FARMER PERCEPTIONS AND THE AGRONOMIC POTENTIAL OF PROVITAMIN A-BIOFORTIFIED MAIZE ON SMALLHOLDER FARMING SYSTEMS OF KWAZULU-NATAL, SOUTH AFRICA

By

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Submitted in fulfillment of the requirements for the degree of Doctor of Philosophy (CROP SCIENCE)

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Preface

The research contained in this thesis was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research was financially supported by National Research Foundation (NRF) Grant 94910 and University of KwaZulu Natal.

The content of this work have not been submitted in any form to another university and , except where the work of others is acknowledged in the text, the results reported are due to the investigations by candidate.

This research was permitted through University of KwaZulu-Natal, Ethical clearance number: HSS/0184/016D

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Signed: Prof A.T Modi

Date:

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Signed: Prof U. Kolanisi

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DECLARATION

I Mthokozisi Kwazi Zuma, declare that:

(i) the research reported in this thesis, except where otherwise indicated or acknowledged, is my original work;

(ii) this thesis has not been submitted in full or in part for any degree or examination to any other university;

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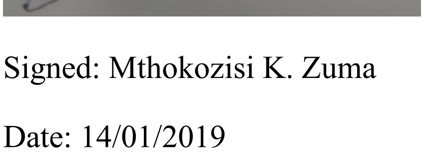

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Date: 14/01/2019

Acknowledgements

National Research Foundation (NRF) is highly acknowledged for funding this study together with the University of KwaZulu-Natal.

I have special thanks to all stakeholders who supported this PhD study especially the farmers from Bulwer and KwaDlangezwa. The efforts baba Msomi and Shandu put through the study period is well acknowledged.

Dr. Ndumiso (Mfulongashi) Ncobela, Mlungisi Gwala, Njabulo Mbedu, Dr. Dlamini, Dr. Mpendulo, Gwazaphansi, Siyanda Mungwe and Mr Mdu for motivational and friendly support

My life partner (Samkelisiwe Sibiya) that for the everyday support you gave to me during this project

Enumerators and friends (Sunnyboy, Sbusiso Shabalala, Boy Mchunu) thanks for field and data assistance.

Profs Modi and Kolanisi thanks for support and guidance

I also thank friends and family who supported during hard times and stressful times of the projects.

Everyone not listed I thank you all.

Lastly, thank God for keeping me alive and active during the course of the study

Dedication

This work is highly dedicated to my late brother Dumsani H. Zuma, Mother E. G Zuma who always wished I completed my studies while they are alive.

My Daughter Kwandokuhle Luthabo Zuma whom I believe one day will read this and be proud to invest in education too.

To God almighty and all researchers.

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GENERAL ABSTRACT

Pro-vitamin A biofortified maize (PVABM) has the potential to reduce Vitamin A deficiency (VAD) for the vulnerable groups of Sub Saharan Africa (SSA). It is therefore important to understand the willingness of farmers to incorporate PVABM into their farming systems and the agronomic potential of these varieties under different environmental conditions to motivate their introduction in smallholder farming systems. The objectives of the study were to (i) determine smallholder farmer perception of the incorporation of PVABM in in two distinctly different climatic regions of KwaZulu-Natal, South Africa, (ii) evaluate production potential and selected seed quality characteristics of PVABM compared with common maize varieties across two seasons (2015/16 and 2016/17) and (iii) access the potential acceptability of PVABM as part of traditional household diet by smallholder farmers. Results showed that farmers have positive perceptions of the incorporation of PVABM into their farming systems and there was a willingness to adopt these varieties. With respect to seed quality, although there were no significant pro-germination characteristics as determined by tetrazolium test for metabolic activity, PVABM showed better germination vigour index and final germination. Germination performance was significantly correlated with crop establishment during field trials over both seasons. This was shown by highly significant differences observed for plant growth and chlorophyll content index in both study areas across two seasons. However, the study showed no significant differences in biomass and grain yield. Sensory evaluation showed that PVABM traditional foods (green mealies and cooked maize meal) were accepted for consumption and the farmers expressed the willingness to consume PVABM in their diets. The study indicated that PVABM can be accepted by farmers into farming systems. It is recommended that plant breeding to identify genetic differences and potential to improve PVABM for a wide range of agro-ecological conditions in regions where poor smallholder farmers grow maize is performed with a view to improve food security.

CHAPTER 1. INTRODUCTION

1.1 Background

Maize (*Zea mays,* L.) belongs to the grass family Poaceae (Gramineae) and is also known as corn (Pillay, 2011). Maize is one of the staple crops in the African continent and one of the three most important crops worldwide (Mabhaudhi, 2009). Maize plays a major role in the livelihoods of the poor families in the sub Saharan Africa region (Khoza, 2012). In these regions maize is used for human consumption while in industrialized countries maize serves many purposes such as feed, fuel, food and as raw material for industrial products (Khoza, 2012; Pillay, 2011). It is also considered as one of the profitable crops due to higher potential yields (Iqbal, 2012). Maize is an important source of carbohydrate, protein, iron, vitamin B, and minerals (Mabhaudi, 2009). One major concern with maize is the unbalanced nutritional composition caused by the lack of vitamin A carotenoids (Govender, 2014). This could justify the existence of malnutrition in countries were maize is the staple crop.

Vitamin A deficiency (VAD) has been described as one of the major micronutrients deficiencies in South Africa (Govender, 2014). Vitamin A plays vital roles in human beings and these include immune function, vision ocular health and reproduction (Howe and Tanumihardjo, 2006). Vitamin A can be accessed through certain foods types and which most of the low socio economics communities cannot access. This is due to the financial and the expensiveness of the vitamin A supplementary products (Pillay, 2011; Govender, 2014). In most rural communities of South Africa people consume starchy staple foods made from maize and less have access to vitamin rich vegetables and animal products (Govender, 2014). Therefore as a strategy to alleviate VAD, breeders have opted for the biofortification of staple crops such maize, sweet potatoes and maize (Stevens and Winter-nelson, 2008). Since maize is a staple crop, it biofortification has the potential to overcome VAD in South Africa (Pillay, 2011).

Previous studies have shown that Provitamin A-biofortified maize a product of breeding maize with high provitamin content has the potential to overcome VAD but there is scientific gaps that needs to be addressed (Pillay et al., 2014). Some studies have also shown that there potential for provitamin A-biofortified maize to be accepted by rural communities (Stevens and Winter-Nelson, 2008). The acceptance of provitamin A-biofortified maize by smallholder famers in rural communities will also depend on it agronomic performance. Farmers attitudes and perceptions towards incorporation of these maize varieties into their smallholder farming systems are worth of importance in the adoption new yellow/ orange maize varieties.. In rural communities of South Africa especially KwaZulu-Natal and Eastern Cape yellow maize is regarded as inferior and is most used for animal feeding (Governder, 2014). The adoption of yellow/orange provitamin A-biofortified maize by smallholder farmers in these communities may be a challenge. Therefore, there is a need for assessing the farmer's perception and willingness towards introduction of provitamin A-biofortified maize in smallholder farming systems in rural communities.

Given all the benefits of provitamin A-biofortified maize, researchers should not overlook the current smallholder farming systems in rural communities where farmers have been utilizing local maize landraces in their marginal agricultural land. Therefore, farmers will need to be well convinced in introducing provitamin A-biofortified maize in their farming systems. A study to compare the agronomic potential of provitamin A-biofortified maize with local maize landraces could contribute in motivating the acceptability of biofortified maize in smallholder farming systems and improving the scientific knowledge of provitamin A-biofortified maize agronomic performance.

1.2 Aim and objectives

The aim of the study is to assess farmer's perception towards the incorporation of provitamin A-biofortified maize into their smallholder farming systems and secondly, to establish the agronomic potential of provitamin A maize in smallholder farming systems of KwaZulu- Natal, South Africa.

The specific objectives are:

1. To assess farmers' perception on the incorporation of provitamin A biofortified maize in smallholder farming systems of KwaDlangezwa and Bulwer, KwaZulu Natal South Africa.
2. To evaluate seed quality characteristics (physiological) and early establishment of provitamin A biofortified maize varieties compared with common maize varieties.
3. To determine the response of provitamin A biorfotiified maize cultivars (commercial and non- commercial) under different agro-ecological conditions across two seasons (2015/16 and 2016/17).
4. To assess the acceptability of PVABM as common household meals by smallholder farmers in Bulwer, South Africa

CHAPTER 2. THE POTENTIAL OF INTEGRATING PROVITAMIN A BIOFORTIFIED MAIZE IN SMALLHOLDER FARMING SYSTEMS: A REVIEW ON NUTRITIOUS FOOD FOR THE FUTURE FOR THE MALNOURISHED IN SOUTH AFRICA

Zuma, M. K., Kolanisi, U., & Modi, A. T. (2018). The Potential of Integrating Provitamin A-Biofortified Maize in Smallholder Farming Systems to Reduce Malnourishment in South Africa. International journal of environmental research and public health, 15(4), 805.

Abstract

Biofortification interventions have the potential to combat malnutrition. This review explored the use of provitamin A-biofortified maize (PVABM) as a vitamin A deficiency (VAD) reduction agricultural-based strategy. Maize has been identified as one of the key staple crops for biofortification to reduce hidden hunger in Africa. Most nutrition interventions have not been successful in reducing hunger because rural communities, who mainly rely on agriculture, have been indirectly excluded. The biofortification intervention proposed here aims to be an inclusive strategy, based on smallholder farming systems. Vitamin A is a micronutrient essential for growth, immune function, reproduction and vision, and its deficiency results in VAD. VAD is estimated to affect more than 250 million children in developing countries. In Africa, especially sub-Saharan Africa, maize is a staple food for rural communities, consumed by most household members. Due to carotenoids, PVABM presents an orange color. This color reportedly leads to negative perceptions about PVABM varieties. The perceived agronomic traits of this maize by smallholder farmers have not been explored. Adoption and utilization of PVABM varieties relies on both acceptable consumer attributes and agronomic traits, including nutritional value. It is therefore important to assess farmers' perceptions of and willingness to adopt the varieties, and the potential markets for PVABM maize. It is essential to establish on-farm trials and experiments to evaluate the response of PVABM under different climatic conditions, fertilizer levels and soils, and its overall agronomic potential. For the better integration of PVABM with smallholder farming systems, farmer training and workshops about PVABM should be part of any intervention. A holistic approach would enhance farmers' knowledge about PVABM varieties and that their benefits out-compete other existing maize varieties.

Keywords: Provitamin A-biofortified maize; vitamin A deficiency; maize

2.1. Introduction

Maize (*Zea mays*, L.), also known as corn, belongs to the grass family Poaceae (*Gramineae*) (Mazvimpakupa et al., 2015). Maize is one of the three most important crops worldwide and the major staple crop on the African continent (Kruger et al., 2009). In the sub-Saharan Africa (SSA) region, maize plays a significant role in reducing poverty and improving the food security status for poor families (Hu et al., 2008). In the sub-Saharan Africa region, maize is used for human consumption, while in developed countries it is used for profit making from feed, fuel and other raw materials for industrial products (Hu et al., 2008; Odendo et al., 2001). It has been reported that maize alone, without following a diversified diet, encourages food and nutrition insecurity. In most rural communities in South Africa, people consume starchy staple diets made from maize, with limited or no diversification, leading to unbalanced diets (Govender, 2014). Maize is characterized by anti-nutritional factors, such as phytate, which is a resistant starch that hinders maize nutrient availability for human consumption (Mabhaudhi et al., 2013). This anti-nutritional factor binds essential nutrients, leading to nutrients not being fully accessible or digested, while other factors inhibit certain enzymes needed for normal functioning or the absorption of minerals and vitamins by humans (Mabhaudhi et al., 2013). This could justify the existence of hidden hunger in countries where maize is the staple crop.

Hidden hunger is a global micronutrient disease, of which there are more than 925 million hungry people in the world (Bouis and Saltzman, 2003). In the 21st century, malnutrition mainly manifests itself as hidden hunger, as opposed to under-nutrition, which used to be the case in previous centuries (19th and 20th centuries). Vitamin A deficiency (VAD) has been reported as one of the major micronutrient deficiencies and a challenge beyond the Millennium Developmental Goals (MDGs) (Bouis and Saltzman, 2003). Vitamin A plays a vital role in supporting immune function, vision, ocular health, and reproduction (Awobusuyi et al., 2016). There are two types of vitamin A: preformed (animal-based) and provitamin A (plant-based) (Bious, 2003). Provitamin carotenoids in foods such as β-carotene are major sources of vitamin A (Aluru et al., 2008). Most provitamin A carotenoids are available in green, orange and yellow crop tissues (Ntila et al., 2018; Egesel at al. 2003). Unfortunately, these food sources are usually costly, thus inaccessible to low income communities (Howe and Tanumihardjo, 2006; Akinnouye and Modi, 2015). Therefore, the enhancement of food crops, especially staple crops, through biofortification can lead to the production of food with sufficient carotenoids to combat VAD.

HarvestPlus organization introduced the biofortification of food plants to improve vitamin A content in staple crops, such as maize, sweet potatoes and wheat (Egesel at al. 2003), with the aim of alleviating hidden hunger in developing countries, such as South Africa. One of the products they produce is provitamin A-biofortified maize (PVABM); a product of breeding maize with a high provitamin A content to combat VAD in Africa. Furthermore, other potential biofortification products are beans (Iron), pearl millet (Iron), cassava (Vitamin A), sweet potatoes (Vitamin A), rice (Zinc) and wheat (Zinc).

A number of studies have been conducted looking at farmers' perceptions, consumer acceptance, breeding and the potential impact of PVABM in combating micronutritional malnutrition. These studies have primarily been conducted in the sub-Saharan region, as per the HarvestPlus programme. Studies conducted on PVABM have shown that there is the potential for this maize to be accepted by rural communities (Egesel at al. 2003). Along with all the previously noted benefits of PVABM, researchers should not overlook the current smallholder farming systems in rural communities, where farmers utilize the local maize landraces in their marginal agricultural land. Farmers will need to be convinced to introduce PVABM into their farming systems. The aim of this review was to explore the potential for incorporating PVABM into smallholder farming systems. The review firstly focuses on the agronomic characteristics of maize as a staple crop in South Africa. Then, the potential of PVABM for reducing VAD, the nutritive value of PVABM, its drought tolerance, and perceptions surrounding PVABM as a food source for rural households, will be discussed.

2.2. Maize as a staple crop in South Africa

Maize (*Zea mays*) is a staple crop in South Africa (Mabhaudhi et al., 2013) and a source of carbohydrates for both humans and animals (Akinnouye and Modi, 2015). In South Africa, maize is grown throughout the country under different climatic conditions. The major producing areas of maize are North West, Free State and Mpumalanga, while in Kwazulu-Natal, it is mostly produced for household consumption (Akinnouye and Modi, 2015). Smallholder farmers prefer to produce white maize for their household consumption and sell it as green maize (Akinnouye and Modi, 2015). On the other hand, yellow maize is mostly produced for animal feed and for brewing traditional drinks.

Many smallholder farmers in South Africa still produce local maize landraces (Mabhaudhi et al., 2013). Regardless of the high yielding varieties bred by researchers, these farmers continue to use local varieties in their farming systems. This justifies the importance of choice and farmer preference as a selection criterion for maize variety. Maize landraces have certain characteristics (phenotypical, genotypic and morphological) that allow them to adapt to the different climatic conditions in the country (De Groote et al., 2010). These characteristics are the motivation smallholder farmers have for keeping their landraces.

Most rural households depend on natural resources for their farming and basic living needs (Pfeiffer and McClafferty, 2007) and in rural areas of South Africa, maize is produced under these natural resources. It is only grown during the rainy season (October to April) due to the inability of smallholder farmers to access water for irrigation (Mabhaudhi and Modi, 2010). Maize in South Africa is usually planted during the growing season, but the specific dates differ with farmer's preference and area (Mabhaudhi and Modi, 2010). According to Pillay (2011), October and November are optimal planting dates for maize in South Africa. Subsistence farmers wait for the first rains to plant their maize during the growing season because their production is a dryland system. Subsistence farmers hardly take to note maize population and planting densities, however these are key determinants of yield. A high plant population results in plant competition for light and space, which can have a negative impact on plant growth and yield. Over recent years, smallholder farm maize production has been successful and has contributed significantly to household financial income and as a food source. However, nutrient balance remains questionable, given the major reliance on and high consumption of maize by rural households.

2.3. Agronomy characteristics of maize production

2.3.1. Seed establishment and maize growth

Seed establishment consists of three stages: germination, emergence and early establishment (Lividini and Fiedler, 2015). Seed establishment is environmentally sensitive (Oerke, 2006); therefore, knowledge of environmental conditions is important to note before planting because these are the determinants of germination. Seed characteristics are an important determinant of seed establishment and the environments in which the seed can establish on. Seed establishment is an important determinant of potential planting date. Poor germination and seedling growth can lead to poor maize grain yields (Mazvimbakupa et al., 2015). Plant establishment influences the growth of a maize crop. Poor maize establishment can result in low maize grain yields. Therefore, it is critical for PVABM maize to have good seed establishment in order to produce better maize yields. Higher PVABM grain yields could reduce the existence of hidden hunger and VAD in South Africa.

2.3.2. Plant density, planting date and maize production

The best maize planting conditions are frost-free environments with warm temperatures and high altitudes areas (Pillay, 2011). Mazvimbakupa et al. (2015) found that average maize yield in high altitude areas was higher than the tropics under field conditions. Climatic factors and genetic variations play a huge role, from plant growth to maize yield. Maize thrives in well-drained soils, but it can also be produced in well-aerated loam and sandy loam soils (Pillay, 2011). Maize has high nutrient demands and the crop is sensitive to soil acidity (Mabhaudhi and Modi, 2010). Maize is also sensitive to nutrient deficiencies in the soil (e.g., nitrogen, phosphorus and potassium). According to Odendo and Odongo (2001), farmers from low income communities tend to use maize–legume intercropping to improve nutrient availability in the soil. Legumes are known to fix nitrogen in the soil and, therefore, their intercropping benefits maize. Farmers use different intercropping systems as a strategy to avail nutrients and reduce pest populations; these mixtures may be bean–maize or cowpea–maize (Smith, 2006).

2.3.3. Effects of drought on maize production

Plant growth is influenced by several factors, including soil fertility, variety, environment, plant density and planting date (Govender et al, 2015). Therefore, it is important to understand how physiological and morphological interactions occur in a plant in certain environments and to understand how to apply proper management practices for better growth and maximized grain yields. Vegetative growth of maize is sensitive to drought, just like other grass species and this sensitivity can lead to reduced growth (Govender et al, 2015). Less grain yield can be expected when maize is produced under water stressed conditions.

South Africa is a water-scarce country (Mabhaudhi and Modi, 2010) and maize is sensitive to drought during growth (Lobell et al, 2014). This is one of the key limiting factors for rain-fed agriculture, which is usually the type of agriculture practiced by smallholder farmers in low income communities. Drought can have a large influence on plant performance as it can affect germination duration and growth rate and can have a negative impact on seedling establishment (Akinnouye and Modi, 2015). Poor seed establishment and poor growth results in a decline in maize grain yield. As a possible solution to drought stress, the use of cultivars with improved drought tolerance may be the only affordable option for many small-scale farmers (Burchi et al., 2011). Cakir (2004) showed that water deficiency strongly affects the different growth stages of corn and that the degree of yield reduction depends on the severity of the water stress. The instability of maize yields caused by drought can have impact on food security at a household level, given the important of maize as a staple crop in rural communities. Similar to maize growth, grain yield is also susceptible to drought (Akinnouye and Modi, 2015); therefore, different yields can be expected for different maize varieties, including the drought resistant breeds.

Global climate change could lead to temperature rises and changes in rainfall distribution (Cakir, 2004). This could produce significant yield losses as a result of drought, especially for smallholder farmers in low income communities who do not have sufficient resources to practice irrigation farming. As a result of drought, farmers will be forced to adopt drought-resistant crops, which come at higher prices compared to the local landraces where subsistence farmers normally produce their maize (Kiria et al., 2010). PVABM is thought to be a drought resistant crop (Bouis and Saltsman, 2017). Moussa and Abdel-Aziz (2008) found that drought-resistant breeds have different responses to drought. These findings suggest that the response of PVABM to drought is dependent on the drought status of the crop and the environment the plant is grown.

2.3.4. Constraints to maize production

2.3.4.1. Pests

Maize loss to pests remains a huge challenge, especially for low income farmers who have less access to crop protection resources (Nestel et al., 2006). Losses have an impact on income, thus affecting the food security status of farmers' households. Sub-Saharan countries have implemented different strategies to combat maize production losses from pests (De Groote et al., 2010). However, these pests still remain a major challenge, regardless of subsidizing interventions. Stem bores rank among the most troublesome pests for maize producers (Nestel et al., 2006). They are estimated to cause about 25–45% of the losses during maize cultivation and 30–90% during postharvest and storage. Due to the high losses caused by stem bores, researchers have been prompted to produce resistant maize breeds. However, these resistant hybrids cannot solve the problem, since stem borer can become resistant to them (Shackleton et al., 2001). A good example is that of *Busseola fusca* (Lepidoptera: *Noctuidae*) resistance to *Bacillus thuringiensis* (Bt) maize (Kanampiu et al., 2003; Fischer et al., 2015). The Bt gene does not control the adult larvae, therefore, it has a reduced ability to control stem bores (Denning et al., 2009). It can also be argued that smallholder farmers with poor resources struggle to purchase these seeds due to high market prices, and the seeds cannot be recycled due to the reduced yield over several years.

2.3.4.2. Weeds

Striga is one of the most common, problematic weeds in maize production in Africa and it also affects many cereal grain crops (Harvestplus, 2015). Smallholder farming systems are most vulnerable to the infestation of crops by striga weeds due to the lack of knowledge of how to effectively control this weed and the correct resources to reduce the infestation. Various weeds affect maize production in South Africa, and they can be reduced through different control measures.

2.4. Vitamin A deficiency: a food and nutrition insecurity challenge

Child malnutrition, mortality rates and disability are continuous challenges beyond the MDGs that require urgent attention. Despite various supplementation programmes, pregnant women and children under 5 years remain vulnerable to hidden hunger and vitamin deficiencies, such as VAD (Pillay, 2011). VAD has become more than just a public health problem, as its severe effects have negative implications for child well-being and reduce children's future potential to actively contribute to the economy of their country. The risks associated with VAD and its effects introduce unjustified expenditure, comparable to if children with VAD were disabled. This results in increased government subsidies, and in South Africa, increases the economic burden of social grants.

United Nations Children's Fund (UNICEF, 2014) reported the successful delivery of vitamin A supplements, through the use of integrated child health events, such as child health days, as well as immunization, in some of the least developed countries. Nevertheless, VAD still continues to be a challenge. As shown in Figure 2.1, there is only 62% of total VAD coverage in eastern and southern Africa.

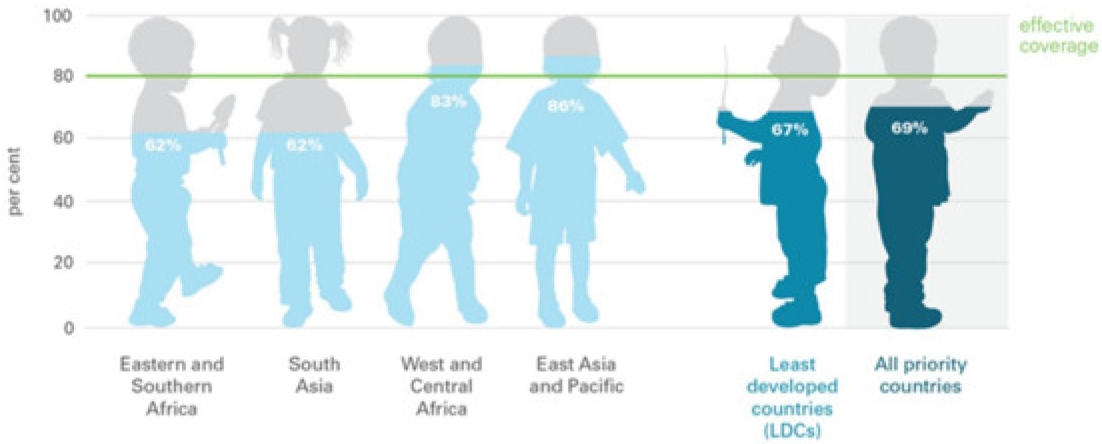

Figure 2.1. Vitamin A deficiency among the least developed countries (United Nations Children's Fund (UNICEF, 2014).

2.5. Vitamin A deficiency in South Africa

Pillay et al. (2011) confirmed that VAD is an underestimated challenge for the African continent, affecting about 33 million pre-school age children. Malnutrition has been reported to exist in South Africa (Sithole, 2014). Most notable is the rise in micronutrient deficiencies, which are reported as hidden hunger. VAD is a rising micronutrient deficiency that is known to affect children, predominantly. VAD is mostly present in rural communities, where staple crops, such as maize, are consumed on a daily basis. Govender (2014) reported that child VAD doubled in South Africa between 1994 and 2006.

Unfortunately, pregnant women and children are most vulnerable to VAD. In South Africa, the number of people affected by VAD is increasing and high incidences of the deficiency have been reported in rural compared to urban communities (Odunitan-Wayas et al., 2016). VAD increases the chance of disability and mortality. Despite the achievement of the Millennium Developmental Goals, the VAD situation still remains a significant challenge (Odunitan-Wayas et al., 2016). In South Africa, there has been no or very little significant difference observed in reducing VAD. The South African government has implemented different strategies to combat VAD in the past 20 years. However, these interventions have had mixed efficacy, which has led to their non-significant impact reducing VAD.

2.6. Remediation strategies applied to reduce vitamin A deficiency in South Africa

The South African Government has implemented various strategies to combat VAD, including dietary diversification, vitamin A supplementation and fortification. These strategies have not been successful enough to address VAD for various reasons (Pillay et al., 2013). Pillay et al. (2013) and Govender et al. (2015) remark that in South Africa, supplementation programmes and the purchasing of vitamin supplements, which are expensive for low income communities (Govender, 2014), have not been successful, and they recommended an agricultural-based intervention targeting poor communities. The authors further argue that low income communities have limited access to commercial vegetables and animal products that are rich in vitamin A (Meenakshi et al., 2012). Consequently, monotonous maize-dominated diets are usually the only meals available and accessible to most poor households.

The national gazette Act No 54 of 1972: Foodstuffs, Cosmetics and Disinfectants mandated a food fortification programme aimed at improving staple crop vitamins and nutrients (Mbata et al., 2009). This did not work for the country due to the crops being expensive for low income households. Even with this Act, the maize consumed in South Africa had imbalanced nutrients. In South Africa, white maize is predominantly consumed, while yellow maize is used for animal feed. Therefore, the Act was not successful because of consumer perceptions about the product and the crops they consume. Food fortification as an intervention was also susceptible to a number of other factors that hindered its success.

Biofortification is a strategy of addressing VAD and other micronutrient deficiencies in Africa that was introduced by HarvestPlus. The introduction of biofortification as a strategy for addressing VAD in the African continent led to the idea of improving the vitamin A content of maize and sweet potatoes (Harvestplus, 2015). Biofortified sweet potatoes have already been successfully introduced in South Africa (Moloto et al., 2018), but PVABM has not been introduced as an intervention to VAD. However, the successful introduction of PVABM in other southern African countries, such as Zambia, instils hope for South Africa too.

2.7. Biofortification of new cultivars for improved vitamin A content

Biofortification is a relatively new agricultural-based strategy to reduce hidden hunger in the SSA region, especially for low income communities (Campos et al., 2004, Nuss et al., 2010). Rural communities are the main targeted beneficiaries of PVABM (Mukanga et al., 2011). Biofortification of staple crops ensures improved nutrient supply to poor households though the most preferred diet (Bious and Saltzman, 2003; Govender, 2014; Mabhaudhi, 2009). The mineral improvement in biofortified staple crops allows these crops to be resistant to certain plant diseases (Bouis et al., 2011), especially fungal root diseases. Moreover, the planted crops are more likely to survive the seedling stage and their initial growth is faster. Bouis et al. (2017) suggested that the biofortification of provitamin A maize improves crops' ability to resist drought, thus improving the vitamin A composition of the grains. Tumuhimbise et al. (2013) also recommended that breeding for biofortification improves drought resistance, vitamin A content and disease tolerance (Table 2.1). Therefore, PVABM is of great benefit to farmers in rural areas where diseases are a major challenge to plant production and during times where farmers are late planting. PVABM should be easily incorporated because of this potential. In South Africa, sweet potatoes as a biofortified crop have been successfully introduced and well-accepted by consumers of different living standards (Mbata et al., 2009). However, the level of acceptance for PVABM may differ.

Table 2.1. Different biofortified staple crops in different countries with their agronomic and micronutrient performance.

Staple crop	Targeted nutrient	Targeted Country	Agronomic traits
Bean	Iron	DR Congo, Rwanda	Virus resistance, heat and drought Tolerance
Cassava	Vitamin A	DR Congo, Nigeria	Disease resistance
Maize	Vitamin A	Nigeria, Zambia	Disease resistance, drought tolerance
Pearl Millet	Iron	India	Mildew resistance, drought tolerance
Rice	Zinc	Bangladesh, India	Disease and pest resistance, cold and submergence tolerance
Sweet Potato	Vitamin A	Mozambique, Uganda, South Africa	Disease resistance, drought tolerance, acid soil tolerance
Wheat	Zinc	India, Pakistan	Disease and lodging resistance

Source: Bious et al. (2011); Pfeiffer and McClafferty, (2007)

2.8. Provitamin A-biofortified maize to reduce hidden hunger: food for the future

One of the advantages of PVABM is that it is cheaper compared to other vitamin A supplementations (Odendo et al., 2001). After crops have been bred and grown, there is a lower cost of production in subsequent years, given the appropriate storage conditions. Moreover, once maize has been produced at the farm level, there is no need for additional fortification or vitamin amendments in people's diets (Pillay et al., 2013).

Staple crops, such as maize, are used to prepare different meals in rural communities; therefore the improvement of nutrients will stabilize the nutrient composition within them (Moloto et al., 2018). Biofortification targets staple crops under smallholder farming systems (Meenakshi et al., 2012). Different maize products can be produced through PVABM to improve the acceptability and accessibility of vitamin A at the household level. The production of PVABM in rural communities, where maize is used for different products, can improve the local economy through people selling snacks, and can improve food security by allowing different meals to be consumed at different times, resulting in reduced VAD in children. There is no doubt that PVABM would improve the food security status of rural households and alleviate VAD (Pillay et al., 2013); however, before it can be incorporated into smallholder farming systems, the challenge is the willingness of smallholder farmers to accept PVABM and the acceptability of these products by consumers. Meenakshi et al. (2012) argued that the success of PVABM depends on the target population, which are rural or low income people and vulnerable groups (i.e., women and children), and if they accept these varieties or not. These authors also pointed out that rural communities usually confuse yellow maize with orange maize, which could be a major challenge given the perceptions around yellow maize.

PVABM has drawn interest from researchers in different fields across the African continent (Egesel et al., 2003; Harvestplus, 2015), including South Africa. PVABM has the potential to alleviate VAD, hidden hunger and improve food security in rural communities, where the target groups are mostly located. The carotenoid content in PVABM is crucial to addressing VAD.

2.9. Carotenoids in pro-vitamin A maize

Maize grain contains different types of carotenoids in the form of provitamin A (Govender et al, 2015) and are found in yellow and orange maize. Xanthophyll and carotenes result in the carotenoid pigments found in yellow and orange maize and are responsible for the endosperm color (yellow or orange). In PVABM, β-carotene and β-cryptoxanthin have been identified as the most abundant carotenoids, whilst α-carotene is present in smaller capacities (Pillay, 2011).

The carotenoids level is higher in dark orange maize compared to other color maize (De Groote et al., 2010). Dark orange maize has higher levels of carotenoids compared to other color maize (Table 2.2), however the orange and dark orange maize are not available for farmers and consumers yet. Pillay et al. (2013) argued that color does not really determine provitamin A content in maize because of variable accumulation in the maize kernel (seed coat, endosperm and germ).

Table 2.2. Carotenoid concentrations for different maize varieties (white, yellow, orange and dark orange).

Carotenoids (nmol/g)

Maize	Lutein	Zeaxanthin	β -cryptoxanthin	β -carotene	β -carotene
White	1.1 ± 0.01	0.09 ± 0.01	-	-	0.05 ± 0.002
Yellow	16.8 ± 0.6	5.4 ± 0.5	2.6 ± 0.4	0.44 ± 0.04	0.77 ± 0.14
Orange	15.7 ± 0.3	11.6 ± 0.3	5.4 ± 0.05	0.58 ± 0.02	5.6 ± 0.1
Dark orange	19.1 ± 4.5	11.8 ± 2.9	5.3 ± 0.7	1.53 ± 0.04	13.9 ± 0.7

Generally, yellow maize contains 0.25 to 2.5 µg/g dry weight (DW) of provitamin A, while PVABM contains higher levels, 15 µg/g DW, of provitamin A (Pillay, 2011), but is not yet available on the market.

2.10. Perceptions and other factors influencing the adoption of maize hybrids

Smallholder farmers usual do not adopt improved maize hybrids (Muzhingi et al., 2011). The main cause for this could be the lack of consideration of farmers' preference in the development of these hybrids. Farmers have different preferences and select maize for different traits and the most preferred trait for selection is yield. Farmers should be considered in the production of new hybrids, as their willingness to adopt and incorporate the product is important (Mbata et al., 2009). Stevens and Winter–Nelson (2008) assessed the acceptance of PVABM through taste and trading. Their findings showed that PVABM was accepted by consumers regardless of its orange color. However, these findings may vary between countries and regions. Nuss et al. (2010) observed similar findings. In their study, they observed that in Zambia, children easily adapt to orange maize (PVABM). However, this may not be the case amongst older groups (Awobusuyi et al., 2016) due to social pressures and diet. Pillay (2011) found that PVABM had the potential to alleviate VAD in Kwazulu-Natal, and their findings showed that orange PVABM maize was accepted by consumers, although white maize remained the most preferred maize type by adults and high school children. Govender et al. (2015) found that PVABM porridge was deemed to be acceptable by caregivers in Kwazulu-Natal. These findings show that preparing diverse meals and products can improve the acceptability of PVABM by consumers, thus reducing hidden hunger at different age levels. Beswa et al. (2016) suggested that PVABM mixed with amaranth leaf powder has the potential to produce a nutrient rich snack; however, the acceptability of these snacks by consumers is of concern.

De Groote et al. (2010) suggested that maize preference plays a major role in maize selection and that these attitudes are regional. Moreover, yellow maize in South Africa is believed to have less of an acceptable taste and is considered a drought crop (Mayer et al., 2008; Meenakshi et al., 2012). Yellow maize is perceived for animal consumption rather than human consumption, while white maize is used primarily for human consumption (Meenakshi et al., 2012). The orange color of PVABM could lead to farmers recommending it for animal consumption (De Groote et al., 2010; Khoza, 2012). These perceptions can be changed through the provision of breeding information and education regarding the benefits of orange maize. Alternatively, Odunitan-Wayas et al. (2016) reported that PVABM can be fed to indigenous and layer chickens as a way of improving vitamin A consumption through meat and egg consumption. Furthermore, their study showed that sensory characteristics had no influence on consumer preference. Animals can be used as a secondary source of vitamin A after feeding them biofortified maize, to balance diets (Odunitan-Wayas et al., 2016). The authors further suggest that this strategy could improve the production of PVABM for both human and animal consumption.

In southern African countries, the price of yellow maize is less than the price of white maize due to consumer preferences and the yellow maize market (Govender et al, 2015). Therefore, questions remain as to whether perceptions and prices of yellow maize could have an impact on PVABM. The low price of orange maize could encourage farmers to adopt the variety and incorporate it into their smallholder farming systems (Pillay et al., 2013). Moreover, this could have economic benefits for smallholder farmers, given the availability of the PVABM market for selling excess maize, should they have a surplus. In Zimbabwe, smallholder farmers have been found to be more willing to pay for maize varieties that improve the food security in their household and generate income (Cakir, 2004). One major reason leading to smallholder farmers not adopting new hybrids, such as PVABM, is the lack of trust farmers have of new breeds. Previous studies in the southern African region have shown that consumers and smallholder farmers are willing to adopt biofortified products, including PVABM (Mayer et al., 2008; Ntila et al., 2018; Pillay et al., 2013). This could be an advantage for the production of biofortified crops, especially in areas where communities have doubts about genetically modified (GMO) crops. More so, willingness to adopt PVABM could be associated with education regarding the impact of maize cross pollination on the local landraces used by smallholder farmers in rural communities (Meenakshi et al., 2012), since in South Africa, most subsistence farmers still use local maize landraces (Lividini and Fiedler, 2015).

2.11. Provitamin A-biofortified maize as income for smallholder farmers

The acceptability of PVABM by consumers of all standards will allow a market for farmers, especially subsistence rural farmers in areas where VAD is prevalent. The willingness to pay for these new maize varieties would create income for low income houses (Cakir, 2004), while also diversifying peoples' diets. However, several factors may impact the successful marketing of PVABM, such as sensitivity to color and taste, and the agronomic potential of these varieties. Zuma et al. (2017) noted that farmers in the Kwazulu-Natal province of South Africa perceived PVABM as similar to common yellow maize. The authors further noted that smallholder farmers would accept PVABM for consumption but mostly they would want to produce it to sell since these varieties are still new in this country. These findings suggest that PVABM can be incorporated into a rural market, for both animal and human consumption.

2.12. Conclusions

PVABM has the potential to reduce VAD in rural South African communities and to aid in alleviating the hidden hunger experienced by low income households. As a biofortified crop, it has improved resistance to drought and disease, therefore its production would improve yields in areas where drought is a challenge. PVABM acceptance relies on its successful introduction to farming systems in rural communities and its potential yield under different climatic conditions. Although PVABM has the potential to alleviate hidden hunger in rural communities, the challenge is in the introduction of these varieties to smallholder farming systems, where local landraces are the dominant maize varieties grown. Additionally, farmers will have to trust the PVABM variety before incorporating it into their crop farming system because of its color. Previous studies have shown that farmers are sensitive to yellow maize and their belief is that yellow maize is for animal feeding. Should there be a willingness to incorporate PVABM crops then farmers will need to be convinced they have higher yields compared to white maize crops and the local landraces they usually produce. Information workshops on the importance of vitamin A and the challenges of VAD to smallholder farmers and their consumers could aid in the acceptance of PVABM in low income communities. This would help to build capacity around the sustainable production of PVABM for the alleviation of VAD and the improvement in nutrient intake by rural households. Collaborative research involving different stakeholders, such as researchers, government agencies, farmers and NGOs, is needed to research current farming systems and the importance of those systems.

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CHAPTER 3. FARMER PERCEPTIONS ON SOUTH AFRICAN POPULAR MAIZE VARIETIES: A PROXY FOR THE INTEGRATION OF PROVITAMIN A BIOFORTIFIED MAIZE INTO SMALLHOLDER FARMING SYSTEM

Zuma, M.K.; Kolanisi, U.; Modi, A.T. (2017). Farmer perceptions on South African popular maize varieties: A proxy for the integration of provitamin A biofortified maize into smallholder farming system. In Proceedings of the 3rd International Conference on Global Food Security, Cape Town, South Africa, 3–6 December 2017.

Abstract

Provitamin A biofortified maize (PVABM) holds the potential to alleviate vitamin A deficiency in rural communities where maize is a staple crop. For successful incorporation of PVABM into smallholder farming systems, it is important to understand the current smallholder maize production systems and the farmers' views on PVABM. The study assessed maize farming practices and farmers' perceptions on the incorporation of PVABM in their farming systems. Smallholder farmers from Bulwer in the Sisonke District and Mhlathuze under UThungulu District (n= 233) were interviewed using semi-structured interviews and focus group discussions. Logistic regression was used to analyse the data. Farmers practise dryland farming in both areas (Bulwer and Mhlathuze) and produce more white maize than yellow maize. Knowledge about PVABM, a type of maize the farmer produces and the average household income highly influenced ($P <0.05$) the farmers' likelihood to accept and incorporate PVABM into their farming systems. About 82% of farmers in both areas were willing to incorporate PVABM in their farming systems and they have positive perceptions about the success of the varieties in their systems. Farmers already growing yellow maize were more willing to integrate PVABM. Provitamin A biofortified maize (PVABM) has the potential to be integrated in the smallholder farming systems.

Keywords: Provitamin A maize; Vitamin A deficiency; maize; Bulwer; Mhlathuze

3.1. Introduction

Maize is the main staple crop in sub Saharan Africa (Pillay et al., 2011). It can also be used for dual purposes, human consumption and as an animal feed. The major challenge with maize consumption is that, beyond food energy, it is largely devoid of nutritional value, especially problematic if there is no diet diversification as observed in most households (Muzhingi et al., 2011). This could predispose the existence of micronutrient deficiency in rural communities where maize is a staple crop (Pillay et al., 2011). Stevens & Winter-Nelson (2008) reported that high consumption of white maize promotes hidden hunger, such as vitamin A deficiency (VAD), especially among children under 5 years. The prevalence of VAD is high in South Africa (Odunitan-Wayas et al., 2016). However, farmers still prefer white maize over yellow maize (Muzhingi et al., 2011). Previous studies have shown that cultural preference and lack of knowledge can result in consumption of white than yellow maize (Pillay et al., 2013).

Different strategies have been implemented to reduce the impact of VAD in South Africa, including supplementation with Vitamin A (Bouis et al., 2011). Biofortification is a newly introduced strategy to increase micronutrients such as zinc, iron and vitamin A in staple crops. Targeted crops through this programme are maize, rice, cassava, sweet potato, beans, wheat and millet (Bouis et al., 2011). Provitamin A biofortified maize (PVABM) is a product of biofortification with provitamin A carotenoids and it has yellow-orange colour.

In South Africa, yellow maize is used for animal feed while white maize is for human consumption. Studies in southern and eastern Africa suggested the potential for PVABM consumption and acceptance (Beswa et al., 2016). However, there is less evidence on farmers' perceptions and the willingness to integrate PVABM in their maize production system in South

Africa. The objective of the study was to assess farmers' perception on the incorporation of PVABM in smallholder farming systems.

3.2. Materials and methods

3.2.1 Study sites

The study was conducted in Bulwer local municipality of Sisonke district and Mhlathuze local municipality of uThungulu district, KwaZulu- Natal province, South Africa. Bulwer falls under Bioresource Group 11 defined as Moist Transitional Tall Grassveld and represent Bioresource Unit (BRU) Wc26 (Camp, 1999). Altitude varies 964- 1555 meters above sea level with mean annual rainfall of 848 mm. Subsistence farming is still in practice by many residents in the communal areas of Bulwer. Maize is their dominant crop which is produced every year.

Mhlathuze municipality consists of many villages and the study specifically was conducted in KwaDlangezwa. KwaDlangezwa falls under Za4 BRU with < 450 m Coast altitude and > 1100 mm mean annual rainfall (Camp, 1999). The Bioresources Group of the area is Moist Zululand Coastal Thornveld (BRG 1). The area is dominated by shallow soils. The common crops produced in the area are sugarcane, maize and vegetables.

3.2.2. Sampling technique

A total of 233 farmers were randomly selected, 124 in Bulwer and 109 Mhlathuze municipality. Selection of the households was characterized by the involvement in smallholder farming and the willingness to participate in the study. Semi-structured interviews were administrated by six trained enumerators from the local community in order to promote co-operation.

3.2.3. Data collection

Participatory research tools such as key informant discussions were held with extension officers, prominent farmers in the communities, officials from active non-governmental organizations and the tribal authority of the villages. This research exercise was complemented by transect walk to explore and observe farming systems and maize production in the villages. For triangulation of data a survey was done through the questionnaires. The data captured farmer's demographics, socio- economic status, farming practices, challenges with maize production, and perceptions on maize production, maize variety preferences and perceptions of PVABM and willingness to incorporate it to their farming systems.

3.2.4. Ethical consideration

The study was granted ethical approval by the University of KwaZulu Natal (HSS/0184/016D). More so, a written and verbal permission was granted by both extension government sector and the tribal authority.

3.2.5. Statistical analysis

Descriptive statistical analysis was performed on the household demographics and socio economic status. Ordinal logistic regression (PROC LOGISTIC) of SAS (2003) was used to predict odds ratio of farmers' knowledge of PVABM and farmers' perceptions on incorporating PVABM in their farming systems. Content analysis was done to gain interpretation of the transact walk and key informant data.

3.3. Results

3.3.1. Household demographic and socio-economic status

A total of 123 females participated in both municipalities compared to 116 male respondents. In Bulwer there were more male respondents (51%) while Mhlathuze had more female respondents (56%), [Figure 3.1]. The male numbers in Bulwer could be justified by the fact that the maize production was a cash crop which was being sold. On the other hand in Mhlathuze, the smallholder farmers were dominantly female were mainly involved for household subsistence and to sell some surplus when possible.

Another prominent trend in smallholder farming is the less involvement of youth (Figure 3.2) and only ages (35-60) were most active in both municipalities.

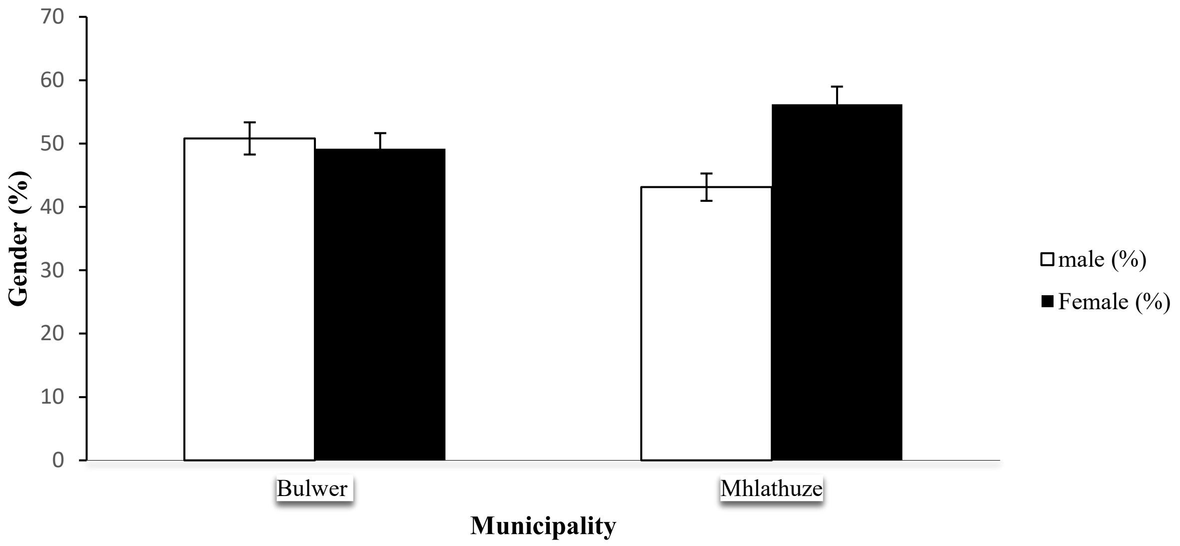

Figure 3.1. Gender percentage of respondents at Bulwer and Mhlathuze municipality

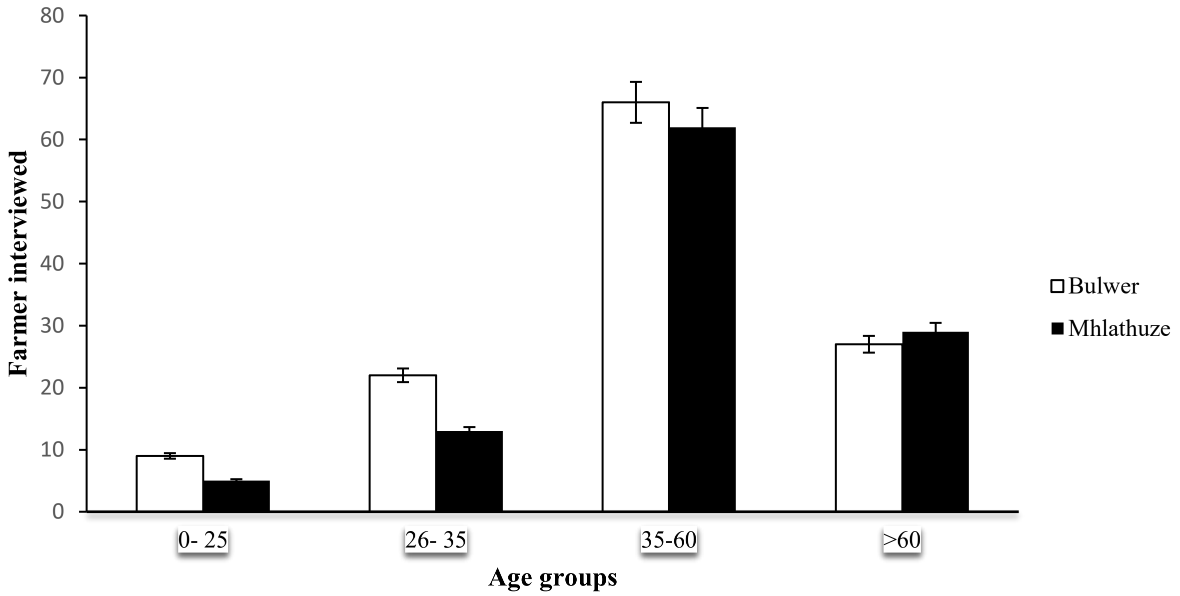

Figure 3.2. Different age groups of farmers interviewed in Bulwer and Mhlathuze municipality

High percentages of the respondents were married in both areas (Table 1) and less widows. In Bulwer there was high dependent on pension grants (old age) which is R1500 per month (R18000 per annum) while in Mhlathuze they showed more dependence on child grant which is R350 and old age pension grant R1520. Most of the respondents were unemployed (60.48 %) in Bulwer and this was similar at Mhlathuze municipality (Table 1). A relatively higher proportion of people in Mhlathuze completed grade 11-12.

Table 3.1. Socio economic status of farmers' respondent in Bulwer and Mhlathuze

	Bulwer (n=124)	**Mhlathuze (n=109)**
Marital status (%)		
Single	43	44
Married	46	51
Divorced	1	3
Widow/widower	9	2
Education (%)		
No formal education	9	19
Lower primary	12	5
Higher primary	19	13
Grade 8-10	26	19
Grade 11-12	27	32
Tertiary education	6	12
Income source (%)		
Wages	17	13
Salary	13	17
Pension	30	26
Grant	23	25
Other	17	19
Employment status (%)		
Full time	10	13
Part time	21	13
Unemployed	61	60
Self employed	8	15
Average income (%)		
Below R800 (ZA)	28	31
R800- R 1500 (ZA)	49	31
R1501- R3500 (ZA)	20	18
Above R3500 (ZA)	3	19

3.3.2. Farming practices

Land available for farming ranged by respondent from 250 m^2 – 25 hectares in Bulwer with the majority percentage owning 0.5 hectares. In Mhlathuze, farmed area ranged 200 m^2- 20 hectares with the majority owning 2 hectares. Respondent showed that they have different farming experience in Bulwer the experience ranged from 1- 52 years as compared to Mhlathuze which ranged from 1- 60 years.

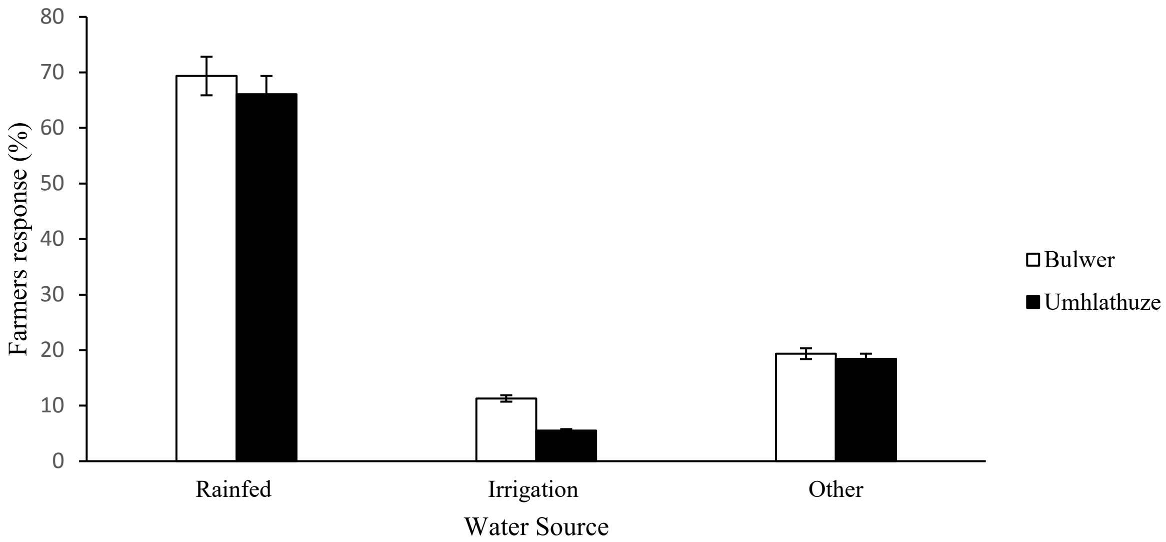

Figure 3.3. Major water source for farming practices in Bulwer and Mhlathuze

Most farmers (nearly 70%) depend on rain for their crop production in both municipalities (Figure 3.3). Different crops are produced the most common in Bulwer are maize, potatoes, beans and leafy vegetable while in Mhlathuze is dominated by sugarcane, maize, amadumbe and sweet potatoes. Farmers preferred to select varieties that are early maturing in their crop production systems (Table 3.2). Furthermore, during dry seasons or seasons when water is limited these farmers grow drought resistant (21%) and short season (21%) crops in Bulwer while in Mhlathuze they prefer resistant crops (45%) and crop rotation (22%) (Table 3.2). During prolonged droughts most do not plant in their fields while others select crops based on their low water requirements.

Table 3.2. Variety selection criteria and coping strategy during dry seasons

		Bulwer (n= 124)	**Mhlathuze (n=109)**
Variety	Early maturity	47	32
	Resistance to diseases	11	17
	Resistance to drought	3	16
	High yield potential	11	6
	Easy market access	1	6
	Easily manageable crop	2	8
	Human consumption	15	14

	Other	10	2
Coping strategy			
	Drought resistant	21	46
	Short season	21	10
	Crop rotation	19	22
	Mixed cropping	11	6
	Revised planting date	15	5
	Change plant density	0	3
	Other	14	7

About 96% of farmers apply fertilizer in their crops in Bulwer compared to 89% in Mhlathuze municipality. These farmers prefer to apply both organic and inorganic fertilizers in their gardens rather than specializing in organic or inorganic fertilizers. Inorganic fertilizers are mostly bought in local suppliers while organic fertilizers are self-made Weeds are mostly managed through manual weeding (hand weeding) for both municipalities 91% (Bulwer) and 86% (Mhlathuze). Furthermore, 85% farmers in Bulwer use family labour to minimize weeding costs while in Mhlathuze 58% prefer family labour for weeding their fields.

3.3.2. Maize preference and impact of maize colour on production systems

Most farmers plant white maize in both municipalities (Bulwer 45%; Mhlathuze 72%) while a few planted yellow maize only at Mhlathuze (8%) compared to Bulwer (23%). Bulwer farmers produce more local landraces than Mhlathuze farmers (Table 3.3). Farmers considered cheapness (Bulwer) and maize colour (Mhlathuze) as their main reasons for maize selection in their maize production systems. Most farmers preferred high yielding maize varieties when they choose their maize for production in both municipalities. Disease resistant and type of variety are less considered when farmers purchase or choose maize attributes.

Table 3.3. Maize selection criteria and preference for production

	Bulwer (n=124)	**Mhlathuze (n=109)**
Maize colour		
Yellow	23	8
White	45	72
Both	32	19

Reason for choice		
Cheaper	37	15
Colour	7	20
Drought tolerance	17	9
Taste	13	19
Products	6	16
Availability	14	17
Other	8	5
Type		
Local landrace	52	42
Varieties	39	43
Both	9	15

3.3.3. Maize consumption

Maize is the major crop produced in Bulwer while in Mhlathuze maize falls behind sugarcane. However, maize is consumed in both areas on different forms. In Bulwer white maize is consumed as green mealies (55%), Phuthu (40%) and as soft porridge while yellow maize is izinkobe (39%), corn bread (33%) and Samp. In Mhlathuze, white and yellow maize are consumed for the same purposes green mealies, izinkobe and corn bread. Other foods made from white maize are amahewu,

3.3.4. Potential and willingness for provitamin A biofortfied maize (PVABM) production under smallholder farming systems

Most farmers reported that they were willing to incorporate PVABM into their maize farming systems. In both areas the response of farmers' willingness was high (Bulwer 82% and Mhlathuze 83%). Furthermore, ninety percent farmers (Mhlathuze) were positive about the success of PVABM varieties in their crop planting system whilst less than seventy percent in Bulwer were positive about the success of these PVABM varieties.

Maize type dominantly grown highly influenced ($P < 0.05$) the likelihood of farmers' knowledge about PVABM (Table 3.4). Farmers producing yellow maize were most likely to have better understanding of PVABM. Furthermore, districts and gender had less influence on the knowledge of PVABM by farmers.

Table 3.4. Odds ratios for respondent knowing provitamin A biofortified maize

Predictor	Odds Ratio	Lower	Upper	Significance
District (Bulwer vs Mhlathuze)	0.2	0.3	1.6	NS
Age (<35 vs >35)	1.3	0.6	2.7	NS
Gender (Male vs Female)	0.5	0.2	1.3	NS
Marital Status (Single vs Married)	1.7	0.8	3.5	NS
Education (< grade 7 vs > grade 7)	1.1	0.5	2.3	NS
Employment Status (Unemployed vs Employed)	1.5	0.7	3.1	NS
Average Household Income (< 800 vs > 800)	0.8	0.9	2	NS
Maize type mainly grown(Yellow vs White)	2.7	1.2	6	*

Knowledge of PVABM was the strongest predictor (5.2) for farmers' stated willingness to produce PVABM in their crop production system (Table 3.5). Farmers with knowledge of PVABM were highly likely ($P < 0.05$) to be willing to plant PVABM varieties. Furthermore, farmers with successful experience in producing hybrids were also likely ($P < 0.05$) to produce PVABM and in addition farmers in Bulwer were less likely to incorporate PVABM in their farming systems. Yellow maize producers are more likely to produce PVABM than white maize producers (Table 3.5).

Table 3.5. Willingness to plant and acceptance of provitamin A maize in their garden.

Predictor	Odds Ratio	Lower	Upper	Significance
District (Bulwer vs Mhlathuze)	0.8	0.4	1.8	NS
Age (<35 vs >35)	0.8	0.4	1.6	NS
Gender (Male vs Female)	0.8	0.3	1.9	NS
Marital status (Single vs Married)	1.2	0.6	2.6	NS
Education (< grade 7 vs > grade 7)	1.3	0.6	2.9	NS
Employment Status (Unemployed vs Employed)	2.1	0.9	5.1	NS
Average Household Income (< 800 vs > 800)	2.2	0.9	5.3	*

Maize type (Yellow vs White)	1.6	0.6	3.9	*
Heard of PVABM (Yes vs No)	5.2	1.2	23.2	*
Hybrid experience (Success vs Failure)	1.7	0.8	3.5	NS

3.4. Discussion

Females play a major role in agricultural productivity in rural livelihoods (Ncobela & Chimonyo, 2015) and are the most vulnerable group to malnutrition and food insecurity in low-income communities. Most females in rural areas are deprived of education as they get married at an early age to perform many tasks (farm operation, cooking, running family, artisan work and many other) when their husbands migrate to cities for jobs. Current findings show that most females operate farming systems in the two areas where subsistence farming is practised. The current findings also showed that social grants and old age pension are major sources of income for rural households, which agrees with Ncobela & Chimonyo (2015).

Agricultural practice is the main source of food for unemployed residence in rural communities (Dhaka et al., 2010). Findings showed that most of the respondent farmers were unemployed and as means of ensuring access to food they grow different crops in their fields. Furthermore most of these farmers have an average income less than R1500 in both municipalities. This suggests that agriculture plays a major role in improving their household food security and their income through selling of produce. Low income for rural communities may suggest the vulnerability of household to poverty, VAD and malnutrition (Muzhingi et al., 2008). Low income and unemployment means farmers perhaps cannot afford to purchase expensive mineral and vitamin supplements.

Farming contributes in both household income and food security (Murugani et al., 2014). Farmers in the study produced a variety of crops according to their soil and climatic condition. Bulwer farmers' plants maize, potatoes, beans as their field crops while Mhlathuze farmers produce sugarcane, maize and amadumbe as their field crops. This suggests that production follows the soil types in the area and the climatic conditions. One challenge with maize production in these areas was the presence of monkeys and drought.

Farmers in these two areas still produce local maize landraces. Most of these landraces are white landraces. Landraces are more tolerant of drought (Mabhaudhi & Modi, 2010), study findings suggests that farmers prefer local landraces due to their adaptability on their soils and climate conditions. One reason for farmers preferring landraces over hybrids is the lack of trust in hybrid varieties by farmers. However, these landraces have poorer yields than commercial hybrids (Mabhaudhi & Modi, 2010).

Rain is the main source of water for crops in the two areas. Maize is grown during the rainy season (October – April) and this is subject to rainfall variation (Denning et al., 2009). Due to climate change and droughts, farmers are left with limited yields especially on late maturing varieties. As a coping strategy farmers in the two areas prefer drought resistant crops, short season crops and implement crop rotation. Furthermore, if a drought persists then farmers don't plant in their fields while in the Mhlathuze area they shift to sugarcane. In 2015, farmers dealt with a dry year in South Africa and they were unable to plant as much maize as they would have wished.

Farmers use inorganic fertilizers brought from local suppliers and they also use organic manure from cow, chicken, crop residues and goats. There was no specific difference with regards to type of fertiliser applied on yellow or white maize. In Bulwer, farmers still produce yellow and white maize landraces with white maize being the most planted maize. Yellow maize is planted in less quantities because of it uses and it vulnerable to be eaten by monkeys since it usually harvested when it dry. Water shortage is the major challenge in both Bulwer and Mahlathuze. In both areas water scarcity affects maize production. Furthermore, poor quality varieties were signalled as key limiting factor in maize production. Pests and diseases were considered as major challenges in maize production.

Maize is consumed in various foods in a rural household (Li et al., 2010). White maize is used for both animal and human consumption and mostly produced rather than yellow maize. Positively, yellow maize was used for foods such as amahewu, samp, inkobe and steam bread while white maize was used all foods (*phuthu, pap, amahewu, samp, inkobe and green mealies*). Govender et al. (2014) study showed that provitamin A biofortifed foods to be accepted by black caregivers and there was a potential for these foods to be consumed by different age and gender in rural areas. Current findings that yellow maize foods are still consumed may assure the future consumption of PVABM once grown. However, Pillay et al. (2014) findings showed that milling of maize to produce different foods such as samp may result in retention of carotenoids in provitamin A maize.

Yellow maize is still produced for animal feeding. Chickens are fed yellow maize production in the two areas. Odunitan-Wayas et al. (2016) suggested feeding chickens with PVABM can be used as an alternative strategy to improve vitamin A consumption by rural families especially those have negative perceptions about orange and yellow maize. However, Gwala (2014) noted that in rural households' men consume more chicken portions as compared to women and children.

Farmers perceived yellow maize taste as good while white maize was perceived very good in taste. In general yellow maize was acceptable by smallholder farmers and the current findings showed no negative perspective on colour, aroma and texture. Govender et al. (2014) reported that provitamin A maize and yellow maize sensory attributes had no negative impact on product acceptance. Similar findings were observed by Groote et al. (2008) that regardless of yellow colour farmers were willing to pay for the product.

Biofortification was new information to most of the farmers in the study however some have an understanding of breeding process and varieties. Most have used different maize varieties and most were successfully introduced and had better adaptability while some were a challenge. However, most farmers in both areas said they were willing to produce PVABM under their crop production systems. Regardless of the colour most farmers were positive on the production of PVABM maize for the future. Similar findings have been observed on previous studies (Stevens & Winter- Nelson. 2008; Meenakashi et al. 2010). However, as those studies report, education training and workshops must be implemented for information improvement and breeding strategies on PVABM.

However, there was lack of trust as to the agronomic productivity of PVABM under their environmental conditions and soils. The successful introduction and acceptation of PVABM must be accompanied by strong agronomic performance in both local landraces and hybrids (Pixley et al. 2013). History of varieties has an influence on the willingness of farmers to accept PVABM because some varieties have not done well for some smallholder farmers. Previous maize varieties introduced in the two communities have been a success but the concern was the ability of varieties to produce seeds every season. Cross breeding of PVABM was questioned as landraces can be contaminated during the production of PVABM breeds close to local landraces. Farmers' willingness to adopt PVABM can be a step towards reducing hidden hunger even through maize as a staple crop in rural areas (Birol et al., 2015).

Provitamin A biofortified maize has the potential to reduce VAD (Wurtzel et al., 2012), therefore by farmers' expressed willingness and positive perception about the incorporation of PVABM in their maize production systems, could lead to adoption of such varieties and thus to positive results in improved malnutrition status in rural communities. Due it improved drought resistance (Pillay et al., 2011) the varieties can easily adapt to different environmental condition. PVABM has the potential to be adopted under various dryland production systems.

3.5. Conclusion

Farmers accepted the idea of growing PVABM and they were willing in principle to incorporate it in their maize production systems regardless of it orange/yellow colour. However, workshops and training would be required to improve information on PVABM breeding and reduce the negative perspective of yellow maize as human food. Positive perceptions about PVABM and it drought resistance would improve maize production during drought periods. Odds ratio estimate showed that farmers planting yellow maize were highly likely to plant PVABM maize. The current findings of the study could encourage the integration of PVABM into smallholder farming systems and it could a greater step to the commercialization of these varieties. Access to PVABM at household level will reduce VAD in low economic households were maize is a staple crop.

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CHAPTER 4. SEED QUALITY CHARACTERISTICS OF PROVITAMIN A BIOFORTIFIED MAIZE VARIETIES COMPARED WITH SELECTED COMMON MAIZE VARIETIES IN SOUTH AFRICA

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Conditionally accepted for publication under the journal of Acta Agriculturae Scandinavica, Section B - Plant Soil Science

Abstract

The understanding of seed quality characteristics and early establishments are key to the acceptance of provitamin A biofortified maize varieties in South Africa. The aim of the study was to evaluate the seed quality characteristics and early establishment of provitamin A biofortified maize varieties (PVABM and SC510) compared with common maize varieties (local landrace [LL], border king [BK] and SC506). The seed quality of five maize varieties was determined by standard germination, tetrazolium (TZ), electrical conductivity (EC) test and seedling establishment. All seed tested viable in the TZ test. Highly significant differences ($P<0.001$) were observed for the daily germination percentage with BK variety recording 100% final germination, while SC510 produced 67.7% final germination. Mean germination time (MGT) recorded no significant differences ($P>0.05$) among maize varieties during the standard germination test, MGT ranged (4.89- 5.02 days). The varieties had highly significant difference ($P<0.01$) recorded for the dry mass (DM). The dry mass ranged from 0.29 – 0.84 g, BK variety recorded the higher DM while SC 510 had the lowest. A positive and highly significant correlation existed between GVI and final germination ($r = 0.90$, $P<0.001$) for standard germination. The overall final seedling emergence ranged from 67.5 to 98.75% across maize varieties with BK recording the highest percentage followed by PVABM (93.75%). Furthermore, a positive correlation was observed for dry mass (DM) with root length ($r= 0.557$, $P<0.05$). Analogous finding observed showed that provitamin a biofortified varieties has the seed quality potential similar to common maize hybrids.

Keywords: germination, seedling, emergence, vigour, viability.

4.1. Introduction

Maize (*Zea mays*) is a staple crop in sub-Sahara Africa (SSA), it is used for human and animal feeding (Mboya et al. 2011). For most households, maize forms the basis of all meals contributing towards food security. Although a variety of food forms could be made from maize, this food item has to be complemented with the consumption of fruits, vegetables and proteins to achieve a balanced meal. Unfortunately, in most household's maize is usually eaten in different forms on its own without these complementary food items. Maize, in particular white maize which is the most popular and most preferred is devoid of nutrition (Pillay et al. 2011). Such behaviour (preferences and consumer perceptions) could engineer a food and nutrition insecurity condition, causing the consumers of maize to suffer from hidden hunger (micronutrient deficiencies).

In attempt to counteract the food and nutrition insecurity situation, maize has been selected as one of the targeted staple crops for the HarvestPlus programme to improve micronutrients through biofortification process. Provitamin A biofortified maize (PVABM) is targeted to improve the health of children and reduce vitamin A difieciency (VAD) which is prevalent in most sub-Saharan regions (Bouis et al. 2011). However, the willingness and acceptability of PVABM by consumers and smallholder farmers can still be hindered by the agronomic potential of the varieties with comparison to local landraces and common hybrids.

The successful incorporation of PVABM is dependent on the quality of the seeds before planting. A good quality seed should have physical, genetical, pathological and physiological (vigour and viability) qualities to contribute to quality yields (Munamava et al. 2014). Seed vigour and viability are key in determining the seed quality of a certain crop. Seed vigour is accountable for germination rate and seedling establishment while viability is responsible for seed germination (Akinnouye and Modi 2015). According to Chibarabada et al. (2014), viable seeds have the potential to germinate when exposed to favourable conditions. Good germinating seeds have the potential to develop into seedlings, however external factors such as water shortage in the seedling medium and temperature influences germination (Akinnouye and Modi, 2015).

Mazvimbakupa et al. (2015) emphasise that seed testing should be used to provide seed quality information because seed germination may vary among varieties. The use of laboratory testing controls external factors to provide uniform and complete germination (Akinnouye and Modi, 2015) while viability can be tested with chemical tests that detects reactions that occurs in the living systems (Tekrony 2003). PVABM seed quality information is limited. If farmers grow PVABM in their farming systems then seed quality tests are required. Therefore, the aim of this study was to evaluate seed quality characteristics (physiological) and early establishment of PVABM varieties compared with common maize varieties.

4.2. Materials and methods

4.2.1. Plant material

Commercial yellow maize (SC 506) and Commercial provitamin A biofortified (SC 510) maize seeds were donated by Seedco Zimbabwe. Light-orange provitamin biofortified A maize (PVABM) seeds were sourced at the University of KwaZulu-Natal (UKZN) plant breeding department, Pietermaritzburg. The local landrace (LL) was sourced from Bulwer (Nkwezela area) while locally-grown commercial seeds (border king [BK]) were sourced from a local seed company (McDonald's seeds, South Africa) as shown in Table 4.1.

Table 4.1 Seed visual characteristics of maize varieties used for the current study

Variety	Type	Seed colour	100 seed mass (g)	Source/ Location
BK	Commercial	White	62.36	Pietermaritzburg, South Africa
LL	Landrace	White	52.61	Bulwer, KwaZulu-natal
PVABM	Provitamin A	Light-Orange	31.90	Pietermaritzburg, South Africa
SC 506	Commercial	Yellow	47.94	Seedco Zimbambwe
SC 510	Commercial Provitamin A	Orange Yellow	26.01	Seedco Zimbambwe

4.2.2. Standard germination test

Seed germination capacity was done using the standard germination test under laboratory condition following recommendation by Sithole et al. (2016). The standard germination test was conducted by germinating four replicates of 20 seeds from each variety (LL, PVABM, BK, SC506, SC510) between brown double-layered paper towels (Guan et al. 2009). The rolled moist paper towels were sealed in zip plastic bags to avoid moisture loss and incubated in a growth chamber with alternating temperatures of 20 °C/30 °C (16/8 h) for eight days. Daily count of germination were taken based on 2 mm or more radicle protrusion. On the last day, final germination percentage was calculated following AOSA (1992) recommendations.

Following this, the germination vigour parameters were determined by measuring root length, shoot length and root: shoot ratio. Fresh mass was then oven dried at 70 ºC for 72 h to determine dry mass.

Germination velocity index (GVI) which measures the speed of seedling germination was calculated according to Maguire (1962) formulae:

$$GVI = G_1/N_1 + G_2/N_2 + ... + G_n/N_n$$

Where GVI is the germination velocity index, G_1, G_2... G_n are the number of germinated seeds in first, second... last count, and N_1, N_2...N_n are the number of sowing days at the first, second... last count, respectively.

Mean germination time (MGT) was calculated according to the formula by Ellis and Roberts (1981):

$$MGT = \Sigma D_n/\Sigma n$$

where MGT is mean germination time, n is the number of seeds that germinated on day D, and D is the number of days counted from the start of germination.

Germination rate (GR) was calculated according to Krishnasamy and Seshu (1990):

Germination rate (%) = (Number of seed germinated at 48h ÷ Number of seed germinated at 120h) ×100

The seed vigour index was calculated according to the formula by Abdul-Baki and Anderson (1973):

Seed Vigour Index = shoot length × germination percentage

4.2.3. Tetrazolium test

Seeds were tested for their viability through tetrazolium (TZ) test. Four replicates of 20 seeds per variety were used for the test. Seeds were preconditioned by soaking in water for 18 h.

Seeds were bisected longitudinally through midsection of the embryonic axis using a razor. Seeds were then placed in petri dishes with 1% TZ solution. The TZ solution was prepared by adding 1g 2,3,5-triphenyltetrazolium chloride powder to 100 ml distilled water. The seeds were soaked for 6 h and the number of stained seeds was recorded.

4.2.4. Electrical conductivity

Electrical conductivity of seeds was measured with a EC meter CDM 210. Twenty five seeds per maize variety were weighed and placed in glass beakers filled with 10 ml distilled water. Electrolyte leakage was measure over 24 hours.

4.2.5. Seedling emergence

Seedling establishment experiment was conducted in the Controlled Environment Facilities (CEF) at the University of KwaZulu-Natal. Four replicates of 20 seeds from each variety were planted in seedling trays using growing media (seedling mix) over the period of 14 days. Trays with medium were weighed and watered to maintain field capacity. Daily emergence, shoot, root and seedling mass (fresh and dry) were data collected.

Mean time to emergence (MET) was determined according to Bewley & Black (1994):

$MET = \Sigma Fn/\Sigma n$

Where MET = mean emergence time,

f =number of newly emerged seedlings at given time (day), and

n= number of days from the date of sowing

4.2.6. Statistical analysis

All data were subjected to analysis of variance (ANOVA) using GenStat® Version 14 (VSN International, Hemel Hempstead, UK). Means were separated using least significant differences (LSD) at the 5% level.

4.3. Results

4.3.1. Standard germination test

Highly significant differences in germination percentages ($P< 0.001$) were observed among maize varieties during the germination period (Figure 4.1). Overall final germination ranged from 67.5 to 100% among the maize varieties. SC510 had the lowest final germination percentage while BK had the highest. With respect to germination rate, no significant differences (P> 0.05) were observed among the maize varieties with respect to germination. The germination rates ranged from 21.56 to 31.71% among the varieties.

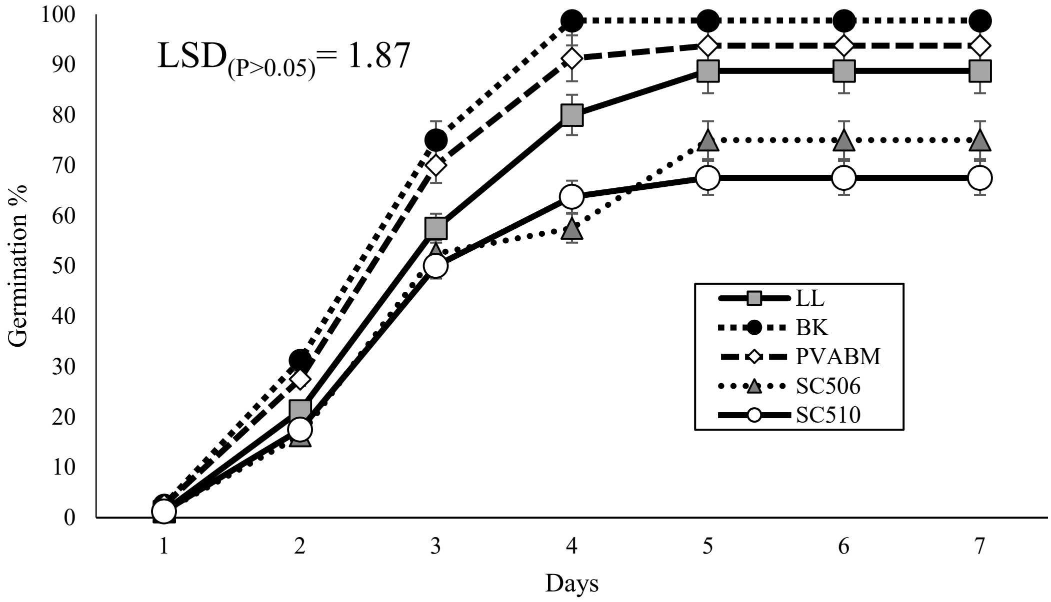

Figure 4.1. Daily germination percentage of maize varieties (LL, BK, and SC506) compared with provitamin A biofortified maize varieties (PVABM and SC510).

4.3.1.1. Germination vigour characteristics

No differences in germination vigour characteristic existed between varieties (Table 4.2). While for GVI, the varieties had highly significant differences (P< 0.001).The SC506 variety had the highest MGT (5.02 days) and BK the lowest (4.89 days). For GVI, BK had highest GVI (23.63) while SC 510 the lowest. There were no significant differences (P> 0.05) for shoot length (SL), root length (RL) and root: shoot ratio (R: S) among the varieties (Table 2). With respect to EC, no significant differences (P>0.05) were observed across the maize varieties. However, the EC ranged 81.38- 227.42 µS g^{-1} with LL recording the lowest whilst SC506 the highest EC. The varieties had highly significant difference (P<0.01) recorded for the dry mass (DM). The dry mass ranged from 0.285 – 0.84 g. Among the maize varieties, BK variety recorded the higher DM while SC 510 had the lowest. The SVI was highly significant, LL (1023) recorded high SVI whilst SC506 recorded the lowest.

Table 4.2. Seed performance of provitamin A biofortified maize varieties (PVABM and SC510) compared with selected maize varieties (LL, BK, SC506).

	MGT (days)	GVI	SVI	SL (cm)	RL (cm)	R: S	EC (µS g^{-1})	DM (g)
BK	4.89a	23.63c	892.40c	12.40ab	10.15a	1.00b	154.13ab	0.84d
LL	5.01ab	19.99b	1023.00d	16.80b	10.35a	0.68a	81.38a	0.80d
PVABM	4.91ab	22.03bc	858.30c	12.75ab	12.00a	1.60b	131.74ab	0.41b
SC506	5.02b	15.89a	473.40a	9.40a	9.20a	1.13ab	227.42b	0.74c
SC510	4.94ab	15.40a	655.60b	13.70ab	9.30a	0.78ab	122.85ab	0.29a
LSD	0.13	2.29	76.37	4.77	3.89	0.81	117.30	0.05
Significance	Ns	**	**	ns	ns	ns	ns	**

*** = P< 0.001; ns = not significance (P > 0.05); MGT = mean germination time; GVI = germination velocity index; SVI = seed vigour index; SL = shoot length; RL= root length; R: S= Root: Shoot, EC=electrical conductivity and DM = Dry mass (Whole plant). Values in the same column with different superscript letter are significant different (P < 0.05). Values within the same column sharing the same letter do not differ significantly at P < 0.05.*

4.3.1.2. Correlation of germination characteristics

Highly significant and strong correlation was observed for the following standard germination variables: GVI and Final germination (r = 0.90, P<0.001); SVI and GVI (r =0.71, P <0.001), RL and DM (r= 0.66, P<0.001) and SVI and final germination (r =0.66, P< 0.001). Positive correlation was also observed for SVI and SL (r =0.61, P<0.001). Mean germination time was negatively correlated to final germination (r= -0.085, P> 0.05) and germination rate (r=-0.571, P<0.05).

4.3.2. Seedling emergence

4.3.2.1. Seedling emergence characteristics

Highly significant differences in emergence (P <0.001) were observed among maize varieties during the seedling emergence period of 14 days (Figure 2). The overall final seedling emergence ranged from 67.5 to 98.75% across maize varieties. The SC510 variety produced the lowest final seedling emergence whilst the BK variety recorded the highest final emergence.

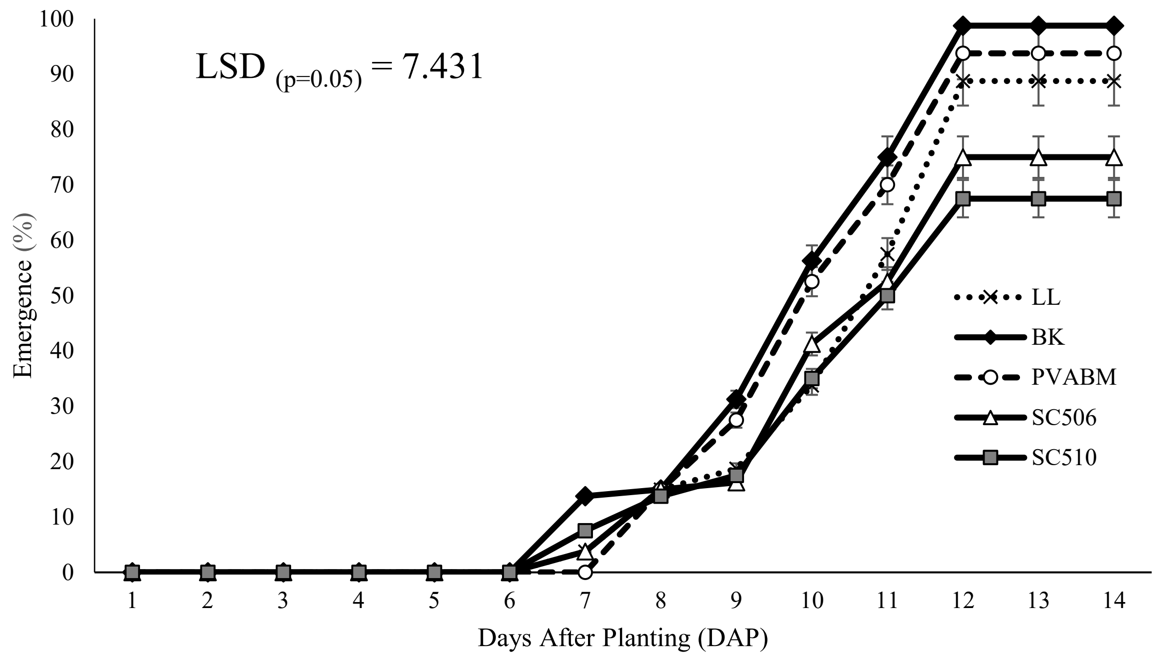

Figure 4.2. Daily emergence percentage of maize varieties (LL, BK, PVABM, SC506 and SC510) over 14 days period.

The Mean Emergence Time (MET) was not significantly different (P>0.05) among maize varieties. Moreover, the LL variety recorded highest MET (12.06 days) while BK (11.766 days) was the lowest (Table 4.3). Significant differences (P<0.05) were observed for root length (RL), the length ranged from 9.79 cm (PVABM) -13.25 cm (BK). With respect to shoot length (SL), there were highly significant differences (P< 0.001) observed with length ranges 16.92-24.92 cm. The LL variety recovered shortest while BK recorded the tallest SL. No significant differences (P> 0.05) were recorded for R: S, however SC510 had the highest R: S compared to other maize varieties (Table 3). The dry mass (DM) of the seedlings was significant different (P<0.05) across the maize varieties after 14 days. Local landraces (LL) recorded higher (0.64 g) DM than other varieties whilst SC510 recorded the lowest (0.37 g).

Table 4.3. Seedling Emergence performance of provitamin A biofortfied maize varieties (PVABM and SC510) compared with selected maize varieties (LL, BK, SC506).

	MET (Days)	RL (cm)	SL (cm)	R: S	DM (g)
BK	11.77a	13.25b	24.92b	0.53a	0.53bc
LL	12.06b	10.21a	16.92a	0.653ab	0.64c
PVABM	11.92ab	9.79a	19.67a	0.519a	0.46ab
SC506	11.92ab	11.07ab	20.00a	0.56ab	0.51bc
SC510	11.86ab	12.50b	18.75a	0.71b	0.38a
LSD	0.27	2.27	3.360	0.16	0.15
Significance	ns	*	**	Ns	*

**=P<0.05; ** = P< 0.001; ns = not significance (P > 0.05); MET = mean emergence time; SL = shoot length; RL= root length; R: S= Root: Shoot and DM = Dry mass. Values in the same column with different superscript letter are significant different (P < 0.05). Values within the same column sharing the same letter do not differ significantly at P < 0.05.*

4.3.2.2. Correlations of emergence

Positive correlation was observed for dry mass (DM) with root length ($r= 0.557$, $P<0.05$), root: shoot ($r= 0.538$, $P= 0.046$) while mean emergence time was negative correlated with emergence ($r= -0.213$, $P>0.05$); Root length ($r=-0.161$, $P<0.05$) and R: S ($r= -0.001$, $P>0.05$) as presented in Table 4.4.

Table 4.4. Association of seedling emergence characteristics during seedling establishment

	DM	Emergence	MET	RL	R: S
Emergence	0.267	-			
MET	0.133	-0.213	-		
RL	0.557	0.309	-0.161	-	
R: S	0.538	-0.199	-0.001	0.404	-
SL	-0.062	0.414	-0.269	0.430	-0.557

MET = mean emergence time; SL = shoot length; RL= root length; R: S= Root: Shoot and DM = Dry mass

4.4. Discussion

Seed quality is an important determinant of the early potential performance of the early crop growth (Mabhaudhi and Modi 2010). Good quality seeds are most likely to yield better germination, seedling establishment and growth (September 2015). The objective of this study was to evaluate seed quality characteristics and early establishment of PVABM varieties compared with common maize varieties.

All seeds used for the current study were viable under the TZ test. However, there was inconsistency between laboratory germination test with TZ findings. All seeds were viable under TZ but not all seeds reached 100% final germination. Naderidarbaghshahi and Bahari (2012) recommended that it is normal for disagreement between for TZ and laboratory germination test. Mazvimbakupa et al. (2015) who found the maize varieties (SC 701 and local landraces) showed inconsistencies in the TZ test. Therefore, the use of the TZ test alone is not a good determinant of seed quality other characteristics are also important.

Bradbeer (1988) suggested that dormancy can be a limitation on the viability of a seed. Seed viability is an important indicator of seed quality, furthermore viable seeds are more likely to germinate and establish (Hampton 2002). Therefore, seeds used for the current study were alive and had the potential to germinate. The EC of the seeds differed with seed type, color and size during the current study.

Results obtained during this study showed that maize seed varieties performed differently with regards to their standard germination test, germination vigour, and seedling emergence. The commercial BK was the only variety to have 100% germination whilst among the provitamin A varieties, PVABM had higher final germination than SC510. As a hybrid, the commercial provitamin A biofortified variety (SC510) had less final germination than local landraces which is contrary to findings by Mabhaudhi and Modi (2010). However, this cannot conclude that provitamin A maize varieties have less planting potential than common maize varieties. Unfortunately, there is scarce information on the provitamin A biofortified varieties germination tests.

Akinnuoye and Modi (2015) found that small seeds have higher germination speed than bigger seeds. Current findings are contrary to their findings as the BK seeds are bigger than the SC510 but it reached 100% germination in four days compared to the other seeds. Furthermore, the difference can be justified by different seed genetics of the current seeds. Large and flat kernels have better viability and vigour than small, round apical and round basal- position kernels

(Peterson et al. 1995). This suggests that not only size but the shape of the seeds has the impact on seed quality.

Mean germination time (MGT) is a serious component in determining the seed gemination and quality (Mavi et al. 2010). The current study showed that MGT of provitamin A biofortified maize (PVABM and SC506) varieties was lower compared to other maize varieties (BK, LL and SC506) during the current study. Seedling emergence results showed no maize variety managed to reach 100% percent emergence in 14 days of establishment. Unlike in past studies where maize varieties managed to reach 100% percent emergence within a period of 7 days (Mazvimbakupa et al. 2014); Akinnuoye and Modi 2015). Similarly, to germination test, the BK variety outclassed other varieties in terms of achieving the highest emergence.

The seedling height and root height of the BK cultivar as assessed in the current study, were high, additionally, its 100-seed weight was greater. These findings conform with Yusuf et al. (2014) observations that larger seed tend to produce better seedling height, roots and biomass. September (2015), further recommends that this could be due to large embryo that enables the seed to have more energy compared to small seeds. However, the importance of seed size on seed quality is debatable because small seeds are needed for fast germination (Souza and Fagundes 2014) while large seeds are crucial for good seedling and larger grain (De Gues et al. 2008). It is therefore important for a seed to have both qualities to be considered a good quality seed while able to produce good seedling.

The disadvantage of provitamin A biofortfied maize varieties (PVABM and SC510) in the current study was their seed mass. Both had low seed mass compared to other maize varieties. Akinnouye and Modi (2015); September (2015) emphasises that the size of the seed is the reflection of the seed potential to germinate and ability to establish as s seedling.

During the seed quality test between provitamin A biofortfied maize varieties (PVABM and SC506), the PVABM obtained better final germination while SC506 recorded the lowest. Furthermore, during the emergence study the PVABM again recorded the better emergence compared to SC506. This could be attributed to several factors including breeding lines, genetic makeup, seed size and shape. Mazvimbakupa et al. (2015) argued that the genetic characteristics of a seed can cause seed germination and emergence. However, there is scant information to support the low germination and emergence of SC510 during the current study.

It can also be noted that there is need for improved gene lines of the provitamin A biorfotified cultivars/ hybrids to outclass the common cultivars used in South Africa.

4.5 Conclusion

The seed quality tests showed that all seeds used for the current study were viable and had the potential to germinate during the standard germination test and emerged in the early establishment test. However, varieties' seed quality differed to that of the hybrids, for example, the provitamin A biorfotified maize variety (SC510) recorded the lowest germination and emergence during the current study. Of the tested hybrids, border king (BK) produced the best results for both standard and early establishment. Furthermore, the provitamin A maize varieties produced contrary findings because PVABM showed different results to SC510 during the study. The analogous performance of these varieties highlights the need for experimental trails to further determine potential of these maize varieties under different environmental conditions. An improvement in breeding lines of provitamin A biofortfied maize may lead to significant findings in the upcoming seed quality tests.

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CHAPTER 5. GROWTH, PHYSIOLOGICAL AND YIELD RESPONSE OF PROVITAMIN A BIOFORTIFIED MAIZE CULTIVARS TO DIFFERENT NATURAL ENVIRONMENT

Under review in the Journal of agriculture and food security, BMC

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Abstract

The aim of the study was to determine the response of provitamin A biorfotiified maize cultivars (commercial and non- commercial) under different environmental conditions. Five cultivars, two provitamin A biofortfied and three common maize varieties were planted in two on farm trails located under different agro ecological zones (Bulwer and Kwadlangewzwa) of KwaZulu-Natal in a two season period (2015/16 and 2016/17)The five cultivars namely Border king (BK), provitamin A biorfotified maize (PVABM), local landrace (LL), SC 506 and SC510 recorded a highly significant ($P<0.001$) plant growth (height and leaf number) in both trail sites across two seasons (2016/17 and 2016/17). Chlorophyll content showed no significant differences for both trial site in both 2015/16 and 2016/17 season. For first season, no significant differences ($P< 0.005$) were observed for biomass among the maize varieties in both trial sites. However, it was observed that SC510 had higher biomass (2.33 t/ha) while BK recorded lowest biomass (0.66g) in Bulwer. In KwaDlangezwa, the biomass ranged for 0.713 t/ha (PVA) – 1.66 t/ha (SC510). For the second season (2016/17), both yield and biomass showed no significant differences ($P> 0.05$) among the maize varieties across the two study sites. Biomass in Bulwer ranged 0.86 t/ha (LL) - 1.52 t/ha (SC510) and 0.94 t/ha (BK) - 1.44 (SC510) in KwaDlangezwa. It can be concluded that the performance of the provitamin A biorfotified varieties (SC510 and PVABM) showed nothing new to the current common varieties. However it can be also noted that there is potential for these varieties to adapt and produce under different environmental conditions of KwaZulu-Natal, South Africa.

Keywords: SC510, Chlorophyll content, KwaDlangezwa, Bulwer.

5.1. Introduction

Maize (*Zea mays*) belongs to the family of grasses Poceace and also known as corn (Mazvimbakupa et al., 2015). Maize is a cross pollinating plant with female and male (tassel) flowers located on the plant (Pillay, 2011) and is the main staple crop in sub Saharan Africa (SSA) and in South Africa it mostly consumed food item in both urban and rural communities (Pillay, 2011). Furthermore, it is an important carbohydrate, iron, vitamin B, minerals and protein source. It can also be used for dual purposes, human consumption and as an animal feed. However, the challenge with maize consumption is it unbalanced nutrient composition especially the low vitamin A levels caused by lack of provitamin A carotenoids (Pillay et al., 2014). This could justify the existence of micronutrient deficiency in rural communities where maize is considered as a staple crop (Pixley et al., 2013).

In smallholder systems where maize is a subsistence crop, there is high existence of vitamin A deficiency (VAD) with the vulnerable group being children under the age of five years (Harjes, 2008). Different strategies have been deployed as means of reducing VAD in rural communities; these strategies are fortification of foods, supplementation with vitamin A and biofortification of staple crops such as sweet potato and maize. Harvestplus programme aim at developing biofortified varieties (maize, millet, rice, sweet potatoes and beans). This program target improving micronutrients (iron, zinc and vitamin A) levels in staple crops for rural communities. Vitamin A deficiency is targeted by provitamin A biofortification maize (De Moura et al., 2015).

Provitamin A biofortified maize (PVABM), a product of biofortification has the potential to, reduce hidden hunger and VAD in low income households. The potential of PVABM is justified by maize being a staple crop in rural communities. PVABM has improved carotenoids with enhanced vitamin A unlike the normal white and yellow maize (Awobusuyi et al., 2016). This variety has the potential to reduce vitamin A deficiency. Moreover, as a product of biofortification, PVABM is drought and disease tolerant hybrid making it perfect for smallholder farmers with drought and diseases challenges in their maize production systems. Studies show that PVABM can be incorporated into smallholder farming systems and there's consumer willingness to include the products into the diets. However, there is scant information on the agronomic potential of PVABM and response of these unde dryland conditions. Therefore, the aim of the study was to determine the response of provitamin A biorfotiified maize cultivars (commercial and non- commercial) under different environmental conditions across two seasons (2015/16 and 2016/17).

5.2. Materials and methods

5.2.1. Site description

The study was carried out in two small-scale farms located in two different locations (Bulwer andKwaDlangezwa) of KwaZulu-Natal, South Africa. These two locations were representatives of distinct agro-ecologies (Table 5.1). Planting dates were in November for summer season of 2015/16 and 2016/17

Table 5.1 Experimental site description for Bulwer and KwaDlangezwa

	Bulwer	KwaDlangezwa
Geographical location	S29.85721 E029.79619	S28.5208 E031.4944
Altitude	964- 1555	< 450
Bioresource Group	Moist Transtional Tall Grassveld	Moist coast forest, thorn & palm veld
Rainfall	848	1230
Frost occurrence	Severe	None
Average temp.	15.9	21.6
Soil type	Clovelly	Dundee
Soil texture	Yellow brown, Orthic A Loam	Sandy

5.2.2. Planting material

Provitamin A biofortified maize seeds were donated by Seedco Zimbabwe while local landraces were donated by local farmers in Nkwezela Area in Bulwer, KwaZulu-Natal, South Africa. Light Orange provitamin A biofortified maize seeds were donated by the plant breeding department in the University of KwaZulu-Natal, Pietermaritzburg. Border king (BK) was sourced at McDonalds (Pietermaritzburg, RSA) was selected due to their popularity amongst farmers.

5.2.3. Experimental design

Two on farm trails were established in Nkwezela Area (Bulwer) and KwaDlangezwa (UMhlathuze) under dryland conditions. Soil properties and climatic conditions of these areas were distinct (Table 5.1). Five maize varieties were planted, two provitamin A biofortified (SC 510 and PVABM), one local landrace (LL) and one commercial variety (Border King [BK] and common yellow maize [SC506]). The experimental design was randomised complete block design (RCBD) consisting of five varieties replicated four times under different ecological conditions and repeated in two season (2015/16 and 2016/17).

5.2.4. Growth parameters

Plant height was measured from the soil surface to the base of the tassel and the number of leaves was also counted. Chlorophyll content index was measured using the CCM 200 and yield component were measured at harvest.

5.2.5. Agronomic practices

Prior to planting, soil samples were taken for fertility tests. Fertiliser applications were based on the soil fertility recommendation. Land preparation was initially done using tractor mounted mouldboard plough and hand. Weeding was done manual using a hand hoe.

5.2.6. Statistical analyses

Data were subjected to statistical analyses of variance (ANOVA) using GenStat® version 17 (VSN International, Hermel Hempstead, UK 2011). Fischer's unprotected test was used to separate means at the 5 % level of significance.

5.3. Results

5.3.1. Plant growth and chlorophyll content

5.3.1.1. Plant height

Maize growth during the first season (2015/16) was highly significant ($P< 0.001$) among varieties between Bulwer and KwaDlangezwa (Figure 5.1a) during the planting period. In both sites a growing trend with time was observed for plant height from 4 WAP to 16 WAP. After 16 weeks the height ranged between 142.27 (LL) - 169.93 cm (SC510) while in KwaDlangezwa 96.47 (SC506) - 117 cm (SC510). Overall, plant height was higher in Bulwer than KwaDlangezwa with SC510 recording tallest height in both sites. In the second season (2016/17), plant height showed highly significant differences ($P< 0.001$) among varieties between Bulwer and KwaDlangezwa during the planting period. A growing trend with time was observed in both trial sites from 4 WAP to 16 WAP (Figure 5.1b). After 16 WAP, the height ranged 145.87(LL) - 172.93 cm (SC510) in Bulwer while in KwaDlangezwa it ranged from 99.47 (SC506) - 124.33 cm (BK).

5.3.1.2. Leaf number

With respect to first season (2015/16), leaf number of the varieties increased with time in both study sites (Figure 5.2a). Highly significant differences (P< 0.001) in leaf number were observed across maize varieties in both sites (Bulwer and KwaDlangezwa). On 16 WAP, leaf number ranged between 14 (SC506) - 16 (SC510) in Bulwer and 12 (BK) -14 (SC510) in KwaDlangezwa. Similar to plant height, the leaf number for SC510 was higher in both sites during the study. With respect to second season (2016/17), there were significant differences (P< 0.001) observed among the maize varieties in both trial sites (Figure 5.2b). A growing trend with time was observed for number of leaves during the study period. At 16 WAP, the leaf number ranged 14 (SC506) - 16 (PVABM) in Bulwer while in KwaDlangezwa it ranged 13 (BK)-14 (SC506).

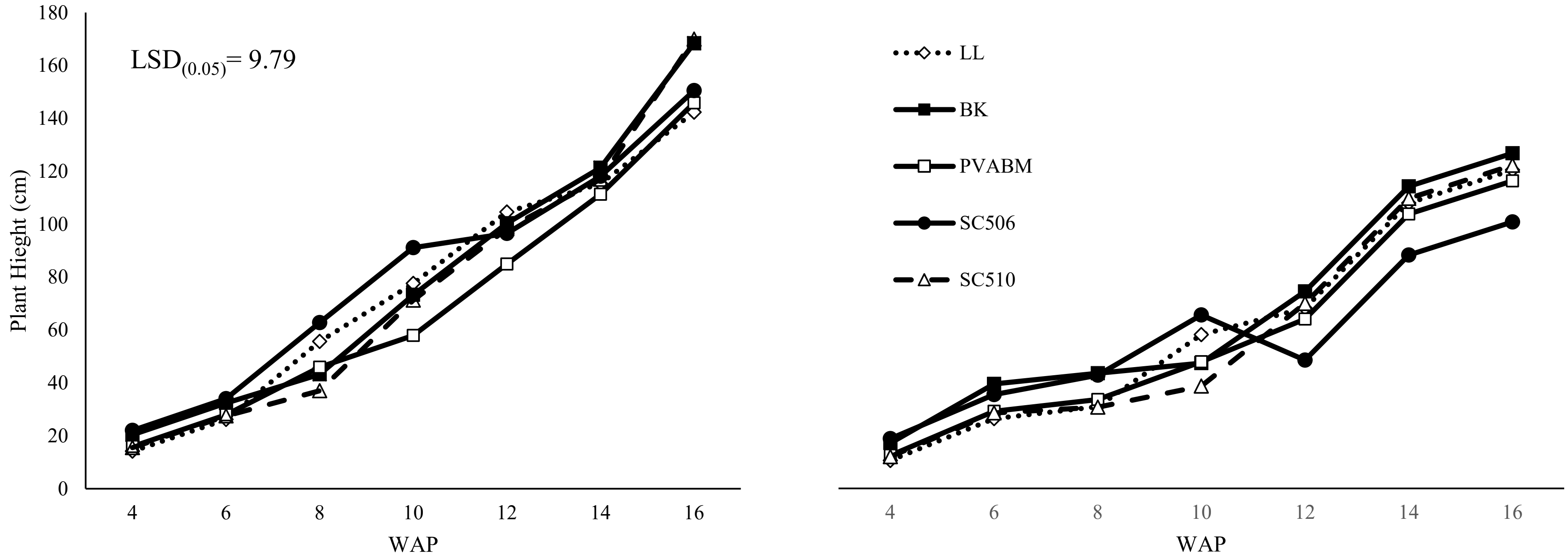

Figure 5.1a: Plant height for maize varieties (LL, BK, PVABM, SC506 and SC510) across two sites, Bulwer (A) and KwaDlangezwa (B) during 2015/16 season

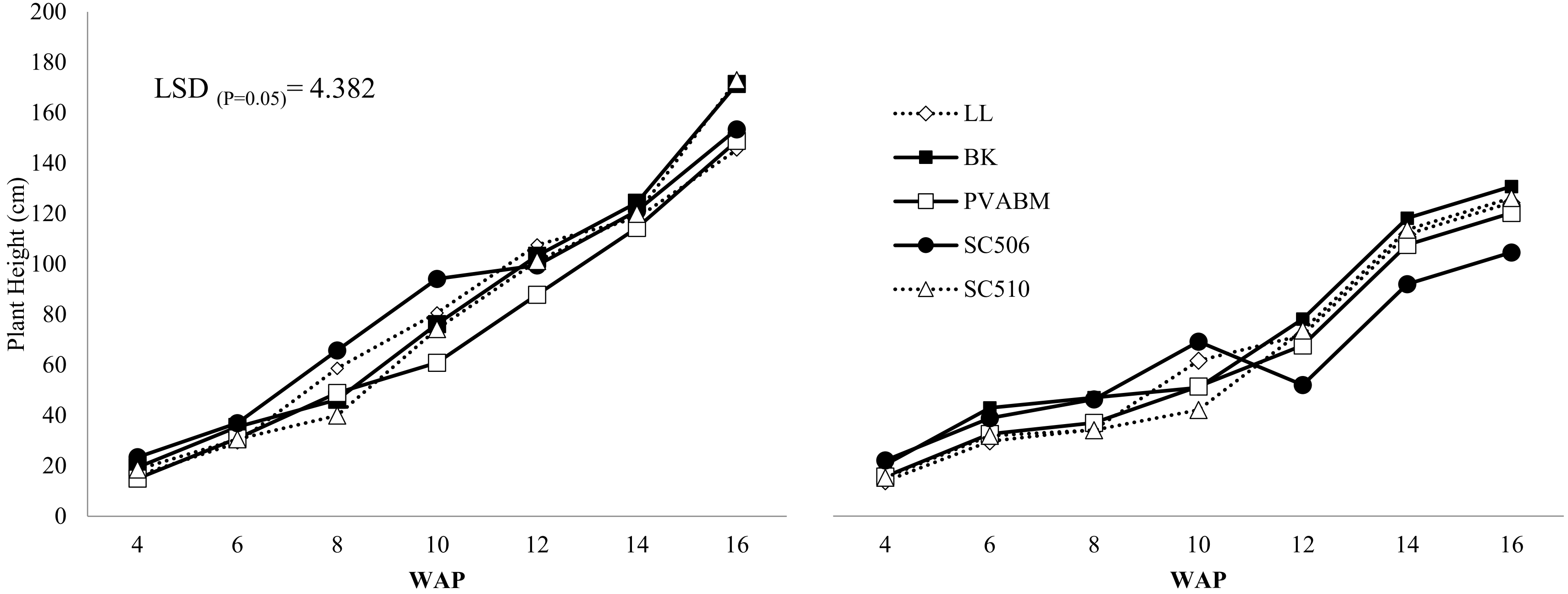

Figure 5.1b: Plant height for maize varieties (LL, BK, PVABM, SC506 and SC510) across two sites, Bulwer (A) and KwaDlangezwa (B) in 2016/17 season.

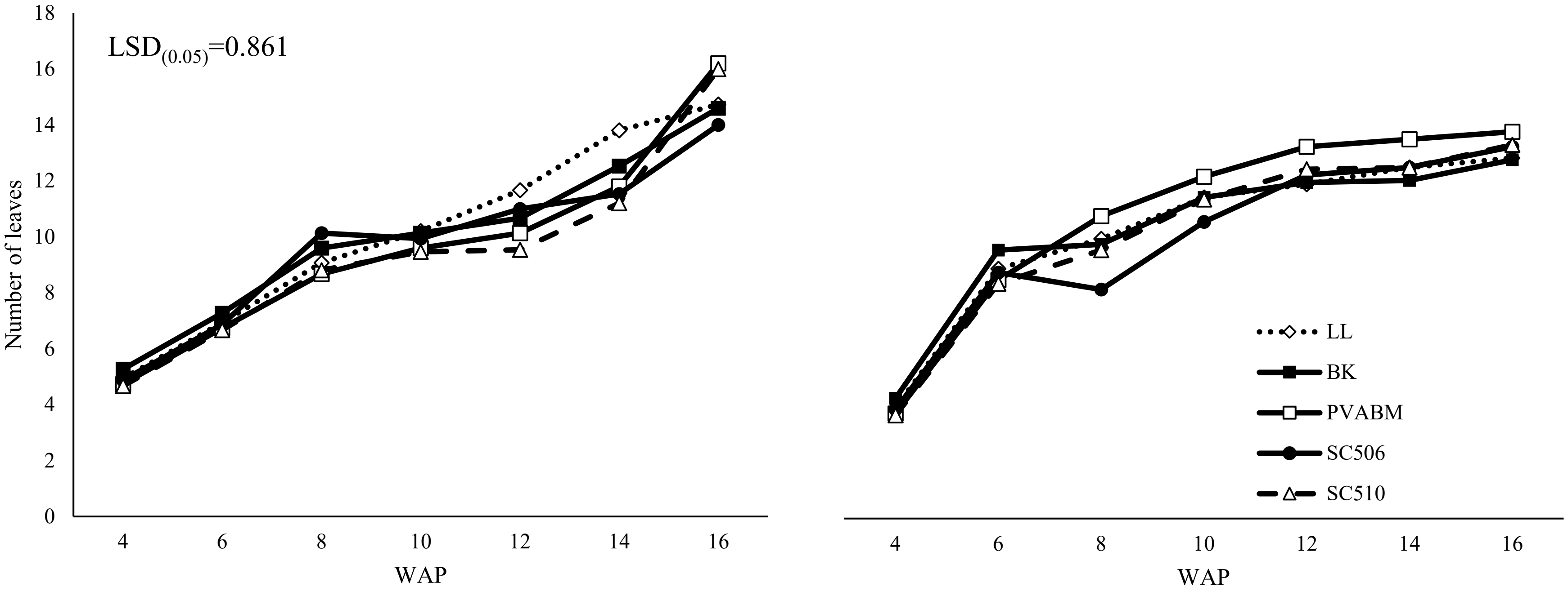

Figure 5.2a: Number of leaves for maize varieties (LL, BK, PVABM, SC506 and SC510) across two sites, Bulwer (A) and KwaDlangezwa (B) during 2015/16 season

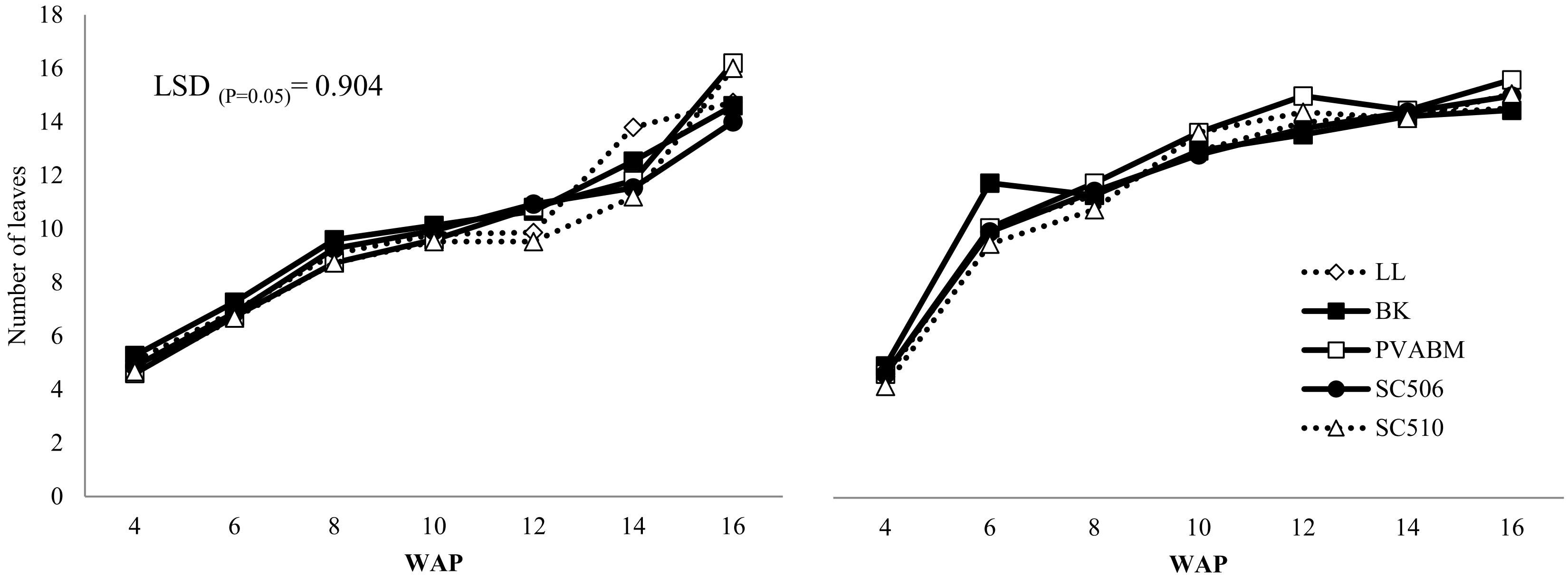

Figure 5.2b: Number of leaves for maize varieties (LL, BK, PVABM, SC506 and SC510) across two sites, Bulwer (A) and KwaDlangezwa (B) in 2016/17 season.

5.3.1.3. Chlorophyll content index

In the 2015/16 season, there were no significant differences (P> 0.05) observed for chlorophyll content on maize varieties across the two study sites. In Bulwer, the chlorophyll content for all varieties increased with time and a similar trend was observed in KwaDlangezwa during the study period (Figure 5.3a). The Chlorophyll content for Bulwer ranged 30.47 (LL) -35.02 (SC506) compared to 29.12 (PVABM) – 31.62(SC506) of KwaDlangezwa (Figure 5.3a).

During the second season (2016/17), maize varieties showed no significant differences (P> 0.05) in the chlorophyll content during the study period. However, there was a growing trend in chlorophyll content with time in both trial sites (Bulwer and KwaDlangezwa). At 15 WAP, the chlorophyll content ranged 27.90 (SC510) -46.5 (PVABM) in Bulwer and in KwaDlangezwa the range was 29.95 (BK) – 48.15 (SC506), (Figure 5.3b).

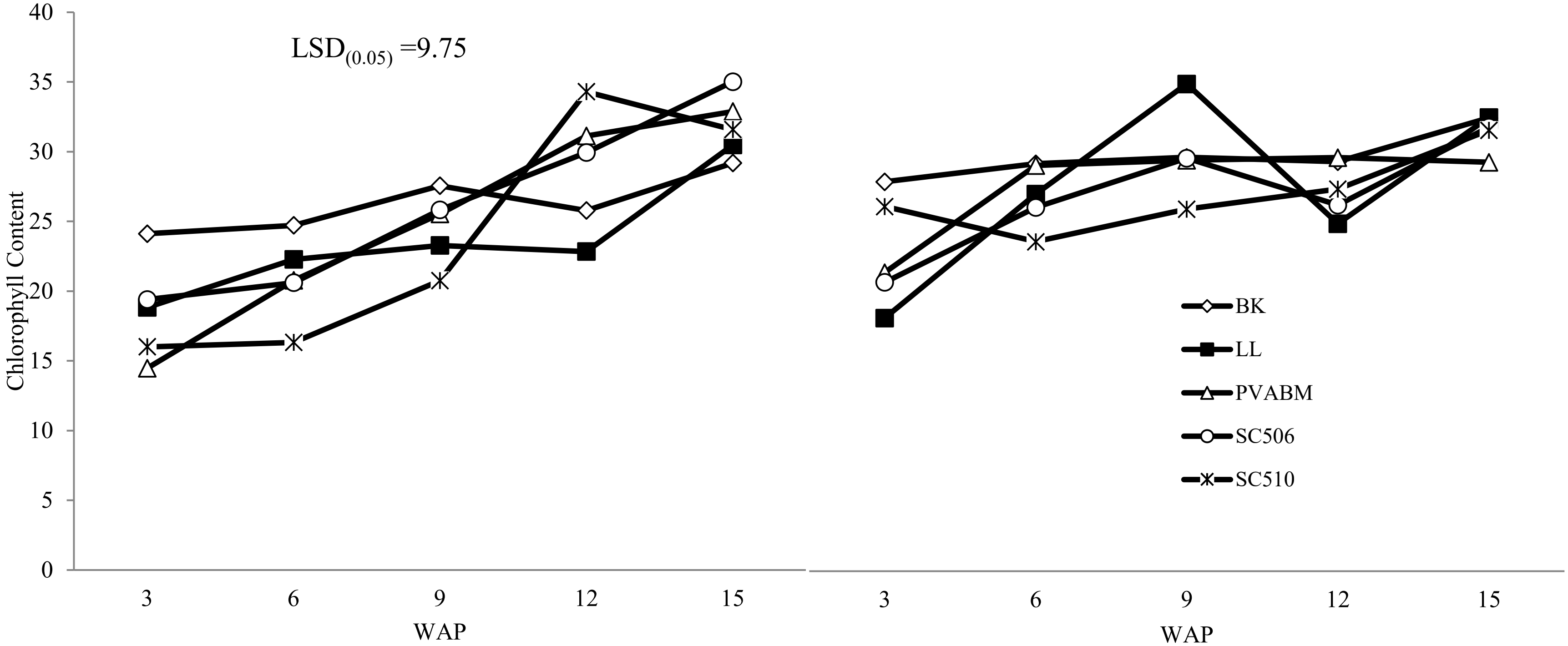

Figure 5.3a Chlorophyll content of maize varieties across two sites, Bulwer (A) and KwaDlangezwa (B) during 2015/16 season

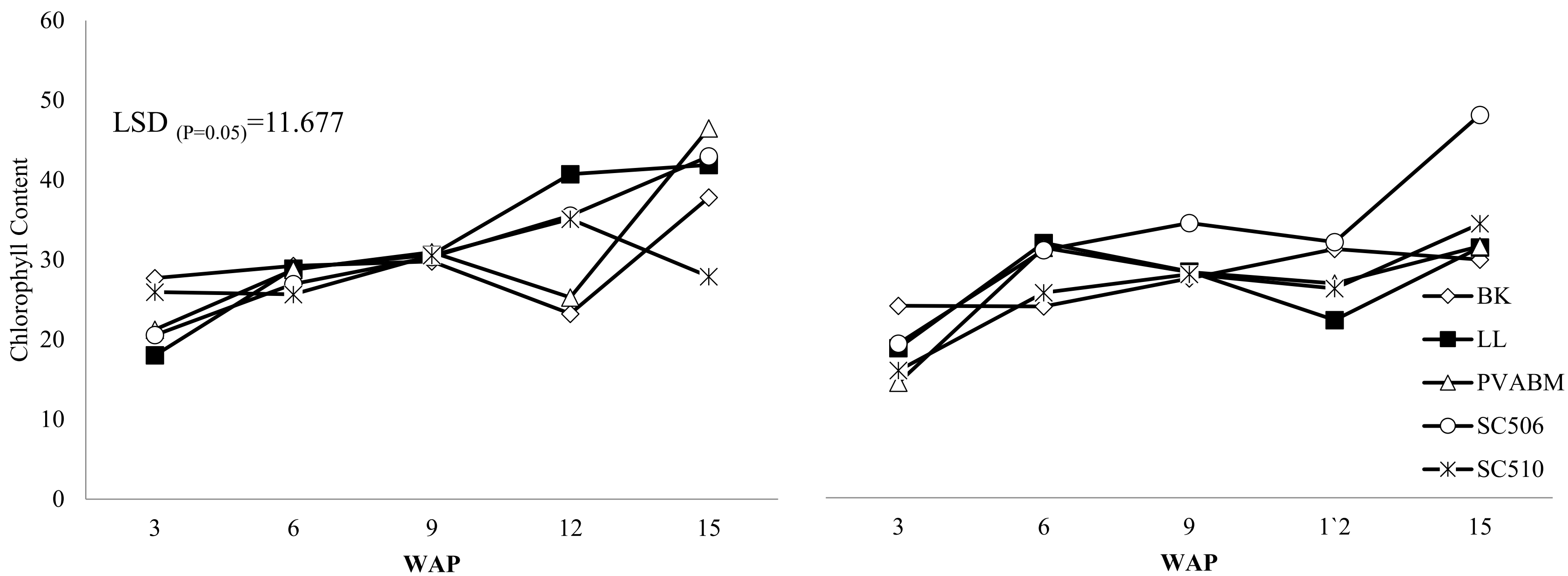

Figure 5.3b Chlorophyll content for maize varieties (LL, BK, PVABM, SC506 and SC510) across two sites, Bulwer (A) and KwaDlangezwa (B) in 2016/17 season

5.3.2. Yield and yield components

There were no significant differences (P>0.05) in cob length for the maize varieties in both sites during the first season (2015/16), (Table 5.2). However, in Bulwer the LL had higher cob length (15.67 cm) then other varieties. In, KwaDlangezwa, the PVABM variety had higher cob length (14.39 cm) while SC510 recorded lowest cob length (12.20 cm). No significant differences (P> 0.05) were observed for cob mass. In Bulwer, it was observed the cob mass per plant ranged from 270.7 g (SC510) - 309g (SC506) while in KwaDlangezwa the cob mass ranged from 243.8 g (SC510) - 283.3 g (SC506). The varieties in both sites showed no significant differences with respect to number of cobs per plant. Results showed in Bulwer the number of cobs per plant ranged from 1.2 (PVA) - 2 (SC510) while in KwaDlangezwa they ranged from 1.2 (PVABM) - 1.93(SC506).

With respect to kernel rows, there were no significant differences (P> 0.05) observed in both experimental sites. However, in Bulwer the SC506 had higher kernels row (12.5) while BK had lowest (8) and a similar observation was recorded in KwaDlangezwa. There were no significant differences (P> 0.05) observed for number of kernels per row for all the maize varieties in both sites (Table 5.2). Biomass showed no significant differences (P> 0.05) for location and variety combination (Table 5.2). However with respect to varieties there were significant differences (P< 0.05). SC510 had higher biomass (2.33 t/ha) while BK recorded lowest biomass (0.66g) in Bulwer. In KwaDlangezwa, the biomass ranged for 0.713 t/ha (PVA) – 1.66 t/ha (SC510).

The 100 seed mass showed no significant differences (P>0.05), In Bulwer there mass ranged from 20.9 g (SC510) -30.89 g (LL) whilst in KwaDlangezwa 24.82 g (PVABM)-30.89 g (LL). Yield obtained during the experiment showed no significant differences (P> 0.05) amongst varieties in both study sites. However, SC510 yielded higher in Bulwer (3.53 t/ha) compared to other varieties. A similar trend was observed in KwaDlangezwa where SC510 yielded (2.64 t/ha) and BK produced lower yield (1.47 t/ha). No significant differences (P> 0.05) observed for harvest index for all the maize varieties in both sites during the study.

During the second season (2016/17), yield components such as cob length recorded highly significant differences (P>0.001) among maize varieties across the two sites (Table 5.3). Cob length in Bulwer ranged from 13.81 (SC510) -15.67 (LL) while in KwaDlangezwa the range was 12.2 (SC510) - 14.93 (PVABM). No significant differences (P>0.05) were observed for cob mass per plant. Kernel rows were significantly differences (P<0.05) among maize varieties during the second season (2016/17) for both sites. The rows ranged 9.6 (BK)-12.27 (SC510) in Bulwer whilst 9.47 (BK) - 11.93 (PVABM) in KwaDlangezwa (Table 5.3).

The 100 seed mass recorded no significant differences (P>0.05), BK variety recorded highest seed mass (36.1 g) while SC510 the lowest (25.5 g) in Bulwer. However, contrary findings were recorded in KwaDlangezwa where SC510 recorded highest (32.4 g) compared to LL (24.6 g). Both yield and biomass during the second season (2016/17) showed no significant differences (P> 0.05) among the maize varieties across the two study sites (Table 5.3). Biomass in Bulwer ranged 0.86 t/ha (LL) - 1.52 t/ha (SC510) and 0.94 t/ha (BK) - 1.44 (SC510) in KwaDlangezwa (Table 5.3). Yield in Bulwer ranged 1.73 t/ha (LL) -2.69 t/ha (SC510) in Bulwer while in KwaDlangezwa it ranged 1.60 t/ha (BK) – 2.51 t/ha (SC510). Harvest index recorded not significant differences (P> 0.05) for the maize varieties in both trail sites (Table 5.3).

Table 5.2. Yield components of different maize varieties under different ecological conditions (Bulwer and KwaDlangezwa) during 2015/16 season

Area	Treatment	Cob length (cm)	Cob mass per plant (g)	Kernel row	Kernel per row	No.of cobs per plant	100 Seed Mass (g)	Biomass (t/ha)	Yield (t/ha)	Harvest Index
	LL	15.67a	293.1de	10.53bc	28.33c	1.333a	30.89ab	0.92ab	1.56a	0.5915a
	BK	14.46abcd	296de	8a	28.73c	1.4a	25.72ab	0.66a	2.07a	0.4121a
Bulwer	**PVABM**	15.16ab	309e	12.4d	27.2c	1.2a	25.4ab	1.10ab	2.38ab	0.4932a
	SC506	14.08bcd	312.1e	12.47d	29.07c	1.6abc	25.92ab	1.41abc	2.4ab	0.6193a
	SC510	13.81bcd	270.7bc	11.6cd	28.07c	2c	20.91a	2.327c	3.53b	0.8095a
		14.64	**296.2**	**11**	**28.28**	**1.507**	**25.8**	**1.29**	**2.39**	**0.585**
	LL	14.13abcd	266.7bc	9.07ab	27.27c	1.4a	30.89ab	0.84ab	1.58a	0.5943a
	BK	13.07de	259.7ab	8.4a	20.33a	1.6abc	26.42ab	0.94ab	1.47a	0.6630a
KwaDlangezwa	**PVABM**	14.93abc	263.8bc	11.27cd	22.87ab	1.2a	24.82ab	0.713a	1.92a	0.5888a
	SC506	13.38cde	283.3cd	11.73cd	24.67bc	1.933bc	31.64b	1.3ab	2.44ab	0.5933a
	SC510	12.2e	243.8a	11.27cd	26.6bc	1.467ab	29.13ab	1.66bc	2.64ab	0.7263a
		13.54	**263.5**	**10.35**	**24.35**	**1.52**	**27.7**	**1.091**	**2.01**	**0.633**
$LSD_{(P=0.05)}$ Treatment*Sites		1.59	10.86	1.48	3.8	0.44	10.24	0.85	1.23	0.5788

Table 5.3. Yield components of different maize varieties under different ecological conditions (Bulwer and KwaDlangezwa) during 2016/17

Area	**Treatment**	**Cob length (cm)**	**Cob mass per plant (g)**	**Kernel row**	**Kernel per row**	**No.of cobs per plant**	**100 Seed Mass (g)**	**Biomass (t/ha)**	**Yield (t/ha)**	**Harvest Index**
Bulwer	**LL**	16.8e	309.5f	11bcd	29.27d	1.87bcd	33.9ab	0.86a	1.73abc	0.63a
	BK	15.92de	285.3cdef	9.6ab	29.8d	1.6abc	36.1b	0.90a	2.64c	0.34a
	PVABM	16.16de	287.3def	12.4de	28.47d	1.4a	26.8ab	0.94a	2.21abc	0.43a
	SC506	15.04bcd	301.8ef	12.53e	29.4d	1.6abc	30.3ab	1.48a	2.25abc	0.69a
	SC510	16.65e	245.5ab	12.27de	28.13d	2.27d	25.5ab	1.52a	2.69c	0.72a
		16.11	**285.9**	**11.56**	**29.01**	**1.74**	**30.5**	**1.14**	**2.3**	**0.561**
KwaDlangezwa	**LL**	15.73cde	270.8bcd	10abc	26.6cd	1.46ab	24.6a	1.05a	1.6ab	0.66a
	BK	13.55b	258.1abc	9.47ab	20.27a	1.47ab	30.1ab	0.94a	1.47a	0.66a
	PVABM	15.03bcd	250.1ab	11.93de	23ab	1.27a	25.4ab	1.11a	2.58c	0.42a
	SC506	14.25bc	278.6cde	11.6de	23.87bc	2cd	31ab	1.40a	2.38abc	0.64a
	SC510	11.53a	241.7a	11.13cde	26.87cd	1.46ab	32.4ab	1.44a	2.51bc	0.59a
		14.02	**259.8**	**10.83**	**24.12**	**1.53**	**28.7**	**1.19**	**2.108**	**0.594**
$LSD_{(P=0.05)}$ Treatment*Sites		1.56	28.29	1.53	3.41	0.42	10.84	0.76	0.97	0.46

5.4. Discussion

Maize is a staple crop in sub Saharan region where VAD cases have been reported. Provitamin A biofortified maize has the potential to reduce VAD (Bouis et al., 2011). The study aimed at determining the agronomic potential of Provitamin A biofortified varieties compared with common varieties under on farm conditions in different environments. The on-farm conditions were different natural environment with different soil types. Successful maize production is a result of interaction of environment, genes, planting dates and soil properties (Akinnouye et al. 2017). The current results showed that maize varieties growth parameters increased with time during the study. The varieties growth differed between the two sites and there were significant differences observed amongst varieties in both study sites. As previously reported by Mazvimbakupa et al. (2015); Mabhaudhi (2010) most maize hybrids have the potential to adapt to KwaZulu-Natal due to the soil types and climatic conditions of the areas. The bioreource groups were different but there was successful productivity of all the maize varieties planted for the study. During the two season period (2015/16 and 2016/17) maize all maize varieties showed the ability to grow under different soil and environmental conditions. Especially the provitamin A biofortified maize varieties which showed there potential to adapt to local climatic condition like local common maize hybrids. This shows, the growing conditions were optimum for all maize varieties. As suggested by Kalaitzandonakes et al. (2015) that temperature and rainfall are key factors that promote maize growth.

Chlorophyll content was inconsistent for the maize varieties across the two seasons. In KwaDlangezwa it was low compared to Bulwer. These findings support Motsa (2014) suggestion that low in the similar bioresource group (Moist coast forest, thorn & palm veld) was due to energy limits and photosynthesis being substrate. The author further suggests the soil profile to have an impact on the chlorophyll content and growth parameters. As observed during the two season study that growth parameters and chlorophyll in KwaDlangezwa was reduced compared to Bulwer, this could suggest the impact of soil type, climatic condition and plant adaptation.

Planting in two different on farm sites influenced plant growth (height and leaf number). The maize varieties, common, local and provitamin A biofortfied recorded a positive growth with time in both sites. Significances observed during the two study site on plant growth parameters (plant height and leaf number) could be promoted by different soil types because Bulwer has Clovelly soils that have Orthic A while KwaDlangezwa have Dundee soils, these soils have different layers that have different characteristics in water retention and nutrient retention. The provitamin A biofortified maize varieties produced inconsistent results on growth across two seasons, however it was noted that they have the potential to grow like other varieties under different natural environmental conditions.

Successful germination and emergence leads to good growth and yield (Akinnouye, 2013) current study findings showed that growth had less impact on yield. Significant differences observed on plant growth were not transferred to plant yield during the two season study. However, positive observations were not on some yield components among the maize varieties on both seasons.

Yield components such as cob mass, 100 seed mass, biomass, yield and harvest index showed no significant differences per growing seasons. However, changes were observed for maize varieties response to different growing seasons and environment. These changes may be caused by soil fertility and climatic changes per growing season and study site. Karimmojeni et al., 2010 suggested that change in fertility, rainfall, temperature, soil moisture may lead to change in yield. Other yield components, cob length, number of cobs per plant, kernel row and kernel per row produced distinct statistically findings. In 2015/16 these components were not significant while in 2016/17 they recorded different significant levels among them.

Yield recorded no significant differences for two seasons. However, there positivity from the current findings was that provitamin A biorfotified maize (SC510) has the potential to produce better yield as a provitamin A biofortified maize variety. The current findings were similar those HarvestPlus (2015a) which demonstrated no significant differences in yield between provitamin A varieties and normal maize varieties in Zambia. The current findings are against the recommendation by Harvestplus (2015b) that provitamin A varieties can produce superior yields due to their ability to adapt under drought conditions and resist pests. However, there is scant information to compare the performance of provitamin A biorfotified maize varities under natural environment. Previous studies have shown that South African environmental conditions are better suited for newly introduced maize varieties (Gouse et al., 2005).

A study with Genetic Modified Bt maize showed significant higher yield in Bt than common hybrids in commercial and smallholder farming systems (Gouse et al., 2006). Similar findings we observed with Quality Protein Maize (QPM) hybrids (Pixley and Bjarnason, 2002). Contrary to current findings, Mabhaudhi (2010) observed that maize hybrids had superior yields to local landraces. Maize hybrids are expected to perform better under different environmental conditions because of their breeding abilities (Gertsis et al. 2015) and provitamin A maize varieties as a drought resistant crop were expected to yield better. However, factors like climate, management and plant dates can impact on the performance of maize varieties (Akinnouye et al. 2017).

5.5. Conclusion

As new varieties the provitamin A biofortified maize varieties are known to be drought resistance and high yielding. Even with no significant differences in yield components, the current findings showed that the provitamin A biorfotified maize varieties (PVABM and SC510) can adapt to different environmental conditions and soils like common and local maize landraces.

5.6. References

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CHAPTER 6. THE ACCEPTABILITY OF PVABM AS GREEN MEALIES (*IFUT*HO) AND CRUMBLED MAIZE (*UPHUTHU*) BY SMALLHOLDER FARMERS IN BULWER, KWAZULU NATAL SOUTH AFRICA

Under review in the South African journal of clinical nutrition

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Abstract
The current maize consumption patterns show that white maize is highly utilized for many dishes while yellow maize is underutilized. Consequently, its human consumption is limited to dishes such as corn bread (isinkwa sombila), boiled maize kennels (izinkobe), samp (istampu) and fermented maize drink (amahewu). The aim of the study was to assess the acceptability of PVABM as green mealies (*ifut*ho) and crumbled maize (*uPhuthu*) by smallholder farmers in the Bulwer area. A series of focus group (FG) discussions (number) were conducted complementing a sensory evaluation conducted to measure the acceptability of two maize-based foods (*ifutho* and *uphuthu*) comparing two maize types classified through colour (PVABM and white maize). A total of 72 farmers participated during the FG and sensory evaluation activity. The demographics of the study showed more female (69.4%) participated on the study.

The current study showed that PVABM was acceptable by the smallholder farmers as ifutho while PVABM uphuthu was less attractive than white maize. The sensory evaluation (colour, taste, aroma and texture) results showed that both ifutho and uphuthu (PVABM and white maize) were rated as good by the farmers' panel. Farmers during the focus group discussions indicated that PVABM maize was sticky compared to white maize and that it had a different smell to the common orange maize. In conclusion, farmers accepted provitamin A biofortified maize for consumption and they expressed the willingness to incorporate them in their food diets for nutritional improvement provided the varieties will adapt well to their farming conditions. However the stickiness of uphuthu remain farmers concern.

Keywords: Sensory evaluation, focus group, Vitamin A deficiency, biofortification

6.1. Introduction
Malnutrition remains a main problem in South Africa (Gwala, 2015) and the most affected are rural communities, where the most vulnerable groups are women and children. Ntila et al. (2018) added that dietary surveys on South African population during year 2000 to 2015 showed that most rural households receive limited dietary diversity. Malnutrition in rural

communities can be caused by various factors such as income, unemployment and too much dependence on staple foods.

Subsequently, micronutrient deficiency continues steadily grow as a challenge in South Africa. One of the concerning deficiencies is Vitamin A deficiency (VAD). Vitamin A deficiency has seen a rise over the past decade (Zuma et al. 2018). The vulnerable groups are children less than 9 years with children aged 0-4 yrs most likely to die of VAD in low income communities. The South African government has tried different strategies to combat VAD and other micronutrient deficiencies for the vulnerable groups (Zuma et al., 2018). Food nutrition enhancement strategies for most consumed foods including starch-based foods (which are mainly staple crops), supplementation with medical interventions, consumption of animal sources and food diversification (Ntila et al., 2017). However, these alternatives have not been successful because the vulnerable groups are from low income communities where most of the income is spent on staple foods. A study conducted in 2012 showed that regardless of the implemented strategies VAD remain a moderate public health problem for the country (Moloto et al., 2018)

Biofortification of staple crops has been identified as new strategy to reduce VAD in SSA including South Africa (Ntila et al., 2017). A rising breeding strategy known as biofortification has the potential to reduce the current growing trend of VAD in South Africa (Pillay et al., 2011; Zuma et al., 2018). Provitamin A biofortfied maize have been successfully introduced to reduce VAD in Zambia, Mozambique and South Africa (Stevens & Winter-Nelson, 2008; Pillay et al., 2011; Meenakshi et al. 2012; Nuss et al., 2012). There was a willingness to accept these maize varieties in Zambia and Mozambique, however in South Africa the maize varieties have not been commercialized. In South Africa, maize colour has high impact on the selection of maize type for production with white maize commonly used for human consumption while yellow for animal consumption. There is scant update data on the farmers' maize colour preferences in South Africa given the change in times. Similarly there is scanty information on the acceptability and farmers perceptions on the incorporation of Provitamin A biorfotified maize for human diets in low income communities of South Africa. The aim of the study was to access the acceptability of PVABM as green mealies (*ifut*ho) and Crumbled (*uPhuthu*) by smallholder farmers in Bulwer, South Africa.

6.2. Materials and methods

6.2.1. Site description

The study was conducted in Bulwer local municipality of Sisonke district in KwaZulu- Natal province, South Africa. Bulwer falls under Bioresource Group 11 defined as Moist Transitional Tall Grassveld and represent Bioresource Unit (BRU) Wc26 (Camp, 1999). Altitude varies 964- 1555 meters above sea level with mean annual rainfall of 848 mm. Subsistence farming is still in practice by many residents in the communal areas of Bulwer. Maize is their dominant crop which is produced every year.

6.2.2. Sampling technique

A sample of 72 maize smallholder farmers were recruited from a survey conducted with the farmers. The participants responded positively to the recruitment invitation for sensory evaluation and participation in focus group discussions. There were three data collection phases used; consumer demographic profiling, sensory evaluation and focus group discussions. The consumer profile questionnaire consisted of a few questions which were specifically on demographics of the respondents. For sensory evaluation, a 5 point pictorial Hedonic scale was used to testing the acceptability of different maize foods and a focus group interview gathered deep insight on maize production and the potential for incorporation of provitamin A biorfortfied maize as food for farmer’s livelihoods. For all the three data collection phases, the participants were grouped into a random group of 10-12 participants. The groups were allocated time slot for profiling and sensory evaluation session and immediately when they finish, they were lead to the focus group discussion session.

6.2.3. Data collection

The participants were gathered in a community hall (also known as tribal court), they were divided into 7 groups of 10 -12 participants. A similar pattern was followed for focus group discussions.

6.2.4. Maize used for sensory evaluation and preparation of maize dishes

Maize used for the current study was harvested in the on farm trials running in Bulwer which consisted of different PVABM and common local varieties. Maize was harvested during the growing season using local practices. Green mealies were boiled using the local method of preparing *ifutho* (steamed mealies in IsiZulu language). Local woman prepared the mealies as it was recommended that it best consumed while warm and no salt was used during the preparation. Maize for uPhuthu was harvested, dried and milled for maize meal. UPhuthu was prepared through boiling with water only and no salt was added to avoid contamination of taste during the sensory evaluation. The method used for preparing was the common procedure for it preparation in the community.

6.2.5. Seating and serving order

Twelve tables and chairs were set back to back spaced in an arm's length distance in-between and cubicles were placed on the tables to prevent participants from talking and influencing each other. Before serving the samples, they were all labeled using three digits code using random permutation and the food were served hot. Four trained (Zulu speaking) administrators were assigned to administer the sensory evaluation and focus group sessions. For focus group discussions, one administrator was a facilitator and the other was a scriber. A tape recorder was used to supplement the scribed notes.

6.2.6. Ethical consideration

The study was granted ethical approval by the University of KwaZulu Natal (HSS/0184/016D). More so, a written and verbal permission was granted by both extension government sector and the tribal authority. A consent form was also obtained from the participants (see Appendix).

6.2.7. Statistical analysis

Demographics were subjected frequency and descriptive analysis using IBM SPSS package version 25.

6.3. Results

6.3.1. Household demographic and socio-economic status

There were about (69.4%) female and (30.6 %) males who participated in the study (Table 6.1). Although in the study area the smallholder farmer's gender ration reflects more men (60.9%) to (29.1%) women, in this case females dominated because they were the principal influencers and decision-makers in food preparation. As previously noted by various researchers, youth involvement and participation in agriculture is a concern. The study showed less youth while the majority of the participants' age ranged between 36- 50 yrs. Studies, justify that most often, this is the age group that has sort of given-up on seeking job opportunities due to limited skills and or lack of education. In the study, the majority of participants had grade 8 – 10 (30.6%) education, (8.3 %) no formal education and only who matric and tertiary qualifications. With limited opportunities to get employment, agriculture becomes the last possible coping strategy for survival and livelihood. Most participants were married (52.8%) but highly dependent on social pension (50%) as their source of income while less dependent on wages (8.3 %). Average house hold income for most participants was between R 801.00 to R 1500 (61.1 %).

Table 6.1. Respondents' demographic data

		Percent (%)
Gender	Male	30.6
	Female	69.4
Age	> 35	16.8
	36 – 50	36.3
	51- 60	19.5
	> 60	27.9
Maritial status	Single	30.6
	Married	52.8
	Divorced	2.8
	Widow	13.9
Education	No formal education	8.3
	Grade 1- 4	11.1
	Grade 5-7	19.4
	Grade 8 – 10	30.6
	Grade 11-12	25
	Tertiary education	5.6
Income	Wages	8.3
	Salary	22.2
	Pension	50
	Grants	19.4
Employment status	Full time	5.6
	Part time	19.4
	Unemployed	66.7
	Self employed	8.3
Average Household income	< R800	30.6
	R801-R1500	61.1
	>R1500	8.3

6.3.2. Maize consumption

The focus group discussions confirmed the previously reported research that white maize was more acceptable as food for human consumption as opposed to yellow maize that is highly acceptable as livestock feed and food for human only during drought periods. Although yellow maize is mainly perceived to be feed, there were some special dishes that were deemed to present good sensory quality attributes when prepared with yellow maize, these dishes include corn bread (*isinkwa sombila*), maize kernel (*izinkobe*), Samp (*isitampu*) and maize fermented beer (*amahewu*).

Due to the yellow-orange color of Provitamin A boifortified maize, PVABM is compared to yellow maize known as uBhokide (yellow maize introduced as food aid in the 90s). Yellow maize as mentioned earlier is perceived as feed, food for the poor and drought food. Therefore, the researcher had to carefully distinguish between these yellow maize varieties without influencing the consumer's preference decisions (see methodology section). There was a positive response with regards to willingness to plant PVABM maize in respondents' fields and gardens.

6.3.3. Sensory evaluation

Sensory attributes of ifutho showed that both PVABM and white maize was acceptable for consumption during the study. The response showed that the taste of ifutho was acceptable for both PVABM (52.8%) and white maize (52.8). The colour of PVABM ifutho was acceptable (50%) and white (44.4%), the aroma was considered to be good for PVABM (58.3%) and very good for white maize (44.4%). The texture for both maize samples was comparably acceptable (good). Overall, both maize sensory attributes were rated as acceptable (Table 6.2).

A different response was noted with respect to PVABM uPhuthu, the taste was neutral (41.7%) for PVABM and good (50%) for white maize (Table 6.2). Also notable was the colour attribute where PVABM was considered as neutral (44.4%) while white maize was very good (58.3%). The texture was also neutral for PVABM (50%) while good (44.4%) for white maize. Similar trend was recorded for aroma, where PVABM was neutral (52.8%) and white was good (44.4%). Overall, the PVABM sensory attributes for uPhuthu were neutral rated while white maize was rated as good (Table 6.2).

Table 6.2. Farmer's sensory acceptability of PVABM maize food *(ifutho and uPhuthu*)

		PVABM					White				
		VB	B	N	G	VG	VB	B	N	G	VG
Ifutho	Taste	0.0	8.3	16.7	52.8	22.2	0.0	2.8	11.1	52.8	33.3
	Colour	8.3	2.8	16.7	50.0	22.2	8.3	5.6	13.9	44.4	27.8
	Aroma	2.8	0.0	19.4	58.3	19.4	2.8	19.4	2.8	30.6	44.4
	Texture	2.8	11.1	22.2	47.2	16.7	5.6	0.0	22.2	55.6	16.7
uPhuthu	Taste	0.0	2.8	41.7	38.9	16.7	8.3	2.8	16.7	50.0	22.2
	Colour	0.0	0.0	44.4	36.1	19.4	2.8	11.1	2.8	25.0	58.3
	Aroma	0.0	8.3	52.8	22.2	16.7	2.8	0.0	19.4	55.6	22.2
	Texture	8.3	2.8	50.0	22.2	16.7	2.8	8.3	19.4	44.4	25

VB= very bad, B= bad, N= Neutral, G= good and VG= Very Good

6.3.4. Willingness to adopt the PVABM cultivars

During the focus group discussions it was reported that farmers were still producing yellow maize in their fields. The planting ratio of the maize in the field was more to white maize (70%) due to white maize being the most preferred for consumption by their households. White maize is produced also for market purpose as green mealies in the nearby towns while yellow is sold to farmers with livestock (chicken, cow, pigs, goats and poultry). Farmers in the community preferred local landraces for maize production due to adaptability of their landraces to different environmental conditions.

Farmers have no problem in consuming yellow maize but they were concern with the aroma and stickiness of yellow maize when cooked as uPhuthu. If asked their perceptions about PVABM as yellow or orange maize, they responded that during the early 90s they had a similar maize type introduced as a food aid. That maize had negative sensory attributes as it was smelly and had bad taste. There was willingness to incorporate new maize varieties that will aid the livelihoods and create income. However, the sensory attributes of the maize such as the smell should be improved but the nutrition element of the maize was well accepted and appreciated. If PVABM, can have good sensory attributes the farmers would be willing to try these varieties in the farming systems and consume them for nutritious purposes. Different food products are produced through yellow maize by the challenge is the age preference, old people are perceived to prefer all dishes from maize while the youth hardly consume those dishes.

6.4. Discussion

More female participated during the current study. Gwala (2014) noted that female participate more than male in group discussions that includes food security and agriculture. Ncobela and Chimonyo (2015) also note that females are the most vulnerable groups of food insecurity than male hence their involvement in food debate has less impact to food security.

The current study showed that farmers consume more of white maize in their households than yellow maize. While yellow maize is selectively used for certain dishes such as inkobe, corn bread, samp and amahewu. This information is common to Meenakshi et al., (2010), who noted in their study that white maize is for human consumption mostly while yellow is less consumed and preferred for animal consumption. According to (Pillay et al., 2011) selection preferences are determined by several factors including beliefs and sensory attributes. Zuma et al. (2018) reported that yellow maize is less preferred because of it taste and aroma when compared to white maize and these factors may have negative effects on the acceptability of PVABM for human consumption. In a study by Zuma et al. (2017) the finding showed a positive recommendation of PVABM by smallholder farmers despite the yellow to orange colour and furthermore, there was willingness to incorporate these maize varieties into smallholder farming systems.

Sensory attributes for ifutho showed less difference between the maize types as it was observed that both PVABM and white maize were ranked as good by the farmers for all attributes (aroma, taste, texture, colour). These finding can suggests that farmers have no challenges with the consumption of PVABM prepared as ifutho meal. Meenakshi et al., (2012) observed similar findings that farmers had no challenge with PVABM in the rural areas of Zambia.

Farmers' response to uphuthu sensory attributes showed a good rating for the meal for both white and yellow (Table 6.2). These findings were similar to those of Pillay (2011) who found that caregivers accepted and rated provitamin A biorfotified food as good as white maize food. The current findings are contrary to suggestions that biofortification affects sensory attributes in a way that can affect it acceptability. Stevens and Winter-Nelson (2007) noted it their findings that existing preferences on white maize did not preclude the acceptance of PVABM (orange) varieties in Maputo. Similar to their findings, the current findings showed that farmers accepted and positively perceived the PVABM meals (ifutho and green mealies)

Overall farmer had positive sensory response to PVABM food during the current study and there was no impact of food colour on the response. Farmers were accepted PVABM for consumption, animal feeding and trading in the current study. Similar to the current findings were, Stevens and Winter-Nelson (2007). The colour and maize type has less impact on the acceptability of the PVABM meals during the current study hence there was a good rating of PVABM food and white maize. Amud et al., (2016) suggested that to improve the rating of flavor and other the acceptability of provitamin A maize is to relish with delicious meals such as chicken stew. Beswa et al., (2016) futher states that the addition of amaranths can also improve the nutritional contect of the common dishes prepared in rural households.

As expected, white maize remain the most preferred maize for consumption but the farmers showed to be highly willing to consume the PVABM maize due to the nutrient content it has and the potential to adapt to drought field conditions. Furthermore, if the opportunity arise for the marketing of the products in South Africa the farmers are willing to produce for the market. The study findings agree with Zuma et al., (2018) that PVABM has the potential of being intergrated in farming systems, food production and marketing by the low income people of South Africa.

Farmers during the focus group discussion also indicated that the PVABM uphuthu was sticky compared to white maize and it had a unique aroma. However, it could be consumable by the older generations but there was a worry that the youth might not be willing to consume that PVABM maize. Farmers further indicated that the PVABM cobs were sweet in taste and had small size kernels and cob size. This could a disadvantage to the incorporation process because one of the traits farmers use to select maize varieties is the cob size and kernel size.

6.5. Conclusion

Farmers from the current study were positive about provitamin A biofortified maize and there was willingness to incorporate these varieties into smallholder farming systems with the aim of improving nutrition and as a new business strategy. Provitamin A biofortified maize was accepted like white maize during the sensory study however this may lead to further studies on different foods prepared by PVABM tested for sensory. Nevertheless, all farmers expressed the willingness to consume PVABM and also complement their diets for improved nutrition in their households. The stickness of uPhuthu remain a challenge for human consumption. Therefore, for future studies and breeding purposes this would need to be addressed to improve PVABM acceptability.

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CHAPTER 7. GENERAL DISCUSSION AND CONCLUSION

The current study was a combination of social and experimental approach where farmers practices, perceptions and attitudes were taken to value to design experiments (seed quality and on farm trials). The soil to the table approach was applied during the current study where provitamin A biofortfied maize was observed in the laboratory (Seed Quality) and (Trails) against the common maize varieties in the country including local landraces of the study sites. The food produced was tested for sensory evaluation to measure it acceptability by smallholder farmers in the two study sites.

The current study aimed at assessing farmer perception towards the incorporation of PVABM into their smallholder farming systems, secondly to establish the agronomic potential of PVABM in smallholder farming systems and thirdly, to access the acceptability of PVABM food by smallholder farmers of KwaZulu-Natal, South Africa.

The specific objectives were (1), to assessed maize farming practices and farmers' perceptions on the incorporation of PVABM in their farming systems in KwaZulu Natal; (2), to evaluate seed quality characteristics and early establishment of PVABM varieties compared with common maize varieties, (3) to determine the response of provitamin A biorfotiified maize cultivars (commercial and non- commercial) under different environmental conditions and (4) to access the acceptability of PVABM as green melies (*ifut*ho) and crumbled maize (*uPhuthu*) by smallholder farmers in Bulwer, South Africa.

The current study finding showed that farmers had positive perceptions about the incorporation of PVABM in their farming systems and high percentage of willingness to adopt these maize varieties for production in their maize systems. It was also observed that farmers were willing to sell PVABM varieties if there market and production is good. However, there success of these PVABM varieties would be based on their agronomic potential and adaptability to different environments of the study areas. The findings from the seed quality characteristics (objective 2) showed that all seeds used for the current study were viable and had the potential to germinate during the standard germination test and emerged in the early establishment test. These findings also showed that compared to local maize hybrids the PVABM varieties have the similar seed quality potential because of the non-significant response in most characteristics. The analogues performance of these varieties highlighted the need for experimental trails to further determine potential of these maize varieties under different environmental conditions.

The findings from the on farm trails produced non-significant responses in yield components which led to conclusion that the PVABM varieties had the similar agronomic potential with other local maize varieties used for study. The two seasons study results could be a motivation for smallholder farmers who are willing to produce theses varieties. Even though statistical significances were observed during the on farm trials it was noted that PVABM varieties can adapt different environmental conditions and produce like common maize varieties used by smallholder farmers. The produced varieties were tested for the acceptability of PVABM as green melies (*ifut*ho) and maize meal (*uPhuthu*) by smallholder farmers in Bulwer.

It was also explored through literature that smallholder farmers from different culture background were willing accept PVABM maize in other African continent where this maize has been successful commercialized. Furthermore the current study suggests that PVABM can be produced for human consumption on different environmental conditions and it can also contribute to diverse diets for household consumption.

Provitamin A biofortified maize can add to food security reduction because of the potential to adapts of the varieties in different conditions. Even though, no statistical significances were highlighted during the on famr trails but there is hope for improved yields with time and PVABM varieties. The positive from the study was the willingness to farm and consume PVABM maize by smallholder farmers of different areas and this suggests that VAD cases would be reduced in these areas of study.