANHANES-1 study found that the prevalence of overweight and obesity was high among women (24.8% and 39.2%, respectively), which was similar to findings of the current study (26.6% and 31.9%, respectively). Additionally, the prevalence of overweight and obesity has been found to increase with age in black African females (Smuts et al., 2008; Zhu et al., 2012; Devanathan et al., 2013; Duncan et al., 2014).

A possible reason for the increase in obesity could be due to incorrect perceptions. Many women residing in rural areas often do not perceive themselves as being overweight or obese and do not consider their weight to be a problem (Devanathan et al., 2013; Duncan et al., 2014; Okop et al., 2016). Another reason could be due to the negative stigma associated with thinness. In some cultures, thinness is associated with illness and HIV, whereas obesity is associated with wealth, happiness and good health (Devanathan et al., 2013; Duncan et al., 2014).

The results of this study indicate that there is a need to address obesity, especially in KZN. It is a challenge to address the problem of incorrect perceptions of body weight as rural black African women have strong cultural beliefs (Duncan et al., 2014). In most cases, individuals that are most affected by overweight and obesity are women that have less than a primary school education (Ziraba et al., 2009). Thus, nutrition education has the potential to contribute to improving the nutritional status of these communities. Women are usually responsible for preparing meals and for feeding children. If nutrition education is targeted at women and they are taught how to modify their diets or prepare nutritious alternative crops, they are more likely to prepare this for themselves and their families, which may result in an improved nutritional status (Omidire et al., 2015). Although the impact of education on food choice was not assessed in the current study, the low level of education of a substantial proportion of the study participants could have contributed to the over-nutrition and undernutrition observed. This hypothesis should be tested in future studies.

4.4.2 Dietary assessment

4.4.2.1 24-hour repeated recall

The results from the 24-hour repeated recall suggest that not all age groups met their nutritional requirements. Protein and carbohydrates were consumed in large quantities, whilst the diet lacked adequate amounts of dietary fibre in most age groups. Although protein was consumed in larger amounts, it was obtained mainly from plant sources, rather than animal sources. These results were similar to results from a study conducted by Kolahdooz et al. (2013), where most of the study participants consumed protein from plant sources. Animal sources of protein are known to contain essential micronutrients, fatty acids and high-quality protein (Schönfeldt et al., 2013). The poor dietary intake of animal proteins could be due to poor availability and accessibility, especially in rural areas (Schönfeldt and Hall, 2012). Many rural communities do not have access to a variety of foods and rely solely on *Spaza* shops (informal convenience shops found in rural areas that sell a small range of food items). These shops do not sell a variety of food items and the food that they stock is usually sold at increased prices and are most often unaffordable. Many rural households purchase foods that are starch-based such as maize meal, as these are cheaper when bought in bulk (Temple and Steyn, 2009; Battersby and Peyton, 2014). A review conducted by Schönfeldt and Hall (2012), points out that plant-based shelf-stable staples are a predominant part of the diet in disadvantaged communities (Schönfeldt et al., 2013). In this study, the food frequency confirmed that *phutu* (n=158) which is made from maize meal, was one of the most frequently consumed food items.

Starch-based foods consumed alone are not nutritionally adequate. However, animal-based proteins are unaffordable to most people. Legumes could be considered as a good alternative to animal protein (Huma et al., 2008). It contains protein as well as fibre which contributes to satiety, resulting in the consumption of smaller portions of food (Slavin and Green, 2007), thus preventing overeating and weight gain. When a starch-based food is consumed together with legumes, it provides complementary proteins. Starch-based foods lack lysine and tryptophan that is found in legumes, and the sulfur-containing amino acids that are limiting in legumes are found in starch-based foods (Serna-Saldivar, 2010). The combination of legumes and starch-based foods together could be considered a more nutritious alternative to starch-based foods consumed alone.

The provision of nutrition education on dietary modification of foods currently consumed and portion control are other strategies to improve nutritional status. Portion control can help to maintain weight. If more calories are consumed than expended, it would result in weight gain (Hawkins et al., 2018). Educating individuals on the correct portion sizes and affordable healthy food choices could result in a change in lifestyle, resulting in a reduction in obesity. However, education alone is not enough as compliance is not always guaranteed. Thus, follow-up sessions and monitoring dietary intake for a certain period of time could help improve eating habits and reduce obesity. Sixty minutes a day of physical activity should be promoted in order to assist with weight loss (Hawkins et al., 2018).

More than 50% of the sample of children and adults had inadequate intake of the following nutrients: magnesium, phosphorus, zinc, riboflavin, niacin, folate, vitamin B_{12}, vitamin A, vitamin C, vitamin E and vitamin K, for most of the age groups. These results were similar to results from the 1999 NFCS, which indicated that South African children, especially rural children, had a low intake of the following micronutrients: vitamin A, calcium, iron, zinc, folate, vitamin B_6, niacin, riboflavin, vitamin C and vitamin E (Labadarios et al., 2000). Possible reasons for the inadequate nutrient intake could be due to seasonal availability of foods or foods not consumed at the time of data collection. The current study results should be interpreted with caution as 24-hour recalls were only collected for two days. Dietary data is very subjective and there is room for inaccurate reporting and analysis (Shim et al., 2014).

Micronutrient deficiency is defined as an inadequate status of one or more micronutrients and is just as serious as under- and over-nutrition. Although micronutrient deficiency is a problem, it is not routinely treated in developing countries. It can result in several health conditions, including growth retardation and delayed development (Bain et al., 2013). Thus, it is important for individuals to consume good quality, nutrient-dense foods in order to avoid micronutrient deficiencies, however, this is not always possible due to the high cost of these foods. The most common micronutrient deficiencies observed in developing countries are iron, iodine, zinc and vitamin A (Bailey et al., 2015). Amongst the micronutrient deficiencies, iron and vitamin A are of concern in South Africa. Many South African national studies have shown this to be true, especially in vulnerable groups such as women and children (Labadarios and Van Middelkoop, 1995; Labadarios et al., 2000; Smuts et al., 2005; Bain et al., 2013; Shisana et al., 2013).

The current study results indicated that 50% of the females aged 14 to > 70 years had an inadequate intake of iron. The low intake could be due to the high cost of iron-rich foods. As mentioned, many rural communities rely predominantly on starch-based diets, which contain limited amounts of fruits, vegetables and animal protein (Shisana et al., 2013). A study conducted in 2016 on 651 healthy South African adults indicated that the prevalence of anaemia was 12.6%, which was lower than the findings of the 2012 SANHANES-1 study (Phatlhane et al., 2016). Further, both studies found the prevalence of anaemia to be higher among females than males (Shisana et al., 2013; Phatlhane et al., 2016). This study showed that dietary intake of iron was low and females were at higher risk of becoming iron deficient or further worsening their already poor iron status. This is a major concern especially for pregnant women as iron requirements are increased during pregnancy. If a mother has a poor nutritional status, she is at increased risk of giving birth to a malnourished child (King, 2016). Furthermore, if a mother has iron-deficiency anaemia during pregnancy, it can result in fetal and maternal mortality, morbidity, pre-eclampsia, bleeding and infection (Abu-Ouf and Jan, 2015). A possible long-term strategy that could be explored to help address iron deficiency is dietary diversification, through the promotion of household and community food gardens, utilisation of indigenous crops and consumption of biofortified foods.

Vitamin A deficiency (VAD) is a major health concern in SA. In this study, vitamin A intake was inadequate in all of the age groups due to poor intake of animal-based foods, fruits and vegetables. Furthermore, no participants had reported that they were taking any vitamin or mineral supplements at the time of data collection. Thus, the analysis of vitamin A did not include any vitamin A supplements. This low intake is in line with national data, which indicated that the vitamin A status of South African children had worsened between 1994 and 2005 (Labadarios and Van Middelkoop, 1995; Labadarios et al., 2000; Labadarios et al., 2008). Further, the 2005 NFCS-FB study indicated that one in 10 women were vitamin A deficient in KZN (Labadarios et al., 2008). The 2012 SANHANES-1 study reported high rates of VAD throughout SA, however, it noted an improvement in the status of women residing in KZN (Shisana et al., 2013). As alluded to earlier, the South African government has employed a number of interventions to combat VAD, including food fortification, vitamin A supplementation and dietary diversity (DoH and UNICEF, 2007; Swart et al., 2008; WHO, 2011b). The current study indicates that although these interventions are in place, vitamin A intake remains inadequate. Possible complementary strategies such as biofortification of already consumed staple foods such as maize with vitamin A, or increased usage of alternative crops, could be used together with already existing strategies in KZN, to improve vitamin A intake.

4.4.2.2 Food frequency

The food frequency results indicated that onion, *phutu*, brown bread, tomato, rice, apple, eggs and chicken were the most commonly consumed food items. This was similar to studies conducted in SA which documented that mealie meal, white sugar, tea, brown bread, non-dairy creamer, brick margarine, chicken meat, full cream milk and dark green leafy vegetables were frequently consumed (Labadarios et al., 2000; Steyn et al., 2003). Similarly, another study conducted in KZN, by Faber et al. (2013), found that sugar, maize meal porridge, bread, rice, cordial squash, hard margarine, tea and legumes were the most commonly consumed food items. Additionally, a study conducted by Faber et al. (2015), found that 50.5% of participants from rural KZN consumed both bread and maize meal (Faber et al., 2015). From this, it is evident that in SA, more specifically in rural areas of KZN, most diets comprise of starch-based foods, either a maize-based dish, bread or rice. This could lead to an excessive intake of carbohydrates and energy, thus contributing to a high prevalence of obesity (Hawkins et al., 2018).

Consumption of high amounts of refined carbohydrates have been associated with an increased risk of coronary heart disease, insulin resistance, obesity, diabetes, hypertension and stroke (López-Alarcón et al., 2014; Li et al., 2015; Okop et al., 2016). Study participants who were overweight and obese were at increased risk of conditions such as cardiovascular disease (CVD), certain cancers, type 2 diabetes and hypertension. A possible reason for this high prevalence could be due to poor food choices, sedentary lifestyle or lack of physical activity (Fabbri and Crosby, 2016; Wiklund, 2016; Hawkins et al., 2018). Increasing physical activity and energy expenditure could be another way of reducing the rates of obesity (Wiklund, 2016). However, this study did not investigate physical activity. Most study participants consumed processed foods or purchased foods prepared with large amounts of fat and sugar, resulting in high energy intake. Sweets were one of the most commonly consumed unhealthy food items in this study. If more fruit was consumed in place of high-energy snacks and if preparation methods such as steaming, baking and boiling, rather than frying were incorporated into daily cooking, this could aid in reducing the prevalence of obesity in the long-term (He et al., 2004; Fabbri and Crosby, 2016). Rural communities could achieve this if they saved the money that is usually spent on unhealthy snacks to buy fruits that are in season and cheaper. If produce is grown, individuals could sell leftover produce and use the money to purchase healthier, affordable snacks.

4.5 Conclusions

The results of the current study indicate that under- and over-nutrition co-exist in the black African rural communities of KZN studied. Stunting was prevalent among children under five years of age, whilst obesity affected children under five years of age and adults, especially females aged 16-35 years. There was frequent consumption of food items high in carbohydrates (mainly the cereal grain foods) and high in protein (chicken and eggs) and low in micronutrients and fibre. The findings suggest that the nutrition transition has influenced the nutritional status of the rural KZN population groups investigated. The use of agriculture to improve the availability of and access to diverse, affordable and nutrient-dense foods should be explored. In this regard, the inclusion of several nutritious alternative crops in such agricultural interventions should be encouraged. Future studies should explore improving current diets with biofortified and alternative crops such as maize, sweet potato and protein-rich crops such as bambara groundnut. Furthermore, there is a need to investigate the nutritional composition of these crops so that these crops can be incorporated into the diets of vulnerable population groups to improve their nutritional status.

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CHAPTER 5

WATER USE, NUTRIENT CONTENT AND NUTRITIONAL WATER PRODUCTIVITY OF SELECTED GRAIN LEGUMES

TP Chibarabada, AT Modi and T Mabhaudhi

5.1 Introduction

Two billion people suffer from micronutrient deficiency, with nearly one billion being calorie deficient (IFPRI, 2016). There is a gap between food supply and nutritional requirements, which has been attributed to lack of nutritional considerations in crop production (Schönfeldt, 2017). There is a need for a paradigm shift in current food production to consider nutrition outcomes (Mabhaudhi et al., 2016). Increasing food production and productivity should be tied to increasing nutrient density. In this regard, agriculture could simultaneously address the challenge of increasing food production and improving nutrition under limited resource availability. However, there are often challenges to linking disciplines as there are often no appropriate metrics for evaluating such linkages. In the case of quantifying the water-food-nutrition nexus, nutritional water productivity (NWP) (Renault and Wallender, 2000) has been proposed as a useful metric.

Nutritional water productivity is a measure of yield and nutrition outcome per unit of water consumed and would be applicable for sustainable food production given the limited water resources and modified diets [Renault and Wallender, 2000; Stockholm International Water Institute (SIWI) and International Water Management Institute (IWMI), 2004]. To date, increasing food production under water scarcity has been evaluated using different metrics such as 'water use efficiency' and 'water productivity' (Stanhill, 1986; Steduto, 1996; Molden et al., 2003; Molden et al., 2010; Descheemaeker et al., 2013). On the other hand, nutritionists have quantified nutritional content of different foodstuffs and suggested diets for improving nutritional status of people. These efforts have been parallel and needed to be merged to address the challenge of producing more nutritious food under water scarcity. Nutritional water productivity would be a useful metric in the semi- and arid tropics, where water scarcity and food and nutrition insecurity are prevalent (Mabhaudhi et al., 2016).

The high prevalence of food and nutrition insecurity has been attributed to the dominance of starch in diets leading to poor dietary diversity. Diets lack protein, micronutrients and minerals (Baker et al., 1996; Bourne et al., 2002; Diskin, 2004; Abrahams et al., 2011). This leads to various forms of malnutrition, including but not limited to, stunting, wasting and underweight in children under five, anaemia in women of the reproductive age, obesity and type 2 diabetes (IFPRI, 2016). Dietary diversity has been recommended to alleviate malnutrition. Dietary diversity is defined as the number of different foods or food groups consumed over a given reference period (Ruel, 2003). Increasing the variety of foods across and within food groups ensures adequate intake of essential nutrients to promote good health. Legumes are being promoted in the semi- and arid tropics, as part of dietary diversity efforts. They are rich in proteins and some micronutrients (Duranti and Guis, 1997; Iqbal et al., 2006; Seena et al., 2006), hence have the potential to alleviate malnutrition. Crop diversification through inclusion of indigenous grain legumes in food and nutrition agendas has been proposed by several authors (Chivenge et al., 2015; Foyer et al., 2016; Mabhaudhi et al., 2016; Chibarabada et al., 2017). A study on nutrient content and NWP of indigenous and exotic vegetables observed that crops differed in their nutrient content and NWP (Nyathi et al., 2016). For some micronutrients, indigenous vegetables were more nutrient dense compared to the reference exotic vegetable swiss chard (*Beta vulgaris*).

In the semi- and arid tropics, water is one of the main limiting factors in agriculture. Yield of grain legumes has been observed to decrease with decreasing water availability (Pandey et al., 2004; Daryanto et al., 2015; Farooq et al., 2017). Grain legumes have also been associated with yield instability across environments. There is not much information on how water availability and different environments affect nutritional content of grain legumes. Moreso, there is need to link yield, water use and nutritional content of grain legumes to establish the best yielding crops that use less water and are nutritionally dense. This should include indigenous grain legumes as they form part of crop diversification efforts. This information will be useful for promotion of grain legumes across different environments. It is hypothesised that nutrient content and NWP of crops will vary with varying water availability and across environments. The aim of the study was therefore to determine NWP of selected alternative indigenous grain legumes [bambara groundnut (*Vigna subterranea*) and cowpea (*Vigna unguiculata*)] and conventional grain legumes [groundnut (*Arachis hypogaea*) and dry bean (*Phaseolus vulgaris*)], in response to production environment. The specific objectives were to determine nutrient content and NWP of selected African indigenous (bambara groundnut and cowpea) and major grain legumes (groundnut and dry bean) in response to (i) water regimes and (ii) environments.

5.2 Material and Methods

5.2.1 Plant material

Two major grain legumes that are recognised internationally (groundnut and dry bean) and two African indigenous grain legumes that are being promoted as healthy alternatives (bambara groundnut and cowpea), were selected for the study (Figure 5.1). Groundnut has high oil content and is usually consumed as a snack or processed to peanut butter or groundnut oil. Bambara groundnut, cowpea and dry bean, are normally harvested as dry grain and consumed after boiling them. Bambara groundnut and groundnut form pods below ground, while dry bean and cowpea form pods above ground. For the study, popular South African varieties of groundnut (Kwarts), dry bean (Ukulinga) and cowpea (mixed brown) were used for the study. For bambara groundnut, a mixed colour landrace from Jozini, South Africa was used.

5.2.2 Site description

Three sites (one on-station and two on-farm) were selected from KwaZulu-Natal Province, South Africa (Table 5.1). Ukulinga, which was the on-station farm, is a Research Farm, belonging to the University of KwaZulu-Natal. Ukulinga has access to irrigation while Umbumbulu and Fountanhill were on farm trials and did not have access to irrigation. Umbumbulu is a rural district in the eThekwini district of KwaZulu-Natal. Fountainhill is an Estate 2 km outside of Wartburg, KwaZulu-Natal.

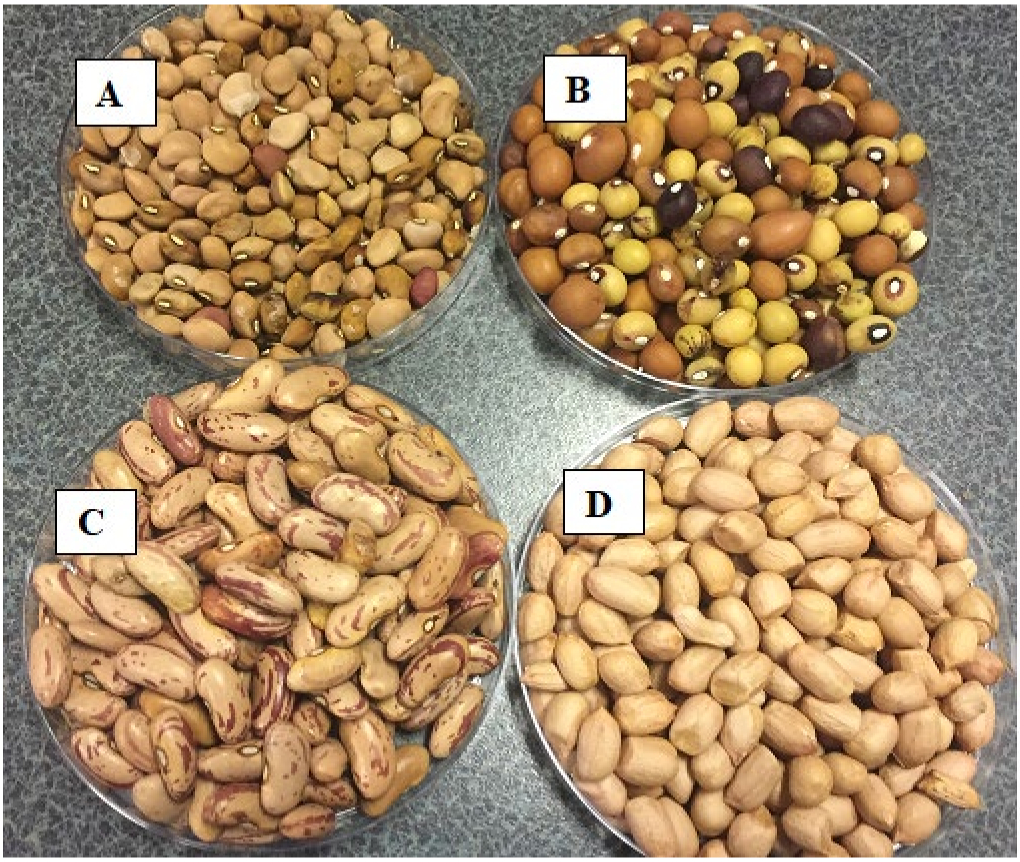

Figure 5.1: Seed of selected varieties of indigenous grain legumes (A = cowpea – mixed brown; B = bambara groundnut – landrace) and major grain legumes (C = dry bean – Ukulinga; D = groundnuts – Kwarts).

5.2.3 Experimental design and trial management

The experimental design at Ukulinga Research Farm, where there was access to irrigation, was a split-plot design arranged in randomised complete blocks with three replications. The main plots were irrigation regimes (optimum irrigation, deficit irrigation and rainfed), while the subplots were the grain legume crops (dry bean, groundnut and bambara groundnut). Irrigation scheduling in the optimum irrigation was based on 80% management allowable depletion (MAD) total available water (TAW). The DI treatment was irrigated (MAD: 80% TAW) at the most sensitive to water stress growth stages (flowering and pod-filling stages). To determine the effect of environment, an experiment was conducted at the three sites (Fountainhill Estate, Ukulinga Research Farm and Umbumbulu Rural District) under rainfed conditions. At all sites, the experimental design was a randomised complete block design with three replications. There was cowpea at Ukulinga. At Umbumbulu, trials only established during the 2016/17 season.

At all the sites, plot size (sub-plot at Ukulinga) was 18.75 m^2. Plant population was 26 667 plants $hectare^{-1}$ for cowpea, 66 667 plants $hectare^{-1}$ for bambara groundnut and 88 889 plants hectare^{-1} for dry bean and groundnut. During 2015/16, trials were planted on 17 November 2015 at Ukulinga and 4 December 2015 at Fountainhill. During 2016/17, trials were planted on 30 November, 14 December and 16 January 2016 at Umbumbulu, Fountainhill and Ukulinga, respectively. At all sites, soil fertility was kept optimum. For the duration of the trials, recommended best management practices (weeding, ridging and pest and disease control) for each crop were applied.

Table 5.1: Site characteristics of the three selected sites (Ukulinga Research Farm, Umbumbulu Rural District and Fountainhill Estate)

Site	Ukulinga Research Farm	Umbumbulu Rural District	Fountainhill Estate
Coordinates	29°37'S; 30°16'E	29.984'S; 30.702'E	29.447'S; 30.546'E
Altitude (m.a.s.l.)	750	593	1020
Annual rainfall	694	1 200	905
Average temperature	25	28	20.4
Average max temperatures	26	27	29
Average min temperatures	10	13	17
Soil type	Heavy Clay	Clay-Loam	Sandy
Bio-resource group	Moist Coast Hinterland Ngongoni Veld	Moist Coast Forest, Thorn and Palm Veld (Moist Coast)	Moist Midland Mistbelt

5.2.4 Measurements

5.2.4.1 Yield and yield components

At harvest, six representative plants were randomly selected from each plot. Thereafter, the plants were air dried in a controlled environment situated at the UKZN Phytosanitary Unit until there was no change in total biomass. Pods were dehulled and grain mass was determined.

5.2.4.2 Determination of evapotranspiration (ET)

Evapotranspiration for each treatment was calculated as the residual of a soil water balance (Allen et al., 1998):

$$ET = P + I - D - R - \Delta SWC \quad \text{Equation 5.1}$$

where: ET = evapotranspiration (mm),

P = precipitation (mm),

I = irrigation (mm),

D = drainage (mm),

R = runoff (mm), and

ΔSWC = changes in soil water content (mm).

Daily rainfall (mm) was obtained from weather stations within a 10 km radius from the sites. At Fountainhill and Umbumbulu, daily rainfall data was obtained from the South African Sugar Association (SASA) weather web portal (http://portal.sasa.org.za/weatherweb). At Ukulinga, daily rainfall data was obtained from an automatic weather station (AWS), which is part of the Agricultural Research Council-Institute for Soil, Climate and Water (ARC-ISCW) network of automatic weather stations. Changes in soil water content (SWC) were measured using a PR2/6 profile probe connected to an HH2 handheld moisture meter (Delta-T, UK). The sensors of the PR2/6 profile probe were positioned to measure volumetric water content at six depths (0.10, 0.20, 0.30, 0.40, 0.60 and 1.00 m along the probe). The effective depth at Ukulinga was 0.40 m, hence the sensors positioned at 0.60 and 1.00 m were considered during analyses.

Drainage was considered as negligible. At Ukulinga there was an impeding layer at 0.4 m, which restricted downward movement of water beyond the root zone. At Fountainhill and Umbumbulu, drainage was considered negligible based on Dancette and Hall (1979), where in semi- and arid environments drainage is negligible if the profile is not periodically saturated to drain excess water. Runoff (R) was not quantified during the trials. However, to account for its effect, the United States Department of Agriculture – Soil Conservation Service (USDA-SCS) procedure (USDA-SCS, 1967) was used to estimate the monthly effective rainfall that is stored in the root zone after subtracting the amount of rainfall lost to runoff. The soil water balance was therefore simplified to;

$$WU = ER + I - \Delta SWC \quad \text{Equation 5.2}$$

where: WU = water use = evapotranspiration (mm),

ER = effective rainfall (mm),

I = irrigation (mm), and

ΔSWC = changes in soil water content (mm).

Values of ET_a in mm (depth) were then converted to m^3 (volume) using the formula;

$$Volume\ (m^3) = Area\ (m^2) \times Depth\ (m) \qquad \text{Equation 5.3}$$

5.2.4.3 Determination of nutritional content (NC)

To preserve nutrients and avoid further metabolic reactions, grain was freeze dried using a model RV3 vacuum freeze drier (Edwards, United States of America) after yield determination. Thereafter, samples were ground using a coffee grinder (Mellerware, South Africa) and sent to the KZN Department of Agriculture and Rural Development Plant Nutrition Lab. The nutrients analysed per dry matter basis included macro-nutrients (energy, fat and protein) and micro-nutrients [calcium (Ca), zinc (Zn), iron (Fe)].

Determination of macro nutrients (energy, fat and protein) followed the Association of Official Analytical Chemists (AOAC) standard procedures for nutrient analysis (AOAC, 1980). Dry matter was determined by drying samples in a fanned oven a 100°C for 24 hours. Nitrogen (N) was determined by the micro-Kjeldahl method. Thereafter, crude protein was calculated as;

$$N \times 6.25 \qquad \text{Equation 5.4}$$

Crude fat was determined according to the soxhlett procedure. Ash was determined by igniting fibre samples in a furnace at 550°C overnight. The carbohydrate content was then determined as the difference between 100% and addition of the percentages of moisture, fat, crude protein, and crude fibre. Gross energy of the diets was measured with a bomb calorimeter (Lab-X, Kolkata, India).

The mineral composition (Ca, Zn, Fe) were determined using the dry ashing (DA) technique (AOAC, 1980). An aliquot of 25 ml was placed in crucibles. Thereafter, samples were placed in an oven set at 50°C to heat overnight. Following this, crucibles with residues obtained after vaporisation of water and most organic compounds were introduced in a high temperature muffle furnace and ashed at 450°C for 24 hours. Thereafter, samples were cooled and residues treated with nitric acid while on a warm hot plate. Samples were then transferred back to the muffle furnace for 24 hours. White ashes obtained were dissolved in a beaker with 20ml 5% (v/v) nitric acid. The solution was then transferred to a 25 ml volumetric flask by rinsing with 5% v/v nitric acid. The solution was then used to determine Ca, Zn, Fe using an atomic absorption spectrophotometer (AAS) (Analytikjena AG, Germany).

2.2.4.4 Determination of nutritional water productivity (NWP)

Nutritional water productivity was calculated based on the formula by Renault and Wallender (2000) where;

$$NWP = \left(\frac{Y_a}{ET_a}\right) \times NP \qquad \textbf{Equation 5.5}$$

where: NWP is the nutritional water productivity (nutrition m^{-3} of water evapotranspired), Y_a is the actual harvested grain yield ($kg \cdot ha^{-1}$), ET_a is the actual evapotranspiration ($m^3 \cdot ha^{-1}$), and NC is the nutritional content per kg of product (nutrition unit$\cdot kg^{-1}$).

5.2.5 Data analysis

Data from Ukulinga (the irrigation treatments) and from the three sites (rainfed trials) were analysed separately. For both data sets, data of the two seasons (2015/16 and 2016/17) were subjected to Bartlett's test for homogeneity of variance in GenStat® 18th Edition (VSN International, UK). Results of both data sets showed evidence of non-homogeneity between the two seasons hence a separate analysis of the seasons was conducted. The data sets (the irrigation treatments) and (the three sites) were subjected to analysis of variances (ANOVA) using GenStat® version 18 (VSN International, UK). Least significance difference (LSD) was used to separate means at the 5% level of significance.

5.3 Results

5.3.1 Rainfall

Total rainfall at Ukulinga and Fountainhill during 2015/16 was 445 and 583 mm, respectively. During 2016/17, total rainfall observed at Ukulinga, Fountainhill and Umbumbulu was 235, 395 and 595 mm, respectively. At Ukulinga during 2015/16, ≈ 25% of the total rainfall (120 mm) was received in two rainfall events [68 and 120 days after planting (DAP)] (Figure 5.2). During 2015/16, daily rainfall at Fountainhill did not exceed 45 mm and it was observed that ≈ 20% of the total rainfall was received during the first 14 days while ≈ 25% was received between 95 and 106 DAP. At Ukulinga, during 2016/17, rainfall did not exceed 30 mm for all the rain days. In addition to being low (235 mm), rainfall was also sparsely distributed (Figure 5.2). At Umbumbulu, where the highest rainfall was observed during 2016/17 (595 mm), it was observed that 120 mm of this rainfall was received in two days (72 and 97 DAP). .

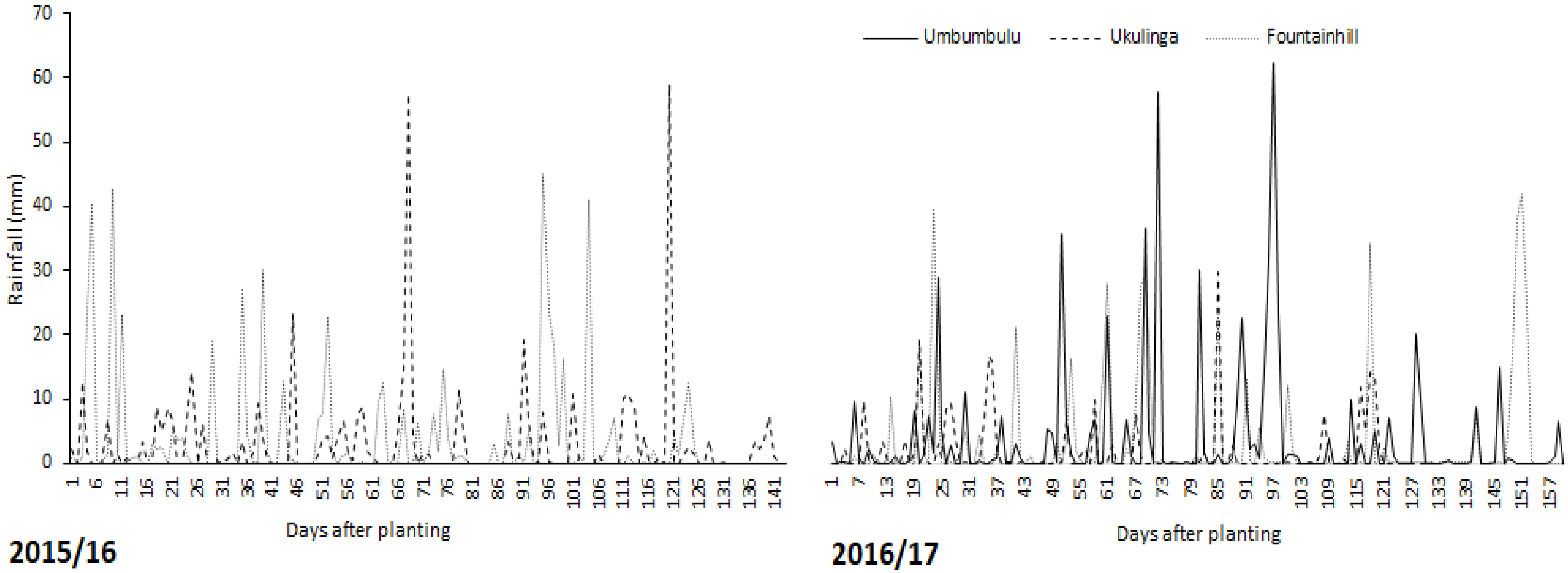

Figure 5.2: Rainfall (mm) observed at three sites (Ukulinga Research Farm, Umbumbulu Rural District and Fountainhill Estate) during 2015/16 and 2016/17 season.

5.3.2 Nutritional content in response to water regimes

With respect to energy and fat content, it was observed that groundnut had the highest energy and fat content, across all seasons and water treatments (Table 5.2). Dry bean had the lowest energy content. Groundnut energy content was 22-58% and 73-115% higher than for bambara groundnut and dry bean, respectively. With respect to water treatments, it was observed that for both seasons, the highest energy content for groundnut was under OI (> 5630 kcal kg^{-1}). For fat content, groundnut had > 900% more than the other crops, across all seasons and water treatments. During 2016/17, bambara groundnut fat content was as low as 6 g kg^{-1}. For all the crops, there was no discernible pattern with respect to the water treatment (Table 5.2). However, during 2015/16, groundnut fat content under the RF treatment was ≈ 100 g kg^{-1} less than under OI and DI. Groundnut had higher protein content during 2015/16, though the differences were not as high as for energy and fat content. Bambara groundnut had the lowest protein content (200-258 g kg^{-1}) (Table 5.2). The highest difference between protein of groundnut and dry bean was 14%. This was observed under RF conditions. During 2016/17, dry bean had the highest protein under RF conditions (287 g kg^{-1}), and the lowest protein under DI (247 g kg^{-1}) (Table 5.2).

For the micronutrients, dry bean had the highest Ca content during 2015/16 under all the water treatments. Under rainfed conditions, Ca content in dry bean was ≈ 100% more than groundnut and bambara groundnut. During 2016/17, bambara groundnut showed high Ca content under DF conditions (100% more than dry bean) (Table 5.2). Contrary to the macronutrients, groundnut was inferior to dry bean and bambara groundnut, showing the lowest Ca content (100 mg kg^{-1}). For Zn and Fe content there was no clear pattern between the crops and the water treatments. For Zn content, the differences between the crops ranged between (5-15% which was lower compared to the differences observed for energy and fat content (22-900%). For Fe content, it was observed that during 2015/16, dry bean had 200-350% more Fe compared to bambara groundnut and groundnut, under all the water treatments. Groundnut had the lowest Fe (Table 5.2). During 2016/17, it was interesting to observe that under OI, bambara groundnut had the highest Fe content (84.1 mg kg^{-1}), while groundnut had the highest Fe content under DI (102.9 mg kg^{-1}) and dry bean had the highest Fe under RF (104.6 mg kg^{-1}) (Table 5.2).

Table 5.2: Macro (energy, protein and fat) and micro (Ca, Zn and Fe) nutrients of four grain legume crops (groundnut, bambara groundnut, dry bean and cowpea) grown under varying irrigation regimes (optimum irrigation, deficit irrigation and rainfed) over two seasons (2015/16 and 2016/17).

			Energy	**Fat**	**Protein**	**Ca**	**Zn**	**Fe**
			kcal kg^{-1}	g kg^{-1}		mg kg^{-1}		
2015/16	OI	Groundnut	5 820	406.65	290.16	710	44.43	38.00
		Bambara	3 678	10.24	210.55	670	28.27	39.01
		Dry Bean	2 697	50.27	260.18	1 270	30.67	85.04
	DI	Groundnut	4 974	400.04	310.58	600	37.31	35.02
		Bambara	3 752	40.06	200.82	630	32.82	39.03
		Dry Bean	2 870	40.36	300.89	990	44.03	103.04
	RF	Groundnut	5 179	301.19	310.19	550	37.12	30.09
		Bambara	4 218	10.27	230.87	590	33.23	42.00
		Dry Bean	3 270	40.60	270.32	1 400	33.95	87.00
2016/17	OI	Groundnut	5 630	405.44	249.77	860	32.92	47.90
		Bambara	3 960	57.24	231.13	580	30.36	84.17
		Dry Bean	3 360	10.13	287.77	1 170	33.28	69.60
	DI	Groundnut	5 030	418.50	288.82	1 110	32.79	102.96
		Bambara	4 030	6.21	258.88	1 260	32.59	60.75
		Dry Bean	2 796	62.99	247.72	650	25.07	70.01
	RF	Groundnut	5 210	438.79	275.59	100	35.70	63.84
		Bambara	3 638	59.57	205.55	600	29.47	42.47
		Dry Bean	3 110	17.90	270.03	1 140	29.39	104.64

5.3.3 Nutritional content in response to environments

Across environments, groundnut maintained its superiority with respect to energy and fat content. With respect to crops, cowpea had the lowest energy content (1 160-1 460 kcal kg^{-1}). Cowpea energy content was 279-356% lower than groundnut (Table 5.3). Groundnut maintained high fat content, > 900% compared to the other crops. The lowest fat content (4.87 g kg^{-1}) was observed for cowpea at Fountainhill during 2016/17. Under the irrigation treatments, there was no discernible pattern of crop performance with respect to protein content. However, across environments, groundnut had the highest protein content during both seasons 275-325 g kg^{-1}). It was also observed that bambara groundnut had the lowest protein content across environments (205-253 g kg^{-1}). During 2016/17, for all the crops, the lowest protein content was observed at Ukulinga (205-275 g kg^{-1}) relative to Fountainhill (214-325 g kg^{-1}) and Umbumbulu (225-316 g kg^{-1}) (Table 5.3).

Under the irrigation regimes, high Ca content in dry bean was limited to 2015/16 (Table 5.3). Under different environments, dry bean had the highest Ca content during both seasons (1.24-1.54 mg kg^{-1}) (Table 5.3). At Fountainhill and Umbumbulu, cowpea, had the second highest Ca content (740-1370 mg kg^{-1}) after dry bean. Groundnut had the highest fat, energy and protein content but had the lowest Ca content at Ukulinga and Fountainhill during both seasons (< 550 mg kg^{-1}). Similar to irrigation treatments, there was no clear pattern on crop performance with respect to Zn content across environments (Table 5.3). However, it was observed that during both seasons, cowpea had the highest Zn content at Fountainhill (67.8 and 53.8 mg kg^{-1}). It was also observed that at all sites during 2015/16 and at Umbumbulu and Fountainhill during 2016/17, bambara groundnut had the lowest Zn (< 33.2 mg kg^{-1}). For bambara groundnut and cowpea there was a Zn content difference of ≈ 100%, with cowpea having the highest (Table 5.3). Dry bean and cowpea had the highest Fe content (61.6-104.6 mg kg^{-1}). Fe in groundnut and bambara groundnut ranged between 21.3 and 63.8 mg kg^{-1}, 100-300% lower than dry bean and cowpea (Table 5.3). Comparing the environments, it was observed that all the crops had the highest Fe (42.4-104.6 mg kg^{-1}) at Ukulinga during 2016/17. This was the environment where all the lowest protein for all the crops was observed (Table 5.3).

Table 5.3: Macro (energy, protein and fat) and micro (Ca, Zn and Fe) nutrients of four grain legume crops (groundnut, bambara groundnut, dry bean and cowpea) grown at three different sites (Fountainhill Estate, Ukulinga Research Farm and Umbumbulu Rural District) over two seasons (2015/16 and 2016/17).

			Energy	Fat	Protein	Ca	Zn	Fe
			kcal kg^{-1}	g kg^{-1}		mg kg^{-1}		
2015/16	Ukulinga	Groundnut	5 700	300.19	310.19	550	37.23	30.93
		Bambara groundnut	3 670	10.27	230.87	590	33.31	42.09
		Dry Bean	3 330	40.60	270.32	1 400	33.59	87.02
	Fountainhill	Groundnut	5 640	430.15	325.87	310	45.86	29.64
		Bambara groundnut	3 380	40.36	214.54	460	30.95	28.03
		Dry Bean	3 460	14.32	282.61	1 240	42.52	85.04
		Cowpea	1 160	47.13	272.99	740	67.38	96.86
2016/17	Ukulinga	Groundnut	4 640	438.79	275.59	100	35.02	63.46
		Bambara groundnut	3 780	59.57	205.55	600	29.71	42.72
		Dry Bean	2 980	17.90	270.03	1 140	29.94	10.42
	Fountainhill	Groundnut	4 930	470.29	324.42	330	46.49	21.75
		Bambara groundnut	3 770	47.42	253.20	620	28.86	23.98
		Dry Bean	3 340	14.26	277.82	1 540	42.28	76.46
		Cowpea	1 290	4.87	314.06	1 160	51.76	60.84
	Umbumbulu	Groundnut	5 540	448.75	316.12	510	41.61	26.91
		Bambara groundnut	2 980	61.74	225.55	380	27.05	21.24
		Dry Bean	3 670	22.91	303.86	1 430	42.23	67.96
		Cowpea	1 460	12.09	295.92	1 370	40.20	61.04

5.3.4 Nutritional water productivity in response to water regimes

During 2015/16, results of yield and NWP for all the nutrients (energy, protein, fat, Ca, Zn and Fe) showed significant differences ($P < 0.05$) among the crops. Water treatments were not significantly different ($P > 0.05$) (Table 5.4). The interaction between water treatments and crops was significantly different ($P < 0.05$) for grain yield, NWP_{fat} and $NWP_{protein}$. Under OI, the highest yield was observed for dry bean (2 260 kg ha^{-1}). Dry bean also had the lowest ET_a (2 680 m^{-3}) translating to high productivity (Table 5.4). This resulted in the highest $NWP_{protein}$ (220 g m^{-3}), despite the crop not having the highest protein content under OI. The high Ca (1 270 mg kg^{-1}) and Fe content (85 mg kg^{-1}) observed for dry bean under OI translated to high NWP_{Ca} (1 060 mg m^{-3}) and NWP_{Fe} (71.9 mg m^{-3}). Groundnut had high energy and fat content resulting in the highest NWP_{energy} (3 568 kcal m^{-3}) and NWP_{fat} (249 g m^{-3}). For bambara groundnut, low NWP for all the nutrients was as a result of combined effect of low yield, high ET_a and low nutritional content (Table 5.4).

In addition to the high energy, fat and protein content observed for groundnut under DI, it also had the highest yield (200% more than the other crops) (Table 5.5). This resulted in higher $NWP_{energy,\ fat\ and\ protein}$ (4 956 kcal m^{-3}, 406 g m^{-3}, 314 g m^{-3}) under DI. It was interesting to observe that despite groundnut having the lowest Ca and Fe, it had the second highest $NWP_{Ca\ and\ Fe}$, (590 and 35.1 mg m^{-3}, respectively) because of the high grain yield (2 900 kg ha^{-1}) (Table 2.5). For bambara groundnut, results were consistent to the OI treatment – it had the lowest NWP for all the nutrients. Dry bean had the highest $NWP_{Ca\ and\ Fe}$ (> 300% more than groundnut and bambara groundnut) (Table 5.4).

During 2016/17, results of grain yield and NWP were similar to 2015/16 – significantly different among crops ($P < 0.05$) and not significantly different among irrigation treatments ($P > 0.05$) (Table 5.5). The interaction between crops and water regime was only significant for $NWP_{fat,\ Ca\ and\ Fe}$. During 2016/17, dry bean had the highest grain yield (1 081-1 296 kg ha^{-1}) and lowest ET_a (1 430-1 950 m^{-3}) across all water treatments. As a result, the highest $NWP_{energy,\ protein,\ Ca,\ Zn\ and\ Fe}$ was highest for dry bean across water treatments. Although groundnut had 800% more fat under DI, dry bean had a higher NWP_{fat} (42 g m^{-3}) due to the high grain yield and low ET_a. During 2015/16, groundnut performed better than bambara groundnut. In 2016/17 due to low grain yield for bambara groundnut and groundnut, the crops had similar $NWP_{energy,\ protein,\ Ca,\ Zn\ and\ Fe}$ despite groundnut having higher nutrient content than bambara groundnut (Table 5.2 and 5.5).

Table 5.4: Yield, ET_a and NWP (energy, protein, fat, Ca, Zn, and Fe), of three legume crops (dry bean, groundnut and bambara groundnut) grown under three water treatments (OI, DI and RF) during the 2015/16 season.

Water treatments	Crop species	Grain yield	ETa	NWP_{energy}	NWP_{fat}	$NWP_{protein}$	NWP_{Ca}	NWP_{Zn}	NWP_{Fe}
		kg ha^{-1}	m^{-3}	kcal m^{-3}	g m^{-3}		mg m^{-3}		
OI	Dry bean	2 260a	2 680	2 270b	44.00c	220.30b	1 060a	25.80	71.90a
	Groundnut	1 950ab	3 160	3 568b	249.20b	178.80c	440b	27.20	23.30b
	Bambara groundnut	1 480b	3 170	1 718c	5.80c	100.70d	310c	13.20	18.30b
	Mean	**1 800**	**3 020**	**2 518**	**99.80**	**166.60**	**600**	**22.10**	**37.80**
DI	Dry bean	1 400b	2 390	1 795c	27.30	193.30b	620b	27.50	64.70a
	Groundnut	2 900a	2 920	4 956a	406.00a	314.70a	590b	37.20	35.10b
	Bambara groundnut	1 410b	2 630	2 011c	21.80c	111.60d	340c	17.60	21.10b
	Mean	**1 930**	**2 650**	**2 921**	**151.70**	**206.50**	**520**	**27.40**	**40.30**
RF	Dry bean	1 960a	2 380	2 565b	38.00c	225.40b	1 150a	28.00	71.80a
	Groundnut	2 770a	2 830	5 074a	308.20b	305.60a	450b	36.40	30.30b
	Bambara groundnut	1 090b	2 770	1 439c	5.00c	94.40d	230c	13.10	16.70b
	Mean	**1 940**	**2 660**	**3 026**	**117.10**	**208.50**	**640**	**13.02**	**39.60**
Significance (P=0.05)	Crops	< 0.001		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Water regime	*ns		*ns	*ns	*ns	*ns	*ns	*ns
	Crops*Water regime	0.031		*ns	0.028	0.040	*ns	*ns	*ns
	LSD $_{(P=0.05)}$	1 069		1455	78.00	32.20	410		26.63

*ns: Not significant at P = 0.05.

Table 5.5: Yield, water use and NWP (energy, protein, fat, Ca, Zn, and Fe), of three legume crops (dry bean, groundnut and bambara groundnut) grown under three water treatments (OI, DI and RF) during the 2016/17 season.

Water treatments	**Crop species**	**Grain yield**	**Water use**	**NWP$_{energy}$**	**NWP$_{fat}$**	**NWP$_{protein}$**	**NWP$_{Ca}$**	**NWP$_{Zn}$**	**NWP$_{Fe}$**
		kg ha^{-1}	m^{-3}	kcal m^{-3}	——— g m^{-3}	———	———	mg m^{-3}	———
OI	Dry bean	1 296a	1 950	2 230a	6.70d	191.00a	1 140a	22.90a	81.20a
	Groundnut	585b	3 450	953b	68.60a	42.30b	140b	5.57b	46.20b
	Bambara groundnut	466b	3 060	463b	8.70d	35.10b	80b	4.61b	12.80c
	Mean	**782**	**2 820**	**1 122**	**28.00**	**89.50**	**460**	**10.76**	**46.70**
DI	Dry bean	1 098a	1 630	1 880a	42.40b	166.30a	430b	16.86a	47.10b
	Groundnut	362b	2 800	417b	34.70c	23.90b	90b	2.72b	8.50c
	Bambara groundnut	402b	2 560	701b	1.10e	45.00b	220b	5.67b	10.60c
	Mean	**592**	**2 330**	**1 000**	**26.00**	**78.40**	**240**	**8.42**	**22.10**
RF	Dry bean	1 081a	1 430	2 347a	13.50d	204.00a	1 110a	22.18a	79.00a
	Groundnut	267b	2 490	557b	46.90b	29.50b	100b	3.82b	6.80c
	Bambara groundnut	292b	2 320	463b	7.50d	25.90b	80b	3.71b	5.30c
	Mean	**547**	**2 080**	**1 122**	**22.60**	**56.40**	**400**	**9.0**	**30.40**
Significance (P=0.05)	Crops	< 0.001		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Water regime	*ns		*ns	*ns	*ns	*ns	*ns	*ns
	Crops*Water regime	*ns		*ns	< 0.001	*ns	0.022	*ns	< 0.001
	LSD $_{(P=0.05)}$	538.5		914.7	11.17	72.30	380	8.30	24.42

*ns: Not significant at P = 0.05.

5.3.5 Nutritional water productivity in response to environments

During 2015/16, sites were not significantly different for grain yield ($P > 0.05$) while NWP for all the nutrients (energy, protein, fat, Ca, Zn and Fe) was significantly different ($P < 0.05$). Grain yield and NWP for all the nutrients (energy, protein, fat, Ca, Zn and Fe) were significantly different ($P < 0.05$) among the crops (Table 5.6). The interaction between crop and site was significant ($P < 0.05$) for grain yield and NWP for all the nutrients (energy, protein, fat, Ca, Zn and Fe). At Fountainhill, despite bambara groundnut having the highest yield (1 978 kg ha^{-1}), it did not have the highest NWP for all the nutrients because of high ET_a (4 370 m^3) and low nutritional content (Table 5.3 and 6). Groundnut had the highest macro nutrient content (Table 2.3) which was translated to the highest $NWP_{energy,\ fat\ and\ protein}$ (2 575 kcal m^{-3}, 197 g m^{-3}, 148 g m^{-3}, respectively). Cowpea had the lowest NWP_{energy} (450 kcal m^{-3}), consistent to the low energy content (1 160 kcal kg^{-1}) and grain yield (1 214 kg ha^{-1}) observed. Dry bean had the highest $NWP_{Fe\ and\ Ca}$ (> 39.7 mg m^{-3} and > 570 mg m^{-3}). Despite low grain yield of cowpea, it had the highest NWP_{Zn} (26.3 mg m^{-3}) due to the high Zn content (67.8 mg kg^{-1}). Comparing the two sites, it was observed that Ukulinga yielded better (1 950 kg ha^{-1}) and had lower ET_a (2 660 m^3) than Fountainhill (1 560 kg ha^{-1} and 3 547 m^3, respectively). This led to 60-110% higher NWP for all the nutrients (energy, protein, fat, Ca, Zn and Fe) at Ukulinga compared to Fountainhill.

During 2016/17, results of crops were significantly different ($P < 0.05$) for $NWP_{energy,\ fat,\ Ca,\ Zn\ and\ Fe}$. For sites, $NWP_{energy,\ protein,\ Ca,\ Zn\ and\ Fe}$ were significantly different ($P < 0.05$). The interaction between crop and site was significantly different ($P < 0.05$) for $NWP_{energy,\ fat,\ protein\ and\ Zn}$ (Table 5.7). During 2015/16, it was observed that Ukulinga was better performing than Fountainhill. In 2016/17, Fountainhill was the best performing site. At Fountainhill, grain yield, $NWP_{energy,\ fat,\ protein,\ Ca\ and\ Zn}$ was ≈ 100% more than at Umbumbulu and Ukulinga. Groundnut had the highest $NWP_{fat,\ protein\ and\ energy}$ at Fountainhill and Umbumbulu (Table 5.7). At Ukulinga, dry bean grain yield was high, and ET_a was low, contributing to the highest $NWP_{energy\ and\ protein}$ (2 347 kcal m^{-3} and 204 g m^{-3}, respectively). Similar to results of 2015/16, dry bean had the highest NWP_{Fe} at Ukulinga and Fountainhill (79 and 46.6 mg m^{-3}), however due to the low grain yield at Umbumbulu (282 kg ha^{-1}), the crop did not have the highest NWP_{Fe} (9.1 mg m^{-3}). Consistent to results of 2015/16, cowpea had the lowest NWP_{energy} (< 478 kcal m^{-3}) compared to the other crops, due to the low energy content (< 1 460 kcal kg^{-1}).

Table 5.6: Yield, ET_a and NWP (energy, protein, fat, Ca, Zn, and Fe), of four legume crops (dry bean, cowpea, groundnut and bambara groundnut) grown at two sites (Fountainhill Estate and Ukulinga Research Farm) during 2015/16 season.

Water treatments	Crop species	Grain yield	ETa	NWP_{energy}	NWP_{fat}	$NWP_{protein}$	NWP_{Ca}	NWP_{Zn}	NWP_{Fe}
		kg ha^{-1}	m^{-3}	kcal m^{-3}	g m^{-3}		mg m^{-3}		
Fountainhill	Dry bean	1 456ab	3 130	1 604b	6.64c	131c	570b	19.87b	39.73b
	Groundnut	1 594ab	3 490	2 575b	197.05b	148.8c	140c	21.00b	13.36c
	Bambara groundnut	1 978a	4 370	1 529c	18.26c	97.1c	200c	13.89c	12.90c
	Cowpea	1 214b	3 200	450d	18.28c	105.8c	280c	26.30b	37.33b
	Mean	**1 560.5**	**3 547**	**1 695**	**66.03**	**122.8**	**290**	**19.4**	**24.19**
Ukulinga	Dry bean	1 960a	2 380	2 565b	38.00c	225.40b	1 150a	28.00a	71.80a
	Groundnut	2 770a	2 830	5 074a	308.20a	305.60a	450b	36.40a	30.30b
	Bambara groundnut	1 090b	2 770	1 439c	5.00c	94.40c	230c	13.10c	16.70c
	Mean	**1 940**	**2 660**	**3 026**	**117.10**	**208.50**	**640**	**13.02**	**39.60**
Significance (P=0.05)	Crops	0.032		< 0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001
	Site	*ns		< 0.001	0.003	< 0.001	< 0.001	0.007	< 0.001
	Crops*Site	0.003		0.001	0.002	0.007	0.002	0.046	0.015
	LSD $_{(P=0.05)}$	745.9		987.3	44.38	63.27	180	8.76	12.48

*ns: Not significant at P = 0.05.

Table 5.7: Yield, water use and NWP (energy, protein, fat, Ca, Zn, and Fe), of four legume crops (dry bean, groundnut and bambara groundnut) grown under three water treatments (Fountainhill Estate, Ukulinga Research Farm and Umbumbulu Rural District) during 2016/17 season.

Site	Crop species	Grain yield	Water use	NWP_{energy}	NWP_{fat}	$NWP_{protein}$	NWP_{Ca}	NWP_{Zn}	NWP_{Fe}
		kg ha^{-1}	m^{-3}	kcal m^{-3}	g m^{-3}		mg m^{-3}		
Fountainhill	Dry bean	1 302a	2 140	2 031	8.67c	169a	930a	25.80	46.67b
	Groundnut	2 387a	2 870	4 098	390.8a	269.6a	270b	38.61	18.09c
	Bambara groundnut	1 359a	2 650	1 933	24.31c	129.8	310b	14.86	12.25c
	Cowpea	1 011a	2 730	478	1.80c	116.3b	420b	19.16	22.32c
	Mean	**1 515**	**2 597**	**2 286**	**115.93**	**172.2**	**490**	**25.10**	**25.06**
Umbumbulu	Dry bean	282c	2 080	497	3.10d	41.2b	190b	5.96	9.12c
	Groundnut	1 213a	2 340	2 863	231.91b	163.4a	260b	21.43	13.96c
	Bambara groundnut	725b	2 840	761	15.6c	57.6b	90b	7.1	5.44c
	Cowpea	953ab	3 340	417	1.80c	84.4b	390b	11.56	17.58c
	Mean	**793.00**	**2 650**	**1 200**	**69.02**	**86.8**	**220**	**11.43**	**10.90**
Ukulinga	Dry bean	1 081a	1 430	2 347	13.50c	204.00a	1 110a	22.18	79.00a
	Groundnut	267b	2 490	557	46.90c	29.50b	10c	3.82	6.80c
	Bambara groundnut	292b	2 320	463	7.50c	25.90b	80b	3.71	5.30c
	Mean	**547**	**2 080**	**1 122**	**22.60**	**56.40**	**400**	**9.90**	**30.40**
Significance (P=0.05)	Crops	*ns		0.002	<0.001	*ns	0.008	0.027	0.006
	Site	0.002		0.005	*ns	0.010	0.012	0.002	0.010
	Crops*Site	*ns		0.009	<0.001	0.004	*ns	0.007	*ns
	LSD $_{(P=0.05)}$	1 007.3			91.89	113.5	350		17.33

*ns: Not significant at P = 0.05.

5.4 Discussion

The objectives of the study were to determine nutrient content and NWP of selected indigenous and major grain legumes in response to water regimes and production environments. Crops differed in their nutritional content. Groundnut had higher fat content relative to the other crops; a 100 g serving of groundnut can supply the Recommended Dietary Allowance (RDA) for fat (40-78 g). A gram of fat contains ≈ 37.6 kJ of energy, hence fat-rich foods are good sources of energy. This explains the high energy content observed for groundnut. High fat content of groundnut has been explored through processing into peanut butter and extraction of oil for household use. This makes groundnut a multi-purpose grain legume, and partly explains the reason why groundnut is an important and major grain legume. However, over consumption of groundnut has risk associated with excess fat consumption, which is one of the major causes of obesity (Ros, 2010; UNDP, 2012). In semi- and arid regions, 30% of the population is overweight and obese (IFPRI, 2016), hence the promotion of groundnut needs to be accompanied with proper consumption recommendations. This also supports the need to diversify grain legumes to avoid over reliance on major legumes such as soybean and groundnut that have high fat content.

For all the grain legumes, protein content was between 205 and 325 g kg^{-1}, implying that a 100 g portion of legume supplies 40-60% of protein RDA (50 g). This confirms arguments by Foyer et al. (2016) and Chibarabada et al. (2017), that legumes can be promoted as alternatives to meat, to avoid protein energy malnutrition. Legumes have also been associated with containing appreciable amounts of micronutrients (Seena and Sridhar, 2005; Boschi and Arnoldi, 2011; Akinyele and Shokunbi, 2015). In the semi- and arid regions, Fe, Ca and Zn are among the problematic micronutrients as their deficiency has devastating consequences such as anaemia in women of reproductive age and birth defects in children (UNDP, 2012). For Fe, Ca, Zn, the RDA for an adult is 18 mg, 1 000 mg and 11 mg, respectively (National Research Council, 1989). Fruits and vegetables are the major sources of micronutrients, but they are not always available due to price and seasonality. Dry bean and cowpea have the potential to supply 40 to 60% of the RDA for Fe and Zn. In the case of Zn, this study showed that cowpea and dry bean contained ≈ 500% more Zn than leafy vegetables, which have been observed to contain 2.9 to 15.1 mg kg^{-1} (Nyathi et al., 2016). While vegetables such as spider flower contain more Fe than grain legumes (200 mg kg^{-1}), Fe content of grain legumes is comparable to those observed for vegetables such as swiss chard and cabbage (38.80-98.40 mg kg^{-1}) (Nyathi et al., 2016). These nutritional values show that legumes' micronutrient value is comparable to that of leafy vegetables and support the role of legumes in increasing dietary diversity, as they can complement cereals and vegetables in diets to meet the required nutrients for a healthy life (Chibarabada et al., 2017).

Among the grain legumes under study, bambara groundnut had the lowest macro- and micronutrient content. Nutrient content of bambara groundnut observed in this study were in the same range of those observed in other studies (Brough and Azam-Ali, 1992; Amarteifio et al., 2006; Kudre and Benjakul, 2013). Amarteifio et al. (2006) assessed micronutrient content of various landraces of bambara groundnut from Botswana, Namibia and Swaziland. They observed large variability within landraces and interestingly landraces from Swaziland had higher micronutrient content than landraces from Namibia and Botswana. This demonstrates that some bambara groundnut landraces are more nutrient dense than others. This non-uniformity in nutrient content within bambara groundnut landraces may hamper its promotion in the semi- and arid tropics. This calls for breeding efforts to select for nutrient dense landraces that can be used in breeding for high and uniform nutrient content.

Nutrient content of crops differed across water treatments and environments. When rainfall was low (Ukulinga during 2016/17), protein content for all the crops was also low. The low protein content under water limited conditions is attributed to low nitrogen (N) uptake by the plant. Nitrogen is correlated to protein content because it is important for synthesis of amino acids, which are building blocks of protein. Under water limited conditions, the activity of the enzyme that converts nitrogen to a form that is readily available to plants (nitrate reductase) is reduced (Da Silva et al., 2011). This ultimately reduced N availability to the plant (Da Silva et al., 2011), and consequently protein synthesis was reduced. Moreso, under water limited conditions, chlorophyll in plants is downregulated (Sanchez et al., 1983; Zhang et al., 2011). Nitrogen (N) is also a structural element of chlorophyll, hence down regulation of chlorophyll reduces N in the plant (Ercoli et al., 1993; Bojovic and Marcovic, 2009). This will have negative consequences on protein synthesis. This implies that water stress does not only affect yield, but can also affect protein content of crops. Fe content was higher at Ukulinga compared to the other sites. Fe is not readily mobile to different plant organs and its delivery to seeds depends on a continuous Fe transport system (Briat, 2005; Da Silva et al., 2011). The moisture of soil affects Fe availability. Wet soils have greater Fe availability for plants due to higher Fe^{2+}/Fe^{3+} ratio (Briat, 2005; 2009; Da Silva et al., 2011). Ukulinga was characterised by shallow soil profile and clay soil, hence good water holding capacity. This could have enhanced Fe mobility from roots to seeds. Inherent environmental conditions influenced grain nutrient content but there is still a dearth of information on how inherent environmental conditions and plant nutrient availability affects grain nutrient content in different crops.

Nutritional water productivity varied significantly among the crops. With respect to fat and energy productivity, groundnut was the most productive producing up to 400 and 5000 kcal m^{-3}, respectively. This was because of high fat and energy content. Values of energy water productivity of groundnut were similar to those estimated by Renault and Wallender (2000) and Annandale et al. (2012) for cereals. For $NWP_{Fe,\ Zn\ and\ Ca}$, dry bean was the most productive followed by cowpea. For groundnut, despite the high grain yield, $NWP_{Fe,\ Zn\ and\ Ca}$ was low due to poor nutrient content. This highlights the need for crop diversification to maximise nutritional productivity as crops showed different qualities. Fe, Zn and Ca contents of dry bean and cowpea observed in this study were comparable to those observed for leafy vegetables. However, $NWP_{Fe,\ Zn\ and\ Ca}$ observed for leafy vegetables by Nyathi et al. (2016) were higher (≈ 200%) than those observed by this study for grain legumes. This could be because leafy vegetables relatively used less water (1 210-3 260 m^{-3}) and had higher yield (600-9 500 kg ha^{-1}) than the grain legumes under study. For maximum benefit of Fe, Zn and Ca under water limited conditions, vegetables would be the recommended option as they are more productive. This highlights the importance of merging aspects of water use, yield and nutritional content for effective recommendations on tackling food and nutritional security.

The major legumes (groundnut and dry bean), had the highest protein water productivity, relative to the indigenous grain legumes. In the case of groundnut, it was mostly as a result of high protein content and high yield observed for the crop. For dry bean, high protein water productivity was contributed but with low water use and high protein content. For the indigenous grain legumes (cowpea and bambara groundnut), protein water productivity was low due to low protein content, high water use and low grain yield for bambara groundnut and low yield for cowpea. If indigenous grain legumes are to be promoted for crop diversification, there is need for yield and nutritional content improvements, to improve protein water productivity. When comparing protein water productivity values of grain legumes (100-300 g m^{-3}) to that estimated for meat products (12-60 g m^{-3}) (Annandale et al., 2012), it is interesting to note that despite meat being the highest protein source, legumes are more productive. This is because water consumption in legume production is less than water consumption for production of meat. This further supports the promotion of legumes as protein alternatives in water scarce areas as they relatively use less water compared to production of meat.

Environments had a significant effect on NWP. This was mostly as a result of yield instability across environments. Fluctuations in NWP followed fluctuations in grain yield. Low grain yield caused low NWP. There has been emphasis on improving yield stability in the context of food security. This study highlights that yield stability also affects NWP. Improving yield stability not only ensures continuous availability of grain but also ensures continuous nutritional gain. Water regimes did not have a significant effect on NW, while grain yield was also not significantly affected by water regimes. This implies that there is scope to tackle the challenge of food and nutritional security in the semi- and arid tropics under rainfed conditions.

5.5 Conclusions

Groundnut had higher fat and energy content relative to the other crops. Dry bean and cowpea had the highest micronutrient and have the potential to supply 40 to 60% of the RDA for Fe and Zn. The protein content of the grain legumes has potential to supply 40-60% of the RDA for protein. This supports the role of legumes in increasing dietary diversity as they can complement cereals and vegetables in diets to meet the required nutrients for a healthy life. Bambara groundnut had the lowest macro- and micronutrient content. This calls for breeding efforts to breed for nutrient density in bambara groundnut. Protein content reduced when rainfall was low. Fe content was higher under clay soil. The major legumes (groundnut and dry bean), had the highest protein water productivity, relative to the indigenous grain legumes. For $NWP_{Fe,\ Zn\ and\ Ca}$, dry bean and cowpea were more productive. Environments had a significant effect on NWP, due to yield instability across environments. Yield stability of grain legumes is key for tackling food and nutritional insecurity. Water regimes did not have a significant effect on NWP, implying that there is scope to tackle the challenge of food and nutritional security in the semi- and arid tropics under rainfed conditions. Future research is needed on understanding the effect of agronomic practices and inherent environmental conditions on nutrient content and NWP of crops.

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CHAPTER 6

CALIBRATION AND TESTING OF AQUACROP FOR GROUNDNUT AND DRY BEAN

TP Chibarabada, AT Modi and T Mabhaudhi

6.1 Introduction

An increase in production of grain legumes is expected in semi- and arid regions following the promotion of sustainable intensification and alleviation of food and nutrition security. Currently, grain legumes have shown suitability to these environments, but they have also shown instability across environments and seasons. In these regions water remains one of the limiting factors to agriculture. There are gaps on how grain legumes adapt to different environments and to varying water availability. For successful promotion of legumes in semi- and arid regions there is need for information on their adaptability to these regions. This requires investments in time and resources on research, which are often limiting. Crop growth models have been developed partly to answer research questions, thus, limiting time and resources spent on carrying out field experiments under various environments and management (Dourago-Neto et al., 1998; Rauff and Bello, 2015).

Crop growth models mimic growth and development of crops under different conditions using empirical and mathematical relationships (Dourago-Neto et al., 1998; Rauff and Bello, 2015). They are useful decision support tools (Boote et al., 1996), making them valuable tools in agriculture. Grain legumes have been modelled successfully with groundnuts, soybeans and dry beans having their own models [PNUTGRO (Boote *et al.,*., 1989), SOYGRO (Jones et al., 1989) and BEANGRO (Hoogenboom et al., 1994), respectively], which are housed in the Decision Support System for Agrotechnology Transfer (DSSAT) model (Jones et al., 2003). Legumes such as groundnut, soybean, cowpea and dry bean have also been calibrated for major models such as the Agricultural Production Systems sIMulator (APSIM) (Keating et al., 2003). While these models were successful in simulating yield under different management conditions (Bhatia et al., 2008; Yadav et al., 2012), their wider use has been limited by their complexity, as they require a relatively large number of input parameters, some of which are challenging to obtain under field conditions (Corbeels et al., 2006; Mourice et al., 2014; Jones et al., 2017). This confines their application to research applications where resources, instrumentation and expertise are available. The FAO overcame the issue of complexity, by developing a simpler model that can still maintain accuracy and robustness – AquaCrop (Raes et al., 2009; Steduto et al., 2009).

The FAO – AquaCrop model was designed to model yield responses to water making it an appropriate model in semi- and arid regions (Raes et al., 2009; Steduto et al., 2009). AquaCrop has been successfully parameterized for several herbaceous crops including, but not limited to, wheat (*Triticum aestivum*) (Andarzian et al., 2011), maize (*Zea mays*) (Heng et al., 2009) sorghum (*sorghum bicolor*) (Araya et al., 2016) and cotton (*Gossypium spp*.) (Farahani et al., 2009). Thus far, a few grain legume crops such as soybean (*Glycine max*) (Steduto et al., 2012; Adeboye et al., 2017), bambara groundnut (*Vigna subterranea*) (Karunaratne et al., 2011; Mabhaudhi et al., 2014a) and pea (*Pisum sativum*) (Paredes and Torres, 2016), have been calibrated and tested for AquaCrop. For these crops, AquaCrop was able to predict yield under different production scenarios (Karunaratne et al., 2011; Mabhaudhi et al., 2014a, Paredes and Torres, 2016; Adeboye et al., 2017). For pea, AquaCrop was successfully applied to assess the impact of sowing dates and irrigation strategies on yield and water use (Paredes and Torres, 2016). AquaCrop could be a useful decision support tool on production of grain legumes in semi- and arid regions. This is currently limited as only a few grain legumes (soybean, bambara groundnut, pea) have been modelled in AquaCrop.

There is need to calibrate and test AquaCrop for more grain legume crops. Groundnut (*Arachis hypogaea*) and dry bean (*Phaseolus vulgaris*) are among the major grain legumes produced by subsistence and commercial farmers in the semi- and arid regions (Chibarabada et al., 2017). Currently, AquaCrop has not been calibrated and validated for both crops. Availability of well-calibrated models, is an initial step to increased application of AquaCrop to answer research questions on adaptability of grain legumes to varying water availability and environmental conditions. The aim of the study was to calibrate and test the performance of AquaCrop model for groundnut and dry bean under varying water regimes and environments in a semi- and arid environment. The specific objectives were to (i) calibrate AquaCrop for groundnut and dry bean, (ii) evaluate its ability to simulate CC, biomass, yield and evapotranspiration (ET) of groundnut and dry bean for varying soils and climates.

6.2 Material and Methods

6.2.1 AquaCrop Model

The FAO's AquaCrop model is an engineering type, water-driven and canopy level model (Raes et al., 2009; Steduto et al., 2009) that builds on previous FAO work related to yield response to water (Doorenbos and Kassam, 1979). It simulates yield response to water availability. Yield is simulated using four phases which are; crop development, crop transpiration, biomass production and yield formation (Steduto et al., 2009; Vanuytrecht et al., 2014). AquaCrop is a canopy level model because it simulates crop development through the canopy's expansion, aging, conductance and senescence. When simulating crop development, AquaCrop describes the green canopy which is above ground as well as development of root zone (below ground). To describe stresses on canopy expansion, AquaCrop uses stress coefficients (Ks) where; Ks is 1 when water stress is non-existent (above upper threshold) and Ks is 0 when water stress completely stops canopy expansion (below lower threshold) (Steduto et al., 2009; Vanuytrecht et al., 2014). In AquaCrop, CC is proportional to transpiration.

The same pathway for transpiration is used for CO_2 intake by the plant, which is then converted to carbohydrates through photosynthesis – hence transpiration is proportional to biomass production (Steduto et al., 2009; Vanuytrecht et al., 2014). The relationship between biomass produced and water consumed by a given species is linear for a given climatic condition, hence AquaCrop uses a normalized crop water productivity function [aboveground dry matter produced per unit land area or per unit of water transpired (mm)] in the simulation of biomass. This relationship is the core of AquaCrop and is where the description 'water driven' emanates from. The equation for the simulation of biomass is therefore (Steduto et al., 2009; Vanuytrecht et al., 2014);

$$B = WP \times \sum T_r \qquad \text{Equation 6.1}$$

where,

B = Above ground biomass (tonne ha^{-1})

WP = Normalised water productivity (g m^{-2}), and

T_r = Crop transpiration (mm).

To calculate the yield, AquaCrop uses the harvest index (HI), taking into consideration the adjustments in HI due to stress at the start of the yield formation, during flowering and during yield formation (Steduto et al., 2009; Vanuytrecht et al., 2014). Therefore;

$$Y = f_{HI} \times HIo \times B \qquad \text{Equation 6.2}$$

where:

Y = yield (tonne ha^{-1})

f_{HI} = multiplier which considers the stresses that adjust the HI from its reference value

HIo = Reference HI (%)

B = Total above ground biomass (tonne ha^{-1}).

To run simulations, AquaCrop requires inputs of climate data, crop characteristics, soil characteristics and description of management practices.

6.2.2 Study areas

Field trials were conducted at three sites (Fountainhill Estate, Ukulinga Research Farm and Umbumbulu Rural District), in KwaZulu-Natal, South Africa. Ukulinga Research Farm [29°37'S; 30°16'E; 750 meters above sea level (m.a.s.l.)] was the on-station research trial, while Umbumbulu (29.984'S; 30.702'E; 593 m.a.s.l.) and Fountainhill Estate (29.447'S; 30.546'E; 1020 m.a.s.l.) were on-farm research trials. A pot trial was conducted in a growth tunnel at the University of KwaZulu-Natal's Controlled Environment Facility, Pietermaritzburg, South Africa (29°37'12"S; 30°23'49"E; 750 m.a.s.l.). The environment in the growth tunnel is semi-controlled with temperatures ranging from ~18/33°C (day/night) and relative humidity (60-80%), which is a warm subtropical climate (Modi, 2007).

6.2.3 Experimental design

6.2.3.1 Field Trials

Experiments were conducted during the 2015/16 and 2016/17 summer seasons. At Ukulinga Research Farm, the experimental design was a split-plot design arranged in randomised complete blocks. The main plots were the water treatments, while subplots were the crops (groundnut and dry bean). The water treatments were optimum irrigation, deficit irrigation and rainfed conditions. Irrigation scheduling was based on management allowable depletion (MAD) of 60% Plant Available Water (PAW). The approach to deficit irrigation was to apply irrigation (MAD: 60% PAW) at the growth stages that were most sensitive to water stress (Geerts and Raes, 2009). All the water treatments were optimally irrigated up to 90% emergence to ensure establishment of all trials. For the rainfed trial, irrigation was withdrawn thereafter. At Umbumbulu and Fountainhill, the trials were entirely rainfed and the experimental design was a randomised complete block design with three replications. Plant population for both crops was 88 889 plants ha^{-1}. Trials from Ukulinga during the 2015/16 were used to calibrate the model, while trials at all the sites during 2016/17 were used for model evaluation (Table 6.1). Planting dates for all the trials are given in Table 6.1.

6.2.3.2 Controlled environment

A pot trial was conducted for 2015/16 summer season for the purposes of determining some parameters needed to calibrate the model (Table 6.1). Planting date is given in Table 6.1. The experimental design included three water treatments (80, 60 and 30% of field capacity) and two grain legume crops (groundnut and dry bean), arranged in a completely randomised design with three replications (3×2×3 = 18 pots). The three water treatments [80, 60 and 30% of field capacity (FC)] represented no water stress, mild water stress and severe water stress, respectively. This was based on previous studies that used the same treatments to impose water stress in pot trials. In addition to the 18 pots, nine pots (three replications × three water treatments) were added to monitor soil evaporation from the pots. Soil evaporation was deducted from the total evapotranspiration of the pots to determine crop transpiration. Fifty-four pots representing (two legume crops × three water treatments × nine intervals), were also added to allow for destructive sampling to determine plant mass fortnightly. This allowed for correction of plant mass when determining irrigation through gravimetric measurements. In total, there were 81 pots.

Table 6.1: Summary of experimental design, planting dates and data sets used for calibration and testing of the model.

Season	Site	Water treatment	Planting date	Calibration	Testing
2015/16	Ukulinga	[a]OI	17 November 2015	✓	
		[b]DI		✓	
		Rainfed		✓	
2015/16	Pot trial	80% [c]FC	20 December 2015	✓	
		60% [c]FC		✓	
		30% [c]FC		✓	
2016/17	Ukulinga	[a]OI	16 January 2016		✓
		[b]DI			✓
		Rainfed			✓
	Fountainhill	Rainfed	14 December 2016		✓
	Umbumbulu	Rainfed	30 November 2016		✓

[a]OI = Optimum irrigation; [b]DI = Deficit irrigation; [c]FC = Field capacity

6.2.4 Model Inputs

6.2.4.1 Climate Data

To create a climate file (.CLI), the AquaCrop model requires daily maximum (Tmax) and minimum (Tmin) air temperatures (.TMP file), FAO Penman-Monteith daily reference crop evapotranspiration (.ETO), daily rainfall (.PLU) and mean annual carbon dioxide (CO_2) concentration. For Ukulinga, .TMP, .PLU and .ETO files were created using daily data obtained from an automatic weather station that is located at the Research Farm. For Fountainhill and Umbumbulu, .TMP, .PLU and .ETO were created using daily data obtained from the South African Sugar Association (SASA) weather web portal (http://portal.sasa.org.za/weatherweb). For all sites, a default file of the mean annual CO_2 concentration measured at the Mauna Loa Observatory in Hawaii that is provided by AquaCrop, was used.

6.2.4.2 Crop parameters

The initial values for the conservative parameters were selected from relatively similar grain legume crops that have been calibrated for AquaCrop. For groundnut, a bambara groundnut crop file (Mabhaudhi et al., 2014a) was used. For dry bean, the soybean.CRO [Default soybean, Calendar (Patancheru, 25Jun96)] in AquaCrop was used. The model was calibrated using data collected from the optimum irrigation treatment at Ukulinga during the 2015/16 season and the pot trials (Table 6.1). For parameters not measured during the experiments, values from the template crop files (bambara groundnut in the case of groundnut and soybean in the case of dry bean) parameters were used as they are relatively similar grain legumes.

Groundnut and dry bean crop files (.CRO) were created using data collected from Ukulinga during 2015/16 and pot trials. Crop parameters from the OI treatment were used to calibrate the model as they represent the crops' potential under no stress (Table 6.2). Data from the DI and rainfed irrigation treatments was used to determine crop response to water stress. In cases where data from field trials was inconclusive, data from pot trials were used to determine crop responses to water stress. Transpiration could not be determined under field conditions; hence WP was determined from the pot trial (Table 6.2). Parameters not considered were biomass production affected by soil salinity and fertility stress. Crop phenology was observed in calendar days and thereafter converted to thermal time (GDD) in AquaCrop.

Table 6.2: Selected crop parameters and values used for the calibration of groundnut and dry bean in AquaCrop.

Parameter	Determination	Unit	Groundnut value	Dry Bean value
Planting method		-	Direct sowing	Direct sowing
Plant population	Plant population based on intra-row spacing of 0.75 m and inter-row spacing of 0.15 m	Plants $hectare^{-1}$	88 889	88 889
Seedling size	Obtained under controlled environment where the mean initial seedling leaf area per plant was measured at 90% emergence on five randomly selected plants using the LI-3100C Leaf Area Meter (LICOR, USA).	cm^2	3	17
Initial canopy cover (CCo)	Model derived	%	0.27	1.51
Time to emergence	Time to emergence was determined as the number of days from planting to when 90% of the plants had > 20 mm hypocotyle protrusion.	Growing Degree days	127	89
Time to maximum canopy cover (CCx)	Leaf area index, which is the one-sided green leaf area per unit ground surface area occupied by the plant was measured with the LAI-2200C Plant Canopy Analyzer (LICOR, USA). LAI values were converted to CC using the formula by Hsiao et al. (2012) where; $CC = 1.005 \times [1 - \exp(-0.6\ LAI)]$ Graphs of weekly CC were plotted and the time to which the canopy reached its constant peak was determined as the maximum canopy cover.	Growing Degree days	1 040	949
Time to canopy senescence	Time taken when at least 10% of leaves had senesced (chlorophyll degradation) without new leaves being formed to replace them.	Growing Degree days	110	1 133
Time to physiological maturity	A plant matured when at least 50% of leaves had senesced (chlorophyll degradation).	Growing Degree days	132	1 559
CCx	Consistent maximum canopy observed.	%	68	70
Canopy decline	Time from maximum CC to when 50% of plants had reached senescence	days	23	20
Canopy growth coefficient (CGC)	Model derived	%/day	12.2	11.0
Canopy decline coefficient (CDC)	Model derived	%/GDD	0.683	0.745
Length building up HI	Time from flowering (50% of the plants had at least one open flower) to maturity (50% of plants reached physiological maturity).	Growing Degree days	943	846
Duration of flowering	This was defined as the period (number of days) that 50% of the experimental plants had at least one flower that was open.	Growing Degree days	798	641
Time to flowering	This was the time taken for 50% of the experimental plants to have at least one fully opened flower.	Growing Degree days	595	640
Determinacy linked with flowering	Determinancy was defined as cessation of vegetative growth when the terminal flower of the main stem started to develop.	–	No	Yes
Minimum effective rooting depth	Plants used for determination of seedling CC were used for determination of minimum effective rooting depth. Seedlings were sampled at 90% emergence and root length was measured using a 30-cm ruler.	m	0.3	0.3
Upper temperature	Upper temperatures were obtained from Vara Prasad et al. (2002) and Vara Prasad et al. (2001), respectively.	°C	28	29
Maximum air temperature affecting pollination	Obtained from Vara Prasad et al. (2002) and Vara Prasad et al. (2001), respectively.	°C	34	34

Water productivity (WP)	This was obtained from the pot trials under 80% FC. A duplicate trial (one with the plant and without the plant) was established. Evapotranspiration (ET) was measured in the pots with the plants while evaporation was measured in the pots without the plants. At the end E was deducted from ET to determine T. WP was then computed from the measured T and total plant biomass WP = Biomass (g)/ T (mm)	tonne ha^{-1}	15	12
Reference HI (HI_o)	Determined from the optimum irrigation trial as; HI = Yg/B where: Yg = economic yield based on grain yield (kg), and B = total biomass (groundnut)/ above ground biomass (dry bean) (kg).	%	24	43
Canopy expansion: (response to water stress)	Determined from values of weekly leaf area measured from the pot trial using the LI-3100C Leaf Area Meter (LICOR, USA).at different water regimes. Data on leaf area was analyzed to determine the crop thresholds and sensitivity class.	–	Moderately tolerant	Moderately tolerant
Stomatal closure (response to water stress)	Weekly stomatal conductance from three water regimes during the pot trial was measured using a Steady State Leaf Porometer Model SC-1 (Decagon Devices, USA) on the abaxial surface of a new fully expanded and fully exposed leaf. Data was analysed to determine sensitivity class.	–	Moderately sensitive	Moderately sensitive
Early canopy senescence (response to water stress)	Determined from values of time to senescence measured during the pot trial at different water regimes. Time taken when at least 10% of leaves had senesced (chlorophyll degradation) without new leaves being formed to replace them. Data on time to senescence was analyzed to determine the crop thresholds and sensitivity class.	–	Moderately tolerant	Moderately tolerant
Aeration stress to waterlogging	Obtained from Liu (2009) and Soltani (2015), respectively	–	Moderately tolerant	Moderately tolerant
Overview of water stress effects on HI	The positive difference between the HI_o and HI under rainfed conditions was considered as the overall positive impact of water stress on HI.	%	6	10

6.2.4.3 Soil parameters

Soil files (.SOL) for each site (Ukulinga, Umbumbulu and Fountainhill) were created using site specific soil data (Table 6.3). Soil characteristics at Ukulinga were obtained from Mabhaudhi et al. (2014b), who used the same field. At Fountainhill and Umbumbulu, soil physical characteristics (depth and texture) were determined and hydraulic properties were calculated using Soil Texture Triangle Hydraulic Properties Calculator (http://hydrology1.nmsu.edu/teaching/soil456/soilwater.html). There was no groundwater file (.GWT) created.

6.2.4.4 Irrigation and field management

Irrigation was applied through a sprinkler system with a distribution uniformity of 85% and 100% soil surface wetting. Three separate irrigation files (.IRR) for the fully irrigated, deficit and rainfed trial were created. For the field management file (.MAN), soil fertility was non-limiting, there was no mulching and soil bunds and there were no practices to prevent surface runoff.

Table 6.3: Soil parameters used for the AquaCrop Soil File

Site	Horizon	Description	Thickness (m)	[a]Sat	[b]FC (% Vol)	[c]PWP	[d]Ksat (mm day^{-1})	[e]TAW (mm)
Ukulinga	1	Clay loam	0.40	48	40	21	25	78.4
Fountainhill	1	Sand	2.0	36	13	6	3000	140
	1	Clay loam	0.40	46	35	17	125	72
Umbumbulu	2	Clay	0.60	50	39	21	35	108

[a]Sat = Volumetric water content at saturation; [b]FC = Field capacity; [c]PWP = Permanent wilting point; [d]Ksat = Saturated hydraulic conductivity; [e]TAW = Total available water.

6.2.4.5 Observations

Above ground destructive sampling was conducted every fortnight and then plants were oven dried at 80°C until there were no changes in total above aground biomass observed to determine accumulation of above ground biomass. Leaf area index (LAI), which is the one-sided green leaf area per unit ground surface area occupied by the plant, was routinely measured using the LAI-2200C Plant Canopy Analyzer (LICOR, USA). Leaf area index values were then converted to CC using the formula by Hsiao et al. (2012);

$$CC = 1.005 \times [1 - \exp(-0.6LAI)]^{1.2} \qquad \text{Equation 6.3}$$

Observed CC data and above ground biomass were used to create field observation files (.OBS) for each water treatment and experimental site.

Crop ET was calculated under field conditions as the residual of a modified soil water balance (Allen et al., 1998);

$$ET = ER + 1 \pm \Delta SWC \qquad \text{Equation 6.4}$$

where;

ET = evapotranspiration,

ER = Effective rainfall (mm) is monthly effective rainfall that is stored in the root zone after subtracting the amount of rainfall lost to runoff and deep percolation (USDA-SCS, 1967),

I = irrigation (mm), and

ΔSWC = changes in soil water content (mm) measured using a PR2/6 soil moisture probe (Delta T, UK).

At harvest, six representative plants were harvested from each plot and air dried for determination of total biomass and yield.

6.2.5 Simulation procedure

AquaCrop version 5.0 (FAO, 2015) was used. The created files (.CLI, .CRO, .SOL, .IRR, .MAN and .OBS) were put into AquaCrop and the model was run in thermal time (growing degree days). Simulation periods were linked to the growing cycle (day one after sowing to maturity; planting dates are given in Table 6.1). At Ukulinga, during 2015/16, initial soil water content was assumed to be at field capacity as planting followed a rainfall event and irrigation was applied soon after planting. During 2016/17, initial soil water content was 50% of TAW at Ukulinga, 42% of TAW at Umbumbulu and 55% of TAW at Fountainhill.

6.2.6 Model evaluation statistics

To evaluate model performance, statistical indicators used were correlation of determination (R^2), root mean square error (RMSE), normalised root mean square error (NRMSEcv), Nash-Sutcliffe model efficiency coefficient (EF) and Willmott's index of agreement (d) (FAO, 2015). Because the different indicators have different strengths and weaknesses, an ensemble is necessary to sufficiently assess the performance of the model (FAO, 2015). Description and calculation of the different indicators can be obtained from Willmott et al. (1985) and FAO (2015).

Correlation of determination measures the strength of the association between observed and simulated values. It represents the data that is closest to the line of best fit. Values range from 0 to 1 with 1 indicating a perfect fit. Due to small number of observed values ($n < 10$), values of $R^2 > 0.90$ were considered as very good, while values between 0.70 and 0.90 were considered good. Values between 0.50 and 0.70 were considered moderately good. Values less than 0.50 were considered poor. Root mean square error measures the average magnitude of the difference between simulated and observed data. It ranges from 0 to positive infinity, and expressed in the units of the studied variable. A RMSE approaching 0 indicates good model performance. Normalized RMSE on the other hand gives an indication of the relative difference between simulated and observed values. It is expressed as a % with < 10% being very good and > 25% being poor. The Nash-Sutcliffe EF model determines the relative magnitude of the residual variance compared to the variance of the observations. An EF of 1 indicates a perfect match between the model and the observations. An EF of 0 means that the model predictions are as accurate as the average of the observed data. A negative EF implies that the mean of the observations gives a better prediction than the model. In this study, EF less than 0.4 was considered poor (FAO, 2015). The Willmott's index of agreement measures the degree to which the observed data are approached by the predicted data. It ranges between 0 and 1, with 0 indicating no agreement and 1 indicating a perfect agreement between simulated and observed data. D-index was acceptable when it was above 0.64 (FAO, 2015). Overall model performance was considered good when at least any 3 of the 5 model evaluation indicators were good to very good.

The final biomass, ET and yield differences were computed as percentage relative differences obtained using the formula;

$$\left[\frac{Simulation - Observed}{Observed}\right] \times 100\%$$ Equation 6.5

Relative differences of ± 10% were considered accurate (Farahani et al., 2009; Steduto et al., 2009), while differences of ± 20% were acceptable.

6.3 Results and Discussion

6.3.1 Groundnut

6.3.1.1 Calibration

For groundnut, model evaluation indicators showed that there was a good match (R^2 = 0.84-0.98; RMSE = 4.8-7.4%; NRMSEcv = 8.8-12%; EF = 0.80-0.96; d-index = 0.94-0.99) between observed and simulated values. However, the model underestimated CC between 60 and 120 days after planting (DAP) (period of maximum CC). Karunaratne et al. (2011) also reported similar outputs for their calibration and validation of bambara groundnut. This study used a bambara groundnut file as a template for calibration of groundnut as they are relatively similar grain legumes. In groundnut, node production may continue up to maturity, given optimum conditions (phyllochron and water availability) (Halilou et al., 2016). AquaCrop does not consider leaf appearance rate and phyllochron; this may explain the underestimation of simulated values. Groundnut could have increased leaf appearance rate in response to favourable environmental conditions during that period which was not captured by the model. Despite AquaCrop's approach of exponential growth and decay of canopy development followed by maximum CC, it was still able to simulate CC satisfactorily. This confirms AquaCrop's simplicity, yet maintaining accuracy.

For biomass, model calibration of groundnut showed a moderately good match under OI (R^2 = 0.96; RMSE = 0.903 tonne ha^{-1}; NRMSEcv = 31.3%; EF = 0.9; d-index = 0.98) and a good fit under DI (R^2 = 0.98; RMSE = 0.798 tonne ha^{-1}; NRMSEcv = 21.7%; EF = 0.95; d-index = 0.99) and RF treatments (R^2 = 0.98; RMSE = 0.650 tonne ha^{-1}; NRMSEcv = 16.7%; EF = 0.96; d-index = 0.94) (Fig 6.2). Under OI, NRMSEcv was poor (31.3%); this was because the OI trials were attacked by monkeys during the later growth stages. AquaCrop does not consider damage from animals, hence the model overestimated. Thus, in this instance, simulated values could be assumed to be representative of crop potential. The model simulated biomass under DI and RF relatively well. Although all the statistical indicators showed a good fit under DI and RF, the model tended to underestimate biomass. This could be a carry-over effect from underestimation of CC. Biomass is used to simulate yield by means of a HI. Under

OI, grain yield was overestimated by 48%. This was due to yield loss from monkeys. Under DI and RF, AquaCrop under- and overestimated grain yield by 0.8% and 2.2%, respectively, thus the model simulated yield accurately (Farahani et al., 2009) (Table 6.4). Since AquaCrop accurately simulated CC, biomass and yield under DI and RF, it can be inferred that it is a suitable model for simulating biomass and yield of groundnut under different water regimes.

The model overestimated final ET by 28% in the OI treatment, 35% in the DI treatment and 34% in the RF treatment (Table 6.4). One of the distinguishing features of AquaCrop is the separation of ET into evaporation (E_s) and transpiration (T_r) based on a simple CC model (Vanuytrecht et al., 2014). It would be assumed that since the model underestimated CC, which is proportional to T_r, (***cf.*** section 2.1), then E_s would be the parameter overestimated. Based on RMSE values, there was more underestimation of CC under RF relative to DI and OI. To support the assumption, it was expected that results of simulated E_s relative to T_r under the different water regimes would show that there was more E_s relative to T_r under rainfed conditions. However, this was not the case as proportion of E_s was the same under all the watering regimes. This shows that the model tended to overestimate both E_s and T_r and this was greater under DI and RF conditions. It is not clear why the model overestimated ET.

6.3.1.2 Testing

At Ukulinga, model performance evaluators showed moderately good to poor model performance in simulating CC across all the water regimes (Fig 6.3). Under OI, R^2 was moderately good (0.75), while it was very good under DI and RF conditions (0.92 and 0.93, respectively). D-index was good across all the water regimes (0.70; 0.78 and 0.84, in the OI, DI and RF treatment respectively). Root mean square error, NRMSEcv and EF were poor across all the water regimes (> 8.6%, > 43.8% and < -0.38, respectively) (Fig 6.3). The coefficient of determination and d-index showed moderately good fit as they are not sensitive to the magnitude of the difference between simulated and observed data. Root mean square error, NRMSEcv and EF were very poor due to their sensitivity to magnitude of the difference between simulated and observed data (***cf.*** section 6.2.6).

The model overestimated CC for groundnut across all the watering regimes. This was mainly as a result of disturbances in our trials by monkeys and wild pigs which could not be factored into the model. The canopy was often disturbed as the monkeys were seeking the groundnut pods. As the canopy was damaged, it would take time to recover which was also not factored into the model. This was evident in the differences between observed and estimated time to maturity (29 May 2017 and 18 May 2017, respectively). While crop damage by pests and animals is a reality in farming, incorporating this in crop growth models remains a challenge (Donatelli et al., 2017). Incorporating damage by animals into crop models is often challenging due to differences in patterns of damage and lack of data on extent of damage (Bayani et al., 2016). This is partly because of lack of proper methods to estimate animal damage.

Consistent to results of CC, overall model performance was poor for groundnut cumulative biomass (Fig 6.4). Similar to CC R^2 (OI = 0.96; DI = 0.96; RF = 0.85), d-index values (OI = 0.49; DI = 0.63; RF = 0.81) showed poor to very good fit, while RMSE (OI = 2.449 tonne ha^{-1}; DI = 1.889 tonne ha^{-1}; RF = 1.024 tonne ha^{-1}), NRMSEcv (OI = 299.1%; DI = 207.7%; RF = 93.5%) and EF (OI =14.21; DI = -5.10; RF = -0.56) were very poor. Cumulative biomass was also overestimated due to animal attacks. Consequently, final biomass was overestimated by 61, 59 and 52% in the OI, DI and RF trials, respectively. Grain yield was overstimated by up to 86% because grain was of interest to the monkeys, hence they were mostly affected. However, the damage by monkeys did not affect estimation of final ET. Final ET was underestimated by 1.4% in the OI treament and overestimated by 9 and 11% in the DI and RF treatments, respectively. It is most probable that the disturbances in the plant canapy would have affected the separation of ET into E_s and T_r, which the study did not quantify.

The model was further tested for its performance at different sites (Fountainhill and Umbumbulu) under rainfed conditions. For Fountainhill, overall model simulation of CC was good (R^2 = 0.82; RMSE = 11.5%; EF = 0.69; d-index = 0.94) although NRMSEcv showed moderately poor performance (26.8%) (Fig 6.5). This could be because the model failed to capture canopy senesence and crop maturity of the crop. This could be as a result of the initial soil water conditions at Fountanhill. At planting, initial soil water content was 55% of TAW. The model overestimated the delay in crop establishment. Initial values of CC showed that the model underestimated CC (Fig 6.5) during crop development as a result of delayed timing of crop establishment. As a result the model delayed time to senescence and time to maturity, leading to poor simulation of CC towards the end of the season. Steduto et al. (2009) reported on the sensitivity of the model to initial soil water conditions. This could be because the model only considers time to emergence under optimal conditions and does not consider the soil water upper and lower thresholds for emergence of different crops.

For biomass accumulation, model performance for Fountainhill was good to very good (R^2 = 0.98; RMSE = 0.540 tonne ha^{-1}; NRMSEcv = 18.5%; EF = 0.9; d-index = 0.99). The model underestimated biomass which could be as a result of carry over effect from CC overestimating time to crop establishment. Interestingly, final biomass was overestimated by 18% despite underestimation of cumulative biomass (Table 6.4). The reason for this overestimation is not clear. Grain yield and ET were underestimated and overestimated by 14 and 11%, respectively which was considered acceptable (Table 6.4). Despite the slightly poor NRMSEcv for CC (26.5%), the model perfomed well for Fountaihill.

For Umbumbulu, the model performed well in simulating both CC and cumulative biomass (R^2 = 0.98 and 1, respectively; RMSE = 3.5% and 0.25 tonne ha^{-1}, respectively; NRMSEcv = 8.4 and 11.2%, respectively, EF = 0.98 for both; d-index = 1 for both) (Fig 6.6). Consequently, only 2% underestimation of final biomass was observed, which was accurate (Faharani et al., 2009). Despite the good simulation of CC and biomass, the model poorly overestimated both final grain yield and ET (34%) (Table 6.4). The model simulated an increase in HI of ≈ 5%. Umbumbulu was chracterised as extremely hot during that season. According to Vara Prasad et al. (1999, 2000) the threshold day temperature for pollen production and viability for groundnut was 34°C. The model was set to consider 34°C as the threshold for pollination. Temperature data showed that during groundnut reproductive stage there were 12 days above 34°C. However, during the runs it could not be established if the model had captured pollination affected by heat stress and to what magnitude. Model output showed that HI had increased 5% and it was not clear which adjustments had been factored in. Without clear indication on the adjustments of HI, it could not be established why the model overestimated grain yield.

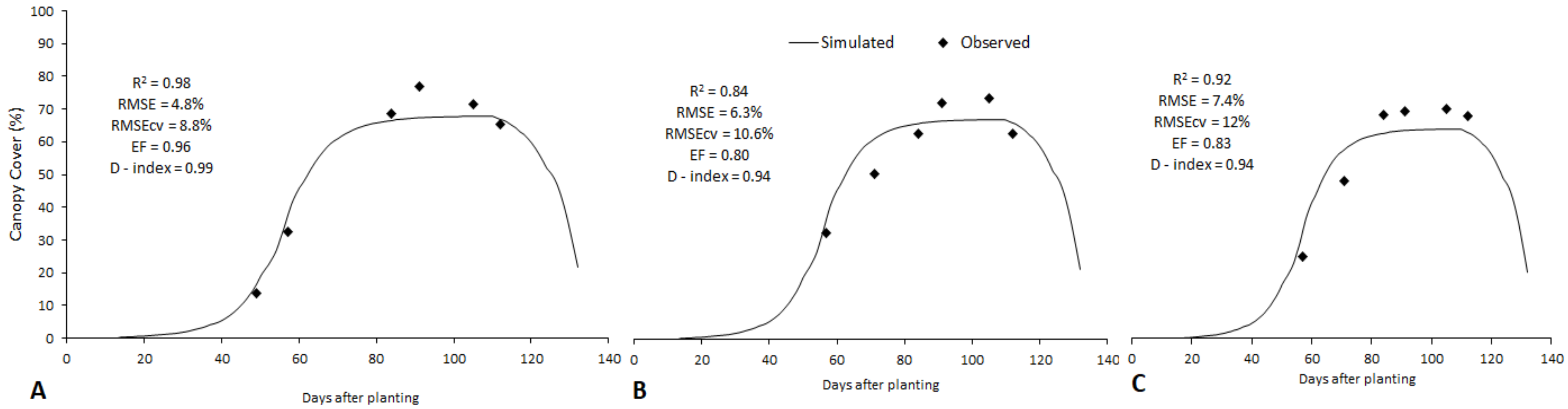

Figure 6.1: Simulated and observed CC for groundnut under A) optimum irrigation B) deficit irrigation C) rainfed conditions during the calibration season 2015/16.

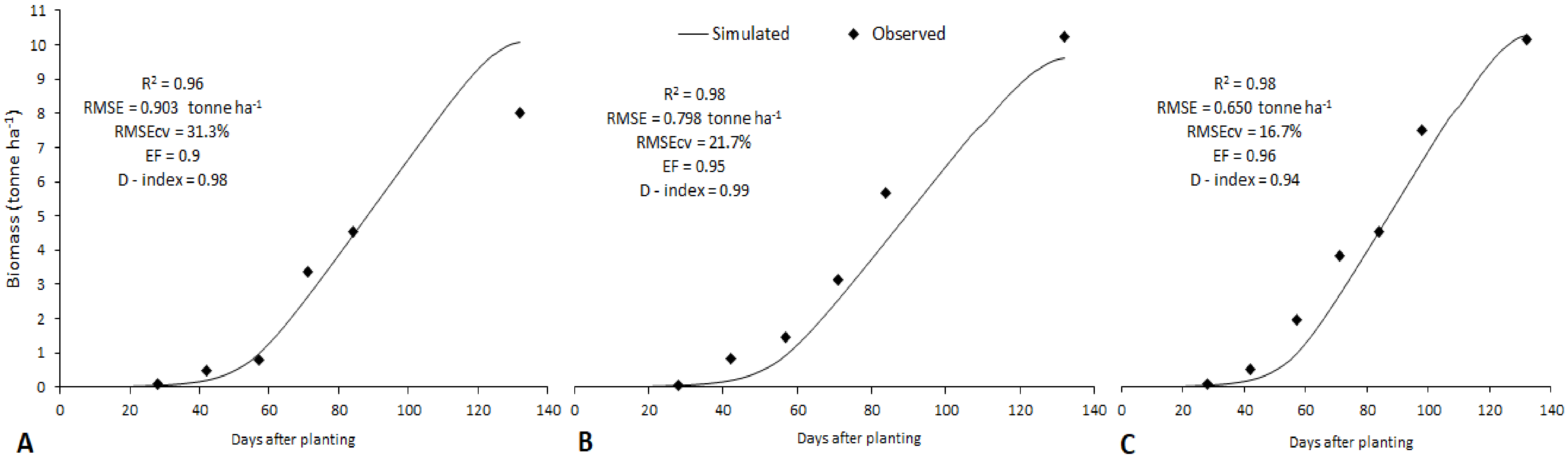

Figure 6.2: Simulated and observed cumulative biomass for groundnut under A) optimum irrigation B) deficit irrigation C) rainfed conditions during the calibration season 2015/16.

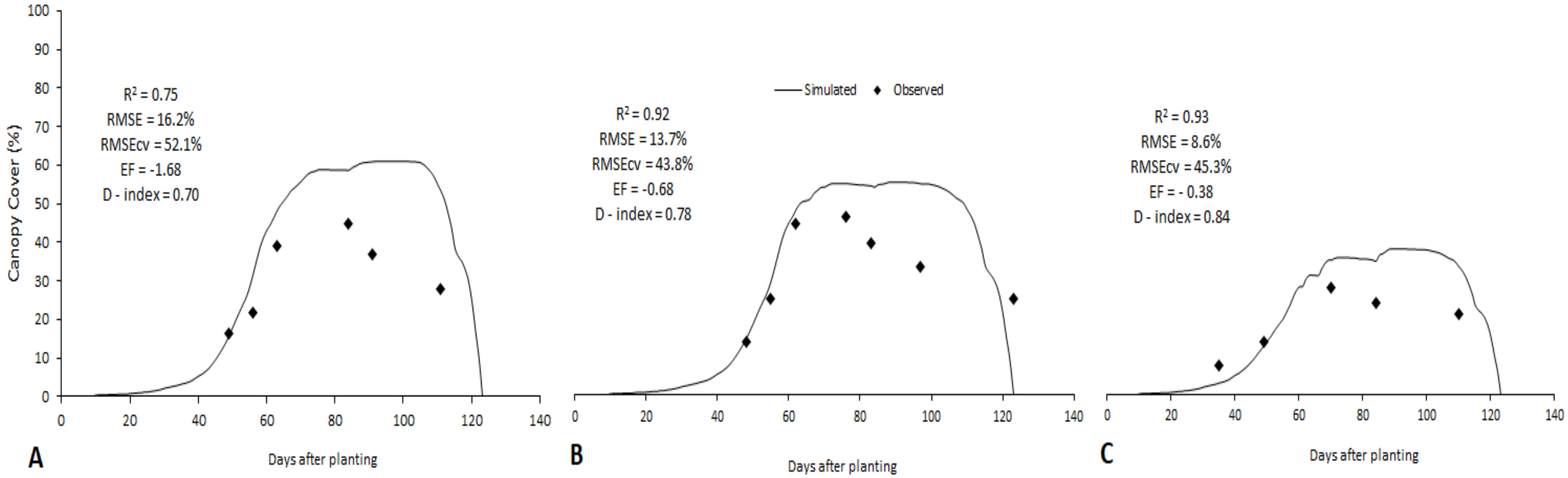

Figure 6.3: Simulated and observed CC for groundnut under A) optimum irrigation B) deficit irrigation C) rainfed conditions during model testing at Ukulinga (2016/17 season).

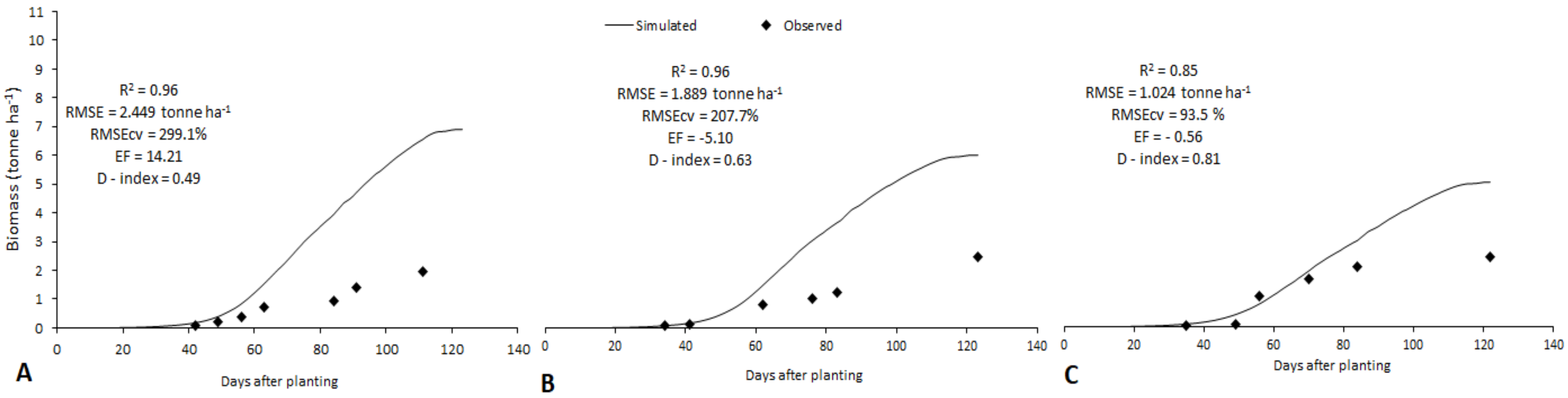

Figure 6.4: Simulated and observed cumulative biomass for groundnut under A) optimum irrigation B) deficit irrigation C) rainfed conditions during model testing at Ukulinga (2016/17 season).

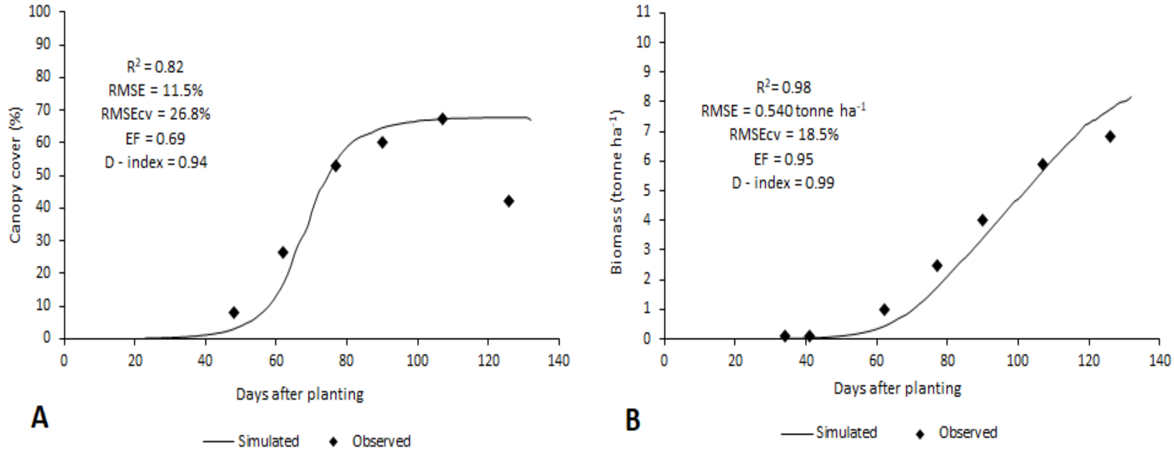

Figure 6.5: Simulated and observed CC (A) and cumulative biomass (B) for groundnut at Fountainhill during model testing (2016/17 season).

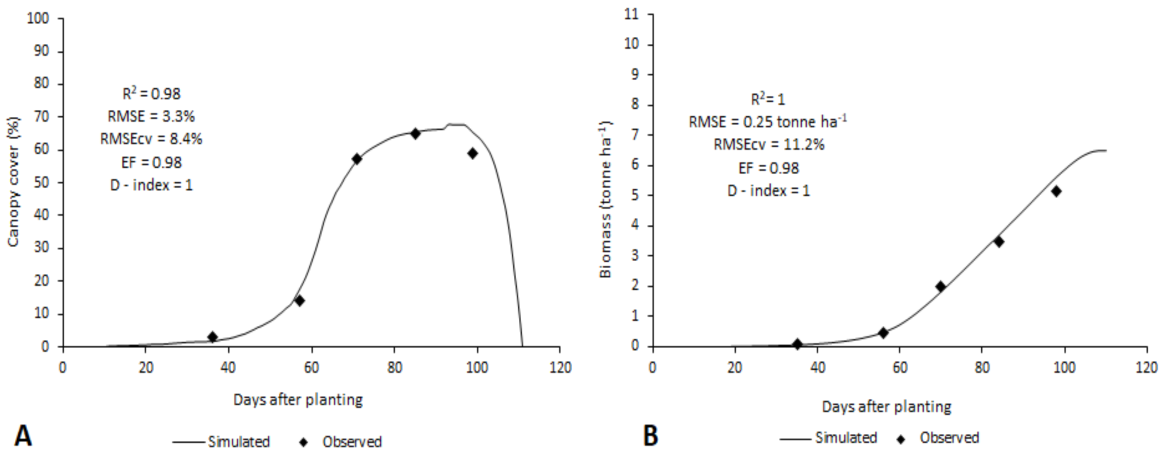

Figure 6.6: Simulated and observed CC (A) and cumulative biomass (B) for groundnut at Umbumbulu during model testing (2016/17 season).

Table 6.4: Simulated and observed grain yield and evapotranspiration (ET) for groundnut during model calibration and testing at Ukulinga, Fountainhill and Umbumbulu.

		Final Biomass			Final Grain yield			Final ET		
		Simulated	Observed	Difference	Simulated	Observed	Difference	Simulated	Observed	Difference
		tonne ha^{-1}		%	tonne ha^{-1}		%	mm		%
Calibration	OI	10.068	8.020	20.3	2.885	1.950	47.94	406	316	28.48
	DI	9.929	10.540	-6	2.874	2.900	-0.89	397	292	35.95
	RF	9.788	9.550	2	2.833	2.770	2.27	380	283	34.27
Testing	OI	6.895	2.681	61.11	1.328	0.585	55.94	340	345	-1.47
	DI	5.768	2.359	59.10	1.712	0.362	78.85	308	280	9.09
	RF	4.475	2.148	52	2.046	0.267	86.95	282	249	11.70
	Fountainhill	8.439	6.855	18.77	2.088	2.387	-14.31	323	287	11.14
	Umbumbulu	6.491	6.669	-2.74	1.858	1.213	34.71	357	234	34.45

6.3.2 Dry Bean

6.3.2.1 Calibration

For dry bean, model calibration showed very good to moderately good fit between observed and estimated values of CC under OI ($R^2 = 0.88$; RMSE = 6.8%; NRMSEcv = 14.8%, EF = 0.84; d-index = 0.96), DI ($R^2 = 0.96$; RMSE = 6.7%; NRMSEcv = 14%, EF = 0.85; d-index = 0.95) and RF ($R^2 = 0.90$; RMSE = 6.5%; NRMSEcv = 16.1%, EF = 0.76; d-index = 0.95) (Fig 6.7). Under RF, the model overestimated CC during crop midseason (30-75 DAP), while under OI and RF the overestimation of CC was limited to period of crop development (40-60 DAP). This was as a result of erratic establishment that was experienced in the field, which was then gap-filled to meet the desired plant population. This caused an uneven plant stand. Under OI and DI, the plants that were planted during gap-filling developed fast due to irrigation and hence the model only underestimated CC up to 60 DAP. In the RF treatment, due to the effect of the gap-filling, canopy was uneven for up to 75 DAP due to limited water availability.

Model evaluation statistics for cumulative biomass showed very good match between observed and simulated values in the OI ($R^2 = 0.98$; RMSE = 0.228 tonne ha^{-1}; NRMSEcv = 7.7%, EF = 0.98; d-index = 1) and RF ($R^2 = 0.98$; RMSE = 0.381 tonne ha^{-1}; NRMSEcv = 13.7%, EF = 0.96; d-index = 0.99) (Fig 6.8). For the DI treatment, RMSE and NRMSEcv were moderately good (0.454 tonne ha^{-1} and 16.2%, respectively), while R^2, EF and d-index were very good (0.96, 0.90 and 0.98, respectively). Similar to groundnut, monkeys attacked the trial towards the end of the season. For groundnut, the animal attacks were in the fully irrigated trial, while for dry bean the DI treatment was affected. Consequently, the model overestimated final biomass in the DI by 15%. In the OI treatment the model was more accurate, only underestimating biomass by 1.6%. In the RF treatment, results of CC were confirmed by biomass, where the model also overestimated biomass from planting. Thereafter, the model underestimated biomass (Fig 6.8). The model hastened canopy senescence under RF conditions relative to the field trials. This led to overestimation of biomass by 14%, which was in the acceptable range (± 20%). For final grain yield, results were inverse to final biomass – yield was accurately estimated in the RF treatment (-0.1%), while in the OI the estimation was acceptable (-14%). True to expectation, final grain yield was overestimated by 28% in the DI treatment, due to yield losses from monkeys. The model overestimated ET by 21% in the OI to 28% in the DI treatment. This was consistent with results of groundnut where the model also overestimated ET by ≈ 30%.

6.3.2.2 Testing

At Ukulinga, model performance evaluators showed that overall model performance was moderately good to poor in simulating canopy under OI (R^2 = 0.77; RMSE = 8.11%; NRMSEcv = 38.5%; EF = 0.20; d-index = 0.85). Although R^2 and d-index were good (0.77 and 0.85, respectively), the criteria was that overall model performance was good when at least three of the statistical indicators were at least moderately good (***cf***. section 6.2.6). Under DI and RF, model performance was very good to moderately good (R^2 = 0.9 for both; RMSE = 4.9 and 9.2%, respectively; NRMSEcv = 16.2 and 22.6%, respectively; EF = 0.89 and 0.98, respectively; d-index = 0.98 and 0.92, respectively) (Fig 6.9). The model overestimated biomass. However, based on observed values, the OI developed in an unpredicted manner with a relatively smaller canopy compared to the DI and RF, despite that it was optimally irrigated. It was not clear during the trials why the plants in the OI were poorly developing as all trials were optimally fertilised and kept disease and weed free.

For cumulative biomass, the same trends as the one for CC were observed – the model was very good to poor under OI (R^2 = 0.96; RMSE = 0.455; NRMSEcv = 52.9%; EF = 0.74; d-index = 0.95) and very good to moderately good under DI (R^2 = 0.98; RMSE = 0.275; NRMSEcv = 21.1%; EF = 0.93; d-index = 0.98) and RF (R^2 = 0.98; RMSE = 0.391; NRMSEcv = 14.1%; EF = 0.96; d-index = 0.99) (Fig 6.10). However, under OI, overall model performance was considered good because three of the statistical indicators (R^2, EF and d-index) were very good. Despite the high NRMSEcv for biomass accumulation, the final estimation of biomass under OI was acceptable (18.7%). Under DI and RF, the model was more accurate in estimating final biomass (-1.7 and -5.8%, respectively). Grain yield was accurately estimated under OI and DI (+6 and +2%, respectively), while it was poorly estimated under RF (26%). During calibration, the model overestimated ET by 21-28% and this was slightly higher during model testing (32-38%).

For Fountainhill, overall model performance for simulation of dry bean CC was moderately good (R^2 = 0.98; RMSE = 9.1%; NRMSEcv = 23%; EF = 0.48; d-index = 0.86) (Fig 6.11). For cumulative biomass, overall model performance was moderately good to poor (R^2 = 0.68; RMSE = 1.496 tonne ha^{-1}; NRMSEcv = 53.7%; EF = 0.6; d-index = 0.84) (Fig 6.11). Based on the criteria for overall model performance (***cf.*** section 2.6), overall model performance was acceptable for cumulative biomass despite the poor RMSE and NRMSEcv (1.496 tonne ha^{-1} and 53.7%, respectively) (Fig 6.11). The model overestimated both CC throughout the whole season, while biomass was only overestimated towards the end of the season. For groundnut, it was observed that the model overestimated delay in crop establishment (***cf.*** section 6.3.1.2). For dry bean, the model simulated earlier establishment relative to the observed. This led to overestimation of CC by the model throughout the season. This further highlights the issue of sensitivity of different crops to initial soil water content, which is not factored into the model. Grain yield was accurately estimated (+9%) and estimation of final ET was acceptable (+18%) (Table 6.5).

For Umbumbulu, model performance for simulating CC and biomass of dry bean was moderately good to poor (R^2 = 0.92 and 0.98, respectively; RMSE = 11.9% and 0.101 tonne ha^{-1}, respectively; NRMSEcv = 71.2 and 30.1%, respectively; EF = -1.43 and 0.78 respectively; d-index = 0.60 and 0.98, respectively) (Fig 6.12). For cumulative biomass, overall model performance was acceptable despite poor NRMSEcv (30.1%). The model underestimated CC throughout the season. Model output showed this was mostly due to canopy expansion stress because of water stress. The model estimated an acceptable final biomass (+12.6%). The model simulated no grain yield although grain yield of 0.285 tonne ha^{-1} was observed. Final ET was overestimated by 27% (Table 6.5).

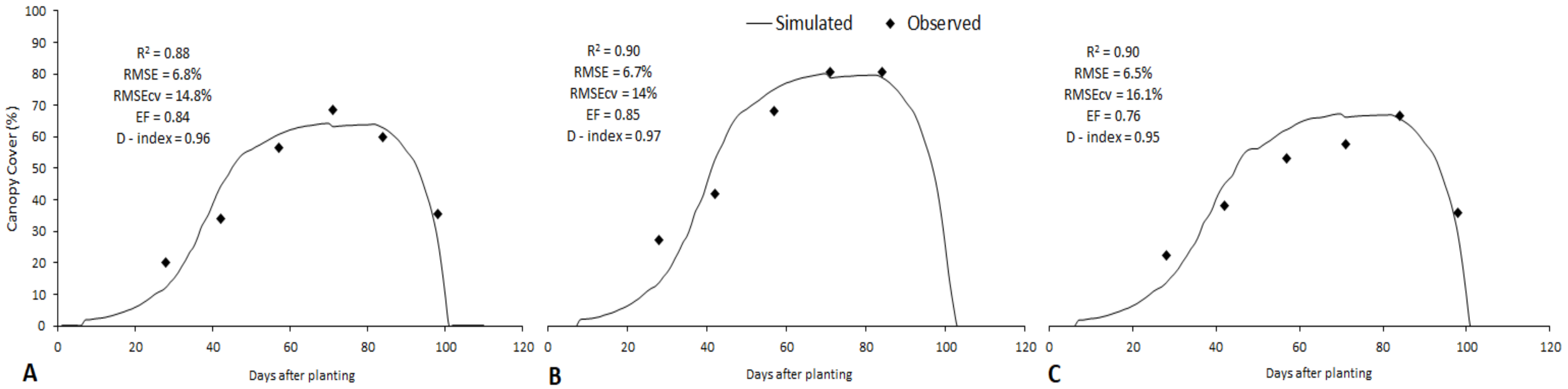

Figure 6.7: Simulated and observed CC for dry bean under A) optimum irrigation B) deficit irrigation C) rainfed conditions during the calibration season 2015/16.

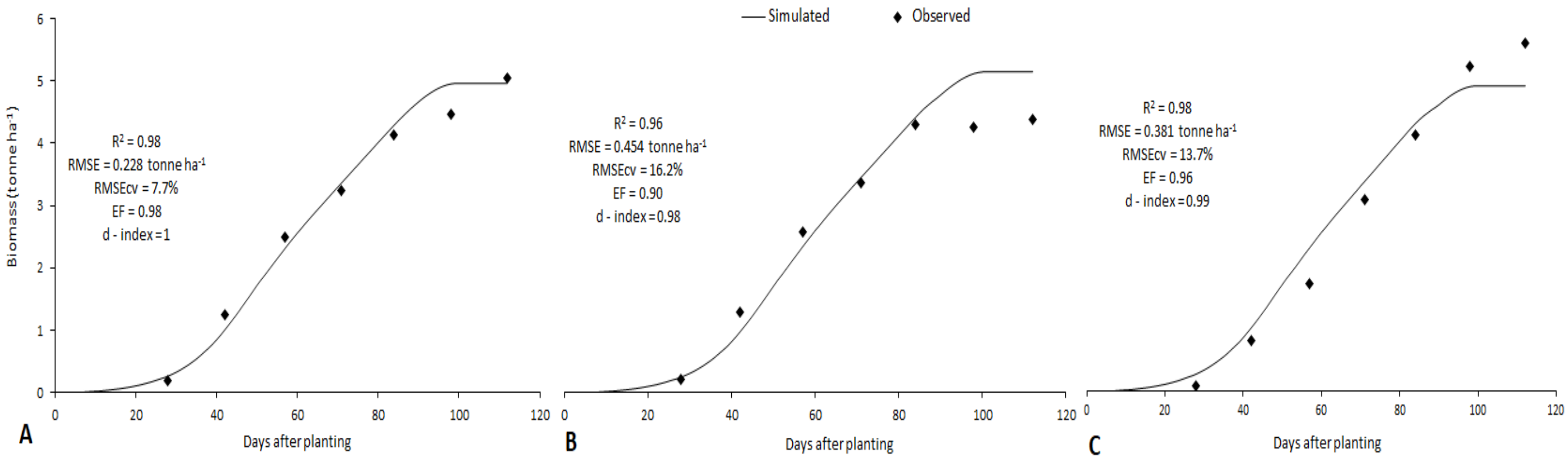

Figure 6.8: Simulated and observed cumulative biomass for dry bean under A) optimum irrigation B) deficit irrigation C) rainfed conditions during the calibration season 2015/16.

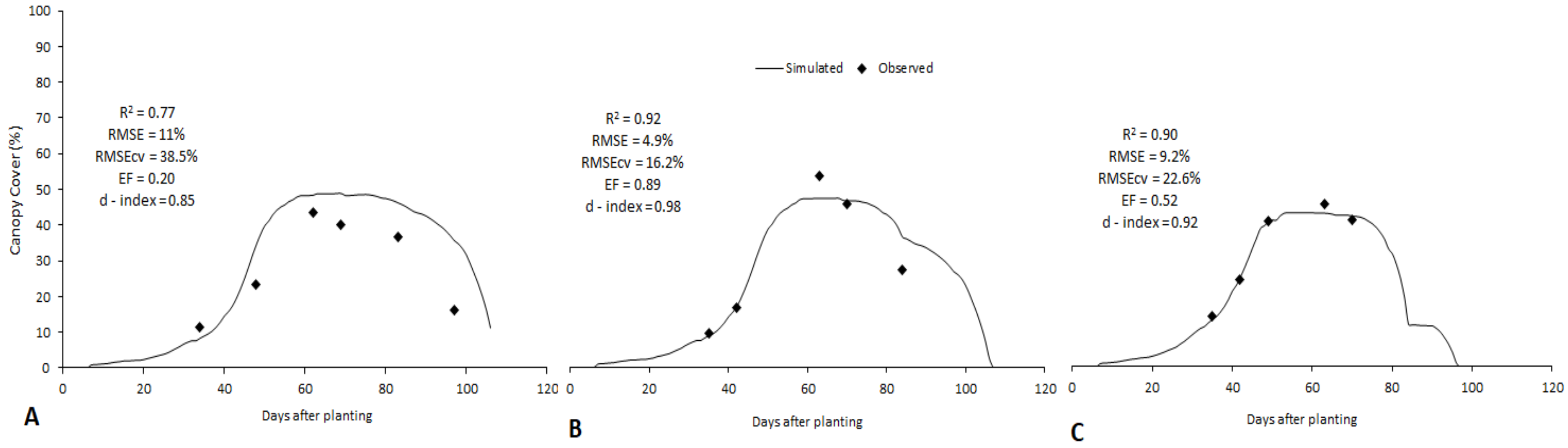

Figure 6.9: Simulated and observed CC for dry bean under A) optimum irrigation B) deficit irrigation C) rainfed conditions during model testing at Ukulinga (2016/17 season).

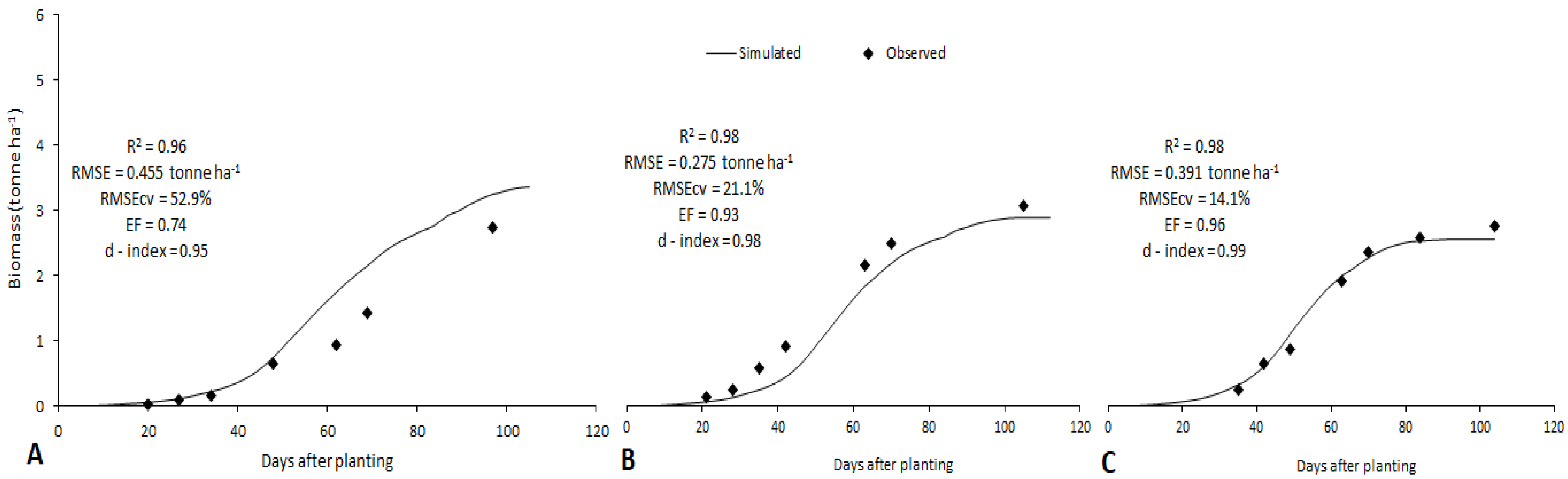

Figure 6.10: Simulated and observed cumulative biomass for dry bean under A) optimum irrigation B) deficit irrigation C) rainfed conditions during model testing at Ukulinga (2016/17 season).

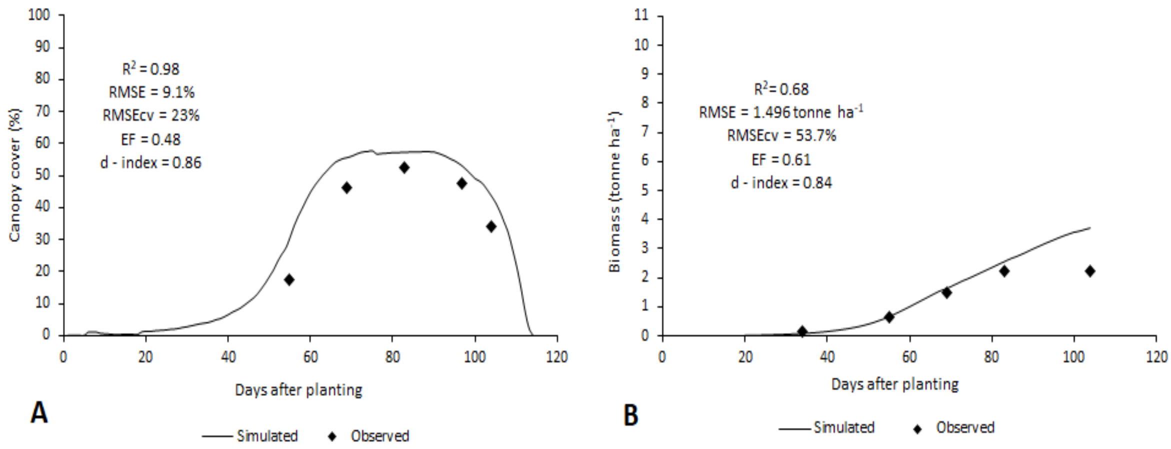

Figure 6.11: Simulated and observed CC (A) and cumulative biomass (B) canopy for dry bean at Fountainhill during model testing (2016/17 season).

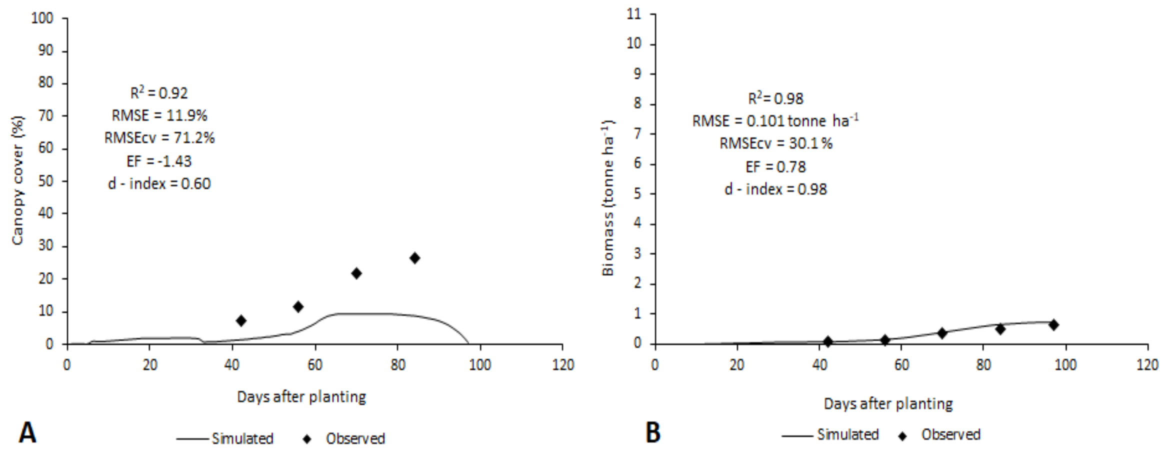

Figure 6.12: Simulated and observed CC (A) and cumulative biomass (B) for dry bean at Umbumbulu during model testing (2016/17 season).

Table 6.5: Simulated and observed grain yield and evapotranspiration (ET) for dry bean during calibration and testing at three different sites (Ukulinga, Fountainhill and Umbumbulu).

		Final Biomass			Final Grain yield			Final ET		
		Simulated	Observed	Difference	Simulated	Observed	Difference	Simulated	Observed	Difference
		tonne ha^{-1}		%	tonne ha^{-1}		%	mm		%
Calibration	OI	4.956	5.040	-1.6	1.953	2.260	-15.7	340	268	21.1
	DI	4.980	4.222	15.2	1.968	1.400	28.8	333	239	28.2
	RF	4.625	5.280	-14.1	1.957	1.960	-0.1	320	238	25.6
Testing	OI	3.359	2.730	18.7	1.385	1.296	6.4	290	195	32.75
	DI	2.860	2.911	-1.7	1.122	1.098	2.1	263	163	38.02
	RF	2.402	2.543	-5.8	0.856	1.081	-26.8	233	143	38.62
	Fountainhill	3.877	2.219	42.7	1.435	1.302	9.1	262	214	18.32
	Umbumbulu	0.746	0.652	12.6	0	0.282	-	286	208	27.27

6.4 Conclusions

During calibration, the model simulated CC and cumulative biomass well for both crops. The model tended to underestimate CC of groundnut during maximum canopy cover. This was attributed to leaf appearance rate and phyllochron. For groundnut, final biomass was overestimated in the OI, while for dry bean, final biomass was overestimated in the DI. This was due to monkey attacks towards the end of the season. For both crops, the model overestimated ET. During model testing for groundnut, model performance was poor for CC and cumulative biomass. The model overestimated CC and cumulative biomass for groundnut across all the water regimes. This was mainly because of disturbances in our trials by monkeys and wild pigs, which could not be factored into the model. Consequently, final biomass and grain yield were overestimated. The model accurately estimated final ET. The model was further tested for two environments (Umbumbulu and Fountainhill), where it simulated CC and biomass well. At Umbumbulu, however, the model overestimated grain yield and ET. For dry bean testing, the model performed well under DI and RF. For Fountainhill, overall model performance for simulating CC and biomass was acceptable. Grain yield was accurately simulated. For Umbumbulu, the model poorly simulated CC. Biomass simulation was acceptable, while ET was overestimated. Overall, the model showed potential for simulating yield and ET of groundnut and dry bean under semi-arid conditions. There is need to improve model parameters for both dry bean and groundnut before the model can be applied for different soils and climates.

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CHAPTER 7

MODELLING BEST MANAGEMENT PRACTICES OF GROUNDNUT AND BAMBARA GROUNDNUT IN DIFFERENT BIO-CLIMATIC REGIONS OF KWAZULU-NATAL

TP Chibarabada, AT Modi and T Mabhaudhi

7.1 Introduction

Groundnut (*Arachis hypogaea*) and bambara groundnut (*Vigna subterranea* L.) are two important grain legumes in Africa. They share the same ecological niche. Bambara groundnut is indigenous to Africa and was widely cultivated during the 1800s and early 1900s. Since the mid-1990s, bambara groundnut has since been replaced by groundnut (Hepper, 1963; Mkandawire, 2007). Groundnut now occupies more land area than bambara groundnut in cropping systems; this has relegated bambara groundnut to the status of neglected and alternative crops (Azam-Ali, 2001). Climate variability and change as well as increased frequency and intensity of drought are threatening agriculture in the sub-tropics (Rijsberman, 2006).

Mean precipitation in many subtropical regions is expected to decrease. This will be coupled by an increase in average temperatures, which will affect crop production. This has given rise to an interest in indigenous crops based on their resilience to harsh environmental conditions (Azam-Ali, 2001; Mayes et al., 2011). Bambara groundnut is no exception to this. It has been identified as a possible future crop because of its greater drought tolerance (Collinson, 1997; Azam-Ali et al., 2001; Mabhaudhi and Modi, 2013; Vurayai et al., 2012), heat tolerance (Berchie, 2012) and high-water use efficiency (WUE) (Mabhaudhi et al., 2013; Chibarabada et al., 2015). This makes it an ideal grain legume for crop diversification.

Chibarabada (2018) evaluated genotype × environment performance of selected grain legumes. It was observed that the grain legumes behaved differently under different environments. It is, however, known that yield (*Y*) is influenced by the interaction between genotype, environment and management practices (Tittonell and Giller, 2013). While Chibarabada (2018) evaluated genotype and environment effects, the influence of management practices remains not well-understood. Management practices such as planting date (Makanda et al., 2009; Wilson, 2012; Hadebe et al., 2017), soil fertility (Ouédraogo et al., 2007; Zhang et al., 2017) and irrigation (Mabhaudhi et al., 2013; Thomas et al., 2004) have been shown to have an effect on Y and water productivity (WP) of crops. Efforts to conserve water have also promoted the use of mulching (Alami-milani et al., 2013; Tian et al., 2013; Dong et al., 2018), deficit irrigation (Araya et al., 2016; Geerts and Raes, 2009) and bunds (Nyssen et al., 2007) to improve Y and WP. This information, however, remains scant for grain legumes.

Models could be of importance for rapid evaluation of production scenarios. The AquaCrop model (Steduto et al., 2009; Raes et al., 2009) was recently calibrated and tested for bambara groundnut (Mabhaudhi et al., 2014) and groundnut (Chibarabada, 2018) under semi-and arid conditions. AquaCrop has been successfully used to evaluate production scenarios in semi-and arid regions (Mhizha et al., 2014; Van Gaelen, 2016). The calibrated and validated model for groundnut and bambara groundnut could be used to evaluate the effect of management practices on Y and water productivity (WP_{ET}) of the two crops. This could aid in developing best management practices for grain legumes under different environments to boost productivity. The aim of the study was therefore to determine best management practices using AquaCrop for increased Y and WP_{ET} of groundnut and bambara groundnut under different environments.

7.2 Materials and Methods

7.2.1 AquaCrop model

AquaCrop (Steduto and Raes, 2009) is a water driven model that simulates attainable biomass and harvestable Y in response to water. AquaCrop is an engineering type model aimed at assisting farmers, extension workers and policy makers in decision making (Steduto et al., 2009). It is a water-driven model meaning that it uses the approach initially highlighted by De Wit (1958), where there is a relationship between seasonal transpiration of crops and biomass production.

The equation at the core of the AquaCrop growth engine is;

$$B = WP \times \sum T_r \quad \text{Equation 7.1}$$

where WP is the water productivity (biomass per unit of cumulative transpiration). The equation arose from the fact that AquaCrop separates evapotranspiration (*ET*) into crop transpiration (Tr) and soil evaporation (E), therefore developing a simple canopy growth and senescence model, treating final Y as a function of biomass (B) and harvest index (HI) and separating effects of water stress into canopy growth, canopy senescence, Tr and HI. AquaCrop uses a normalized WP parameter, increasing its applicability, robustness and transferability across different regions of the world. AquaCrop has a field management module that allows for simulation of effects of field surface practices, mulches, weed management and soil fertility (FAO, 2015). More information on AquaCrop's concepts and calculation procedures can be obtained from Raes et al. (2009) and Steduto et al. (2009).

7.2.2 Study Sites

Three sites representing different agro-ecological zones of KwaZulu-Natal were used (Umbumbulu, Ukulinga and Wartburg) (Table 7.1).

Table 7.1: Soil and climate description of the agro-ecological zones (Umbumbulu, Ukulinga, Wartburg) used in this study.

	Umbumbulu	**Ukulinga**	**Wartburg**
Geographical location	29.98° S, 30.70° E	29.60° S, 30.37° E	29.43° S, 30.58° E
Altitude (*m a.s.l.)	632	775	880
Bio-resource group/ agroecological zone	Moist coast hinterland and ngongoni veld	Moist coast hinterland and ngongoni veld	Moist coast hinterland and ngongoni veld
Annual rainfall	800-1160 mm	694-750 mm	900-1200 mm
Average temperature	17.9°C	17°C	20°C
Frost occurrence	Light and occasional	Light and occasional	Light and occasional

*m.a.s.l. = meters above sea level

7.2.3 Climate data

Climate data was sourced from the SASRI weather site (http://sasex.sasa.org.za/irricane/tables/Ash_tables_AR.pl) using the nearest station to the location except for Ukulinga, where an Agricultural Research Council (ARC), automatic weather station (AWS) is located on site.

Climate data from the different sites was classified into normal and dry seasons based on the sum of summer rainfall season for yearly growing seasons. Seasonal rainfall was calculated as the sum of the daily rainfall from September to April based on the cropping period and summer season in KwaZulu-Natal. Growing seasons with seasonal rainfall with an exceedance probability of at least 80% or less than 20%, were classified as dry and normal, respectively (Raes, 2004). Table 7.2 shows the mean seasonal rainfall and standard deviation for each site and the mean seasonal rainfall and standard deviation for dry and normal seasons for each site. Rainfall data showed that Umbumbulu had the highest mean total rainfall (636 mm). Wartburg exhibited the highest spread in total rainfall (189 mm). This was also reflected in the site having the highest mean rainfall for normal seasons (702 mm) and lowest mean rainfall for dry seasons (316 mm), relative to the other sites (Table 7.2).

Table 7.2: Mean seasonal rainfall and standard deviation total rainfall, dry and normal seasons for each site.

Site		n	Mean	Std Dev
Umbumbulu	Total	27	636	157
	Normal	22	685	129
	Dry	5	420	37
Wartburg	Total	19	621	189
	Normal	15	702	112
	Dry	4	316	83
Ukulinga	Total	8	599	125
	Normal	6	646	101
	Dry	2	457	98

7.2.4 Scenarios

Studies have highlighted management practices such as (i) planting dates (ii) irrigation and (iii) soil water conservation to be key for improving productivity of smallholder farmers (Thomas et al., 2004; Nyssen et al., 2007; Geerts and Raes, 2009; Makanda et al., 2009; Wilson, 2012; Alami-milani et al., 2013; Mabhaudhi et al., 2013; Tian et al., 2013; Hadebe et al., 2017; Dong et al., 2018). Due to the crop files not being calibrated and tested for soil fertility, soil fertility was not considered in this analysis. Scenarios were then developed based on three key management strategies (planting dates, irrigation, and soil water conservation) (Table 7.3).

A reference scenario that represents the current practices by most rural farmers in KwaZulu-Natal, together with eight different management scenarios, was assessed for each year (Table 7.3). For the reference scenario, planting date was generated based on Raes et al. (2004) on the basis of 'sum of rainfall in a 15-day period at least 40 mm' starting from the first of September, which is generally the beginning of summer planting season in South Africa. The first day of occurrence generated by the model was selected for the simulations. Soil fertility was optimum and there were no other management practices. The first, second and third scenario were based on early, optimum and late planting dates, respectively. Early planting date was defined as the 15th of October, while optimum planting date was 1 December and late planting was 15 January. Optimum planting date was based on the Department of Agriculture's (DAFF) recommended planting date of groundnut in KwaZulu-Natal, South Africa. Similar to the reference scenario, soil fertility was optimum and there were no other management practices. For the fourth scenario, the reference scenario applied, except that a field management strategy of 100% organic mulches was added (Table 7.3).

The fifth and sixth scenario included irrigation in addition to the reference scenario. The fifth scenario referred to optimum irrigation requirement, where management allowable root zone depletion was 20% of Field Capacity (Alberta Agriculture and Forestry, 2016). For the deficit irrigation scenario, management allowable root zone depletion was 40% of Field Capacity. The seventh scenario included management practices that prevented loss of rainfall by surface runoff (tied ridges), while the eighth scenario included building of bunds 0.25 m high (Table 7.3).

Table 7.3: Scenarios used for the simulation of groundnut and bambara groundnut *Y* and WP_{ET}.

	Scenario								
Management Practice	**Reference**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Planting date	Generated	15 October	1 December	15 January	Generated	Generated	Generated	Generated	Generated
Irrigation	nc	nc	nc	nc	nc	Optimum-irrigation	Deficit irrigation	nc	nc
Soil fertility	Non-limiting	Non-limiting	Non-limiting	Non-limiting	Non-limiting	Non-limiting	Non-limiting	Non-limiting	Non-limiting
Mulch	n/a	n/a	n/a	n/a	100% cover	n/a	n/a	n/a	n/a
Bunds	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.25 m high
Tied ridges	n/a	n/a	n/a	n/a	n/a	n/a	n/a	yes	n/a

7.2.5 Simulation procedure

AquaCrop Version 5.0 (http://www.fao.org/nr/water/aquacrop.html) was used. Crop files (.CRO) were obtained from previously calibrated and tested crop files. The Bambara Red Landrace crop file (RedbambaraGDD.Cro) was used to simulate *Y* of bambara groundnut (Mabhaudhi et al., 2014). The groundnut crop file (GroundnutGDD.Cro) was calibrated for a South African cultivar (Kwarts) during 2015/16 season and tested during 2016/17 season (Chibarabada, 2018). Simulations were run in thermal time (growing degree days). For both crops, plant density was 88 889 plants hectare^{-1} across the different sites.

To create a climate file (.CLI), the AquaCrop model requires daily maximum (Tmax) and minimum (Tmin) air temperatures (.TMP file), FAO Penman-Monteith daily reference crop evapotranspiration (.ETO), daily rainfall (.PLU) and mean annual carbon dioxide (CO2) concentration. Climate files were created based on historical observed climate. Management files (.IRR and .Man) were created for each scenario (***c.f section 7.2.4***). Soil files were created using measured soil characteristics for the specific sites (Table 7.4) Due to absence of observations of initial soil water content at the time of sowing the initial conditions file (.SW0), the simulation period was set to start on the 1st of August every year. Soil water content was assumed to be at permanent wilting point as August follows the winter season that is dry with no rain. The simulation period was therefore not linked with the growing cycle.

Table 7.4: Soil parameters for each study site (Ukulinga, Wartburg and Umbumbulu) used for the AquaCrop soil file

Site	Horizon	Description	Thickness (m)	^{a}Sat	^{b}FC	^{c}PWP	^{d}Ksat (mm day^{-1})	^{e}TAW (mm)
				——(% Vol) ——				
Ukulinga	1	Clay loam	0.40	48	40	21	25	78.4
Wartburg	1	Sand	2.0	36	13	6	3000	140
Umbumbulu	1	Clay loam	0.40	46	35	17	125	72
	2	Clay	0.60	50	39	21	35	108

7.2.6 Data Analyses

Model outputs were used for data analyses. The *Y* and WP_{ET} response to eight different management practices was analysed making a distinction between dry and normal growing seasons for each site. The effectiveness of each agricultural management practice was assessed by means of the *Y* and WP_{ET} response given by:

$$\left[\frac{\text{Y/WPETof management scenario} - \text{Y/WPET of reference scenario}}{\text{Y/WP of reference scenario}}\right] \times 100\% \qquad \text{Equation 7.2}$$

where;

Y/WP_{ET} of management scenario is mean *Y* or water productivity (WP_{ET}) under different management scenarios and *Y*/WP_{ET} of reference scenario is mean Y or water productivity WP_{ET} under the reference scenario.

Response values were expressed in % as the relative increase (positive response values) or decrease (negative response values) of the average *Y* and WP_{ET} for certain environmental conditions due to a certain management strategy in comparison to the reference management. Results that showed zero grain *Y*, hence failure to harvest were analysed separately. Additional frequency analysis of failure to harvest seasons for every management practice was conducted.

7.3 Results and Discussion

7.3.1 Groundnut

Results from Umbumbulu showed that early planting decreased both *Y* and WP_{ET} during normal and wet seasons. This effect was more pronounced during the dry seasons (Figure 7.1). In contrast to Umbumbulu, early planting was greatly beneficial at Wartburg especially during dry seasons (*Y* increased by 35% while WP_{ET} increased by 20%) (Figure 7.2). Results from Ukulinga echoed those from Umbumbulu – early planting decreased *Y* and WP_{ET} and this was more marked during dry seasons (*Y* and WP_{ET} decreased by ≈ 10%) (Figure 7.2). Interestingly, recommended planting date showed different effects across the three sites. At Umbumbulu, recommended planting date of groundnut did not increase *Y*, but increased WP_{ET} (Figure 7.1). At Wartburg, recommended planting date increased *Y* by ≈ 30% during dry seasons (Figure 7.2). At Ukulinga, recommended planting date improved *Y* and WP_{ET} relative to the reference period (Figure 7.3). Several studies observed late planting to decrease *Y* of plants (Sinefu, 2011; Hadebe et al., 2017; Chibarabada, 2018). This was true for Ukulinga during dry seasons (*Y* and

WP_{ET} decreased by up to 20%). At Umbumbulu and Wartburg, late planting had a positive effect on both *Y* and WP_{ET} (WP_{ET} increased by 60%).

Mulching is an important practice for integrated soil management. It is associated with soil water conservation, which is beneficial in semi-and tropics where rainfall is low and water is one of the major limiting factors to high *Y* (Erenstein, 2003). This study confirmed the benefits of mulching as *Y* and WP_{ET} improved by up to 50% across the three sites. Mulching was more effective under dry seasons compared to normal seasons, further confirming its role in soil water conservation (Fig 7.1, 7.2 and 7.3). There have been several debates around the impact of irrigation to increase crop *Y* in the semi-and arid tropics. The study confirms findings by other studies that irrigation significantly increases *Y*, but has negative implications on WP_{ET} (Oweis, 1997; Kar et al., 2006; Geerts and Raes, 2009; Borivoj et al., 2012). Despite *Y* increasing by up to (50%), WP_{ET} decreased due to optimum irrigation (Fig 7.1, 7.2 and 7.3). At Ukulinga, WP_{ET} decreased by ≈ 15% at Ukulinga (Fig 7.3). The semi-and arid tropics are also affected by water scarcity, hence strategies to increase should consider both *Y* and WP_{ET} improvement. Strategies such as deficit irrigation have been recommended to improve WP_{ET} with minimum *Y* trade-offs. This was confirmed by results from all sites – deficit irrigation improved *Y* and WP_{ET} by up to 40 and 15%, respectively. An exception, however, was at Ukulinga for the dry seasons, where deficit irrigation increased *Y* by 9%, but decreased WP_{ET} by ≈ 2% (Fig 7.3).

AquaCrop allows for simulation of tied ridges that prevent runoff. In addition, AquaCrop simulates the effect of soil bunds that not only prevent surface runoff, but also store excess water between the bunds (FAO, 2015). This study explored these scenarios across the different seasons. A positive response across all the sites and seasons was observed for tied ridges and soil bunds (Fig 7.1, 7.2 and 7.3). These practices were more beneficial during the dry seasons. At Umbumbulu and Ukulinga, tied-ridges and closed-end furrows showed potential to increase *Y* and WP_{ET} by up to 30 and 40%, respectively. At Fountainhill, increases in *Y* and WP_{ET} were less than 3% implying that the soil characteristics may not be suitable for tied ridges. For the dry seasons, soil bunds were more effective (*Y* increased by 23% while WP_{ET} increased by 13%) (Fig 7.2).

Farmers in rural areas depend on annual grain *Y* for food and livelihood. Any crop failures have significant effects on their livelihood. The study went further to analyse the number of seasons that there was no *Y* for each scenario. This is to guide farmers in making decisions that minimize risk of crop failures. While optimum irrigation showed decrease in WP_{ET}, it also showed no risk of harvest failure across all sites – an attribute that may be attractive for continuous grain. For the other scenarios, Umbumbulu and Ukulinga were susceptible to *Y* failures despite it being a normal year or dry year (Figure 7.4). There were more seasons of harvest failure at Ukulinga during the dry seasons for the reference scenario. Early planting showed much risk at Umbumbulu during the dry seasons and at Ukulinga during normal seasons. Recommended planting date, mulching and deficit irrigation showed less risk across all the sites and seasons (Figure 7.4). Despite tied ridges and soil bunds showing potential to increase *Y* and WP_{ET}, there may be seasons with zero *Y* (Figure 7.4).

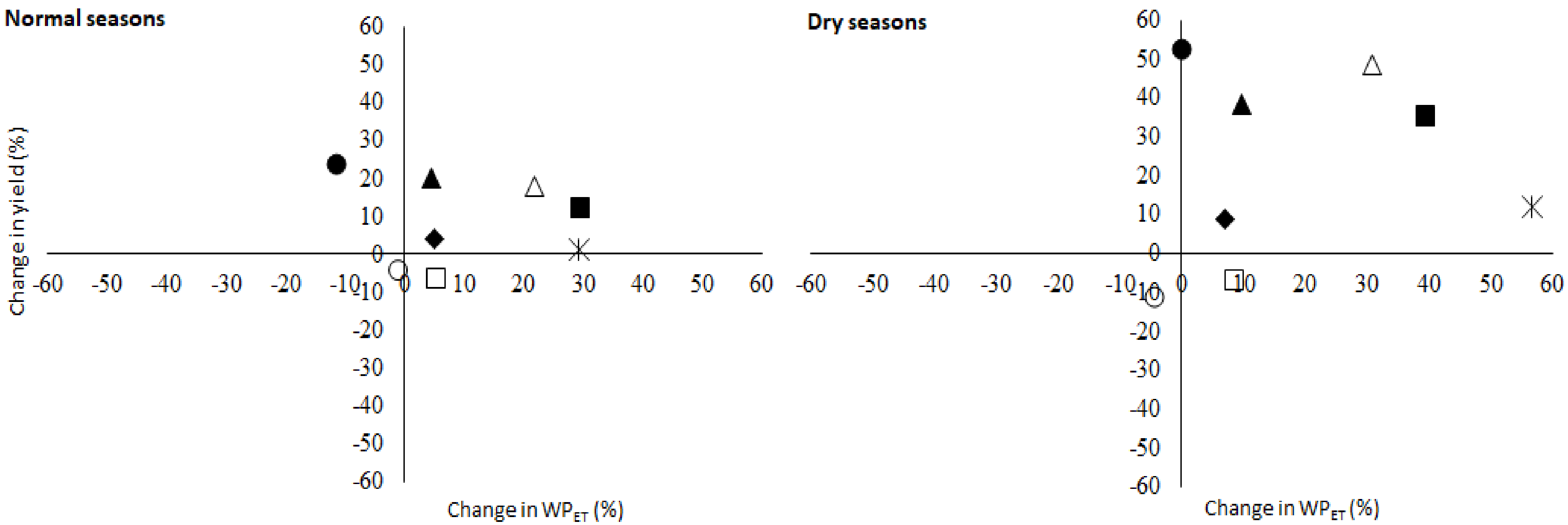

Figure 7.1: Change in *Y* (y-axis) and WP_{ET} (x-axis) of groundnut at Umbumbulu during normal and dry seasons under eight different scenarios. Points in the top – left quadrant represent increase in *Y* and decrease in WP_{ET}, points in the top-right quadrant represent increase in both *Y* and WP_{ET}, points in the bottom – left quadrant represent decrease in both *Y* and WP_{ET} and points in the bottom right quadrant represent increase in WP_{ET} and decrease in *Y*. Coordinate 0:0 represents the reference scenario, ○ = Scenario 1, □ = scenario 2, ⁎ = scenario 3, Δ = scenario 4, ● = scenario 5, ▲= scenario 6, ■ = scenario 7, ♦ = scenario 8.

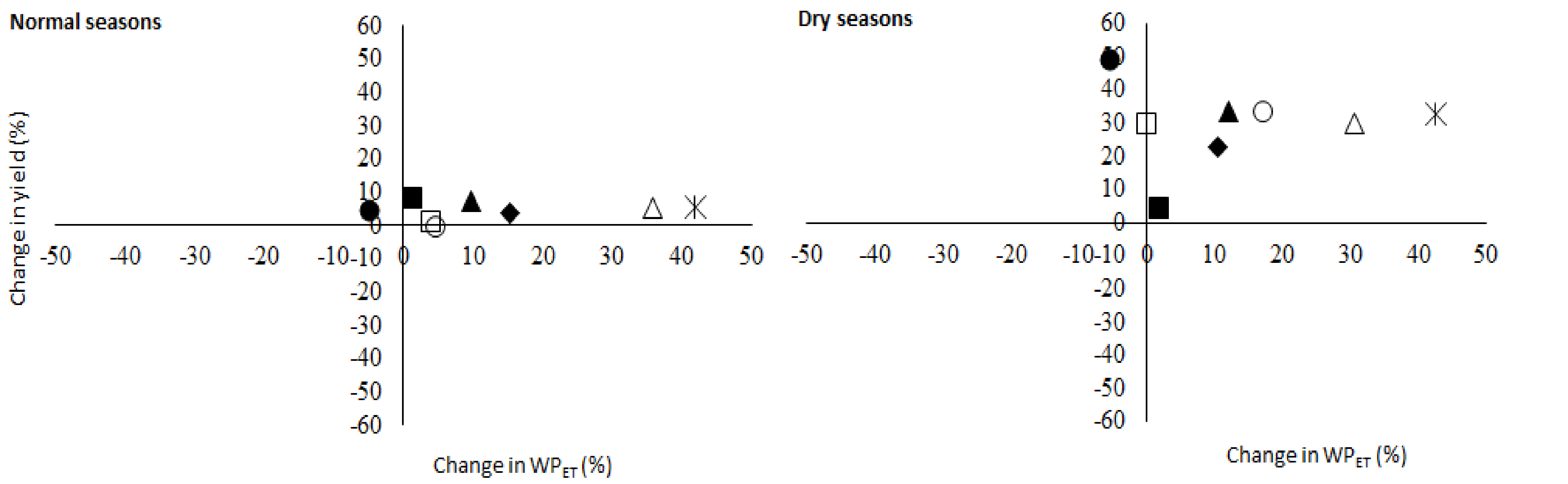

Figure 7.2: Change in *Y* (y-axis) and WP_{ET} (x-axis) of groundnut at Wartburg during normal and dry seasons under eight different scenarios. Points in the top – left quadrant represent increase in *Y* and decrease in WP_{ET}, points in the top-right quadrant represent increase in both *Y* and WP_{ET}, points in the bottom – left quadrant represent decrease in both *Y* and WP_{ET} and points in the bottom right quadrant represent increase in WP_{ET} and decrease in *Y*. Coordinate 0:0 represents the reference scenario, ○ = Scenario 1, □ = scenario 2, ∗ = scenario 3, Δ = scenario 4, ● = scenario 5, ▲= scenario 6, ■ = scenario 7, ♦ = scenario 8.

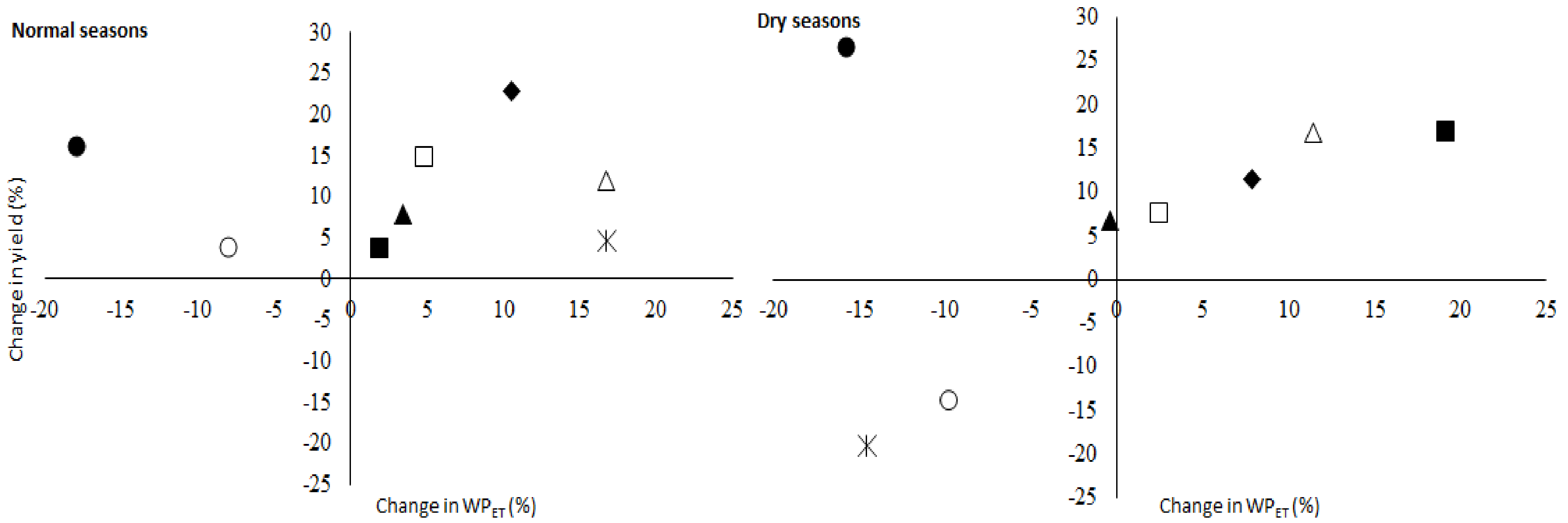

Figure 7.3: Change in *Y* (y-axis) and WP_{ET} (x-axis) of groundnut at Ukulinga during normal and dry seasons under eight different scenarios. Points in the top – left quadrant represent increase in *Y* and decrease in WP_{ET}, points in the top-right quadrant represent increase in both *Y* and WP_{ET}, points in the bottom – left quadrant represent decrease in both *Y* and WP_{ET} and points in the bottom right quadrant represent increase in WP_{ET} and decrease in *Y*. Coordinate 0:0 represents the reference scenario, ○ = Scenario 1, □ = scenario 2, ⁎ = scenario 3, Δ = scenario 4, ● = scenario 5, ▲= scenario 6, ■ = scenario 7, ♦ = scenario 8.

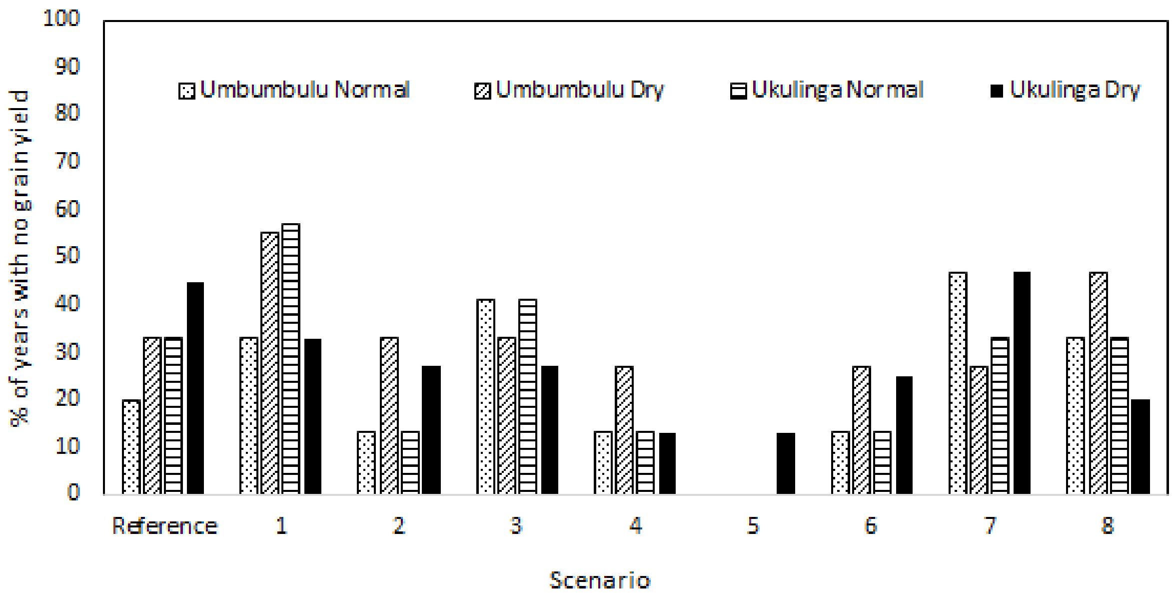

Figure 7.4: % of seasons with no *Y* of groundnut under the reference practice and eight different scenarios (scenario 1 = early planting, scenario 2 = optimum planting, scenario 3 = late planting, scenario 4 = mulching, scenario 5 = optimum irrigation, scenario 6 = deficit irrigation, scenario 7 = tied ridges, scenario 8 = soil bunds) across two different sites (Umbumbulu and Ukulinga) and seasons with different rainfall patterns (normal and dry).

7.3.2 Bambara groundnut

Contrary to groundnut, bambara groundnut responded positively to early planting during the normal seasons (Fig 7.5, 7.6 and 7.7). At Umbumbulu, WP_{ET} increased by 60% as a result of early planting. The positive effect of early planting was only observed during normal seasons – during the dry seasons early planting decreased *Y* and WP_{ET}. For late planting, all the sites and growing seasons showed negative *Y* and WP_{ET} response. Consistent across sites and seasons, optimum planting showed positive *Y* and WP_{ET} responses for bambara groundnut (Fig 7.5, 7.6 and 7.7).

Bambara groundnut is popular for its poor canopy development and lengthy time to emergence (Mabhaudhi et al., 2013; Chibarabada, 2018). These characteristics are associated with significant loss of unproductive water through soil evaporation. Mulching is a practice recommended to reduce loss of unproductive water through soil evaporation. True to expectation, findings of the scenario analysis showed that for bambara groundnut, mulching increased *Y* and WP_{ET} by up to 40 and 50%, respectively across all sites and seasons (Fig 7.5, 7.6 and 7.7). The increase in *Y* was ≈ 10% higher during dry seasons compared to normal seasons. An interesting trend was that of optimum irrigation on bambara groundnut. Optimum irrigation is usually associated with decreases in WP_{ET}. For dry seasons, results showed an anomaly – *Y* was increased by 80% and WP_{ET} also increased by 10 and 40%. For normal seasons optimum irrigation increased *Y* by ≈ 40% and decreased WP_{ET} by ≈ 30%. Similar to groundnut, deficit irrigation increased *Y* and WP_{ET} across all sites seasons (Fig 7.5, 7.6 and 7.7). The highest benefits of deficit irrigation were observed during dry seasons relative to normal seasons. With respect to sites, Umbumbulu had ≈ 50% more *Y* and WP_{ET} improvements compared to the other sites with respect to both deficit and optimum irrigation (Fig 7.5).

For groundnut, tied ridges increased *Y* and WP_{ET} by up to 30 and 40%, respectively. This was not the case for bambara groundnut. Tied ridges did increase *Y*, but this was by ≈ 5% across all sites and seasons (Fig 7.5, 7.6 and 7.7). Soil bunds were more beneficial compared to tied ridges. At all the sites, soil bunds improved *Y* and WP_{ET} by ≈ 20 and 15%, respectively during the dry seasons. During normal seasons, *Y* and WP_{ET} by was improved by ≈ 50% of the dry seasons improvement (Fig 7.5, 7.6 and 7.7).

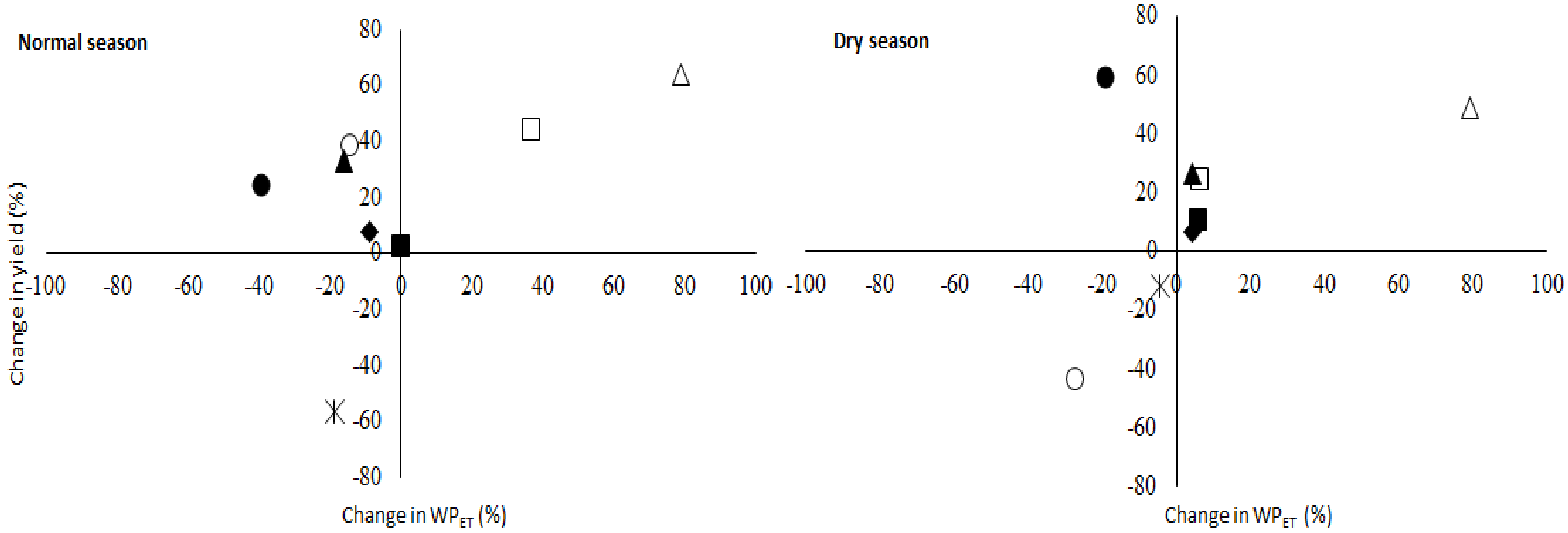

Figure 7.5: Change in *Y* (y-axis) and WP_{ET} (x-axis) of bambara groundnut at Umbumbulu during normal and dry seasons under eight different scenarios. Points in the top – left quadrant represent increase in *Y* and decrease in WP_{ET}, points in the top-right quadrant represent increase in both *Y* and WP_{ET}, points in the bottom – left quadrant represent decrease in both *Y* and WP_{ET} and points in the bottom right quadrant represent increase in WP_{ET} and decrease in *Y*. Coordinate 0:0 represents the reference scenario, ○ = Scenario 1, □ = scenario 2, ⁎ = scenario 3, ∆ = scenario 4, ● = scenario 5, ▲= scenario 6, ■ = scenario 7, ♦ = scenario 8.

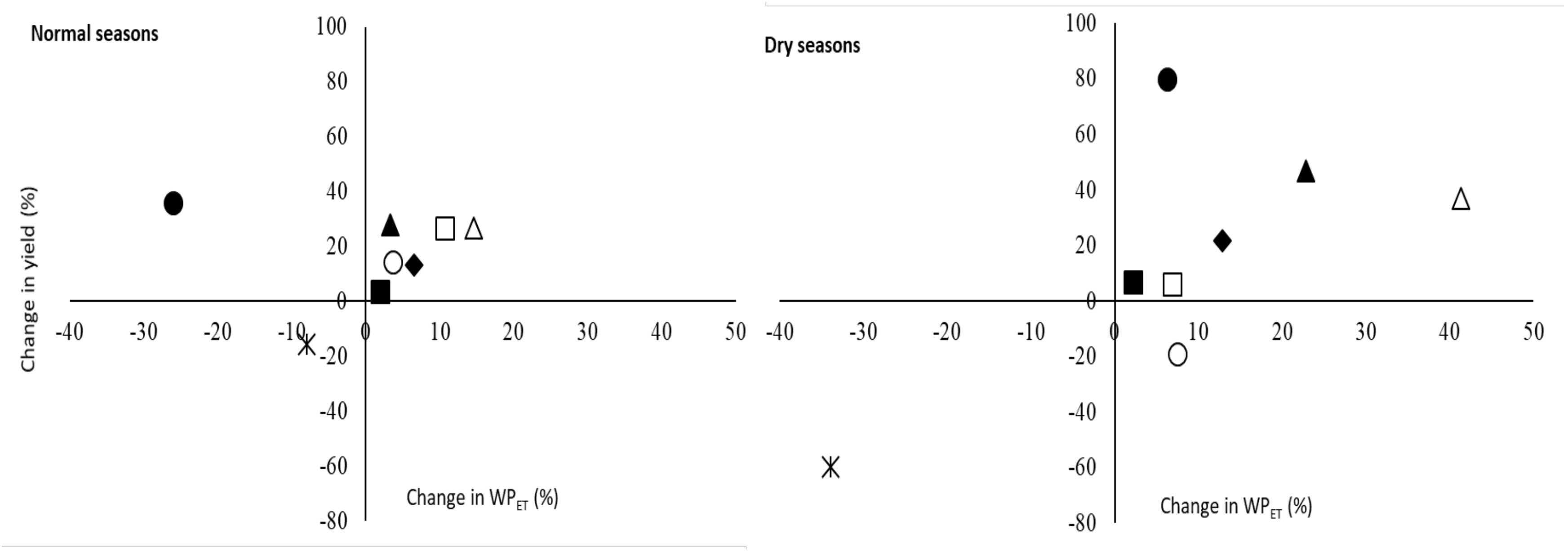

Figure 7.6: Change in *Y* (y-axis) and WP_{ET} (x-axis) of bambara groundnut at Wartburg during normal and dry seasons under eight different scenarios. Points in the top – left quadrant represent increase in *Y* and decrease in WP_{ET}, points in the top-right quadrant represent increase in both *Y* and WP_{ET}, points in the bottom – left quadrant represent decrease in both *Y* and WP_{ET} and points in the bottom right quadrant represent increase in WP_{ET} and decrease in *Y*. Coordinate 0:0 represents the reference scenario, ○ = Scenario 1, □ = scenario 2, ∗ = scenario 3, Δ = scenario 4, ● = scenario 5, ▲= scenario 6, ■ = scenario 7, ♦ = scenario 8.

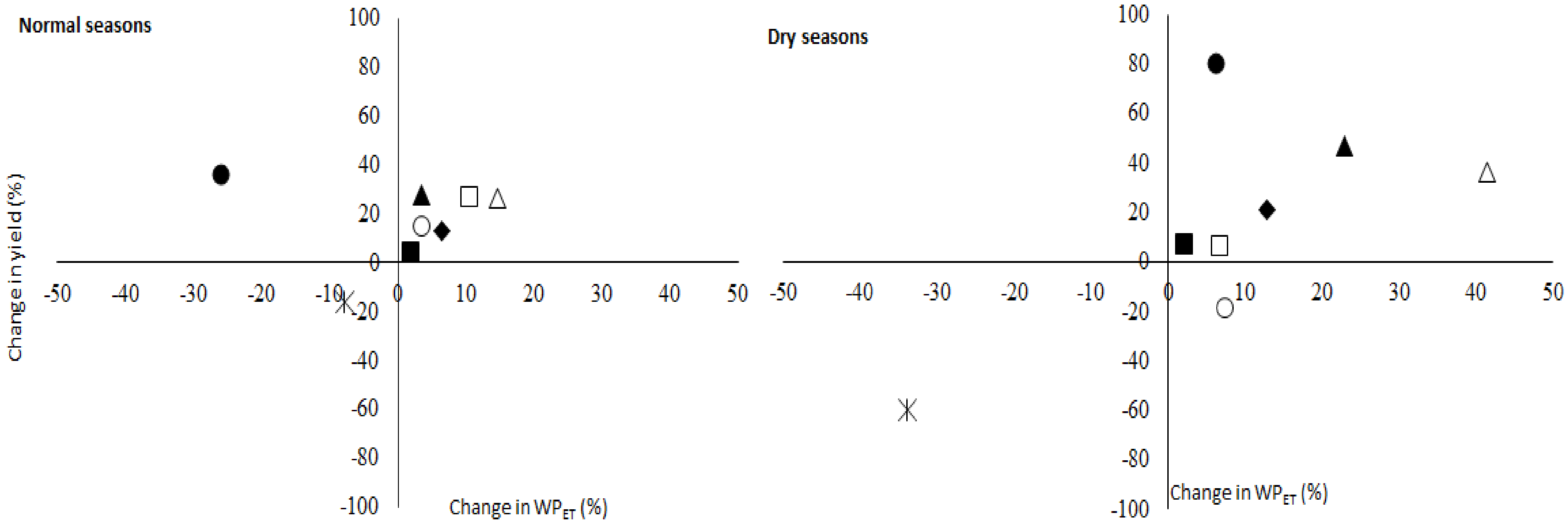

Figure 7.7: Change in *Y* (y-axis) and WP_{ET} (x-axis) of bambara groundnut at Ukulinga during normal and dry seasons under eight different scenarios. Points in the top – left quadrant represent increase in *Y* and decrease in WP_{ET}, points in the top-right quadrant represent increase in both *Y* and WP_{ET}, points in the bottom – left quadrant represent decrease in both *Y* and WP_{ET} and points in the bottom right quadrant represent increase in WP_{ET} and decrease in *Y*. Coordinate 0:0 represents the reference scenario, ○ = Scenario 1, □ = scenario 2, ⁎ = scenario 3, Δ = scenario 4, ● = scenario 5, ▲= scenario 6, ■ = scenario 7, ♦ = scenario 8.

Similar to groundnut, an analysis of the number of seasons for when there was no *Y* for each scenario, was conducted. It is worth noting that bambara groundnut had overall less seasons (by ≈ 30%) with no *Y* compared to groundnut. There were less seasons with no *Y* with planting bambara groundnut compared to groundnut. Similar to groundnut, Wartburg did not show any crop failure across all the seasons. Deficit and optimum irrigation reduced the % of seasons of no *Y* to 0% for bambara groundnut (Figure 7.8). Late planting exhibited the highest risk of crop failure as it had the highest % of seasons with no *Y* (20-60%). This was highest under the dry seasons and at the Ukulinga site. The reference scenario and early planting were relatively similar with respect to the % of seasons with no *Y*. Despite mulching showing positive effects on *Y* and WP_{ET}, there were seasons were there was crop failure (Figure 7.8).

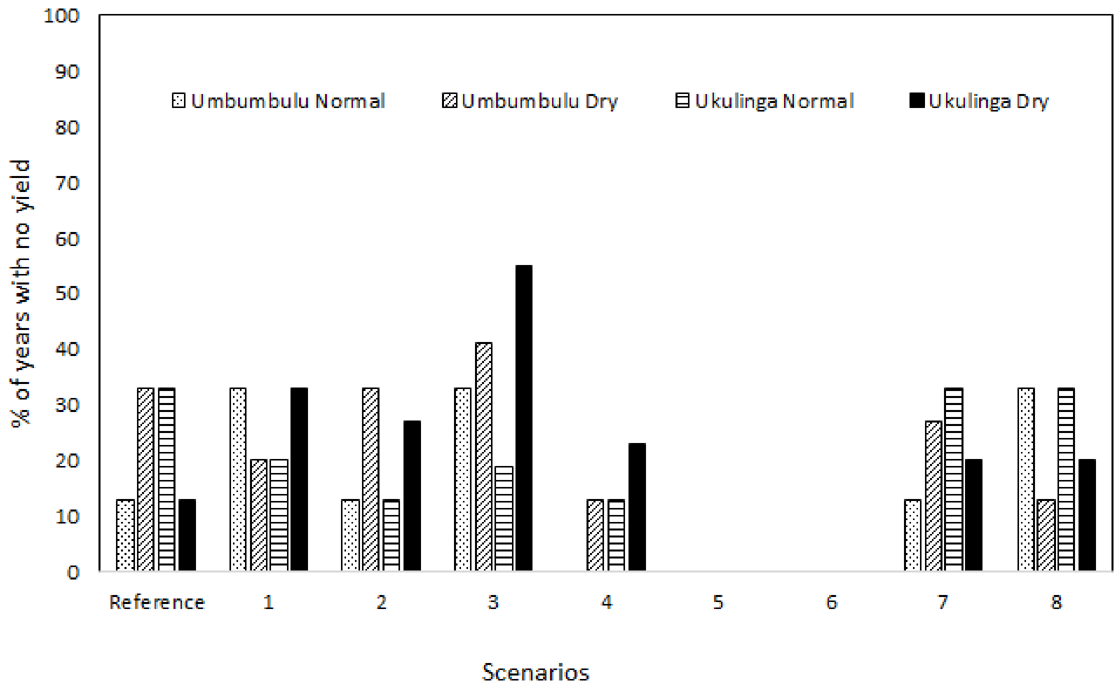

Figure 7.8: % of seasons with no *Y* of bambara groundnut under the reference practice and eight different scenarios (scenario 1 = early planting, scenario 2 = optimum planting, scenario 3 = late planting, scenario 4 = mulching, scenario 5 = optimum irrigation, scenario 6 = deficit irrigation, scenario 7 = tied ridges, scenario 8 = soil bunds) across two different sites (Umbumbulu and Ukulinga) and seasons with different rainfall patterns (normal and dry).

7.4 Conclusions

The study determined best management practices for increased Y and WP_{ET} of groundnut and bambara groundnut under different environments. Early planting improved Y and WP_{ET} of groundnut at Wartburg, while at Ukulinga and Umbumbulu the current recommended planting dates should be maintained. However, during dry seasons, the study recommends late planting for groundnut as it was associated with Y and WP_{ET} improvements. Late planting could also be explored as a climate change adaptation strategy. Bambara groundnut is day length sensitive, hence performed poorly to late planting (Y and WP_{ET} decreased by more than 40%). For bambara groundnut, early planting is recommended. Mulching improved Y and WP_{ET} during dry seasons at all the sites. For strategies to increase Y, optimum irrigation is recommended but for WP_{ET} improvements deficit irrigation is recommended. For groundnut, tied ridges and soil bunds should be promoted during dry seasons at Ukulinga and Umbumbulu. For bambara groundnut, soil bunds should be promoted during both normal and dry seasons across all the sites. Optimum irrigation is recommended for reduced risk of crop failure. This may, however, not be feasible due to water scarcity. Crop diversification remains a viable option as the study observed bambara groundnut to have less risk of crop failure, compared to groundnut.

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CHAPTER 8

REPLACING NON-BIOFORTIFIED WHITE MAIZE AND SWEET POTATO WITH PROVITAMIN A-BIOFORTIFIED MAIZE AND ORANGE-FLESHED SWEET POTATO IN POPULAR TRADITIONAL FOODS OF KWAZULU-NATAL

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8.1 Introduction

Biofortification is a process that improves the nutrient content of staple crops through plant breeding or recombinant deoxyribonucleic acid technology (rDNA). Biofortified crops could play a vital role in improving the nutritional status of vulnerable population groups, where supplementation, conventional fortification, or dietary diversity is limited or problematic to implement (WHO, 2018). HarvestPlus, a global Challenge Programme, aims to reduce micronutrient malnutrition by developing crops that are higher in vitamin A, iron and zinc and have selected seven crops for biofortification, namely: beans (*Phaseolus vulgaris*), maize (*Zea mays*), pearl millet (*Pennisetum glaucum*), wheat (*Triticum aestivum*), cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), and rice (*Oryza sativa*). Of these crops, cassava, maize and sweet potato have been selected for PVA-biofortification (HarvestPlus, 2018; WHO, 2018). The current PVA breeding targets for maize and sweet potato are 15 µg/g and 32 µg/g, respectively (HarvestPlus, 2009a; HarvestPlus, 2009b). White maize and cream-fleshed sweet potato (CFSP) are two commonly grown and consumed crops in SA (DAFF, 2017; Low et al., 2017) and are therefore ideal for PVA-biofortification (Mitra, 2012; Low et al., 2017; DAFF, 2017). Although these crops are widely consumed in SA, they are deficient in PVA carotenoids, the precursors of vitamin A found in plants (Mitra, 2012; Low et al., 2017). This could partly explain the slow improvement in the vitamin A status of the South African population, especially children (Shisana et al., 2013).

Vitamin A is an essential micronutrient that has several physiological roles including immunity, vision and protein synthesis (Sizer and Whitney, 2017). In SA, between 1994 and 2005, the number of children that had VAD increased from 33.3% to 63.6% (Labadarios and Van Middelkoop, 1995; Labadarios et al., 2008). Although, the results from the 2012 SANHANES-1 study showed a decrease in VAD prevalence from the 2005 NFCS-FB, the prevalence of VAD is still high (43.6%) (Labadarios et al., 2008; Shisana et al., 2013).

Biofortification could be used as a complementary strategy to reduce VAD in vulnerable population groups. However, PVA-biofortified foods, especially maize, have been found less acceptable compared to their non-PVA-biofortified counterparts. This has been attributed to the unfamiliar sensory attributes imparted by carotenoid pigments present in PVA-biofortified foods (De Groote and Kimenju, 2008; De Groote et al., 2010; De Groote et al., 2011; Nuss et al., 2012; Talsma et al., 2017). Consumer acceptability of PVA-biofortified foods could be improved by combining them with other commonly consumed food items (plant or animal based) as they could mask the undesirable properties of PVA-biofortified foods. A published South African study that investigated the acceptance of combining PVA-biofortified foods with other foods, reported an improvement in consumer acceptability. *Phutu*, a traditional crumbly porridge made from PVA-maize was well accepted when it was combined with chicken stew (Amod et al., 2016). Unlike biofortified maize, OFSP has been well accepted by consumers (Tomlins et al., 2007; Low and Van Jaarsveld, 2008; Chowdhury et al., 2011; Laurie and Van Heerden, 2012; Pillay et al., 2018). Therefore, there are fewer challenges with the consumer acceptability of OFSP.

Apart from increasing the PVA content of popular vitamin A-deficient traditional and indigenous plant-based dishes of KwaZulu-Natal (KZN), PVA-biofortified maize and OFSP are also likely to significantly affect the concentration of other nutrients in the dishes. The study objective was to determine the effect of replacing white maize and CFSP with PVA-biofortified maize and OFSP, respectively, on the nutritional composition of traditional dishes of KZN province of SA. The food products studied were *phutu*[25]prepared with white maize meal and PVA-biofortified maize meal served with curried[26] chicken, cabbage or bambara groundnut and boiled sweet potato[27] (CFSP and OFSP). The *phutu* combinations were selected based on a survey that was conducted in four selected rural study sites in KZN.[28]

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[25] Maize meal cooked into a crumbly porridge.
[26] Curry was selected as the preparation method as it was reported by study participants as the most common way in which the food items were prepared.
[27] Prepared using the boiling method.
[28] More details are found in section 9.2.2

8.2 Methodology

8.2.1 Plant materials

Dried (about 10% moisture) grain of two maize varieties, a PVA-biofortified variety (PVA A) and white variety (WE-3172) (control), were used in this study. Plant breeders at the UKZN produced the maize grains. Orange maize inbred lines were developed through pedigree breeding. During phenotypic selection, emphasis was placed on grain colour intensity such that lines exhibiting deep orange colour were advanced to the next generation. The deep orange grain colour is positively correlated with total carotenoid content in maize grain (Rajagopal et al., 2013). Experimental F1 maize hybrids were then developed by cross-pollination of the inbred lines. The hybrids were divided into three groups depending on the colour intensity as follows: Group A-deep orange, B-medium and C-light orange. Each group was used to make a synthetic population by mixing the grain of the hybrids and allowing them to mate randomly. For the purpose of the study, the one synthetic population was designated PVA A. The maize varieties were grown at the UKZN Ukulinga Research Farm, Pietermaritzburg, SA. Standard cultural practices for maize production were followed. The maize was harvested manually and left to dry under ambient conditions (±25°C) for 21 days at the Ukulinga Research Farm. The maize was then threshed by hand and the grain was stored in a cold room (approximately +4°C) at Ukulinga Research Farm, until it was required for the research. A grain cleaner (R.G Garvie and sons, Agricultural Engineers, Aberdeen, Scotland, UK) was used to clean the maize grains. After cleaning the grains, moisture was adjusted to 15% (w/v). A hammer roller (Zhauns Business Opportunities and Engineering, Cape Town, SA) was then used to mill the maize grains. This maize meal passed through a 1 mm hammer mill screen.

The OFSP (A45) and CFSP (A40) genotypes were developed by controlled pollination. The female and male parent was known. The parents of A40 were Merikan x Yan Shu 1 and A45 were Excel x Xushu 18. They were among the progeny of the first set of crosses conducted among elite parental lines imported from the International Potato Centre (CIP), Peru. This first series of crosses were referred to as the "A" series and proved the most successful with seven crosses being released and grown by small and large-scale farmers. The bambara groundnut landrace was purchased from Umvoti beans in Moolla industrial township in Stanger and cabbage was purchased from a local (Pietermaritzburg) supermarket for the study.

8.2.2 Preparation of food products

Phutu was prepared from the maize meal of the two maize varieties [the PVA-biofortified variety and the white maize variety (control)] using a standardised recipe (see Supplementary Information, Appendix L). The phutu was served with curried cabbage, chicken, and bambara groundnut and prepared using standardised recipes (see Supplementary Information – Appendix M, N and O). *Phutu* served with either curried cabbage or chicken were selected because they are popular traditional dishes in KZN. The *phutu* and curried bambara groundnut were selected as a plant-based alternative to animal food sources (chicken) that are usually combined with *phutu*. The two varieties of sweet potato were boiled separately using a standardised recipe and served as stand-alone dishes, i.e. they were not composited with other food items (see Supplementary Information, Appendix P).

8.2.3 Nutritional composition of maize composite dishes and sweet potato

The nutritional composition of uncooked and cooked food samples was determined using standard or referenced methods. Before nutritional analysis, raw (uncooked) and cooked food samples with high moisture content (all cooked samples, as well as uncooked PVA-biofortified and white maize meal) were freeze-dried. Two replicates of each sample were analysed.

8.2.3.1 Protein

The protein content of the samples was measured with a LECO Truspec Nitrogen Analyser (LECO Corporation, St Joseph, Michigan, USA) using the Association of Official Analytical Chemists (AOAC) Official Method 990.03 (AOAC, 2003). Controls and samples were measured in duplicate and placed into a combustion chamber at 950°C with an autoloader. The following equation (AOAC, 2003) was used to calculate the percentage of protein:

$$\%\, crude\ protein = \%\, N \times 6.25 \qquad \text{Equation 8.1}$$

8.2.3.2 Fat

The fat content of the samples was determined following the Soxhlet procedure. The Büchi 810 Soxhlet Fat extractor (Büchi, Flawil, Switzerland) was used for the analysis according to the AOAC Official Method 920.39 (AOAC, 2003). Petroleum ether was used for extraction, and the percentage of crude fat was calculated using the following equation (AOAC, 2003):

$$\%\, crude\ fat = \frac{beaker + fat - beaker \times 100}{sample\ mass} \qquad \text{Equation 8.2}$$

8.2.3.3 Moisture

The moisture content of the samples was measured using the AOAC Official Method 934.01 (AOAC, 2003). The samples were dried at 95°C for 72 hours in an air-circulated oven. Thereafter, the weight loss of the samples was used to calculate the moisture content. The following equation (AOAC, 2003) was used to calculate the moisture content:

$$\% \, moisture = \frac{(mass\ of\ the\ sample + dish) - (mass\ of\ sample\ after\ drying)}{(mass\ of\ the\ sample + dish) - (mass\ of\ petri\ dish\ without\ the\ lid)} \times 100$$ Equation 8.3

8.2.3.4 Total mineral content (ash)

The total mineral content of the samples was determined using the AOAC Official Method 942.05 (AOAC, 2003). The samples were weighed and placed in a furnace at 550°C for 24 hours. The minerals remained as a residue of ash in the crucibles after the volatilisation of the organic matter from the samples. The following equation (AOAC, 2003) was used to determine the percentage of ash:

$$\% \, ash = \frac{(mass\ of\ sample + crucible\ after\ ashing) - (mass\ of\ pre\text{-}dried\ crucible)}{(mass\ of\ sample + crucible) - (mass\ of\ pre\text{-}dried\ crucible)} \times 100$$ Equation 8.4

8.2.3.5 Fibre

Fibre was determined as neutral detergent fibre (NDF) using the Van Soest method (FAO, 2011; Van Soest and Robertson, 1979; Van Soest, 1963). The sample was weighed using an analytical balance and 0.5 g was added into a scintered glass crucible (34 × 2.8mm, porosity 2). Neutral detergent solution (NDS) (50 ml) and marble/buffer beads were added to the glass crucible holder. The NDS was prepared with 124 g ethylene diamine tetra-acetic acid, 45.3 g disodium tetraborate, 200 g sodium lauryl sulphate, 67 ml 2-ethoxy ethanol and 30.4 g disodium hydrogen phosphate. Thereafter, the crucible containing the sample was placed into the glass crucible holder. The crucible holder with crucible, sample and NDS were placed into a digestive block set at 110°C. Subsequently, 1 ml of termamyl (α-amylase) was added and covered with stoppers. After 1 hour 10 minutes, the glass crucible holder containing the crucible, sample, and NDS was removed and placed into the glass crucible holder rack. Next, the glass crucible was removed and placed on a draining rack. The sample was then suctioned in a filtration unit which was connected to a vacuum system and washed three times with boiling water. The sample and sides of the crucible were rinsed with acetone. Thereafter, samples were placed in a drying oven set that was maintained at 105°C for at least 4 hours. The sample was then removed from the oven and placed in a desiccator to cool. The crucible was weighed and the following equation was used to calculate the NDF of the sample (Van Soest et al., 1991):

$$\% \, NDF = \frac{(crucible + dry\ residue) - (crucible + ash)}{sample\ mass} \times 100$$ Equation 8.5

8.2.3.6 Amino Acids

Amino acids were analysed by the hierarchical clustering linear combination (HCLC) method after HCl hydrolysis and derivatization. The method was according to the International Analytical Group (International Analytical Group, 2016) and is briefly described below. The freeze-dried sample was added to a glass vial and 6 N HCl was added. Thereafter, the vial was flushed with argon or nitrogen gas to eliminate oxygen, before the lid was closed. The vial was placed in an oven at 110°C for 18-24 hours. The vial was removed from the oven and allowed to cool. The hydrolysate was filtered using centrifuge tube filters (Corning® Costar® Spin-X tubes, Sigma-Aldrich, St. Louis, MO, USA). The filtrate was transferred to Eppendorf tubes and allowed to dry using a speedvac and thereafter reconstituted in borate buffer for derivatization. The borate buffer was transferred into a 200 µl glass insert in a 2 ml glass vial, and 10 µl of either standard solution or diluted sample was added. The 6-aminoquinolyl-N-hydroxysccinimidyl carbamate (AQC) reagent was added, and then the vial was placed in a vortex to ensure that the sample was mixed properly. The vial was then placed in an oven at 55°C for 10 minutes, and then loaded into the autosampler tray for analysis. An H-class Waters Acquity ultra performance liquid chromatography (UPLC) linked to a Waters photodiode array detector (Waters, Milford, MA, USA), was used for high-resolution UPLC-UV analysis. The separation was achieved on an Acquity UPLC BEH C18 (2.1 × 150 mm; 1.7 µm particle size) column at 60°C and a flow rate of 0.4 ml/min. Data were collected at a wavelength of 254 nm. An injection volume of 1 µl was used, and gradient separation was performed using Solvents A and B from the Waters Accutag kit.

8.2.3.7 Mineral elements

Calcium, phosphorous, iron, and zinc, were analysed using the Agricultural Laboratory Association of Southern Africa (ALASA) Method 6.1.1 (ALASA, 1998). The first step of this process was to freeze-dry the samples in a freeze drier (Edwards, High vacuum international, Sussex, England). Samples were ashed for 24 hours at 550°C in a furnace. The samples were dissolved in HCl and then HNO_3 was added. The samples were analysed using an atomic absorption spectrophotometer. Calcium and phosphorus were determined using the Analytik Jena Spekol 1300 spectrophotometer (Analytik Jena AG, Achtung, Germany). Iron was determined with the Varian SpectrAA atomic absorption spectrophotometer (Varian Australia Pty Ltd, Mulgrave, Victoria), and zinc with the GBC 905AA spectrophotometer (GBC Scientific Equipment Pty Ltd., Dandenong, Victoria, Australia).

8.2.3.8 Provitamin A

The provitamin A content of the food samples was determined by high-performance liquid chromatography (HPLC), according to the procedures described by Lacker et al. (1999).

8.2.4 Determining usual portion sizes for children aged 1-5 years

Usual portion sizes of composite dishes (*phutu* and curried cabbage, *phutu* and curried chicken and *phutu* and curried bambara) and boiled CFSP was obtained from caregivers of children aged 1-5 years, as part of the consumer acceptability study (Chapter 9). Portion sizes were obtained from caregivers for 65 children aged 1-5 years. Table 8.1 indicates the number of portion sizes obtained for each age group.

Table 8.1: The number of portions sizes obtained for each age category (n=65)

Age group	n (%)
1-3 years	37 (56.9)
4-5 years	28 (43.1)

Caregivers were provided with a bowl or plate and a dishing spoon and were required to plate the amount of *phutu* and curry together, that they would usually serve the child in their care. Additionally, the caregivers selected the size of CFSP that they felt best resembled the usual portion they would serve the child. The food portions were then weighed using an electronic scale (Soehnle, Leifheit AG 56377, Nassau, Germany) and the measurements recorded. The mean usual intake was calculated for each of the composite dishes. Tables 8.2 and 8.3 presents the mean usual portion sizes for each age category. These values were used to determine if the usual portion sizes for the different age groups met the EAR for vitamin A for children in the different age groups.

The caregivers served the children the same portion of *phutu* with either curried cabbage, chicken or bambara groundnut. The independent samples t-test indicated that only the chicken portions were significantly different for the two age groups ($p<0.05$). The chicken portion served to 4-5-year olds was significantly greater than the portion served to 1-3 year olds ($p<0.05$).

Table 8.2: Mean usual portion sizes of meals prepared with *phutu* and combined with either curried chicken, cabbage or bambara groundnut reported by caregivers (n=65) of children aged 1-5 years

1-3 YEARS OLD				4-5 YEARS OLD			
Composite dish	**n**	**Usual portion (g)**	**Weight range of usual portions (g)**	**Composite dish**	**n**	**Usual portion (g)**	**Weight range of usual portions (g)**
Phutu and curried chicken	37	158.54[a] (40.80)[b]	72-236	*Phutu* and curried chicken	28	188.07 (60.30)	100-386
Phutu and curried cabbage	37	165.24 (52.05)	84-268	*Phutu* and curried cabbage	28	195.64 (65.96)	110-394
Phutu and curried bambara groundnut	37	176.51 (59.56)	67-278	*Phutu* and curried bambara groundnut	28	200.25 (78.38)	106-452

[a] Mean weight (g); [b] Standard deviation.

Table 8.3: Mean usual portion sizes of sweet potato reported by caregivers (n=65) of children aged 1-5 years

Age	n	Usual portion (g)	Weight range of usual portion (g)
1-3 years	37	142.73[a] (97.50)[b]	40-360
4-5 years	28	179.50 (95.13)	50-448

[a] Mean weight (g); [b] Standard deviation.

8.2.5 Data quality control

A template was designed for data collection and checked by the statistician to ensure that all relevant variables were included in the template. Data from the nutritional analysis was entered onto two Microsoft Excel spreadsheets with the same template. These two spreadsheets were compared to ensure that there were no discrepancies. Thereafter, the two spreadsheets were consolidated into one and analysed statistically.

8.2.6 Reduction of experimental errors

A number of steps were taken to reduce experimental errors. Foods were prepared using the same brands of ingredients, measuring cups, spoons, pots and model of stove. All dry ingredients were measured on a calibrated food scale. Samples of the cooked dishes were taken on the day it was prepared and freeze-dried to stop the cooking process and prevent any chemical changes. Nutritional analysis was conducted in duplicate, using standardised methods.

8.2.7 Statistical analysis

Nutritional composition data were analysed using the Statistical Package for Social Science (SPSS) (version 25.0 SPSS Inc, Chicago III USA). Mean values and standard deviations were determined for all duplicate measurements for 13 cooked and uncooked samples. The Kruskal Wallis non-parametric test was used to determine if there were significant differences in nutritional composition across uncooked and cooked food products. Where significant differences were identified, the Mann-Whitney U test was used to determine the specific differences. The Mann-Whitney U test was also used to determine significant differences in nutritional composition across the two sweet potato varieties. Significance was measured at the 5% level throughout. Data for the usual portion size was analysed using the statistical package, SPSS (version 25.0 SPSS Inc, Chicago III USA). Mean values and standard deviations were determined for all duplicate measurements. The independent samples t-test was used to test for significant differences in mean values between the portion size of the *phutu* composite dishes and sweet potato for the two age groups (1-3 years and 4-5 years).

8.3 Results

8.3.1 Proximate composition of uncooked and cooked food samples

The concentration of all the nutrients analysed differed significantly according to the Kruskal Wallis test: $p<0.05$, across the 13 food samples (Table 8.4). The protein concentration of PVA-biofortified maize meal/flour (8.68 g/100 g) was not significantly different from that of white maize meal/flour (10.22 g/100 g) ($p=1.000$) (Table 8.4). Provitamin A-biofortified *phutu* (8.74 g/100 g) had a significantly lower protein concentration than that of curried chicken ($p<0.05$), but was not significantly different from the protein concentration of curried cabbage (13.04 g/100 g) and bambara groundnut (17.00 g/100 g) ($p=0.995$ and $p=0.682$, respectively). The protein content of curried chicken (71.23 g/100 g) was approximately quintuple that of curried cabbage (13.04 g/100 g) and approximately quadruple that of curried bambara groundnut (17.00 g/100g) ($p<0.05$). Provitamin A-biofortified *phutu* served with either curried cabbage, chicken or bambara groundnut did not have a significantly different protein concentration in comparison to white *phutu*, served with either curried cabbage, chicken or bambara groundnut ($p=1.000$, $p=0.954$ and $p=1.000$, respectively).

When comparing the three PVA biofortified composite dishes, there were no significant differences in the protein concentration ($p>0.05$). The fibre concentration of PVA-biofortified maize/flour (13.53 g/100 g) was not significantly different from that of white maize meal/flour (control) (5.44 g/100 g) (Table 8.4) ($p=0.998$). Replacing white maize *phutu* (control) with PVA *phutu* in the composite dishes had no effect on the fibre concentration of PVA *phutu* and curried chicken; PVA *phutu* and curried cabbage; or *phutu* and curried bambara groundnut ($p=1.000$, $p=1.000$ and $p=0.993$, respectively). A similar fibre concentration was observed in all three composite dishes containing PVA-biofortified *phutu* ($p>0.05$).

The total mineral content (ash) of white maize meal/flour (control) (1.21 mg/100 g) was not significantly different from that of PVA-biofortified maize meal/flour (1.35 mg/100 g) (Table 8.4) ($p=1.000$). The ash content of PVA-biofortified *phutu* (2.64 mg/100 g) was significantly lower than curried cabbage (11.19 mg/100 g), curried chicken (14.15 mg/100 g) and curried bambara groundnut (8.00 mg/100 g) ($p<0.05$). Curried chicken (14.15 mg/100 g) had a significantly higher ash content compared to curried cabbage and bambara groundnut ($p<0.05$). However, the ash content did not change significantly when white *phutu* was replaced with PVA-biofortified *phutu* in the three composite dishes ($p>0.05$). Orange-fleshed sweet potato had a significantly lower protein concentration relative to the CFSP, but a significantly higher fibre and total mineral concentration (ash) (Table 8.5) ($p<0.05$).

Table 8.4: Proximate composition of uncooked and cooked food samples, except for sweet potato

Sample	Moisture (%)	Protein (g/100 g, DW[a])	Fat (g/100 g, DW)	NDF[b] (g/100 g, DW)	Total mineral content (ash) (mg/100 g, DW)
Raw maize meal/flour					
White maize flour (control)	9.88[c] (0.59)[d]	10.22 (0.21)	3.89 (0.61)	5.44 (6.62)	1.21 (0.12)
PVA[e]-biofortified maize flour	9.20 (1.77)	8.68 (0.01)	2.97 (0.15)	13.53 (0.85)	1.35 (0.04)
Individual dishes					
White *phutu* (control)	4.88 (0.17)	9.71 (0.15)	2.48 (0.21)	9.65 (0.62)	5.10 (0.37)
PVA-biofortified *phutu*	4.91 (0.50)	8.74 (0.03)	2.70 (0.28)	17.45 (0.66)	2.64 (0.15)
Curried cabbage	15.48 (1.68)	13.04 (0.56)	20.56 (0.03)	28.64 (1.75)	11.19 (0.28)
Curried chicken	9.17 (1.18)	71.23 (9.43)	22.62 (3.03)	40.82 (17.47)	14.15 (0.74)
Curried bambara groundnut	8.00 (0.27)	17.00 (0.17)	12.13 (0.97)	29.21 (4.71)	8.00 (0.27)
Composite dishes					
White *phutu* and curried chicken	4.17 (0.00)	28.60 (2.59)	7.27 (0.13)	10.77 (1.43)	3.42 (0.24)
PVA *phutu* and curried chicken	4.38 (0.54)	22.86 (0.87)	8.87 (1.29)	15.94 (4.55)	3.46 (0.06)
White *phutu* and curried cabbage	6.83 (0.82)	10.10 (0.11)	9.19 (0.35)	18.95 (2.81)	4.18 (0.25)
PVA *phutu* and curried cabbage	6.70 (0.63)	9.00 (0.15)	9.46 (0.10)	18.63 (0.23)	4.63 (0.17)
White *phutu* and curried bambara groundnut	7.14 (1.44)	13.29 (0.15)	8.98 (0.38)	17.45 (0.10)	3.24 (0.09)
PVA *phutu* and curried bambara groundnut	4.51 (2.75)	12.86 (0.93)	8.00 (0.77)	26.63 (2.19)	3.45 (0.11)
P-value[f]	**0.036**	**0.017**	**0.019**	**0.029**	**0.017**

[a]DW: dry weight basis; [b]NDF: Neutral detergent fibre; [c]Mean of duplicate values; [d]Standard deviation; [e]PVA: Provitamin A; [f]Kruskal Wallis test; Values in bold indicate $p<0.05$.

Table 8.5: Nutritional composition of cooked orange-fleshed sweet potato compared to the cream-fleshed sweet potato (control)

Sweet Potato	Moisture (%)	Protein (g/100 g, DW[a])	Fat (g/100 g, DW)	NDF[b] (g/100 g, DW)	Total mineral content (ash) (mg/100 g, DW)
Boiled CFSP[c]	3.90[d] (0.64)[e]	6.38 (0.32)	0.50 (0.11)	4.14 (0.18)	3.28 (0.92)
Boiled OFSP[f]	4.88 (0.17)	4.51 (0.30)	0.64 (0.17)	5.97 (0.25)	5.83 (1.45)
P-value[g]	**<0.05**	**<0.05**	1.000	**<0.05**	**<0.05**

[a]DW: dry weight basis; [b]NDF: Neutral detergent fibre; [c]CFSP: Cream-fleshed sweet potato; [d] Mean of duplicate values; [e] Standard deviation; [f]OFSP: Orange-fleshed sweet potato; [g] Mann-Whitney U test; Values in bold indicate p<0.05.

8.3.2 Amino acid content of uncooked and cooked food samples

Results from the Kruskal Wallis test showed that the concentration of the essential amino acids histidine, lysine, and phenylalanine (Table 8.6) differed significantly ($p<0.05$) across the 13 food samples analysed (Table 8.7). Further analysis with the Mann-Whitney U test revealed specific differences in nutrient concentrations, which are described below.

Lysine concentration in white maize meal/flour (control) (0.40 g/100 g) was not significantly different from the lysine concentration in PVA-biofortified maize meal/flour (0.36 g/100 g) ($p=1.000$). There was no significant difference in lysine concentration between PVA-biofortified *phutu* and curried cabbage (0.27 g/100 g) and curried bambara groundnut (1.80 g/100 g) ($p=1.000$ and 0.183, respectively). However, the lysine content was 11.53 g/100 g higher in curried chicken than in PVA-biofortified flour ($p<0.05$). The curried chicken had an 11.22 g/100 g and 10.01 g/100 g higher lysine concentration in comparison to curried cabbage and curried bambara groundnut, respectively ($p<0.05$). Although not statistically significant, the mean lysine concentration was higher in curried bambara groundnut (1.80 g/100g) than in curried cabbage (0.59 g/100g). The lysine concentration did not change when white *phutu* (control) was replaced with PVA-biofortified *phutu* in all three composite dishes. When comparing the three composite dishes containing PVA-biofortified *phutu*, it was evident that there was no significant difference in the lysine concentration ($p>0.05$). Orange-fleshed sweet potato had higher lysine, isoleucine, leucine, aspartate, glutamate and alanine concentration, but a lower phenylalanine concentration than CFSP (Tables 8.8 and 8.9) ($p<0.05$).

Table 8.6: Essential amino acid composition of uncooked and cooked samples, except sweet potato (g/100 g, DW[a])

Sample	Histidine	Threonine	Lysine	Methionine	Valine	Isoleucine	Leucine	Phenylalanine
Raw milled maize meal/flour								
White maize flour (control)	0.27[b] (0.04)[c]	0.33 (0.04)	0.40 (0.03)	ND[d]	0.38 (0.06)	0.58 (0.06)	0.78 (0.01)	0.81 (0.11)
PVA[e]-biofortified maize flour	0.20 (0.03)	0.27 (0.04)	0.36 (0.01)	ND	0.35 (0.05)	0.59 (0.10)	0.71 (0.11)	0.71 (0.02)
Individual dishes								
White *phutu* (control)	0.28 (0.02)	0.35 (0.11)	0.45 (0.11)	0.06 (0.08)	0.40 (0.19)	0.66 (0.59)	0.81 (0.37)	0.91 (0.05)
PVA-biofortified *phutu*	0.20 (0.01)	0.27 (0.03)	0.28 (0.00)	0.08 (0.00)	0.35 (0.01)	0.43 (0.06)	0.67 (0.10)	0.68 (0.08)
Curried cabbage	0.15 (0.05)	0.33 (0.06)	0.59 (0.06)	0.05 (0.03)	0.36 (0.04)	0.63 (0.24)	0.30 (0.08)	0.59 (0.07)
Curried chicken	2.01 (0.07)	3.98 (0.27)	11.81(0.67)	2.27 (0.25)	3.18 (0.39)	7.63 (0.68)	4.69 (0.17)	3.02 (0.13)
Curried bambara groundnut	0.44 (0.06)	0.63 (0.07)	1.80 (0.04)	0.13 (0.02)	0.78 (0.06)	1.56 (0.14)	0.97 (0.08)	1.40 (0.35)
Composite dishes								
White *phutu* and curried chicken	0.55 (0.13)	1.03 (0.30)	2.23 (0.73)	0.36 (0.12)	0.88 (0.15)	1.95 (0.30)	1.52 (0.40)	1.31 (0.10)
PVA *phutu* and curried chicken	0.42 (0.12)	0.83 (0.16)	1.85 (0.61)	0.34 (0.07)	0.69 (0.12)	1.40 (0.63)	1.13 (0.28)	1.07 (0.06)
White *phutu* and curried cabbage	0.21 (0.05)	0.34 (0.05)	0.45 (0.03)	0.05 (0.01)	0.43 (0.02)	0.85 (0.13)	0.71 (0.00)	0.77 (0.12)
PVA *phutu* and curried cabbage	0.17 (0.08)	0.26 (0.06)	0.27 (0.15)	ND	0.35 (0.10)	0.38 (0.12)	0.59 (0.16)	0.97 (0.11)
White *phutu* and curried bambara groundnut	0.32 (0.04)	0.36 (0.06)	0.69 (0.22)	0.09 (0.02)	0.48 (0.08)	1.03 (0.10)	0.79 (0.02)	1.17 (0.11)
PVA *phutu* and curried bambara groundnut	0.25 (0.03)	0.32 (0.10)	0.69 (0.20)	0.08 (0.01)	0.45 (0.13)	0.73 (0.03)	0.62 (0.07)	1.09 (0.13)
P-value[f]	**0.030**	0.072	**0.021**	0.065	0.080	0.050	0.053	**0.024**

[a]DW: dry weight basis; [b] Mean of duplicate values; [c] Standard deviation; [d]ND: Not detected; [e]PVA: Provitamin A; [f]Kruskal Wallis test; Values in bold indicate $p<0.05$.

Table 8.7: Non-essential amino acid composition of uncooked and cooked samples, except for sweet potato (g/100 g, DW[a])

Sample	Serine	Arginine	Glycine	Aspartate	Glutamate	Alanine	Proline	Tyrosine
Raw milled maize meal/flour								
White maize flour (control)	0.60[b] (0.01)[c]	0.42 (0.01)	0.76 (0.01)	0.45 (0.04)	1.89 (0.03)	0.66 (0.01)	0.76 (0.00)	0.15 (0.21)
PVA[d]-biofortified maize flour	0.53 (0.06)	0.25 (0.05)	0.67 (0.16)	0.40 (0.05)	1.72 (0.30)	0.65 (0.07)	0.71 (0.11)	0.10 (0.13)
Individual dishes								
White *phutu* (control)	0.65 (0.30)	0.34 (0.09)	0.77 (0.22)	0.64 (0.29)	2.06 (1.01)	0.74 (0.32)	0.85 (0.28)	0.12 (N/A[e])
PVA-biofortified *phutu*	0.48 (0.04)	0.24 (0.00)	0.66 (0.03)	0.47 (0.06)	1.64 (0.23)	0.58 (0.04)	0.68 (0.01)	0.24 (N/A)
Curried cabbage	0.52 (0.06)	0.38 (0.05)	0.71 (0.21)	0.71 (0.04)	2.84 (0.47)	0.48 (0.06)	0.48 (0.13)	ND[f]
Curried chicken	4.29 (0.18)	4.09 (0.08)	7.49 (0.59)	6.92 (0.26)	14.67 (0.59)	5.19 (0.23)	2.64 (0.16)	2.27 (0.07)
Curried bambara groundnut	1.26 (0.18)	0.88 (0.08)	1.45 (0.24)	1.81 (0.16)	3.68 (0.23)	0.85 (0.04)	0.68 (0.15)	0.46 (0.04)
Composite dishes								
White *phutu* and curried chicken	1.30 (0.31)	1.02 (0.30)	2.34 (0.27)	1.62 (0.49)	4.37 (1.21)	1.62 (0.32)	1.15 (0.12)	0.53 (0.14)
PVA *phutu* and curried chicken	1.08 (0.20)	0.78 (0.14)	1.79 (0.28)	1.26 (0.33)	3.48 (0.98)	1.32 (0.23)	0.96 (0.16)	ND
White *phutu* and curried cabbage	0.65 (0.01)	0.27 (0.05)	0.77 (0.01)	0.57 (0.02)	2.28 (0.12)	0.71 (0.06)	0.77 (0.01)	ND
PVA *phutu* and curried cabbage	0.52 (0.12)	0.24 (0.13)	0.63 (0.16)	0.50 (0.18)	1.99 (0.62)	0.61 (0.17)	0.67 (0.14)	ND
White *phutu* and curried bambara groundnut	0.75 (0.09)	0.47 (0.07)	0.96 (0.04)	0.83 (0.12)	2.22 (0.47)	0.71 (0.04)	0.69 (0.01)	0.32 (0.02)
PVA *phutu* and curried bambara groundnut	0.76 (0.20)	0.42 (0.16)	0.83 (0.22)	0.89 (0.15)	1.90 (0.42)	0.61 (0.09)	0.57 (0.04)	0.22 (0.02)
P-value[g]	**0.043**	**0.032**	0.063	**0.032**	0.068	0.074	0.088	0.088

[a]DW: dry weight basis; [b]Mean of duplicate values; [c] Standard deviation; [d] PVA: Provitamin A; [e]N/A: Not applicable; [f]ND: Not detected; [g]Kruskal Wallis test; Values in bold indicate $p<0.05$.

Table 8. 8: Essential amino acid composition of cooked orange-fleshed sweet potato compared to the cream-fleshed sweet potato (control) (g/100g, DW[a])

Sweet potato	Histidine	Threonine	Lysine	Methionine	Valine	Isoleucine	Leucine	Phenylalanine
Boiled CFSP[b]	ND[c]	0.13[d] (0.03)[e]	0.24 (0.04)	ND	0.20 (0.05)	0.14 (0.04)	0.08 (0.01)	0.66 (0.03)
Boiled OFSP[f]	0.05 (0.01)	0.19 (0.06)	0.38 (0.04)	ND	0.20 (0.06)	0.26 (0.02)	0.16 (0.04)	0.32 (0.03)
P-value[g]		0.500	**< 0.05**		1.500	**< 0.05**	**< 0.05**	**< 0.05**

[a]DW: dry weight basis; [b]CFSP: Cream-fleshed sweet potato; [c] ND: Not detected; [d] Mean of duplicate values; [e] Standard deviation; [f] OFSP: Orange-fleshed sweet potato; [g] Mann-Whitney U test; Values in bold indicate p<0.05.

Table 8.9: Non-essential amino acid composition of cooked orange-fleshed sweet potato compared to the cream-fleshed sweet potato (control) (g/100 g, DW[a])

Sweet potato	Serine	Arginine	Glycine	Aspartate	Glutamate	Alanine	Proline	Tyrosine
Boiled CFSP[b]	0.30[c] (0.04)[d]	0.09 (0.02)	0.34 (0.07)	0.48 (0.08)	0.35 (0.06)	0.26 (0.01)	0.09 (0.01)	ND[e]
Boiled OFSP[f]	0.33 (0.10)	0.12 (0.03)	0.39 (0.10)	0.77 (0.15)	0.59 (0.11)	0.30 (0.03)	0.13 (0.04)	0.04 (N/A[g])
P-value[h]	2.000	0.500	1.000	**< 0.05**	**< 0.05**	**< 0.05**	0.500	

[a]DW: dry weight basis; [b]CFSP: Cream-fleshed sweet potato; [c] Mean of duplicate values; [d]Standard deviation; [e]ND: Not detected; [f] OFSP: Orange-fleshed sweet potato; [g] N/A: Not applicable; [h] Mann-Whitney U test; Values in bold indicate p<0.05.

8.3.3 Mineral composition of uncooked and cooked food samples

Results from the Kruskal Wallis test showed that the concentration of selected mineral elements analysed differed significantly across all the 13 food samples ($p<0.05$), except zinc concentration, for which no significant difference was found (Table 8.10). The Mann-Whitney U test showed specific differences and these are described below.

Iron concentration in white maize meal/flour (control) was not significantly different from iron concentration in the PVA-biofortified maize meal/flour ($p=1.000$). Provitamin A-biofortified *phutu* had a 96.8 mg/100 g lower iron concentration compared with curried chicken ($p=0.001$). The iron concentration of curried chicken (98.50 mg/100 g) was significantly higher than that of curried cabbage and curried bambara groundnut ($p=0.001$). The iron concentration did not change significantly when white *phutu* was replaced with PVA *phutu* in the three composite dishes. A similar iron concentration was found in all three composite dishes containing PVA-biofortified *phutu.* The zinc concentration of CFSP was significantly higher than that of OFSP, but the OFSP had a significantly higher iron concentration than the CFSP.

Table 8.10: Selected mineral content of uncooked and cooked food samples, except sweet potato (mg/100 g, DW[a])

Sample	Calcium	Magnesium	Potassium	Sodium	Phosphorous	Zinc	Iron
Raw milled maize meal/flour							
White maize flour (control)	0.00[b](0.00)[c]	0.11 (0.01)	0.31 (0.01)	0.00 (0.00)	0.26 (0.01)	1.80 (0.14)	2.05 (2.21)
PVA[d]-biofortified maize flour	0.01 (0.01)	0.11 (0.00)	0.33 (0.01)	0.00 (0.00)	0.27 (0.01)	1.80 (0.14)	2.10 (0.28)
Individual dishes							
White *phutu* (control)	0.01 (0.00)	0.10 (0.00)	0.36 (0.01)	1.73 (0.02)	0.25 (0.01)	1.55 (0.07)	1.60 (0.00)
PVA biofortified *phutu*	0.01 (0.00)	0.11 (0.01)	0.34 (0.01)	0.60 (0.00)	0.26 (0.01)	1.70 (0.00)	1.70 (0.42)
Curried cabbage	0.35 (0.00)	0.15 (0.00)	1.56 (0.01)	2.75 (0.02)	0.27 (0.00)	1.60 (0.14)	3.25 (0.07)
Curried chicken	1.52 (0.67)	1.90 (0.10)	29.20 (2.44)	28.02 (3.92)	13.82 (0.81)	3259.10 (1450.70)	98.50 (39.46)
Curried bambara groundnut	0.04 (0.00)	0.15 (0.01)	1.60 (0.45)	2.00 (0.11)	0.25 (0.00)	1.90 (0.14)	1.90 (0.00)
Composite dishes							
White *phutu* and curried chicken	0.10 (0.03)	0.11 (0.01)	0.60 (0.01)	0.71 (0.00)	0.38 (0.03)	1.80 (0.00)	2.15 (0.07)
PVA *phutu* and curried chicken	0.03 (0.00)	0.10 (0.00)	0.59 (0.05)	0.75 (0.03)	0.36 (0.00)	2.40 (0.42)	2.75 (0.07)
White *phutu* and curried cabbage	0.08 (0.00)	0.11 (0.01)	0.56 (0.01)	0.92 (0.00)	0.25 (0.01)	2.15 (0.64)	2.65 (0.21)
PVA *phutu* and curried cabbage	0.10 (0.01)	0.11 (0.01)	0.58 (0.01)	1.07 (0.04)	0.23 (0.00)	1.70 (0.14)	2.25 (0.21)
White *phutu* and curried bambara groundnut	0.02 (0.00)	0.13 (0.00)	0.78 (0.01)	0.44 (0.00)	0.28 (0.01)	2.05 (0.21)	2.15 (0.07)
PVA *phutu* and curried bambara groundnut	0.02 (0.00)	0.12 (0.00)	0.73 (0.04)	0.47 (0.02)	0.26 (0.00)	1.80 (0.00)	2.10 (0.14)
P-value[e]	**0.016**	**0.037**	**0.018**	**0.015**	**0.024**	0.085	**0.042**

[a]DW: dry weight basis; [b]Mean of duplicate values; [c]Standard deviation; [d]PVA: Provitamin A; [e]Kruskal Wallis test; Values in bold indicate $p<0.05$.

Table 8.11: Selected mineral content of cooked orange-fleshed sweet potato compared to the cream-fleshed sweet potato (control) (mg/100 g, DW[a]).

Sweet potato	Calcium	Magnesium	Potassium	Sodium	Phosphorous	Zinc	Iron
Boiled CFSP[b]	0.13 [c] (0.02) [d]	0.13 (0.01)	1.35 (0.03)	0.07 (0.01)	0.21 (0.00)	1.30 (0.14)	2.25 (0.21)
Boiled OFSP[e]	0.06 (0.00)	0.09 (0.00)	1.70 (0.01)	0.03 (0.01)	0.15 (0.00)	0.45 (0.64)	2.55 (0.07)
P-value[f]	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**

[a]DW: dry weight basis; [b]CFSP: Cream-fleshed sweet potato; [c]Mean of duplicate values; [d] Standard deviation; [e] OFSP: Orange-fleshed sweet potato; [f] Mann-Whitney U test; Values in bold indicate $p<0.05$.

8.3.4 Provitamin A (PVA) carotenoid composition of uncooked and cooked food samples

Results from the Kruskal Wallis test showed that the concentration of PVA carotenoids analysed differed significantly across the 13 food samples analysed (Table 8.12) ($p<0.05$). The Mann-Whitney U test showed specific differences in nutrient concentration, as described below.

Provitamin A-biofortified maize meal/flour had a much higher PVA carotenoid concentration (1.43 µg/g) than white maize meal/flour (control) (0.62 µg/g) ($p<0.05$). The PVA-biofortified *phutu* had a 0.37 µg/g, 1.13 µg/g and 0.71 µg/g higher PVA carotenoid concentration than curried cabbage, curried chicken, and curried bambara groundnut, respectively ($p=0.039$; $p<0.05$ and $p<0.05$, respectively). Both curried cabbage and bambara groundnut had a significantly higher PVA carotenoid concentration than curried chicken ($p<0.05$ and $p=0.016$, respectively). The composite dish that comprised PVA-biofortified *phutu* and curried chicken (1.12 µg/g) had a significantly higher PVA carotenoid concentration than the composite dish of white *phutu* and curried chicken (control) (0.60 µg/g) ($p=0.002$). The PVA carotenoid concentration increased by 0.36 µg/g when white *phutu* was replaced with PVA-biofortified *phutu* in the composite dish containing curried bambara groundnut ($p=0.047$). The PVA carotenoid concentration of the OFSP (55.84 µg/g DW) was much higher than that of the CFSP (0.77 µg/g DW) (control) (Table 8.13) ($p<0.05$).

Table 8.12: Provitamin A content of provitamin A-biofortified maize composite dishes (µg/g, DW[a])

Sample	Zeaxanthin	β-cryptoxanthin	Lutein	β-carotene isomers			Total β-carotene[b]	Provitamin A carotenoids[c]	Total carotenoids[d]
				β-carotene	9-cis	13-cis			
Raw milled maize meal/flour									
White maize flour (control)	0.27[e] (0.02)[f]	0.00 (0.00)	0.03 (0.00)	0.22 (0.01)	0.20 (0.01)	0.20 (0.01)	0.62 (0.04)	0.62 (0.04)	0.92 (0.06)
PVA[g]-biofortified maize flour	6.35 (0.46)	0.53(0.42)	1.12 (0.08)	0.51 (0.04)	0.36 (0.03)	0.29 (0.02)	1.16 (0.09)	1.43 (0.11)	9.15 (0.67)
Individual dishes									
White *phutu* (control)	0.20 (0.01)	0.00 (0.00)	0.03 (0.00)	0.21 (0.01)	0.20 (0.01)	0.19 (0.01)	0.60 (0.04)	0.60 (0.04)	0.83 (0.05)
PVA-biofortified *phutu*	2.44 (0.16)	0.51 (0.04)	0.74 (0.04)	0.47 (0.04)	0.35 (0.03)	0.26 (0.01)	1.08 (0.08)	1.34 (0.09)	4.76 (0.32)
Curried cabbage	0.92 (0.09)	0.10 (0.14)	0.16 (0.02)	0.43 (0.04)	0.26 (0.02)	0.23 (0.03)	0.92 (0.09)	0.97 (0.11)	2.09 (0.22)
Curried chicken	0.70 (0.04)	0.00 (0.00)	0.03 (0.00)	0.21 (0.01)	0.00 (0.00)	0.00 (0.00)	0.21 (0.01)	0.21 (0.01)	0.94 (0.05)
Curried bambara groundnut	0.20 (0.01)	0.00 (0.00)	0.03 (0.00)	0.23 (0.01)	0.20 (0.01)	0.20 (0.01)	0.63 (0.04)	0.63 (0.04)	0.85 (0.04)
Composite dishes									
White *phutu* and curried chicken	0.50 (0.04)	0.00 (0.00)	0.14 (0.01)	0.20 (0.01)	0.20 (0.01)	0.18 (0.05)	0.58 (0.08)	0.60 (0.05)	1.21 (0.12)
PVA *phutu* and curried chicken	1.35 (0.09)	0.35 (0.02)	0.43 (0.28)	0.39 (0.03)	0.32 (0.02)	0.24 (0.01)	0.95 (0.06)	1.12 (0.07)	3.07 (0.21)
White *phutu* and curried cabbage	1.25 (0.08)	0.00 (0.00)	0.28 (0.02)	0.20 (0.01)	0.20 (0.01)	0.20 (0.01)	0.60 (0.04)	0.60 (0.04)	2.12 (0.14)
PVA *phutu* and curried cabbage	0.81 (0.06)	0.14 (0.01)	0.17 (0.01)	0.27 (0.02)	0.23 (0.01)	0.21(0.01)	0.71 (0.05)	0.78 (0.06)	1.83 (0.13)
White *phutu* and curried bambara groundnut	0.16 (0.01)	0.00 (0.00)	0.03 (0.00)	0.20 (0.01)	0.21 (0.01)	0.20 (0.01)	0.61 (0.04)	0.61 (0.04)	0.79 (0.04)
PVA *phutu* and curried bambara groundnut	1.02 (0.06)	0.25 (0.01)	0.30 (0.02)	0.34 (0.02)	0.28 (0.01)	0.23 (0.01)	0.85 (0.05)	0.97 (0.06)	2.41 (0.15)
P-value[h]	**0.016**	**0.015**	**0.016**	**0.028**	**0.028**	0.055	**0.029**	**0.028**	**0.017**

[a] DW: dry weight basis;[b] (β-carotene + 9-cis +13-cis); [c](β-cryptoxanthin/2 + β-carotene + 9-cis + 13-cis); [d](Total β carotene + Zeaxanthin, + β-cryptoxanthin + Lutein); [e]Mean of duplicate values; [f]Standard deviation; [g]PVA: Provitamin A; [h]Kruskal Wallis test; Values in bold indicate p<0.05.

Table 8.13: Provitamin A content of cooked orange-fleshed sweet potato compared to the cream-fleshed sweet potato (control (µg/g, DW[a])

Sweet potato	Zeaxanthin	β-cryptoxanthin	Lutein	β-carotene isomers			Total β-carotene[b]	Provitamin A carotenoids[c]	Total carotenoids[d]
				β-carotene	**9-*cis***	**13-*cis***			
Boiled CFSP[e]	0.20[f] (0.01)[g]	0.10 (0.01)	0.03 (0.00)	0.27 (0.01)	0.22 (0.01)	0.23 (0.01)	0.72 (0.04)	0.77 (0.04)	1.05 (0.06)
Boiled OFSP[h]	0.40 (0.02)	0.35 (0.14)	0.05 (0.01)	43.29 (1.99)	3.18 (0.15)	9.20 (0.42)	55.67 (2.57)	55.84 (2.57)	56.46 (2.61)
P-value[i]	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**

[a]DW: dry weight basis; [b](β-carotene + 9-cis +13-cis); [c](β-cryptoxanthin/2 + β-carotene + 9-cis + 13-cis); [d](Total β carotene + Zeaxanthin, + β-cryptoxanthin + Lutein); [e]CFSP: Cream-fleshed sweet potato; [f] Mean of duplicate values; [g]Standard deviation; [h]OFSP: Orange-fleshed sweet potato; [i]Mann-Whitney U test; Values in bold indicate p<0.05.

Table 8.14: Percentage of the Estimated Average Requirement met for vitamin A for children aged 1-5 years from the consumption of usual portions of cooked *phutu* composite dishes and boiled sweet potato

Food combinations[29]	**1-3 years**			**4-5 years**		
	Vitamin A content (µg/RAE)[a]	**EAR**[b] **(µg/day)**	**% of EAR met**	**Vitamin A content (µg/RAE)**	**EAR (µg/day)**	**% of EAR met**
Non-biofortified maize composite dishes						
White *phutu* and curried cabbage	8.26	210	3.9	9.78	275	3.6
White *phutu* and curried chicken	7.66	210	3.6	9.09	275	3.3
White *phutu* and curried bambara groundnut	8.97	210	4.3	10.18	275	3.7
CFSP[c]	9.16	210	7.6	11.52	275	4.2
Biofortified maize composite dishes						
PVA[d]-biofortified *phutu* and curried cabbage	10.74	210	5.1	12.72	275	4.6
PVA-biofortified *phutu* and curried chicken	14.86	210	7.1	17.63	275	6.4
PVA-biofortified *phutu* and curried bambara groundnut	14.34	210	6.8	16.27	275	5.9
OFSP[e]	664.23	210	316.3	835.35	275	303.8

[a] RAE (Retinol activity equivalents): 12µg β-carotene = 1 RAE; 24 µg β-cryptoxanthin = 1 RAE. Sum of β-carotene and β-cryptoxanthin using values presented in tables 8.2, 8.3, 8.12 and 8.13. (Institute of Medicine, 2006); [b] EAR (Estimated average requirement) (Institute of Medicine, 2006); [c] CFSP: Cream-fleshed sweet potato; [d] PVA: Provitamin A; [e] OFSP: Orange-fleshed sweet potato.

[29] Tables 8.2 and 8.3 presents the usual portion sizes.

8.3.5 Determining the percentage of EAR met for vitamin A from cooked phutu composite dishes and sweet potato

Table 8.14 presents the percentage of EAR met for vitamin A for children aged 1-5 years. The usual portion size is based on Table 8.2 and 8.3. Table 8.14 indicates that none of the PVA-biofortified *phutu* composite dishes met the EAR for vitamin A. However, the OFSP met approximately three times the EAR for vitamin A for children aged 1-3 years and 4-5 years.

8.4 Discussion

Globally, about two billion people suffer from micronutrient malnutrition, mainly because of low dietary diversity (Smuts et al., 2005; Bain et al., 2013). Undernutrition, particularly protein-energy malnutrition and micronutrient deficiencies are more prevalent in developing regions, especially SSA, where a significant proportion of the population groups are poor and food insecure (Labadarios and Van Middelkoop, 1995; Smuts et al., 2005; Pinstrup-Andersen, 2009; Bain et al., 2013). Poor communities cannot afford a nutritious, diversified diet and are heavily reliant on monotonous diets of starchy staples, which are generally low in essential nutrients, including micronutrients and protein (Altman et al., 2009; StatsSA, 2017; StatsSA, 2018). Among the micronutrient deficiencies, VAD as well as iron and zinc deficiencies, are generally leading (WHO, 2015). This emphasises the need to provide affordable, alternative food sources of essential nutrients, such as vitamin A, zinc, iron, and protein. Biofortified staple crops, which are being developed to contain much higher concentrations of target nutrients, like vitamins and minerals, compared to the corresponding non-biofortified crops, if consumed regularly, would result in significant improvements in human health and nutrition (WHO, 2018).

As is the case with most of the countries in the SSA region, micronutrient deficiencies, especially vitamin A deficiency (VAD), are a significant problem in SA (Labadarios and Van Middelkoop, 1995; Labadarios *et al.,* 2008; Shisana et al., 2013). The KZN province has the largest proportion of poor households in SA and has been one of the poorest provinces in SA since 2011 (Argent et al., 2009; StatsSA, 2017). Many of these impoverished communities are unable to purchase foods that form a diversified diet and end up consuming mainly starch-based foods (Smuts et al., 2005). A basic food basket in SA, comprising 28 items costs about R883.16/month, which is unaffordable to most rural population groups (NAMC, 2019). Poor households are at a high risk of malnutrition, as they cannot afford a diversified diet (Wenhold et al., 2012; Mabhaudhi et al., 2016). Increasing the concentration of provitamin A carotenoids in staple crops through biofortification is a promising strategy for contribution to combating VAD. The results of this study are encouraging, as they indicate that PVA-biofortified maize contained a much higher PVA carotenoid concentration compared to white maize (control), which is consistent with a previous study (Pillay et al., 2014).

It appears that, currently, there are no published data on the nutritional composition of composite dishes containing PVA-biofortified maize food products like *phutu*. However, when either curried cabbage, chicken, or bambara groundnut were combined with PVA-biofortified *phutu*, the PVA carotenoid concentration of the composite dishes was higher than that of the corresponding composite dishes containing white maize (controls). The results indicate that composite dishes in which PVA-biofortified *phutu* is combined with other commonly consumed food items would be suitable carriers of provitamin A, for delivery to the target population groups, such as the poor, rural communities of KZN. In the current study, bambara groundnut was included in the dishes containing maize, because it could be used as an affordable protein source, with the added advantage of thriving in the predominantly harsh agro-ecological conditions of most of the marginal rural areas of sub-Saharan African countries, including the rural areas of KZN (Chibarabada et al., 2017). Previous consumer acceptability studies conducted on bambara groundnut showed promising results, but the studies investigated bambara groundnut food types different from that of the current study (Okafor et al., 2015; Oyeyinka et al., 2017; Oyeyinka et al., 2018). In terms of nutritional composition, the composite dish consisting of PVA-biofortified *phutu* and curried bambara groundnut shows a potential for improving the vitamin A and protein status of vulnerable population groups, but the acceptability of such dishes to the target population groups should be investigated, because bambara groundnut is not a familiar food item to the majority of South Africans (Oyeyinka et al., 2017).

While it is important to note that PVA carotenoids must be converted into vitamin A to be used by the human body (La Frano et al., 2014), a study conducted by Palmer et al. (2016), found improved serum β-carotene levels in Zambian pre-school children that routinely consumed dishes prepared with biofortified maize (Palmer et al., 2016). Other studies have found that the consumption of biofortified maize resulted in an effective conversion of PVA into vitamin A (Li et al., 2010; Muzhingi et al., 2011). These results reinforce the hypothesis that PVA biofortified maize could be used as a sustainable and effective complementary strategy to address VAD. This study further investigated the percentage of the EAR for vitamin A that could be met in the 1-3- and 4-5-year age groups with the consumption of usual portions of PVA-biofortified *phutu* and curried cabbage, PVA-biofortified *phutu* and curried chicken and PVA-biofortified *phutu* and curried bambara groundnut. It was found that although all three PVA-biofortified *phutu* composite dishes contained a higher vitamin A concentration, these combinations did not meet the EAR for vitamin A for the 1-3- and 4-5-year age groups. This was different from a study conducted by Pillay (2011) who found that the consumption of usual portions of PVA-biofortified maize products (thin porridge, *phutu* and samp) would meet a significant portion of the EAR for vitamin A if consumed three times a day. A study limitation of the current study was that only one variety of PVA-biofortified maize was used in the study and if other varieties were used at a higher PVA carotenoid content and served three times a day, a similar result to Pillay (2011) could have been obtained.

The PVA carotenoid concentration of OFSP was much higher than that of the CFSP, which, was expected. The PVA values obtained for CFSP in the current study agree with values reported in the literature (Williams et al., 2013). The high PVA carotenoid concentration in OFSP could contribute to reducing VAD in vulnerable population groups. Another strategy that could be investigated is combining OFSP with other commonly consumed food item/s to enhance the nutrient content of the dishes, including provitamin A as well as other micronutrients with a high prevalence of deficiency. However, this study did not investigate the nutritional composition of composite dishes of OFSP combined with other commonly consumed food items, and, therefore, further investigations are required.

The study further investigated whether the consumption of usual portions of OFSP by the 1-3- and 4-5-year age groups would meet the EAR for vitamin A and found that it met more than three times the EAR value for vitamin A for both age groups. When comparing the vitamin A values to the tolerable upper intake level (UL), it was found that the vitamin A intake from OFSP was higher than the UL for the 1-3-year age group (600 µg/day), but lower than the UL for the 4-5 year age group (900 µg/day). Although the vitamin A intake was higher than the UL in the 1-3-year age group, it will not cause any adverse effects. Orange-fleshed sweet potato contains vitamin A in the form of PVA carotenoids. In the human body PVA carotenoids are converted to vitamin A as required, thus consuming foods that are high in PVA carotenoids will not cause toxicity (Mezzomo and Ferreira, 2016). The current study results are encouraging as it indicates that OFSP could possibly be used to reduce the VAD prevalence in children under the age of five years, investigated in this study.

As stated earlier, mineral deficiencies, especially iron and zinc deficiencies, are a serious health problem in SSA countries, including SA, but, unfortunately, they are often unnoticed and are not routinely treated. In the current study, the total mineral content (ash) of the individual curries (cabbage, chicken, and bambara groundnut, separately) was higher than that of PVA-biofortified *phutu*, which implies that the mineral content would be increased if either of the three curries were combined with PVA-biofortified *phutu.* Yet again, the curried chicken was the best option to improve the mineral content. Biofortified crops, if consumed in the correct quantities, could improve the micronutrient status of the affected communities (Govender et al., 2017). Unlike a study conducted by Pillay et al. (2013), which found that the concentration of iron was lower in PVA-biofortified maize than the white maize (Pillay et al., 2013), the current study found no significant difference in iron concentration between white maize and PVA-biofortified maize. Furthermore, the results of the current study indicate that there would be no benefit in replacing white *phutu* with PVA-biofortified *phutu* in the composite dishes, with respect to the iron and zinc concentration (Table 8.10). However, curried chicken had a higher iron content, thus implying that if it were consumed together with PVA-biofortified *phutu*, this could improve the iron intake of vulnerable populations. However, as mentioned earlier, chicken is unaffordable to many poor rural communities. Therefore, the more affordable combination of *phutu* and curried bambara groundnut could be an alternative to improving the protein and micronutrient content of human diets. However, it needs to be emphasised that there is an urgent need to test the consumer acceptability of this composite dish as it is not commonly consumed, especially in South Africa. Further studies should also investigate the effect of combining iron biofortified beans with PVA-biofortified *phutu*, on the iron concentration in composite dishes.

Although fibre and total mineral concentrations were higher in OFSP than CFSP, the protein content of the OFSP was lower (Table 8.5). The OFSP used in this study was higher in iron (2.55 mg/100g) but lower in zinc (0.45 mg/100g), compared to the CFSP (2.25 mg/100g; 1.30 mg/100g, respectively) (Table 8.11). The results suggest that the OFSP could be used to improve the iron content of dishes in which sweet potato is a major ingredient, and, thereby, contribute to the alleviation of iron deficiency among target communities. The OFSP could be composited with locally available, affordable food item/s rich in zinc, to simultaneously address zinc deficiency.

Although, the protein content of the OFSP used in this study was lower than that of the CFSP, it was higher than the values reported by Sanoussi et al. (2016), who found that the protein content ranged from 2.03-4.19 g/100 g, DW in pale-dark orange sweet potato (Sanoussi et al., 2016). The results of the current study and previous studies indicate that OFSP generally has a low protein content, and there is a need to develop the OFSP further to increase its protein content. Despite its low overall protein content, the concentration of the essential amino acid lysine was higher in OFSP than in the CFSP (Table 8.8). The consumption of OFSP could contribute to improving the fibre and iron content in the diets of vulnerable individuals. It is noteworthy that the current study did not investigate the nutritional composition of composite dishes comprised of OFSP and other locally available, affordable food items. Furthermore, consumer acceptability of OFSP should be investigated and, if necessary, improved to ensure that OFSP would be consumed by the target population groups.

This study investigated the effect of replacing white maize and CFSP with PVA-biofortified maize and OFSP on the nutritional composition of traditional dishes. With respect to the protein and lysine concentration, the results of the current study indicate that there would not be an advantage in replacing white maize with PVA-biofortified maize (Table 8.4). This result is obviously because the protein content in white maize was not significantly different from PVA-biofortified maize. In contrast, Pillay et al. (2013) found that PVA-biofortified maize had a higher protein concentration than white maize, whereas Oluba and Oredokun-Lache (2018) found that white maize had a significantly higher protein value than PVA-biofortified maize. The reason for the differences seen in protein concentration could be attributed to genetic and/or environmental factors (Nhamo et al., 2019). However, this study did not develop PVA-biofortified maize to improve the protein content, but focused on whether the PVA carotenoid and micronutrient content would be increased. This was the reason why the results also indicated that PVA-biofortified maize had a similar lysine concentration to white maize (Table 8.7).

The protein content of dishes containing PVA-biofortified maize could be increased by combining the biofortified maize with protein-rich food items. For example, in the current study, when PVA-biofortified *phutu* was combined with curried chicken, the composite dish had a higher protein content compared to the PVA-biofortified *phutu* alone. This was expected, because, generally an animal food product such as chicken contains a higher protein content and quality than plant products. This is confirmed by the results of the current study, where the curried chicken had a higher lysine content than all three plant products, PVA-biofortified *phutu,* curried cabbage, and curried bambara groundnut. Thus, combining PVA-biofortified *phutu* with curried chicken would result in an improved protein content of the composite dish. However, the challenge is that chicken is not affordable to a large proportion of population groups in SA, especially those living in rural areas of KZN, where poverty and food insecurity are prevalent (Argent et al., 2009; StatsSA, 2017; NAMC, 2019). Although the protein concentration of the two composite dishes, PVA-biofortified *phutu* and curried cabbage, and PVA-biofortified *phutu* and curried bambara groundnut were not significantly different (Table 8.4), the protein concentration of the composite dish containing curried bambara groundnut was higher numerically.

It is well known that legumes generally contain higher concentrations of protein than leafy vegetables (Maphosa and Jideani, 2017). Furthermore, legumes contain adequate concentrations of lysine and tryptophan, whereas cereal grains contain an adequate concentration of methionine, but lysine and tryptophan are limiting (FAO, 1992). Combining maize with a food item that is higher in lysine and tryptophan would improve the protein quality of the diet (Sizer and Whitney, 2017). The deviation from the norm observed in this study could be attributed to the statistically small sample size. Therefore, it is still recommended that PVA-biofortified *phutu* should be combined with curried bambara groundnut rather than curried cabbage to improve the lysine concentration, thus improving the overall protein quality of the composite dish. Composite dishes with an improved protein content would be highly beneficial, especially to individuals that suffer from protein-energy malnutrition (PEM). This condition is caused predominately by a deficiency in protein and energy and leads to several serious health conditions (Sizer and Whitney, 2017). Providing an affordable composite dish that combines PVA-biofortified *phutu* and curried bambara groundnut would not only contribute to reducing VAD, but also PEM. The main challenge with incorporating bambara groundnut into the diet of vulnerable groups is that this legume is not a common food source in South Africa (Oyeyinka et al., 2017). It seems there are no published studies on the consumer acceptability of composite dishes in which PVA-biofortified *phutu* is combined with other food items such as cabbage and bambara groundnut. Thus, further investigation of consumer acceptability of these composite dishes is required.

8.5 Conclusions

The introduction of biofortified crops could provide nutritious, affordable food sources whose consumption would contribute significantly to improving the vitamin A status of vulnerable population groups. The biofortified crops could be composited with underutilised nutrient-dense indigenous crops, such as bambara groundnut, to further fortify the dishes with essential nutrients and protein. The present study indicated that replacing white maize with PVA-biofortified maize in all the three composite dishes studied, resulted in an improved PVA carotenoid content. Although the PVA-biofortified *phutu* and curried chicken was the ideal composite dish for improving the PVA carotenoid content and protein quality, the composite dish containing PVA-biofortified *phutu* and curried bambara groundnut would be a more affordable alternative. It also has a high PVA carotenoid content and would have both high protein quality and content, due to the complementary protein concept. There was no significant difference in the iron and zinc concentration of all the three composite dishes containing PVA-biofortified *phutu*. The results further indicated that bambara groundnut would be a suitable alternative food source for compositing with provitamin A (PVA)-biofortified maize, to improve the nutritional value of the traditional dishes that normally contain white maize as the main ingredient. However, further studies need to be conducted using different varieties of PVA-biofortified maize in order to determine the usual portion sizes of composite dishes that would meet the EAR for vitamin A for children under five years of age. Furthermore, consumer acceptability of the composite dishes containing bambara groundnut should be investigated further, as the legume is not familiar to most South Africans.

The OFSP had high PVA carotenoid, fibre and iron concentration and a lower protein concentration, compared to the CFSP. The usual portion size of OFSP met approximately three times the EAR for vitamin A in both age groups. It is evident that OFSP has the potential to improve the vitamin A status of VAD-vulnerable population groups in SA if consumed with another food item, especially a protein-rich food. Such a composite dish could contribute to combating both VAD and malnutrition.

Overall, the findings of the current study have indicated that PVA-biofortified *phutu*, when combined with other foods, such as curried cabbage, chicken or bambara groundnut as well as OFSP, have the potential to improve nutrient intake and dietary diversity of rural population groups in KZN and other rural areas of South Africa. The proposed composite foods (PVA-biofortified *phutu* with either curried cabbage, chicken or bambara groundnut) would be new to the target population groups. As such it is not known whether they would be acceptable to the consumers. Therefore, future studies should investigate the consumer acceptability and perceptions of combining PVA-biofortified *phutu* with either curried cabbage, chicken and bambara groundnut and OFSP in traditional dishes.

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CHAPTER 9

ACCEPTANCE OF TRADITIONAL DISHES MADE WITH PROVITAMIN A-BIOFORTIFIED MAIZE AND ORANGE-FLESHED SWEET POTATO IN KWAZULU-NATAL

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9.1 Introduction

Worldwide, VAD is a serious health problem affecting children and pregnant women (WHO, 2019), and is particularly prevalent among countries (including SA) in developing regions, especially SSA (Ramakrishnan, 2002; Smuts et al., 2005; Bain et al., 2013). In SA, national studies showed that between 1994 and 2005, the VAD situation among children had worsened. The prevalence increased from 33.3% in 1994 to 63.6% in 2005 (Labadarios and Van Middelkoop, 1995; Labadarios et al., 2008). Additionally, the 2005 National Food Consumption Survey-Fortification baseline (NFCS-FB) study reported that two in three women had VAD in SA and six in ten women living in KZN had VAD. Overall, KZN had the second highest prevalence of VAD (Labadarios and Van Middelkoop, 1995; Labadarios et al., 2000; Labadarios et al., 2008).

The more recent 2012 South African National Health and Nutrition Examination Survey (SANHANES-1) study found that VAD in children was still significantly high (43.6%) (Shisana et al., 2013). The 2012 SANHANES-1 study further reported that 45.5% of rural South Africans had VAD, and individuals with the lowest education levels were the most affected by VAD (Shisana et al., 2013). It is important to try to improve the vitamin A status of South Africans, especially children and vulnerable groups such as pregnant women, as vitamin A is an essential micronutrient that has several physiological roles including immunity, vision and protein synthesis (Webb and Whitney, 2017). Vitamin A deficiency can result in an increased risk of mortality due to infections, thus emphasising the need to improve the vitamin A status of vulnerable groups (UNICEF, 2019).

One of the leading factors contributing to VAD is household food and nutrition insecurity (Pinstrup-Andersen, 2009). In comparison to other regions in the world, Africa has the highest level of moderate (30%) and severe food insecurity (20%) (Development Initiatives, 2017). Poor access to food, an element of food insecurity, is a common problem in SA, where 21.3% of households have severely inadequate or inadequate food access (StatsSA, 2017a; StatsSA, 2018). Although the general household survey (GHS) conducted in SA in 2017 showed a 1% decrease in the number of individuals with inadequate or severely inadequate access to food in comparison to the 2016 GHS (StatsSA, 2017a; StatsSA, 2018), micronutrient malnutrition remains a challenge. Suboptimal utilisation of available and accessible food is another dominant element of food insecurity in Africa. In SA, access to and utilisation of nutritious foods are a major problem, especially among impoverished individuals (Altman et al., 2009; StatsSA, 2018). The consumption of nutritious foods promotes human development and enables an individual to perform the basic tasks needed for survival (Kolahdooz et al., 2013). The South African government has implemented a number of strategies to reduce micronutrient deficiencies. These strategies include supplementation, food fortification and dietary diversity. Despite the implementation of these strategies, there has been no significant improvement in the vitamin A status of the South African population (Labadarios et al., 2000; DoH and UNICEF, 2007; Swart et al., 2008; DoH, 2018). This emphasises the need for a complementary strategy such as biofortification to address VAD (Bouis and Saltzman, 2017).

White maize and CFSP are two commonly grown and consumed staple crops in SA (DAFF, 2017; Low et al., 2017), and are therefore ideal for PVA-biofortification (Mitra, 2012; Low et al., 2017; DAFF, 2017). Three crops have been identified for PVA-biofortification in Africa by HarvestPlus, namely cassava (*Manihot esculenta),* maize (*Zea mays*) and sweet potato (*Ipomoea batatas*) (HarvestPlus, 2018). However, a number of studies conducted in Zambia, SA, Kenya and Ghana found that there were challenges with consumer acceptability of biofortified crops (De Groote and Kimenju, 2008; De Groote et al., 2010; De Groote et al., 2011; Pillay et al., 2011; Nuss et al., 2012). The poor acceptability of PVA-biofortified crops found in some studies may be attributed to the yellow/orange colour exhibited by carotenoid pigments found in the crops and the strong aroma and flavour of the biofortified crops, also attributed to the carotenoid pigments (Nuss and Tanumihardjo, 2010; Chapman, 2012). In addition, several studies have found that a stigma attached to the consumption of PVA-biofortified maize has negatively affected consumer acceptance of the biofortified maize crops (De Groote and Kimenju, 2008; De Groote et al., 2010; De Groote et al., 2011; Nuss et al., 2012). There are a number of factors that impact on the consumer acceptability of PVA-biofortified crops, such as gender, income, education, ethnicity, geographical location and background (Khumalo et al., 2011). Additionally, Pillay et al. (2011), found that the acceptability of PVA-biofortified maize varied with food type, which suggested that the acceptability of the biofortified maize could be improved by processing it into suitable food types (Pillay et al., 2011).

Combining PVA-biofortified crops with other commonly consumed plant and animal food sources, could mask any undesirable sensory properties associated with biofortified crops and thereby increase their acceptability. For example, a study conducted by Amod et al. (2016), found that when PVA-biofortified *phutu* was combined with chicken stew, its acceptability increased (Amod et al., 2016). Additionally, PVA-biofortified composite dishes could improve the nutritional intake of vulnerable individuals (Govender et al., 2019). A major problem in SA is poverty; it is a leading cause of food and nutrition insecurity (Govender et al., 2016). Currently, in 2019, a basic food basket in SA costs about R883.16/month which is a 3% increase from 2018 (NAMC, 2019). This rise in food prices makes animal food sources unaffordable to VAD-vulnerable population groups, who are predominantly of low socioeconomic status. Thus, suitable food items should be sought from among the more affordable plant products for combining with PVA-biofortified foods to improve their acceptability.

Plant products have also risen in price, but are generally cheaper than animal products (NAMC, 2018). The most commonly consumed plant-based foods in SA are maize (milled into maize meal) and green leafy vegetables (Modi et al., 2006; Lewu and Mavengahama, 2011). In the KZN province, maize (cooked maize meal) and legumes are leading (Labadarios et al., 2000; Faber et al., 2013). Legumes could be suitable for combining with PVA-biofortified maize because they are rich in several nutrients, including protein (Huma et al., 2008). Starch-based cereal crops such as maize have limited amounts of lysine and tryptophan (Serna-Saldivar, 2010, p98). Lysine and tryptophan are also essential amino acids. Lysine is required for the synthesis of peptide-hormones, antibodies, enzymes and muscle mass, whereas tryptophan is needed as it is a precursor for niacin, nicotinamide and serotonin (Serna-Saldivar, 2010, p94). Legumes generally contain higher amounts of lysine and tryptophan and have a lower content of sulfur-containing amino acids, especially methionine (Serna-Saldivar, 2010, p580). Thus, the consumption of a starch-based food such as maize together with a legume such as bambara groundnut would result in a balanced amino acid profile (Linnemann and Azam-Ali, 1993; Mwale et al., 2007; Lichtfouse, 2016).

Bambara groundnut is an indigenous crop in Africa. It is well-adapted to and thrives in the agronomical marginal regions (Chibarabada et al., 2017), where a significant proportion of vulnerable population groups live in SSA countries, including SA (Labadarios et al., 2000; Labadarios et al., 2007; Bain et al., 2013; Shisana et al., 2013). Unlike other legumes, bambara groundnut contains the essential amino acid methionine (Mwale et al., 2008; Stone et al., 2011). Furthermore, bambara groundnut has been found to have high levels of essential fatty acids, vitamins and minerals (Adeleke et al., 2018). Unfortunately, despite the fact that bambara groundnut is nutrient-dense, it is generally underutilised as a food source in SSA due to several factors (Bogart et al., 2012). Bambara groundnut has hard-to-cook and hard-to-mill properties and exhibits antinutritional properties, a bitter taste and a strong beany flavour, which contribute to its limited utilisation as a food source (Uvere et al., 1999; Boye et al., 2010; Ndidi et al., 2014). In SA, another factor limiting the acceptability of bambara groundnut is the fact that South Africans are generally not accustomed to it (Oyeyinka et al., 2017). Although underutilised, a few studies have shown that bambara groundnut when prepared in some food types, was positively accepted by consumers (Okafor et al., 2015; Oyeyinka et al., 2017; Oyeyinka et al., 2018). Further, heat processing methods such as roasting have been found to improve the taste and protein quality of bambara groundnut (Okafor et al., 2015).

Unlike biofortified maize, for which mixed responses in consumer acceptability have been found, OFSP seems acceptable to consumers in SA, although data on its acceptability to different population groups are limited (Tomlins et al., 2007; Low and Van Jaarsveld, 2008; Khumalo et al., 2011; Chowdhury et al., 2011; Laurie and Van Heerden, 2012; Pillay et al., 2018). With regard to specific rural population groups in the KZN province of SA, only one study has been conducted to assess consumer acceptance of PVA-biofortified maize foods served with other commonly consumed food items (Amod et al., 2016). Similarly, there are limited reports of consumer acceptability of OFSP in KZN. Thus, this study aimed to investigate the effect of replacing white maize and CFSP with PVA-biofortified maize and OFSP, respectively, on consumer acceptability and perceptions of traditional dishes of selected rural communities in KZN, SA.

9.2 Methodology

9.2.1 Study population and sample selection

For the first phase of the study, systematic randomised sampling was used to obtain a sample of 50 households at Swayimane, Tugela Ferry and Umbumbulu and 21 households at Fountain Hill Estate. Purposive sampling was used to select households from Swayimane, Umbumbulu and Tugela Ferry in order to avoid collecting data from extended families and neighbouring households. From each of the households, one person was selected to answer the survey questions. This person was either the head of the household or the person responsible for purchasing the groceries. Pilot study participants were excluded from the study (this is discussed further in section 9.2.6).

One hundred and twenty black African participants living in two selected rural areas (60 participants each from Swayimane and Umbumbulu) were recruited for the study. Black

African participants were selected for this study, as they are at high risk for malnutrition (Shisana et al., 2013; nDoH et al., 2017). Furthermore, 120 participants were selected as this number falls between 75-150 participants, which is the total recommended size to obtain a significant result for a sensory evaluation (Lawless and Heymann, 2010; Stone, 2018). Focus group participants were recruited on a voluntary basis from the sensory evaluation panel. Thirty participants from each of the research sites were randomly selected from the sensory evaluation participants. Each participant had a participant number which was put into a box when they volunteered. Thirty numbers were randomly selected from the box and those participants were selected to participate in the FGDs. This procedure was followed for Swayimane. All volunteers (n=26) from Umbumbulu participated in the FGDs. The second phase of the study was conducted at Gcumisa tribal hall in Swayimane and at Ezimiwini community hall in Umbumbulu.

9.2.2 Survey on the consumption of white maize[30]

Survey questions were formulated in English (Supplementary Information Appendix Q1) to determine the consumption patterns of white and PVA-biofortified maize and CFSP. The questions that were formulated were based on the information that the researcher needed to collect. The questions were structured and simple. This survey was translated into isiZulu by a research assistant who was fluent in isiZulu (see Supplementary Information Appendix Q2). The survey took the form of an interview survey, and only one survey was completed for each household, by a research assistant. Questions 1-5 in the survey focused on the consumption and production of white maize, question six focused on yellow maize consumption and question seven focused on the consumption and production of CFSP.

Participants were asked to provide the research assistants with a list of foods that were commonly consumed with the cooked white maize meal, as well as the corresponding recipes. The foods most regularly eaten with cooked white maize meal are presented in Table 9.1. The participants provided the research assistant with recipes that were used to cook the maize dishes and the composite food dishes.

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[30] Survey results were presented under study methods and materials to enlighten the reader about why maize, sweet potato, cabbage, bambara groundnut and chicken were selected for the study.

Table 9.1: Food items commonly paired with cooked maize meal

Food item	n (%)*
Beef	85 (51.5)
Chicken	69 (41.8)
Green leafy vegetables	58 (35.2)
Cabbage	51(30.9)
Potatoes	28 (17)

*Percentage of households (n=165 households)

Recipes were collected from all 165 households. *Phutu*, sweet potato and curried cabbage were prepared the same in all recipes collected. Curried beef and chicken were prepared the same in most of the recipes collected. The only variations that were noted were with the flavour of stock cubes used, the addition of beans to either curry or the addition of mixed vegetables. The curried bean was cooked similarly by all households, however, a few households added raw tomato. The recipes that were finally used in the study were those that were prepared by the majority of the study participants. After the recipes were selected, they were standardised. Popular food combinations were identified from the answers to the survey questions and the relevant recipes were obtained. Participants (n=57 households) selected the food combinations they preferred. Figure 9.2 and Figure 9.3 indicate the food items that study participants consumed with either *phutu* or stiff pap (a stiff porridge made from maize meal). The least preferred meat composite dish was stiff pap and cooked fish in tomato chutney.[31] The most preferred meat composite dishes were *phutu* with curried beef and stiff pap with curried beef. However, standardised recipes were not formulated for these combinations as beef is not regularly consumed, as it is expensive. Therefore, chicken was selected for this study. The most preferred vegetarian options were *phutu* with curried cabbage and stiff pap with curried cabbage.

[31] Tomato chutney is cooked following a traditional recipe with oil, onions, tomatoes, water, salt and Raja curry powder spice. It is eaten alone or with another food item such as cooked fish.

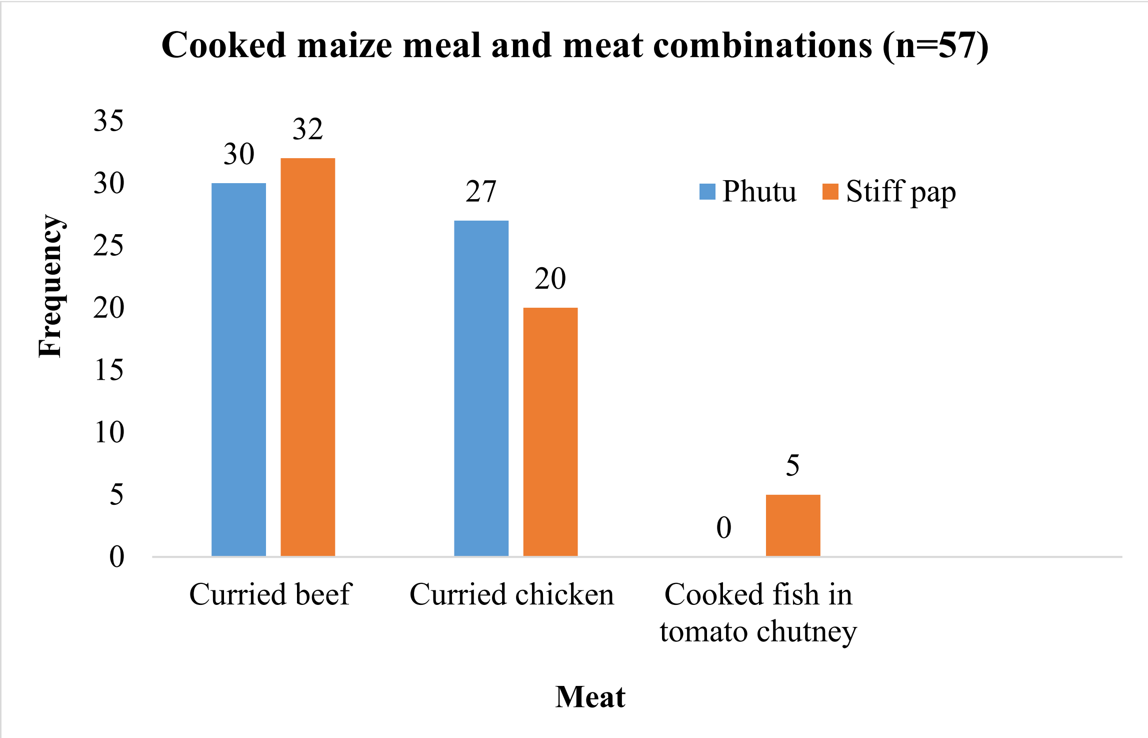


Figure 9.1: Participants preference for cooked white maize meal dishes and meat composite dishes

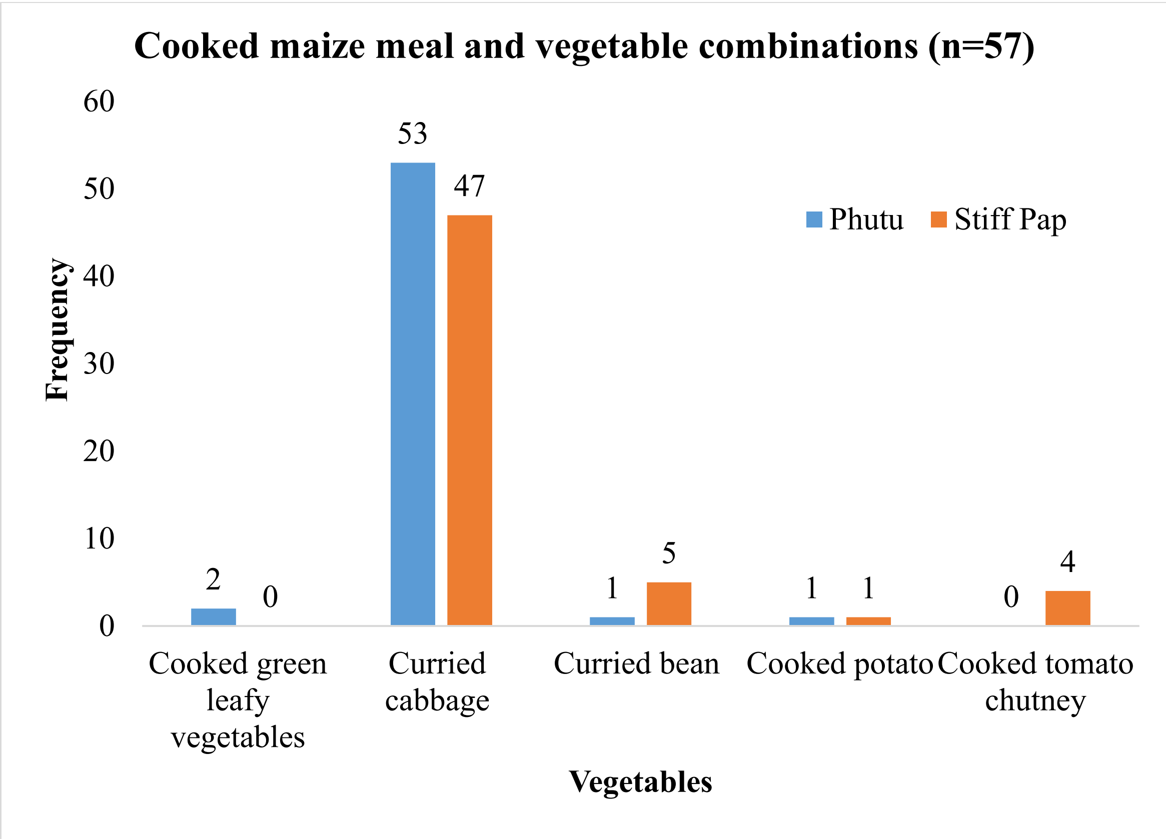


Figure 9.2: Participants preference for cooked white maize meal dishes and vegetable composite dishes

For the purpose of this study, *phutu* was selected as the cooked maize meal dish. Curried cabbage was selected as the vegetarian dish, while curried chicken was the selected meat dish. Curried chicken was selected for this study as it is a cheaper alternative to beef. Although the study participants preferred curried beef, they did not consume it frequently, as it is expensive. Many rural individuals rely solely on government grants (child support grant, old age grant, disability grant and care dependency grant) to purchase food items and cannot always afford animal sources of protein (StatsSA, 2017b; South African Social Security Agency, 2018; NAMC, 2018). Bambara groundnut was also selected for this study as it is an indigenous legume that can be used as an alternative to animal protein. Not only is it a good source of protein, but also contains carbohydrates, minerals and vitamins (Huma et al., 2008). Although bambara groundnut is grown in certain areas of KZN, it is underutilised (Chivenge et al., 2015; Agriculture, Forestry and Fisheries, 2016). Thus, bambara groundnut could provide a nutritious alternative to animal protein, if deemed acceptable to impoverished communities in rural KZN.

9.2.3 Plant materials

A PVA-biofortified maize type (PVA A) and a white maize variety (control) (WE-3172) were selected for the study. The provitamin A-biofortified maize coded PVA A is an experimental type; it has not been commercialised and hence does not have a variety name. The maize grain was produced by plant breeders from UKZN and milled into maize for this study, using methods described in chapter 8. Two varieties of sweet potato were selected for this study, OFSP (A45) and CFSP (A40). The bambara groundnut landrace was purchased from Umvoti beans in Moollas industrial township Stanger and cabbage was purchased from a local (Pietermaritzburg) supermarket for the study.

9.2.4 Sensory evaluation

9.2.4.1 Panellists

A total of 120 black African adults comprising of males and females were randomly selected from Swayimane and Umbumbulu rural areas of KZN to participate in sensory evaluation of the study food samples. One hundred and twenty participants were recruited as this number falls between 75-150 participants, which is the total recommended size to obtain a significant result for a sensory evaluation (Lawless and Heymann, 2010; Stone, 2018). Research assistants went to different areas within Swayimane and Umbumbulu to recruit participants. Participation was voluntary and panellists were allowed to leave the study at any point if they so wished. Research assistants fluent in isiZulu were recruited from UKZN and trained prior to data collection. The research assistants were postgraduate students and were trained on how to complete the consent forms, sensory evaluation and paired preference test data collection sheets. They were also trained on the procedure to be followed during data collection. An English version of the consent form was available but was not used by any of the participants (Supplementary Information Appendix S1). A research assistant explained the isiZulu version of the consent form (Supplementary Information Appendix S2) to each participant in isiZulu so that it could be better understood and issued a participant number to each participant. IsiZulu was the selected language as it is the local language spoken by the study participants. The participant number was given to maintain anonymity and for the research assistants to issue the correct sensory evaluation sheet to each participant. Research assistants asked the volunteers if anyone had participated in the pilot study the previous week and if they had, they were excluded from the study. It was assumed that everyone answered the question honestly. Additionally, a local member of the community was also present at the main study to identify participants that had participated in the pilot study. If any pilot study participants were identified, they were excluded from the study.

9.2.4.2 Preparation of food samples

All food dishes were prepared each morning during the sensory evaluation data collection in the Food Processing Laboratory in the Human Nutrition and Dietetics Department at UKZN, Pietermaritzburg. A black African woman (Figure 9.3) was recruited from a rural area in the UMgungundlovu District, KZN with appropriate cooking experience to cook *phutu*, curried cabbage, curried chicken, curried bambara groundnut and the sweet potato. This ensured that the food items prepared were culturally acceptable to participants as it was prepared by someone residing in one of the study sites with experience in cooking traditional dishes.

Figure 9.3: Cooking of food dishes by an experienced cook

The food products were not made at the research sites, as there were no cooking facilities available. The cooked food samples were transported in insulating plastic containers closed with tight-fitting lids. Prior to this study, surveys were conducted to determine the commonly consumed food combinations and recipes were collected. Foods were prepared over two trial sessions a week prior to the pilot study to ensure that the recipes were accurate and culturally acceptable. These recipes were standardised for *phutu* (Supplementary Information Appendix L), curried cabbage (Supplementary Information Appendix M), curried chicken (Supplementary Information Appendix N), curried bambara groundnut (Supplementary Information Appendix O) and sweet potato (Supplementary Information Appendix P). The curried bambara groundnut was cooked in the same manner as the curried bean (Supplementary Information Appendix R); however, extra water was added during the cooking process, and more time was needed to cook the curried bambara groundnut. This was due to the hard-to-cook properties of bambara groundnut (Mubaiwa et al., 2017). The food dishes were tasted by four black African males and seven black African females working at UKZN, who had a similar sociodemographic profile to the study participants to test for cultural acceptability. The UKZN workers gave their consent to taste the dishes. The tasting was conducted during the trial cooking. The UKZN workers perceived the dishes as culturally acceptable. The pilot study was conducted after the trial cooking session and is discussed in section 9.2.6. Although the UKZN workers were from similar areas as used in the main study, they would be at work during data collection, thus preventing them from participating in the main study. Table 9.2 gives a summary of the preparation methods of food items used in the current study.

Table 9.2: Preparation methods for food items used in the study

Food item	Description
White maize *phutu* (control)	A popular crumbly maize porridge and traditional maize food product consumed in KZN.
PVA maize *phutu* (test sample)	Crumbly maize porridge made with PVA maize in place of white maize.
CFSP (control)	The traditional, popular CFSP was boiled until soft as is commonly done by the studied communities.
OFSP (test sample)	The traditional, popular CFSP was replaced by the OFSP, which was boiled in the same manner as the CFSP.
Curried cabbage	Cooked following a traditional recipe obtained from study participants, with oil, Raja curry powder (It is a spice comprising of coriander, turmeric, garlic, Bengal gram, chilli, yellow mustard, fenugreek, bay leaves, cassia, fennel and salt and cumin), onions, shredded cabbage, water, salt and a stock cube.
Curried chicken	Cooked following a traditional recipe obtained from study participants with oil, Raja curry powder, onions, cut chicken pieces, water, salt and two stock cubes.
Curried bambara groundnut	Cooked following a modified traditional recipe obtained from study participants for curried dry bean, which was prepared with oil, Raja curry powder, onions, bambara groundnut (soaked overnight), water, salt, bicarbonate of soda and a stock cube.

PVA: provitamin A; CFSP: creamed-fleshed sweet potato; OFSP: orange-fleshed sweet potato.

9.2.4.3 Sample coding, serving order and sensory evaluation set up

Each of the food combinations was assigned a unique three-digit code obtained from a Table of Random Numbers (Heymann, 1995). The three-digit codes were known to the researcher, but not to the panellists, to prevent bias. The serving order of the food samples was determined by a Table of Random Permutations of Nine (Heymann, 1995). Each sample was carefully dished out so there was uniformity with portion size and appearance. Lawless and Heymann (2010) reported that there are different variables to consider when deciding on a suitable food sample size. The researcher should consider the number of samples tested, what the mouthful of the specific product is, and what the study is trying to evaluate (Lawless and Heymann, 2010). The quantities selected for the samples were based on the fact that taste and texture were the only attributes that required tasting in order to rate it. The other attributes relied on other senses such as sight and smell. Each participant received ±75 ml of white and PVA *phutu,* separately with ±75 ml of curried cabbage, ±75 ml of white and PVA *phutu,* separately with ±75 ml curried chicken and ±75 ml of white and PVA *phutu*, separately with ±75 ml of curried bambara groundnut. Participants were also given a quarter piece (±25g) of sweet potato in a 250 ml polystyrene cup, separately.

Additionally, the paired preference test also required participants to taste and compare the samples. The food sample quantities were tested at the pilot study to determine if the participants required more of either food item to evaluate the dishes. Thereafter, the quantity was selected for the main study. At the pilot study, the participants received ±30 ml of white *phutu* and each of the curries and ±30 ml of PVA-biofortified *phutu* and each of the curries. This was not enough for testing, thus the quantity was increased for the main study. The samples were warmed for ten seconds in a microwave prior to being served to ensure that it was warm before being served to each participant. The ideal temperature was determined during the pilot study. This was done to ensure that the samples were not cold, as cold samples could negatively affect the outcome of the sensory evaluation (Bajec et al., 2012).

Panellists were randomly selected and given a consent form in isiZulu (Appendix S2 Supplementary Information) to sign after the contents were explained. Thereafter, the panellists were escorted to their sensory evaluation station by the research assistant. Panellists were told not to communicate with one another during the sensory evaluation. A separating board divided the panellists (Figure 9.4) so that they could not communicate with each other during the sensory evaluation session.

Figure 9.4: Sensory evaluation set-up

Each panellist was provided with a pen, a cup of water to rinse the palate between samples and sensory evaluation questionnaires [five-point hedonic facial scale (Appendix T1 Supplementary Information) and paired preference test (Appendix T2 Supplementary Information) developed in isiZulu, the local language in KZN. The English versions of the sensory evaluation questionnaires [five-point hedonic facial scale (Appendix T3 Supplementary Information) and paired preference test (Appendix T4 Supplementary Information) were translated into isiZulu, and then back to English by two separate translators proficient in both languages, to ensure that the translation was accurate. The English version was not used by participants. The five-point hedonic facial scale (1=very bad; 5=very good) was used so that the semi-literate/illiterate participants could record their responses.

The five-point hedonic facial scale tested the sensory attributes (taste, texture, aroma, colour and overall acceptability) of six maize combination food samples (white *phutu* and curried cabbage; PVA-biofortified *phutu* and curried cabbage; white *phutu* and curried chicken; PVA-biofortified *phutu* and curried chicken; white *phutu* and curried bambara groundnut; PVA-biofortified *phutu* and curried bambara groundnut). The same scale was used to test the sensory attributes of two sweet potato samples (boiled CFSP and boiled OFSP).

The maximum number of samples that should be tasted at one point in time is six for a full description sensory analysis. However, if a researcher is testing less than 10 sensory attributes, a maximum of 10 samples may be tasted (Kemp et al., 2018). For the purpose of the study, the six maize samples were tasted first and thereafter the two sweet potato dishes. One sample was given to the participant at a time.

Participants were required to put a cross over the face that they felt best described the attributes of the sample that was tasted. The research assistant explained each sensory attribute to the participant before the samples were evaluated so that the participant knew what was meant by each of the five attributes. Figure 9.5 illustrates an example of the five-point hedonic facial scale for the sensory attribute aroma that was used in this study.

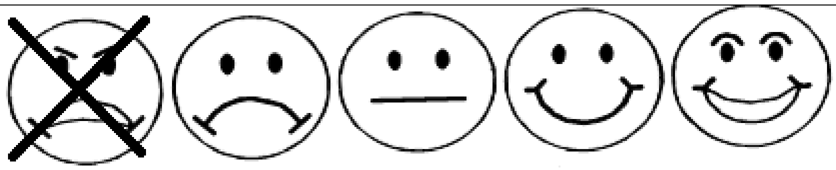
Aroma	 Very bad Average Good Very good

Figure 9.5: Example of the five-point hedonic scale for the sensory attribute aroma

The hedonic scale is a popular sensory evaluation tool that indicates the degree of likes and dislikes (Lim, 2011). The hedonic scale is best used when there are elderly participants or participants that have difficulty reading (Lawless and Heymann, 2010, p332). It is simple and does not involve any mathematical equations, thus it was selected for this study. Each panellist completed the paired preference test after tasting all eight-food samples. Samples of white *phutu* combinations were compared to PVA *phutu* combinations and CFSP was compared to OFSP.

The paired preference test helps to validate the results from the sensory evaluation using a five-point hedonic facial scale, which was done in this study (Lawless and Heymann, 2010).

The paired preference test is used to investigate the preference after tasting two products and adapted versions are simple to use for semi-literate/illiterate participants (Lawless and Heymann, 2010). The same three-digit code that was allocated to the two samples during the initial sensory evaluation using the five-point facial hedonic scale, was used in the paired preference test. The participant was requested to put a circle around the three-digit number on the questionnaire that corresponded to the three-digit number on the container of the sample that they preferred. The paired preference test conducted alone does not give a true reflection on whether or not a sample is liked, as both samples may be disliked, and one may be more preferred (Lawless and Heymann, 2010).

9.2.5 Focus group discussions

Fifty-six black African adults comprising of males and females from Swayimane and Umbumbulu were randomly selected from the sensory evaluation panel to participate in the FDGs. On completion of the sensory evaluation survey, FGD participants were recruited on a voluntary basis. The participants were then randomly selected in order to reduce bias that could be created when a participant is personally recruited (Krueger and Casey, 2009). Each participant had a participant number which was put into a box when they volunteered. Thirty numbers were randomly selected from the box and those participants were selected to participate in the FGDs. This procedure was followed for Swayimane. All volunteers (n=26) from Umbumbulu participated in the FGDs. A total of 56 participants from both areas agreed to participate in the FGDs. The participants were divided into five groups of between 7 and 10 participants each. This was decided as the ideal size for a focus group discussion is between 6 and 10 participants (Bogart et al., 2012; Tolley et al., 2016; Silverman, 2017). However, FGDs can have as little as four participants and as many as 12 participants (Krueger and Casey, 2009).

The FGDs were facilitated by two trained research assistants (one male and one female), who were fluent in isiZulu and had experience with conducting FGDs. The research assistants alternated facilitating the FGDs. The FGD questions were developed in advance from the themes that were identified. The FGD questions were first formulated in English by the researcher (Appendix U1 Supplementary Information) and then translated into isiZulu (Appendix U2 Supplementary Information) by two isiZulu speaking individuals. The FGD questions were checked by an individual with experience in working with FGDs. The FGD questions were tested on the four black African males and seven black African females working at UKZN that also tasted the samples for appropriateness. The UKZN workers gave consent before participating. The UKZN workers clearly understood the questions and were able to give feedback on the composite dishes and OFSP that they tasted. They perceived all food samples as culturally acceptable. The PVA-biofortified *phutu* and bambara groundnut composite dish was new to some of the UKZN workers, however, they enjoyed the taste. The most preferred composite dish was the PVA-biofortified *phutu* and curried chicken. The UKZN workers preferred the OFSP over the CFSP. Two research assistants were involved in the translation to ensure that the FGD questions were translated accurately into isiZulu and the intended questions were not lost in translation. No changes were made to the FGD questions prior to the pilot study and after the pilot study, as all participants understood the questions. A digital voice recorder was used to record the FDGs after all participants consented to the use of the voice recorder. The recordings were later translated into English by both focus group discussion facilitators. The translated recordings were cross-checked by an isiZulu speaking person against the English translation, for accuracy.

9.2.6 Pilot study

6.2.6.1 Survey results

A sample of 18 households was used for the survey pilot study to test the appropriateness of the questionnaires. This also allowed changes to be made before the main study was conducted. However, no changes were made to the survey questions as all the questions were understood by individuals representing each of the households. The survey was collected at two selected sites (Swayimane and Tugela Ferry). The households were purposively selected, thus the research assistants did not go back to the same households during the main data collection.

6.2.6.2 Sensory evaluation results

A pilot study of the sensory evaluation and FGDs were conducted at the Gcumisa tribal hall in Swayimane, KwaZulu-Natal, prior to the main study. This was one of the selected research sites for the main study. Ten black African participants comprising of four males and six females were randomly recruited from the Swayimane area, to participate in the pilot study. Ten participants were selected for the pilot study, as this is the lowest recommended number of participants that can be used in a sensory evaluation study, to obtain a statistically significant result (Stone, 2018).

The participants from the pilot study were not allowed to participate in the main study. To ensure this, the researcher randomly selected one participant from different areas of Swayimane. An English version of the consent form was available for participants if needed (Appendix S1 Supplementary Information). All participants signed consent forms in isiZulu (Appendix S2 Supplementary Information), before commencing with the study. Participants, who could not read due to low literacy levels or did not understand the data collection sheets, received a detailed explanation from the research assistants. Each participant was allocated a number from 1-10 to assist with identification and issuing of sensory evaluation sheets. This was done to protect the participant's identity.

Focus group discussions were conducted after the sensory evaluation using the sensory evaluation panellists. Four focus group discussion questions were developed in English (Appendix U1 Supplementary Information) and translated into isiZulu (Appendix U2 Supplementary Information). All 10 participants were invited to participate in the FGDs and included both males and females. Only one focus group session was conducted and was facilitated by a male assistant with experience in conducting focus group discussions.

The aims of the pilot study were as follows:

1. To determine if the standardised recipes that were developed after the first phase of the study were culturally acceptable.
2. To determine if the sensory evaluation questionnaires in isiZulu were user-friendly and understood by participants.
3. To finalise the methodology used for the sensory evaluation and the FGDs.
4. To determine if the research assistants were able to collect data efficiently and if they understood the process to be followed.

The outcomes of the pilot study were as follows:

1. The recipe used to cook the curried bambara groundnut was modified to ensure that it was acceptable to the study participants. The bambara groundnut took a longer period to cook and soften. Bambara groundnut was soaked overnight to reduce cooking time and 1 ml of bicarbonate of soda was added during cooking to reduce the hard-to-cook phenomenon and allow the bambara groundnut to soften. The addition of one teaspoon of bicarbonate of soda has been shown to soften legumes that have hard-to-cook properties (Polak et al., 2015). In this study, 1 ml of bicarbonate of soda was used to cook the bambara groundnut as no studies have been conducted on the maximum amount of bicarbonate of soda that can be added during cooking to soften it, without affecting the taste. The addition of 1 ml of bicarbonate of soda did not affect the taste of the cooked bambara groundnut. This was determined as the participants did not report any changes in taste.

2. The quantity of the samples issued for sensory evaluation was increased from 30 ml to 75 ml, as it was found that 30 ml each of food sample was insufficient for the sensory

evaluation. During the pilot study participants requested more of the sample to taste so that they could rate the sample. Thus, it was determined that 75 ml of each sample would be adequate to use for the sensory evaluation.

3. The research assistants needed to be trained after the pilot study to ensure that the correct procedures were followed and there was no confusion regarding the tasks that needed to be conducted by each research assistant. During the pilot study, the research assistants tried to assist each other with tasks and it became confusing. Each research assistant was allocated one specific task for the duration of the main study.

4. For the pilot study, a FGD was conducted by a male research assistant with experience in conducting FGDs. The group consisted of both males and females of varying age. Elderly female participants were not comfortable with expressing their views in the presence of male participants. The change made for the main study was that two research assistants (one male and one female) with experience with conducting FGDs, were used. The female research assistant conducted FGDs with female participants and the male research assistant conducted FGDs with the male participants.

5. Some female participants did not understand the contents of the consent form when it was explained to them as a group. For the main study, the consent form was explained in detail by the same research assistant to all participants individually, so that any queries could be addressed immediately.

9.2.7 Data quality control

Research assistants were responsible for inspecting all completed sensory evaluation and paired preference sheets to ensure that all the samples were tasted and rated. Data from the sensory evaluation and paired preference sheets were captured on a Microsoft Excel spreadsheet by research assistants. The data entry was cross-checked for accuracy by another research assistant.

9.2.8 Reduction of bias

During the preparation for the sensory evaluation, various steps were taken to reduce bias. All ingredients to be cooked were weighed using a calibrated scale. The same brands of ingredients were used to cook the composite dishes and the same measuring cup, measuring jug and measuring spoons were used to measure the ingredients. Insulated airtight containers were used for the transportation of food products. All participants were served the same amount of samples using measuring spoons in a 250 ml polystyrene container. All food products were warmed before testing in a microwave for ten seconds. This was done as cold samples could negatively affect the rating of the samples during the sensory evaluation (Bajec et al., 2012). All samples were clearly labelled using a permanent marker on one side of the 250 ml polystyrene container. The serving order was randomised using a Table of Random Permutations of Nine (Heymann, 1995). For the FGDs, the same questions were asked to the FGD participants in the same order and participants were randomly selected from those that volunteered to participate in the FGDs.

9.2.9 Statistical analysis

Data from the sensory evaluation questionnaires were analysed using the Statistical Package for Social Sciences (SPSS) (version 25.0 SPSS Inc, Chicago, IL, USA) at the 5% level of significance. The Friedman's test, a nonparametric statistical test was used to test for significant differences in sensory attributes across the *phutu* combinations. The specific differences were then analysed using the Wilcoxon test for the *phutu* combinations and two varieties of sweet potato. The independent samples t-test was used to determine significant differences across gender for the average sensory attributes of the food samples. Analysis of variance (ANOVA) was used to determine significant differences between different age groups for the sensory attributes for all food samples. The Welch test was used when conditions for the ANOVA test were not met. The paired preference results were analysed using a Pearson chi-square test. The responses from the FGDs were subjected to thematic content analysis. Thematic analysis is a method used to identify patterns or themes that are related to the research question (Barbour, 2018, p124, 125). This process does not just entail summarising the main points but interpreting the content into a meaningful output (Barbour, 2018, p125). Verbatim comments from the FGDs were extracted from the voice recorder and translated from isiZulu into English. Data from the FGDs and the notes were coded. Similar coded ideas were then arranged into appropriate themes. Thereafter, a discussion was written for each theme to interpret the results from the FGDs.

9.2.10 Ethical considerations

Ethical approval was obtained from the UKZN, Humanities and Social Science Ethics Committee (HSS/0256/016D). Gatekeeper's permission was obtained to conduct the study at the Swayimane, Tugela Ferry, Umbumbulu and Fountain Hill Estate. Each panellist was required to sign a consent form before participating in the sensory evaluation. The consent form was available in English (Appendix S1 Supplementary Information) and isiZulu (Appendix S2 Supplementary Information). The consent form was read to the participants in isiZulu so that all participants understood the contents of the consent form. All participants were able to sign the consent form. The participants were shown where to sign on the consent form if they understood what was explained. If they did not understand something, it was re-explained and they signed once they understood. The consent form also allowed participants to grant permission to be photographed and audio and video recorded.

9.3 Results

9.3.1 Survey

Results from the survey indicated that all 165 households consumed meals made with cooked white maize meal. Sixty-one percent of the participants (n=100) reported that they had consumed cooked maize meal in different forms, several times a week. Table 9.3 indicates the different forms of food prepared using white maize meal. White maize meal was most commonly prepared as *phutu* (84.8%; n=140) by the study participants.

Table 9.3: Various forms of cooked white maize meal (n=165 households)

Name of dish	Description	n (%)
Amaheu	Fermented porridge made from maize meal (cold)	27 (16.4%)
Incwancwa	Fermented soft porridge made from maize meal (liquid)	4 (2.4%)
Isicukwane	Maize meal cooked into a soft porridge with lemon juice added	4 (2.4%)
Isigwamba	Spinach and maize meal cooked together	4 (2.4%)
Isigwaqane	Beans and maize meal cooked together	38 (23.0%)
Isijingi	Butternut and maize meal cooked together to form a soft porridge	37 (22.4%)
Mealie meal porridge	Soft porridge made with maize meal	107 (64.8%)
Phutu	Maize meal cooked into a crumbly porridge	140 (84.8%)
Steamed bread	A type of bread made with maize meal and prepared by steaming	7 (4.2%)
Stiff pap	Maize meal cooked into a stiff porridge	70 (42.4%)

Seventy-five (66.4%), thirty-nine (34.5%), thirty-two (28.3%) and six (5.3%) of the study participants reported that they produced white maize meal for use as food, for an animal feed, for selling and from remnant seeds, respectively. The majority of the participants purchased their seeds from McDonalds seeds[32] (23.9%; n=26) and Madiba store[4] (21.1%; n=23) (Table 9.4).

Table 9.4: Source of white maize seeds (n=109 households)

Source	**n (%)**
Checkers	2 (1.8)
Dalton seed company	2 (1.8)
Donation	5 (4.6)
KaMfundisi Esphingo	2 (1.8)
Khwezi	2 (1.8)
Ladysmith	3 (2.8)
Local grocery store	7 (6.4)
Madiba	23 (21.1)
McDonalds	26 (23.9)
Mike Hardware	12 (11.0)
Remnant seeds	10 (9.2)
Tugela Ferry	11 (10.1)
Wartburg	4 (3.7)

Moreover, from the 52 participants not growing their own white maize, 38% (n=16) indicated that it was due to a shortage of space. Maize meal was purchased from supermarkets, with the most popular brand purchased being White Star (39.4%; n=13) and the least popular brand being Blue bird (3.0%; n=1) (Table 9.5).

[32] These are stores were seeds are purchased for agricultural purposes.

Table 9.5: Different brands of white maize meal purchased (n=33 households)

Maize meal brand	n (%)
ACE	5 (15.2)
Blue bird	1 (3.0)
Meliver King	2 (6.1)
Nyala	4 (12.1)
Sharp sharp	3 (9.1)
Spar brand	5 (15.2)
White star	13 (39.4)

Participants were asked further questions related to yellow maize meal. Eighty-three households (50.3%) reported that they had used yellow maize meal before. However, 82 households (49.7%) reported that they had never used yellow maize. The households that reported using yellow maize meal, used it for human consumption (42.2%; n=35), animal feed (55.4%; n=46) and both human consumption and animal feed (2.4%; n=2). Participants that consumed yellow maize meal, identified food items that they consumed together with yellow maize. In contrast to the cooked white maize meal, cooked yellow maize meal was consumed mostly with cabbage (38.6%; n=32). A small percentage of participants consumed yellow maize with dry beans (10%; n=8). The main reason why yellow maize was not consumed by households was that the participants had not seen it before (29.5%; n=18) (Table 9.6).

Table 9.6: Reasons why yellow maize was not consumed (n=52 households)

Reason why yellow maize was not consumed	n (%)
Paticipants did not like it	13 (21.3)
Participants have not seen yellow maize before	18 (29.5)
Yellow maize seeds are not accessible	3 (4.9)
Unfamiliar	12 (19.7)
Used during times of drought	6 (9.8)

Eighty-seven households (52.7%) reported that they consumed CFSP and 78 households (47.3%) reported that they did not. From the 87 households that consumed sweet potato, it was consumed daily (17.2%; n=15), bi-weekly (23%; n=20), weekly (23%; n=20), monthly (24.1%; n=21), several times a week (9.2%; n=8) and seasonally (3.4%; n=3). Sixty-eight households that consumed sweet potato prepared the sweet potato by boiling it in water with the skin on, until soft.

9.3.2 Consumer acceptance and perceptions of PVA-biofortified maize and OFSP

9.3.2.1 Sample characteristics

The majority of participants that participated in the sensory evaluation and FGDs were female. (Tables 9.7 and 9.8). Although most of the sensory evaluation participants were above 60 years of age (n=29; 24.2%), the majority of the FGDs comprised of participants aged 40-49 years (n=16; 28.6%).

Table 9.7 presents the total number of black African rural participants of both genders within specific age groups that participated in the sensory evaluation. Most of the participants were ≥ 60 years (n=29; 24.2%) and the least number of participants were from the 20-29 age group (n=14; 11.7%). Table 9.8 indicates the total number of participants of both genders within specific age groups that participated in the FGDs.

Table 9.7: Characteristics of sensory evaluation participants (n=120)

Characteristics	n (%)*
Gender	
Males	34 (28.3)
Females	86 (71.7)
Age group (years)	
20-29	14 (11.7)
30-39	24 (20.0)
40-49	28 (23.3)
50-59	25 (20.8)
≥ 60	29 (24.2)

* Percentage of sample calculated using total sample (n=120).

Table 9.8: Characteristics of the focus group discussion participants (n=56)

Characteristics	n (%)*
Gender	
Males	16 (28.6)
Females	40 (71.4)
Age group (years)	
20-29	4 (7.1)
30-39	12 (21.4)
40-49	16 (28.6)
50-59	15 (26.8)
≥ 60	9 (16.1)

* Percentage of sample calculated using total sample (n=56).

9.3.3 Sensory evaluation

The panellists rated the sensory attributes (taste, texture, aroma, colour and overall acceptability) of all eight dishes as 'good'. Tables 9.9 and 9.10 indicates the percentages of panellists who gave different ratings for the sensory attributes and composite dishes evaluated.

Table 9.9: Number and percentages of panellists who gave the different ratings for the sensory attributes evaluated for the composite dishes (n=120)

Composite dishes	Rating	Taste	Texture	Aroma	Colour	Overall acceptability
White *phutu* and curried chicken	Very bad	1[a] (0.8)[b]	2 (1.7)	0 (0.0)	0 (0.0)	0 (0.0)
	Bad	11 (9.2)	12 (10.0)	4 (3.3)	4 (3.3)	1 (0.8)
	Average	15 (12.5)	13 (10.8)	14 (11.7)	20 (16.7)	12 (10.0)
	Good	65 (54.2)	65 (54.2)	74 (61.7)	78 (65.0)	83 (69.2)
	Very good	28 (23.3)	28 (23.3)	28 (23.3)	18 (15.0)	24 (20.0)
PVA *phutu* and curried chicken	Very bad	1 (0.8)	2 (1.7)	1 (0.8)	0 (0.0)	0 (0.0)
	Bad	8 (6.7)	13 (10.8)	4 (3.3)	10 (8.3)	6 (5.0)
	Average	11 (9.2)	8 (6.7)	12 (10.0)	10 (8.3)	6 (5.0)
	Good	72 (60.0)	75 (62.5)	81 (67.5)	67 (55.8)	78 (65.0)
	Very good	28 (23.3)	22 (18.3)	22 (18.3)	33 (27.5)	30 (25.0)
White *phutu* and curried cabbage	Very bad	2 (1.7)	2 (1.7)	0 (0.0)	0 (0.0)	0 (0.0)
	Bad	11 (9.2)	13 (10.8)	10 (8.3)	9 (7.5)	7 (5.8)
	Average	15 (12.5)	29 (24.2)	22 (18.3)	30 (25.0)	15 (12.5)
	Good	65 (54.2)	53 (44.2)	66 (55.0)	62 (51.7)	77 (64.2)
	Very good	27 (22.5)	23 (19.2)	22 (18.3)	19 (15.8)	21 (17.5)
PVA *phutu* and curried cabbage	Very bad	0 (0.0)	1 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)
	Bad	9 (7.5)	12 (10.0)	8 (6.7)	9 (7.5)	8 (6.7)
	Average	24 (20.0)	26 (21.7)	24 (20.0)	16 (13.3)	14 (11.7)
	Good	62 (51.7)	57 (47.5)	64 (53.3)	69 (57.5)	60 (50.0)
	Very good	25 (20.8)	24 (20.0)	24 (20.0)	26 (21.7)	38 (31.7)
White *phutu* and curried bambara groundnut	Very bad	12 (10.0)	10 (8.3)	2 (1.7)	1 (0.8)	6 (5.0)
	Bad	18 (15.0)	22 (18.3)	18 (15.0)	12 (10.0)	13 (10.8)
	Average	10 (8.3)	13 (10.8)	22 (18.3)	23 (19.2)	11 (9.2)
	Good	62 (51.7)	62 (51.7)	68 (56.7)	71 (59.2)	70 (58.3)
	Very good	18 (15.0)	13 (10.8)	10 (8.3)	13 (10.8)	20 (16.7)
PVA *phutu* and curried bambara groundnut	Very bad	13 (10.8)	11 (9.2)	6 (5.0)	3 (2.5)	4 (3.3)
	Bad	20 (16.7)	20 (16.7)	14 (11.7)	16 (13.3)	17 (14.2)
	Average	20 (16.7)	16 (13.3)	26 (21.7)	22 (18.3)	11 (9.2)
	Good	60 (50.0)	55 (45.8)	62 (51.7)	65 (54.2)	73 (60.8)
	Very good	7 (5.8)	18 (15.0)	12 (10.0)	14 (11.7)	15 (12.5)

[a] Number of subjects; [b] Percentage of total number of participants; PVA = Provitamin A; Acceptability rating 1-5: 1 = very bad; 5 = very good.

Table 9.10: Number and percentages of panellists who gave the different ratings for the sensory attributes evaluated for two types of sweet potato (n=120)

Sweet potato	Rating	Taste	Texture	Aroma	Colour	Overall acceptability
CFSP	Very bad	1[a] (0.8) [b]	0 (0.0)	0 (0.0)	2 (1.7)	2 (1.7)
	Bad	9 (7.5)	8 (6.7)	6 (5.0)	6 (5.0)	2 (1.7)
	Average	3 (2.5)	16 (13.3)	24 (20.0)	20 (16.7)	10 (8.3)
	Good	61 (50.8)	50 (41.7)	63 (52.5)	67 (55.8)	70 (58.3)
	Very good	46 (38.3)	46 (38.3)	27 (22.5)	25 (20.8)	36 (30.0)
OFSP	Very bad	2 (1.7)	2 (1.7)	1 (0.8)	4 (3.3)	3 (2.5)
	Bad	7 (5.8)	11 (9.2)	12 (10.0)	7 (5.8)	4 (3.3)
	Average	6 (5.0)	8 (6.7)	26 (21.7)	13 (10.8)	9 (7.5)
	Good	62 (51.7)	60 (50.0)	58 (48.3)	67 (55.8)	62 (51.7)
	Very good	43 (35.8)	39 (32.5)	23 (19.2)	29 (24.2)	42 (35.0)

[a] Number of subjects; [b] Percentage of total number of participants; CFSP = Cream-fleshed sweet potato; OFSP = Orange-fleshed sweet potato; Acceptability rating 1-5: 1 = very bad; 5 = very good.

Most of the study participants rated the taste, texture and aroma of PVA *phutu* and curried chicken as "good" compared with white *phutu* and curried chicken (control). The texture and colour of PVA *phutu* and curried cabbage were rated "good" by more study participants in comparison to white *phutu* and curried cabbage (control). The PVA *phutu* and curried bambara groundnut composite dish was rated as "good" for the overall acceptability when compared with white *phutu* and curried bambara groundnut (control). When comparing the composite dishes made with PVA *phutu*, the PVA *phutu* and curried chicken composite dish was rated "good" by most study participants for all five sensory attributes. Although the PVA *phutu* and curried cabbage composite dish and PVA *phutu* and curried bambara groundnut composite dish was rated as "good" by most participants, the taste, texture, aroma and colour of the PVA *phutu* and curried cabbage composite dish was rated "good" by more participants in comparison to PVA *phutu* and curried bambara groundnut. The OFSP was rated "good" by most participants for taste and texture in comparison to CFSP, however the same number of participants rated OFSP and CFSP as "good".

The mean scores for the sensory evaluation of the composite dishes and sweet potato are presented in Table 9.11. Results from the Friedman test showed that there was a significant difference in taste, texture, aroma, colour and overall acceptability across the dishes that included *phutu* ($p<0.05$).

Table 9.11: Mean scores for the sensory evaluation of PVA-biofortified maize and OFSP dishes compared with the white maize (control) and CFSP dishes (n=120)

Sensory attributes	Taste	Texture	Aroma	Colour	Overall acceptability
Composite dishes					
White *phutu* and curried chicken	3.9[a] (0.9)[b]	3.9 (0.9)	4.1 (0.7)	3.9 (0.7)	4.1 (0.6)
PVA *phutu* and curried chicken	4.0 (0.8)	3.9 (0.9)	4.0 (0.7)	4.0 (0.8)	4.1 (0.7)
White *phutu* and curried cabbage	3.9 (0.9)	3.7 (1.0)	3.8 (0.8)	3.8 (0.8)	3.9 (0.7)
PVA *phutu* and curried cabbage	3.9 (0.8)	3.8 (0.9)	3.9 (0.8)	3.9 (0.8)	4.1 (0.8)
White *phutu* and curried bambara groundnut	3.5 (1.2)	3.4 (1.2)	3.6 (0.9)	3.7 (0.8)	3.7 (1.1)
PVA *phutu* and curried bambara groundnut	3.2 (1.1)	3.4 (1.2)	3.5 (1.0)	3.6 (0.9)	3.7 (1.0)
p-value [c]	<0.05	<0.05	<0.05	<0.05	<0.05
Sweet potato					
CFSP	4.2 (0.9)	4.1 (0.9)	3.9 (0.8)	3.9 (0.9)	4.1 (0.8)
OFSP	4.1 (0.9)	4.0 (1.0)	3.8 (0.9)	3.9 (0.9)	4.1 (0.9)
p-value [d]	ns	ns	ns	ns	ns

[a] Mean; [b] Standard deviation; [c] Friedman's test; [d] The Wilcoxon test; PVA= Provitamin A; CFSP = Cream-fleshed sweet potato; OFSP = Orange-fleshed sweet potato; ns = not significant.

In order to determine the specific significant differences between the composite dishes for each of the sensory attributes, the Wilcoxon test was applied. Results are summarised in Tables 9.12 and 9.13.

Table 9.12: Significant differences between composite dishes and the sensory attributes of taste, texture and aroma

Composite dish A is preferred over composite dish B	Composite dish A	Composite dish B	p-value[a]
Taste	White *phutu* and curried chicken	White *phutu* and curried bambara groundnut	p=0.001
		PVA *phutu* and curried bambara groundnut	p<0.05
	PVA *phutu* and curried chicken	White *phutu* and curried bambara groundnut	p<0.05
		PVA *phutu* and curried bambara groundnut	p<0.05
	White *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	p=0.003
		PVA *phutu* and curried bambara groundnut	p<0.05
	PVA *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	p=0.005
		PVA *phutu* and curried bambara groundnut	p<0.05
	White *phutu* and curried bambara groundnut	PVA *phutu* and curried bambara groundnut	p=0.010
Texture	White *phutu* and curried chicken	White *phutu* and curried bambara groundnut	p<0.05
		PVA *phutu* and curried bambara groundnut	p=0.001
	PVA *phutu* and curried chicken	White *phutu* and curried bambara groundnut	p<0.05
		PVA *phutu* and curried bambara groundnut	p=0.001
	White *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	p=0.031
		PVA *phutu* and curried bambara groundnut	p=0.024
	PVA *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	p=0.003
		PVA *phutu* and curried bambara groundnut	p=0.019
Aroma	White *phutu* and curried cabbage	White *phutu* and curried cabbage	p=0.017
		PVA *phutu* and curried cabbage	p=0.025
		White *phutu* and curried bambara groundnut	p<0.05
		PVA *phutu* and curried bambara groundnut	p<0.05
	PVA *phutu* and curried bambara groundnut	White *phutu* and curried bambara groundnut	p<0.05
		PVA *phutu* and curried bambara groundnut	p<0.05
	White *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	p=0.005
		PVA *phutu* and curried bambara groundnut	p=0.005
	PVA *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	p=0.005
		PVA *phutu* and curried bambara groundnut	p=0.002

Composite dish A is preferred over composite dish B for the respective sensory attribute; [a] Wilcoxon Test.

Table 9.13: Specific significant differences between composite dishes and the sensory attributes of colour and overall acceptability

Composite dish A is preferred over composite Dish B	Composite dish A	Composite dish B	p-value[a]
Colour	White *phutu* and curried chicken	White *phutu* and curried bambara groundnut	p=0.019
		PVA *phutu* and curried bambara groundnut	p=0.005
	PVA *phutu* and curried chicken	White *phutu* and curried cabbage	p=0.014
		White *phutu* and curried bambara groundnut	p=0.002
		PVA *phutu* and curried bambara groundnut	p<0.05
	PVA *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	p=0.017
		PVA *phutu* and curried bambara groundnut	p=0.001
Overall acceptability	White *phutu* and curried chicken	White *phutu* and curried bambara groundnut	p=0.001
		PVA *phutu* and curried bambara groundnut	p<0.05
	PVA *phutu* and curried chicken	White *phutu* and curried cabbage	p=0.029
		White *phutu* and curried bambara groundnut	p<0.05
		PVA *phutu* and curried bambara groundnut	p<0.05
	White *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	p=0.032
		PVA *phutu* and curried bambara groundnut	p=0.015
	PVA *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	p<0.05
		PVA *phutu* and curried bambara groundnut	p<0.05

Composite dish A is on average significantly better than composite dish B for the respective sensory attribute;
[a] Wilcoxon Test.

The sensory attributes taste, texture, aroma, colour and overall acceptability of PVA *phutu* combined with curried chicken were rated similarly by participants in comparison to white *phutu* served with curried chicken ($p>0.05$). Provitamin A-biofortified *phutu* and curried cabbage combination had a similar rating for all five sensory attributes in comparison to white *phutu* and curried cabbage ($p>0.05$). The PVA *phutu* and curried bambara groundnut had a significantly lower rating for taste in comparison to white *phutu* and curried bambara groundnut (control) ($p<0.05$); however, both composite dishes were rated similarly for the other sensory attributes ($p>0.05$). When comparing the PVA composite dishes, it was found that when PVA *phutu* was combined with either curried cabbage or chicken, the taste, texture and overall acceptability was rated better than that of PVA *phutu* and curried bambara groundnut ($p<0.05$). Although the PVA *phutu* and curried chicken had a significantly better rating for colour in comparison to PVA *phutu* and curried cabbage, the PVA *phutu* and cabbage combination was rated higher for colour in comparison to PVA *phutu* and curried bambara groundnut ($p<0.05$). The Wilcoxon test found that the two varieties of sweet potato were rated similarly for taste, texture, aroma, colour and overall acceptability ($p>0.05$) (Table 9.10).

Results from the independent samples t-test found that there were no significant differences across gender for the average sensory attributes of all eight dishes ($p>0.05$). In terms of the *phutu* composite dishes, the male participants rated the taste of white *phutu* and curried cabbage the highest, whereas females rated the taste of PVA *phutu* and curried chicken the highest. Both males and females least liked the taste of the PVA *phutu* and bambara groundnut combination. The male participates liked the texture of the composite dishes that contained curried chicken, whereas female participants preferred the texture of the white *phutu* and curried chicken composite dish. Female participants preferred the aroma and colour of PVA *phutu* and curried chicken, while the male participants preferred the aroma and colour of white *phutu* and curried chicken. The overall acceptability of white *phutu* and curried chicken and PVA *phutu* and curried chicken was rated the same by males, however, female participants preferred the PVA *phutu* and curried chicken composite dish. The taste and texture of CFSP were liked by both males and females in comparison to OFSP. Female participants preferred the aroma of CFSP to OFSP, while the male participants rated the aroma of both types of sweet potato the same. Conversely, females preferred the colour of OFSP to CFSP, while the male participants rated the colour of OFSP and CFSP the same. The overall acceptability of OFSP was rated higher by males and lower by females in comparison to CFSP.

Results from applying ANOVA indicated a significant difference in the average sensory attribute taste for white *phutu* and curried cabbage and white *phutu* and curried bambara groundnut, across certain age categories (p>0.05) (Table 9.14).

Table 9.14: Significant differences in the acceptability ratings of composite dishes across age groups

Composite dishes	Sensory attribute	p-value[a]	Specific difference across age[b]
White *phutu* and curried cabbage	Taste	<0.05 [c]	>60 (A) rated higher than 50-59 (B)
White *phutu* and curried bambara groundnut	Taste	<0.05 [c]	>60 (A) rated higher than 20-29 (B)
White *phutu* and curried bambara groundnut	Aroma	<0.05 [d]	>60 (A) rated higher than 50-59 (B)
White *phutu* and curried bambara groundnut	OA	<0.05 [d]	>60 (A) rated higher than 20-29 (B)

[a] Result from testing for differences across all age groups regarding the specific product and sensory attribute; [b] Indicates the age category (years) (A) that gave a statistically higher rating for the respective composite dish and sensory attribute than age category (years) (B); [c]ANOVA test; [d] Welch test; OA= Overall acceptability.

The Welch test indicated that there was a significant difference between certain age categories and the sensory properties of aroma and overall acceptability for white *phutu* and curried bambara groundnut (p<0.05) (Table 9.14). There was no significant difference in the acceptability ratings of PVA-biofortified composite dishes across age groups (p>0.05). The taste of the PVA *phutu* and curried chicken and the PVA *phutu* and curried cabbage were preferred by participants aged 30-39 years and 40-49 years, respectively. The 40-49 age group preferred the texture and aroma of the PVA *phutu* and curried chicken and PVA *phutu* and curried cabbage in comparison to the other age groups. The colour was preferred by both the 30-39 and 50-59 year age groups. Participants older than 60 years of age preferred the colour and overall acceptability of the PVA *phutu* and cabbage composite dish more, in comparison to the other age groups. The taste, texture, aroma, colour and overall acceptability of PVA *phutu* and curried bambara groundnut were rated higher by those older than 60 years of age, in comparison to other age groups. The 20-29 year old participants preferred the taste, texture, aroma, colour and overall acceptability of OFSP, in comparison to the other age groups. The paired preference results are presented in Tables 9.15 and 9.16.

Table 9.15: Variation in paired preference with gender (n=120)

Gender	*Phutu* and curried chicken		*Phutu* and curried cabbage		*Phutu* and curried bambara groundnut		Sweet potato	
	White *phutu* and curried chicken	**PVA *phutu* and curried chicken**	**White *phutu* and curried cabbage**	**PVA *phutu* and curried cabbage**	**White *phutu* and curried bambara groundnut**	**PVA *phutu* and curried bambara groundnut**	**CFSP**	**OFSP**
Males	1[a] (56) [b]	15 (44)	17 (50)	17 (50)	19 (56)	15 (44)	14 (41)	20 (59)
Females	40 (46)	46 (54)	44 (51)	42 (49)	47 (55)	39 (45)	41 (48)	45 (52)
Total no. of participants	59 (49)[c]	61 (51)	61 (51)	59 (49)	66 (55)	54 (45)	55 (46)	65 (54)

[a] Number of participants; [b] Percentage (%) of the sample within a gender group; [c] Percentage (%) of the total number of participants; PVA = Provitamin A; CFSP = Cream-fleshed sweet potato; OFSP = Orange-fleshed sweet potato.

There was no statistical significance noted for the preference of PVA-biofortified and non-PVA-biofortified food combinations between males and females (p>0.05). Although not statistically significant, males from this sample preferred the white *phutu* and curried chicken (n=19; 56%), white *phutu* and curried bambara groundnut (n=19; 56%) and OFSP (n=20; 59%). The females participants preferred the provitamin A-biofortified *phutu* and curried chicken (n=46; 54%), white *phutu* and curried cabbage (n=44; 51%), white *phutu* and curried bambara groundnut (n=47; 55%) and OFSP (n=65; 54%).

Table 9.16: Preference ratings across age groups (n=120)

Age group (years)	*Phutu* and curried chicken		*Phutu* and curried cabbage		*Phutu* and curried bambara groundnut		Sweet potato	
	White *phutu* and curried chicken	PVA *phutu* and curried chicken	White *phutu* and curried cabbage	PVA *phutu* and curried cabbage	White *phutu* and curried bambara groundnut	PVA *phutu* and curried bambara groundnut	CFSP	OFSP
20-29	7[a] (50)[b]	7 (50)	9 (64)	5 (36)	9 (64)	5 (36)	5 (36)	9 (64)
30-39	7 (29)	17 (71)[c]	11 (46)	13 (54)	13 (54)	11 (46)	10 (42)	14 (58)
40-49	11 (39)	17 (61)	12 (43)	16 (57)	16 (57)	12 (43)	14 (50)	14 (50)
50-59	17 (68)	8 (32)	11 (44)	14 (56)	13 (52)	12 (48)	10 (40)	15 (60)
>60	17 (59)	12 (41)	18 (62)	11 (38)	15 (52)	14 (48)	16 (55)	13 (45)
Total no. of participants	59 (49)	61 (51)	61 (51)	59 (49)	66 (55)	54 (45)	55 (46)	65 (54)

[a] Number of participants; [b] Percentage (%); [c] Bold values within the same column are significantly different at p<0.05 (Pearson chi-square); PVA = Provitamin A; CFSP = Cream-fleshed sweet potato; OFSP = Orange-fleshed sweet potato.

Significantly more participants aged 30-39 years preferred provitamin A-biofortified *phutu* and chicken (n=17; 71%) than the other age groups (p<0.05). Moreover, participants aged 50-59 years who preferred white *phutu* and chicken (n=17; 68%), was statistically significantly higher than participants from the other age groups. There was a tendency for all age groups to prefer white *phutu* with cabbage, white *phutu* with bambara groundnut and OFSP, although this was not statistically significant (p>0.05).

9.3.4 Focus group discussions

Focus group discussions revealed both positive and negative responses to the PVA-biofortified *phutu* and bambara groundnut composite dish However, overall the participants had positive perceptions about the sensory properties of the PVA-biofortified composite dishes and OFSP. The participants offered suggestions as to how the meals could be prepared to increase the acceptability. Although the participants were not asked how to improve the meals, they did offer suggestions during the discussions. The participants expressed a willingness to purchase PVA-biofortified maize and sweet potato if it was available at local stores. The participants were also keen to grow their own biofortified produce if seeds were accessible. The results are presented in Table 9.17.

Table 9.17: Participants' perceptions towards the consumption of OFSP and PVA-biofortified *phutu* with curried chicken, cabbage and bambara groundnut

Themes	Concepts	Quotes	Discussion
Consumer perceptions about PVA-biofortified composite dishes and OFSP	Preference of combinations: • *Phutu* and chicken • *Phutu* and cabbage • *Phutu* and bambara groundnut • OFSP	*'Yellow phutu and chicken was nice.'* *'Cabbage and yellow phutu went good together.'* *'I did not like these beans.'* *'This type of beans was different from what I am used to. I love it.'* *'Orange sweet potato taste nice.'* *'These beans must be mixed with dry mealies to make iznkobe. It will taste better.'*	The FGDs indicated that participants had positive perceptions of the PVA *phutu* when served with curried chicken or curried cabbage. However, they had mixed perceptions when served with curried bambara groundnut. The older FGDs participants perceived that some of the combinations such as *phutu* and bambara would not be acceptable to younger consumers, as they were not accustomed to bambara.
	Food preparation methods	*'Yellow maize could have been cooked for longer.'* *'Too much water in the orange sweet potato.'* *'Beans should be cooked with the maize for more flavour.'* *'Beans could be cooked for longer.'* *'Chicken would have tasted better with stiff pap.'* *'Food cooked like I cook at home.'*	Participants suggested names of other dishes made with PVA-biofortified maize that could be better accepted. Stiff pap was one of the suggestions given by FGD participants. Although there were mixed responses concerning bambara, participants offered a few suggestions to improve the acceptability. Participants would have preferred the bambara to be cooked for a longer period or cooked together with the maize meal.
Cultural acceptance of PVA-biofortified composite dishes and OFSP	Expectations of sensory qualities: • Smell • Appearance • Taste • Texture	*'Foods were made like I eat at home.'* *'Our kids may not accept the preparation of the food as it has less oil and spice.'* *'Thought the orange sweet potato was butternut.'*	The majority of the FGD participants perceived the foods as culturally acceptable, however, they felt that some foods would not be as acceptable to their children and grandchildren. Foods that the younger generation like are prepared with more oil, salt and spices. Most of the FGD participants perceived the OFSP as butternut due to its orange colour, sweet taste and visual appeal and enjoyed the taste.

Table 9.18: Participants' perceptions towards the consumption of OFSP and PVA-biofortified *phutu* with curried chicken, cabbage and bambara groundnut continued

Themes	Concepts	Quotes	Discussion
Comparison with white maize food combinations and CFSP	Expectations of sensory qualities: • Smell • Appearance • Taste • Texture	*'Preferred the white sweet potato as too much water in the orange one.'* *'The orange sweet potato was nicer as it had an orange colour and taste sweet.'* *'The chicken and yellow maize and beans and yellow maize looked nice.'* *'First time I had this yellow phutu and it was very nice with the cabbage and meat. I won't eat it alone.'* *'I did not like the smell of yellow maize.'*	Participants would have preferred it if OFSP contained less water in comparison to CFSP. However, they found the sweet taste and orange colour of the OFSP very appealing and preferred it to the CFSP. The smell of PVA-biofortified *phutu* and curried bambara groundnut and PVA-biofortified *phutu* on its own were disliked by some of the participants. On the contrary, PVA-biofortified maize was well accepted with the curried cabbage and curried chicken.
Willingness to use yellow maize and OFSP for human consumption	• Affordability • Availability • Accessibility	*'Not accessible, if it was, I would buy yellow maize and OFSP.'* *'We use yellow maize in drought times.'* *'It is fed to animals.'* *'People are not familiar with yellow maize but will buy if educated on it.'* *'I would plant if I get seeds.'*	Some participants reported that PVA-biofortified maize was used to feed animals and eaten during times of drought, however, they expressed a willingness to grow and purchase the PVA-biofortified maize and OFSP if planting materials were made available or if the two types of biofortified crops were available as food in the market. The acceptance of PVA-biofortified maize could be improved by educating people on the nutritional benefits of PVA-biofortified crops and preparation methods that could be used to cook these crops.

9.4 Discussion

Malnutrition is the leading contributor to the global disease burden (Faber and Wenhold, 2007; UNICEF, 2016; UNICEF et al., 2019). SA is faced with the double burden of malnutrition (Shisana et al., 2013). There are many interventions that focus on under and over-nutrition in vulnerable population groups; however, micronutrient deficiencies are still prevalent. Although the fortification of maize meal and wheat flour was legislated in SA in October 2003, the accessibility of these commercially fortified foods to rural households remains questionable (DoH and UNICEF, 2007). Although PVA-biofortified crops improve the nutrient content of foods, their acceptability to target consumers should be improved through research. Thus, this study aimed to investigate the effect of replacing white maize and CFSP with PVA-biofortified maize and OFSP, respectively, on consumer acceptability and perceptions of traditional dishes of selected rural communities in KZN, SA.

The study results are encouraging as the sensory attributes taste, texture, aroma, colour and overall acceptability were rated as good by most study participants for all of the PVA *phutu* composite dishes. Over a millennia ago, in rural South African communities, indigenous and traditional crops were the main source of food. However, with urbanisation, there has been a shift from traditional foods to more western foods with less consumption of indigenous and traditional foods (Van der Hoeven et al., 2013). The older generation has displayed some knowledge of bambara groundnut (Oyeyinka et al., 2017), which was also found in the current study during the FGDs. The older generation (above 60 years) rated the overall acceptability of *phutu* and curried bambara groundnut better than the younger generation (20-29 years). Chowdhury et al. (2011), reported that introducing an unfamiliar product could negatively affect consumer acceptance. This could have been the case in the current study with the younger generation, specifically with regards to the *phutu* and curried bambara groundnut composite dish which was least preferred in comparison to the other composite dishes.

Although bambara groundnut is an unfamiliar food crop, it was introduced and investigated in this study as it could be a cheaper alternative to animal protein. Crops like bambara groundnut could be included in the meals used in school feeding programmes. This would not only improve the nutritional intake of these children, but would result in earlier exposure to this food item. Early and frequent exposure to a food item improves the acceptance of the food item (Appleton et al., 2018). Another suggestion would be to prepare bambara groundnut into different food types using preparation methods that have been shown to improve acceptance, such as roasting. A study conducted by Oyeyinka et al. (2017) found that bambara groundnut made into a pureed infant complementary food was acceptable to caregivers. Another study conducted in Nigeria using a snack made from bambara groundnut flour found that the aroma, colour, crunchiness and overall acceptability were higher than those of the control made with cowpea (Oyeyinka et al., 2017). Additionally, Okafor et al. (2015) found that substituting roasted bambara groundnut at different substitution levels for wheat flour in biscuits, had a higher sensory rating for the attributes investigated. However, the flavour of the biscuits was similar to that of the control for up to 70% substitution (Okafor et al., 2015). These studies further confirm that the way in which a food item is prepared and the geographic location of consumers influence its acceptability (Okafor et al., 2015; Oyeyinka et al., 2018; Oyeyinka et al., 2018).

As alluded to earlier, poverty is a problem and in some cases, impoverished individuals rely on social grants as their sole source of income for purchasing food (Jacobs et al., 2010). Hence, there is a lack of dietary diversity and a high reliance on starch-based foods, such as maize meal as they are cheaper (Temple and Steyn, 2009; Battersby and Peyton, 2014). Thus, it is important to introduce impoverished individuals to affordable nutritious food alternatives such as bambara groundnut that can be consumed together with cooked maize meal. It is important to note that an individual's background, traditions, socioeconomic standing and geographical location are important factors that influence the types of foods consumed and the preparation methods used (Kearney, 2010; Wenhold et al., 2012; Kamphuis, 2015; Emily et al., 2017).

The participants from the present study were unfamiliar with bambara groundnut and the younger generation lacked basic knowledge about this crop. This emphasises the need for education on the nutritional benefits of bambara groundnut and methods for preparation, in order to improve exposure and acceptance of this underutilised crop. It is noteworthy that this study did not educate participants about the composite dishes prior to the sensory evaluation and FGDs. Future studies could investigate the impact of nutritional education on consumer acceptability.

The acceptance of PVA-biofortified maize has been previously investigated by several authors (Stevens and Winter-Nelson, 2008; De Groote et al., 2010; Pillay et al., 2011; Khumalo et al., 2011; Govender et al., 2014; Awobusyi et al., 2016). Provitamin A-biofortified maize has been found to have an undesirable colour. The grain colour changes from white to either yellow or orange due to the carotenoid pigments (Stevens and Winter-Nelson, 2008; Muzhingi et al., 2008), thus contributing to poor acceptability (De Groote et al., 2010). However, the change did not hinder colour acceptability of the PVA-biofortified *phutu* and OFSP in this study. A number of studies have investigated the preference of PVA-biofortified maize to white maize and found mixed responses (Stevens and Winter-Nelson, 2008; Muzhingi et al., 2008; Nuss et al., 2012; Govender et al., 2014; Awobusuyi et al., 2016). However, there is a paucity of information regarding the preference of PVA-biofortified *phutu* composite dishes compared to corresponding white maize composite dishes. The PVA *phutu* and curried chicken combinations were well accepted in the current study. This result was similar to the results obtained by Amod et al. (2016), who investigated the sensory acceptability of PVA-biofortified *phutu* consumed together with chicken stew. The authors found that the combination of PVA-biofortified *phutu* and chicken was well accepted by caregivers attending the paediatric outpatient department at Edendale Hospital in KZN (Amod et al., 2016). The participants of the study conducted by Amod et al. (2016) were similar to the current study participants, as Edendale Hospital mainly services individuals living in surrounding rural areas (DoH, 2019). In the current study, it was reported that the aroma and colour of the chicken and yellow *phutu* were well-accepted. These findings suggest that the combination of curried chicken and PVA-biofortified *phutu* was well-accepted by study participants and could help improve the vitamin A intake in vulnerable groups. However, as mentioned earlier, animal food sources are not affordable. Thus, bambara groundnut should be considered not only as a nutritious alternative, but also a viable production option in these areas.

A number of studies conducted on OFSP have shown positive responses from participants, despite the orange colour (Tomlins et al., 2007; Chowdhury et al., 2011; Tomlins et al., 2012; Laurie et al., 2013; Pillay et al., 2018). A study conducted by Pillay et al. (2018) on infant caregivers found that a complementary food made with OFSP was well accepted by the caregivers (Pillay et al., 2018). Additionally, another study that investigated the acceptance of OFSP by caregivers, reported that the OFSP was preferred to the pale-fleshed sweet potato for all sensory attributes investigated (Low and Van Jaarsveld, 2008). Moreover, a study conducted in Uganda found that the deep orange coloured sweet potato was preferred over yellow or white sweet potato (Chowdhury et al., 2011). Although not statistically significant, numerically, OFSP was preferred to CFSP in the current study. This could be due to the sweet taste and colour of OFSP. The results from this study are encouraging as they suggest that there is a potential to use OFSP in some rural areas of KZN similar to the study sites, to improve the vitamin A status of vulnerable individuals.

Consumption of biofortified crops such as maize and OFSP and the consumption of an indigenous crop like bambara groundnut could potentially increase the dietary diversity of impoverished individuals and improve their nutritional status (Mavengahama et al., 2013). However, bambara groundnut should be introduced in a different cooked form rather than curried to improve acceptability. For this study, bambara groundnut was cooked in a similar manner to curried bean to investigate the acceptance. The younger generation was unaccustomed to bambara groundnut and the older generation that were familiar with it, enjoyed the taste. Acceptance of bambara groundnut could be improved if it is cooked together with *phutu* or mealie meal or milled into a flour and used to prepare other products. There is a need to further investigate the sensory acceptability of combining other cooked PVA-biofortified maize foods such as stiff pap, mealie meal porridge, *amaheu, isigwaqane* or *isijingi*, with commonly consumed food items in rural KZN, and the other provinces within SA. Furthermore, future studies could explore the impact of education on the nutritional benefits of these crops and the acceptance, perception and consumption of these crops.

The FGD results correlate with the results obtained from the sensory evaluation as the FDG participants had positive perceptions of the composite dishes made from PVA-biofortified *phutu* and chicken and cabbage. However, there were mixed responses with regard to PVA-biofortified *phutu* and curried bambara groundnut. This result was not surprising, as bambara groundnut is an indigenous nutritious crop; however, it is not usually consumed in rural areas of KZN (Chivenge et al., 2015). The older generation of participants perceived the *phutu* and bambara groundnut combination as something the younger generation would not like, as they are not accustomed to it. A study conducted by Oyeyinka et al. (2017) found that the older generation was familiar with the preparation of bambara groundnut. This study further identified that a lack of knowledge may be a reason for the underutilisation of this crop (Oyeyinka et al., 2017). It is important to educate the younger generation on the nutritional benefits of consuming this crop, as well as good agricultural practices to produce this crop. Knowing the nutritional value of a particular food item could improve the acceptance of that specific item (Meenakshi et al., 2012). Furthermore, indigenous crops such as bambara groundnut should be promoted to local farmers to improve the production and access to these crops. These crops could become cash crops and further provide not only nutrients, but also income for the local farmers.

Participants from the FGDs perceived the foods to be culturally acceptable and familiar; however, they made suggestions as to what should be changed to improve the combinations. A few male participants from the FGDs suggested that PVA-biofortified maize should be cooked into stiff pap and served with curried chicken instead of *phutu*. A survey conducted at the start of this study, found that 84.4% of the study participants consumed *phutu*, whereas only 42.4% consumed stiff pap. From the combinations investigated, more participants preferred *phutu* and curried chicken (n=27), rather than stiff pap and curried chicken (n=20). Although, it was suggested that the PVA-biofortified maize should be cooked into stiff pap and served with curried chicken, the *phutu* combination was still well perceived. Future studies should investigate consumer perceptions of cooking PVA-biofortified maize into food forms other than *phutu*, and served with commonly consumed foods. This would offer a variety of more acceptable foods that individuals could consume to improve their nutritional status, particularly vitamin A.

The OFSP prepared for the sensory evaluation in this study seemed to retain water. Some of the participants mentioned that they would have enjoyed it more if it were boiled for longer in less water. The same amount of water and time taken for straining was used to cook the CFSP. A possible reason for excess water content could be attributed to a relatively lower dry matter content of the OFSP (Kathabwalika et al., 2016). The genotypes found in the different varieties of OFSP influence the dry matter content and affect consumer acceptability (Kathabwalika et al., 2016). Some participants suggested that the curried bambara groundnut needed to be cooked for a longer period of time and that less water should be used when cooking OFSP. Further studies could investigate the acceptance of OFSP when prepared with different amounts of water and cooking times to improve acceptability. If OFSP is well accepted and consumed in areas where VAD is a significant problem, it has the potential to improve the vitamin A status of these individuals.

Many study participants perceived the OFSP to be butternut due to the orange colour, sweet taste and visual appeal, which was similar to the findings of a study conducted by Pillay et al. (2018) on the acceptance of OFSP (Pillay et al., 2018). Moreover, other studies have also reported that OFSP has been compared to pumpkin (Tomlins et al., 2007; Laurie et al., 2013). Although OFSP may be unfamiliar to some individuals, it resembles other familiar food items. Participants can therefore relate to it and are more likely to consume it. Generally, individuals are more inclined to consume foods that are familiar to them (Chowdhury et al., 2011). The participants mentioned that they would not have enjoyed PVA-biofortified *phutu* on its own. This was possibly due to the undesirable sensory properties of biofortified foods and some participants being unfamiliar with it (Nuss and Tanumihardjo, 2010; Chapman, 2012). This further suggests that if yellow maize is consumed with another food item, it may mask the undesirable sensory changes noted with biofortified foods, thus increasing its acceptance. Participants' also indicated that the PVA-biofortified *phutu* was appealing when served with curried chicken or curried bambara groundnut. These results were consistent with the study conducted by Amod et al. (2016).

Many participants expressed that yellow maize was used as an animal feed or during drought. This was similarly expressed in other studies (Muzhingi et al., 2008; Nuss et al., 2012; Govender et al., 2014; Amod et al., 2016). However, study participants expressed a willingness to grow and purchase PVA-biofortified maize and OFSP if seeds were made available or they could be found in shops. At the time of the study, the crops used in this study were experimental and not available on the market. Although PVA-biofortified foods have been found to be less acceptable by some studies, foods investigated in the study were positively perceived by most of the FGD participants. Therefore, PVA-biofortified maize and OFSP could replace white maize and CFSP, respectively, as these foods are rich in vitamin A and could contribute to addressing VAD, which is prevalent in rural areas of SA. However, there is a need to provide education on the health benefits of these crops especially to the younger generation, who are not accustomed to these crops, to improve their acceptance.

9.5 Conclusions

Provitamin A-biofortified foods served on their own have been well-accepted in some studies, while other studies have found a poor acceptance due to several factors. The results of this study were encouraging as foods investigated in this study were positively perceived by the majority of the study participants. This study indicates that the undesirable properties of PVA-biofortified foods that were found in other studies could be masked by serving it with another commonly consumed food item, thus improving its acceptance. Although *phutu* and curried bambara groundnut were not as preferred in comparison to the other composite dishes investigated, it was rated as 'good' for all the sensory attributes. This indicated that although it was least preferred in comparison to the other composite dishes, if served on its own it would be acceptable to consumers. *Phutu* and curried chicken was the most preferred composite dish, however, it contains animal protein which is less affordable to impoverished individuals. Bambara groundnut can be used as an alternative affordable plant-based protein source; however, the acceptance needs to be further investigated in other food products, such as incorporating the bambara groundnut and *phutu* during cooking, addition of bambara groundnut to maize meal to make a traditional drink or serving it with another form of cooked maize meal. Overall, it appears that PVA-biofortified maize combined with curried cabbage, chicken, bambara groundnut and boiled OFSP have the potential to be used as healthy alternatives to white maize combined with curried cabbage chicken, bambara groundnut and boiled CFSP. However, more studies need to be conducted on trying to improve the exposure to and acceptance of PVA-biofortified maize and bambara groundnut together, especially to the younger generation. The bambara groundnut and PVA *phutu* combination could be used in school feeding programmes as a cheaper alternative to animal protein. Not only will it improve the nutritional intake of young children, but provide exposure of these crops to consumers at a young age. Additionally, more education needs to be conducted on the nutritional benefits of PVA-biofortified crops and bambara groundnut, especially for the younger generation as many of them are not familiar with these crops. Moreover, PVA-biofortified crops (maize and sweet potato) and bambara groundnut should be promoted to local farmers. Local farmers should be educated on the production of these crops and possibly be given or sold seeds at a reduced cost. This would result in an increased production of these crops by farmers, which could lead to improved consumption. This study suggests that PVA-biofortified maize and OFSP could be incorporated into the diets of the rural communities studied to contribute to combating VAD, which is a major problem in SA and SSA.

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CHAPTER 10

GENERAL CONCLUSIONS AND RECOMMENDATIONS

AT Modi and T Mabhaudhi

10.1 General Discussion

The triple burden of malnutrition, under- and over-nutrition as well as micronutrient deficiency, pose a continuing and serious health concern to South Africa. Undernutrition presents as wasting, stunting, underweight and micronutrient deficiencies, such as iron, zinc and vitamin A, while over-nutrition manifests as overweight, obesity and several non-communicable diseases. Vulnerable groups, such as children under the age of five years and pregnant women, are most affected by malnutrition. In developing countries, such as South Africa (SA), the major contributing factors to all forms of malnutrition are poverty, food and nutrition insecurity as well as the shift from traditional diets towards westernised diets. The malnutrition situation is quite dire in poor rural households, which coincidentally are located in marginal production areas. In these areas, water remains the primary limiting factor to successful production. This also makes food production and access to healthy and diverse foods challenging in these areas. Through a multidisciplinary study that included dieticians, crop scientists and social scientists working together, this project sought to determine water use and nutritional water productivity for improved production, nutrition and health in poor rural communities.

At inception, the project undertook systematic reviews to (i) update available knowledge on water use and nutritional water productivity, (ii) identify food intake, food sources and nutritional value of food consumed in poor rural communities, (iii) food intake and sources of food in poor rural households, and (iv) identify the reasons behind choices of food intake in poor rural households and nutritional evaluation of food intake. The work took a global perspective as well as a more focused perspective on the study population of KwaZulu-Natal. The results highlighted that both under- and over-nutrition remain a public health concern, particularly in children, and especially among poor rural households. Both stunting and obesity were prevalent in children under five years, while the prevalence of obesity was highest in adult black African females. Dietary intake plays an important role in determining nutritional status. The dietary intake patterns of poor rural households investigated indicated a high carbohydrate and protein intake with a low micronutrient and fibre intake. More than 50% of the sample of children and adults had inadequate intake of the following nutrients: magnesium, phosphorus, zinc, riboflavin, niacin, folate, vitamin B_{12}, vitamin A, vitamin C, vitamin E and vitamin K, for most of the age groups. These results confirmed that malnutrition (under- and over-nutrition) are equally a serious health issue and are directly linked to the consumption of diets that lack dietary diversity. Although there are interventions in place to tackle malnutrition, progress is slow, which seems largely due to poor project designs, most of which lack or have limited linkages between agriculture, environment and health. To address the challenge of reliance on nutrient-deficient diets and the resultant prevalence of malnutrition especially among the poor rural households in sub-Saharan Africa, there is a need for adoption of alternative and/or complementary strategies such as biofortification of staple foods or the introduction of nutrient-dense indigenous crops, with commitant maximal water use in the production of the nutrious crops.

The second phase of the study, which built-on from the first phase, then focused on (i) measuring water use and nutritional water productivity, (ii) modelling yield and water use, and (iii) formulating best management practices for the range of identified crops. Based on the initial reviews (***cf.* Chapters 2 and 3**), it was shown that lack of dietary diversity was central to malnutrition. As such, any crop intervention should focus on crops that have low water use and are nutrient dense since there was no problem with energy intake but with micronutrient intake. Therefore, it was decided to focus on legumes (conventional and alternative) and sweet potato (conventional and alternative). This was also supported by reports of nutritional content values reported in Deliverable No. 6, which clearly showed that legumes offered great diversity in terms of nutritional value. As such, the project focused on evaluating conventional (groundnut and dry beans) and alternative (bambara groundnut and cowpeas) legumes.

This study was a first to benchmark conventional grain legumes to alternative grain legumes under similar conditions. It was observed that the conventional grain legumes had higher yield compared to bambara groundnut. In this study, bambara groundnut showed attributes that were not favourable for farmers. Conventional legumes were also well-adapted relative to bambara groundnut. Any successful promotion of alternative/underutilised crops should be preceded by crop improvement for the crops to be accepted by farmers. The study highlighted areas of improvement for bambara groundnut (improved canopy development, yield and harvest index), which could act as a starting point for breeders. This study was a first to determine NWP of grain legumes. Crops differed in their nutrient content. Groundnut had higher fat content relative to the other crops. Any promotion of groundnut should be accompanied with awareness of the risk associated with its over consumption, such as obesity. Measured protein content (205 and 325 g kg^{-1}) for all grain legumes, was enough to supply 40-60% of the recommended dietary allowance (RDA) for protein. Furthermore, dry bean and cowpea can supply 40-60% of the RDA for Fe and Zn. Interestingly, compared to leafy vegetables in previous reports, cowpea and dry bean contained ≈500% more Zn content, confirming that grain legumes have a role to play in dietary diversity.

With respect to NWP, it varied among the conventional and alternative crops. With respect to fat productivity, groundnut was the most productive, producing up to 400 g_{FAT} m^{-3}. For $NWP_{Fe, Zn \text{ and } Ca}$, dry bean was the most productive followed by cowpea. For groundnut, despite the high grain yield, $NWP_{Fe, Zn \text{ and } Ca}$ were low due to poor nutrient content. The conventional legumes (groundnut and dry bean), had the highest $NWP_{protein}$, relative to the alternative grain legumes. In the case of groundnut, this was attributed to high protein content and high yield observed for the crop. For dry bean, high $NWP_{protein}$ was attributed to low ET and high protein content. For the alternative grain legumes (cowpea and bambara groundnut), $NWP_{protein}$ was low due to low protein content, high ET and low grain yield for bambara groundnut and low yield for cowpea. Results of NWP further highlight the issue of crop improvement in alternative grain legumes to improve yield as this also had negative implications on NWP.

Another first emanating from the project, was to calibrate the FAO AquaCrop model groundnut and dry bean – the conventional legumes. With respect to the alternative legumes, AquaCrop has already been calibrated and tested for bambara groundnut (WRC K5/1771//4), while frequent animal attacks targeting cowpea and subsequent yield losses meant that there was insufficient data to calibrate and test the model. Model calibration and validation was done under varying water regimes and environments. AquaCrop was successfully calibrated for both crops; there was a good match between simulated and observed values. Overall, model performance for simulating yield and water use was acceptable; the model could be useful for assessing growth, yield and water use under semi-and arid conditions.

Further to model calibration and validation, the model was then applied to develop best management practice recommendations for one conventional and alternative crop. Early planting improved Y and WP_{ET} of groundnut; however, during dry seasons, late planting is recommended as it was associated with Y and WP_{ET} improvements. Late planting could also be explored as a climate change adaptation strategy. Bambara groundnut is day length sensitive, hence it performed poorly due to late planting (Y and WP_{ET} decreased by more than 40%). For bambara groundnut, early planting is recommended. Mulching improved Y and WP_{ET} during dry seasons; however, the feasibility of mulching is of concern due to competing needs for crop residues and labour involved in obtaining straw. With respect to increasing Y, optimum irrigation is recommended, while deficit irrigation is recommended if the goal is to optimise WP_{ET}. While optimum irrigation reduces the risk of crop failure, this may not be feasible due to water scarcity, hence deficit irrigation is recommended. Tied ridges and soil bunds should be promoted as a soil water conservation technique; they were shown to be most effective during dry seasons. Consistent with the trend of results, crop diversification remains a viable option for crop production in water scarce environments; the study observed bambara groundnut to have low risk of crop failure, compared to groundnut.

The third phase of the project was to then test the feasibility of promoting these alternative crops among the target populations. For this phase, the study focused on PVA-biofortified maize, OFSP and bambara groundnut. The aim was to (i) determine the nutrient content of dishes prepared with these alternative crops, and (ii) consumer acceptability of such dishes. The results were encouraging as they showed that PVA-biofortified maize had higher PVA carotenoid concentration relative to white maize. PVA-biofortified *phutu* composite dishes were shown to be nutritionally superior compared to non-biofortified composite dishes. Combining the PVA maize *phutu* with either curried cabbage, chicken, or bambara groundnut further improved the PVA carotenoid concentration and overall nutrient content of the composite dishes. For example, the PVA *phutu* and curried chicken composite dish also had improved protein content when compared to white *phutu* and curried chicken. Because of the cost of animal-sourced foods, the PVA *phutu* and bambara groundnut composite dish could be a suitable and affordable alternative for poor rural households. Similar to PVA-biofortified maize, OFSP was nutritionally superior, in terms of PVA carotenoid and fibre content relative to CFSP. The OFSP met three times more the EAR for vitamin A for the 1-3- and 4-5-year age groups. Our findings support the hypothesis that PVA-biofortified composite dishes could reduce VAD and improve the protein quality of the diet in poor rural communities.

In terms of consumer acceptability, the PVA-biofortified composite dishes were positively perceived by the majority of participants. Orange-fleshed sweet potato was similarly acceptable to CFSP. This was contrary to our initial assumptions that consumer acceptance of composite foods made with PVA-biofortified maize or OFSP would be low due to the unacceptable sensory properties exhibited by PVA-biofortified foods. Thus, PVA-biofortified composite dishes have the potential to be used as healthy alternatives to reduce VAD in poor rural communities.

10.2 Conclusions

The general aim of the project was to determine water use and nutritional water productivity for improved production, nutrition and health in poor rural communities. Secondary to this was to also identify food intake, food sources and nutritional value of food consumed in poor rural communities and link these to the choice of crops that could be used to address nutritional gaps in poor rural communities that also face water scarcity.

Little attention has been given to linking agriculture to nutritional outcomes well. Consequently, despite well-intentioned agricultural interventions, poor rural households still suffer unacceptably high levels of malnutrition. Undernutrition, specifically stunting, remains a problem in children. Over-nutrition, including both overweight and obesity are a problem among black African females. Malnutrition, in all its forms, in poor rural communities was mainly associated with a lack of dietary diversity and limited access to and non-availability of nutrient dense foods. Availability and access to nutritious foods is a major obstacle to improving the diets of poor, rural people. The majority of them rely on social grants, which restricts them to a narrow food basket that lacks diversity. Under these circumstances, agriculture offers an opportunity to address the availability and accessibility of diverse nutrient-dense foods in poor rural communities. In this regard, promoting underutilised crops that are water use efficient and nutrient dense, as alternative crops, could increase dietary diversity and increase access to nutrient-dense foods in poor rural communities.

The study determined water use and nutrient content of two conventional (groundnut and dry beans) and alternative (bambara groundnut and cowpea) crops. Notably, this was a first with regards to benchmarking conventional and alternative crops under similar conditions. This study was also the first to determine NWP of grain legumes. As expected, the conventional crops out-yielded the alternative crops and had superior yield, water use, water productivity, and NWP. Although alternative crops had reasonably good nutrient content and NWP, there is a need to improve them, especially to increase the yield and improve WP. Thus, any successful promotion of alternative/underutilised crops should be preceded by crop improvement for the crops to be accepted by farmers.

With regards to acceptability of composite dishes prepared using alternative crops such as PVA-biofortified maize and OFSP as well as bambara groundnut, the project highlighted that such composite dishes were favourably perceived and there was potential for consumption within poor rural communities targeted by the study. However, the promotion of alternative crops as part of composite dishes should be supported by education and awareness campaigns, as much of the knowledge related to utilisation has been lost.

The project was also the first to calibrate the FAO AquaCrop model for groundnut and dry bean, both conventional legumes. AquaCrop was successfully calibrated for both crops with overall, model performance for yield and water use being regarded as acceptable. The availability of validated crop models will contribute to future research on assessing crop suitability of the various crops.

10.3 Recommendations

The major recommendations derived from this study are:

- There is a need to link agricultural interventions to nutrition outcomes for improved human health and well-being. This should include adopting a sustainable food systems approach that links agriculture, the environment and health outcomes;
- Access to diverse and nutrient foods remains problematic as most rural households cannot afford to purchase diverse foods. Therefore, promotion of community and homestead gardens has the potential to address dietary diversity among poor rural households;
- In areas that have limited water availability, crop choice should be informed by more than just crop suitability. It should also be informed by gaps in nutrition within target areas, food choices and reasons thereof. Therefore, the use of metrics such as NWP which link water to nutrition may be useful to advise better advice on nutrient dense crops for water scarce environments;
- Alternative crops such as underutilised indigenous and traditional crops have the potential to provide nutrient dense options and may be better suited for production in water scarce environments; however, they still lack improvement and often produce yields that are lower than those of conventional crops, making them unattractive. Therefore, crop improvement should target improving the yield and sensory attributes of these crops; and

- The challenges of food and nutritional insecurity are systemic by nature and linked to other drivers. Therefore, in planning interventions for improving food and nutrition security, more transdisciplinary approaches that include agriculture, environment and health practitioners working together, is needed to tackle the growing burden of malnutrition. Furthermore, education and awareness campaigns are needed to promote nutrient dense crops and biofortified crops in order to increase their uptake

10.4 Proposed Future Research

Based on the findings of this project, the following future research is proposed:

- Scaling up the study to other rural areas of South Africa, especially Limpopo and the Eastern Cape, which also face similar circumstances as those described in the current study;
- transitioning rural food systems towards sustainable food systems, with a focus on linking agriculture, the environment and health;
- investigating the potential of promoting underutilised crops as nutrient dense alternatives in water scarce environments;
- the role of indigenous fruit trees in agroecology and income generation initiatives for sustainable rural livelihoods;
- developing metrics such as the NWP that help the assessment of the water-food-nutrition-health nexus;
- determining the water use of biofortified crops and options for mainstreaming them into rural diets; and
- building education and awareness among consumers on healthy dietary habits. Finally, transdisciplinary approaches that straddle the science-policy interface should be promoted in such research in order to inform policy and decision makers.

APPENDIX I: CAPACITY DEVELOPMENT REPORT

Project No: **K5/2493//4**
Project Title: **WATER USE OF CROPS AND NUTRITIONAL WATER PRODUCTIVITY FOR FOOD PRODUCTION, NUTRITION AND HEALTH IN POOR RURAL COMMUNITIES**
Project Leader: **PROF. ALBERT T. MODI**
Organisation: **UNIVERSITY OF KWAZULU-NATAL**

STUDENT NAME AND SURNAME	GENDER	RACE	DEGREE	UNIVERSITY	COUNTRY OF ORIGIN	STATUS
TENDAI CHIBARABADA	FEMALE	AFRICAN	PHD	UKZN	ZIMBABWE	COMPLETED
LAURENCIA GOVENDER	FEMALE	AFRICAN	PHD	UKZN	SOUTH AFRICA	COMPLETED
INNOCENT MASEKO	MALE	AFRICAN	PHD	UKZN	ZIMBABWE	COMPLETED
LADYFAIR N. DLADLA	FEMALE	AFRICAN	MSC	UKZN	SOUTH AFRICA	COMPLETED
PRETTY SHELEMBE	FEMALE	AFRICAN	MSC	UKZN	SOUTH AFRICA	COMPLETED
GUMEDE MBALI THEMBI	FEMALE	AFRICAN	MSC	UKZN	SOUTH AFRICA	COMPLETED
SIHLE SHELEMBE	MALE	AFRICAN	MSC	UKZN	SOUTH AFRICA	ONGOING
RACHEAL AKINOLA	FEMALE	AFRICAN	MSC	STELLENBOSCH	ZAMBIA	ONGOING

APPENDIX II: REPORT ON RESEARCH DISSEMINATION

A. Published Articles

1. Chibarabada T.P.*, Modi A.T. and Mabhaudhi T. 2020. Calibration and evaluation of AquaCrop for groundnut (*Arachis hypogaea*) under water deficit conditions. Agricultural and Forest Meteorology 281, 107850. https://doi.org/10.1016/j.agrformet.2019.107850. IF = 4.189; 5-Year IF = 5.317.

2. Chibarabada T.P.*, Modi A.T. and Mabhaudhi T. 2020. Options for improving water productivity: a case study of bambara groundnut and groundnut. Physics and Chemistry of the Earth https://doi.org/10.1016/j.pce.2019.10.003. IF = 1.923; 5-year IF = 2.228.

3. Maseko, I.*, Ncube, B., Mabhaudhi, T., Tesfay, S., Chimonyo, V.G.P., Araya, H. T., Fezzehazion, M. and Du Plooy, C.P. 2019. Nutritional quality of selected African leafy vegetables cultivated under varying water regimes and different harvest. South African Journal of Botany 126, 78-84. https://doi.org/10.1016/j.sajb.2019.06.016. IF = 1.442; 5-Year IF = 1.594.

4. Maseko, I.*, Ncube, B., Mabhaudhi, T., Tesfay, S., Chimonyo, V.G.P., Araya, H. T., Fezzehazion, M. and Du Plooy, C.P. 2019. Moisture stress on physiology and yield of some indigenous leafy vegetables under field conditions. South African Journal of Botany 126, 85-91. https://doi.org/10.1016/j.sajb.2019.07.018. IF = 1.442; 5-Year IF = 1.594.

5. Maseko, I.*, Mabhaudhi, T., Ncube, B., Tesfay, S., Araya, H. T., Fezzehazion, M., Chimonyo, V.G.P., Ndhlala, A.R. and Du Plooy, C.P. 2019. Postharvest drying maintains phenolic, flavonoid and gallotannin content of some cultivated African Leafy Vegetables. Scientia Horticulturae 225, 70-76. https://doi.org/10.1016/j.scienta.2019.05.019. IF = 1.760; 5-year IF = 1.954.

6. Govender, L.*, Pillay, K., Siwela, M., Modi, A.T. and Mabhaudhi T. 2019. Consumer perceptions and acceptability of traditional dishes prepared with provitamin A-biofortified maize and sweet potato. Nutrients 11, 1577; doi:10.3390/nu11071577. IF = 4.171; 5-Year IF = 4.813.

7. Govender, L.*, Pillay, K., Siwela, M., Modi, A.T. and Mabhaudhi T. 2019. Improving the dietary Vitamin A content of rural communities in South Africa by replacing non-biofortified white

maize and sweet potato with biofortified maize and sweet potato in traditional dishes. Nutrients, 11, 1198; doi:10.3390/nu11061198. IF = 4.171; 5-Year IF = 4. 813.

8. Chibarabada T.P.*, Modi A.T. and Mabhaudhi T. 2019. Water use of selected grain legumes in response to varying irrigation regimes Water SA 45, 110-120. http://dx.doi.org/10.4314/wsa.v45i1.13. IF = 0.851; 5-Year IF = 1.052.

9. Mabhaudhi T., Chibarabada T.P.*, Chimonyo V.G.P, Murugani V.G., Pereira L.M., Sobratee N., Govender L., Slotow R and Modi A.T. 2019. Mainstreaming indigenous crops into food systems: A South African perspective. Sustainability 11, 172; doi:10.3390/su11010172. IF = 2.075.

10. Dladla L.N.T.*, Modi A.T., Mabhaudhi, T. and Chibarabada T.P. 2019. Yield, water use and water use efficiency of sweet potato under different environments. Acta Hort. 1253: 287-294. DOI: 10.17660/ActaHortic.2019.1253.38

11. Mabhaudhi T., Chibarabada T.P.* and Modi A.T. 2019. Nutritional water productivity of selected sweet potato cultivars (*Ipomoea batatas* L.). Acta Hort. 1253: 295-302. DOI: 10.17660/ActaHortic.2019.1253.39

12. Maseko I.*, Mabhaudhi T., Beletse Y.G., Nogemane N., Du Plooy C.P. and Modi A.T. 2019. Growth and yield responses of *Amaranthus cruentus, Corchorus olitorius and Vigna unguiculata* to nitrogen application under drip irrigated commercial production. Acta Hort. 1253: 303-310. DOI: 10.17660/ActaHortic.2019.1253.40

13. Chibarabada, T.P.*, Modi, A.T. and Mabhaudhi, T. 2018. Adaptation and productivity of selected grain legumes in contrasting environments of KwaZulu-Natal, South Africa. International Journal of Plant Production 12: 169-180. DOI 10.1007/s42106-018-0017-z. IF = 0.961; 5-Year IF = 1.285.

14. Chibarabada, T.P.*, Modi, A.T. and Mabhaudhi, T. 2017. Nutrient content and nutritional water productivity of selected grain legumes in response to production environment. Int. J. Environ. Res. Public Health 14, 1300 doi:10.3390/ijerph14111300. IF = 2.145; 5-Year IF = 2.608.

15. Govender, L.*, Pillay, K., Siwela, M., Modi, A. and Mabhaudhi, T. 2017. Food and nutrition insecurity in selected rural communities of KwaZulu-Natal, South Africa – linking human

nutrition and agriculture. Int. J. Environ. Res. Public Health 14, 17; doi:10.3390/ijerph14010017. IF = 2.145; 5-Year IF = 2.608.

16. Chibarabada, T.P.*, Modi, A.T. and Mabhaudhi, T. 2017. Expounding the value of grain legumes in the semi- and arid tropics. Sustainability 9, 60; doi:10.3390/su9010060. IF = 2.075; 5-Year IF = 2.177.

17. Mabhaudhi, T., Chibarabada T*. and Modi, A. 2016. Water-food-nutrition-health nexus: Linking water to improving food, nutrition and health in Sub-Saharan Africa. Int. J. Environ. Res. Public Health 13, 1-19. IF = 2.145; 5-Year IF = 2.608.

B. Other publications

18. Govender, L.*, Pillay, K., Siwela, M., Modi, A.T. and Mabhaudhi T. 2019. Rediscovering indigenous crops. RESOURCE (Special Issue), November/December, 16 (6), 7-8.

19. Mainstreaming of neglected and underutilised crop species in South Africa. Policy Briefing Note. Sustainable and Healthy Food Systems programme. https://shefsglobal.lshtm.ac.uk/wp-content/uploads/2019/09/Underutilised-Crops-Brief-SHEFS-FINAL.pdf

C. Theses

1. Dladla, Ladyfair Ntokozo Thobekile. 2017. Nutritional and water productivity of sweet potato. MSc Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa
2. Shelembe, Pretty Jabulisile. 2017. Seed quality and yield of selected traditional and commercial crops: vegetable water use and nutritional productivity perspectives. MSc Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa
3. Chibarabada, Tendai Polite. 2018. Water use and nutritional water productivity of selected major and underutilised grain legumes. PhD Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa
4. Maseko Innocent. 2019. Pre and Post-harvest response of selected indigenous leafy vegetables to stress. PhD Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa
5. Akinola Racheal. 2019. Exploring the potential of Amaranth in mainstream South African diets. MSc thesis at Stellenbosch University, Cape Town, South Africa

6. Mbali Gumede. 2019. Common bean seed quality: Comparing sourced and harvested material in response to different seeding rates. MSc Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa
7. Govender Laurencia. 2020. The potential of provitamin a-biofortified maize and sweet potato, and bambara groundnut for improving the nutritional status of rural communities in KwaZulu-Natal, South Africa. PhD Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa
8. Sihle Shelembe. 2020. Water use and water nutrient productivity of Taro landraces. MSc Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa

D. Conference presentations

1. Siwela, M., Govender, L., Pillay, K., Modi, A.T and Mabhaudhi. T. 2019. Enriching the nutritional values of traditional meals in KwaZulu-Natal, South Africa by incorporating provitamin A-biofortified maize and orange sweet potatoes. AACCI meeting (Cereals & Grains 19) that will be held in Denver Colorado from the 3-5 November 2019.
2. Govender, L., Pillay, K., Siwela, M., Modi, A.T and Mabhaudhi. T. 2019. Dietary patterns of rural communities of KZN and their willingness to adopt biofortified traditional dishes. SAAFoST Congress that was held in Johannesburg from the 1-4 September 2019.
3. Chibarabada, T.P., Modi, A.T. and Mabhaudhi T. 2018. Options for improving water productivity: a case study of bambara groundnut and groundnut. 19th WaterNet/WARFSA/GWP-SA Symposium, 31 October-2 November 2018, Avani Victoria Falls Hotel, Zambia.
4. Govender, L., Pillay, K., Siwela, M., Mabhaudhi, T. and Modi, A.T. 2018.Consumer perceptions of composite dishes made with biofortified maize and sweet potato. 19th World Congress of Food Science and Technology in Mumbai, India from the 23-27 October 2018.
5. Siwela, M., Govender, L., Pillay, K., Mabhaudhi, T, and Modi, A.T. 2018. Comparative consumer acceptance of creamed-fleshed and biofortified orange-fleshed sweet potato. 19th World Congress of Food Science and Technology in Mumbai, India from the 23-27 October 2018.

6. Govender, L., Pillay, K., Siwela, M., Mabhaudhi, T. and Modi, A.T. 2018. An assessment of the nutritional status of four rural communities in KwaZulu-Natal, South Africa. Nutrition Congress that was held in Johannesburg from the 5-7 September 2018.
7. Dladla N.T., Modi, A.T., Mabhaudhi, T. and Chibarabada T.P. 2018. Yield, water use and water use efficiency of sweet potato under different environments. The 30th International Horticultural Congress, 12-16 August 2018, Istanbul-Turkey.
8. Mabhaudhi, T., Chibarabada, T.P. and Modi, A.T. 2018. Nutritional water productivity of selected sweet potato varieties. The 30th International Horticultural Congress, 12-16 August 2018, Istanbul-Turkey.
9. Chibarabada, T.P., Modi, A.T. and Mabhaudhi T. 2018. Yield, water use and productivity of selected grain legumes in a controlled environment. African Combined Conference, Cape Town, South Africa, 14-18 January 2018.
10. Chibarabada, T.P., Modi, A.T. and Mabhaudhi T. 2017. Nutritional water productivity of tropical grain legumes. WUN Symposium cum Research Summit on Impacts of Grain Legume Research & Development in Developing Countries, 8-17 June 2017, Chinese University of Hong Kong, Hong Kong
11. Chibarabada, T.P., Modi, A.T. and Mabhaudhi T. 2017. Water use of crops and nutritional water productivity for food production, nutrition and health in poor rural communities. Combined Congress 23-25 January 2017, Klein Kariba, Limpopo, South Africa