TARO (*COLOCASIA ESCULENTA* L. SCHOTT) YIELD AND QUALITY RESPONSE TO PLANTING DATE AND ORGANIC FERTILISATION

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MSc. Crop Science (University of KwaZulu-Natal)

Submitted in fulfillment of the requirements for the degree of

Doctor of Philosophy (Crop Science)

in the

School of Agricultural Sciences and Agribusiness

University of KwaZulu-Natal

Pietermaritzburg

DECEMBER 2009

DECLARATION

The experimental work presented in this thesis was carried out at the University of KwaZulu-Natal, Pietermaritzburg, from February 2007 to December 2009 under the supervision of Professor Albert T. Modi.

These studies are my original work except where acknowledged and have not been submitted in any form for any degree at any other university.

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I declare that the above statement is correct.

………………………………..
Professor Albert T. Modi
December 2009

ACKNOWLEDGEMENTS

I would like to thank Almighty God for giving me strength and perseverance to complete this study.

I am grateful to my family and friends for their love, encouragement and support.

I express my gratitude to my supervisor, Professor Albert T. Modi for his determined supervision, guidance and encouragement.

I extend my sincere appreciation to the technical staff for their assistance on the experimental farm.

I would also like to thank Mr. Shakes Mabhida for allowing me to use his land for the Umbumbulu trial.

This study was funded by **SANPAD** (South Africa-Netherlands Research Programme on Alternatives in Development): Project Number 05/32.

DEDICATION

I would like to dedicate this thesis to my sons, Mpho and Tšepo for understanding when I couldn`t be there when they needed me most.

ABSTRACT

Despite the importance of taro (*Colocasia esculenta* L. Schott) as a food security crop, scientific research on it is scanty in South Africa. Production site, planting date and fertiliser regime affect crop performance and quality, particularly that of cultivars, because they tend to be adapted to specific localities. Storage temperature and packaging method on the other hand affect the shelf-life. To investigate performance and quality of three taro cultivars in response to planting date and fertilisation, a study was carried out at two sites in KwaZulu-Natal, South Africa (Ukulinga and Umbumbulu), during the 2007/2008 growing seasons. The effect of two storage temperatures (12^{o}C and ambient temperature) and three packaging methods (polyethylene bags, mesh bags and open boxes) on cormel quality following storage was also investigated for three cultivars. Delayed planting negatively affected the number of cormels plant^{-1} and fresh cormel mass plant^{-1}. Fertilisation and cultivar affected the number of cormels plant^{-1} and fresh cormel mass plant^{-1} only when planting was done in October and November at both sites. Fertilisation increased the number of cormels plant^{-1} for all cultivars except *Dumbe-dumbe*. *Dumbe-dumbe* had the lowest number of cormels plant^{-1} but the highest number of marketable cormels plant^{-1}. *Dumbe-dumbe* showed the lowest fresh cormel mass plant^{-1} in October and the highest in November at Ukulinga. Fertisation increased fresh cormel mass plant^{-1} in October at Umbumbulu. Dry matter content was negatively affected by fertilisation at Ukulinga. The response of dry matter content, specific gravity, protein, minerals, reducing sugars and starch content was variable depending on cultivar. Delayed planting negatively affected starch content for *Dumbe-dumbe* and *Pitshi* at Ukulinga. Fertilisation decreased starch content of *Pitshi,* while delayed planting increased sugar content for *Dumbe-dumbe* and decreased it for *Mgingqeni* and *Pitshi* at Umbumbulu. *Dumbe-dumbe* had higher starch content and higher reducing sugars. Considering all growth and quality parameters, it is recommended that *Dumbe-dumbe* is the best taro cultivar for crisping and the best time to plant it is October with 160 kg N ha^{-1} of organic fertiliser and November with 320 kg N ha^{-1} at Ukulinga whereas at Umbumbulu the best time to plant *Dumbe-dumbe* is October with 320 kg N ha^{-1} of the fertiliser. Starch granules degradation, alpha-amylase activity and sprouting increased

with storage time and storage temperature. Cormels of *Mgingqeni* stored in polyethylene bags showed highest alpha-amylase activity and sprouting. Reducing sugar content increased and starch content decreased with time in storage and decline in storage temperature. It is recommended that taro cormels be stored in mesh bags at 12^{o}C.

The chapters of this thesis represent different studies presented as different papers. Chapter 1 is a general introduction to explain the study background and hypothesis. Chapter 2 is a general review of literature. Chapter 3 is on growth, development and yield of taro in response to planting date and fertilisation. Chapter 4 is on the influence of planting date and organic fertiliser on crisping quality of taro cormels. Chapter 5 is on changes in the surface morphology of starch granules and alpha-amylase activity of taro during storage. Chapter 6 is on the effects of pre- and post-harvest practices on starch and reducing sugars of taro. The last chapter is a general discussion and conclusions.

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CHAPTER 1
GENERAL INTRODUCTION

Taro, *Colocasia esculenta* (L.) Schott belongs to the monocotyledonous family *Araceae* of the order *Arales* whose members are known as aroids (Henry, 2001; Van Wyk, 2005). *Araceae* includes about 100 genera and 1500 widely distributed species (Merlin, 1982; Vinning, 2003). Taro is one of the few edible species in the genus *Colocasia* within the sub-family *Colocasioideae* (Ezumah, 1972) and the most widely cultivated species (Vinning, 2003). The species is considered to be allogamous and polymorphic (Ivancic *et al*., 2003). *Colocasia* species can be classified as follow: (1) *Colocasia esculenta* (L) Schott var. *esculenta* (produces a large cylindrical central corm with very few cormels and is known as dasheen); and (2) *Colocasia esculenta* (L) Schott var. *antiquorum* (produces a small globular central corm surrounded by numerous side cormels and is also known as eddoe) (Purseglove, 1972; Lebot and Aradhya, 1991).

Originating in Asia, this root crop is now found primarily in tropical and subtropical regions of the world (Bradbury *et al*., 1988; Macleod, 1990). In South Africa, taro is mainly a KwaZulu-Natal coast and hinterland traditional crop (Modi, 2004), hence the Zulu name amadumbe. It is an important staple crop in the subtropical coastal area starting at Bizana district in the Eastern Cape and the rest of coastal KwaZulu-Natal. There is less cultivation of the crop in the Midlands and generally none in the northern parts of the province where the climate is drier and cooler. The crop is also cultivated in the subtropical and tropical parts of Mpumalanga and Limpopo provinces (Shange, 2004).

Taro is used as food, prepared the same way as potatoes. Its flour is considered good baby food because its starch is easily digestible; and it helps with digestive problems and supplements iron (Onwueme, 1999; Shange, 2004; Van Wyk, 2005). According to Vinning (2003), taro starch digestibility is as high as 98%. It is also suitable as a specialty food for allergic infants and persons with alimentary disorders and for those allergic to cereal starch as well as those sensitive to animal milk ((Salunkhe and Kadam, 1998; Onwueme, 1999; Vinning, 2003). Various parts of the plant are also used in traditional medicine practice (Tsitsiringos, 2002). Taro is also used as an ornamental in Australia, Japan, Italy and elsewhere. Although, it is irritating to the human skin, mouth and throat, acridity protect taro against herbivores. The crop is thus well suited for organic farming (Krech *et al.*, 2004). Taro is regarded as potential and important because of its nutritional status and the role it plays in food security, especially in the rural areas. In many rural areas, taro industry provides meaningful employment and plays an important part in the cultural practices and as a vehicle for rural development (Onwueme, 1999). Taro is an excellent multipurpose food crop for subsistence agriculture and home gardens. Its ability to tolerate salinity makes it suitable for localities where few other crops grow (Grubben and Denton, 2004). As such, it merits more attention in research focusing on yield (Grubben and Denton, 2004).

Most taro production in South Africa is consumed as subsistence food on the farms and a small proportion finds its way to the market (Shange, 2004). According to Modi (2003), only Umbumbulu farmers market it. Taro is of increasing importance as a subsistence crop in the rural areas of KwaZulu-Natal. The rise in importance of the crop can be attributed to the fact that 7 years ago the subsistence farmers from Umbumbulu started to supply fresh certified organic taro to Woolworths Foods and Pick`n ‘Pay chain stores which sell it in Durban, Johannesburg and Cape town. The subsistence farmers are only able to supply taro after harvest. They do not meet a regular continuous demand of consumers by providing availability of taro for longer periods of time. This is mainly because storage life of taro is usually rather short owing to its high moisture content. This short storage life of taro has emphasized the need to improve its storage potential. The potential of local cultivars for food processing needs to be explored, to improve marketing opportunities and household income for the farmers. Their potential for processing into crisp chips has been identified in KwaZulu-Natal to add value to the product.

Despite its contribution to food security over centuries, including the times before the advent of commercial crops originating in Europe, which predominate traditional agriculture today (e.g. potatoes), agronomic research into taro is very recent in South

Africa (Mare, 2006, Modi, 2003; 2007; Shange, 2004). Among the aspects that have not been studied in detail regarding South African taro include the relationship between agronomy and quality with respect to storability and possibly food processing, as is the case in root crops such as potato.

A neglect of the crop is found in the extension services, so that the technical knowledge base of the producers is very low. Most of the above constraints in the taro production system can be effectively tackled and possibly solved through research. A lot of taro production still relies on age-old traditional production methods. Research into various agronomic and storage practices is needed to improve the productivity and storability of taro. There is need to establish, through research, the best pre- and post-harvest practices with respect to planting date, fertilisation and storage requirements of taro among others. All the above research priorities need to be addressed in order to sustain the taro industry.

With the potential production of chips from taro, there is a need for an increased understanding of how corm chipping quality is impacted by planting date, landrace, fertilisation and storage. The specific objectives of the study were

1. To investigate the effect of planting date and fertilisation on growth and yield of taro cultivars found in Umbumbulu, KwaZulu-Natal.
2. To determine the effects of planting date, fertilisation on chipping quality of taro cormels.
3. To examine changes in the surface morphology of starch granules, alpha-amylase activity and sprouting of taro cormels during storage.
4. To investigate effects of pre- and post-harvest practices on starch and reducing sugars of taro.

This dissertation is presented in the form of manuscripts, written according to the style of the African Crop Science Journal, for convenience. The last chapter is a generalized discussion and conclusion.

References

Bradbury, J.H., Holloway, W.D., Bradshaw, K., Jealous, W. and Phimpisane, T. 1988. Effect of cooking on nutrient content of tropical root crops from the South Pacific. *Journal of Science of Food and Agriculture* 43: 333–342.

Ezumah, H.C. 1972. The growth and development of taro, *Colocasia esculenta* (L.) Schott, in relation to selected cultural management practices. Ph.D. Thesis. University of Hawaii.

Grubben, G.J.H. and Denton, O.A. 2004. Vegetables. Plant Resources of Tropical Africa. PROTA.

Henry, R. J. 2001. Plant genotyping: The DNA fingerprinting of plants. CAB Publishing, Southern Cross University, Australia.

Ivancic, A., Quero-Garcia, J. and Lebot, V. 2003. Development of visual tools for selecting qualitative corm characteristics of taro (*Colocasia esculenta* (L.) Schott). *Australian Journal of Agriculture* 54: 581-587.

Krech, S., McNeill, J.R. and Merchant, C. 2004. Encyclopedia of world environmental history. Routledge

Lebot, V. and Aradhya, K. M. 1991. Isozyme variation in taro (*Colocasia esculenta* (L.) Schott) from Asia and Oceania. *Euphytica* 56: 55-66.

Macleod, G. 1990. Combined gas chromatography-mass spectrometric analysis of the aroma components of cooked taro (*Colocasia esculenta L.*). *Food Chemistry* 38: 89–96.

Mare, R.M. 2006. Phytotron and field performance of taro [*Colocasia esculenta* (L.) Schott] landraces from Umbumbulu. MSc. Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Merlin, M. 1982. The origins and dispersal of true taro. Native Planters: Ho`okupu Kalo.

Modi, A.T. 2003. What do subsistence farmers know about indigenous crops and organic farming? Preliminary case in KwaZulu-Natal. *Development Southern Africa* 20: 673-682.

Modi, A.T. 2004 . Short-term preservation of maize landrace seed and taro propagules using indigenous storage methods. *South African Journal of Botany* 70 (1): 16-23.

Onwueme, I.C. 1999. Taro cultivation in Asia and the Pacific. FAO PAR publication 1996/16. Bangkok, Thailand

Purseglove, J.W. 1972. Tropical crops: Monocotyledons. Wiley, New York.

Salunkhe, D.K. and Kadam, S.S. 1998. Handbook of vegetable science and technology: Production, composition, storage and processing. Marcel Dekker. USA.

Shange, L.P. 2004. Taro (*Colocasia esculenta* (L.) Schott) production by small-scale farmers in KwaZulu-Natal: Farmer practices and performance of propagule types under wetland and dryland conditions. MSc. Thesis. University of KwaZulu-Natal, Pietermaritzburg.

Tsitsiringos, V.K. 2002. Financial engineering, E-commerce and supply chain. Kluwer Academic Publishers, The Netherlands.

Van Wyk, B.E. 2005. Food plants of the world: Identification, culinary uses and nutritional value. Briza Publications, Pretoria, South Africa.

Vinning, G. 2003. Select markets for taro, sweet potato and yam. RIRDC Project No. UCQ-13A.

CHAPTER 2
LITERATURE REVIEW

2.1 Quality of taro cormels for crisp making

Quality refers to the suitability of cormels for a particular manufacturing process. It is important with regard to food processing and it is a combination of characteristics that give a commodity value. The relative importance given to a specific quality characteristic varies in accordance with the commodity concerned and with the individual or market concerned with quality assessment (Kader and Rolle, 2004). According to Hollyer *et al*. (2000), making taro chips is similar to making potato chips so the quality parameters required for chip making are similar. Potato processors require precise tuber characteristics to optimize product quality and quantity (Williams and Cobb, 1993). In potatoes, high yield is an important quality attribute to producers while tuber size is important to processors (Kader and Rolle, 2004; Carputo *et al*., 2005) Potato industry requires large grade tubers with better crisping quality (Kader and Rolle, 2004). Chemical composition is of utmost importance in tubers destined for crisp making, and in potatoes, these includes specific gravity, dry matter content, starch content, starch quality, sugar content (sucrose, glucose and fructose), protein content, minerals and shelf life (Eskin, 1989; Kader and Rolle, 2004; Carputo *et al*., 2005; Gebhardt *et al*., 2005; O`Keefe *et al*., 2005).

2.1.1 Yield

Yield traits include total weight of cormels plant^{-1}, number of cormels plant^{-1} and mass of individual corms. Smith (1987) stated that the size of the tuber is the key criterion for determining suitability of a potato cultivar for crisping. Potato processors prefer medium sized tubers, 170-284g in weight to produce uniform crisps (Smith, 1987). The cultivar suitable for crisping must, therefore, have high yields with a high proportion of usable tubers having a good size. In potatoes, a 45 kg sample with about 250 tubers will have many tubers in this size range and an average weight close to 184 g per tuber (Smith, 1987). According to Panhwar (2005), tubers of about 50-350 g in weight are preferred because they produce the crisp of the right size and pass through the processing line with less need for hand trimming.

2.1.2 Chemical composition of taro cormels

2.1.2.1 Specific gravity

Specific gravity is a major characteristic of tubers for processing. It influences the processing quality of potatoes and is used by processors to assess the acceptability (Laboski and Kelling, 2007). High specific gravity indicates maturity and corresponds to high quality (Bowers *et al*., 1964), but specific gravity should also not be excessively high since tubers with excessively high specific gravity are susceptible to bruising (Mosley and Chase, 1993). Tubers with high specific gravity produce high chip yield, absorb less oil and need less energy to process and hence less processing costs (Smith, 1987; Xiong and Tai, 2003). According to Hollyer *et al*. (2000), specific gravity of raw taro corms varies in a narrow range of 0.94 – 0.98, with more mature corms having the greater value. Taro corms selected for crisping must have moderately high specific gravity. Tubers with very high specific gravity bruise easily. In potatoes, tubers with specific gravity of 1.070 – 1.109 can be used for crisping but excellent crisps can be obtained with specific gravity of 1.090 – 1.099 (Smith, 1987). Panhwar (2005) suggested the minimum acceptable levels of 1.07.

2.1.2.2 Dry matter content

Dry matter needed in the raw product depends on its processing destination. Quality characteristics of potatoes processed into crisps are largely dependent on the dry matter content (Talburt and Smith, 1987). In potatoes, tubers high in dry matter are suitable for the manufacture of crisps (Lisińska and Laszczyński, 1989) and this attribute need to be present at harvest and remain through storage (Smith, 1987). Higher dry matter content in raw products improves recovery rate during processing and directly influences texture and appearance of and indirectly colour of potato crisps (Smith, 1987). Hollyer *et a*l. (2000) also reported that chips made from the bottom of the corm are rated better in appearance than those made from the top part because the bottom part is dryer with around 5 percent greater dry matter content than the top part. According to Smith (1987), dry matter content for crisping should be in the range of 20-23% whereas Kita (2002), on the other hand, suggested that percentage of dry matter in potatoes for crisp production should be 20 – 25%. This was also confirmed by Panhwar (2005) who suggested that the minimum dry matter content acceptable for crisping should be 20%.

2.1.2.3 Starch content

Starch content was reported to influence corm quality for making crisp chips in taro (O`Keefe *et al*, 2005). Kita (2002) observed the texture of crisps to be dependent on the content of starch in potato tubers. The ideal crisping potato must have high starch and dry matter content, it should be high at harvest and through storage (Smith, 1987; O`Keefe *et al*., 2005). According to Kita (2002), starch content for crisping should be more than 15%.

2.1.2.4 Alpha-amylase activity

Alpha amylase is a starch degrading enzyme that takes part in the breakdown of starch in potatoes (Witt and Sauter, 1996; Ramachandran *et al.*, 2004). In cereal grains it is of prime importance in initial stages of starch degradation (Macgregor, 1983). It is one of the three enzymes that can convert starch back to glucose (Kays, 1991). Alpha amylase is inhibited by calcium (Duffus and Duffus, 1984; Witt and Sauter, 1996; Ramachandran *et al.*, 2004). Kumar and Ramesh (undated) stated that the enzyme is heterogeneous and that some of its components might be more efficient than others in hydrolyzing starch granules. The activity of the enzyme is therefore of utmost importance to monitor its part in starch degradation. The low thermal stability and the high affinity to granules at low temperature might suggest a role for the enzyme especially in cold-induced sweetening.

2.1.2.5 Reducing sugar content

Sugar content of potato tubers is another important factor accounting for their usability as processing raw material (Talburt and Smith 1987). Reducing sugars are responsible for enzymatic browning during frying which is a negative aspect for the potato processing industry (Allison *et al*., 1999). O'Keefe *et al*. (2005) reported that chips produced from the top of the taro corm were a darker colour than chips produced from the middle of the corm due to a higher reducing sugar content in the top part than the middle of the corm (an average of 0.15% higher). According to Roe *et al*. (1990) 90% of the variation in colour of potato chips could be accounted for by variation in sugar content. Potatoes suitable for crisping must have low reducing sugars and sucrose contents to minimize the browning during frying and like with other attributes they need to be low at harvest and throughout storage (Smith, 1987). Smith (1987) reported that the best levels for potato chip colour occur when sucrose levels are equal to or below 1.5mg/g tuber and glucose levels are equal to or below 0.35 mg/g tuber. Kumar *et al*. (2007) stated that tubers with high reducing and total sugar (>2%) were found to be unsuitable for crisp-making. According to Lisińska and Leszczyński (1989), reducing sugar should not exceed 0.25 – 0.5% whereas according to Kita (2002), the content of total sugars should be less than 0.23% and reducing sugars less than 0.12%. Panhwar (2005), on the other hand, suggested that reducing sugars should not exceed 0.2%.

2.1.2.6 Protein and mineral content

Protein nitrogen could influence the quality of crisps. Besides starch content of the potato tubers, crisp texture also depends on the sum of other components including protein nitrogen (Kita, 2002). Tuber proteins also include amino acids which together with sugars are responsible for the production of the colour of fried chips. According to Roe *et al*. (1990), 8% of the variation in the colour of crisps could be accounted for by amino acids.
Total proteins and levels of minerals in taro are important because they are components of the human diet. And foodstuff is regarded as important based on its composition of components of the human diet. Mineral content also affect the colour of chips by

affecting the reducing sugar content. Success in making taro chips varies with varieties due to the acridity nature of the taro corms (Hollyer *et al*., 2000; Bradbury and Nixon, 1998). Ndimantang and Obiakor (2006) reported that frying in oil to doneness reduced oxalates. Therefore frying is greatly recommended for the quality processing of Cocoyams. High temperatures are known to cause the calcium oxalate containing cells (raphides) to collapse leading to the break down of oxalate structure. The mechanism of oxalate reduction by heat has not been fully clarified (Ndimantang and Obiakor, 2006).

2.2 Taro growth stages

Corm quality is determined at different growth stages in taro. According to Sivan (1982) there are three growth stages in taro, namely establishment, vegetative growth and corm initiation and bulking through maturation.

2.2.1 Establishment

The period of establishment is the root formation and leaf production during the first month (Sivan, 1982). This stage is characterized by sprouting and root growth. Successful establishment is a critical prerequisite for efficient crop production and is primarily determined by propagule quality (Modi, 2007). In taro, propagule size is crucial for successful establishment because at this stage plants are entirely supported by available carbohydrates from the seed piece up to a plant leaf area of 400cm^2 plant^{-1} (Singh *et al*., 1998). A study by Modi (2007) showed that large propagules in taro improved stand establishment by increasing the number of plants reaching the third leaf stage and leaf area plant^{-1} one month after planting.

2.2.2 Vegetative growth and corm initiation

This is a period of rapid root and shoot development with initiation of corm development during two to four months (Sivan, 1982). The stage is marked by increase in plant height, number of leaves and leaf area and slow corm growth (Tumuhimbise *et al*., 2007; Silva *et* *al*, 2008). The leaf and stem are the dominant sinks for assimilates at this stage (Singh *et al.*, 1998). Maximal total leaf area indices were obtained at about 117 days after planting and then declined sharply (Goenega, 1995). This was confirmed by Mare (2006) who found leaf number, plant height and leaf area to reach maximum at 120 days after planting. Corm formation commences at about three months after planting and cormel formation follows soon afterwards in cultivars that produce appreciable cormels (Onwueme, 1999).

2.2.3 Corm bulking and maturation

This is the period of a climax of root and shoot growth with a rapid increase in corm formation during five to six months and a senescence period of decreasing root and shoot growth with continued increase in corm size during six through nine months (Sivan, 1982). The leaf development decreases in intensity and the plant growth is reduced (Silva *et al.*, 2008). This was also confirmed by Onwueme (1999), who reported that the rapid decline in shoot growth and total shoot dry weight was shown at about six months after planting. And this was characterized by a reduction in the number of active leaves, decrease in the mean petiole length, a decrease in the total leaf area per plant, and a decrease in the mean plant height on the field (Onwueme, 1999). According to Goenega (1995), corm bulking occurred after the attainment of maximal leaf area indices and the partitioning of dry matter to the corms remained constant almost especially after 150 days after planting. Tumuhimbise *et al*. (2007) also reported that it is a period of growth in which corm diameter and length increased rapidly throughout the 150 days. Singh *et al*. (1998) on the other hand reported assimilate partitioning to corms to be maximum at 120 days after planting and levelled until 160 days after planting under non limiting water and nitrogen conditions. Corms and cormels are given the first priority and become the main sink for available assimilates at this point and grow very rapidly (Singh *et al.*, 1998; Onwueme, 1999).

2.3 Factors influencing taro quality

The yield of taro is affected by planting date with temperature being the most important factor affecting growth (Lu *et al*., 2001). Water availability and fertilisation also affect yield and quality of taro (Chun-Feng and Kun, 2004; Scheffer *et al*., 2005). In potatoes, yield and chemical composition varies with variety (Karam *et al*., 2009). It is also influenced by climatic conditions, which are dependent upon the site and planting date. Storage environment also bring changes to the chemical composition of potato tubers (Lisińska and Laszczyński, 1989).

2.3.1 Genetic factors

Yield and chemical composition of root crops differs with different cultivars. Proietti *et al*. (2005) suggested quality attributes in potatoes to be affected mainly by cultivar. Osiru *et al*. (2009) recorded variation in root yield among sweet potato genotypes. Babaji *et al*. (2009) also reported Nicola, RC 767-2 and WC 732-1 which are Irish potato cultivars to have produced more tubers and unmarketable tuber yield than Greta, whereas Greta and RC 767-2 produced larger tubers than Nicola and WC 732-1. Variation in water content (55.8 to 74.4 g 100 g^{-1}), starch content (20.0 to 35.1 g 100 g^{-1}), protein content (0.5 to 2.1 g 100 g^{-1}) and mineral content (Wills *et al*., 1983) and starch content (509.1 to 705.7 g kg^{-1} dry weight) (Agbor-Egbe and Rickard, 1990) between taro cultivars was recorded.

According to Smith (1987), specific gravity is an inherited trait determined by the genetic makeup of a cultivar. They reported that some cultivars of potatoes develop higher specific gravity than others and that a cultivar with inherently low specific gravity cannot produce tubers with a high specific gravity through cultural management (Smith 1987). Long *et al*. (2004) also reported that genotype was the major factor that influenced specific gravity, sucrose and glucose content of Michigan potato cultivars. Highly significant differences in dry matter content between tested potato varieties were reported by Musa *et al*. (2009). Wills *et al*. (1983) indicated starch properties in taro to be influenced by genetic variation. Significant variations in amylase activity were reported between cultivars in sweet potatoes (Nandutu *et al*., 2000).

Sugar content was highly varied between potato cultivars and the ratios of reducing sugars to sucrose and fructose to glucose differed from variety to variety (Lisińska and Laszczyński, 1989). Similarly, protein content and mineral levels in different cultivars of taro were also found to be variable (Wills *et al*, 1983; Bártová *et al*., 2009). This confirmed previous studies that found wide differences in the content of protein, carbohydrate, iron, calcium and phosphorus of 9 cultivars of edible aroids (Rashid and Daunicht, 1979). Islam *et al*. (2007) found that in sweet potatoes, different cultivars were different in terms of storability.

2.3.2 Planting date

Planting date influences yield of tuber crops (Khan *et al*., 2003; Martin *et al*., 2005). Planting date effects on the yield and chemical composition of a crop are dependent on the environmental conditions prevailing during the crop life cycle. A differential response of the genotypes to the varying climatic conditions at different locations was also reported for cocoyam (Reyes - Castro *et al*., 2005). These environmental conditions or weather variations among locations and the planting dates include temperature and rainfall or water availability. The optimum planting date is related to soil and air temperatures as well as soil moisture content (Lisińska and Laszczyński, 1989). The soil moisture in turn depends on rainfall or water availability. The ideal planting date is the one that does not allow the stages of crop growth to coincide with the periods when the crop is very sensitive to temperature or moisture stress to avoid drastic effects on yield and quality. Lu *et al*., (2001) found that in Taiwan final harvest index in taro was highest for January and March plantings, whereas July and September plantings had the lowest harvest index, and that was attributed to high temperature during the vigorous top-growth stage for January and March crops and declining temperature during the vigorous top-growth stage for July and September crops.

2.3.2.1 Temperature

Temperature was found to be the primary factor governing growth rate in taro (Chan *et al*., 1998). Transpiration, translocation, photosynthesis and respiration which all affect yield and chemical composition of root crops are temperature dependent (Smith, 1987). According to Bazzaz and Sombroek (1996), all stages of crop development are sensitive to temperature and the sensitivity differs with phenological stages and genotype. They also stated that in general, development accelerates as temperature increases.

Wolf *et al*. (1990) found that translocation of assimilates to the vegetative organs was greater at higher temperatures while translocation to the tubers was less in both potato varieties studied. This was confirmed by Almekinders and Struik (1996) who reported increased number of leaves per stem and stems per shoot in potatoes at warmer temperatures which altered assimilate production and partitioning and hence yield. Ghosh *et al*. (2000) observed maximum yield reduction at high temperature at vegetative to tuber initiation which was most critical for tuber yield, and highest yield at low temperature at tuber initiation to initial tuber bulking which was considered as more advantageous step towards yield improvement. Many studies reported that high temperature reduce yield (Rykaczewska, 2004). High temperature (30^{o}C) compared to 15 ^{o}C and 25^{o}C was found to degrade potato tuber quality by reducing specific gravity (Ghosh *et al*., 2000).

Dry matter content is reduced by temperature and water stresses (Smith, 1987; Bakayoko *et al*., 2009). Mittra and George (2000) reported lower tuber dry matter content in sweet potatoes planted in June, July and August in India compared to those planted in September and October and this was attributed to high dry matter accumulation in leaves and vines in plants grown during the period of high temperature (June, July and August). The same observations were made by Colla *et al*. (2005) who found that dry matter of potatoes grown in 2003 was lower than in 2004 due to the very high temperature, especially night temperature, which may have reduced the rate of photosynthesis and increased respiratory losses. These findings were confirmed by Hammer *et al*. (2007) who found dry matter of cassava storage roots to be highest during the cooler months when canopy vigour was lowest.

The influence of environmental factors on starch properties in chickpea are greater than varietal differences (Debon and Tester, 2000). Excessively high day temperatures decrease photosynthesis and increase respiration and these causes loss of starch. Starch in the tubers particularly near the stem end is then converted into sucrose and the dry matter of the tuber decreases whereas the sugar levels are raised. High air temperatures may be accompanied by water stress, resulting in uneven tuber growth or bulking rate (Smith, 1987). Temperature influences the uptake and metabolism of mineral nutrients by plants by increasing transpiration rates (Kader and Rolle, 2004).

2.3.2.2 Rainfall

Water availability influences yield and tuber size distribution in potatoes (Casa *et al*., 2005). Al-Omran (1991) recorded maximum average yields at the highest irrigation level in potatoes. It was also reported that in taro inadequate rainfall during the time of greatest water need resulted in lower yield and percentage corm dry matter (Miyasaka *et al*., 2001). Similar results were reported by Yuan *et al*. (2003) who found that total fresh tuber yields and marketable tuber yields increased with increasing amounts of irrigation water and that highest yields were obtained at highest irrigation level. They also found that irrigation increased tuber number and mean weight of the tubers (Yuan *et al*., 2003). Reduced potato yields were also reported with water stress (Rykaczewska, 2004; Alsharari *et al*., 2007).

Adequate moisture produces potatoes with high specific gravities and starch content whereas water deficiency leads to low specific gravity (Smith, 1987). Yuan *et al*. (2003) reported irrigation to decrease specific gravity. Irrigation influences dry matter content (Casa *et al*., 2005). According to Smith (1987), water stress reduces dry matter content. Mittra and George (2000), on the contrary reported lower tuber dry matter content in sweet potatoes planted during the period of high rainfall. This is in line with what Hollyer *et al*. (2000) found that wet-grown taro varieties have too high a moisture content to make a good chip. Irrigation influences sugar content. Water deficiency lead to high sugar content (Smith, 1987).

2.3.3 Fertilisation

Nitrogen, phosphorus and potassium are the three major nutrients, which individually and/or together maintain growth, yield and quality of plants (Mazid, 1993; Ivonyi *et al*., 1997). Additional nutrients are applied to the soil to produce optimum yields and quality since many soils do not supply enough phosphorus and potassium (Smith, 1987). Crops respond differently to different fertiliser elements, and proper fertiliser management for a plant species is important for increasing yield and quality.

Fertilisation influences the water and nutrient supply to the plant, which can in turn affect the nutritional quality of the harvested plant part. The effects of mineral and elemental uptake from fertilisers by plants are, however, significant and variable (Kader and Rolle, 2004). Proper nitrogen fertilisation is important to achieve optimum yields and quality of potatoes for processing (Smith, 1987). Deficits or excesses in nitrogen availability are both negative for optimization of yield and quality (Allison *et al*., 1999). Many tuber quality attributes are promoted by an adequate nitrogen supply, but decreased by an excess (Casa *et al*., 2005). However, many of the effects of nitrogen on tuber quality are strongly influenced by other factors, such as variety and water status (Casa *et al*., 2005). Potassium fertilisation also affects yield in potatoes (Kumar *et al.*, 2004).

Nitrogen is responsible for 26-41% of crop yields (Maier *et al*., 1994; Mazid, 1993). Nitrogen excesses is negative for tuber yield in the sense that it increases leaf area and prolong leaf production leading to delay in tuber maturity. According to Allison *et al*. (1999), nitrogen deficiencies decrease the fraction of larger size tubers. This was confirmed by Casa *et al*. (2005) who reported that nitrogen deficiency in addition to causing yield decreases, also affects tuber number and size distribution. Zelalem (2009) also reported that nitrogen fertilisation increase tuber number and average tuber yield in potatoes.

Phosphorus indirectly promotes plant growth and absorption of potassium as well as other nutrients (Oya, 1972). Root crops have a large requirement for phosphorus and it contributes to early tuberisation and increase the number of tubers per plant (Jenkins and

Ali, 2000). This confirmed earlier report by Ali (1998) that phosphorus increases the number of tubers per plant. Ali *et al*. (2004) compared tuber number and yield of potato cv. Desiree fertilised with six levels of phosphorus fertiliser and observed that tuber number m^{-2} increased up to 200 kg P_2O_5 ha^{-1}. Dubetz and Bole (1975), on the other hand, previously reported number and tuber yield to increase up to 224 kg P_2O_5 ha^{-1} with mean weight per tuber continuing to increase up to 448 kg P_2O_5 ha^{-1}. According to Smith (1987) deficiency of phosphorus also leads to very small tubers.

Potatoes use large amounts of potassium (Smith, 1987). Tuber size is one of the tuber quality parameter most affected by potassium fertilisation (McDole *et al*., 1978; Sharma and Arora, 1987; Chapman *et al*., 1992; Westermann *et al*., 1994). An increase in the proportions of large tubers relative to small ones was reported in response to potassium fertilisation (Martin-Prevel, 1989; Singh *et al*., 1996; Karam *et al*., 2005). Tawfik (2001) reported that high rate of potassium increased yield of medium (28-60 mm) and over-sized tubers (> 60 mm) by about 15 and 40% respectively. The increase in large size tubers in response to potassium nutrition was attributed to an increase in water accumulation in tubers (Perrenoud, 1993). Smith (1987) also reported the deficiency of potassium to lead to many small sized tubers. Chapman *et al*., 1992 and Westermann *et al*., 1994 reported total tuber yield increase with increase in potassium fertilisation. Plants fertilised with high rate of potassium (120 kg K. Fed^{-1}) showed 25-30% increase in fresh weight of tubers compared to those of low potassium (60 kg K. Fed^{-1}) (Tawfik, 2001). A sufficient supply of potassium also promotes nitrogen uptake efficiency of plants due to its stimulant effect on plant growth (Oya, 1972). Deficiencies in sulfur, calcium, boron and zinc may also lower yield and lead to earlier vine death (Smith, 1987). Increasing soil calcium may increase average tuber size and decrease tuber number (Ozgen *et al*., 2003).

Adequate soil fertility produces potatoes with high specific gravities whereas nutrient excess and deficiency lead to low specific gravity (Smith, 1987). Specific gravity often decreases as rate of applied nitrogen increases (Laurence *et al*., 1985; Porter and Sisson, 1991; Feibert *et al*., 1998; Sparrow and Chapman, 2003). Dahlenberg *et al*. (1990), however, reported lower specific gravity in nitrogen deficient tubers as well as in those from plants where nitrogen was in excess of that needed for maximum yield, in 3 out of 4 sites in South Australia. This is in line with findings that that nutrient deficiency leads to low specific gravity (Smith, 1987) and that excessive nitrogen promotes excessive vine growth late in the season resulting in potato tubers having much lower specific gravity (Smith, 1987; Laboski and Kelling, 2007).

Excessive application rates of potassium may reduce tuber solids and hence lower specific gravity (Laboski and Kelling, 2007). Specific gravity and dry matter content of potatoes were not affected by phosphorus fertilisation when 0, 20, 40 and 60 kg ha^{-1} of phosphorus were applied on vertisols of Debre Berhan in the highlands of central Ethiopia (Zelalem, 2009). According to (Laboski and Kelling, 2007), phosphorus applications may improve specific gravity when soil test phosphorus levels are low. A high potassium level has been associated with slightly lower specific gravity (Smith, 1987). Potassium did not influence tuber specific gravity and dry matter content when 0-166 kg K ha^{-1} was applied (Kumar *et al.*, 2004).

Fertiliser application to nutrient deficient soils will usually improve dry matter content. Tubers from nutrient-deficient plants are usually lower in dry matter content. Excessive nitrogen also results in potato tubers having much lower dry matter content (Smith (1987); Allison *et al*. (1999); Casa *et al*. (2005)) but this can be improved by phosphorus application (Smith, 1987). Hollyer *et al*. (2000) found similar results in taro that the more nitrogen, the lower the dry matter. Deficiency of phosphorus and potassium, and excess potassium fertilisation also lowers dry matter content in potatoes (Smith, 1987; Perrenoud, 1993). Starch content was found to decrease with increasing nitrogen fertiliser rates (Shan *et al*., 2004).

Nutrient deficiency stresses raise sugar levels. Nutrient deficiency leads to high sugar content (Smith, 1987). Nitrogen excesses have been shown to delay tuber maturity and this lead to higher reducing sugars content in the harvested tubers (Smith, 1987; Allison *et al.*, 1999). Potassium application has been found to reduce reducing sugar content of tubers (Kader and Rolle, 2004) but potassium did not influence reducing sugars when 0-166 kg K ha^{-1} was applied (Kumar *et al.*, 2004).

Colla *et al*. (2005) reported increased nitrogen concentration of tubers with nitrogen increases in the fertiliser rate in agreement with the findings of Meyer and Marcum (1998). Millard (1985) also reported increased tuber nitrogen concentrations from 0.68-0.81 to 1.27-1.49% dry matter with increasing nitrogen fertiliser over the range 0-250 kg ha^{-1}. This also means increased protein content since protein content is calculated from the nitrogen content.

2.4 Shelf life

Shelf life is crucial in the use of root parts as raw materials for processing. In potatoes, crisping industries use stored tubers for most of the processing since potatoes are not harvested throughout the year (Smith, 1987). Likewise, taro is harvested from August to February in Umbumbulu and there is a need therefore to store it for the five months when it is not harvested. Proper storage management helps retain the quality standard important to processing. The major quality concerns for stored potatoes destined for processing are specific gravity, dry matter content, starch content, alpha amylase activity, sprouting and sugar accumulation (Smith, 1987). The ideal taro cultivars should be able to store and maintain the quality of corms for crisping as long as possible. In potatoes, tubers must also exhibit long dormancy and amenable to storage at low temperatures for up to 240 days (Williams and Cobb, 1993).

2.4.1 Factors affecting shelf life of taro

The shelf life of root crops is influenced among others by genotype, storage temperature and packaging (Kay, 1987; Brown *et al*., 1990; Yosuke *et al*., 2000). The chemical composition of potato tubers changes during storage (Lisińska and Laszczyński, 1989). According to Bowers *et al*. (1964) corms with high specific gravity tend to have the longer the shelf life. Smith (1987) stated that in Russet Burbank potatoes, less glucose tend to accumulate in storage when tubers have a high specific gravity. Biemelt *et al*. (2000) reported that alpha-amylase did not change significantly during storage and that it was stimulated by 30% after the onset of sprouting. They therefore concluded that starch degradation is not a prerequisite for the initiation of sprouting since no change in starch degrading enzymes was detected prior to visible sprout growth. High levels of calcium in tubers can improve its storability by reducing respiration rates (Ozgen *et al*., 2003; Kader and Rolle, 2004).

2.4.1.1 Storage temperature

Temperature is the most important environmental factor that influences the deterioration of harvested commodities (Kader and Rolle, 2004). It has great influence on many factors that cause loss during storage (Diop, 1998). Low temperature storage causes tubers to develop reducing sugars and decrease starch content hence become unsuitable for processing into crisps (Wong Yen Cheong and Govinden, 1998; Pal *et al*., 2008). This was confirmed by Yosuke *et al*. (2000) by reporting that sugar accumulation tends to increase and starch content to decrease more at a lower temperature compared to a higher temperature. Agbor-Egbe and Rickard (1990) reported a significant reduction to 39.8-47.4 g kg^{-1} in starch content and increase to 8.0-11.6 g kg^{-1} in total sugars content to occur during storage of cormels for two weeks under tropical ambient conditions (24-29°C; 86-98% RH).

Higher temperatures, on the other hand, cause sprouting and weight loss to occur earlier (Wong Yen Cheong and Govinden, 1998; Pal *et al*., 2008). Sprouting can result in dramatic loss as the stored starch is transformed to sugars and utilized by the elongating shoots with appreciable loss of both food value and moisture (FAO, 1981). Storage at 20^oC, particularly under high relative humidity conditions resulted in excessive sprouting (Midmore *et al*., 2006). This was in line with what was reported earlier by Wong Yen Cheong and Govinden (1998) that tubers stored at 8-10 °C or at ambient temperature lost much weight because of excessive sprouting as from about 12 weeks compared to those stored at 2-4°C. High temperatures reduce specific gravity by increasing respiration rates whereas low relative humidity increases specific gravity by allowing tubers to lose more water. An increase in temperature causes an increase in the rate of natural breakdown of all produce as food reserves and water content become depleted. High temperature can greatly increase the loss of water from stored produce beyond that unavoidably lost from natural causes (FAO, 1989).

Cocoyam has a considerably longer shelf life of several weeks and this can be extended further with refrigerated storage (O'Hair, 1990). Agbo-Egbe and Rickard (1991) reported taro to be successfully stored for 5-6 weeks at 15°C and 85% relative humidity. Midmore *et al*. (2006), on the other hand reported storage of corms to be possible at 7–12°C in a dark well ventilated room for up to eight weeks without quality compromise whereas Hicks and Nguyen (2004) recommended storage of corms under the same conditions and same time at 7–15°C. According to Opara (1998), if storage environment can be maintained at 11-13°C and 85-90% relative humidity, the length of storage of taro can be extended to about 150 days. This implies that storage life can be generally improved at conditions of lower temperature and high humidity. The cooling of produce extends its life by slowing the rate of breakdown. Losses have been decreased with improved storage systems that control temperature and humidity. Maximum storage life can be achieved by storing only undamaged produce at the lowest temperature and highest relative humidity tolerable by the crop (FAO, 1989), however care should be taken not use very low temperatures. For sweet potato, storage is particularly successful when temperature is kept relatively cool, although if held below 12°C chilling damage can occur (FAO, 1981). A previous Japanese study by Rhee and Iwata (1982) had found taro showing chilling at 4°C storage.

2.4.1.2 Packaging

Packaging methods affect storage of harvested crops by influencing air flow rates around the commodities, thereby affecting temperature and relative humidity (Kader and Rolle, 2004). Kader and Rolle (2004) further stated that relative humidity can be controlled by adding polyethylene liners in packing containers and using perforated polymeric films for packaging. Aroids can be successfully stored in plastic bags. It was observed in Fiji that packaging of taro in plastic bags enhances keeping quality (FAO, 1981). Compared to the open box, the conditions created inside the bag reduce moisture loss. Quevedo *et al*. (1991) reported that packing taro corms in plastic bags and closely tying the open end with rubber bands reduced weight loss. Kay (1987) reported that the storage life of corms in polyethylene bags was 26-40 days over those packed in cartons. Taros stored in polyethylene bags showed a 6% loss in fresh weight and 50% decay (Passam, 1982).

2.5 Conclusion

It is clear from the preceding review of literature that the agronomy of taro is well understood. However, the majority of agronomic knowledge about the crop was derived from environments outside South Africa. Therefore, basic agronomic studies on taro species occurring in South Africa are still relevant. With respect to quality attributes associated with processing of taro, there is still a paucity of knowledge, hence the tendency to use potato as a model crop in this review. The gap of knowledge about the influence of agronomic practices, specifically fertilisation, on taro cormel quality is the focus of the current study.

References

Agbor-Egbe, T. and Rickard, J.E. 1990. Evaluation of the chemical composition of fresh and stored edible aroids. *Journal of the Science of Food and Agriculture* 53 (4): 487-495.

Agbor-Egbe, T. and Rickard, J.E. 1991. Study of the factors affecting storage of edible aroids. *Annals of Applied Biology* 119: 121-130.

Ali, H. 1998. Studies on phosphorus nutrition of potatoes. Ph.D. Thesis. University of Wales, Aberystwyth, UK.

Ali, H., Anjum, M.A. and Randhawa, S.A. 2004. Influence of phosphorus on yield potential of potato (*Solanum tuberosum* L.) crops. *International Journal of Agriculture and Biology* 6 (1): 165-167.

Allison, M.F., Allen, E.J. and Fowler, J.H. 1999. The nutrition of the potato crop. British Potato Council Research Review 1991/1. BPC Oxford, UK.

Almekinders, C.J.M. and Struik, P.C. 1996. Shoot development and flowering in potato (*Solanum tuberosum* L.). *Potato Research* 39 (4): 581-607.

Al-Omran, 1991. Effect of deficit irrigation on potatoes production. *Journal of King Saud University Agricultural science* 3 (1): 139-147.

Alsharari, S.F., Alsadon, A.A. and Alharbi, A.R. 2007. Evaluation of drought tolerance of potato cultivars under greenhouse conditions. *Acta Horticulturae* 747: 67-74.

Babaji, B.A., Amans, E.B., Chiezey, U.F., Falak, A.M., Tanimu, B. and Mukhtar, A.A. 2009. Unmarketable tuber yield and other agronomic parameters of four varieties of Irish potato (*Solanum tuberosum* L.) as influenced by NPK fertilizer rate and type of seed tuber at Samaru, Nigeria. *Asian Journal of Crop Science* 1(1): 26-33.

Bakayoko, S., Tschannen, A., Nindjin, C., Dao, D., Girardin, O. and Assa, A. 2009. Impact of water stress on fresh tuber yield and dry matter content of cassava (*Manihot esculenta* Crantz) in Côte d'Ivoire. *African Journal of Agricultural Research* 4 (1): 21-27.

Bártová, V., Bárta, J., Diviš, J., Švajnar, J. and Peterka, J. 2009. Crude protein content in tubers of starch processing potato cultivars in dependence on different agro-ecological conditions. *Journal of Central European Agriculture* 10 (1): 57-66.

Bazzaz, F. and Sombroek, W. 1996. Global climate change and agricultural production. Direct and indirect effects of changing hydrological, pedological and plant physiological processes. John Wiley & Sons Ltd. Baffins Lane, Chichester.

Biemelt, S., Hajirezaei, M., Hentschel, E. and Sonnewald, U. 2000. Comparative analysis of abscisic acid content and starch degradation during storage of tubers harvested from different potato varieties. *Potato Research* 43 (4): 297-393.

Bowers, F.A., Plucknett, D.L. and Young, O.R. 1964. Specific gravity evaluation of corm quality in dasheen. Circular 61. Hawaii Agricultural Experimental Station, College of Tropical Agriculture and Human Resources, University of Hawaii.

Bradbury, J. H. and Nixon, R. W., 1998. The acridity of raphides from the edible aroids. *Journal of the Science of Food and Agriculture* 76 (4): 608-616.

Brown, J., Mackay, G.R., Bain, H., Griffith, D.W. and Allison, MJ. 1990. The Processing potential of tubers of the cultivated potato, *Solanum tuberosum* L., after storage at low temperature. 2. Sugar concentration. *Potato Research* 33: 219 - 227.

Carputo, D., Aversano, R. and Frusciante, L. 2005. Breeding potato for quality traits. *Acta Horticulturae* 684: 55-64.

Casa, R., Pieruccetti, F., Sgueglia, G. and LoCascio, B. 2005. Potato tuber quality improvement through nitrogen management optimization: Review of methodologies. *Acta Horticulturae* 684: 65-71.

Chan, L.F., Lu, C.T., and Lu, H.Y. 1998. Growth analysis of wetland taro [*Colocasia esculenta* (L.) Schott] under various crop seasons. *Journal of Agricultural Research of China* 47: 220–241.

Chapman, K.S.R., Sparrow, L.A., Hardman, P.R., Wright, D.N. and Thorp, J.R.A. 1992. Potassiun nutrition of Kennebec and Russet Bursank potatoes in Tasmania: Effect of soil and fertilizer potassium on yield, petiole and tuber potassium concentrations, and tuber quality. *Australian Journal of Experimental Agric*ulture 32: 521-527.

Chun-Feng, S. and Kun, X. 2004. Effect of nitrogen and potassium on yield and quality of taro. *Plant nutrition and fertilizer science* 10 (2): 167-170.

Colla, G., Cardarelli, M., Ruophael, Y., Fiorillo, A. and Cirica, B. 2005. Response of potato to organic fertiliser rate: yield, tuber quality and nutrient uptake. *Acta Horticulturae* 684: 73-77.

Dahlenburg, A.P., Maier, N.A. and Williams, C.M.J. 1990. Effect of nitrogen on the size, specific gravity, crisp colour and reducing sugar concentration of potato tubers (*Solanum tuberosum* L.) cv Kennebec. *Australian Journal of Experimental Agriculture* 30: 123-130.

Debon, S.J.J. and Tester, R.F. 2000. "In vivo" and "In vitro" annealing of starches. In: P.A. Williams and G.O. Phillips, Editors, *Gums and stabilizers for the food industry*, The Royal Society of Chemistry, Cambridge (2000), pp. 270–276.

Diop, A. 1998. Storage and Processing of Roots and Tubers in the Tropics. FAO Corporate Document Repository. Rome. FAO.

Dubetz, S and Bole, J.B. 1975. Effect of nitrogen, phosphorus and potassium fertilizer on yield components and specific gravity of potatoes. *American Potato Journal* 52: 399-405.

Duffus, C.M. and Duffus, J.H. 1984. Carbohydrate metabolism in plants. Longman Inc., New York. USA.

Eskin, N.A.M. 1989. Quality and preservation of vegetables. CRS Press, Florida, USA.

FAO. 1981. Food loss prevention in perishable crops. 1981. FAO Agricultural Services Bulletin No.43.

FAO. 1989. Prevention of post-harvest food losses fruits, vegetables and root crops: A training manual. FAO Training Series No.17/2.

Feibert, E.B.G., Shock, C.G. and Saunders, L.D. 1998. Nitrogen fertilizer requirements of potatoes using carefully scheduled sprinkler irrigation. *Horticultural science* 33: 262-265.

Gebhardt, C., Menendez, C., Chen, X., Li, L. Schäfer-Pregl, R. and Salamini, F. 2005. Genomic Approaches for the Improvement of Tuber Quality Traits in Potato *Acta Horticulturae* 684: 85-91.

Ghosh, S.C., Asanuma, K., Kusutani, A. and Toyota, M. 2000. Effects of temperature at different growth stages on nonstructural carbohydrate, nitrate reductase activity and yield of potato. *Environment Control in Biology* 38 (4): 197-206.

Goenega, R. 1995. Accumulation and partitioning of dry matter in taro [*Colocasia esculenta* (L.) Schott]. *Annals of Botany* 76: 337-341.

Hammer, G.L., Hobman, F.R. and Shepherd, R.K. 2007. Effects of planting time and harvest age of cassava (*Manihot esculenta*) in Northern Australia. I. Crop growth and yield in moist environments. *Environmental Agriculture* 23: 401- 414.

Hicks, D. and Nguyen, V.Q. 2004. Japanese taro. In Asian vegetables: The new industries handbook, RIRDC.

Hollyer, J., Robert Paull, R. and Huang, A. 2000. Processing Taro Chips.

Islam, S., Porter, O.A., Izekor, S.E. and Garner, J.O. 2007. Quality characteristics and yield attributes of sweetpotato (*Ipomoea batatas* L.) genotypes grown under sustainable cultural conditions. *International Journal of Food, Agriculture and Environment* 5: 220-224.

Ivonyi, I., Izsoki, Z. and van der Werf, H.M.G. 1997. Influence of nitrogen supply and P and K levels of the soil on dry matter and nutrient accumulation of fiber hemp (*Cannabis sativa,* L.). *Journal of the International Hemp Association* 4: 84-89.

Jenkins, P.D. and Ali, H. 2000. Phosphorus supply and progeny tuber numbers in potato crops. *Annals of Applied Biology* 136: 41-46.

Kader, A.A. and Rolle, R.S. 2004. The role of post-harvest management in assuring the quality and safety of horticultural produce. FAO Agricultural Services Bulletin 152.

Karam, F., Lahoud, R., Masaad, R. and Stephan, C. 2005. Yield and tuber quality of potassium treated potato under optimum irrigation conditions. *Acta Horticulturae* 684: 103-108.

Karam, F., Rouphael, Y., Lahoud, R., Breidi, J. and Colla, G. 2009. Influence of genotypes and potassium application rates on yield and potassium use efficiency of potato. *Journal of agronomy* 8 (1): 27-32.

Kay, D.E. 1987. Crop and product digest No. 2 Root crops. 2nd Edition. London: Tropical Development and Research Institute. 380 pp.

Kays, S.J. 1991. Post harvest physiology of perishable plant products. Van Nostrand Reinhold, New York.

Khan, I.A., Deadman, M.L., Al-Nabhani, H.S. and Al-Habsi, K.A. 2003. Interactions between temperature and yield components in exotic potato cultivars grown in Oman. *Acta Horticulturae* 619: 353-359.

Kita, A. 2002. The influence of potato chemical composition on crisp texture. *Food Chemistry* 76 (2): 173-179.

Kumar, P., Pandey, S. K., Singh, S. V., Rawal, S. and Kumar D. 2004. Effect of potassium fertilization on processing grade tuber yield and quality parameters in potato (*Solanum tuberosum*). *Indian Journal of Agricultural Science* 74 (4): 177-179.

Kumar, S., Khade, H.D., Dhokane, V.S., Behere, A.G. and Sharma, A. 2007. Irradiation in combination with higher storage temperatures maintains chip-making quality of potato. *Journal of food science* 72(6): 402-406.

Kumar, B. and Ramesh, B. (undated). Activity of alpha-amylase in induced mutants of barley, Department of Genetics & Plant Breeding, Ch. Charan Singh University, Meerut (U P) – 250004, India.

Laboski, C.A.M. and Kelling, K. A. 2007. Influence of fertilizer management and soil fertility on tuber specific gravity: A review. *American Journal of Potato Research* 84 (4): 283-290.

Laurence, R.C.N., Armour, J.D., Shepherd, R.K., Loader, L.R. and Dwyer, M.J. 1985. Nitrogen fertiliser requirements of irrigated potatoes on the Atherton Tableland, North Queensland. *Australian Journal of Experimental Agriculture* 25: 954-958.

Lisińska, G. and Laszczyński, W. 1989. Potato Science and technology. Elsevier Science Publishers Ltd, England.

Long, C.M., Snapp, S.S., Douches, D.S. and Chase, R.W. 2004. Tuber yield, storability, and quality of Michigan cultivars in response to nitrogen management and seedpiece spacing. *American Journal of Potato Research* 81 (5): 347-357.

Lu, H.Y., Lu, C.T., Chan, L.F. and Wei, M.L. 2001. Seasonal Variation in linear increase of taro harvest index explained by growing degree days. *Agronomy Journal* 93: 1136-1141.

MacGregor, A.W., 1983. Cereal alpha-amylases: Synthesis and action pattern. In: Seed Proteins (J. Daussant; J. Mosse and J. Vaughan, eds.). Annual Proceedings of the Phytochemical Society of Europe, 20, 1-34. Academic Press, London.

Maier, N.A., Dahlenburg, A.P. and Williams, C.M.J. 1994. Effects of nitrogen, phosphorus and potassium on yield, specific gravity, crisp colour and tuber chemical composition of potato (*Solanum tuberosum* L.) cv. Kennebec. *Australian Journal of Experimental Agriculture* 34: 813-824.

Mare, R.M. 2006. Phytotron and field performance of taro [*Colocasia esculenta* (L.) Schott] landraces from Umbumbulu. MSc. Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Martin, R.J., Scheffer, J.J.C., Deo, B. and Halloy, S.R.P. 2005. Effect of planting date on Ulluco yield. *Acta Horticulturae* 670: 181-187.

Martin-Prevel, P.J. 1989. Physiological processes related to handling and storage quality of crops. P. 219-248. in: Proceedings of the 21st IPI Colloquium on Methods of K research in plants, Louvain-la-Neuve, Belgium, 19-21 June 1989. Institute of Potash Institute, Bern, Switzerland.

Mazid, M.A. 1993. Sulfur and nitrogen for sustainable rainfed lowland rice. PhD Thesis, University Philippines at Los Banos. 1-232.

McDole, R.E., Stallknecht, G.F., Dwelle, R.B. and Pevek, J.J. 1978. Response of four potato varieties to potassium fertilization in a seed growing area of eastern Idaho. *American Potato Journal* 55: 495-504.

Meyer, R.D. and Marcum, D.B. 1998. Potato yield, petiole nitrogen and soil nitrogen response to water and nitrogen. *Agronomy Journal* 90: 420-429.

Midmore, D., White, D., Nguyen, V., Hicks, D., Coleman, E., Newman, S., Wilk, P., Reeve, D. and McLaughlin, P. 2006 Development of taro, yam, yam bean and sweet potato exports to Japan and USA. RIRDC Publication No 06/101.

Millard, P. 1985. The nitrogen content of potato (*Solanum tuberosum* L.) tubers in relation to nitrogen application - the effect on amino acid composition and yields. *Journal of the Science of Food and Agriculture* 37 (2): 107 – 114.

Mittra, B. N. and George, J. 2000. Effect of time of planting on the growth and dry matter partitioning in sweet potato. *Journal of Root Crops* 26 (2): 57-60.

Miyasaka, S.C., Hollyer, J.R. and Cox, L.J. 2001. Impacts of organic inputs on taro production and returns. CTAHR SCM-3.

Modi, A.T. 2003. What do subsistence farmers know about indigenous crops and organic farming? Preliminary case in KwaZulu-Natal. *Development Southern Africa* 20: 673-682.

Modi, A.T. 2007. Effect of indigenous storage method on performance of taro [*Colocasia esculenta* (L.) Schott] under field conditions in a warm subtropical area. *South African Journal of Plant and Soil* 24: 214-219.

Mosley, A. R. and Chase, R. W. 1993. Selecting cultivars and obtaining healthy seed lots. Pages 20-21 in: Potato Health Management. R. C. Rowe, ed. The American Phytopathological Society, St. Paul, MN.

Musa, F., Berisha, D., Kelmendi, B., Rusinovci, I., Zhitia, O., Bekqeli, R. and Lushi, I. 2009. Tuber yield and other relevant parameters of some Netherlands potato varieties in agro-climatic conditions of Kosova. 44th Croatian & 4th International Symposium on Agriculture. Faculty of Agriculture. University of J.J. Strossmayer in Osijek.

Nandutu, A., Carasco, J. and Hagenimana, V. 2000. Using sweet potato amylase extracts for the determination of starch in foodstuffs. *The Journal of food technology in Africa* 5 (2): 66-69.

Ndimantang, B., Asinobi, C. O., Obiakor, N. 2006. The effect of different processing methods on some anti-nutritional factors content of Ede uhie (*Xanthosoma sagittifolium*) and Ede ocha (*Colocasia esculenta*). *International Journal of Agriculture and Rural Development.* ISSN: 1595 – 9716.

O'Hair, S.K. 1990. Tropical Root and Tuber Crops. p. 424-428. In: J. Janick and J.E. Simon (eds.), Advances in new crops. Timber Press, Portland, OR.

O`Keefe, O., Mason, G., Willis, A. and Bell, G. 2005. Commercial taro chip development using agri-chain partnerships: A processing, marketing and financial analysis. RIRDC Publication No 05/144. RIRDC Project No DAQ-296A.

Onwueme, I. 1999. Taro Cultivation in Asia and the Pacific. FAO RAP Publication: 1999/16.

Opara, L.U. 1998. Edible aroids: Post harvest operation. Rome. FAO.

Osiru, M.O, Olanya, O.M., Adipala, E., Kapinga, R. and Lemaga, B. 2009. Yield stability analysis of *Ipomoea batatus* L. cultivars in diverse environments. *Australian Journal of Crop Science* 3 (4): 213-220.

Oya, K. 1972. Evaluation of potassium availability of four Michigan soils. The science bulletin of the College of Agriculture, University of Ryukyus 19: 123-257.

Ozgen, S., Palta, J.P and Kleinhenz, M.D. 2003. Influence of supplemental calcium fertilization on potato tuber size and tuber number. *Acta Horticulturae* 619: 329-336.

Pal, S., Bhattacharya, A., Konar, A., Mazumdar, A. and Das, A.K. 2008. Chemical composition of potato at harvest and after cold storage. *International Journal of Vegetable Science* 14 (2): 162 – 176.

Panhwar, F. 2005. Potato (*Solanum tuberosum* L.) – Cultural practice in Sindh Pakistan. Digitalverlag GmbH, Germany.

Passam, H.C. 1982. Experiments on the storage of eddoes and tannia (*Colocasia* and *Xanthosoma* spp.) under tropical ambient conditions. *Tropical Science* 24 (2) 39-46.

Perrenoud, S. 1993. Fertilizing for high yield potato. IPI Bulletin 8, 2nd Edition. International Potash Institute, Basel, Switzerland.

Porter, G.A. and Sisson, J.A. 1991. Response of Russet Burbank and Shepody potatoes to nitrogen fertilizer in two cropping systems. *American Potato Journal* 68: 425-443.

Proietti, S., Moscatello, S., Battistelli, A., Mauromicale, G. and Ierna, A. 2005. Quality of early potato in Sicily as affected by cultivar, sowing time and irrigation. *Acta Horticulturae* 684: 171.

Quevedo, M.A., R.T. Sanico, M.E. Baliao. 1991. The control of post-harvest diseases of taro corms. *Tropical Science* 31: 359.

Ramachandran, S., Patel, A.K., Nampoothiri, K.M., Chandran, S., Szakacs, G., Soccol, C.R. and Ashok Pandey, A. 2004. Alpha-amylase from a fungal culture grown on oil cakes and its properties. *Brazilian Archives of Biology and Technology* 47 (2): 309-317.

Rashid, M.M. and Daunicht, J.J. 1979. Chemical composition of nine edible aroid cultivars of Bangladesh. *Scientia Horticulturae* 10 (2): 127-134

Reyes - Castro. G., Nyman, M. and Rönnberg-Wästljung, A.C. 2005. Agronomic performance of three cocoyam (*Xanthosoma violaceum* Schott) genotypes grown in Nicaragua. *Euphytica* 142 (3): 265-272.

Rhee, J.K. and Iwata, M. 1982. Histological observations on the chilling injury of taro tubers during cold storage. *Journal of the Japanese Society for Horticultural Sci*ience 51 (3): 362-368.

Roe, M.A., Faulks, R.M. and Belsten, J.L. 1990. Role of reducing sugars and amino acids in fry colour of chips from potatoes grown under different nitrogen regimes. *Journal of the Science of Food and Agriculture* 52: 207–214.

Rykaczewska K. 2004. Effect of high temperature during vegetation on potato (*Solanum tuberosum* L.) yield, period of tuber dormancy and seed tuber yielding ability. Part I. Plant development and yield. *Zeszyty Problemowe Postepow Nauk Rolniczych* 496: 185-198.

Scheffer, J.J.C., Douglas, J.A. and C.M. Triggs, C.M. 2005. Factors Affecting the Production and Quality of Japanese Taro Cormels. *Acta Horticulturae* 670: 167-172.

Shan, L., Sattelmacher, B., Kutzmutz, E., Mühling, K. H. and Dittert, K. 2004. Influence of nitrogen nutrition on tuber quality of potato with special reference to the pathway of nitrate transport into tubers. *Journal of Plant Nutrition* 27 (2): 341-350.

Shange, L.P. 2004.Taro (*Colocasia esculenta* (L.) Schott) production by small-scale farmers in KwaZulu-Natal: Farmer practices and performance of propagule types under wetland and dryland conditions. MSc. Thesis. University of KwaZulu-Natal, Pietermaritzburg.

Sharma, U.C. and Arora, B.R. 1987. Effect of nitrogen, phosphorus and potassium application on yield of potato tubers (*Solanum tuberosum* L.). *Journal of Agricultural Science* 108: 321-329.

Singh, J.P., Marwaha, J.S. and Grewal, J.S. 1996. Effect of sources and levels of potassium on potato yield, quality and storage behaviour. *Journal of Indian Potato Assoc*iation 23: 153-156.

Singh, U., Matthews, R.B., Griffin, T.S., Ritchie, J.T., Hunt, L.A. and Goenaga, R. 1998. Modeling growth and development of root and tuber crops. In: Understanding options for agricultural production. Ed Tsuji, G.Y., Hoogenboom, G. and Thornton, P.

Silva, E .E. da, Azevedo, P. H. S de, Almeida, M. M. T. B., De-Polli, H. and Guerra, J. G. M. 2008. Influence of intercropping and irrigation frequencies in the leaf development and taro (Cocoyam) productivity under organic management. 16th IFOAM Organic World Congress, Modena, Italy, June 16-20, 2008.

Sivan, P. 1982. Growth and development of taro under dryland conditions in Fiji. p. 637–646. *In* Proc. Int. Symp. Trop. Root and Tuber Crops, 5th, Los Banos, Philippines. 17–21 Sept. 1979. Philippine Council for Agriculture and Resource Research. Los Banos, Philippines.

Smith, O. 1987. Potato chips. In: W. Talburt and O. Smith, Editors, *Potato processing*, Van Nostrand Reinhold Company Inc, New York.

Sparrow, L.A. and Chapman, K.S.R. 2003. Effects of nitrogen fertilizer on potato (*Solanum tuberosum* L., cv Russet Burbank) in Tasmaria. 1. Yield and quality. *Australian Journal of Experimental Agriculture* 43: 631-641.

Talburt, W.F. and Smith, O. 1987. Potato Processing 4th edition, NY. 491-534.

Tawfik, A.A. 2001. Potassium and calcium nutrition improves potato production in drip-irrigated sandy soil. *African Crop Science Journal* 9 (1): 147-155.

Tumuhimbise, R., Talwana, H.L., Osiru, D.S.O., Serem, A.K., Ndabikunze, B.K., Nandi, H. and Palapala, V. 2007. Growth and development of wetland-grown taro under different plant populations and seedbed types in Uganda. *African Crop Science Journal* 17: 49 – 60.

Westermann, D.T., Tindall, T.A., James, D.W. and Hurst, R.L. 1994. Nitrogen and potassium fertilization of potatoes: yield and specific gravity. *American Potato Journal* 71: 417-432.

Williams, R.O. and Cobb, A.H. 1993. The relationship between storage temperature, reconditioning and tuber storage. *Potato Research* 36: 373-392.

Wills, R.B.H., Lim, J.S.K., Greenfield, H. and Bayliss-Smith, T. 1983. Nutrient composition of taro (*Colocasia esculenta*) cultivars from the Papua New Guinea highlands. *Journal of the Science of food and Agriculture* 34 (10): 1137 – 1142.

Witt, W. and Sauter, J.J. 1996. Purification and properties of a starch granule-degrading alpha-amylase from potato tubers. *Journal of experimental botany* 47 (304): 1789-1795.

Wolf, S., Marani, A. and Rudich, J. 1990. Effects of temperature and photoperiod on assimilate partitioning in potato plants. *Annals of Botany* 66: 513-520.

Wong Yen Cheong, J.K.C and Govinden, N. 1998. Quality of potato during storage at three temperatures. AMAS 1998. Food and Agricultural Research Council, Réduit, Mauritius.

Xiong, X. and Tai, G.C.C. 2003**.** Comparison of specific gravity profiles inside tubers of potatoes. *Acta Horticulturae* 619:

Yosuke, M., Yaptenco, K.F., Tomohiro, N., Toshiro, S., Hiroaki, S., Shinji, M. and Katsumi, T. 2000. Property changes in potato tubers (*Solanum tuberosum* L.) during cold storage at 0 and 10^{o}C. *Food Preservation Science* 26 (3): 153-160.

Yuan, B.Z., Nishiyama, S. and Kang, Y. 2003. Effects of different irrigation regimes on the growth and yield of drip-irrigated potato. *Agricultural Water Management* 63: 153-167.

Zelalem, A., Tekalign, T. and Nigussie, D. 2009. Response of potato (Solanum tuberosum L.) to different rates of nitrogen and phosphorus fertilization on vertisols at Debre Berhan, in the central highlands of Ethiopia. *African Journal of Plant Science* 3 (2): 16-24.

CHAPTER 3

GROWTH, DEVELOPMENT AND YIELD OF TARO IN RESPONSE TO PLANTING DATE AND FERTILISATION

Abstract

Despite the importance of taro (*Colocasia esculenta* L. Schott) as a food security crop, scientific research on it is scanty in South Africa. Production site, planting date and fertiliser regime affect crop performance, particularly that of cultivars, because they tend to be adapted to specific localities. To investigate performance of three taro cultivars, a study was carried out at two sites in KwaZulu-Natal, South Africa (Ukulinga and Umbumbulu), during the 2007/2008 growing season. A split-split-plot design was used with four planting dates (October 2007, November 2007, December 2007 and January 2008) as main plots, three taro cultivars (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) as sub-plots and three organic fertiliser (Gromor Accelerator®) application rates (0, 160 and 320 N kg ha^{-1}) as sub-sub-plots. Treatments were replicated three times. Delaying planting significantly decreased crop emergence (%), leaf number plant^{-1}, plant height plant^{-1}, leaf area plant^{-1}, number of cormels plant^{-1} and fresh cormel mass plant^{-1} at both sites. *Mgingqeni* had the highest emergence for earlier planting dates. *Dumbe-dumbe* plants were taller for November than for October planting when 160 N kg ha^{-1} was applied at Ukulinga. Application of Gromor Accelerator® enhanced leaf number plant^{-1}, plant height plant^{-1}, leaf area plant^{-1}, number of cormels plant^{-1} and fresh cormel mass plant^{-1} at Umbumbulu. Taro cultivars responded differently at both sites. *Dumbe-dumbe* had significantly lowest number of cormels and lowest proportion of cormels falling under the small size class. In this study, environmental variability due to site and planting date; and fertilisation had an effect on taro growth and yield. It is recommended that taro producers should plant in October at both sites with no fertiliser at Ukulinga and 160 N kg ha^{-1} of Gromor Accelerator® at Umbumbulu.

Key Words: *Colocasia esculenta,* fertilisation, planting date, site, yield.

3.1 Introduction

Taro (*Colocasia esculenta* L. Schott) is an important crop grown for its starchy corms and it is a traditional staple food throughout the rural subtropical and tropical regions of the world, most notably in the Pacific and Caribbean islands and West Africa (Vinning, 2003; Hancock, 2004). In South Africa, it is grown in the subtropical coastal area, starting at Bizana district in the Eastern Cape and the rest of the coastal KwaZulu-Natal. The crop is also cultivated in the subtropical and tropical parts of Mpumalanga and Limpopo provinces (Shange, 2004). Taro is grown organically under dryland conditions from July to January by the EFO (Ezemvelo Farmers` Organisation) farmers who market it on contract to two large South African grocery store chains; Pick 'n' Pay and Woolworths (Modi, 2003; Agergaard and Birch-Thomsen, 2006; Mare, 2006). According to Miyasaka *et al*. (2003) taro grown under rainfed conditions can take 6 to 12 months to reach maturity.

Root and modified stem crop yield is a positive function of the number of roots/tubers/corms and weight of roots/tubers/corms per planting hill (Khan *et al.*, 2003; Kader and Rolle, 2004). The number and size of tubers vary with cultivar (Khan *et al.*, 2003). Planting date and fertiliser regime affect crop performance, regardless of whether the crop is a landrace or an improved cultivar. Yield of root crops has been shown to be affected by water availability and temperature at different sites and planting dates (Lu *et al.*, 2001; Khan *et al.*, 2003; Scheffer *et al.*, 2005; Kumar *et al.*, 2007; Hagman *et al.*, 2009). Time of planting and fertilisation of taro are, therefore, likely to be critical factors affecting crop performance in response to agronomic practices. Tuber total yields were found to be significantly higher in planting date four compared to other planting dates when potatoes were planted on 11 January 2005 and every two weeks until 22 March 2005 in Florida (Worthington and Hutchinson, 2006). Sangakkara (1993) reported highest yields when sweet potatoes were planted with the onset of rains in October in India and this was attributed to adequate rainfall and higher diurnal variation in temperatures over the growth cycle. Miyasaka *et al*. 2003 confirmed this and reported that corm fresh weight increased significantly when taro was planted in Spring and

Summer compared to Winter and fall plantings. Supplementary irrigation gave a total yield of 62t ha^{-1} compared to 26 t ha^{-1} under rainfed conditions (Scheffer *et al.*, 2005). This confirmed the findings of Shock (1992), Bussell and Bonin (1998), Bèlanger *et al.* (2002) and Yuan *et al*. (2003) that supplementary irrigation had positive effect on total fresh tuber yields, and that it increased yields by increasing tuber number and mean weight of the tubers. Increased corm weight in the high watering-level treatment was attributed to the earlier increased leaf and root growth (Bussell and Bonin, 1998). Wolfe *et al.* (1983), on the other hand, reported a slight yield depression in the wettest treatment, possibly due to poor soil aeration and nitrogen deficiency near the end of the season. Higher temperatures were found to speed up development between emergence and tuber initiation whereas total and tuber dry mass and canopy leaf area were reported to decrease with increasing temperatures in potatoes (Kooman *et al*., 1996, Fleisher *et al*., 2006). Timlin *et al*. (2006) also found end-of-season tuber mass to decrease with increasing temperature above 24^{o}C in potatoes.

Nitrogen fertilisation was reported to increase the average fresh tuber weight with distinct effects for one cultivar than for the other (Bèlanger *et al.*, 2002). According to Kumar *et al*. (2007) plant height, leaf number and tuber weight per plant responded positively to nitrogen application. Leaf area increased with increase in nitrogen and then decreased at 4.0 mM nitrogen in taro (Osorio *et al.*, 2003). O'Beirne and Cassidy (1990) also reported yield to increase with the use of 100-150 kg ha^{-1} nitrogen after which it remained constant. In contrast to this, it was found that nitrogen fertilisation had a negative effect on time of emergence and little or no effect on yield whereas phosphorus and potassium increased yields (Wadas *et al.*, 2004; Hagman *et al.*, 2009). Zelalem *et al*. (2009) on the other hand reported that average number and tuber weight were not influenced by phosphorus fertilisation.

Since tuber yield is influenced by temperature and moisture, fertilisation and cultivar, planting taro at appropriate times and using suitable fertilisation and cultivars can enhance taro growth and hence yields. The objective of this study was to determine the growth and yield of three taro cultivars grown at different planting dates using different organic fertiliser regimes in KwaZulu-Natal, South Africa.

3.2 Materials and methods

3.2.1 Planting material

Three taro cultivars of the eddoe type *Dumbe-dumbe*, *Mgingqeni* and *Pitshi* were used for this study (Fig. 3.1). Cormel size for the taro cultivars vary between and within cultivars. The cormels planted for this study were selected to be in the following size ranges (cormel $^{-1}$): 21 – 60 g for *Dumbe-dumbe*, 11 – 40g for *Mgingqeni* and 5 – 20g for *Pitshi.* The cormels were 2007 harvest from Ukulinga except for *Dumbe-dumbe* which was obtained from farmers of Ezigeni, Umbumbulu district, KwaZulu-Natal, South Africa.

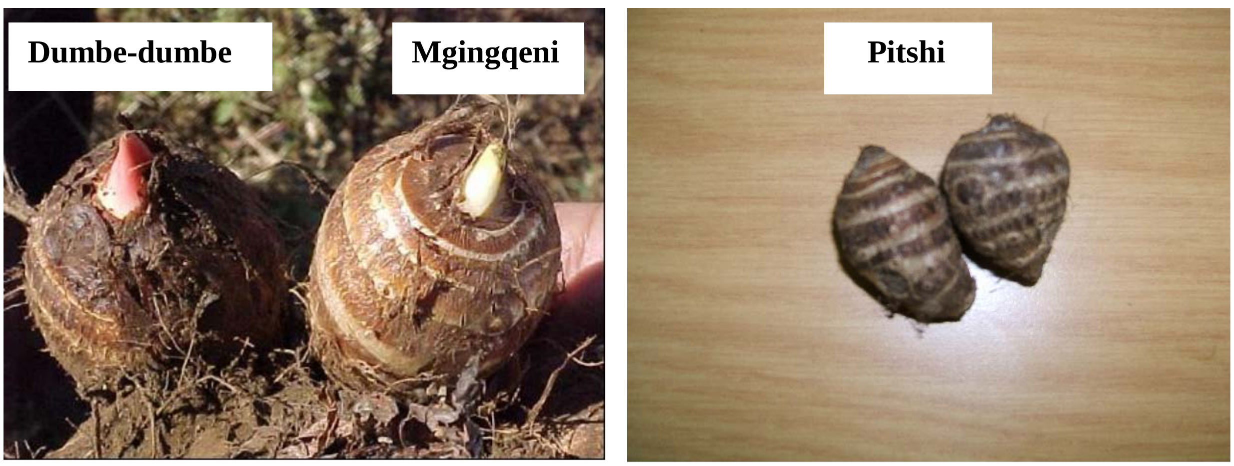

Figure 3.1 Taro cultivars of KwaZulu-Natal.

3.2.2 Site description

Field experiments were carried out at two sites, Ukulinga (29^{o} 37′S 30^{o} 16′E) and Umbumbulu (29^{o} 36′S 30^{o} 25′E) with different environmental conditions (Table 3.1) and soil physical and chemical properties (Table 3.2). Temperature and rainfall data for both sites were obtained from Weather South Africa for the past 10 years (Figs. 3.2, 3.3, 3.4 and 3.5) and for the duration of the experimental period (Table 3.1). Soil samples were collected from both sites and analysed according to Naramabuye *et al.* (2008). The pH of the soils from both sites (Table 3.2) were below 6 to 6.5 which is the soil pH at with taro is known to grow best. Addition of organic manure was expected to increase the soil pH as it was reported by Pocknee and Summer (1997), Wong *et al*. (1998), Mokolobate and Haynes (2002) and Naramabuye *et al.* (2008) that organic manure has a rapid liming effect. However, no soil analysis was performed at harvest.

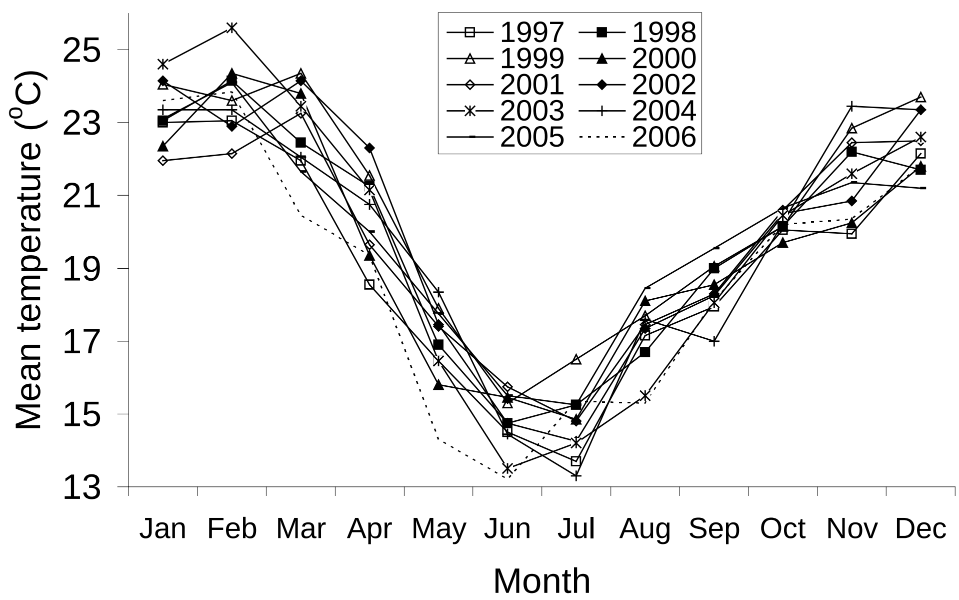

Figure 3.2 Mean temperature distribution at Ukulinga for a 10 year period to 2006.

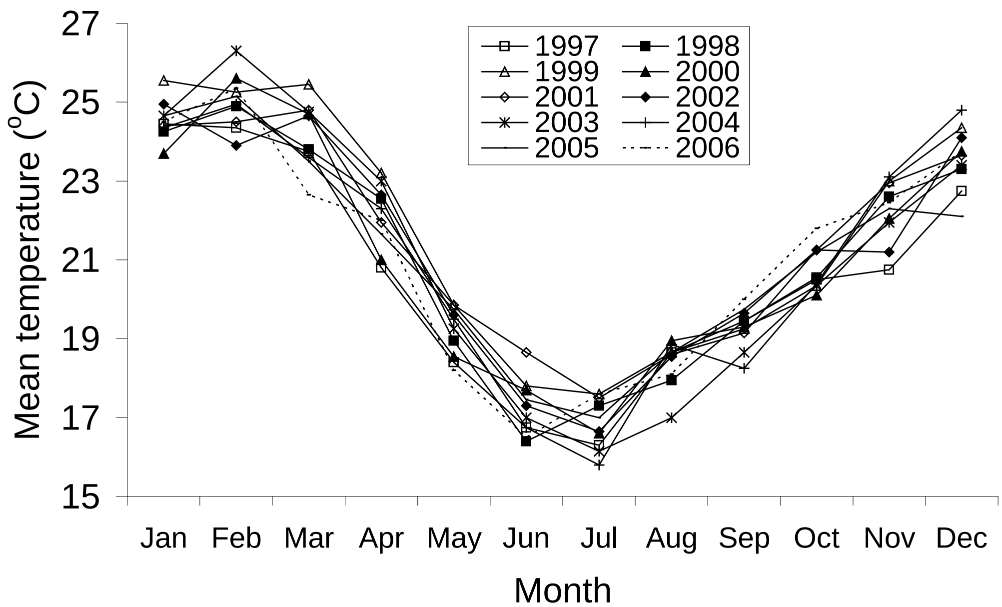

Figure 3.3 Mean temperature distribution at Umbumbulu for a 10 year period to 2006.

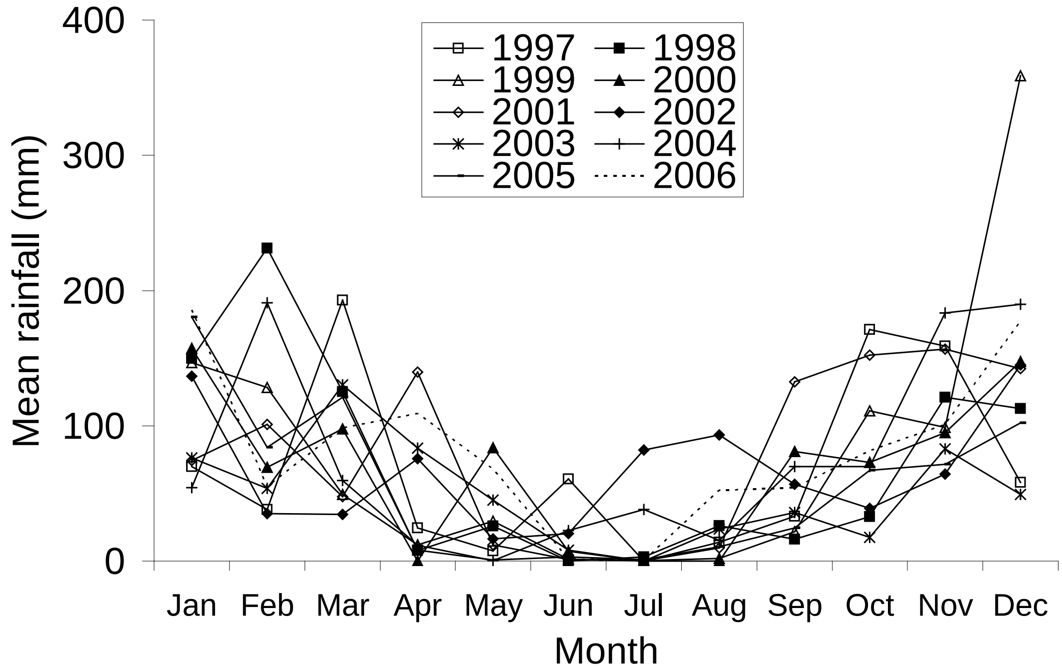

Figure 3.4 Mean rainfall distribution at Ukulinga for a 10 year period to 2006.

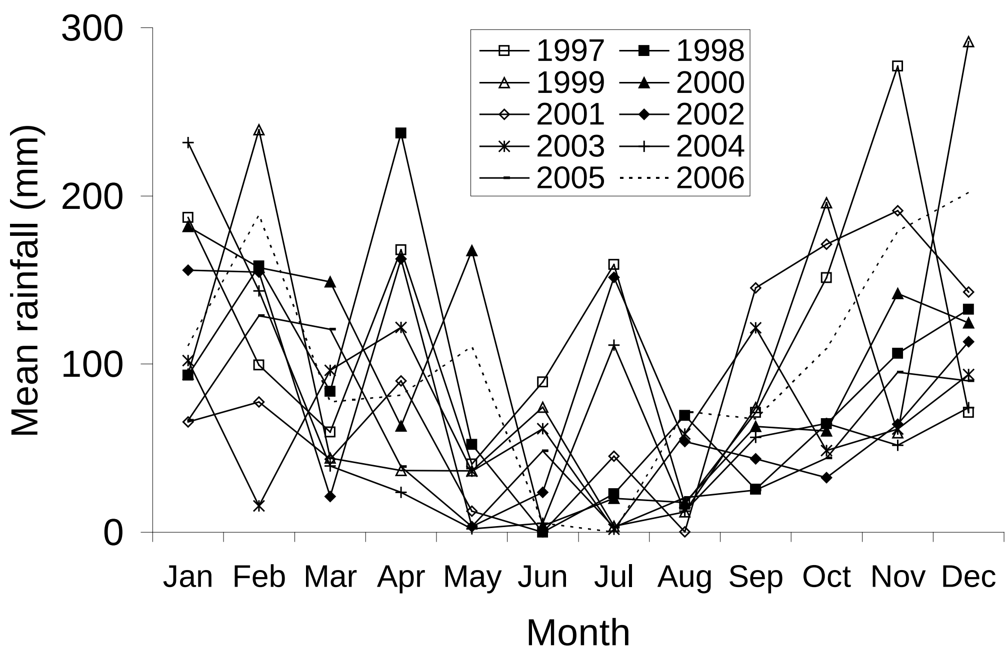

Figure 3.5 Mean rainfall distribution at Umbumbulu for a 10 year period to 2006.

Table 3.1 Mean temperature and mean rainfall data for Ukulinga and Umbumbulu for the duration of the experimental period.

Site		Total	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Ukulinga	**Rainfall(mm)**	883.4	171.2	159	58.2	178.2	78.6	77.4	86.2	0	17	0	4	53.6
	Temperature (^oC)	19.6	18.6	19.6	21.9	23.7	24.3	22.7	19.3	18.8	15.3	15.4	18	18.4
Umbumbulu	**Rainfall(mm)**	1334.1	139.5	301.2	57.3	133.8	78.7	196.2	122.1	28.4	171.2	3.5	1.8	100.4
	Temperature (^oC)	20.8	20.4	21.4	22.8	24.3	25	23.8	20.7	20	17.3	17	18.3	18.5

Table 3.2 Physical and chemical properties of soils from Ukulinga and Umbumbulu.

Site	pH (KCl)	Sample density ($g\ ml^{-1}$)	Exch. Acidity ($cmol\ L^{-1}$)	Total cations ($cmol\ L^{-1}$)	P ($mg\ L^{-1}$)	K ($mg\ L^{-1}$)	Ca ($mg\ L^{-1}$)	Mg ($mg\ L^{-1}$)	Zn ($mg\ L^{-1}$)	Mn ($mg\ L^{-1}$)	Cu ($mg\ L^{-1}$)	Acid saturation (%)	MIR Organic C (%)	MIR clay (%)	MIR N (%)
Ukulinga	5.07	1.08	0.05	25.22	10	223	2780	1303	4.6	27	7.1	0	1.8	31	0.25
Umbumbulu	4.16	0.96	1.68	6.72	3	97	658	183	1.3	8	5.4	25	4.5	59	0.31

*MIR – Mid infrared

3.2.3 Experimental design and agronomic practices

The experiment was designed as a split-split-plot design with four planting dates: October 2007, November 2007, December 2007 and January 2008 (Table 3.3) as main plots, three taro cultivars: *Dumbe-dumbe*, *Mgingqeni* and *Pitshi* (Fig. 3.1) as sub-plots and three organic fertiliser (Gromor Accelerator®) application rates (0, 160 and 320 N kg ha^{-1}) as sub-sub-plots. The nutritional composition of Gromor Accelerator® is shown in table 3.3. Each planting date was replicated three times. Plot size was 4 m^2 containing 16 plants spaced 0.5m between and within rows. Sowing was done by hand on ploughed and harrowed fields. Planting holes were opened with a hand-hoe and organic fertiliser was mixed with soil before one cormel was planted per hole. Weeds were controlled by hand-hoeing at one, two, three and four months after planting.

Table 3.3 Nutritional composition of Gromor accelerator®.

N	P	K	Mg	Ca	S	Fe	Cu	Zn	B	Mn	Mo
		(g kg^{-1})						(mg kg^{-1})			
30	15	15	5	20	0.6	2000	40	250	40	400	4

3.2.4 Data collection and analysis

Emergence percentage was calculated from the final emergence recorded four months after planting. Plant vigour parameters (number of leaves $plant^{-1}$, plant height $plant^{-1}$ and leaf area $plant^{-1}$) were determined from sampling unit (four innermost plants of each experimental plot) at monthly intervals from one month after planting to four months thereafter when positive change in growth was no longer occurring (Mare, 2006). Leaf area $plant^{-1}$ (A) was determined non-destructively by regressing the product of leaf length (L) and leaf width (W) (Loomis & Connor, 1992; Modi, 2007).

A = b (LW), where b is the coefficient of regression.

Yield was determined by the number of cormels $plant^{-1}$ and fresh cormel mass $plant^{-1}$ from sampling unit nine months after planting and cormels were weighed individually and graded into sizes <20, 21-40, 41-60, 61-80, 81-100, 101-120, 121-140, 141-160 and 161-180 g. Analysis of variance was performed using GenStat Version 11.1 (2008). Least significant difference (LSD) was used to separate means. A probability level of 0.05 was considered to be statistically significant.

3.3 Results

3.3.1 Emergence

The interaction of planting date, cultivar and organic fertilisation were observed to play a significant role in taro emergence at Ukulinga ($P = 0.006$). At Umbumbulu, emergence was affected by the interactions of planting date and cultivar ($P < 0.001$) and cultivar and Gromor Accelerator® application rate ($P = 0.047$). Emergence for earlier planting dates was significantly higher than that of the latter planting dates at both sites (Table 3.5 and Fig. 3.6). Taro cultivars showed the same trend of emergence for October plantings at both sites but the trend changed at Umbumbulu for the latter plantings, whereas at Ukulinga the same trend was displayed for other planting dates. The different trends were probably due to the different response of different taro cultivars to different sites. Application of the organic matter did not enhance emergence of all cultivars at both sites (Table 3.4 and Fig. 3.7). *Pitshi* generally displayed lowest emergence whereas *Mgingqeni* showed highest emergence.

Table 3.4 Effect of planting date, Gromor Accelerator® application rate and cultivar on emergence at Ukulinga. Means of the interaction effect within columns and rows ($LSD_{(0.05)}$ = 18.01) followed by the same letter are not significantly different

Planting date	**Gromor Accelerator® (N kg ha^{-1})**	**Taro cultivar** *Dumbe-dumbe*	*Mgingqeni*	*Pitshi*
October	0	95.83k	100.00k	89.67jk
	160	91.67k	100.00k	75.00ij
	320	89.67 jk	100.00k	68.67hi
November	0	58.67ghi	100.00k	69.00hi
	160	56.67gh	100.00k	75.33ij
	320	52.00efgh	91.67k	67.00hi
December	0	16.83ab	48.00efg	6.67a
	160	12.33ab	54.00fgh	11.17ab
	320	18.83abc	37.67def	19.42abc
January	0	16.83ab	18.67abc	16.50ab
	160	12.50ab	34.93cde	22.87abcd
	320	16.67ab	25.20bcd	8.34ab

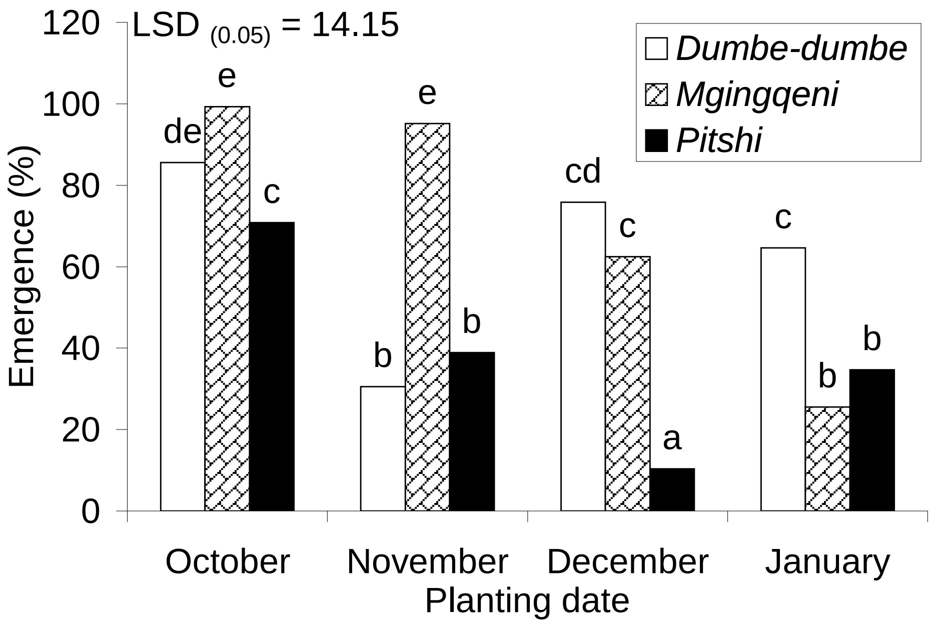

Figure 3.6 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on emergence at Umbumbulu.

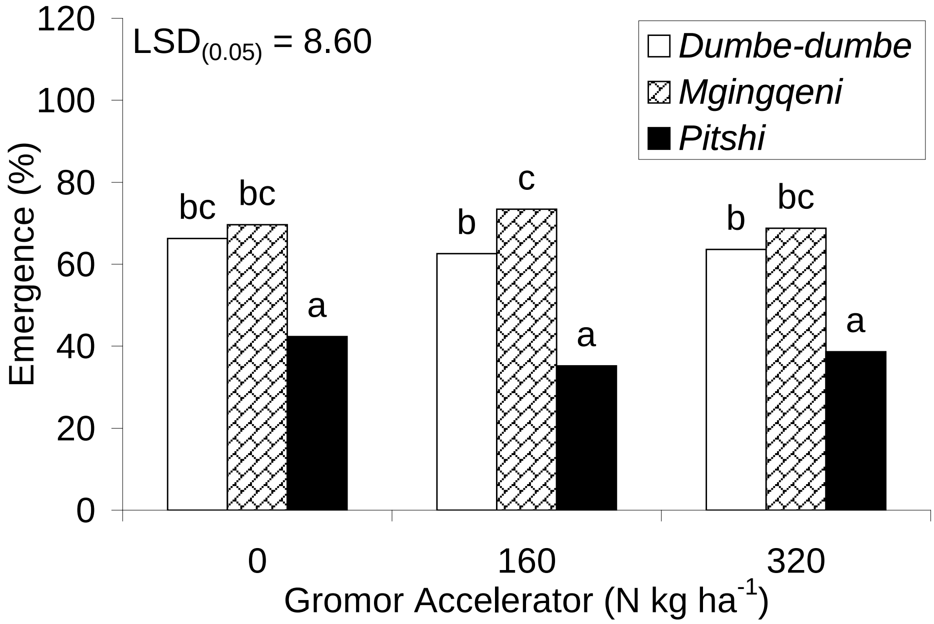

Figure 3.7 Effect of cultivar and Gromor Accelerator® application rate averaged across planting date on emergence at Umbumbulu.

3.3.2 Growth parameters

3.3.2.1 Number of leaves

Figure 3.8 shows the number of leaves plant^{-1} of taro cultivars planted at four different dates at Ukulinga. Planting date was observed to play a significant role in number of leaves plant^{-1} ($P < 0.001$). The first two planting dates showed significantly higher number of leaves than the latter planting dates. This is an indication that delaying planting by two months at Ukulinga decreases the number of leaves plant^{-1}. Cultivar and Gromor Accelerator® application rate and their interactions with planting date had no effect on the number of leaves plant^{-1} at Ukulinga.

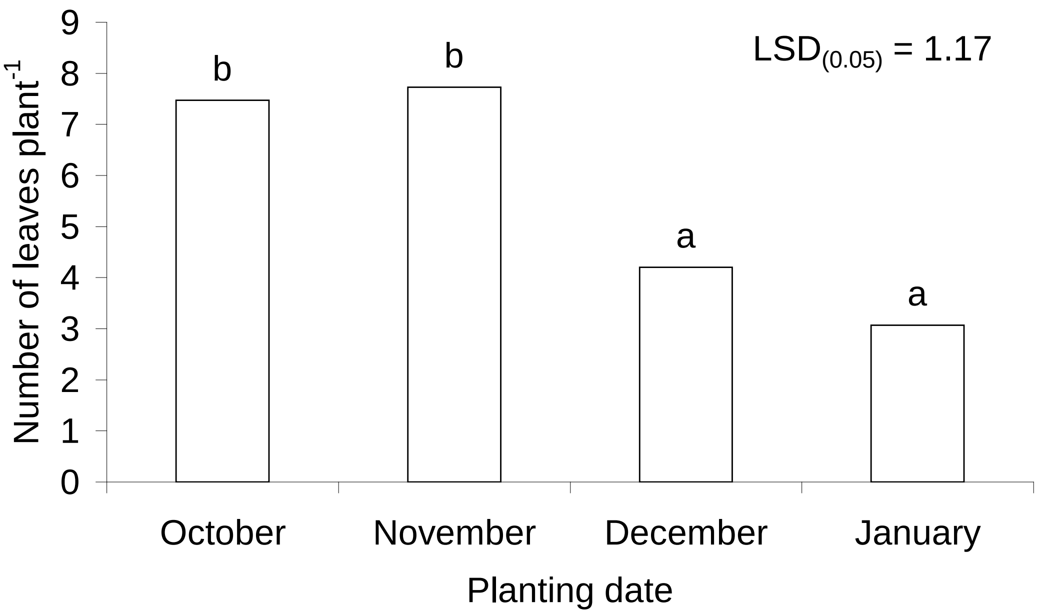

Figure 3.8 Effect of planting date averaged across cultivar and Gromor Accelerator® application rate on number of leaves plant^{-1} at Ukulinga.

At Umbumbulu, planting date (P = 0.009) and cultivar (P = 0.001) had significant main effects on number of leaves plant^{-1}. Delaying planting by one month from October led to reduction in the number of leaves plant^{-1} from 5.13 to 3.76, but a further delay had no effect ($LSD_{(0.05)}$ = 1.20) (Fig.3.9). Application of Gromor Accelerator® had no effect on the number of leaves plant^{-1}. *Dumbe-dumbe* displayed a significantly higher number of leaves plant^{-1} (4.45 leaves) than *Mgingqeni* (3.42 leaves) and *Pitshi* (3.01 leaves), and the latter two were not significantly different from each other ($LSD_{(0.05)}$ = 0.70) (Fig. 3.10).

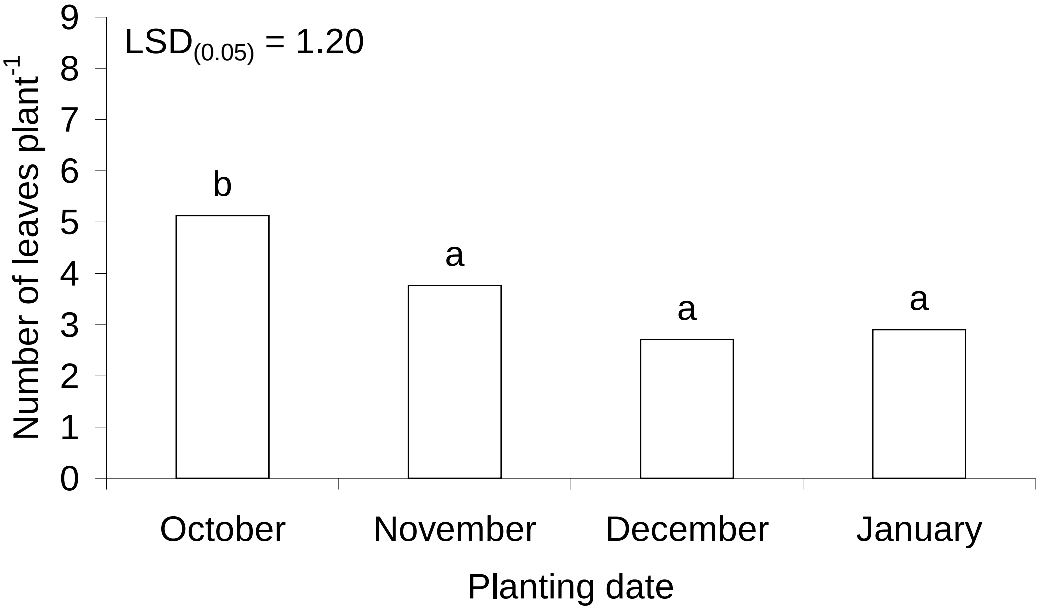

Figure 3.9 Effect of planting date averaged across cultivar and Gromor Accelerator® application rate on number of leaves plant^{-1} at Umbumbulu.

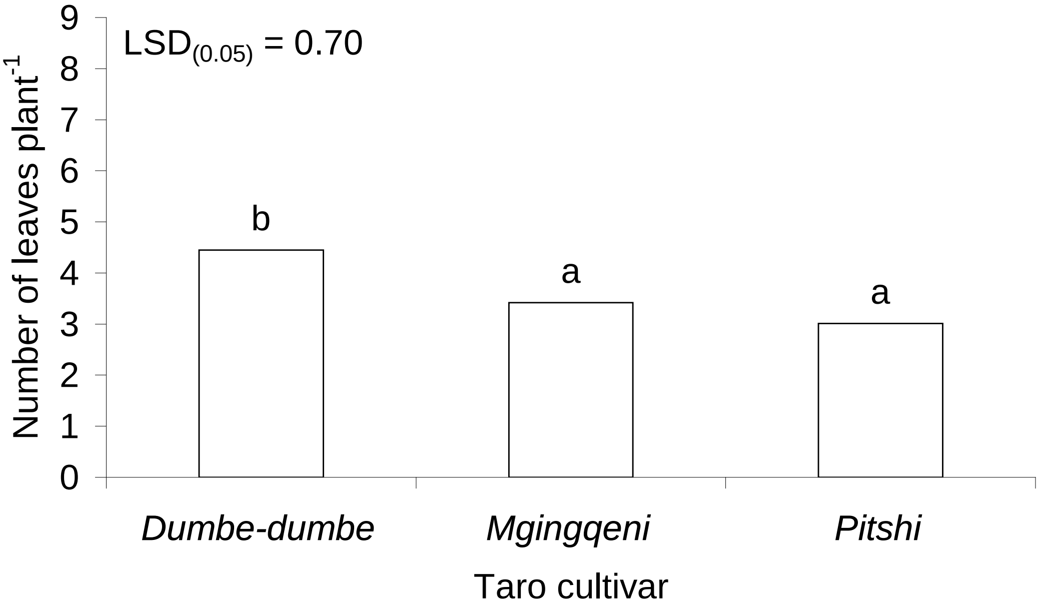

Figure 3.10 Effect of cultivar averaged across planting date and Gromor Accelerator® application rate on number of leaves plant^{-1} at Umbumbulu.

3.3.2.2 Plant height

There was a significant interaction of planting date, Gromor Accelerator® application rate and cultivar on plant height at Ukulinga (P = 0.002). The tallest plants were obtained with all treatments except for *Pitshi* planted with no fertiliser and *Dumbe-dumbe* planted with 160 N kg ha^{-1} organic fertiliser for October planting and *Dumbe-dumbe* planted in November (Table 3.5). Application of organic fertiliser enhanced plant height for *Dumbe-dumbe* planted in January and *Pitshi* planted in December.

Table 3.5 Effect of planting date, Gromor Accelerator® application rate and cultivar on plant height at Ukulinga. Means of the interaction effect within columns and rows ($LSD_{(0.05)}$ = 8.28) followed by the same letter are not significantly different.

Planting date	**Gromor Accelerator® (N kg ha^{-1})**		**Taro cultivar**	
		Dumbe-dumbe	***Mgingqeni***	***Pitshi***
October	0	41.92ghij	45.00ij	35.58fg
	160	33.75f	48.75j	42.08ghij
	320	44.75hij	43.92hij	47.92j
November	0	48.17j	38.00fghi	36.58fgh
	160	42.17ghij	33.42f	31.25f
	320	49.25j	35.08fg	32.50f
December	0	15.33bcde	19.08de	9.62abc
	160	10.83abcd	17.25cde	13.56bcde
	320	13.00bcde	17.83cde	19.33e
January	0	15.92bcde	7.72ab	18.17de
	160	19.03de	10.89abcd	2.96a
	320	10.25abc	14.90bcde	16.90cde

The interaction of planting date and cultivar (P < 0.001), planting date and Gromor Accelerator® application rate (P = 0.003) and Gromor Accelerator® application rate and cultivar (P = 0.050) significantly affected plant height of taro at Umbumbulu. Plant height of all cultivars was negatively affected by delayed planting (Fig. 3.11). Delaying planting by one month from October decreased plant height for *Dumbe-dumbe*, whereas the decrease was observed for *Mgingqeni* and *Pitshi* with two and three months delay in planting respectively (Fig. 3.11). *Pitshi* had shorter plants than *Dumbe-dumbe* and *Mgingqeni* which were not significantly different from each other for October and December plantings. For November planting, *Mgingqeni* had tallest plants compared to both *Dumbe-dumbe* and *Pitshi* which were not significantly different from each other. *Dumbe-dumbe* showed tallest plants followed by *Pitshi* and *Mgingqeni* respectively when planting was done in January.

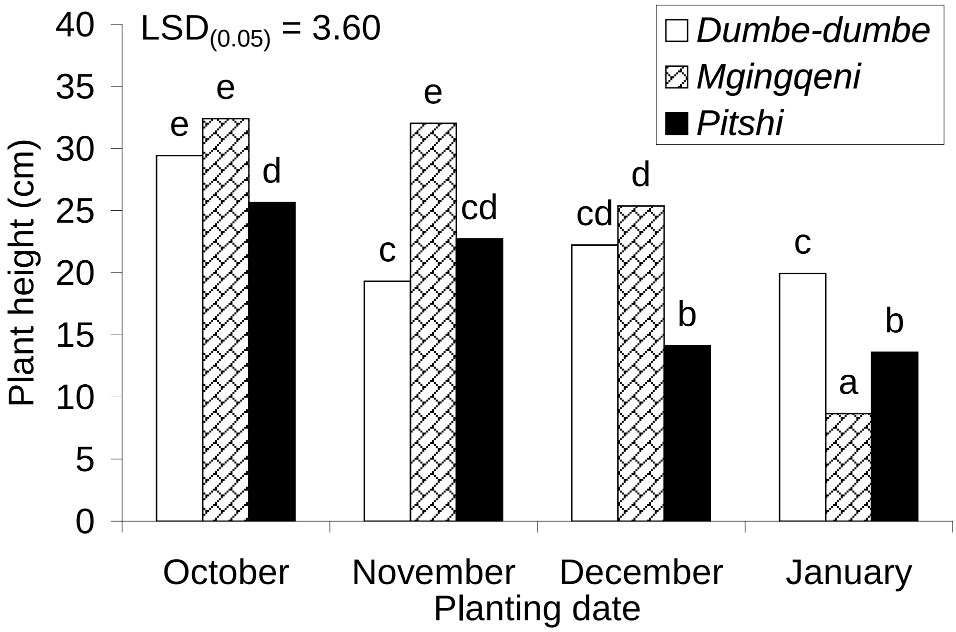

Figure 3.11 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on plant height at Umbumbulu.

Fertilisation enhanced plant height at all planting dates except for December where there was no significant difference between all fertiliser application rates (Fig. 3.12). Application of 160 N kg ha^{-1} of the fertiliser significantly increased plant height but incorporating more fertiliser had no effect. When no fertiliser was applied, a decrease in plant height was observed with delay in planting until January. Plant height decreased when planting was delayed by one and two months with application of 160 N kg ha^{-1} of the fertiliser, and by one, two and three months when 320 N kg ha^{-1} of the fertiliser was applied.

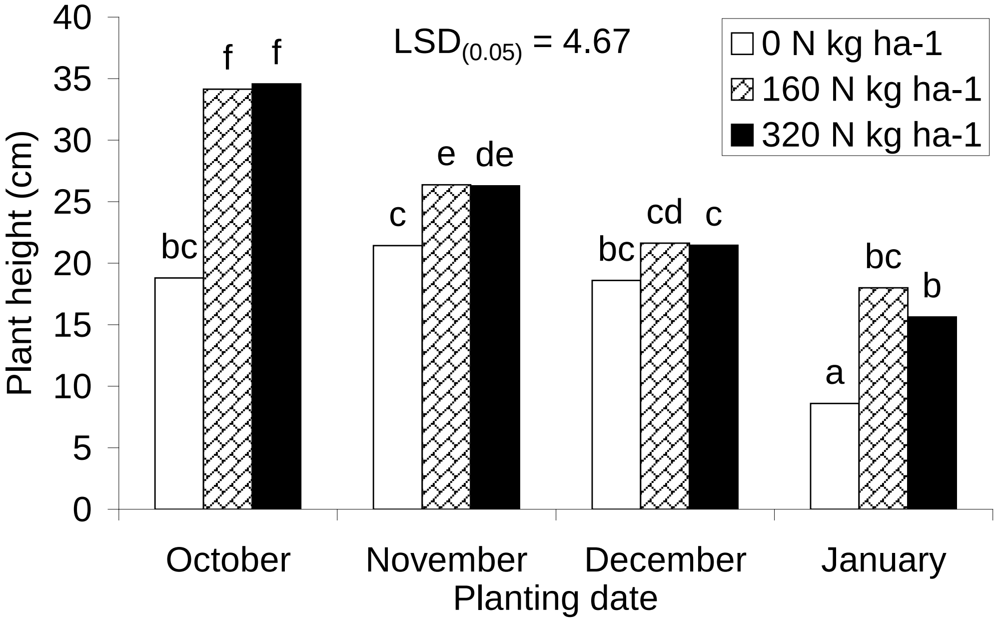

Figure 3.12 Effect of planting date and Gromor Accelerator® application rate averaged across cultivar on plant height at Umbumbulu.

Fertiliser application enhanced plant height of all taro cultivars (Fig. 3.13). Application of 160 N kg ha^{-1} increased plant height for all cultivars but adding more fertiliser was not effective. There was no difference in plant height between cultivars when no fertiliser was added. When 160 N kg ha^{-1} of the fertiliser was applied, *Pitshi* had shorter plants than other cultivars which were not different whereas *Mgingqeni* had tallest plants compared to the other two which were also not significantly different when 320 kg ha^{-1} of the fertiliser was added.

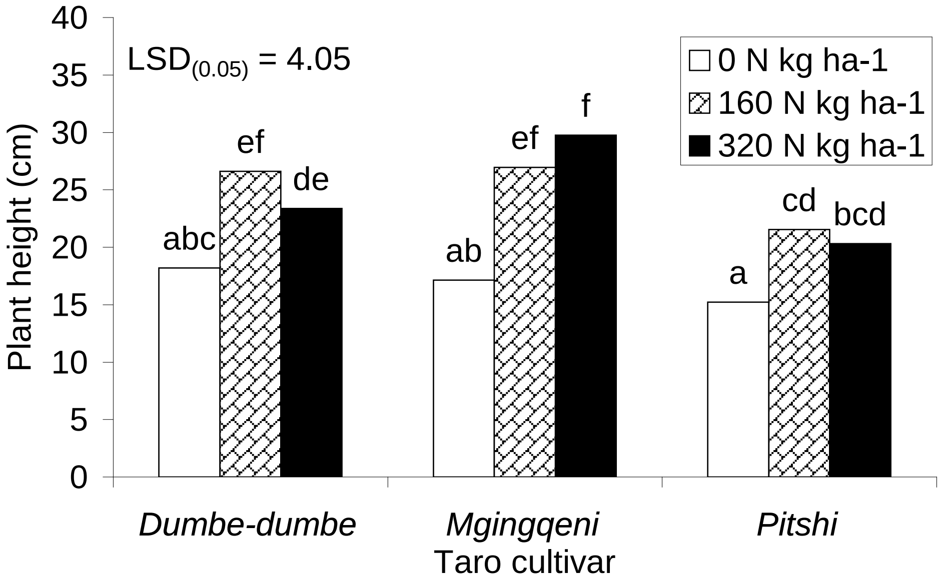

Figure 3.13 Effect of Gromor Accelerator® application rate and cultivar averaged across planting date on plant height at Umbumbulu.

3.3.2.3 Leaf area

Leaf area plant^{-1} was affected by planting date ($P < 0.001$). There was no significant effect of cultivar on leaf area plant^{-1}, although the effect of planting date was dependent on cultivar (Planting date x cultivar interaction: $P = 0.024$) at Ukulinga. At Umbumbulu, leaf area plant^{-1} was affected by planting date ($P < 0.001$), cultivar ($P < 0.001$), fertiliser ($P < 0.001$), interactions of planting date and cultivar ($P < 0.001$) and planting date and fertiliser ($P < 0.001$). Leaf area plant^{-1} of taro cultivars was negatively affected by delayed planting at both sites (Fig. 3.14 and 3.15). At Ukulinga, significantly higher leaf area plant^{-1} was observed when cultivars were planted in October followed by November, which was also significantly higher than the last two planting dates (Fig. 3.14). The exception was *Dumbe-dumbe* which showed significantly highest leaf area plant^{-1} for the November planting. *Dumbe-dumbe* showed lowest leaf area plant^{-1} compared to *Mgingqeni* and *Pitshi* which were not different from each other when planting was done in October. For November planting, *Dumbe-dumbe* had significantly higher leaf area plant^{-1} than *Mgingqeni* but not Pitshi which was also not significantly different from *Mgingqeni*. There was no difference in leaf area plant^{-1} between the cultivars when they were planted in December and January.

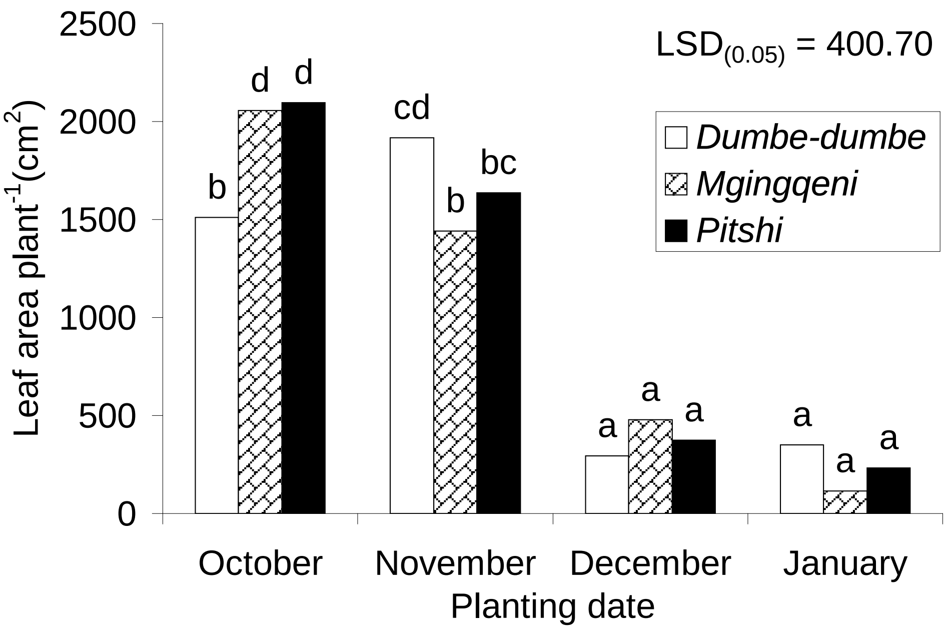

Figure 3.14 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on leaf area plant^{-1} at Ukulinga.

At Umbumbulu, leaf area plant^{-1} decreased for all cultivars with one month delay in planting (Fig. 3.15). Further delay in planting by two and three months for *Mgingqeni* and by one month for *Pitshi* was also significant in decreasing leaf area plant^{-1}. *Pitshi* had lowest leaf area plant$^{-1,}$ *Mgingqeni* had highest leaf area plant^{-1} and *Pitshi* had lowest leaf area plant^{-1} for October, November and December plantings respectively compared to the other cultivars which were not significantly different from each other. For January planting, *Dumbe-dumbe* had higher leaf area plant^{-1} than *Mgimgqeni* but not *Pitshi* which was also not significantly different from *Mgingqeni*.

Delaying planting by one and two months decreased leaf area plant^{-1} when fertiliser was applied, whereas when no fertiliser was applied the decrease was only observed with three months delay in planting (Fig. 3.16). Fertilisation enhanced leaf area plant^{-1} for October planting only.

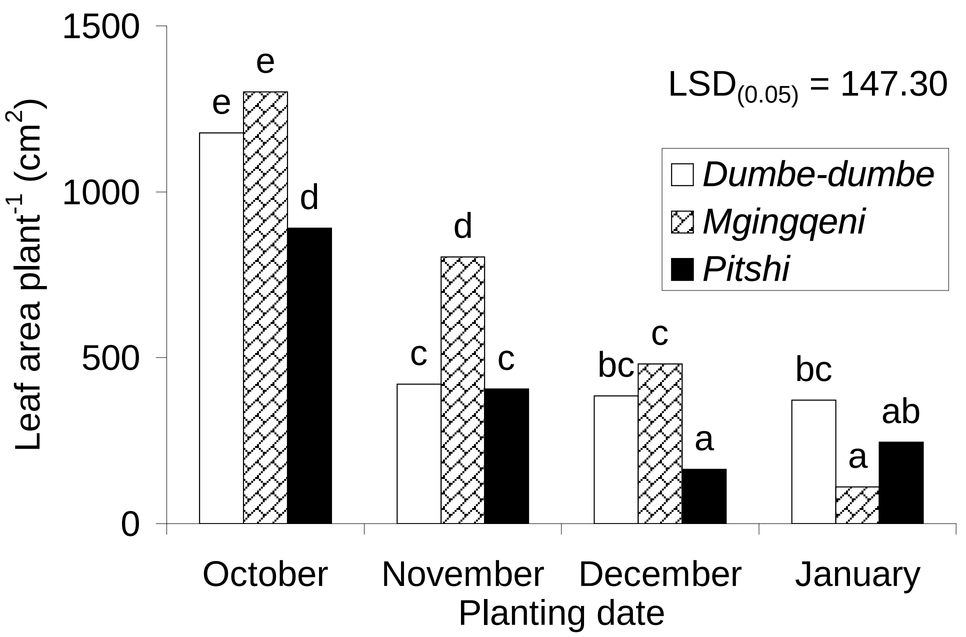

Figure 3.15 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on leaf area plant^{-1} at Umbumbulu.

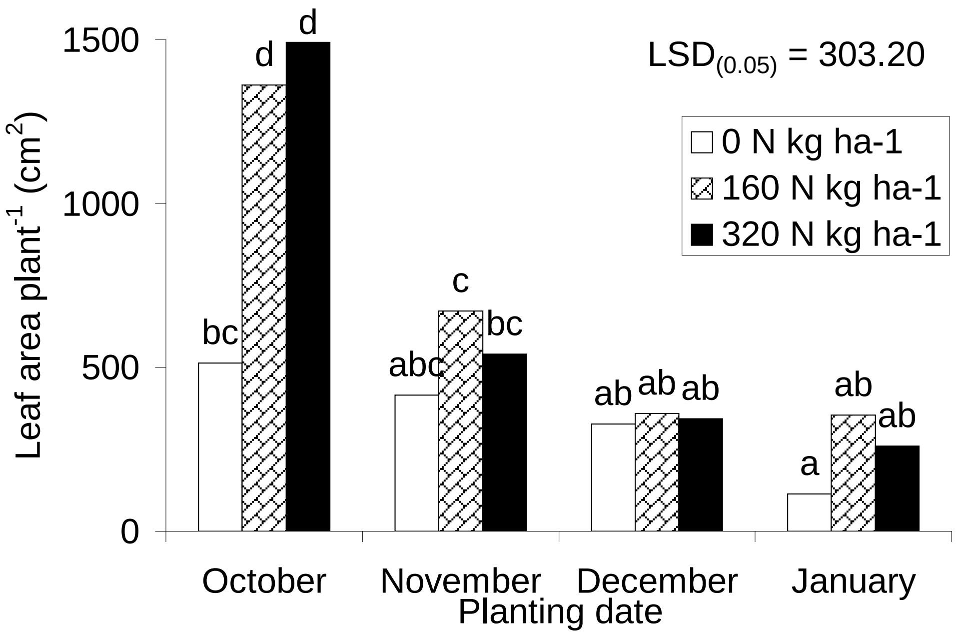

Figure 3.16 Effect of planting date and Gromor Accelerator® averaged across cultivar on leaf area plant^{-1} at Umbumbulu.

3.3.3 Yield

3.3.3.1 Number of cormels

The number of cormels plant^{-1} was significantly affected by the interaction of planting date and cultivar at Ukulinga (P = 0.004) and Umbumbulu (P = 0.034). The interactions of planting date and fertiliser (P < 0.001) and cultivar and fertiliser also affected the number of cormels plant^{-1}(P = 0.020) at Umbumbulu. The number of cormels plant^{-1} significantly decreased when planting was delayed by two months, two and three months, and one and two months for *Dumbe-dumbe, Mgingqeni* and *Pitshi* respectively at Ukulinga (Fig. 3.17). *Pitshi* had highest number of cormels plant^{-1} followed by *Mgingqeni* and *Dumbe-dumbe* respectively for October planting. When cultivars were planted in November, *Mgingqeni* and *Pitshi* which were not significantly different from each other had significantly higher number of cormels plant^{-1} than *Dumbe-dumbe.*

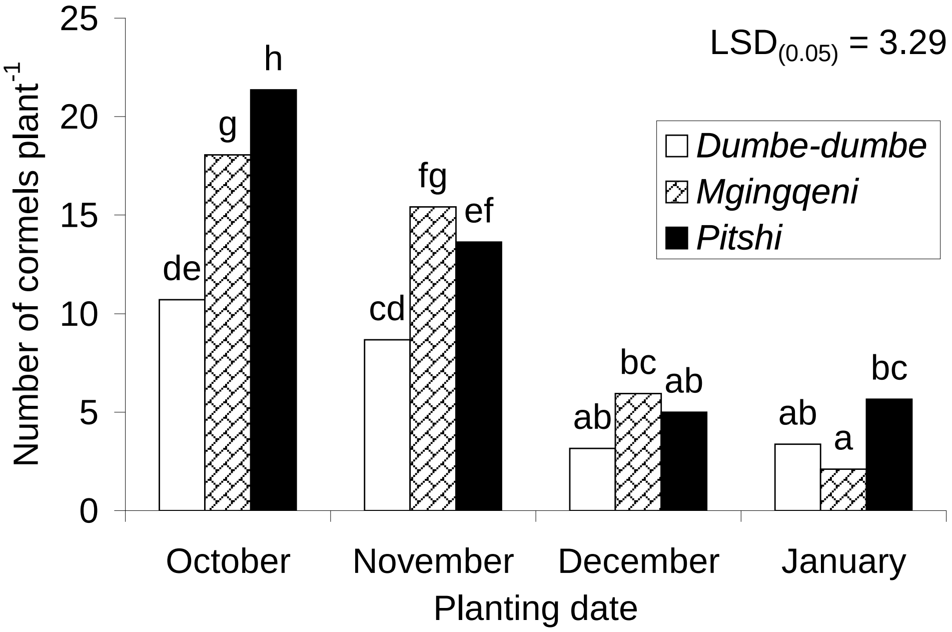

Figure 3.17 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on number of cormels plant^{-1} at Ukulinga.

At Umbumbulu, number of cormels plant^{-1} decreased for all cultivars when planting was delayed by one month from October (Fig. 3.18). A further decrease for *Mgingqeni* and *Pitshi* was also observed with a further one month delay in planting. *Dumbe-dumbe* had the fewest cormels plant^{-1} for both October and November plantings.

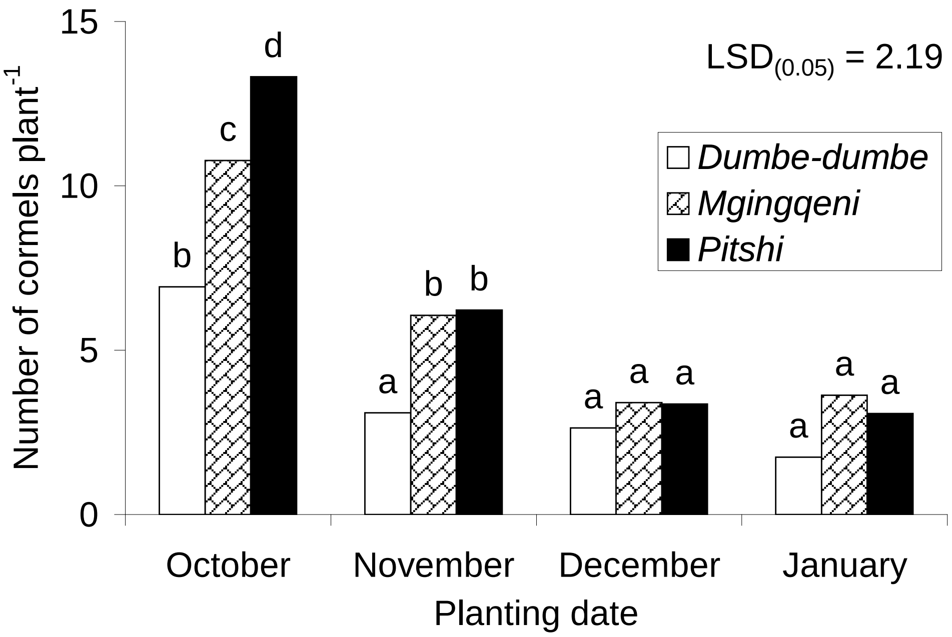

Figure 3.18 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on number of cormels plant^{-1} at Umbumbulu.

Number of cormels plant^{-1} was decreased by delaying planting by one and two months when fertiliser was applied. When no fertiliser was applied, delaying planting had no effect on the number of cormels plant^{-1}. Application of organic fertiliser enhanced the number of cormels plant^{-1} for October and November plantings only (Fig. 3.19). Addition of 160 N kg ha^{-1} of the fertiliser increased the number of cormels plant^{-1} but adding more had no additional effect. Application of organic fertiliser had no effect when planting was delayed until December and January.

Number of cormels plant^{-1} was enhanced for both *Mgingqeni* and *Pitshi* by application of 160 N kg ha^{-1}, whereas for *Dumbe-dumbe* it was increased by application of 320 N kg ha^{-1} (Fig. 3.20). There was no significant difference in number of cormels plant^{-1} between cultivars when no fertiliser was applied, but when fertiliser was applied *Dumbe-dumbe* showed significantly lower number of cormels plant^{-1} than *Mgingqeni* and *Pitshi* which were not significantly different from each other.

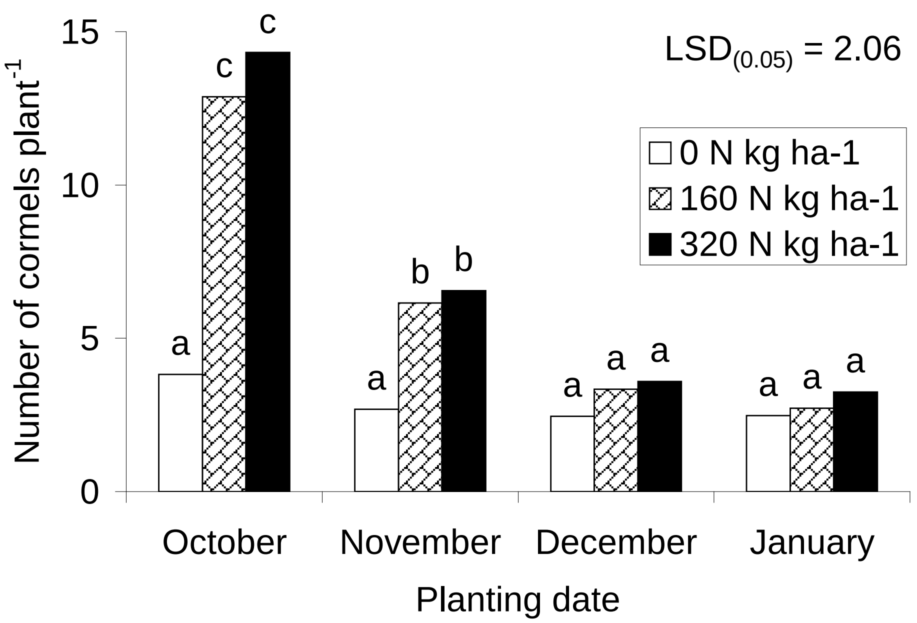

Figure 3.19 Effect of planting date and Gromor Accelerator® averaged across cultivar on number of cormels plant^{-1} at Umbumbulu.

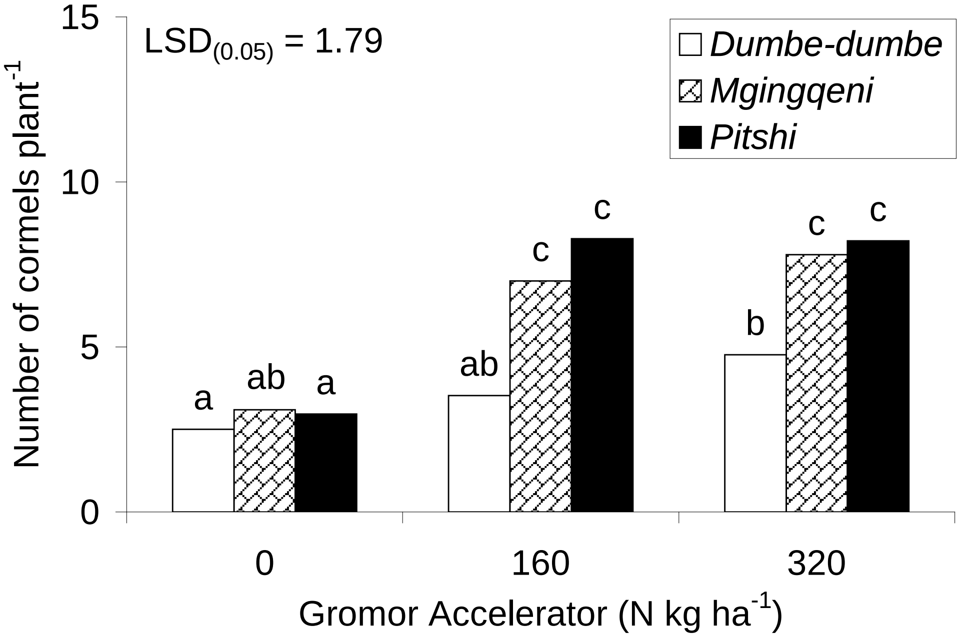

Figure 3.20. Effect of Gromor Accelerator® and cultivar averaged across planting date on number of cormels plant^{-1} at Umbumbulu.

3.3.3.2 Grading of cormels

Most of the cormels were very small when they were graded according to size. About 70%, 80% and 85% of *Dumbe-dumbe*, *Mgingqeni* and *Pitshi* cormels respectively, from both sites, planting dates, organic fertiliser application rates and cultivars, fell under the >20 – 40g size class (Fig. 3.21, 3.22, 3.23, 3.24, 3.25, 3.26, 3.27 and 3.28).

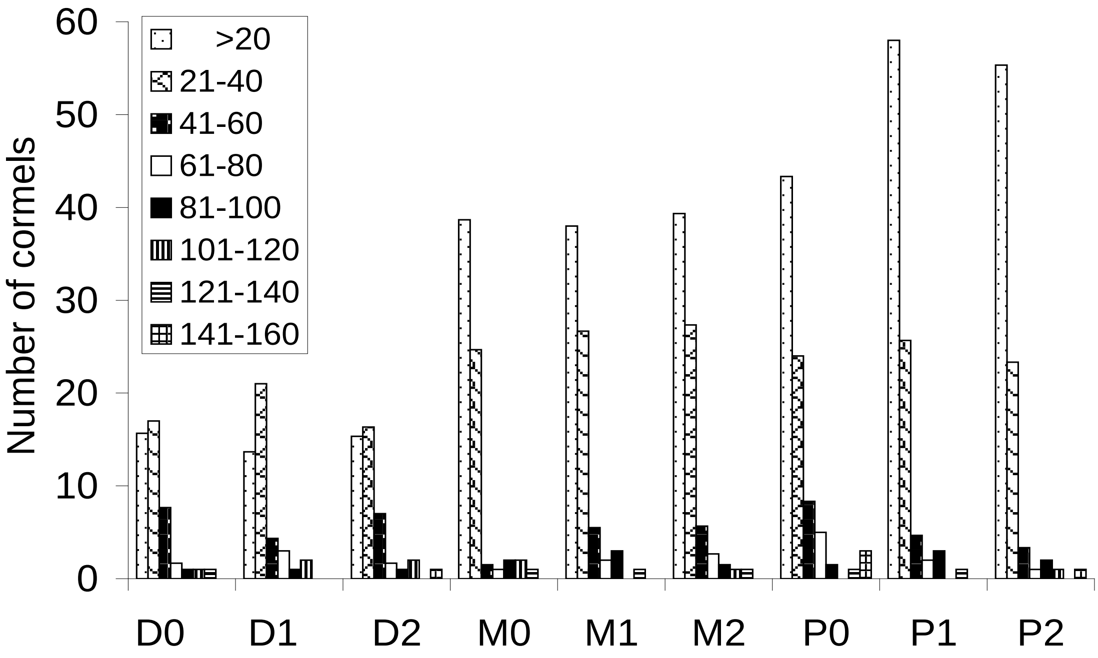

Figure 3.21 Number of cormels plant^{-1} for three taro cultivars (D = *Dumbe-dumbe,* M = *Mgingqeni* and P = *Pitshi*) planted with three Gromor Accelerator® application rates (0 = 0 N kg ha^{-1}, 1 = 160 N kg ha^{-1} and 2 = 320 N kg ha^{-1}) obtained for October planting at Ukulinga.

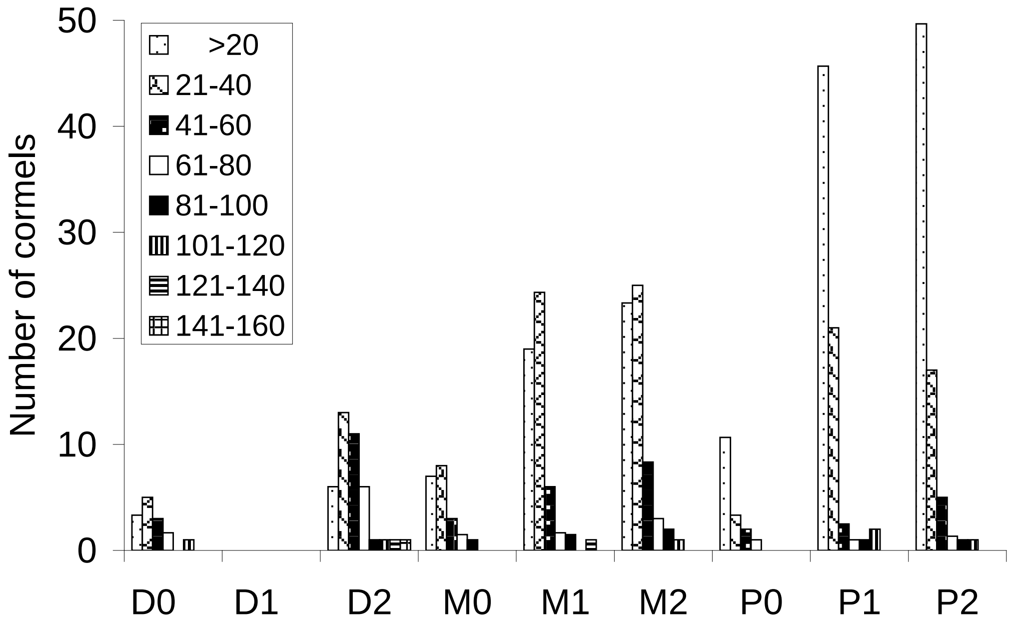

Figure 3.22 Number of cormels plant^{-1} for three taro cultivars (D = *Dumbe-dumbe,* M = *Mgingqeni* and P = *Pitshi*) planted with three Gromor Accelerator® application rates (0 = 0 N kg ha^{-1}, 1 = 160 N kg ha^{-1} and 2 = 320 N kg ha^{-1}) obtained for October planting at Umbumbulu.

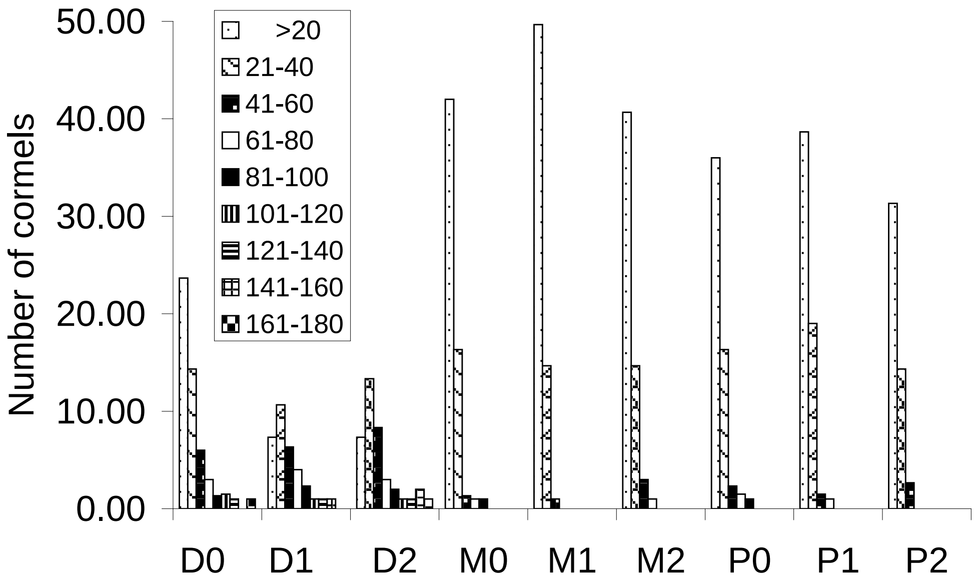

Figure 3.23 Number of cormels plant^{-1} for three taro cultivars (D = *Dumbe-dumbe*, M = *Mgingqeni* and P = *Pitshi*) planted with three Gromor Accelerator® application rates (0 = 0 N kg ha^{-1}, 1 = 160 N kg ha^{-1} and 2 = 320 N kg ha^{-1}) obtained for November planting at Ukulinga.

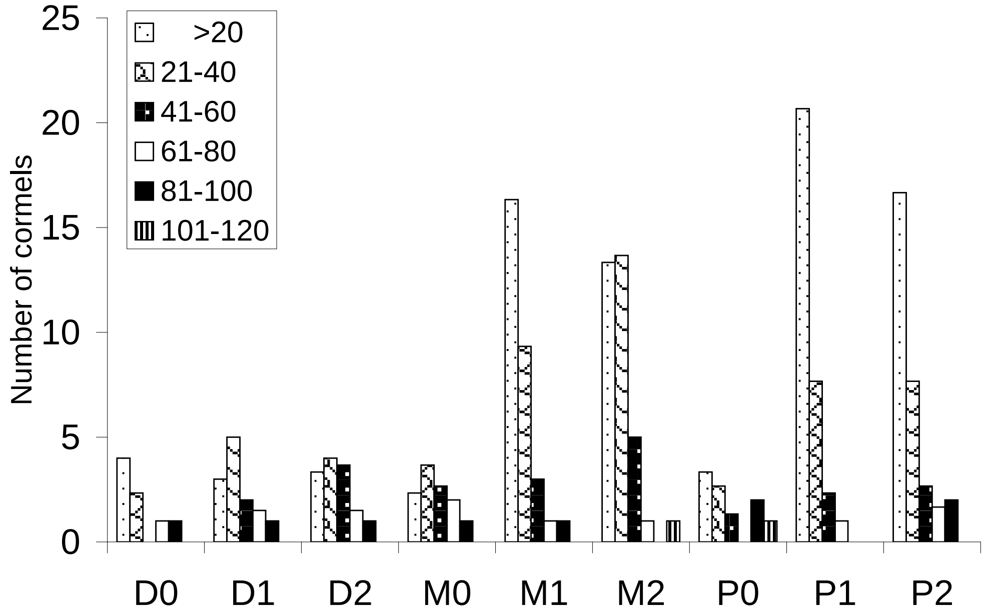

Figure 3.24 Number of cormels plant^{-1} for three taro cultivars (D = *Dumbe-dumbe*, M = *Mgingqeni* and P = *Pitshi*) planted with three Gromor Accelerator® application rates (0 = 0 N kg ha^{-1}, 1 = 160 N kg ha^{-1} and 2 = 320 N kg ha^{-1}) obtained for November planting at Umbumbulu.

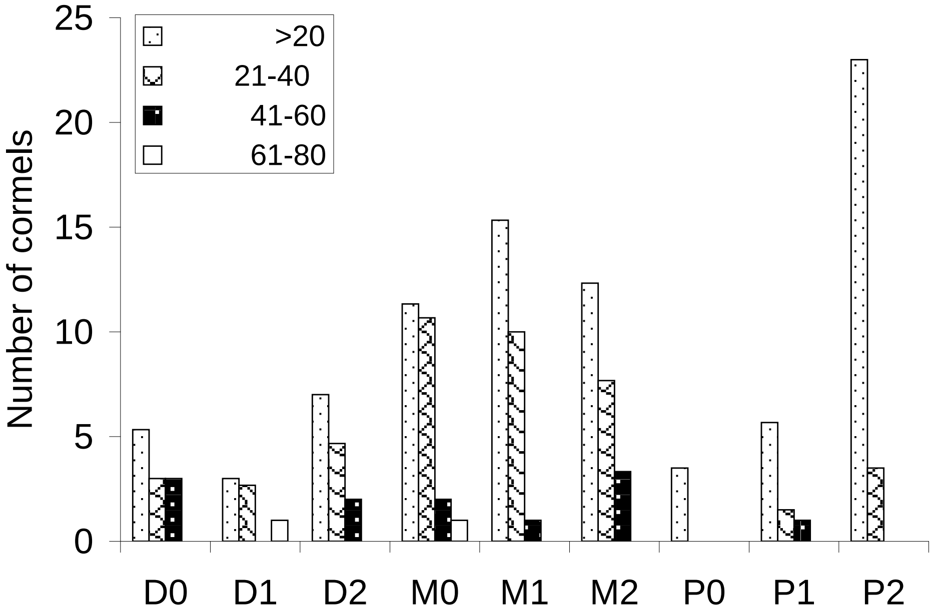

Figure 3.25 Number of cormels plant^{-1} for three taro cultivars (D = *Dumbe-dumbe*, M = *Mgingqeni* and P = *Pitshi*) planted with three Gromor Accelerator® application rates (0 = 0 N kg ha^{-1}, 1 = 160 N kg ha^{-1} and 2 = 320 N kg ha^{-1}) obtained for December planting at Ukulinga.

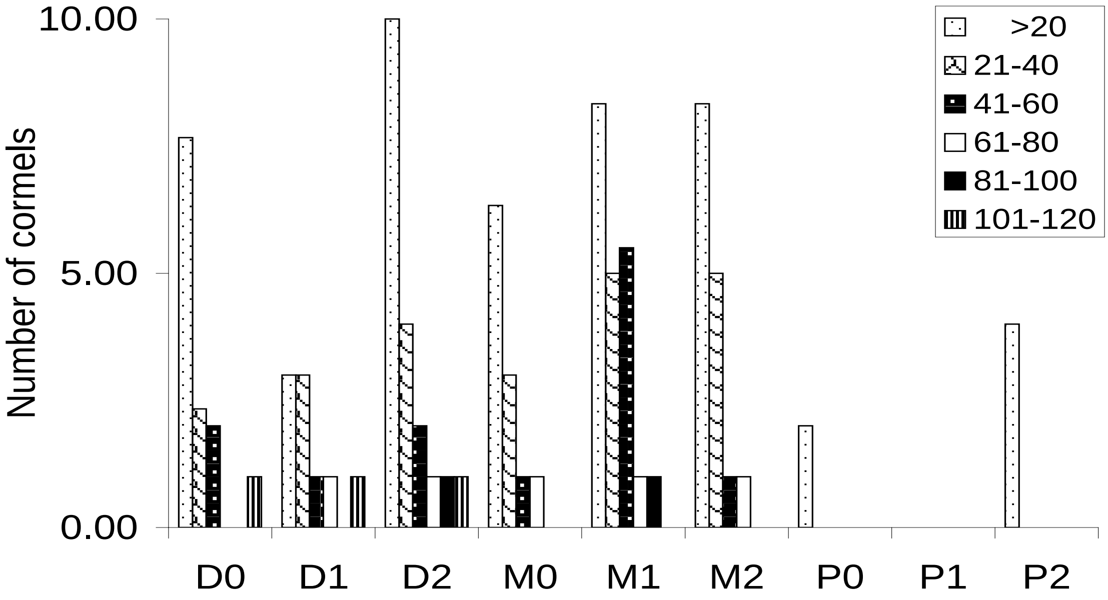

Figure 3.26 Number of cormels plant^{-1} for three taro cultivars (D = *Dumbe-dumbe*, M = *Mgingqeni* and P = *Pitshi*) planted with three Gromor Accelerator® application rates (0 = 0 N kg ha^{-1}, 1 = 160 N kg ha^{-1} and 2 = 320 N kg ha^{-1}) obtained for December planting at Umbumbulu.

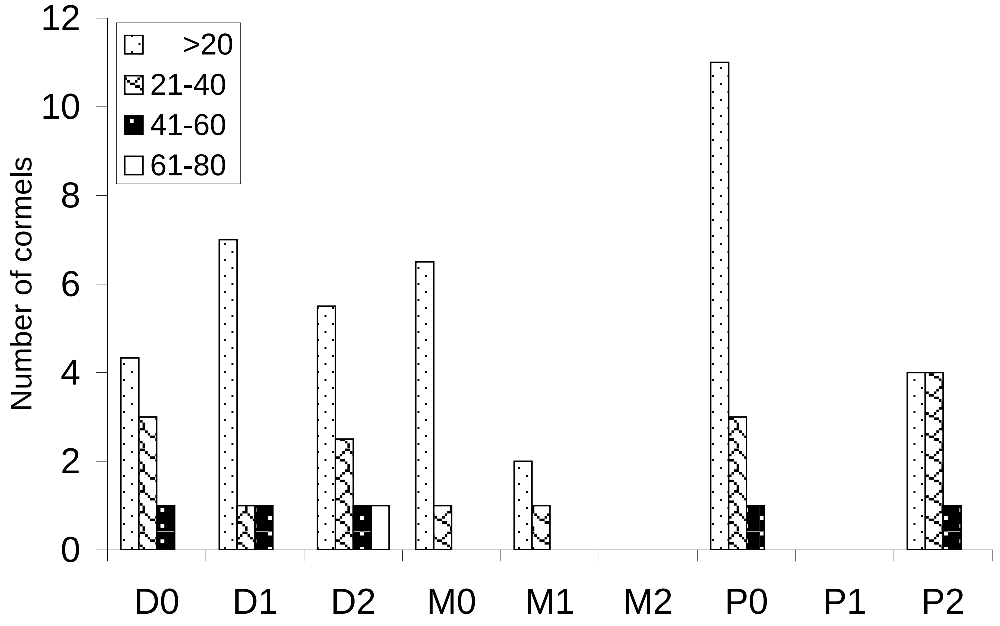

Figure 3.27 Number of cormels plant^{-1} for three taro cultivars (D = *Dumbe-dumbe*, M = *Mgingqeni* and P = *Pitshi*) planted with three Gromor Accelerator® application rates (0 = 0 N kg ha^{-1}, 1 = 160 N kg ha^{-1} and 2 = 320 N kg ha^{-1}) obtained for January planting at Ukulinga.

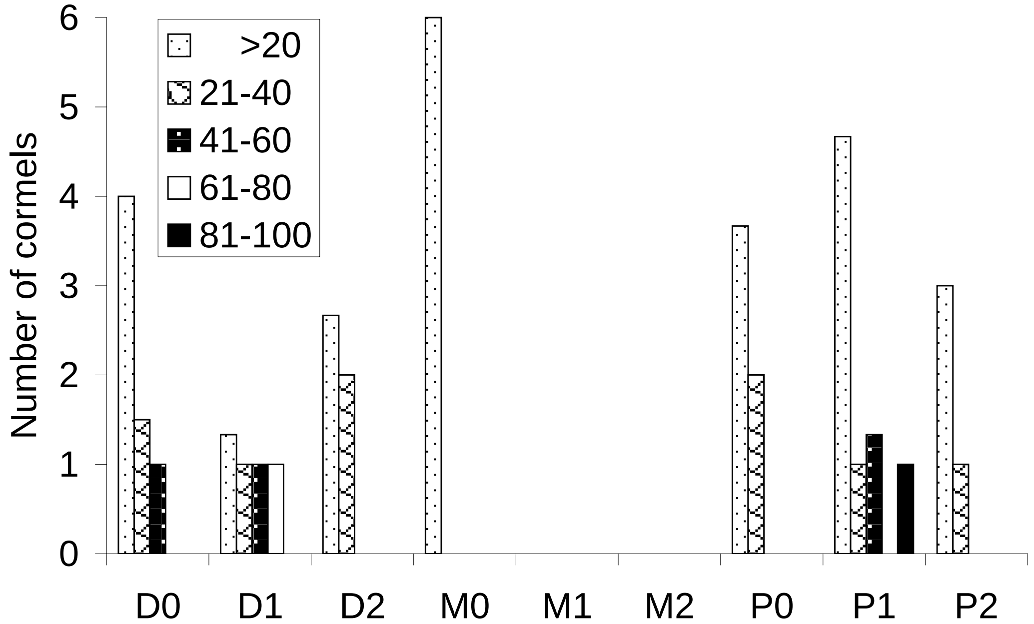

Figure 3.28 Number of cormels plant^{-1} for three taro cultivars (D = *Dumbe-dumbe,* M = *Mgingqeni* and P = *Pitshi*) planted with three Gromor Accelerator® application rates (0 = 0 N kg ha^{-1}, 1 = 160 N kg ha^{-1} and 2 = 320 N kg ha^{-1}) obtained for January planting at Umbumbulu.

3.3.3.3 Fresh cormel mass

Fresh cormel mass plant^{-1} was negatively affected by delayed planting at Ukulinga (P < 0.001). There was no significant effect of cultivar on fresh cormel mass plant^{-1}, although the effect of planting date depended on cultivar (Planting date x cultivar interaction: P = 0.011). Fresh cormel mass plant^{-1} significantly decreased for *Dumbe-dumbe* when planting was delayed by two months, whereas for both *Mgingqeni* and *Pitshi,* the decrease was observed when planting was delayed by one month (Fig. 3.29). *Dumbe-dumbe* had the lowest fresh cormel mass plant^{-1} for October planting, but the highest mass for November planting. There was no significant effect of fertilisation for fresh cormel mass plant^{-1}.

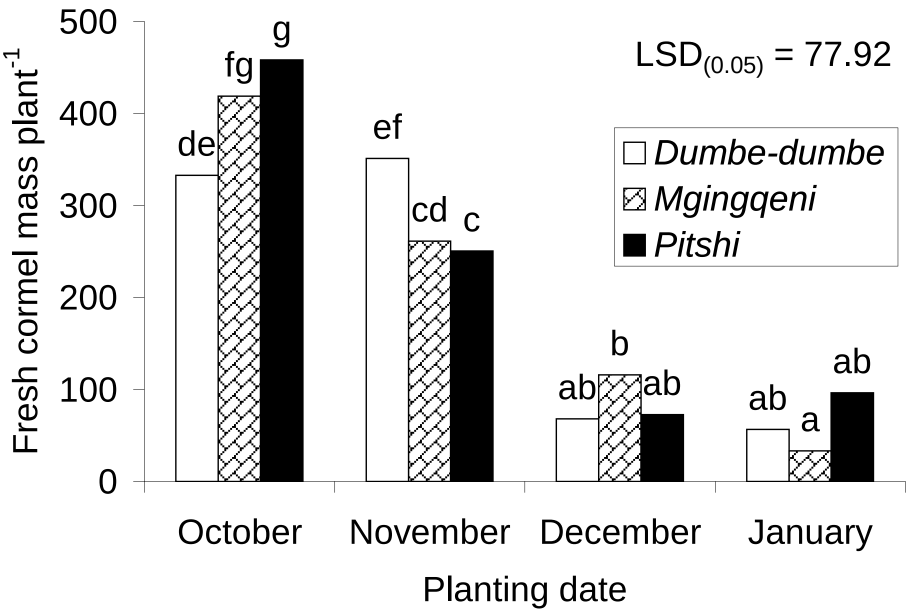

Figure 3.29 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on fresh cormel mass plant^{-1} at Ukulinga.

At Umbumbulu, similar to the site at Ukulinga, fresh cormel mass plant^{-1} was negatively affected by delayed planting (P < 0.001). There was also no significant effect of cultivar on fresh cormel mass plant^{-1}. In contrast to the site at Ukulinga, fresh cormel mass plant^{-1} was significantly affected by fertilisation (P < 0.001). Fertilisation increased fresh cormel mass plant^{-1}, although its effect depended upon planting date (Planting date x fertilisation interaction: P < 0.001. Fertilisation enhanced fresh cormel mass plant^{-1} only for the October and November plantings (Fig. 3.30). For both October and November plantings, the fresh cormel mass plant^{-1} was enhanced when 160 N kg ha^{-1} of the organic fertiliser was added, but increasing the amount of fertiliser to 320 N kg ha^{-1} was not effective.

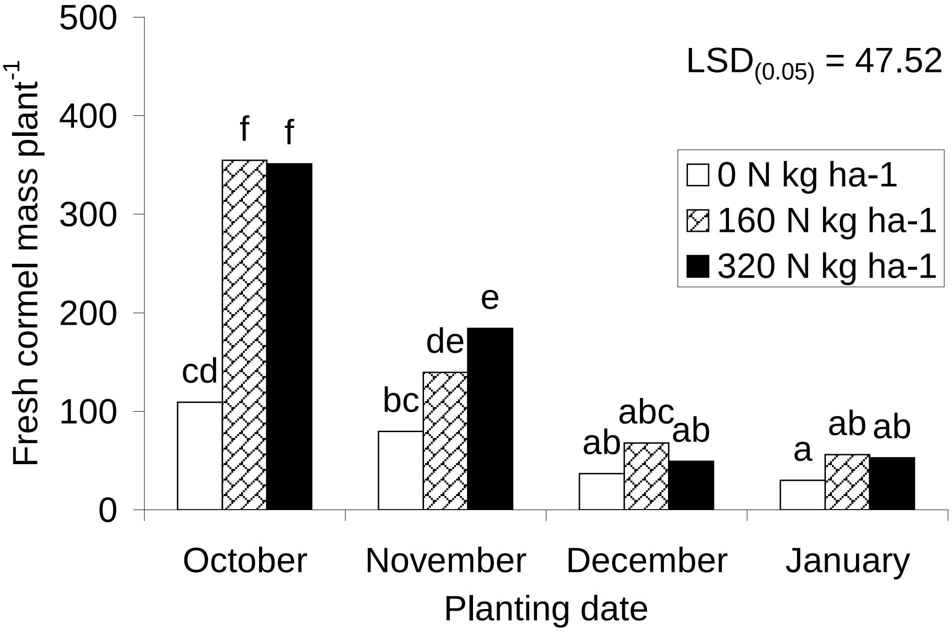

Figure 3.30. Effect of planting date and Gromor Accelerator® application rate averaged across cultivar on fresh cormel mass plant^{-1} of taro cormels at Umbumbulu.

All variables (emergence, leaf number plant$^{-1,}$ plant height, leaf area plant^{-1} and number of cormels plant^{-1}) except for number of cormels plant^{-1} at Ukulinga and leaf area plant^{-1} at Umbumbulu significantly affected fresh cormel mass plant^{-1} of taro when eliminating the effect of other variables (Appendix 3.3).

3.4 Discussion

The weather during the year of the field trial was normal and it is not shifting over time due to global climate change (Figs. 3.2, 3.3, 3.4 and 3.5). It is evident from Table 1 that higher rainfall and temperature were experienced during the first two planting dates and emergence of taro was greatly affected by rainfall and temperature. This confirms statements by Horton (1987) and Ali (1989) that a liberal amount of water and temperature should be available in the soil at planting to enhance rapid emergence. Almekinders and Struik (1996) observed an increase in the number of leaves at warmer temperatures. Deblonde and Ledent (2001) found drought to reduce the number of green leaves in two out of six potato cultivars. The different number of leaves plant^{-1} displayed by the cultivars in the present study was attributed to the difference between genotypes.

The taller plants observed with the early two planting dates when rainfall was high at both sites confirms the findings of Deblonde and Ledent (2001) that plant height was sensitive to moderate drought conditions. This was also in line with what was found by Zrust (1995) that water stress adversely affects plant height. Alsharari *et al*. (2007) also found plants exposed to low water stress to be the tallest. The plants at Umbumbulu were taller than those at Ukulinga probably because of the higher rainfall at Umbumbulu (Table 3.1). Organic fertiliser application on the other hand enhanced plant height. This finding was in line with findings of Allison *et al*. (1999). It is evident from Figure 6 that plant height of taro corms was enhanced by fertiliser application at Umbumbulu, confirming the findings of Mondal and Sen (2005) that plant height of eddoe taro increased with increase in fertiliser levels.

The increased leaf area in response to earlier planting dates may have been attributed to higher rainfall and temperature experienced over the growth period (Bussell and Bonin 1998; Rinaldi, 2003). Ojala *et al*. (1990) previously reported leaf area to be reduced by drought. Figure 8 shows that *Mgingqeni* and *Dumbe-dumbe* may have had larger leaf area ascribed to the larger seed corms that were used as planting material compared with *Pitshi*, which has a naturally small corm size. The effect of corm size on plant leaf area confirms previous findings that early plantings and large gloves produced larger leaf area in garlic (Stahlschmidt *et al*., 1997). In another study, Jefferies (1992) also showed that in all the potato genotypes that were studied, final size of leaves was reduced by drought, but the magnitude of the effect differed significantly with genotype.

The number of cormels plant^{-1} and total fresh cormel mass plant^{-1} decreased with delay in planting, improved with application of Gromor Accelerator® and vary with cultivars. There are many reports that yield of root crops, which is a positive function of the number of tubers and weight of tubers planted hill^{-1} is affected by water availability and temperature due to planting date (Lu *et al.*, 2001; Khan *et al.*, 2003;

Scheffer *et al.*, 2005). In this study, the number of cormels plant^{-1} and total fresh cormel mass plant^{-1} were highest at earlier planting dates which were characterized by higher rainfall and lower temperature. The increased cormel mass in earlier planting dates may have been attributed to the earlier increased leaf growth as a result of higher rainfall and temperatures (Bussell and Bonin, 1998). This observation supports the earlier findings that highest yields obtained when sweet potatoes were planted with the onset of rains, when taro was planted in Spring and Summer compared to Winter and fall plantings and when taro was planted under supplementary irrigation rather than rainfed conditions were attributed to adequate rainfall or water availability over the growth period (Sangakkara, 1993; Miyasaka *et al.*, 2003; Scheffer *et al.*, 2005).

It was also shown in this study that organic fertiliser increased yields of taro. As was the case with growth parameters, the effect of organic fertiliser was more pronounced for earlier planting dates. This observation is consistent with findings reported in other studies (Kumar *et al.*, 2007; Hagman *et al.*, 2009)

3.5 Conclusions and recommendations

In this study, it has been shown that taro growth and yield are affected by planting date and fertilisation rate, but the response varies with cultivar. Taro growth and yield parameters decrease with delay in planting and are positively affected by increasing fertiliser rates. *Mgingqeni* and *Pitshi* had significantly higher fresh cormel mass plant^{-1} than *Dumbe-dumbe* but a higher proportion of the cormels were small in size so it was concluded that *Dumbe-dumbe* was the best performer. It is then recommended that in order to improve taro yield at Ukulinga, *Dumbe-dumbe* should be planted in October and November without organic fertiliser, whereas at Umbumbulu, on the other hand, *Dumbe-dumbe* should be planted in October with 160 N kg ha^{-1} Gromor Accelerator®. Appendix 3.3 shows net returns hectare^{-1} of taro in KwaZulu-Natal when 160 N kg ha^{-1} Gromor Accelerator® is applied and this shows that a smallholder taro enterprise is profitable by returning R12.89 for every R1.00 spent. It is not clear why there is a negative effect of fertiliser on yield the later the crop is planted. A future study will investigate the physiological characteristics of taro cormels that influence sprouting, emergence and storability.

References

Agergaard, J. and Birch-Thomsen, T. 2006. Transitional rural landscapes: The role of smallscale commercial farming in former homelands of Post-Apartheid KwaZulu-Natal. *Danish Journal of Geography* 106 (2): 87-102.

Ali, A.M. 1989. Effects of planting on different sides of the ridge on emergence, plant growth, yield and quality of potato (*Solanum tuberosum*) in the Sudan. *Experimental Agriculture* 25: 409-415.

Allison, M.F., Allen, E.J. and Fowler, J.H. 1999. The nutrition of the potato crop. British Potato Council Research Review 1991/1. BPC Oxford, UK.

Almekinders, C.J.M and Struik, P.C. 1996. Shoot development and flowering in potato (*Solanum tuberosum* L.). *Potato Research* 39 (4): 581-607.

Alsharari, S.F., Alsadon, A.A. and Alharbi, A.R. 2007. Evaluation of drought tolerance of potato cultivars under greenhouse conditions. *Acta Horticulturae* 747: 67-74.

Bèlanger, G., Walsh, J.R., Richards, J.E., Milburn, P.H. and Ziadi, N. 2002. Nitrogen fertilisation and irrigation affects tuber characteristics of two potato cultivars. *American Journal of Potato Research* 79 (4): 269-279.

Bussell, W.T. and Bonin, M.J. 1998. Effects of high and low watering levels on growth and development of taro. *New Zealand Journal of Crop and Horticultural Science* 26: 313-317.

Deblonde, P.M.K. and Ledent, J.F. 2001. Effects of moderate drought conditions on green leaf number, stem height, leaf length and tuber yield of potato cultivars. *European Journal of Agronomy* 14: 31–41.

Fleisher, D.H., Timlin, D.J. and Reddy, V.R. 2006. Temperature influence on potato leaf and branch distribution and on canopy photosynthetic rate. *Agronomy Journal* 98:1442–1452.

Hagman, J.E., Mårtensson, A. and Grandin, U. 2009. Cultivation practices and potato cultivars suitable for organic potato production. *Potato Research DOI* 10.1007/s11540-009-9128-3.

Hancock, J.F. 2004. Plant evolution and the origin of crop species. CABI Publishing. Wellingford. UK, p. 222.

Horton, D.E. 1987. Potatoes: production, marketing and programs for developing countries, Westview Press, London, p. 39.

Jefferies, R.A. 1992. Responses of potato genotypes to drought. I. Expansion of individual leaves and osmotic adjustment. *Annals of Applied Biology* 122 (1): 93-104.

Kader, A.A. and Rolle, R.S. 2004. The role of post-harvest management in assuring the quality and safety of horticultural produce. FAO Agricultural Services Bulletin 152.

Khan, I.A., Deadman, M.L., Al-Nabhani, H.S. and Al-Habsi, K.A. 2003. Interactions between temperature and yield components in exotic potato cultivars grown in Oman. *Acta Horticulturae* 619: 353-359.

Kooman, P.L., Fahem, M., Tegera, P. and Haverkort, A.J. 1996. Effects of climate on different potato genotypes 2. Dry matter allocation and duration of the growth cycle. *European Journal of Agronomy* 5: 207-217.

Kumar, P., Pandey, S.K., Singh, B.P. Singh, S.V. and Kumar, D. 2007. Effect of nitrogen rate on growth, yield, economics and crisps quality of Indian potato processing cultivars. *Potato Research* 50 (2): 143-155.

Loomis, R.S. and Connor, D.J. 1992. Crop ecology: productivity and management in agricultural systems. Cambridge University Press, New York.

Lu, H.Y., Lu, C.T. Chan, L.F and Wei, M.L. 2001. Seasonal variation in linear Increase of taro harvest index explained by growing degree days. *Agronomy Journal* 93: 1136-1141.

Naramabuye, F.X., R.J. Haynes, R.J and Modi, A.T. 2008. Cattle manure and grass residues as liming materials in a semi-subsistence farming system. *Agriculture, Ecosystems and Environment* 124: 136-141.

Mare, R.M. 2006. Phytotron and field performance of taro [*Colocasia esculenta* (L.) Schott] landraces from Umbumbulu. MSc. Thesis. University of KwaZulu-Natal.

Miyasaka, S.C., Ogoshi, R.M., Tsuji, G.Y. and Kodani, L.S. 2003. Site and planting date effects on taro growth: Comparison with aroid model predictions. *Agronomy Journal* 95: 545–557.

Modi, A.T. 2003. What do subsistence farmers know about indigenous crops and organic farming? Preliminary case in KwaZulu-Natal. *Development Southern Africa* 20: 673-682.

Modi, A.T. 2007. Effect of indigenous storage method on performance of taro [*Colocasia esculenta* (L.) Schott] under field conditions in a warm subtropical area. *South African Journal of Plant and Soil* 24: 214-219.

Mokolobate, M.S. and Haynes, R.J. 2002. Comparative liming effect of four organic residues applied to an acid soil. *Biology and Fertility of Soils* 35: 79–85.

Mondal, S. and Sen, H. 2005. Growth and productivity of eddoe taro (*Colocasia esculenta* var. *antiquorum*) as influenced by fertiliser levels and spacings. *Journal of root crops* 31(1). .

O'Beirne, D. and Cassidy, J. C. 1990. Effects of nitrogen fertiliser on yield, dry matter content and flouriness of potatoes. *Journal of the Science of Food and Agriculture* 52 (3): 351-363.

Ojala, J.C., Stark, J.C. and Kleinkopf, G.E. 1990 Influence of irrigation and nitrogen management on potato field and quality. *American Potato Journal* 67: 29–43.

Osorio, N.W., Shuai, X., Miyasaki, S., Wang, B., Shirey, R. L. and Wigmore, W. J. 2003. Nitrogen level and form affect taro growth and nutrition. *Horticultural Science* 38 (1): 36-40.

Pocknee, S. and Summer, M.E. 1997. Cation and nitrogen contents of organic matter determine its liming potential. *Soil Science Society of American Journal* 61: 86-92.

Rinaldi, M. 2003. Variation of specific leaf area for sugar beet depending on sowing date and irrigation. *Italian Journal of Agronomy* 7 (1): 23-32.

Sangakkara, U.R. 1993. Response of sweet potato (*Ipomoea batatas* L.) to different planting times. *Journal of Agronomy and Crop Science* 172 (2): 113 – 118.

Scheffer, J.J.C., Douglas, J.A. and Triggs, C.M. 2005. Factors affecting the production and quality of Japanese taro cormels. *Acta Horticulturae* 670: 167-172.

Shange, L.P. 2004. Taro (*Colocasia esculenta* (L.) Schott) production by small-scale farmers in KwaZulu-Natal: Farmer practices and performance of propagule types under wetland and dryland conditions. MSc. Thesis. University of KwaZulu-Natal.

Shock, C.C., Zalewski, J.C., Stieber, T.D. and Burnett, D.S. 1992. Impact of early-season water deficits on Russet Burbank plant development, tuber yield and quality. *American Journal of Potato Research* 69 (12): 793-803.

Stahlschmidt, O., Cavagnaro, J.B. and Borgo, R. 1997. Influence of planting date and seed cloves size on leaf area and yield of two garlic cultivars (*Allium sativum* L.). *Acta Horticulturae* 433: 519-522.

Timlin, D., Lutfor-Rahman, S. M., Baker, J., Reddy, V. R. Fleisher, D. and Quebedeaux, B. 2006. Whole plant photosynthesis, development, and carbon partitioning in potato as a function of temperature. *Agronomy Journal* 98: 1195–1203.

Vinning, G. 2003. Select markets for taro, sweet potato and yam. RIRDC Project No. UCQ-13A.

Wadas, W., Jablońska-Ceqlarek, R. and Kosterna, E. 2004. Effect of plastic covering and nitrogen fertilisation on yield and quality of early potatoes. *Folia Horticulturae* 16 (2): 41-48.

Wolfe, D.W., Fereres, E. and Voss, R.E. 1983. Growth and yield response of two potato cultivars to various levels of applied water. *Irrigation Science* 3 (4): 211-222.

Wong, M.T.F., Nortcliff, S. and Swift, R.S. 1998. Method for determining the acid ameliorating capacity of plant residue compost, urban waste compost, farmyard manure and peat applied to tropical soils. *Communication in Soil Science and Plant Analysis* 29: 2927-2937.

Worthington, C.M. and Hutchinson, C.M 2006. Yield and quality of \`Atlantis\` and \`Harley Blackwell\` potatoes as affected by multiple planting dates, nitrogen rates and growing degree days. *Proceedings of the Florida State Horticultural Society* 119: 275-278.

Yuan, B.Z., Nishiyama, S. and Kang, Y. 2003. Effects of different irrigation regimes on the growth and yield of drip-irrigated potato. *Agricultural Water Management* 63: 153–167.

Zelalem, A., Tekalign, T. and Nigussie, D. 2009. Response of potato (*Solanum tuberosum* L.) to different rates of nitrogen and phosphorus fertilization on vertisols at Debre Berhan, in the central highlands of Ethiopia. *African Journal of Plant Science* 3 (2): 16-24.

Zrust, J. 1995. The effect of drought on the potato leaf area. *Scientia Agriculturae Bohemica*. 26 (3):177–188.

CHAPTER 4

INFLUENCE OF PLANTING DATE AND ORGANIC FERTILISER ON SPECIFIC GRAVITY, DRY MATTER CONTENT AND MINERAL CONTENT OF TARO CORMELS

Abstract

Taro (*Colocasia esculenta* L. Schott) is an important traditional crop in Africa, but its contribution to food security is limited by lack of research on its agronomy and commercialisation. A study was carried out to investigate the performance of three taro cultivars at two sites in KwaZulu-Natal, South Africa (Ukulinga and Umbumbulu), during the 2007/2008 growing season, with respect to chemical quality of cormels. A split-split- plot design was used with four planting dates (October 2007, November 2007, December 2007 and January 2008) as main plots, three cultivars (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) as sub-plots and three organic fertiliser (Gromor Accelerator®) application rates (0, 160 and 320 N kg ha^{-1}) as sub-sub-plots. At Ukulinga, application of 320 N kg ha^{-1} of Gromor Accelerator® significantly (P = 0.007) decreased dry matter content. Dry matter content was significantly highest for *Dumbe-dumbe* with November planting, whereas for both *Mgingqeni* and *Pitshi* the highest dry matter content was obtained with December planting and declined thereafter at Ukulinga. At Ukulinga, specific gravity was significantly lowest for *Dumbe-dumbe* with January planting, whereas for *Mgingqeni* it was significantly highest with December planting. Application of 5330 kg ha^{-1} of Gromor Accelerator® significantly decreased specific gravity only when planting was done in January. At Umbumbulu, delaying planting until December significantly decreased (P = 0.013) specific gravity for *Dumbe-dumbe* and *Pitshi*. Specific gravity was significantly highest for October planting with 0 N kg ha^{-1} of Gromor Accelerator® and lowest for December planting with 320 Nkg ha^{-1} of the organic fertiliser at Umbumbulu. Mineral content of cormels was significantly ($P < 0.05$) affected by both planting date and fertiliser application. It is recommended that to improve taro chemical composition, the crop should be planted in October at the study sites.

Key Words: *Colocasia esculenta*, cormel quality, fertilisation, planting date, site.

4.1 Introduction

Taro (*Colocasia esculenta* L. Schott) is an important traditional staple crop in the rural areas of South Africa and other African countries, but its contribution to food security is limited by lack of research on its agronomy and commercialisation. It is grown in the subtropical coastal area of South Africa, starting at Bizana district in the Eastern Cape and the rest of coastal KwaZulu-Natal. The crop is also cultivated in the subtropical and tropical parts of Mpumalanga and Limpopo provinces (Shange, 2004). Taro has an emerging market in KwaZulu-Natal and there is an initiative to process it into crisps. Corm quality is the main concern when taro is considered for processing. Like in potatoes, the processing industry requires corms of higher dry matter content and specific gravity in order to qualify for crisping. Different taro cultivars are grown organically at different planting dates. The different environmental conditions due to different planting dates and the different organic fertiliser rates interact to influence the corm quality of these cultivars. An understanding of these factors is essential for management so that corm quality can be altered or maintained to suit the crisping industry without compromising the nutritional quality of the corms.

Studies have been reported on dry matter content, specific gravity and nutritional composition of root crops under different management practices, environmental conditions (Mohamed, 1985; Casa *et al.*, 2005; Long *et al.*, 2004; Haase *et al.*, 2007; Huang *et al.*, 2007; Kumar *et al.*, 2007; El-Sirafy *et al.*, 2008). They found planting date, fertilisation, cultivar and environmental conditions to be the most important factors that affect corm or tuber quality.

Response to planting date is, however variable depending on cultivar. Dry matter was found to be highest at early planting for two of the potato cultivars while it was highest for the other cultivar when it was planted at a later date. Protein content of the tubers, on the other hand was higher when planting was delayed after the first planting date regardless of the cultivar (Mohamed, 1985). Tuber specific gravity and dry matter content were highest for three of the seven examined potato cultivars for spring planting whereas the same cultivars and an additional cultivar emerged superior for fall planting (Tawfik, 2002). Mittra & George (2000) found tuber dry matter content to be lower in plants planted during the period of high rainfall and temperature (June, July and August) compared to those planted in September and October in sweet potatoes in India.

El-Sirafy *et al.* (2008) found application of farm yard manure to increase dry matter content, protein content, specific gravity as well as nitrogen, phosphorus and potassium content of potato tubers whereas soil potassium increase protein content. They also reported that the interactions of farm yard manure and soil potassium decrease dry matter content but increase protein content, specific gravity and nitrogen, phosphorus and potassium content of potato tubers. McPharlin & Lancaster (2005) reported that potato varieties grown at different sites respond differently to nitrogen fertilisation and further stated that higher specific gravity in one cultivar was associated with a higher calcium content and lower nitrogen content in the tubers. Mondy & Koch (1978) reported potassium content to decrease and dry matter to increase with increasing levels of nitrogen fertilisation in potatoes whereas Manrique (1994) found excessive nitrogen fertilization to reduce dry matter allocated to the corms in taro. This was in line with what Bèlanger *et al.* (2002) and Zelalem (2009) found that nitrogen fertilisation significantly reduced dry matter content and tuber specific gravity of potatoes. Bèlanger *et al.* (2002) further reported that tuber specific gravity was strongly related to tuber nitrogen concentration, which in turn depended primarily on nitrogen fertilisation and that the risks of low specific gravity are greater when fertilisation exceeds the nitrogen requirements to reach maximum tuber yield. On the contrary, Wadas *et al.* (2004) reported that nitrogen fertilisation had no effect on quality of potato tubers. Phosphorus was found to have no effect on dry matter content and specific gravity of sweet potatoes and potatoes respectively (Rashid and Waithaka, 1985; Zelalem, 2009).

Upland-cultivated taro corms were found to retain higher moisture content and tended to have higher mineral content than paddy taro (Huang *et al.*, 2007). Abundant rainfall during the month of June resulted in lower dry matter content (Fontana *et al.*, 1990). Supplemental irrigation had a limited effect on specific gravity and tuber nitrogen concentrations (Bèlanger *et al.*, 2002). The potassium fertilisation effect on specific gravity depended upon the K concentration in the harvested tuber (Westermann *et a*l., 1994).

Midseason stress also appeared to reduce specific gravity (Lynch *et al.*, 1995). Accumulation of dry matter in the tubers was increased by water deficit (Nadler and Heuer, 1995). Significant increases in specific gravity, dry matter and significant decreases in protein content were observed due to the frequent irrigation at planting-stolon initiation and stolon initiation-tuber bulking stages. Frequent irrigations at tuber bulking stage were found to have deleterious effects on specific gravity and dry matter, especially when irrigation continued until maturity (Günel and Karadoĝan, 1998). Nitrogen fertilisation, irrigation, and cultivars affect tuber characteristics such as specific gravity, and nitrogen concentration. Nitrogen fertilisation increased tuber N and $N0_3$-N concentrations, and decreased specific gravity.

Suitable planting date, fertiliser application should improve the quality of taro corms. The objective of this study was to determine the dry matter content, specific gravity, protein content and mineral composition of corms of three taro cultivars grown at different planting dates using different organic fertiliser regimes in KwaZulu-Natal, South Africa.

4.2 Materials and methods

4.2.1 Planting material

Three taro cultivars of eddoe type *Dumbe-dumbe, Mgingqeni* and *Pitshi* were used for this study (Fig. 3.1). Cormel size for the taro cultivars vary between and within a cultivar. The cormels planted for this study were selected to be in the following size ranges (cormel $^{-1}$): 21 – 60 g for *Dumbe-dumbe*, 11 – 40g for *Mgingqeni* and 5 – 20g for *Pitshi*. The cormels were harvested in 2007 from Ukulinga except for *Dumbe-dumbe* which was obtained from farmers of Ezigeni, Umbumbulu district, KwaZulu-Natal, South Africa.

4.2.2 Site description

Field experiments were carried out at two sites, Ukulinga (29^o 37′S 30^o 16′E) and Umbumbulu (29^o 36′S 30^o 25′E) with different environmental conditions (Table 3.1) and soil physical and chemical properties (Table 3.2). Temperature and rainfall data for both sites were obtained from Weather South Africa for the past 10 years (Figs. 3.2, 3.3, 3.4 and 3.5) and for the duration of the experimental period Table 3.1). Soil samples were collected from both sites and analysed according to Naramabuye *et al.* (2008). The pH of the soils from both sites (Table 3.2) were below 6 to 6.5 which is the soil pH at with taro is known to grow best. Addition of organic manure was expected to increase the soil pH as it was reported by Pocknee and Summer (1997), Wong *et al*. (1998), Mokolobate and Haynes (2002) and Naramabuye *et al.* (2008) that organic manure has a rapid liming effect. However, no soil analysis was performed at harvest.

4.2.3 Experimental design

The experiment was designed as a split-split-plot design with four planting dates: October 2007, November 2007, December 2007 and January 2008 (Table 3.3) as main plots, three taro cultivars: *Dumbe-dumbe*, *Mgingqeni* and *Pitshi* (Fig 3.1) as sub-plots and three organic fertiliser (Gromor Accelerator®) application rates (0, 160 and 320 N kg ha^{-1}) as sub-plots. The nutritional composition of Gromor Accelerator® is shown in table 3.3. Each planting date was replicated three times. Plot size was 4 m^2 containing 16 plants spaced 0.5m between and within rows. Sowing was done by hand on ploughed and harrowed fields. Planting holes were opened with a hand-hoe and organic fertiliser was mixed with soil before one cormel was planted per hole. Weeds were controlled by hand-hoeing at one, two, three and four months after planting. Harvesting was done eight months after planting.

4.2.4 Data collection and analysis

Dry matter content and specific gravity were determined on freshly harvested taro cormels at harvest. Other cormels were peeled, cut into slices, immediately frozen in liquid nitrogen, freeze dried and ground into powder for mineral content analysis. Analysis of variance was performed using GenStat Version 11.1 (2008). Least significant difference (LSD) was used to separate means. A probability level of 0.05 was considered to be statistically significant.

4.2.4.1 Dry matter content

Cormels were weighed to find fresh weight. They were then sliced before they were oven dried at 70^{o}C for 96 hours to a constant weight and weighed again. Dry matter was determined by dividing the dry weight by fresh weight then multiplied by 100.

(Dry weight / Fresh weight) x 100 = % Dry matter.

4.2.4.2 Specific gravity

Cormels were weighed and then submerged in water to measure their volumes by displacement. Cormel weight was divided by volume to determine specific gravity (Yuan *et al*., 2003; Robin, 2004).

4.2.4.3 Protein content and total protein

The protein content was calculated by multiplying the nitrogen value, which was determined by running on a LECO CNS instrument calibrated with an imported sample and checked against known standard samples, by the conversion factor 6.25. Total protein is the amount of protein in the fresh cormel mass plant^{-1}.

4.2.4.4 Mineral content

For mineral content determination, the ground samples were analysed for nitrogen, phosphorus, potassium, calcium, magnesium, sodium, zinc, copper, manganese and iron content. Nitrogen was run on a LECO CNS instrument calibrated with an imported sample and checked against known standard samples. The analyses for calcium, magnesium, potassium, sodium, zinc, copper, manganese, iron, phosphorus and aluminium were done using the I.C.P instrument which was calibrated on four different levels of imported standards for each of the elements. Internal controls were run every tenth sample and the instrument was checked regularly using an imported multi element standard (Naramabuye *et al.*, 2008).

4.3 Results

4.3.1 Dry matter content

Dry matter content of taro cormels was significantly affected by Gromor Accelerator® application rate (P = 0.020) and the interaction of planting date and cultivar (P = 0.031) at Ukulinga. Application of 320 N kg ha^{-1} of Gromor Accelerator® significantly decreased dry matter content from 27.56% to 24.55% (Fig. 4.1).

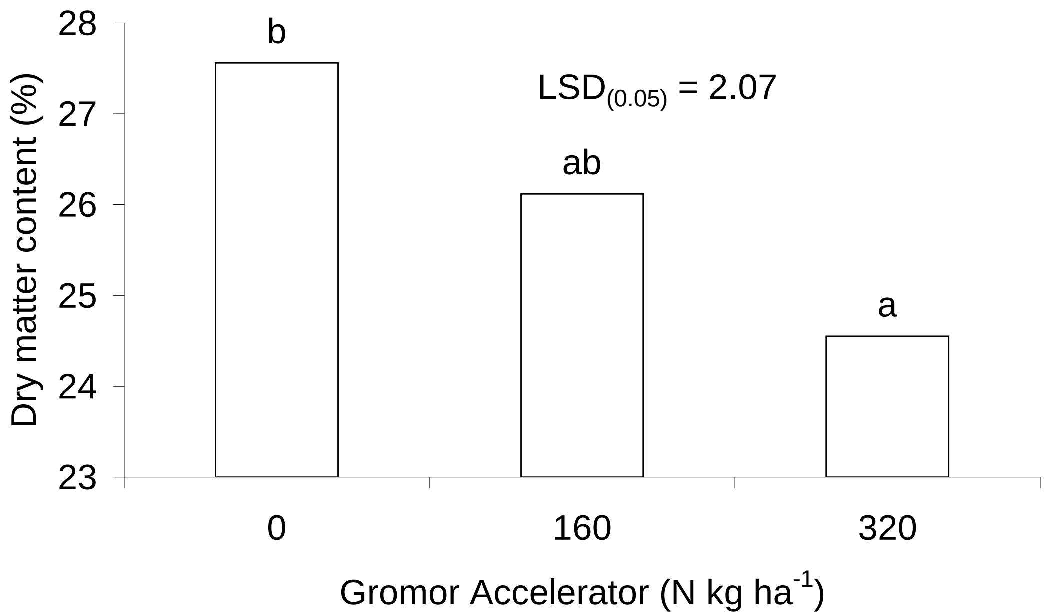

Figure 4.1 Effect of Gromor Accelerator® application rate averaged across planting date and cultivar on dry matter content of taro cormels at Ukulinga.

Delaying planting by one month from October significantly increased dry matter content of *Dumbe-dumbe* and significantly decreased it again with January planting (Fig. 4.2). For *Mgingqeni*, dry matter content was significantly increased when planting was delayed by two months. Planting date had no effect on dry matter content of *Pitshi*. *Dumbe-dumbe* displayed significantly highest dry matter content for November planting, whereas for January planting *Mgingqeni* showed significantly higher dry matter content than *Dumbe-dumbe* but not *Pitshi* which was also not significantly different from *Dumbe-dumbe*. There was no significant difference in dry matter content of the cultivars when they were planted in both October and December. Gromor Accelerator® and/or planting date had no effect on dry matter content of all taro cultivars at Umbumbulu.

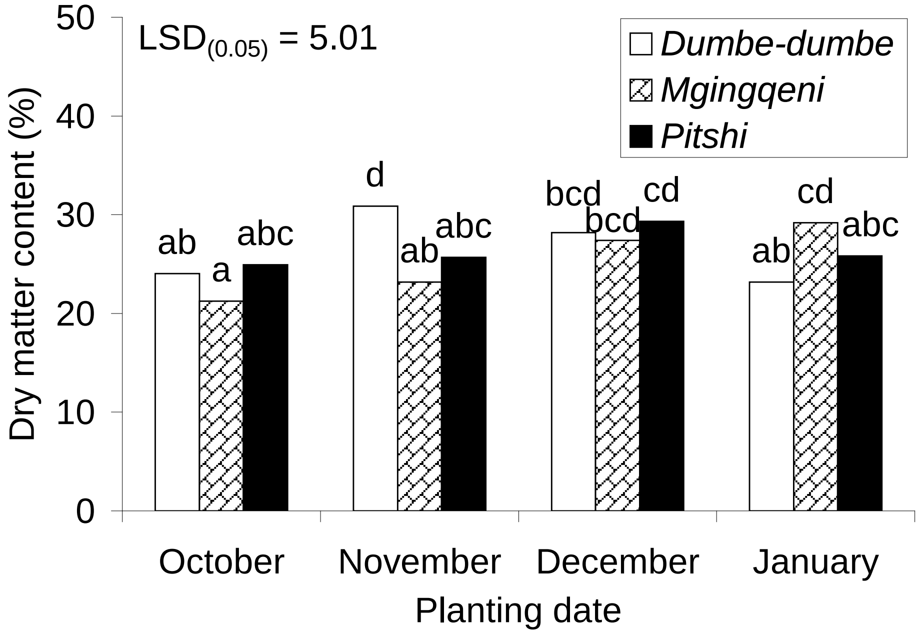

Figure 4.2 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on dry matter content at Ukulinga.

4.3.2 Specific gravity

At Ukulinga, specific gravity was significantly affected by the interactions of planting date and cultivar (P = 0.001) as well as planting date and Gromor Accelerator® application rate (P = 0.013). Cormels of *Dumbe-dumbe* from Ukulinga displayed a significant decline in specific gravity with delay in planting by three months from October (Fig. 4.3). *Dumbe-dumbe* had significantly higher specific gravity than *Pitshi* but not *Mgingqeni* for October planting, whereas *Mgingqeni* showed significantly higher specific gravity than *Dumbe-dumbe* but not *Pitshi* for January planting. The significant difference in specific gravity was only significant between cultivars when planting was done in October and January.

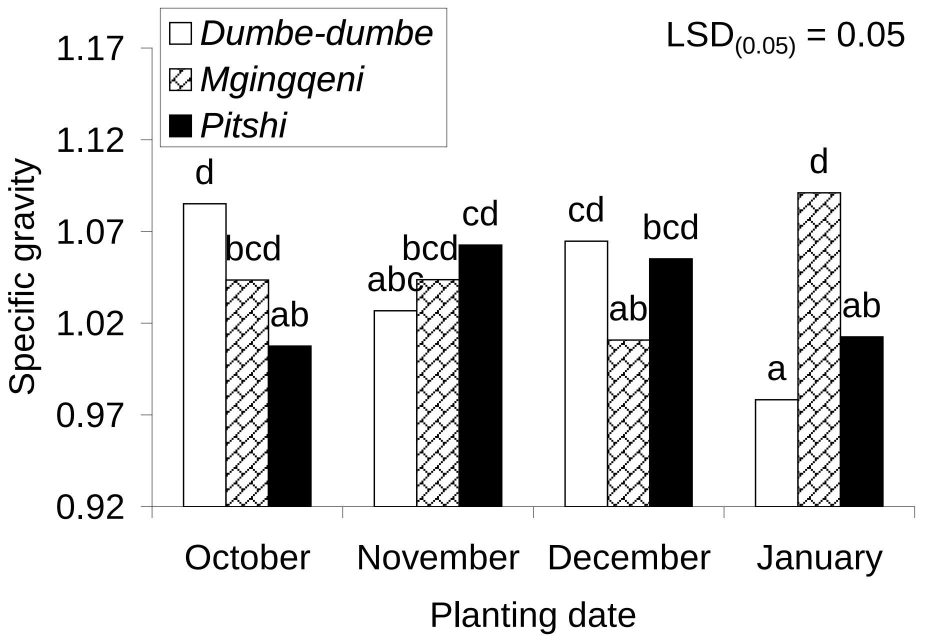

Figure 4.3 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on specific gravity at Ukulinga.

Delaying planting by three months from October significantly decreased specific gravity when 160 N kg ha^{-1} of Gromor Accelerator® was applied (Fig. 4.4). The significantly lowest specific gravity was obtained with 160 N kg ha^{-1} of Gromor Accelerator® for January planting.

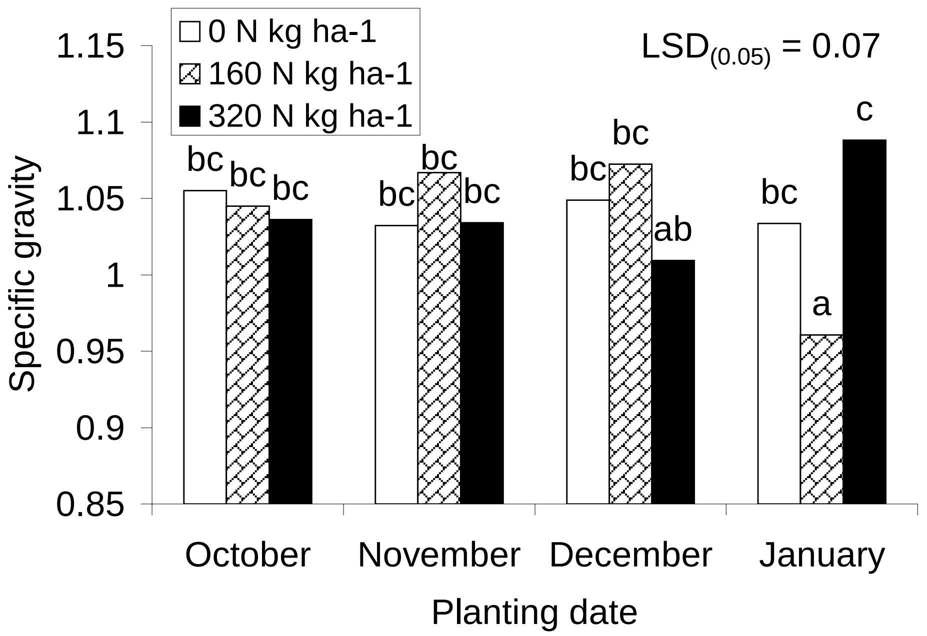

Figure 4.4 Effect of planting date and Gromor Accelerator® application rate averaged across cultivar on specific gravity at Ukulinga.

Specific gravity responded significantly to the interactions of planting time and cultivar (P = 0.033) and planting date and Gromor Accelerator® application rate (P = 0.002) at Umbumbulu. Delaying planting by two months significantly decreased specific gravity of *Dumbe-dumbe* and *Pitshi* but it increased again for *Pitshi* with January planting (Fig. 4.5). Specific gravity was significantly lowest for *Pitshi* with December planting.

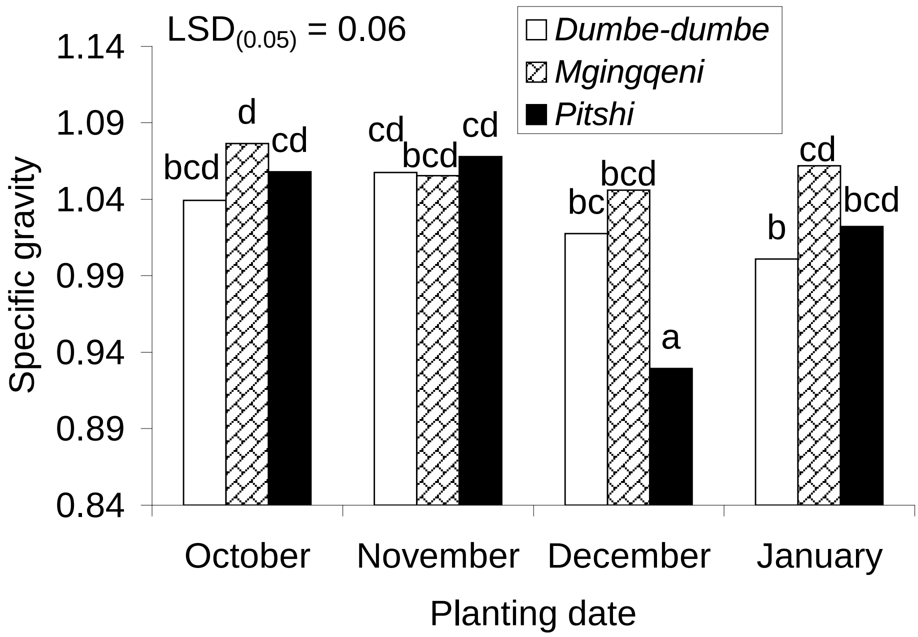

Figure 4.5 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on specific gravity at Umbumbulu.

Delaying planting by one month from October significantly decreased specific gravity when no organic fertiliser was applied (Fig. 4.6). When 320 N kg ha^{-1} of Gromor Accelerator® was applied specific gravity was decreased with delay in planting by two months, and increased thereafter with January planting. The significantly highest specific gravity was obtained with October planting when organic fertiliser was not applied, whereas the lowest was obtained with December planting when 320 N kg ha^{-1} was applied.

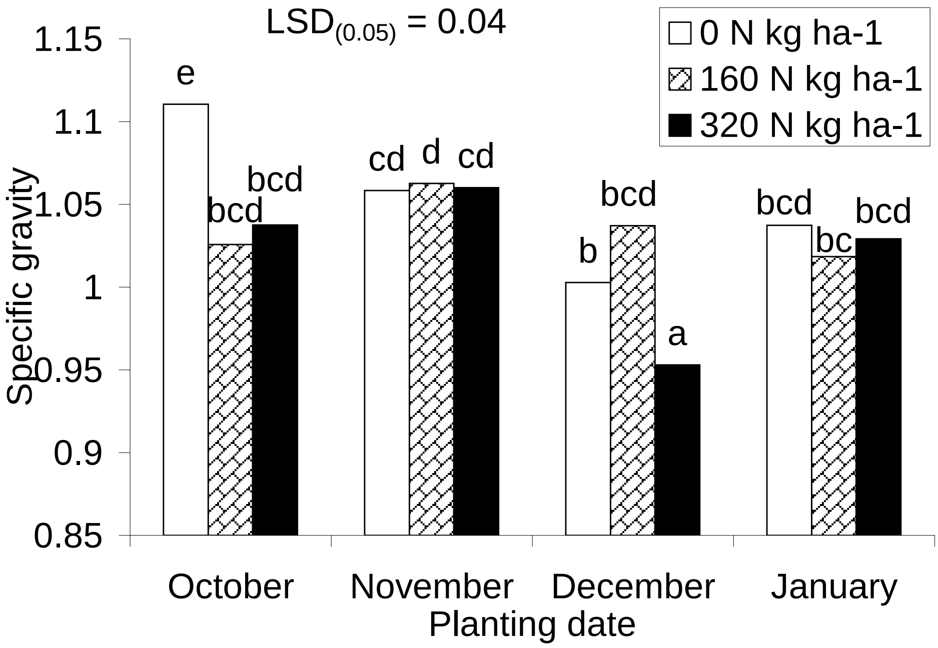

Figure 4.6 Effect of planting date and Gromor Accelerator® application rate averaged across cultivar on specific gravity at Umbumbulu.

4.3.3 Protein content and total protein

4.3.3.1 Protein content

Planting date ($P < 0.001$) and Gromor Accelerator® application rate ($P = 0.032$) significantly affected protein content of taro cormels at Ukulinga. Delaying planting significantly increased protein content of taro cormels. January planting displayed significantly highest protein content (16.70%) followed by December planting (14.69%), and both November (12.76%) and October (11.99%) plantings which were not significantly different from each other (Fig. 4.7). Adding 160 N kg ha^{-1} of Gromor Accelerator® significantly increased protein content from 13.55% - 14.54%, but further incorporation of 320 N kg ha^{-1} of the organic fertiliser did not further increase protein content (14.01%) (Fig. 4.8). Cultivar and the interactions of planting date, cultivar and fertiliser had no effect on protein content of cormels at Ukulinga.

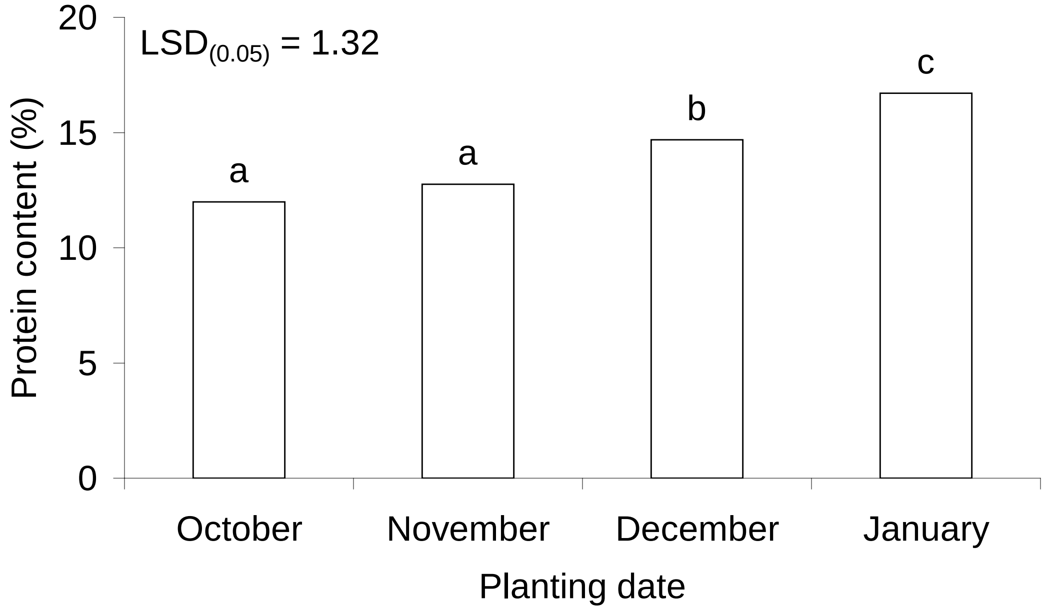

Figure 4.7 Effect of planting date averaged across cultivar and Gromor Accelerator® application rate on protein content of taro cormels at Ukulinga.

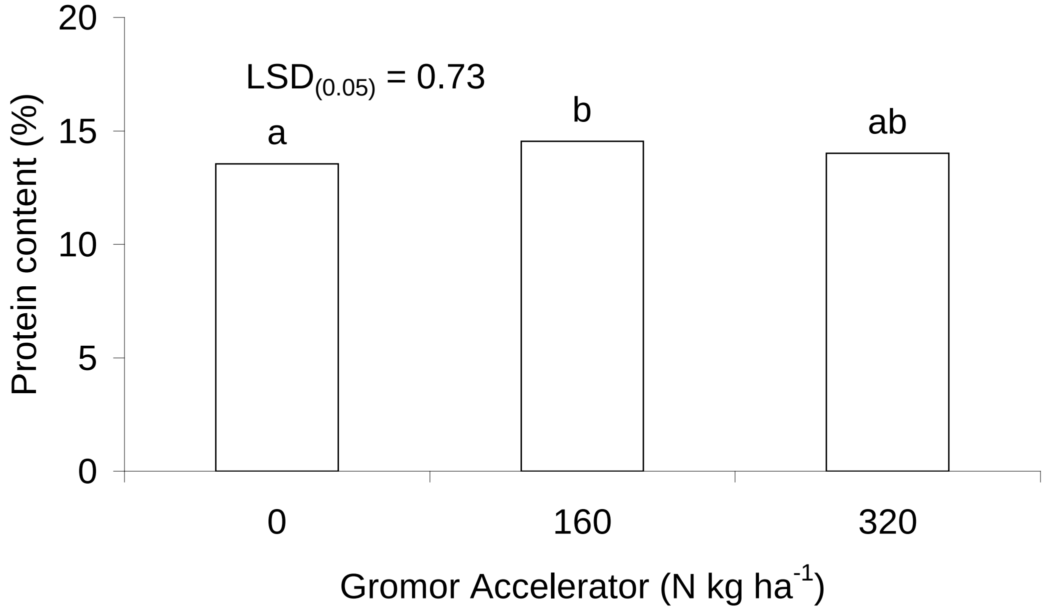

Figure 4.8 Effect of Gromor Accelerator® application rate averaged across planting date and cultivar on protein content of taro cormels from Ukulinga.

At Umbumbulu, protein content significantly ($P < 0.001$) decreased with application of Gromor Accelerator®. Addition of 160 N kg ha^{-1} of organic fertiliser significantly decreased protein content of cormels from 11.50 % to 9.41 %, but further increase of the organic fertiliser had no further significant effect (9.21 %) (Fig. 4.9). The interaction of planting date and cultivar also significantly ($P = 0.002$) affected protein content of taro cormels at Umbumbulu. Protein content of *Dumbe-dumbe* was significantly increased by delaying planting until November (Fig. 4.10). For *Mgingqeni*, protein content was significantly increased when planting was delayed from October to December whereas for *Pitshi* the increase was observed with delay in planting from November to December and decreased thereafter. The significantly highest protein content was obtained with *Pitshi* for December planting.

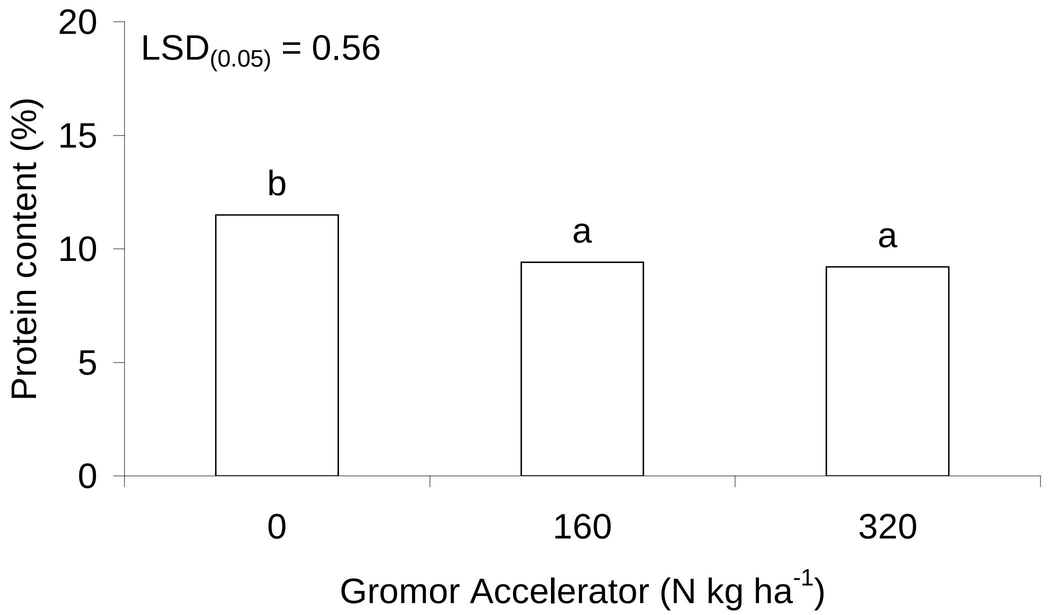

Figure 4.9 Effect of Gromor Accelerator® application rate averaged across planting date and cultivar on protein content of taro cormels from Umbumbulu.

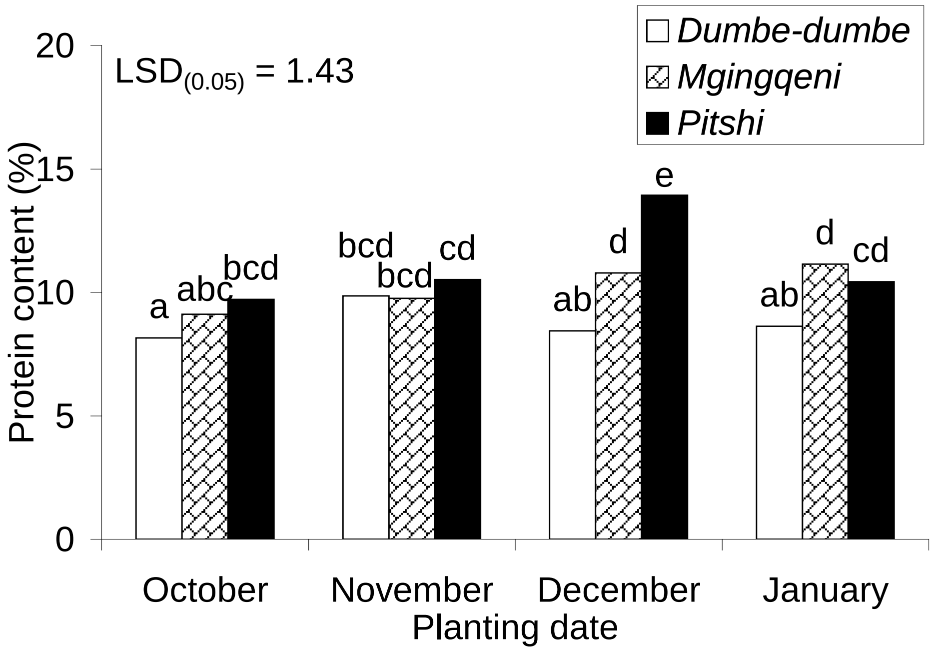

Figure 4.10 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on protein content of taro cormels from Umbumbulu.

4.3.3.2 Total protein

The interaction of planting date and cultivar significantly affected total protein plant^{-1} at Ukulinga (P = 0.004). Total protein plant^{-1} was increased and decreased for *Dumbe-dumbe* and *Pitshi* respectively when planting was delayed by one month from October (Fig. 4.11). Delaying planting by one month had no effect on total protein plant^{-1} of *Mgingqeni*. Further delaying planting by two months significantly reduced total protein plant^{-1} for all cultivars. *Pitshi* had higher total protein plant^{-1} than other cultivars when they were planted in October, whereas *Dumbe-dumbe* had higher protein content plant^{-1} when planting was done in November. There was no difference in total protein plant^{-1} between cultivars when they were planted in December and January.

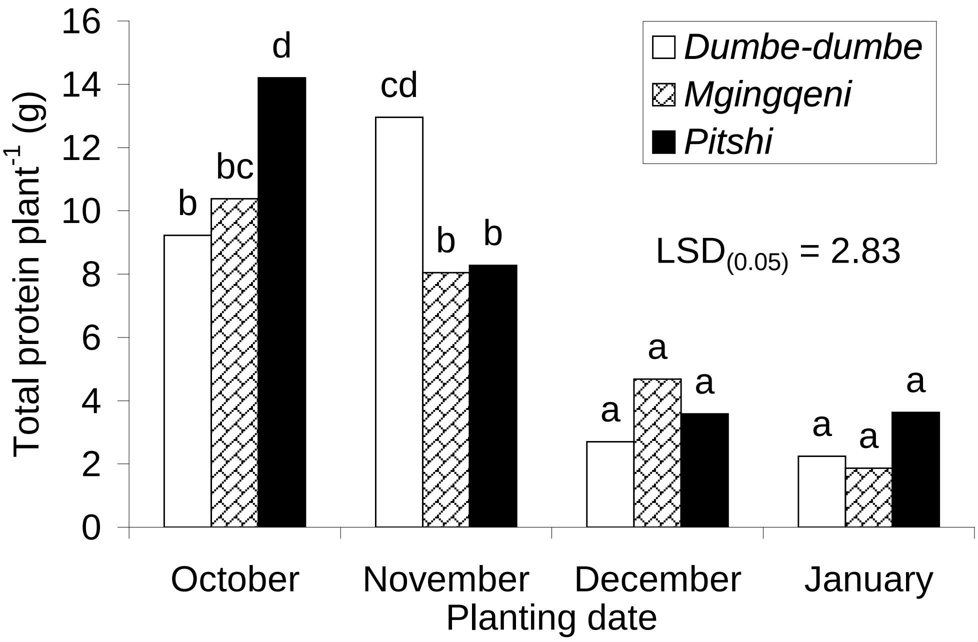

Figure 4.11 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on total protein of taro cormels from Ukulinga.

At Umbumbulu, delaying planting by two months decreased total protein plant^{-1} when 0 or 320 N ka ha^{-1} of fertiliser was applied, whereas when 160 N kg ha^{-1} was applied the decrease was observed with delay in planting by one and two months (Fig, 4.12). Total protein plant^{-1} was significantly affected by the interactions of planting date and fertiliser (P < 0.001) and cultivar and fertiliser (P = 0.022). Application of 160 N kg ha^{-1} increased total protein plant^{-1} of taro cormels when planting was done in October, whereas when planting was done in November, it was increased by adding 320 N kg ha^{-1}. Fertiliser had no effect on total protein plant^{-1} when planting was done in December and January.

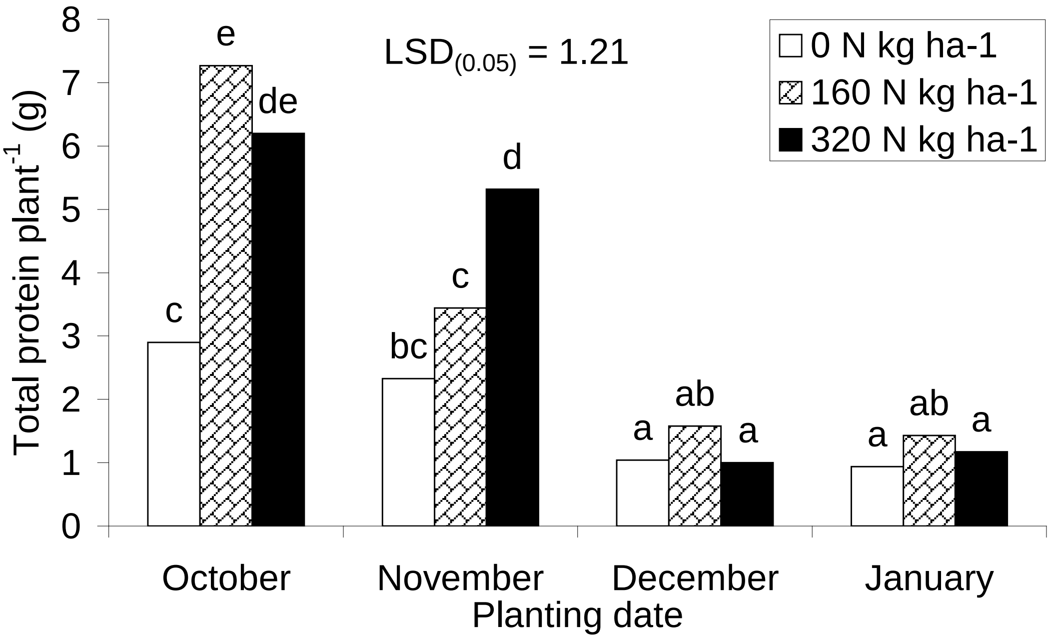

Figure 4.12 Effect of planting date and Gromor Accelerator® application rate averaged across cultivar on total protein of taro cormels from Umbumbulu.

Application of fertiliser increased total protein plant^{-1} for all cultivars, but further increase of the fertiliser decreased total protein plant^{-1} for *Pitshi* (Fig.4.13). *Mgingqeni* had higher total protein plant^{-1} than other cultivars when 320 N kg ha^{-1} was applied whereas there was no difference in total protein plant^{-1} between cultivars when 0 and 160 N kg ha^{-1} was applied.

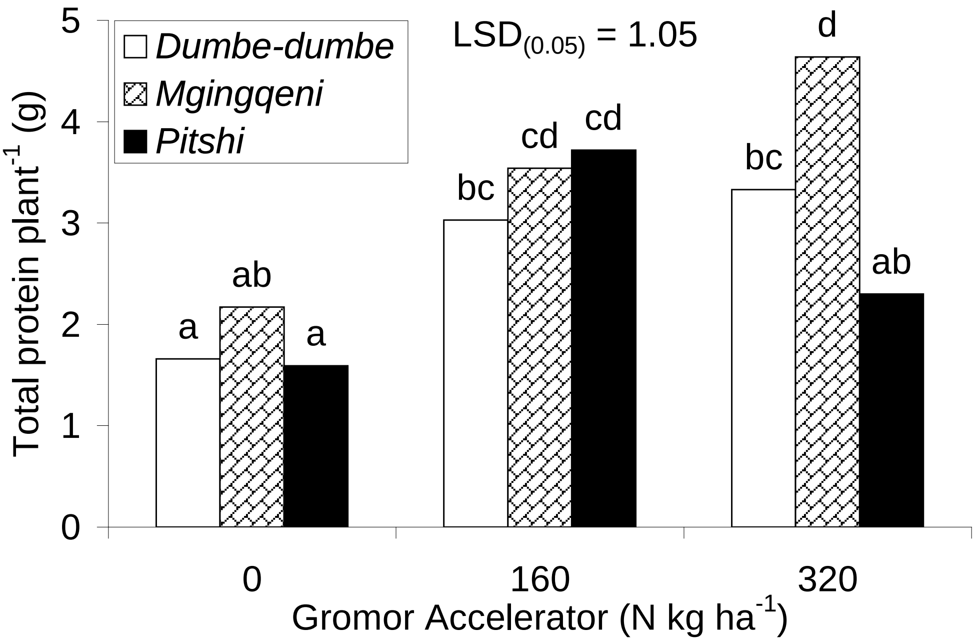

Figure 4.13 Effect of cultivar and Gromor Accelerator® application rate averaged across planting date on total protein of taro cormels from Umbumbulu.

4.3.4 Mineral content of taro cormels

Mineral content of taro cormels was significantly ($P < 0.05$) affected by planting date, Gromor Accelerator® application rate and cultivar with the exception of calcium, copper and iron content of cormels from Ukulinga, and magnesium, iron and sodium content of cormels from Umbumbulu which were not affected.

4.3.4.1 Nitrogen content

Nitrogen content of taro corms was positively affected by delayed planting ($P < 0.001$) and fertilisation ($P = 0.032$) at Ukulinga. Cultivar and interactions of planting date, cultivar and fertilisation were not significant for nitrogen content. January planting displayed significantly highest nitrogen content (2.67%) followed by December planting (2.35%), and both November (2.04%) and October (1.92%) plantings which were not significantly different from each other Fig. 4.14). Adding 160 N kg ha^{-1} of Gromor Accelerator® significantly increased nitrogen content but further incorporation of 320 N kg ha^{-1} of the organic fertiliser had no further effect (Fig. 4.15).

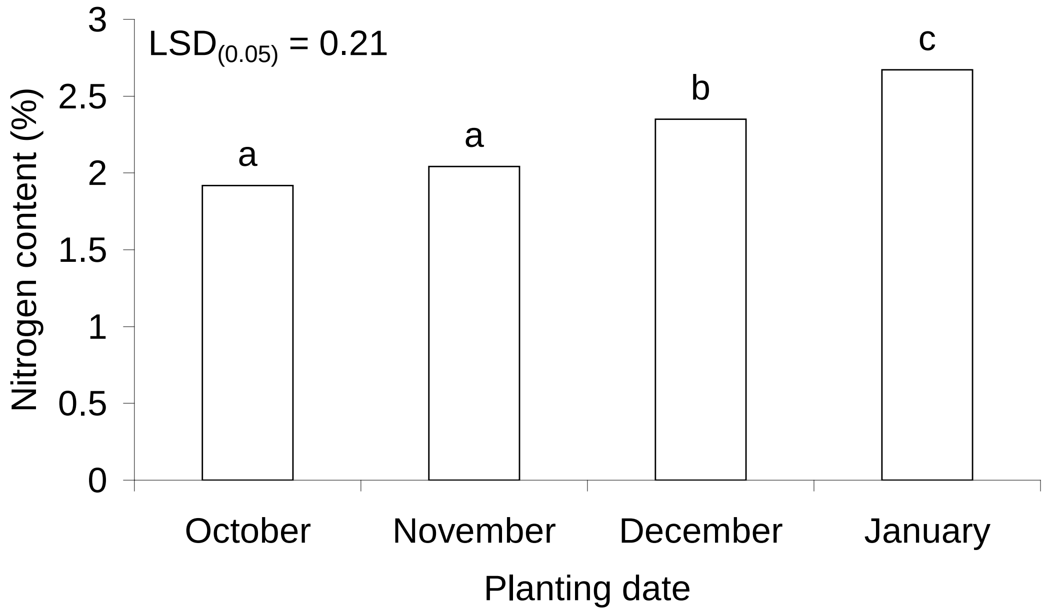

Figure 4.14 Effect of planting date averaged across Gromor Accelerator® application rate and cultivar on nitrogen content of taro cormels at Ukulinga.

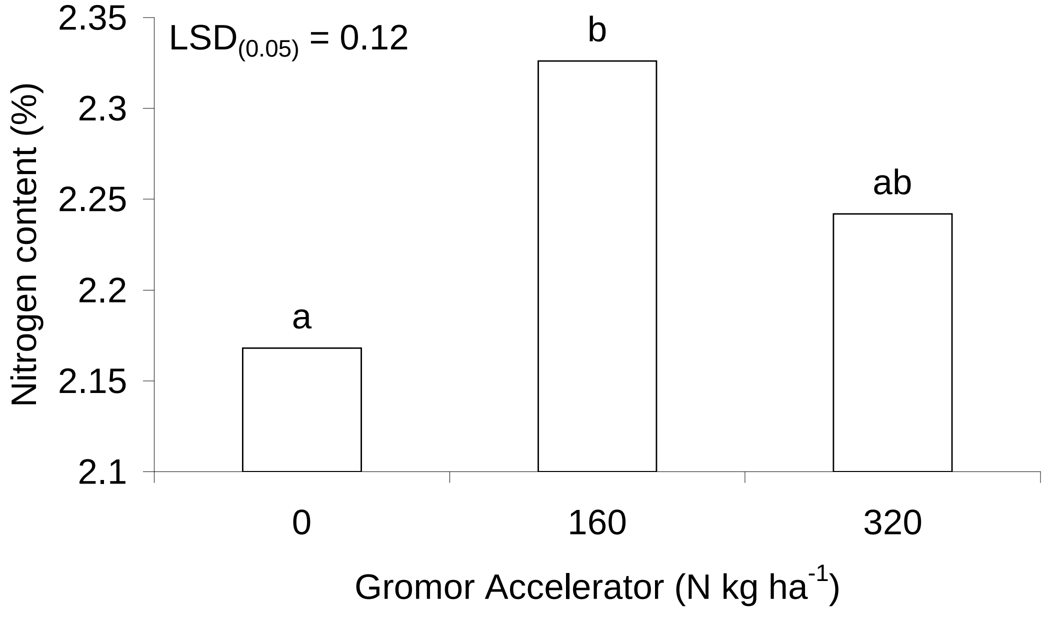

Figure 4.15 Effect of Gromor Accelerator® application rate averaged across planting date and cultivar on nitrogen content of taro cormels at Ukulinga.

At Umbumbulu, nitrogen content was significantly affected by Gromor Accelerator® application rate ($P < 0.001$) and the interaction of planting date and cultivar ($P = 0.002$). Addition of 160 N kg ha^{-1} of Gromor Accelerator® significantly decreased nitrogen content of cormels from 1.84 % to 1.50 % but further increase of the organic fertiliser was not significant (Fig. 4.16).

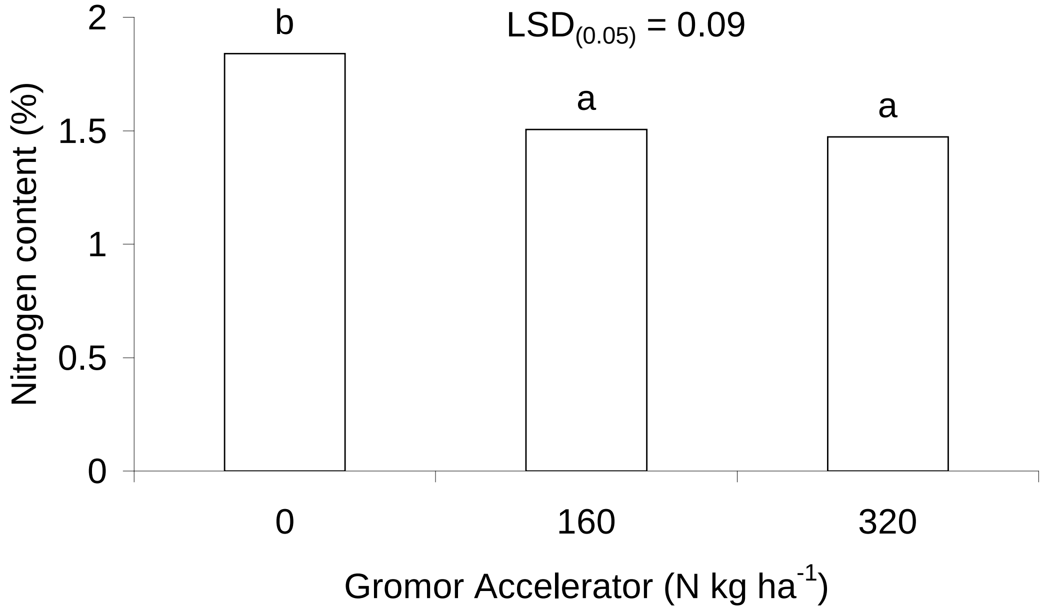

Figure 4.16 Effect of Gromor Accelerator® application rate averaged across planting date and cultivar on nitrogen content of taro cormels at Umbumbulu.

Delaying planting by one month from October significantly increased nitrogen content of *Dumbe-dumbe* (Fig.4.17). Nitrogen content was increased for *Mgingqeni* when planting was delayed until December, whereas for *Pitshi*, it was significantly increased with a delay in planting by two months, and it decreased again with an additional one month delay for *Pitshi* only. *Pitshi* showed significantly higher nitrogen content than *Dumbe-dumbe* but not *Mgingqeni* which was also not significantly higher than *Dumbe-dumbe* for October planting. For December planting, *Pitshi* had significantly highest nitrogen content followed by *Mgingqeni*. *Dumbe-dumbe* displayed significantly lowest nitrogen content for January planting.

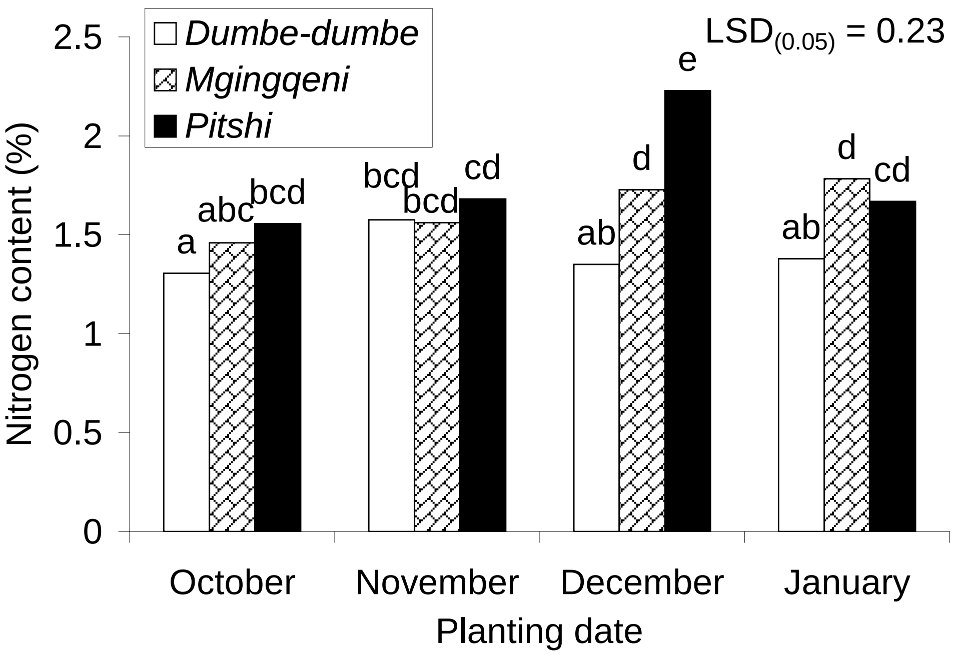

Figure 4.17 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on nitrogen content of taro cormels at Umbumbulu.

4.3.4.2 Phosphorus content

Phosphorus content of taro cormels was negatively affected by delayed planting (P = 0.001). The interaction of planting date and cultivar significantly (P = 0.027) affected phosphorus content of taro cormels at Ukulinga. Delaying planting from October to November significantly decreased phosphorus content of all taro cultivars (Fig. 4.18). A further delay in planting to December significantly decreased phosphorus content of *Mgingqeni* only, whereas a further delay to January was not significant for all cultivars. *Dumbe-dumbe* displayed significantly highest phosphorus content at all planting dates, with the exception of November, where it was not significantly higher than *Mgingqeni*. Phosphorus content of *Mgingqeni* and *Pitshi* was not different for all planting dates. There was no significant effect of fertilisation for phosphorus content.

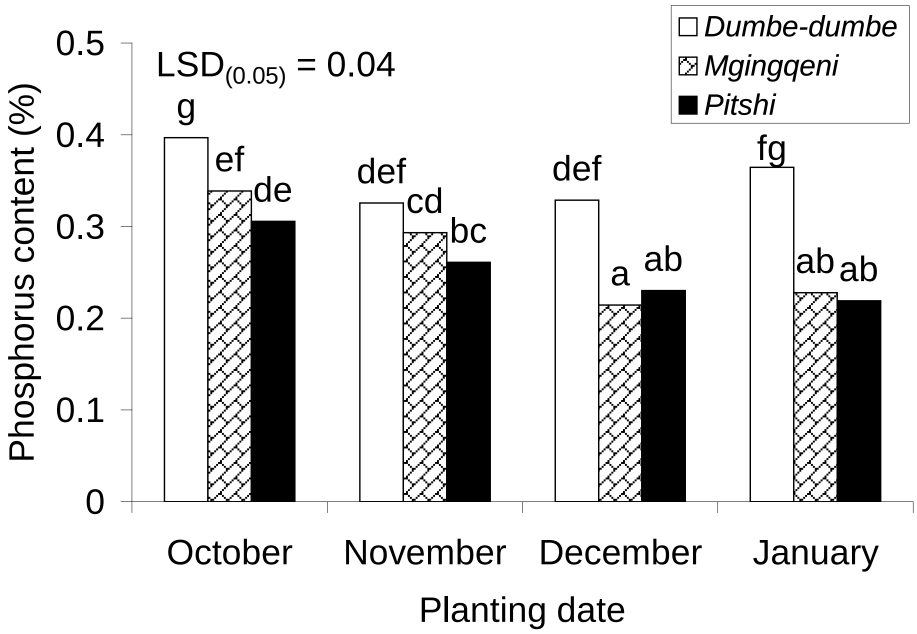

Figure 4.18 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on phosphorus content of taro cormels at Ukulinga.

At Umbumbulu, phosphorus content of taro cormels was positively affected by fertilisation ($P < 0.001$). There was no significant effect of planting date and cultivar on phosphorus content, although the effect of fertilisation depended on both planting date and cultivar (Planting date x cultivar x fertiliser interaction: $P = 0.014$). Applying 160 N kg ha^{-1} of fertiliser enhanced phosphorus content of taro cormels except for *Dumbe-dumbe* planted in December and *Mgingqeni* and *Pitshi* planted in January where phosphorus content was enhanced by application of 320 N kg ha^{-1} of the organic fertiliser (Table 4.1). *Pitshi* had significantly lower phosphorus content than *Dumbe-dumbe* when the cultivars were planted in December without fertiliser. Phosphorus content was significantly decreased for *Mgingqeni* when planting with 160 N kg ha^{-1} of the organic fertiliser was delayed from October to January. When 320 N kg ha^{-1} of the organic fertiliser was applied, delaying planting by one and two months increased phosphorus content for *Dumbe-dumbe* and *Pitshi* respectively and decreased it thereafter for *Dumbe-dumbe* only.

Table 4.1 Effect of planting date and Gromor Accelerator® application rate on phosphorus content of taro cormels of different cultivars at Umbumbulu. Means of the interaction effect within columns and rows (LSD $_{(0.05)}$ = 0.05) followed by the same letter are not significantly different.

Planting time	Cultivar	Gromor Accelerator® (N kg ha^{-1})		
		0	**160**	**320**
October	*Dumbe-dumbe*	0.10bcd	0.18fgh	0.16efgh
	Mgingqeni	0.09abc	0.19hi	0.17fgh
	Pitshi	0.09ab	0.17fgh	0.15defgh
November	*Dumbe-dumbe*	0.10bcd	0.19hi	0.27j
	Mgingqeni	0.08ab	0.14cdefgh	0.17fgh
	Pitshi	0.09abc	0.17fgh	0.16efgh
December	*Dumbe-dumbe*	0.11bcde	0.16efgh	0.17fgh
	Mgingqeni	0.09abc	0.15defgh	0.18hi
	Pitshi	0.04a	0.16efgh	0.23ij
January	*Dumbe-dumbe*	0.08ab	0.14cdefgh	0.19hi
	Mgingqeni	0.09ab	0.13bcdefg	0.18gh
	Pitshi	0.09abc	0.12bcdef	0.19hi

4.3.4.3 Potassium content

Potassium content was affected by delayed planting ($P < 0.001$) at Ukulinga. There was no significant effect of cultivar on potassium content, although the effect of planting date depended on cultivar (Planting date x cultivar interaction: $P = 0.011$). Delaying planting from October to November decreased potassium content of all cultivars (Fig. 4.19). Potassium content was decreased further for *Mgingqeni* and *Pitshi* when planting was further delayed by one month and increased thereafter for *Dumbe-dumbe* and *Pitshi*. *Mgingqeni* had higher potassium content than *Pitshi* for October planting whereas t had lowest potassium content than both *Dumbe-dumbe* and *Pitshi* for January planting. There was no difference in potassium content between the cultivars when they were planted in November and December. Fertilisation had no significant effect on potassium content.

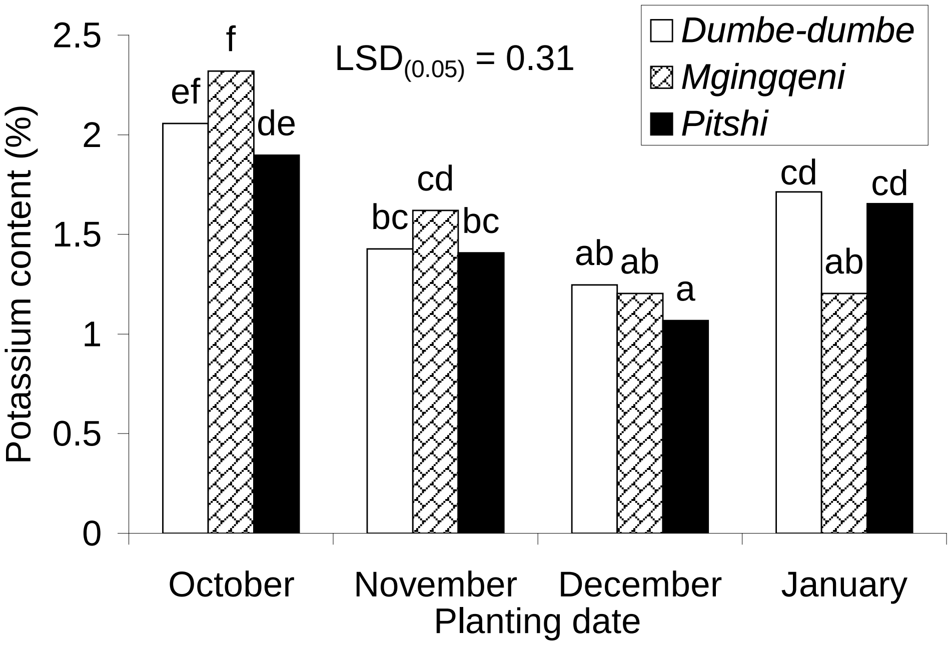

Figure 4.19 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on potassium content of taro cormels at Ukulinga.

At Umbumbulu, cultivar ($P < 0.001$) and Gromor Accelerator® application rate ($P < 0.001$) displayed significant effect on potassium content of taro cormels. There was no significant effect of planting date and the interactions of planting date, cultivar and fertiliser. *Dumbe-dumbe* (1.73%) and *Mgingqeni* (1.73%) had significantly higher potassium content than *Pitshi* (1.40%) but they were not significantly different from each other (Fig. 4.20). Application of Gromor Accelerator® enhanced potassium content. Adding 160 N kg ha^{-1} of the organic fertiliser significantly increased the potassium content of corms but further increasing of Gromor Accelerator® to 320 N kg ha^{-1} did not further increase potassium content of cormels (Fig. 4.21).

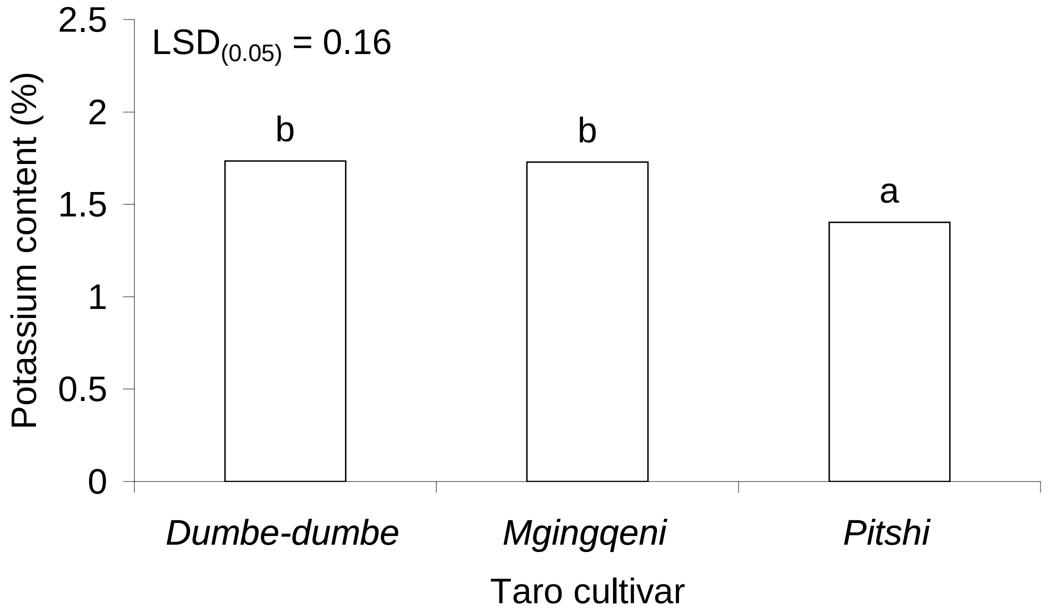

Figure 4.20 Effect of cultivar averaged across planting date and Gromor Accelerator® application rate on potassium content of taro cormels at Umbumbulu.

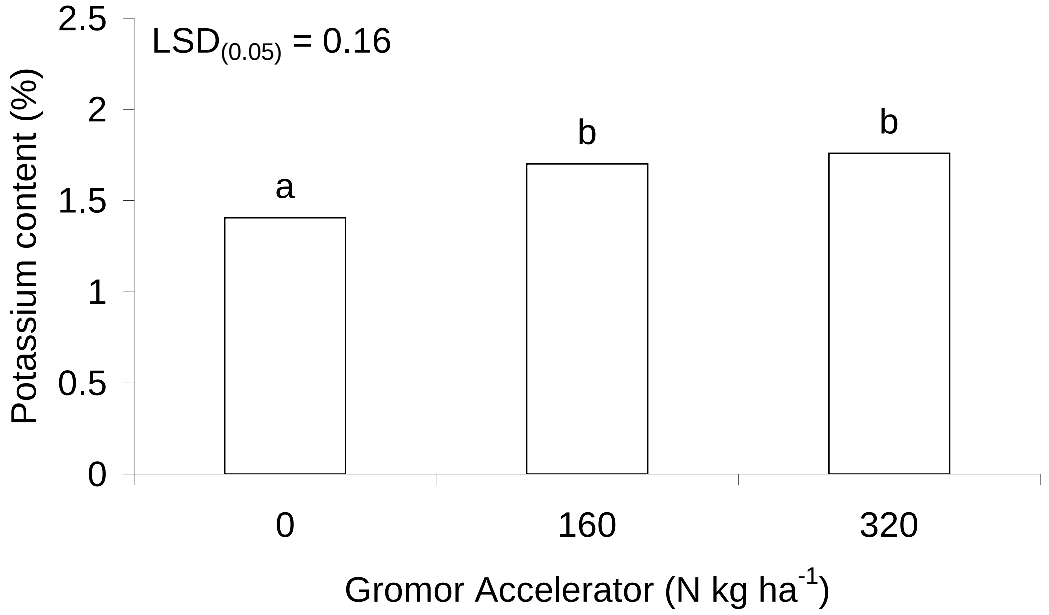

Figure 4.21 Effect of Gromor Accelerator® application rate averaged across planting date and cultivar on potassium content of taro cormels at Umbumbulu.

4.3.4.4 Calcium content

All treatments and their interactions had no significant effect on calcium content at Ukulinga, whereas at Umbumbulu only cultivar had significant effect on calcium content (P = 0.002). *Pitshi* (0.0926%) displayed significantly highest calcium content followed by *Mgingqeni* (0.0731%) and *Dumbe-dumbe* (0.0549%) respectively at Umbumbulu (Fig. 4.22).

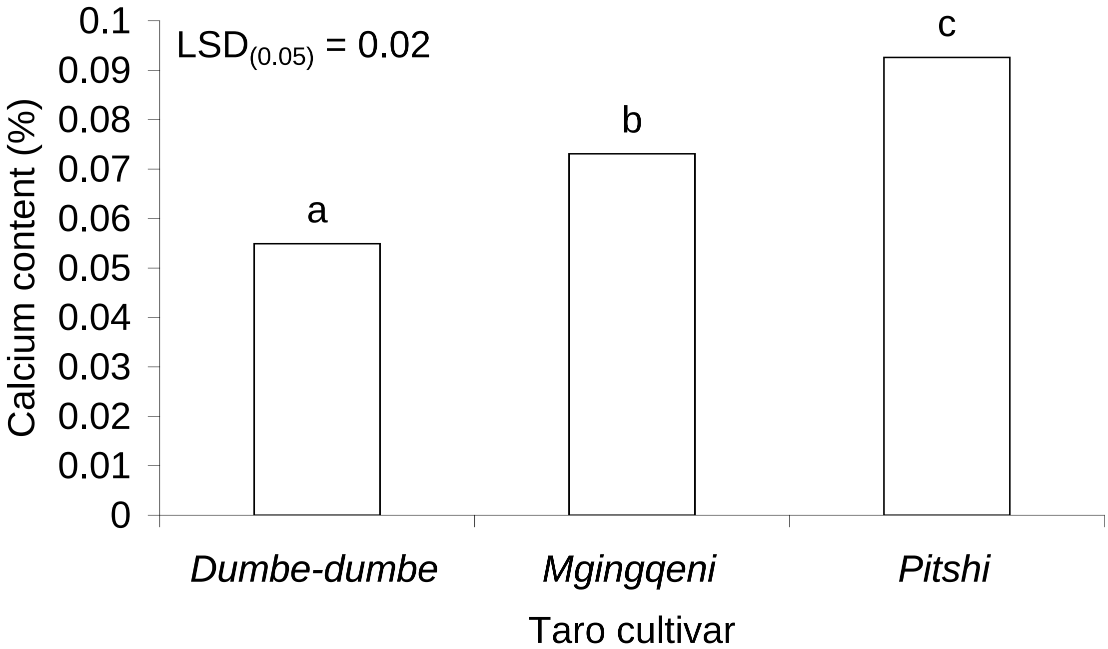

Figure 4.22 Effect of cultivar averaged across planting date and Gromor Accelerator® application rate on calcium content of taro cormels at Umbumbulu.

4.3.4.5 Magnesium content

All treatments and their interactions had no significant effect on calcium content at Umbumbulu, whereas at Ukulinga only cultivar had significant effect on calcium content ($P < 0.001$). Cormels of *Dumbe-dumbe* (0.2243%) showed a significantly higher magnesium content than *Mgingqeni* (0.1839%) and *Pitshi* (0.1710%) which were not significantly different from each other (Fig. 4.23).

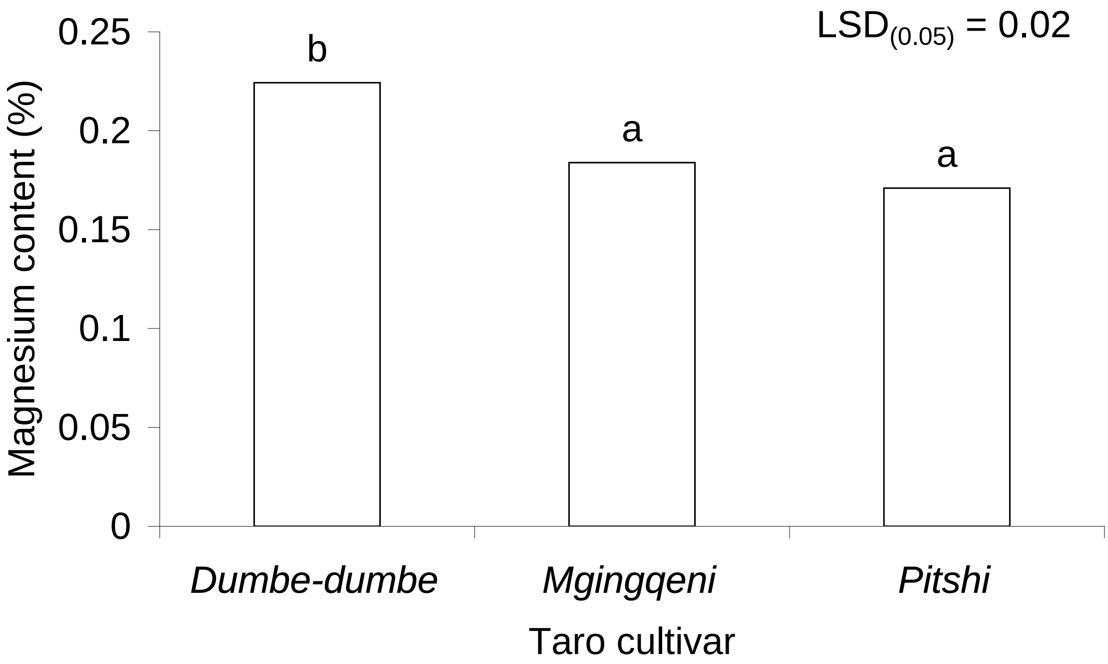

Figure 4.23 Effect of cultivar averaged across planting date and Gromor Accelerator® application rate on magnesium content of taro cormels at Ukulinga.

4.3.4.6 Zinc content

Planting date significantly affected zinc content of taro cormels at Ukulinga (P = 0.041) and Umbumbulu (P = 0.026). Zinc content was also affected by fertilifation at Umbumbulu (P = 0.034). Delaying planting from October to December increased zinc content from 57.6 to 86.2 mg kg^{-1} but further delay in planting had no effect at Ukulinga (Fig. 4.24). At Umbumbulu, zinc content was significantly increased when planting was delayed by one month from October but further delay in planting decreased zinc content to level obtained with October planting (Fig. 4.25). 320 N kg ha^{-1} of fertiliser yielded higher zinc content than 160 N kg ha^{-1} of fertiliser but both were not significantly higher than zinc content obtained when no fertiliser was applied at Umbumbulu (Fig. 4.26).

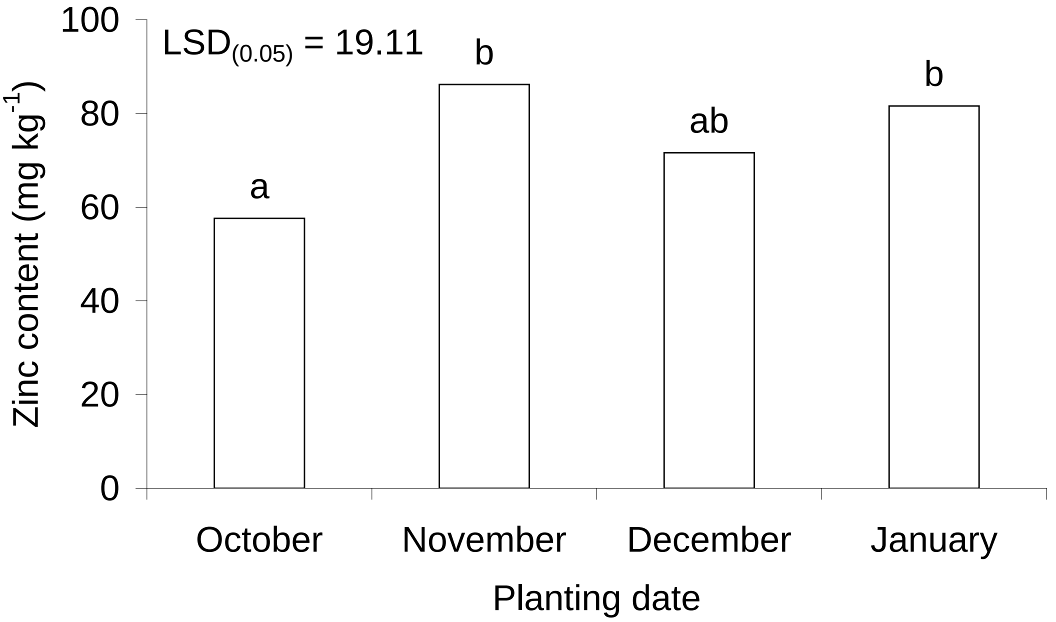

Figure 4.24 Effect of planting date averaged across cultivar and Gromor Accelerator® application rate on zinc content of taro cormels at Ukulinga.

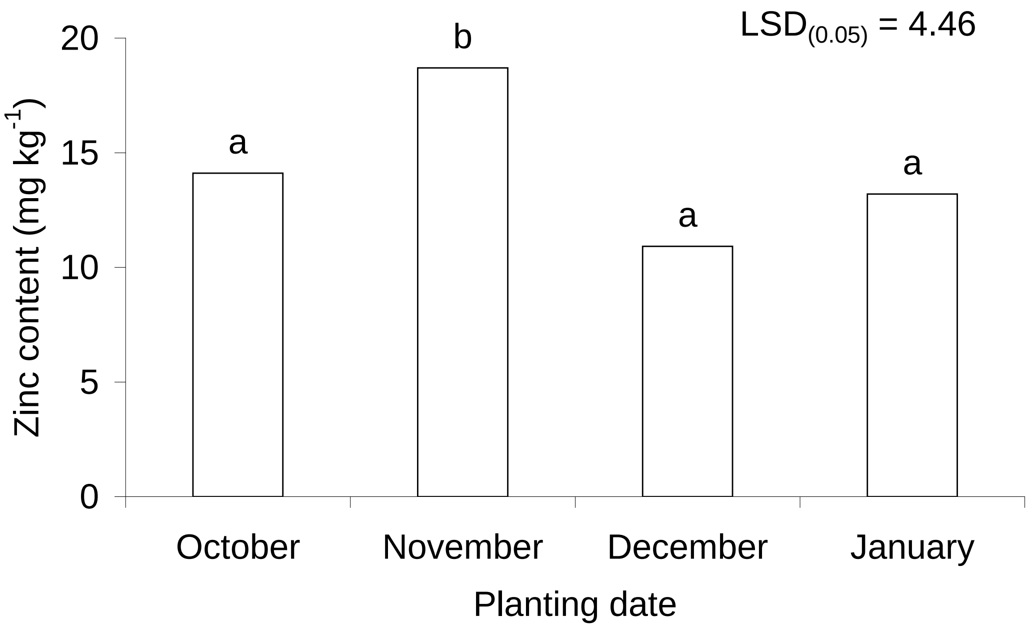

Figure 4.25 Effect of planting date averaged across cultivar and Gromor Accelerator® application rate on zinc content of taro cormels at Umbumbulu.

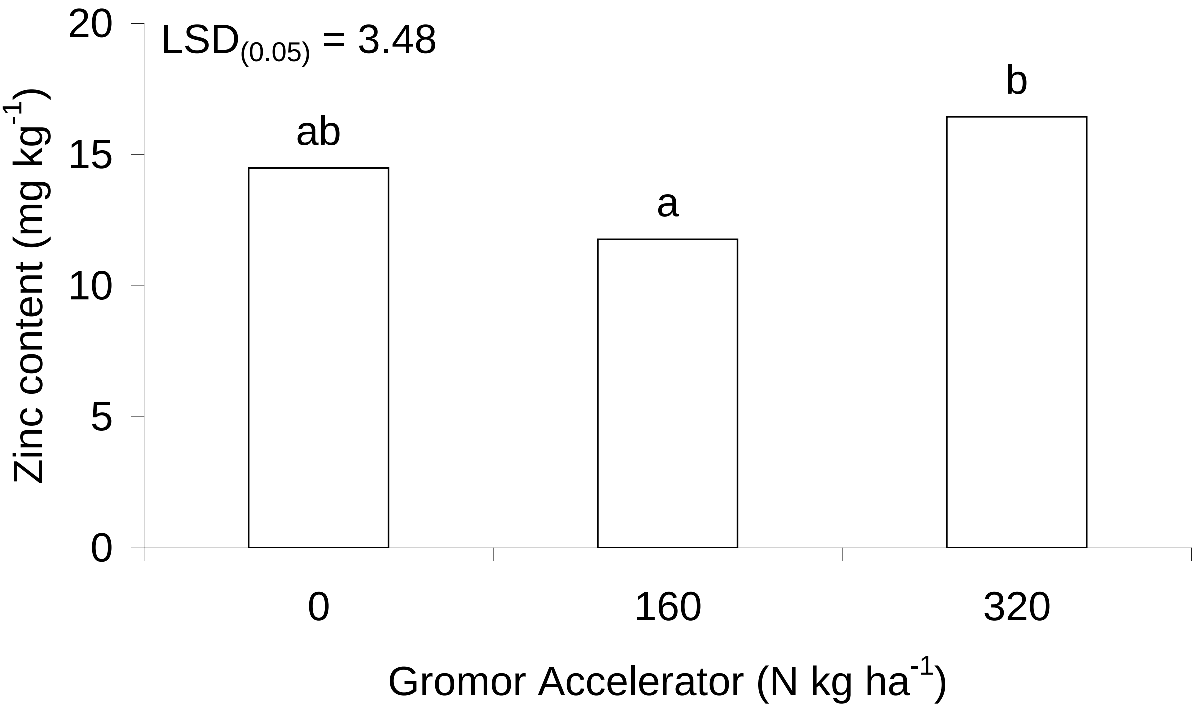

Figure 4.26 Effect of Gromor Accelerator® application rate averaged across planting date and cultivar on zinc content of taro cormels at Umbumbulu.

4.3.4.7 Copper content

There was significant (P = 0.012) interaction between planting date, cultivar and Gromor Accelerator® application rate in the copper content of the corms at Umbumbulu. When no fertiliser was applied, delaying planting of *Pitshi* from October to December decreased copper content of corms but further delay of planting to January increased it again (Table 4.2). When 320 N kg ha^{-1} of Gromor Accelerator® was applied, delaying planting of *Mgingqeni* from November to December significantly decreased copper content and increased it again when planting was further delayed until January. For *Pitshi*, when 320 N kg ha^{-1} of Gromor Accelerator® was applied, delaying planting until December significantly increased copper content of corms. *Dumbe-dumbe* had significantly higher copper content with 320 N kg ha^{-1} than with 160 N kg ha^{-1} of Gromor Accelerator® for November planting. For December planting *Mgingqeni* displayed significantly higher copper content with 0 kg ha^{-1} than with 320 N kg ha^{-1} of Gromor Accelerator®, whereas for *Pitshi* applying the organic fertiliser enhanced copper content of corms. For January planting *Dumbe-dumbe* showed significantly highest copper content with 320 N kg ha^{-1}.

Table 4.2 Effect of planting date and Gromor Accelerator® application rate on copper content of taro cormels of different cultivars at Umbumbulu. Means of the interaction effect within columns and rows (LSD (0.05) = 1.67) followed by the same letter are not significantly different.

Planting time	**Cultivar**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	*Dumbe-dumbe*	4.83ab	5.53aef	5.80ah
	Mgingqeni	7.87cdj	8.57gj	7.60hij
	Pitshi	7.97dg	7.30fg	6.83ghi
November	*Dumbe-dumbe*	5.27ab	4.93be	7.00ahi
	Mgingqeni	7.47cd	8.20cg	9.27cjk
	Pitshi	7.70fcd	7.63fg	7.83fij
December	*Dumbe-dumbe*	4.90abe	5.87ef	6.27ehi
	Mgingqeni	8.83d	7.57dfg	6.93ghi
	Pitshi	6.56bc	8.64gk	10.14k
January	*Dumbe-dumbe*	4.33ae	4.33e	6.43hi
	Mgingqeni	9.27dl	9.03gl	9.27jkl
	Pitshi	8.27cdm	8.93gm	8.99jkm

4.3.4.8 Manganese content

Manganese content of taro cormels was significantly (P = 0.028) affected by the interaction of planting date and cultivar at Ukulinga. Delaying planting from November to December significantly decreased manganese content of *Pitshi*, whereas for *Mgingqeni* manganese content was significantly decreased by delaying planting from October to December and from December to January (Fig. 4.27). The lowest manganese content was obtained with January planting.

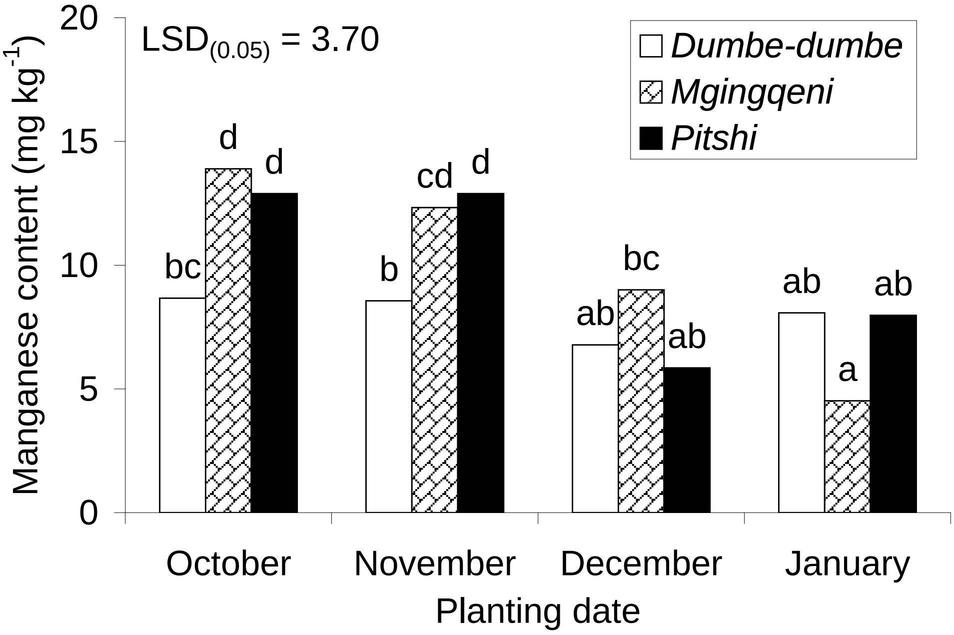

Figure 4.27 Effect of planting date and cultivar averaged across Gromor Accelerator® application rate on manganese content of taro cormels at Ukulinga.

Cultivar ($P < 0.001$) and the interaction of planting date and Gromor Accelerator® application rate ($P = 0.028$) significantly affected manganese content at Umbumbulu. *Dumbe-dumbe* showed significantly lower (11.80 mg kg^{-1}) manganese content than *Mgingqeni* (17.81 mg kg^{-1}) and *Pitshi* (17.78 mg kg^{-1}) which were not significantly different from each other (Fig. 4.28). Delaying planting by one month from October significantly increased manganese content of taro cormels when no fertiliser was added followed by a significant decline when planting was done in December (Fig. 4.29). When 320 N kg ha^{-1} of the organic fertiliser was applied, manganese content was increased by delaying planting until November and it thereafter decreased. There was no difference between planting dates when 160 N kg ha^{-1} of the fertiliser was applied. There was also no significant difference in manganese content between fertiliser application rates when planting was done in October, December and January. When planting was done in November, applying 160 N kg ha^{-1} of the fertilizer yielded lowest manganese content compared to the other application rates.

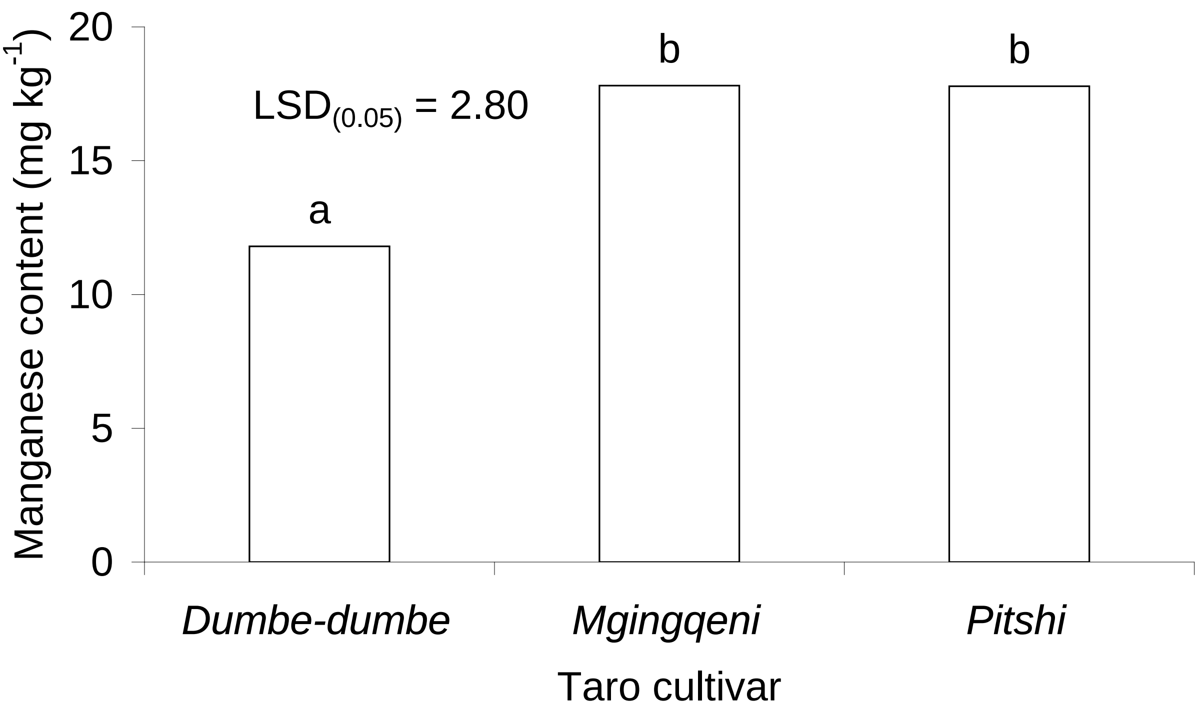

Figure 4.28 Effect of cultivar averaged across planting date and Gromor Accelerator® application rate on manganese content of taro cormels at Umbumbulu.

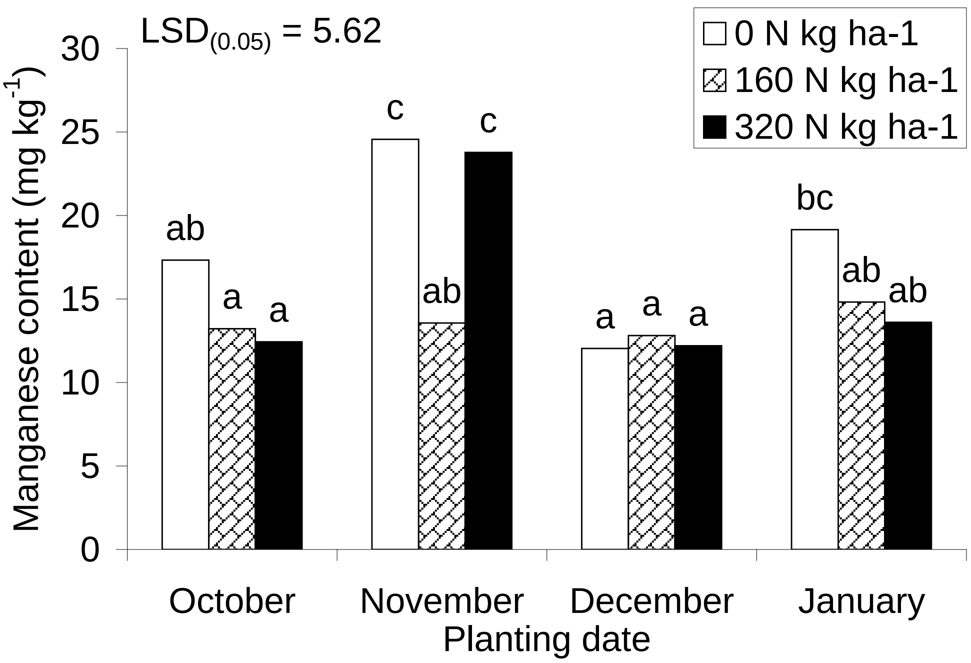

Figure 4.29 Effect of planting date and Gromor Accelerator® application rate on manganese content of taro cormels at Umbumbulu.

4.4 Discussion

Mohamed (1985) found dry matter to be highest at early planting for two of the potato cultivars while it was highest for the other cultivar when it was planted at a later date. It has been indicated that excessive nitrogen fertilisation reduces the proportion of dry matter allocated to the corms (Manrique, 1994). Allison *et al*. (1999) also found tuber dry matter content to decrease at increased nitrogen rates. Bèlanger *et al*. (2002), Casa *et al*. (2005) and Zelalem *et al*. (2009) obtained similar results in potatoes.

Feltran *et al*. (2004) found specific gravity to be influenced by cultivar. Similar results were also found by Long *et al*. (2004) that the major factor influencing specific gravity in potatoes was genotype. Contrasting results have been reported by different studies. Sparrow and Chapman (2003) reported that specific gravity often decreases as the rate of nitrogen increases, whereas El-Sirafy *et al*. (2008) found that application of farm yard manure increased specific gravity of tubers. However, it was shown that specific gravity was lower in nitrogen deficient tubers as well as in those from plants where nitrogen was in excess of that needed for maximum yield, at three out of four sites in South Australia (Dahlenberg *et al*., 1990).

The chemical composition of potatoes varies with variety, area where they are grown and cultural practices. Previous studies have shown that fertilisation influences the water and nutrient supply to the plant, which can in turn affect the nutritional quality of the harvested plant part (Kader and Rolle, 2004). Huang *et al.* (2007) on the other hand, indicated that upland-cultivated taro corms tended to have higher mineral content than paddy taro which might explain the higher mineral content of corms from Ukulinga due to lower rainfall. Kader and Rolle (2004) stated that temperature influences the uptake and metabolism of mineral nutrients by plants and this possibly also explain the high content of other minerals at Umbumbulu as a result of higher temperatures. Increase in the fertiliser application was also found to increase nitrogen concentration of tubers (Colla *et al*., 2005).

4.5 Conclusions and recommendations

The chemical composition of taro is influenced by both planting date and organic fertiliser amount, but the response differs with cultivar. Organic fertiliser level has no linear positive effect on its improvement of taro corm quality, but dry matter content and specific gravity are generally negatively affected by increasing fertiliser levels. *Dumbe-dumbe* performed better than the other two cultivars, especially when planted in October with no fertiliser. It is recommended that to improve taro specific gravity, dry matter content and mineral content, the crop should be planted in October at both study sites.

References

Allison, M.F., Allen, E.J. and Fowler, J.H. 1999. The nutrition of the potato crop. British Potato Council Research Review 1991/1. BPC Oxford, UK.

Bèlanger, G., Walsh, J.R., Richards, J.E., Milburn, P.H. and Ziadi, N. 2002. Nitrogen fertilisation and irrigation affects tuber characteristics of two potato cultivars. *American Journal of Potato Research* 79 (4): 269-279.

Casa, R., Pieruccetti, F., Sgueglia, G. and LoCascio, B. 2005. Potato tuber quality improvement through nitrogen management optimisation: Review of methodologies. *Acta Horticulturae* 684: 65–71.

Colla, G., Cardarelli, M., Rouphael, Y., Fiorillo, A. and Cirica, B. 2005. Response of potato to organic fertiliser rate: yield, tuber quality and nutrient uptake. *Acta Horticulturae* 684: 73-77.

Dahlenberg, A.P., Maier, N.A. and Williams, C.M.J. 1990. Effect of nitrogen on the size, specific gravity, crisp colour and reducing sugar concentration of potato tubers (*Solanum tuberosum* L.) cv Kennebec. *Australian Journal of Experimental Agriculture* 30: 123-130.

El-Sirafy, Z.M., Abbady, K.A., El-Ghamry, A.M and El-Dissoky, R.A. 2008. Potato yield quality, quantity and profitability as affected by soil and foliar potassium application. *Research Journal of Agriculture and Biological Sciences* 4 (6): 912-922.

Feltran, J.C., Lemos, L.B. and Vieites, R.L. 2004. Technological quality and utilization of potato tubers. *Scientia Agricola* 61 (6): 598-603.

Fontana, F., D'Amato, A., Cremaschi, D. and Salmi, A. 1990. Water requirements and nitrogen fertilization in potato growing in the Padana Plain. *Acta Horticulturae* 278: 563-569.

Günel, E. and Karadoĝan, T. 1998. Effect of irrigation applied at different growth stages and length of irrigation period on quality characters of potato tubers. *Potato Research* 41 (1): 9-19.

Haase, T., Schüler, C., Haase, N.U. and Heß, J. 2007. Suitability of organic potatoes for industrial processing: Effect of agronomical measures on selected quality parameters at harvest and after storage. *Potato Research* 50 (2): 115-141.

Huang, C.C., Che, W.C. and Wang, C.C.R. 2007. Comparison of Taiwan paddy and upland-cultivated taro (*Colocasia esculenta* L.) cultivars for nutritive values. *Food Chemistry* 102: 250-256.

Kader, A.A. and Rolle, R.S. 2004. The role of post-harvest management in assuring the quality and safety of horticultural produce. FAO Agricultural Services Bulletin 152.

Kumar, P., Pandey, S.K., Singh, B.P., Singh, B.P. and Kumar, D. 2007. Effect of nitrogen rate on growth, yield, economics and crisps quality of Indian potato processing cultivars. *Potato Research* 50 (2): 143-155.

Long, C.M., Snapp, S.S., Douches, D.S. and Chase, R.W. 2004. Tuber yield, storability and quality of Michigan cultivars in response to nitrogen management and seed spacing. *American Journal of Potato Research* 81: 347-357.

Manrique, L. A. 1994. Nitrogen requirements of taro. *Journal of plant nutrition* 17(8): 1429-1441.

McPharlin, I.R. and Lancaster, R.A. 2005. Applied nitrogen effects on yield and crisping quality of ‘Atlantic’, ‘Bliss ‘ and ‘Dawmor’ potatoes. *Acta Horticulturae* 684: 119-126.

Mittra, B. N. and George, J. 2000. Effect of time of planting on the growth and dry matter partitioning in sweet potato. *Journal of Root Crops* 26 (2): 57-60.

Mohamed, A.I. 1985. Dry matter, protein content and yield of potato as affected by cultivar and planting date in Sudan. *Acta Horticulturae* 158: 139- 141.

Mokolobate, M.S. and Haynes, R.J. 2002. Comparative liming effect of four organic residues applied to an acid soil. *Biology and Fertility of Soils* 35: 79–85.

Mondy, N.I. and Koch, R.L. 1978. Influence of nitrogen fertilisation on potato discoloration in relation to chemical composition. 1. Lipid, potassium, and dry matter content. *Journal of Agricultural Food Chemistry* 26 (3):666 – 669.

Nadler, A. and Heuer, B. 1995. Effect of saline irrigation and water deficit on tuber quality. *Potato Research*. 38:119–123.

Naramabuye, F.X., R.J. Haynes, R.J and Modi, A.T. 2008. Cattle manure and grass residues as liming materials in a semi-subsistence farming system. *Agriculture, Ecosystems and Environment* 124: 136-141.

Pocknee, S. and Summer, M.E. 1997. Cation and nitrogen contents of organic matter determine its liming potential. *Soil Science Society of American Journal* 61: 86-92.

Rashid, K.and Waithaka, K. 1985. The effect of phosphorus fertilization on growth and tuberization of sweet potato , *Ipomoea batatas* L. *Acta Horticulturae* 153: 345-353.

Shange, L.P. 2004.Taro (*Colocasia esculenta* (L.) Schott) production by small-scale farmers in KwaZulu-Natal: Farmer practices and performance of propagule types under wetland and dryland conditions. MSc. Thesis. University of KwaZulu-Natal, Pietermaritzburg.

Sparrow, L.A. and Chapman, K.S.R. 2003. Effects of nitrogen fertiliser on potato (*Solanum tuberosum* L., cv. Russet Burbank) in Tasmania. 1. Yield and quality. *Australian Journal of Experimental Agriculture* 43: 631- 641.

Tawfik, A.A., Mansour, S.A., Ramadan, H.M. and Fayad, A.N. 2002. Processing quality of selected potato varieties for chip and French fry industries in Egypt. *African Crop Science Journal* 10 (4): 325-333.

Wadas, W., Jabłońska-Ceqlarek, R. and Kosterna, E. 2004. Effect of plastic covering and nitrogen fertilisation on yield and quality of early potatoes. *Folia Horticulturae*16 (2): 41-48.

Westermann, D.T., Tindall, T.A., James, D.W. and Hurst, R.L. 1994. Nitrogen and potassium fertilization of potatoes: yield and specific gravity. *American Potato Journal* 71: 417-432.

Wong, M.T.F., Nortcliff, S. and Swift, R.S. 1998. Method for determining the acid ameliorating capacity of plant residue compost, urban waste compost, farmyard manure and peat applied to tropical soils. *Communication in Soil Science and Plant Analysis* 29: 2927-2937.

Zelalem, A., Tekalign, T. and Nigussie, D. 2009. Response of potato (*Solanum tuberosum* L.) to different rates of nitrogen and phosphorus fertilisation on vertisols at Debre Berhan, in the central highlands of Ethiopia. *African Journal of Plant Science* 3 (2): 16-24.

CHAPTER 5

CHANGES IN THE SURFACE MORPHOLOGY OF STARCH GRANULES, ALPHA AMYLASE ACTIVITY AND SPROUTING OF TARO, *COLOCASIA ESCULENTA* L. SCHOTT DURING STORAGE.

Abstract

The surface morphology of starch grains changes during storage. Scanning electron microscopy was used to examine the changes that occur to the surface morphology of starch granules of cormels of *Dumbe-dumbe*, *Mgingqeni* and *Pitshi* stored at ambient temperature. Alpha-amylase activity and sprouting were determined to establish relationships between physical changes in the starch granules and alpha-amylase activity as well as sprouting. The surface of the *Dumbe-dumbe* and *Pitshi* starch granules were smooth at harvest but during storage the surface of the granules became progressively more pitted. The surface of starch granules of *Mgingqeni* was not smooth at harvest and during storage degradation was more pronounced for *Mgingqeni* compared to the other two taro cultivars. The degradation of starch granules, alpha amylase activity and sprouting increased with storage time. The results also show that alpha-amylase activity and sprouting increase with storage temperature. Cormels stored in polyethylene bags and *Mgingqeni* showed highest alpha-amylase activity and sprouting and hence starch degradation.

Key Words: alpha-amylase, *Colocasia esculenta,* sprouting, starch granules, storage.

5.1 Introduction

The surface morphology of starch granules changes during storage (Cottrell *et al*., 1993). This is observed by various patterns of erosion and it is due to starch degradation. Extensive surface erosion was shown to indicate a high degree of hydrolysis, whereas less surface erosion indicated less degradation (Zhang and Oates, 1999). The normal visible response to degradation in vivo appeared to be varying degrees of roughness of the granule surface (Silva and Luh, 1978, Wetzstein and Wetzstein, 1981) or holes bored through the granule (Dronzek *et al*, 1972). The same results were found by Cottrell *et al*. (1993) who reported pitting and indentations in potatoes, Hoover and Sosulki (1991) who reported surface pitting and erosion in legumes and Valetudie *et al*. (1993) who reported that roughening of the surface with pitting and fissures along the edges of the planes of contact of the starch granules in tannia, sweet potato and cassava and external pitting on only one face of the granule to produce an internal cavity in yams. In chickpea, on the other hand, no difference in character of starch granules could be seen during starch degradation (Fernandez and Berry, 1989).

The erosion is believed to be brought about by alpha-amylase because cereal starch granules showed holes in the surface and corroded channels into the interior when subjected to in vitro digestion with alpha amylase (Dronzek *et al*., 1972, Macgregor and Balance, 1980; Sreenath 1992). The activity of the enzyme was reported to increase during storage (Cochrane *et al*., 1991; Cottrell *et al*., 1993). Fincher (1989) previously stated that degradation is initiated by synthesis of new alpha amylase in wheat and barley. The surface of potato granules showed resistance to enzyme attack with a few shallow pits and ridges initially but it degrades rapidly once the enzyme reaches the interior of the granule (Gallant *et al*, 1972, 1973).

According to Biemelt *et al*. (2000) starch degradation is not a prerequisite for the initiation of sprouting. They observed no change in starch degrading enzymes prior visible sprout growth and stimulated alpha-amylase activity by approximately 30% was observed after the onset of sprouting in potatoes. Lorenz *et al*. (1981), on the other hand, found that the production of modified starches was possible by sprouting corn, barley and triticale grains. They also reported that the starches susceptibility to the enzyme increased with sprouting. Sun and Henson (1990) indicated that alpha-amylase is synthesized during germination in barley and this might be the case in taro, that alpha-amylase is synthesized during sprouting. Fernandez and Berry (1989) and Frias *et al*. (1998) reported that germination sharply increased the enzymatic digestibility of starch granules from the chickpea and lentil, but no change in the appearance of scanning electron micrographs could be attributed to germination (Fernandez and Berry, 1989).

The present study was undertaken to study the differences in the changes in the surface morphology of three taro starches and the relationship between these changes and alpha-amylase activity and sprouting of corms, and the effect of storage temperature and packaging on sprouting and alpha-amylase of taro corms.

5.2 Materials and methods

5.2.1 Plant material used

Cormel materials used in this study were of the three taro cultivars *Dumbe-dumbe*, *Mgingqeni* and *Pitshi* which were planted in October without fertiliser at Ukulinga. The post harvest storage experiment was arranged in a split-split plot design with temperatures (12^{o}C and ambient temperature) as main plots, packaging (polyethylene bag, box and mesh bag) as sub-plots and cultivars as sub-sub-plots. Each storage temperature was replicated three times and the cultivars were randomised within packaging within storage temperatures. Each packaging contained 7, 11 and 13 cormels of *Dumbe-dumbe*, *Mgingqeni* and *Pitshi* respectively. One cormel was sampled, peeled, cut into slices, immediately frozen in liquid nitrogen and freeze-dried monthly for four months starting one month after storage for chemical analysis.

5.2.2 Scanning electron microscopy

Scanning electron microscopy was performed at harvest and monthly for four months starting one month after storage for cormels of the three taro cultivars which were stored at ambient temperature. The freeze-dried cormel materials were mounted on the brass stubs using double-sided cellotape, and then coated with gold palladium, using a Polaron E5100 sputter coater. Samples were viewed at 10kW using a Hitachi S-570 scanning electron microscope (SEM). Starch grains were spot viewed and the area for starch grain viewing was selected randomly. The micrographs were used to compare the morphology (form and structure) of the starch granules.

5.2.3 Alpha-amylase activity

Alpha-amylase activity was determined at harvest and monthly for four months starting one month after storage according to Modi and Cairns (1994) with modifications. Only alpha amylase activity of corms stored at ambient temperature was used to study the relationship between the changes in the surface morphology of three taro starch granules, alpha-amylase activity and sprouting of cormels. Freeze-dried corm material was ground to pass through a 0.5mm motor mill sieve. Approximately 0.1g was weighed into a 100mL Erlenmeyer flask and incubated in 10mL of the extraction buffer [5g NaCl: 0.2g Ca $(C_2H_3O_2)_2$, mass/mass]. Alpha-amylase was extracted by shaking the contents for 20 min in a water bath at 30^oC. Contents were then filtered through a Whatman No.1 filter paper into a test tube. One millilitre of the supernatant was diluted 10 times in the extraction buffer and one Phadebas tablet (Pharmacia Diagnostics AB, Uppsala, Sweden) was introduced into the test tube. Phadebas tablet is composed of a substrate made made by cross-linking partially hydrolysed starch, using 1.4 butandiol-diglycidether as a cross-linking agent. The soluble starch is transformed into a three-dimensional insoluble lattice network which expands in water. The number of cross-linking bridges regulate the degree of expansion and susceptibility of the substrate to alpha-amylase attack. The substrate is labeled with Cibachron Blue by covalent bonds. Each tablet contains 45 mg of blue starch polymer, and 25 mg buffer salt to give 0.2 mol dm^{-3} phosphate buffer, pH 7 and 0.05 mol dm^{-3} NaCl when appropriately dissolved. The tablets also contain bovine serum albumin. The contents of the test tube were mixed for 30 sec on a vortex mixer and then incubated in the shaking water bath at 50^oC for 10 min. The reaction was then terminated by adding 1mL of 0.5M NaOH and the contents were filtered through Whatman No.1 filter paper. Absorbance of the supernatant was determined at 620 nm in a spectrophotometer.

5.2.4 Sprouting

Number of sprouted cormsel was counted monthly for four months starting one month after storage and percentages were calculated. Cormels were considered sprouted when they had developed either shoot or roots =/>3.0 mm.

5.2.5 Statistical analysis

Analysis of variance was performed using GenStat Release 11.1 (2008). Least significant difference (LSD) was used to separate means. A probability level of 0.05 was considered to be statistically significant.

5.3 Results

5.3.1 Scanning electron microscopy

The appearance of starch granules changed considerably during storage. The starch granules of *Dumbe-dumbe and Pitshi* appeared smooth at harvest (Figs 5.1 and 5.3). For *Mgingqeni*, some granules were smooth while some were rough (Fig. 5.2). After one month in storage all cultivars showed signs of degradation, although the severity varied between them. *Dumbe-dumbe* (Fig.5.4 1a) and *Mgingqeni* (Fig.5.4 1b) were showing some indentations whereas *Pitshi* (Fig. 5.4 1c) was showing some depressions. The indentations appeared shallow and did not penetrate deep into the body of the granules.

By the second sampling after two months, granules from all cultivars showed evidence of erosion. Granules from *Dumbe-dumbe* (Fig.5.4 2a) and *Pitshi* (Fig.5.4 2c) showed deep indentations but they were not as deep as those showed by *Mgingqeni* (Fig.5.4 2b). After three months in storage, *Mgingqeni* (Fig.5.4 3b), like after two months showed more degradation compared to *Dumbe-dumbe* (Fig.5.4 3a) and *Pitshi* (Fig.5.4 3c) which were still showing some indentations though they seemed to be deeper than after two months. By the final sampling after four months, further more degradation was evident and it was more pronounced for *Mgingqeni* (Fig.5.4 4b) followed by *Pitshi* (Fig.5.4 4c) and *Dumbe-dumbe* (Fig.5.4 4a) respectively. The smaller pieces were starting to break and fall from the starch granules.

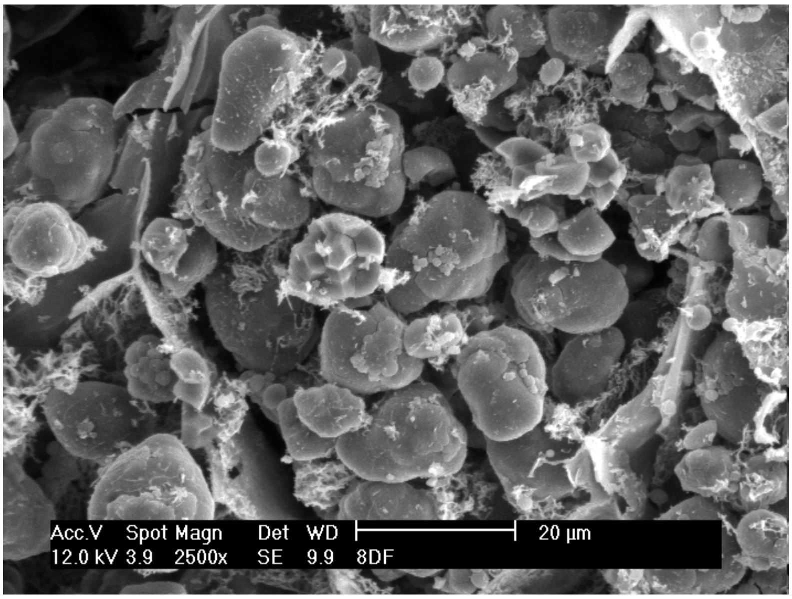

Figure 5.1 Scanning electron micrographs showing starch granules of *Dumbe-dumbe* at harvest.

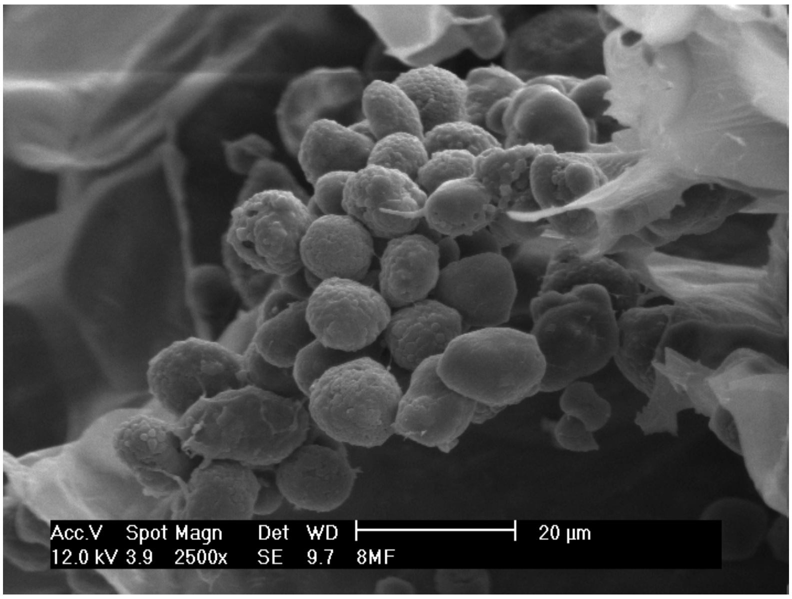

Figure 5.2 Scanning electron micrographs showing starch granules of *Mgingqeni* at harvest.

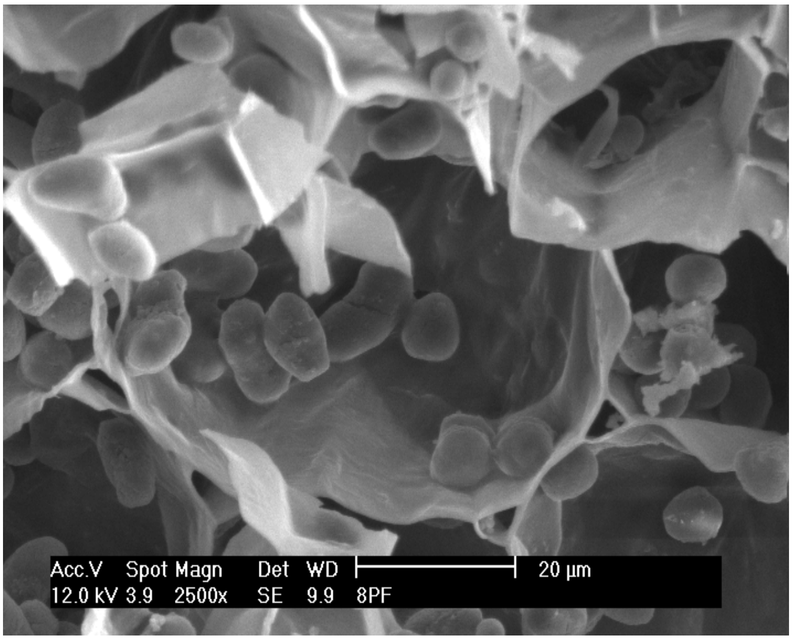

Figure 5.3 Scanning electron micrographs showing starch granules of *Pitshi* at harvest.

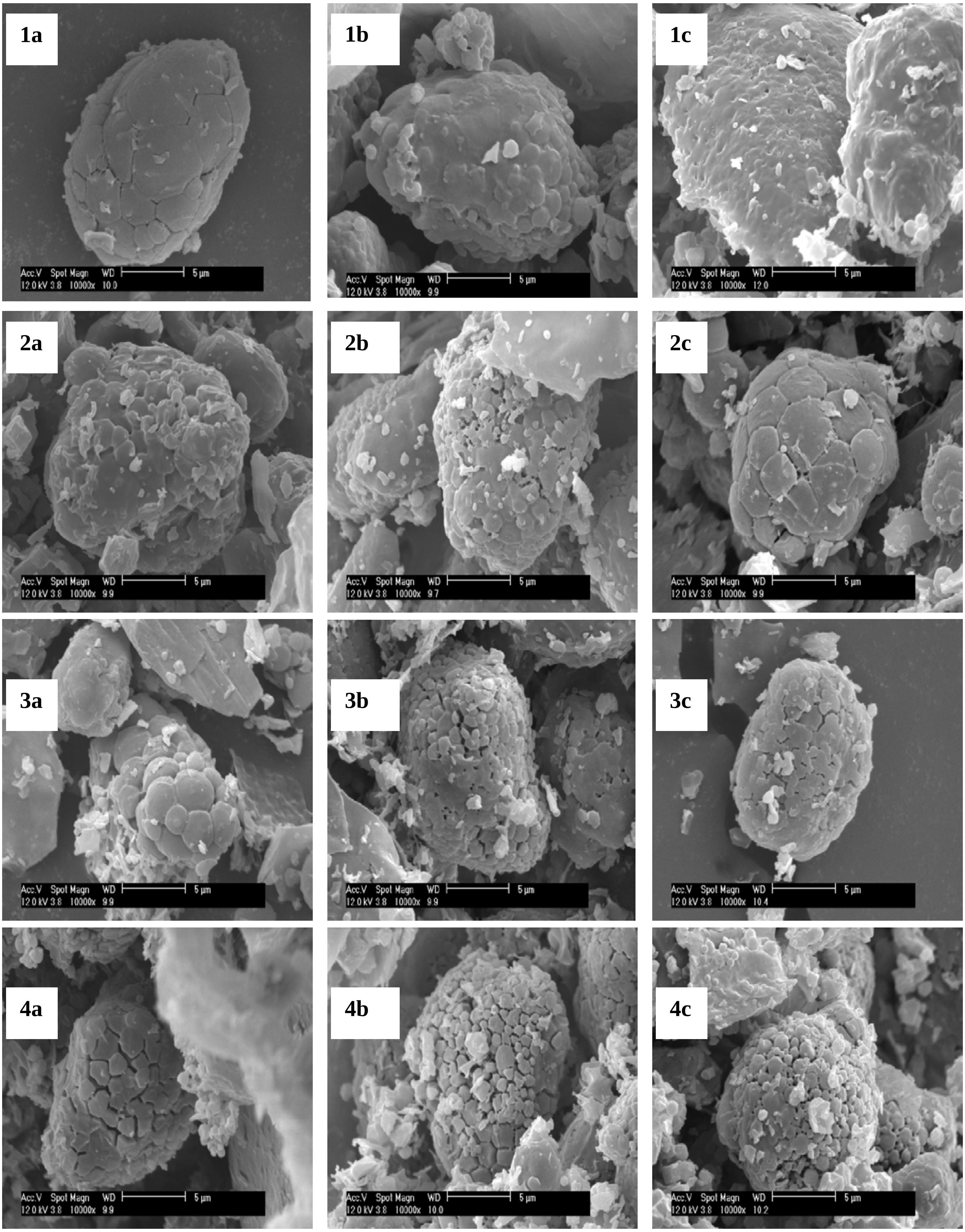

Figure 5.4 Scanning electron micrographs showing starch granules of taro cultivars stored in polyethylene bags for four months at ambient temperature. (a, b and c represents *Dumbe-dumbe*, *Mgingqeni* and *Pitshi* respectively and 1, 2, 3 and 4 represents the sampling time in months (The whitish substances are fragments of cell walls).

5.3.2 Alpha-amylase activity

Alpha-amylase activity of cormels planted without fertiliser in October at Ukulinga generally increased with time in storage (Fig. 5.5). After one month in storage alpha-amylase increased slightly for all cultivars with *Dumbe-dumbe* having the highest alpha-amylase activity followed by *Pitshi* and *Mgingqeni* respectively. A decline was observed after two months for both *Dumbe-dumbe* and *Mgingqeni* whereas *Pitshi* increased slightly until three months after storage. *Mgingqeni* displayed the lowest alpha-amylase activity from one to four months after storage. Alpha-amylase activity increased rapidly from three to four months after storage.

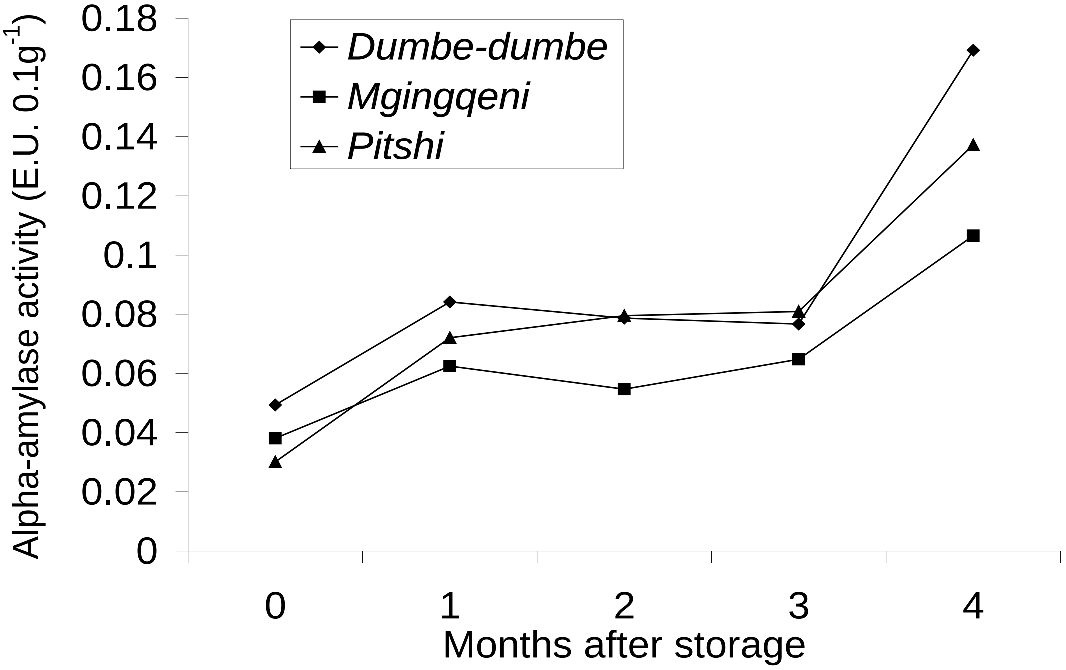

Figure 5.5 Alpha-amylase activity in taro cormels at harvest up to four months after storage in polyethylene bags at ambient temperature.

The interaction between storage temperature, packaging method and months after storage significantly affected the alpha-amylase activity of taro cultivars ($P < 0.001$). Alpha-amylase activity generally increased with time in storage. The cultivars were not different from each other in alpha-amylase activity at harvest (Table 5.1). Ambient temperature generally showed higher alpha-amylase activity than 12^{o}C. Polyethylene packaging and *Pitshi* also displayed higher alpha-amylase activity compared to mesh bag and box and *Mgingqeni* and *Dumbe-dumbe* respectively.

Table 5.1 Alpha-amylase activity of taro cultivars stored at different temperatures in different packaging materials. Means of the interaction effect within columns and rows ($LSD_{(0.05)} = 0.04$) followed by the same letter are not significantly different.

			Months after storage				
Temperature	**Packaging**	**Landrace**	**0**	**1**	**2**	**3**	**4**
12^{o}C	Polyethylene	*Dumbe-dumbe*	0.05 a	0.08 b	0.10 c	0.08 a	0.09 abc
		Mgingqeni	0.04 a	0.08 b	0.09 bc	0.08 a	0.11 cd
		Pitshi	0.03 a	0.08 b	0.09 bc	0.10 a	0.08abc
	Box	*Dumbe-dumbe*	0.05 a	0.08 b	0.07 bc	0.07a	0.07 abc
		Mgingqeni	0.04 a	0.07 ab	0.06 abc	0.02 a	0.06 ab
		Pitshi	0.03 a	0.05 ab	0.05 ab	0.07a	0.09 abc
	Mesh bag	*Dumbe-dumbe*	0.05 a	0.06 ab	0.08 bc	0.07a	0.05 a
		Mgingqeni	0.04 a	0.08 b	0.07 abc	0.08 a	0.10 bd
		Pitshi	0.03 a	0.06 ab	0.06 abc	0.07 a	0.05 a
Ambient Temperature	Polyethylene	*Dumbe-dumbe*	0.05 a	0.08b	0.08 bc	0.08 a	0.17 e
		Mgingqeni	0.04 a	0.06 ab	0.06 abc	0.07 a	0.11 cd
		Pitshi	0.03 a	0.07 ab	0.08 bc	0.08 a	0.14 de
	Box	*Dumbe-dumbe*	0.05 a	0.07 ab	0.07 bc	0.07 a	0.08abc
		Mgingqeni	0.04 a	0.08 b	0.08 bc	0.08 a	0.08 abc
		Pitshi	0.03 a	0.07 ab	0.06 abc	0.08 a	0.14 de
	Mesh bag	*Dumbe-dumbe*	0.05 a	0.06 ab	0.07 bc	0.07 a	0.07 abc
		Mgingqeni	0.04 a	0.08 b	0.03 a	0.06 a	0.05 a
		Pitshi	0.03 a	0.03 a	0.08 bc	0.08 a	0.11 cd

5.3.3 Sprouting

The three cultivars did not sprout in polyethylene bags after one month in storage at ambient temperature (Fig. 5.6). After one month in storage the cormels started sprouting slowly with *Mgingqeni* showing a significantly higher sprouting percentage followed by *Dumbe-dumbe* which was not different from *Pitshi*. The cultivars started sprouting rapidly after two months in storage with *Pitshi* sprouting more rapidly than *Dumbe-dumbe.* At four months in storage, all cormels of *Mgingqeni* had sprouted followed by *Pitshi* and *Dumbe-dumbe* respectively.

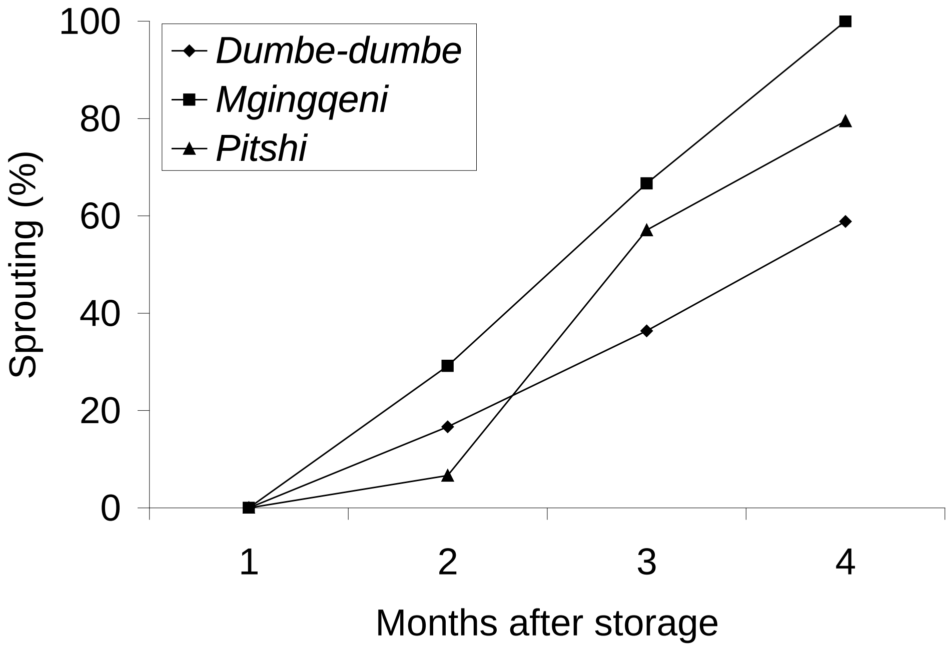

Figure 5.6 Sprouting in taro cormels at harvest up to four months after storage in polyethylene bags at ambient temperature.

The interaction between storage temperature, packaging method and months after storage significantly affected the sprouting of taro cultivars ($P < 0.001$). Sprouting increased with time in storage (Table 5.2). At 12^{o}C, the cormels did not sprout until after three months in storage in all packaging methods. After four months the cormels of all cultivars had sprouted with polyethylene bags showing significantly highest sprouting followed by those in boxes and mesh bags which were also significantly different from each other. *Mgingqeni* and *Pitshi* in mesh bags did not show significantly different sprouting after four months in storage at 12^{o}C. At ambient temperature, sprouting started after one month for polyethylene packaged cormels only with *Mgingqeni* showing significantly highest sprouting than the other cultivars. After two months in storage sprouting had started for all packaging methods. Cormels in mesh bags showed significantly lowest sprouting after three months in storage with *Dumbe-dumbe* showing more sprouting than the other cultivars in mesh bags and boxes. *Mgingqeni* showed the highest sprouting in polyethylene bags. After four months, *Dumbe-dumbe* displayed the highest sprouting than other cultivars except in polyethylene bags where all *Mgingqeni* cormels had sprouted. Ambient temperature generally showed rapid sprouting with highest number of sprouted cormels compared to the colder temperature.

Table 5.2 Sprouting of taro cormels stored at different temperatures in different packaging materials. Means of the interaction effect within columns (LSD $_{(0.05)}$ = 5.57) followed by the same letter are not significantly different.

			Months after storage			
Temperature	**Packaging**	**Cultivar**	**1**	**2**	**3**	**4**
12^{o}C	Polyethylene	*Dumbe-dumbe*	0	0	0	36.36de
		Mgingqeni	0	0	0	60.61h
		Pitshi	0	0	0	50.51f
	Box	*Dumbe-dumbe*	0	0	0	54.55fg
		Mgingqeni	0	0	0	33.33cd
		Pitshi	0	0	0	21.21b
	Mesh bag	*Dumbe-dumbe*	0	0	0	16.16b
		Mgingqeni	0	0	0	10.10a
		Pitshi	0	0	0	7.07a
Ambient Temperature	Polyethylene	*Dumbe-dumbe*	0	5.56a	36.36d	58.84gh
		Mgingqeni	0	19.44b	66.67f	100.00k
		Pitshi	0	2.22a	57.07e	79.49i
	Box	*Dumbe-dumbe*	0	0	79.49g	87.18j
		Mgingqeni	0	0	40.61d	55.57fgh
		Pitshi	0	0	30.77c	40.61e
	Mesh bag	*Dumbe-dumbe*	0	0	25.15b	30.77c
		Mgingqeni	0	0	10.00a	20.51b
		Pitshi	0	0	11.62a	15.81b

5.4 Discussion

Scanning electron micrographs showing the changes in surface morphology of starch granules of taro cultivars during storage demonstrate that starch break down occurs early in storage but the extent varies with cultivars. The starch granules breakdown starts with roughening of the surface followed by development of small pits and indentations which becomes deeper with time and cause the granules to open up and breakdown onto smaller granules. The same results were previously reported in legumes, potatoes, tannia, sweet potato and cassava (Hoover and Sosulki, 1991; Cottrell *et al*., 1993; Valetudie *et al*., 1993). Extensive surface erosion was displayed by *Mgingqeni* and according to Zhang and Oates (1999) that might suggests a higher degree of hydrolysis compared to the other cultivars.

The alpha-amylase increase during the first month of cormel storage and decrease thereafter was previously reported by Modi (2004) though it increased again after two months in this study. This increase was also reported by Panneerselvam *et al*. (2009) in *Dioscorea esculenta* that alpha-amylase activity was lower up to 35 days after harvest and afterwards it increased to a rapid phase. The activity of the enzyme was also reported to increase in potatoes during storage (Cochrane *et al*., 1991; Cottrell *et al*., 1993). Modi (2004) reported that corm sprouting is associated with alpha-amylase activity which enhanced starch mobilisation. This is possible considering the increase in alpha-amylase activity which correlates with the starch granules break down (Fig. 5.4) and sprouting (Fig. 5.6). This suggests that the enzyme is responsible for the break down of starch granules and sprouting, moreover because of a report that at the time of sprouting alpha-amylase activity increased to a higher level when compared to early storage period (Panneerselvam *et al*., 2009). The increase in alpha-amylase was positively correlated with germination in cherry tomato (Modi and White, 2004).

The starch granules breakdown was only monitored at ambient temperature but it is believed that the same process takes place at a lower temperature though it might be slower since alpha-amylase activity and sprouting were lower at lower temperature. This was in contrast with what was earlier reported by Nielsen *et al*. (1997) that alpha-amylase was not affected by low storage temperature. Findings of the previous study (Modi, 2004) suggested that air and temperature conditions could have influenced corm sprouting.

5.5 Conclusions and recommendations

The present work demonstrates the changes in surface morphology of starch granules during storage. The degradation of starch granules, alpha-amylase activity and sprouting increased with storage time. This might suggest that the starch granules degradation and sprouting are as a result of alpha-amylase activity. The results also show that alpha amylase activity and sprouting increase with storage temperature and this suggests that starch degradation increases with increase in storage temperature. Corms of *Mgingqeni* stored in polyethylene bags showed highest alpha-amylase activity as well as sprouting and hence starch degradation.

References

Biemelt, S., Hajirezaei, M., Hentschel, E. and Sonnewald, U. 2000. Comparative analysis of abscisic acid content and starch degradation during storage of tubers harvested from different potato varieties. *Potato Research* 43 (4): 297-393.

Cochrane, M.P., Duffers, C.M., Allison, M.J. and Mackay, G.R. 1991. Amylolytic activity in stored potato tubers. 2. The effect of low temperature storage on the activities of α- and β-amylase and α-glucosidase in potato tubers. *Potato Research* 34: 333–341.

Cottrell, J.E., Duffus, C.M., Mackay, G.R. and Allison, M.J. 1993. Changes in the surface morphology of starch granules of the cultivated potato, *Solanum tuberosum* L. during storage. *Potato Research* 36 (2): 119-125.

Dronzek, B.C., Huwang, P. and Bushuk, W. 1972. Scanning electron microscopy of starch from spouted wheat. *Cereal Chemistry* 49: 232-239.

Fernandez, M.L. and Berry, J.W. 1989. The effect of germination on chickpea starch. *Starch/Staerke* 41: 17–21.

Fincher, G.B. 1989. Molecular and cellular biology associated with endosperm mobilization in germinating cereal grains. *Annual Review of Plant Physiology and Plant Molecular Biology* 40: 305-346.

Frias, J., Fornal, J., Ring, S.G. and Vidal-Valverde, C., 1998. Effect of germination on physicochemical properties of lentil starch and its components. *Lebensmittel-Wissenschaft und-Technologie* 30: 178–183.

Gallant, D., Mercier, C. and Guilbot, A. 1972. Electron microscopy of starch granules modified by bacterial alpha-amylase. *Cereal Chemistry* 49: 354-365.

Gallant, P. D., Derrien, A., Aumaitre, A., and Massy, A. 1973. Dégradation in vitro de l'amidon par le suc pancréatique. *Starch/Staerke* 25:5 6-64.

Hoover, R. and Sosulki**,** F.W. 1991. Effect of cross- linking on functional properties of legume starches. *Starch/Stärke* 38: 149-155.

Lorenz, K, Collins, F. and Kulp, K. 1981. Sprouting of cereal grains. Effects on starch characteristics. *Starch/Stärke* 33: 183–187.

MacGregor, A.W. and Balance, D.L. 1980. Hydrolysis of large and small starch granules from normal and waxy barley cultivars by alpha-amylases from barley malt, *Cereal Chemistry* 57: 397–402.

Modi, A.T. and Cairns, A.L.P. 1994. Molybdenum deficiency in wheat results in lower dormancy levels via reduced ABA. *Seed Science Research* 4: 329-333.

Modi, A.T. 2004. Short-term preservation of maize landrace seed and taro propagules using indigenous storage methods. South African Journal of botany 70: 16-23.

Modi, A.T and White, B.J. 2004.Water potential of cherry tomato (*Lycopersicon esculentum* Mill.) placenta and seed germination in response to desiccation during fruit development. Seed Science Research 14: 249-257.

Nielsen, T.H., Deiting, U. and Stitt, M. 1997. A β-amylase in potato tubers is induced by storage at low temperature. *Plant Physiology* 113: 503-510.

Panneerselvam, R., Abdul Jaleel, C., Somasundaram, R., Sridharan, R. and Gomathinayagam, M. 2007. Carbohydrate metabolism in *Dioscorea esculenta* (Lour.) Burk. Tubers and *Curcuma longa* L. rhizomes during two phases of dormancy. *Colloids and Surfaces B: Biointerfaces* 59: 59-66.

Silva, H.C. and Luh, B.S. 1978. Scanning electron microscopy studies on starch granules of red kidney beans and bean sprouts. *Journal of Food Science 43* (5): 1405-1408.

Sreenath, H.K. 1992. Studies on starch granules digestion by alpha-amylase. *Starch/Stärke* 44 (2)61–83.

Sun, Z. and Henson, C. A. 1990. Degradation of Native Starch Granules by Barley alpha-Glucosidases. *Plant Physiology* 94 (1): 320–327.

Valetudie, J.C., Colonna, P., Bouchet, B. and Gallant, D.J. 1993. Hydrolysis of tropical tuber starches by bacteria and pancreatic α-amylases. *Starch/Stärke* 45: 270–276.

Wetzstein, H.Y. and Wetzstein, M.E. 1981. Scanning electron microscopy and size analysis of temperature induced in vivo potato starch breakdown. *Journal of the American Society for Horticultural Science* 106: 688-690.

Zhang, T. and Oates, C.G. 1999. Relationship between α-amylase degradation and physico-chemical properties of sweet potato starches. *Food Chemistry* 65 (2): 157-163.

CHAPTER 6

EFFECTS OF PRE- AND POST-HARVEST PRACTICES ON CARBOHYDRATES OF TARO (*COLOCASIA ESCULENTA*).

Abstract

The effect of four planting date (October, November, December and January) and three fertiliser application rates (0, 160 N and 320 N kg ha^{-1}) on starch and reducing sugars content was investigated for the three taro cultivars from KwaZulu-Natal at Ukulinga and Umbumbulu. The effect of two storage temperatures (12^{o}C and ambient temperature) and three packaging methods (polyethylene bags, mesh bags and open boxes) on starch and reducing sugars following storage was also investigated for three cultivars. At Ukulinga, delaying planting significantly decreased starch content whereas at Umbumbulu starch content was significantly decreased by application of fertiliser. Reducing sugars were reduced by delay in planting when no fertiliser was applied but increased when 320 N kg ha^{-1} was applied at Ukulinga. Fertilisation had no effect on reducing sugars of *Dumbe-dumbe* but increased reducing sugars of *Mgingqeni.* For *Pitshi* reducing sugars were increased when 320 N kg ha^{-1} of fertiliser was applied. At Umbumbulu, delaying planting generally increased reducing sugars for *Dumbe-dumbe* and *Pitshi* and decreased reducing sugars for *Mgingqeni.* Ambient temperature and mesh bag showed the best combination for taro cormel storage.

Key Words: *Colocasia esculenta*, planting date, starch, storage, sugars.

6.1 Introduction

Taro [*Colocasia esculenta* (L.) Schott] commonly known as *amadumbe* in Zulu, has high potential for alleviation of food insecurity in rural areas of KwaZulu-Natal. Recent developments indicated that taro also has a potential to compete with potato (*Solanum tuberosum*) as a processing crop to produce crisp chips. However, no research has been done on the pre- and post-harvest physiology of taro. Starch and sugar contents are important quality parameters in crisp making as texture and colour of crisps depend on them (Kita, 2002; Lisińska and Laszczyński, 1989; Pavlista 1997). There is lack of knowledge on the effects of pre- and post-harvest practices on the carbohydrates of the crop. It is important to understand the factors that influence the starch and sugar contents especially reducing sugars of taro so as to reduce losses during storage. In potatoes, higher starch content is required for processing (Mitch, 1984). Starch and sugar properties vary with potato cultivars (Lisińska and Laszczyński, 1989). Starch and sugar contents are also affected by cultivar, temperature, moisture and fertilisation (Lisińska and Laszczyński, 1989; Wolfe *et al*, 1991; Feltran *et al*, 2004). Starch quality is influenced by environmental conditions during crop growth and storage. Potato cultivars differ in their sensitivity to storage temperature. Reducing sugar content of tubers was reported to have increased sharply during the first weeks of storage at 4°C whereas at 10°C, reducing sugar content remained constant or increased only slightly (Cottrell *et al*., 1993).

Proietti *et al*. (2005) reported large variation in total soluble sugars (glucose, fructose and sucrose) between cultivars and the sowing times in potatoes. Reduced incorporation of assimilates into starch in the tubers at high temperatures and increased amount of labelled sucrose was reported by Wolfe *et al.* (1991). Nitrogen has a more pronounced effect than phosphorus or potassium fertilisers. High doses of nitrogen (200 kg ha^{-1}) results in low starch content and high reducing sugars in potatoes due to prolonged growing season which results in immature tubers at harvest (Lisińska and Leszczyński, 1989; Sowokinos, 1990). Kyriacou *et al*. (2009), on the contrary, reported that tuber sucrose and reducing sugars content were not affected by nitrogen fertilisation rate when 0, 100, 200 and 300 kg ha^{-1} were applied in spring potatoes. Water deficit during growth was found to increase reducing sugars (Sowokinos, 1990; Nadler and Heuer, 1995). High nitrogen fertilisation was also reported to reduce storability of potato tubers (Casa *et al.*, 2005).

Planting taro at appropriate times, using suitable fertilisation and cultivars and proper storage can enhance taro carbohydrates properties required for processing. The objective of this study was to evaluate carbohydrate changes in three taro cultivar of KwaZulu-Natal, South Africa, as affected by planting date and fertilisation during growth and temperature and packaging during storage.

6.2 Materials and methods

Taro cormels harvested from trials that were planted at Ukulinga (29^o 37′S 30^o 16′E) and Umbumbulu (29^o 36′S 30^o 25′E) were used to assess the effect of planting date and fertilisation on reducing sugars and starch content of three taro cultivars. The experiment was designed at each site as a split-split-plot design with four planting dates: October 2007, November 2007, December 2007 and January 2008 as main plots, three taro cultivars (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) as sub-plots and three organic fertiliser (Gromor Accelerator®) application rates (0, 160 N and 320 N kg ha^{-1}) as sub-sub-plots. Each planting date was replicated three times. Plot size was 4 m^2 containing 16 plants spaced 0.5m between and within rows. Sowing was done by hand on ploughed and harrowed fields. Planting holes were opened with a hand-hoe and organic fertiliser was mixed with soil before one cormel was planted per hole. Weeds were controlled by hand hoeing at 30, 60, 90 and 120 days after planting. Harvesting was done eight months after planting.

Cormels harvested from Ukulinga trial that was planted without fertiliser in October were also used to evaluate the effect of storage temperature and packaging method on reducing sugars and starch content. The post-harvest storage experiment was arranged in a split-split plot design with temperatures (12^{o}C and ambient temperature) as main plots, packaging (polyethylene bag, box and mesh bag) as sub-plots and cultivars (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) as sub-sub-plots. Each storage temperature was replicated three times and the cultivars were randomised within packaging within storage temperatures. Each packaging contained 7, 11 and 13 cormels of *Dumbe-dumbe*, *Mgingqeni* and *Pitshi* respectively. One cormel was sampled monthly for four months starting one month after storage.

The cormels were then peeled, cut into slices, immediately frozen in liquid nitrogen, freeze-dried and milled for reducing sugars and starch content analysis.

6.2.1 Reducing sugar determination

Sugars were determined at harvest and monthly for four months starting one month after storage according to Matsuura-Endo *et al*. (2006) with modifications. 0.2g of peeled freeze-dried and ground cormel material was homogenized for 30 seconds using Ultraturrax in 10 ml of 80% ethanol. The sugars in the homogenate were extracted at 80^{o}C for 1 hour and then stored overnight at 4^{o}C. They were centrifuged at 10,000 rpm for 15 minutes at 4^{o}C. The supernatant was filtered through glass wool and dried overnight in a Savant Vacuum drier. Dried samples were resuspended in 2 ml ultra pure water and then centrifuged for 15 minutes. 0.4 micron nylon syringe filters were used to filter into HPLC sample vials. The concentrations of sugars in the filtrate were then determined using HPLC (Shimadza) (Kontron Autosampler HPLC 360, 515 HPLC pump) with a Ca2+- column. Reducing sugars content was calculated by adding glucose and fructose content together.

6.2.2 Starch content determination

Starch content was determined as glucose equivalents resulting from enzymatic hydrolysis of the centrifugate from sugar determination using method used by Rasmussen and Henry (1990).

6.2.3 Statistical analysis

Analysis of variance was performed using GenStat Version 11.1 (2008). Least significant difference (LSD) was used to separate means. A probability level of 0.05 was considered to be statistically significant.

6.3 Results

6.3.1 Reducing sugar content

Reducing sugars content was significantly affected by the interaction of planting date and fertilisation (P = 0.001) at Ukulinga. When no fertiliser was applied, reducing sugars significantly decreased when planting was delayed by one month from October (Fig. 6.1). Planting date had no effect on reducing sugars when 160 N kg ha^{-1} of fertiliser was applied. Delaying planting until January increased reducing sugar content of cormels when 320 N kg ha^{-1} of fertiliser was applied. There was no significant difference between fertiliser rates when planting was done in October and November. Fertiliser application of 160 N kg ha^{-1} showed higher reducing sugar content than when no fertiliser was applied but not higher than when 320 N kg ha^{-1} was applied which was also not significantly different from fertilizer was not applied for December planting. 320 N kg ha^{-1} displayed significantly higher reducing sugars than both 0 kg ha^{-1} and 160 N kg ha^{-1} when planting was done in January.

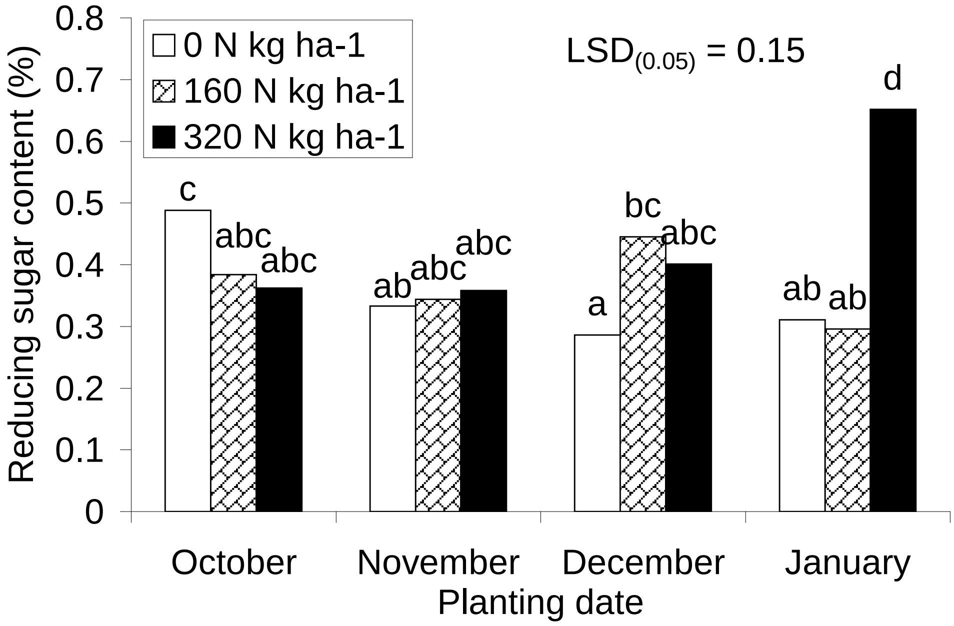

Figure 6.1 Reducing sugar content of taro cormels planted at different planting dates averaged across cultivar at Ukulinga.

At Umbumbulu, planting date significantly ($P = 0.018$) affected reducing sugar content of taro cultivars. Delaying planting by one month from October significantly increased reducing sugar content (Fig. 6.2). Further delay in planting until January decreased reducing sugar content to level not significantly different from that that was obtained with October planting.

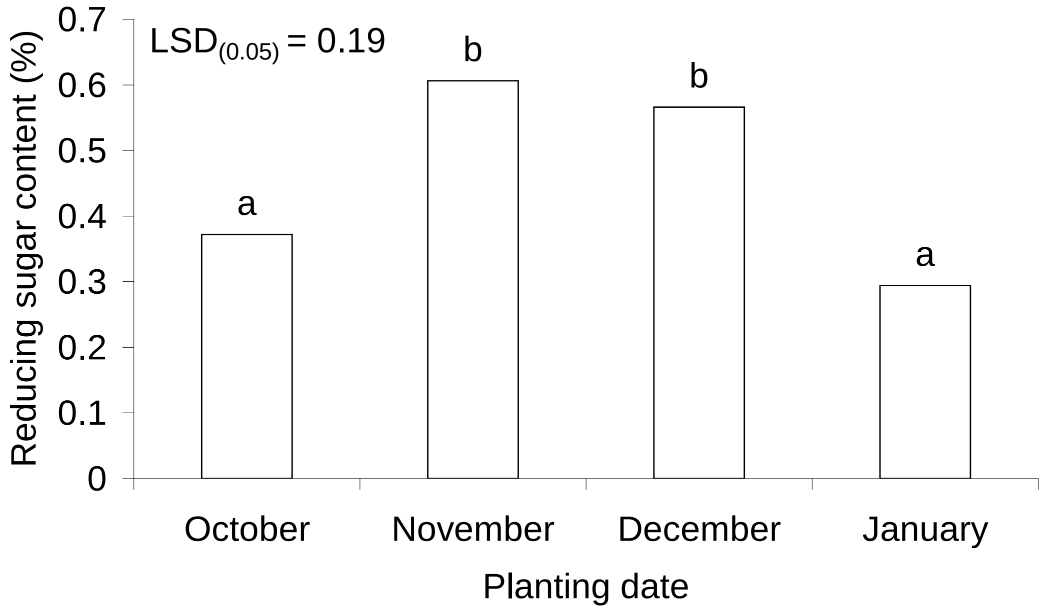

Figure 6.2 Reducing sugar content of taro cormels planted at different planting dates averaged across cultivar and Gromor Accelerator® application rate at Umbumbulu.

In the storage experiment, reducing sugars were significantly (P = 0.002) affected by the interaction of temperature, packaging, cultivar and sampling month. Reducing sugars generally increased with time in storage. Taro cormels stored at 12^{o}C generally showed higher reducing sugars than those stored at ambient temperature especially after 4 months after storage (Table 6.1). Cormels of *Dumbe-dumbe* and *Mgingqeni* packaged in boxes displayed higher reducing sugars compared to those packaged in polyethylene and mesh bags.

Table 6.1 Reducing sugar content of taro cultivars stored at different temperatures in different packaging materials. Means of the interaction effect within columns ($LSD_{(0.05)}$ = 0.12) followed by the same letter are not significantly different.

			Months after storage			
Temperature	**Packaging**	**Cultivar**	**1**	**2**	**3**	**4**
12^oC	Polyethylene	*Dumbe-dumbe*	0.09 abc	0.09 ab	0.13 a	0.36d
		Mgingqeni	0.08 abc	0.10 abc	0.28 bc	0.34 cd
		Pitshi	0.03 a	0.10abc	0.37 c	0.39 d
	Box	*Dumbe-dumbe*	0.07 abc	0.11 abc	0.16 ab	0.65e
		Mgingqeni	0.11 abc	0.18 bc	0.41 c	0.68 e
		Pitshi	0.09 abc	0.10 abc	0.11 a	0.34 cd
	Mesh bag	*Dumbe-dumbe*	0.15 bc	0.21 c	0.31 c	0.43 d
		Mgingqeni	0.08 abc	0.10 abc	0.15 a	0.36 d
		Pitshi	0.04 ab	0.08 ab	0.12 a	0.14 ab
Ambient Temperature	Polyethylene	*Dumbe-dumbe*	0.05 abc	0.15 abc	0.15 a	0.17 ab
		Mgingqeni	0.17c	0.11 abc	0.11 a	0.13 ab
		Pitshi	0.06 abc	0.07 ab	0.12 a	0.17 ab
	Box	*Dumbe-dumbe*	0.09 abc	0.10 abc	0.18 ab	0.20 ab
		Mgingqeni	0.08 abc	0.09 ab	0.16 a	0.20 ab
		Pitshi	0.06 abc	0.09 ab	0.11 a	0.14 ab
	Mesh bag	*Dumbe-dumbe*	0.05 ab	0.07ab	0.10 a	0.23 bc
		Mgingqeni	0.04 ab	0.04 a	0.09 a	0.10 a
		Pitshi	0.10 abc	0.12 abc	0.14 a	0.16 ab

6.3.2 Starch content

Starch content was significantly (P = 0.014) affected by the interaction of planting date and cultivars at Ukulinga. Starch content significantly decreased for *Dumbe-dumbe* with delay in planting from November to December whereas for *Pitshi* the decrease was observed with delay in planting from December to January (Fig. 6.3). Planting date had no effect on starch content of *Mgingqeni*. *Dumbe-dumbe* displayed significantly highest starch content when planting was done in November. There was no significant difference between cultivars when they were planted in October, December and January.

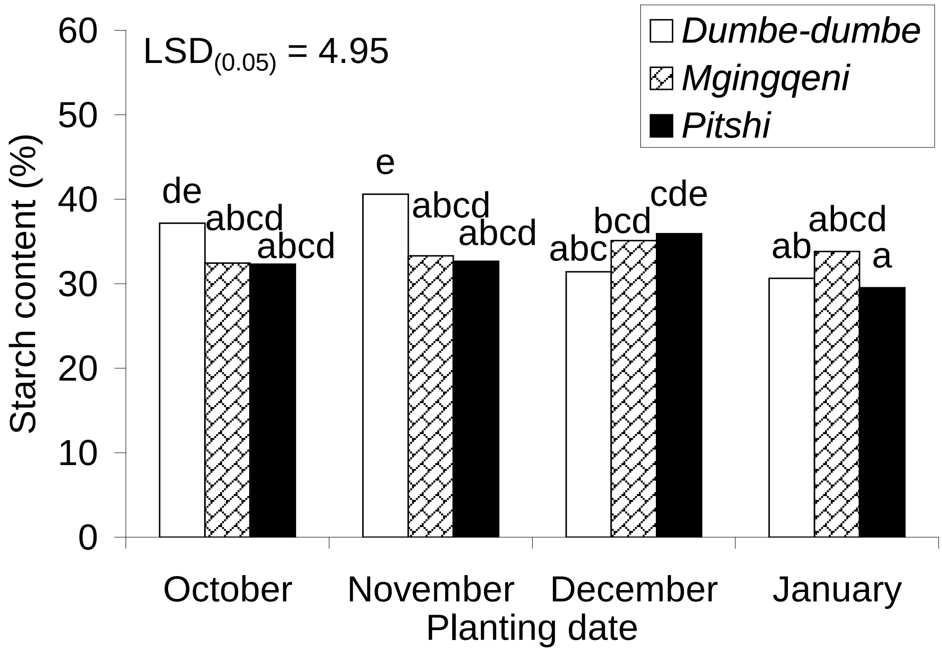

Figure 6.3 Starch content of taro cultivars planted at different planting dates averaged across Gromor Accelerator® application rates at Ukulinga.

At Umbumbulu, planting date (P = 0.045) and the interaction of cultivar and fertilisation (P = 0.01) had a significant effect on starch content of taro cormels. Starch content was significantly increased when planting was delayed by two months from October (Fig. 6.4). Application of 320 N kg ha^{-1} of fertiliser decreased starch content of *Dumbe-dumbe* to the level not significantly different from that obtained with no fertiliser (Fig. 6.5). Fertiliser application had no effect on starch content of *Mgingqeni*, whereas it decreased starch content of *Pitshi*. When fertiliser was not applied, *Pitshi* showed higher starch content than *Mgingqeni* but not *Dumbe-dumbe* which was also not significantly different from *Mgingqeni*. Pitshi showed lower starch content than *Dumbe-dumbe* and *Mgingqeni* which were not different from each other when 160 N kg ha^{-1} of fertiliser was applied. There was no significant difference between starch content of the cultivars when 320 N kg ha^{-1} of fertiliser was applied.

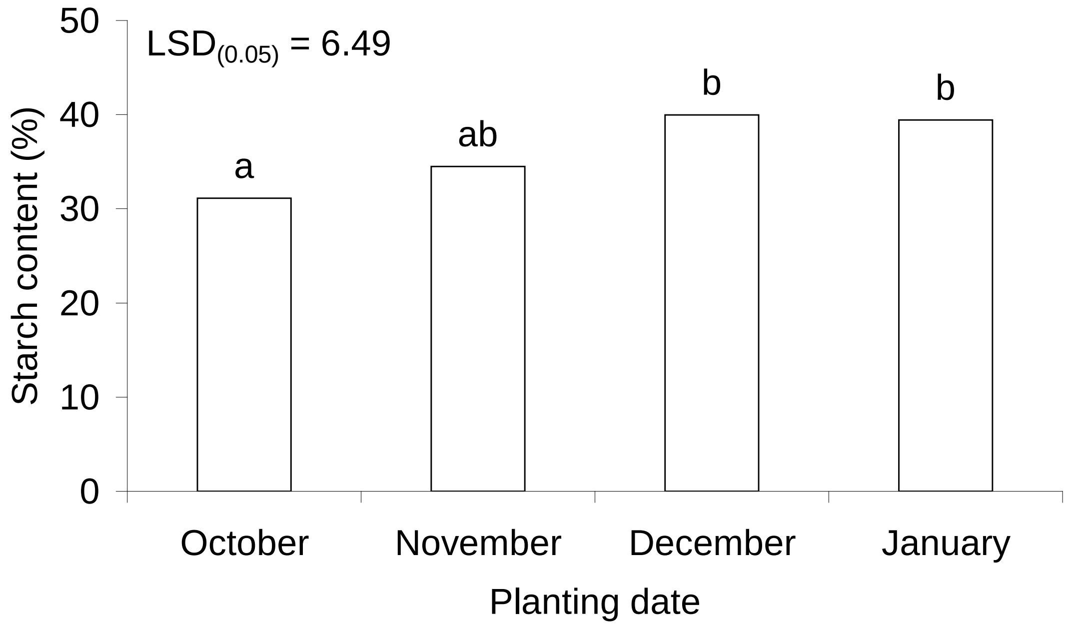

Figure 6.4 Starch content of taro cultivar planted at different planting dates at Umbumbulu.

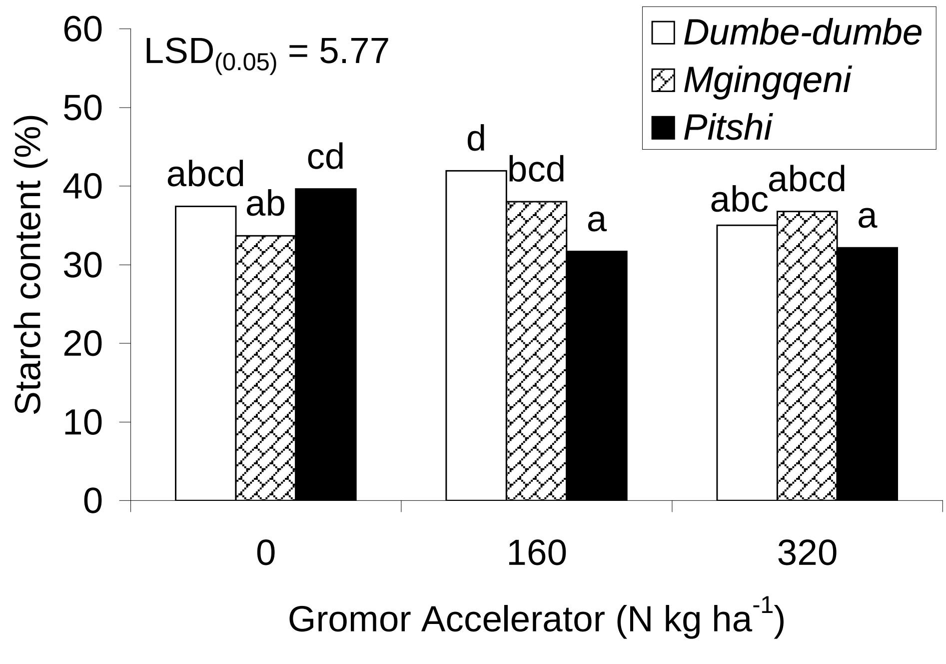

Figure 6.5 Starch content of taro cultivars planted with different Gromor Accelerator® application rates averaged across planting dates at Umbumbulu.

In the storage experiment, starch content was significantly ($P < 0.001$) affected by the interaction of temperature, packaging, cultivar and sampling month. Starch content generally decreased with time in storage. Ambient temperature generally showed higher starch content than 12°C (Table 6.2). Cormels packaged in mesh bags and

Dumbe-dumbe also displayed higher starch content compared to those packaged in polyethylene bags and boxes; and *Mgingqeni* and *Pitshi* respectively.

Table 6.2 Starch content of taro cultivars stored at different temperatures in different packaging materials. Means of the interaction effect within columns (LSD $_{(0.05)}$ = 0.37) followed by the same letter are not significantly different.

			Months after storage			
Temperature	**Packaging**	**Cultivar**	**1**	**2**	**3**	**4**
12°C	Polyethylene	*Dumbe-dumbe*	36.44 i	33.52 j	30.42 i	29.06 k
		Mgingqeni	32.25 fg	31.22 g	27.08 f	26.39 g
		Pitshi	30.65 d	29.67 e	23.21 b	25.54 f
	Box	*Dumbe-dumbe*	36.40 hi	27.88c	27.63 g	26.82 h
		Mgingqeni	32.39 fg	31.72h	26.86 ef	24.36 e
		Pitshi	25.65 a	24.89 a	17.12 a	14.64 a
	Mesh bag	*Dumbe-dumbe*	36.21 hi	34.99 l	36.67 l	32.73 m
		Mgingqeni	32.09 f	31.45gh	30.88 j	27.76 j
		Pitshi	30.14 c	25.24 a	23.41 bc	22.34 d
Ambient Temperature	Polyethylene	*Dumbe-dumbe*	37.14 j	33.13 i	28.40 h	27.24 i
		Mgingqeni	32.47 g	31.44 gh	30.98 j	26.37 g
		Pitshi	31.51 e	30.85 f	27.79 g	26.30 g
	Box	*Dumbe-dumbe*	36.06 h	30.55 f	30.31 i	27.24 i
		Mgingqeni	28.78 b	27.44 b	26.21 d	19.98 c
		Pitshi	30.32 cd	29.93 e	23.72 c	18.36 b
	Mesh bag	*Dumbe-dumbe*	36.18 hi	33.94 k	32.35 k	31.86 l
		Mgingqeni	32.21 fg	30.72 f	27.98 g	27.58 ij
		Pitshi	31.26 e	29.24 d	26.51 de	25.90 f

6.4 Discussion

Application of fertiliser had no effect on reducing sugars when taro was planted early in the season in October, November and December at Ukulinga. The findings are in line with what was also found by Sharma and Arora (1988) that applied nitrogen significantly did not affect the sugar content of potato tubers. A negative impact of applying fertiliser on reducing sugars was evident when taro was planted in January. According to Long *et al*. (2004) genotype is the major factor that influenced sugar content in potatoes. This might also be true for taro since application of fertiliser had no effect on reducing sugars of *Dumbe-dumbe* and increased reducing sugars of *Mgingqeni*, whereas they were increased for *Pitshi* when 10660 kg ha^{-1} of fertiliser was applied. This is also in line with what was reported that sugar content is highly varied between cultivars (Lisińska and Laszczyński, 1989). Water deficiency lead to high sugar content (Davies *et al*., 1989; Ilin *et al*., 1997). This was evident at

Umbumbulu where reducing sugars generally increased with delay in planting since it was observed that lower rainfall was experienced late in the season.

Starch content at Ukulinga was negatively impacted by delay in planting. This may be related to the fact that earlier planted taro experienced higher rainfall during the first months of corm bulking and lower temperatures during maturation as mentioned by Smith (1987) that adequate moisture results in high starch content in potatoes. Starch content of *Dumbe-dumbe* significantly decreased when planting was delayed by two months whereas in *Pitshi* it decreased to the level not significantly different from those of October and November planting and *Mgingqeni* was not affected by planting date. The different response of the taro cultivars confirmed what was reported by Willis *et al*. (1983) that starch properties in taro are influenced by genetic variation. Applying fertiliser negatively affected starch content of *Pitshi* at Umbumbulu. This seems to suggest that increasing nitrogen fertiliser rates significantly decreases starch content as stated by Sharma and Arora (1988) and Shan *et al*. (2004). *Mgingqeni* was however not affected by increasing nitrogen.

Reducing sugars seemed to have lowered before storage and this might have been a result of keeping corms in mesh bags at ambient temperature before storage as it was reported by Heinze *et al*. (1955) and Kirkpatrick *et al*. (1976) that reducing sugars can be lowered by holding tubers at 21^{o}C. Starch decreased progressively over storage time while sugars increased (Rivero *et al*., 2003). This is confirmed by the findings of the present study that also shows decreasing starch content and increasing reducing sugars with time in storage. The shelf life of root crops is said to be influenced by genotype, storage temperature and packaging (Kay, 1987; Brown *et al*., 1990; Yosuke *et al*., 2000). .This is also with taro. Starch content of taro corms was found to be higher at ambient temperature compared to 12^{o}C whereas reducing sugars were higher at 12^{o}C as compared to ambient temperature. This was also reported by Williams and Cobb (1993), Wiltshire and Cobb (1996), Wong Yen Cheong and Govinden (1998), Yosuke *et al*. (2000) and Pal *et al*. (2008) that low temperature storage causes tubers to develop reducing sugars and decrease starch content hence become unsuitable for processing into crisps.

It was also found in this study that cormels stored in the mesh bag had the higher starch content whereas those in open box had the higher reducing sugars. This might be due to the fact that the mesh back somehow warmed the taro cormels stored in them and the corms stored in the box were more exposed to lower temperature especially at 12^{o}C. The higher starch content and reducing sugars displayed by *Dumbe-dumbe* compared to other cultivars might be because the cultivar naturally has higher starch content than *Mgingqeni* and *Pitshi,* and even if it develops more reducing sugars a large proportion of starch remains at the end.

6.5 Conclusions and recommendations

The study shows that delaying planting reduced starch content for *Dumbe-dumbe* and *Pitshi* at Ukulinga. Delaying planting decreased reducing sugars when no fertiliser was applied and application of 320 N kg ha^{-1} increased reducing sugar content. *Dumbe-dumbe* had high reducing sugars when no fertiliser was applied. *Mgingqeni* reducing sugars were increased by fertilisation. At Umbumbulu, fertilisation decreases starch content of *Pitshi* only and delay in planting increases sugar content for *Dumbe-dumbe* and decrease it for *Mgingqeni* and *Pitshi.* Starch of taro corms decreases and reducing sugars increase with time in storage. Low temperature decreases starch content while increases reducing sugars. Mesh bags had higher starch content while open boxes had higher reducing sugars. *Dumbe-dumbe* had higher starch content and higher reducing sugars.

It is then recommended that *Dumbe-dumbe* be planted in October and November without fertiliser at Ukulinga and the same cultivar be planted without fertiliser in October at Umbumbulu. It is also recommended that taro cormels be stored at 12^{o}C for two months and at ambient temperature for four months to maintain the acceptable level of reducing sugars for crisp making.

References

Brown, J., Mackay, G.R., Bain, H., Griffith, D.W. and Allison, MJ. 1990. The Processing potential of tubers of the cultivated potato, *Solanum tuberosum* L., after storage at low temperature. 2. Sugar concentration. *Potato Research* 33: 219 - 227.

Casa, R., Pieruccetti, F., Sgueglia, G. and LoCascio, B. 2005. Potato tuber quality improvement through nitrogen management optimization: Review of methodologies. *Acta Horticulturae* 684: 65-71.

Cottrell, J.E., Duffus, C.M., Mackay, G.R. and Allison, M.J. 1993. Changes in the surface morphology of starch granules of the cultivated potato, *Solanum tuberosum* L. during storage. *Potato Research* 36 (2): 119-125.

Davies, H.V., Jefferies, R.A. and Scobie, L. 1989. Hexose accumulation in cold-stored tubers of potato (*Solanum tuberosum* L.): the effects of water stress. *Journal of Plant Physiology* 134 (4): 471-475.

Feltran, J.C., Lemos, L.B. and Vieites, R.L. 2004. Technological quality and utilization of potato tubers. *Scientia Agricola* 61 (6): 598-603.

Heinze, P.H., Kilpatrick, M.E. and Dochterman, E.F., 1955. Cooking quality and compositional factors of potatoes of different varieties from several commercial locations. *USDA Technology Bulletin* 1106, p. 69.

Ilin, Ž., Durovka, M. and Marković. V. 1997. Effect of fertility and irrigation on sugar content in potato tubers. *Acta Horticulturae* 462: 303-309.

Kay, D.E. 1987. Crop and product digest No. 2 Root crops. 2nd Edition. London: Tropical Development and Research Institute. 380 pp.

Kirkpatrick, M., Heinze, P.H., Craft, C.C., Mountjay, B.M. and Falatko, C.F., 1956. French frying quality of potatoes as influenced by cooking methods storage conditions and specific gravity of tubers. *USDA Technology Bulletin* 1142, p. 46.

Kyriacou, M.C., Siomos, A.S., Ioannides, I.M. and Gerasopoulos, D. 2009. Cold storage, reconditioning potential and chip processing quality of spring potato (*Solanum tuberosum* L. cv. Hermes) tubers in response to differential nitrogen fertilization. *Journal of the Science of Food and Agriculture* 89 (11): 1955-1962.

Kita, A. 2002. The influence of potato chemical composition on crisp texture. *Food Chemistry* 76 (2): 173-179.

Lisińska, G. and Laszczyński, W. 1989. Potato Science and technology. London UK: Elsevier Science Publishers Ltd, England.

Long, C.M., Snapp, S.S., Douches, D.S. and Chase, R.W. 2004. Tuber yield, storability and quality of Michigan cultivars in response to nitrogen management and seed spacing. *American Journal of Potato Research* 81: 347-357.

Matsuura-Endo, C., Ohara-Takada, A., Chuda, Y., Ono, H. Yada, H., Yoshida, M., Kobahashi, A., Tsuda, S., Takigawa, S., Noda, T., Yamauchi, H. and Mori, M. 2006. Effects of storage temperature on the contents of sugars and free amino acids in tubers from different potato cultivars and acrylamide in chips. *Bioscience, Biotechnology and Biochemistry* 70 (5): 1173-1180.

Mitch, E.L. 1984. Potato starch: Production and uses. In: R.L. Whistler, J.N. BeMiller and E.F. Paschall, Editors, *Starch: Chemistry and technology*, Academic Press, New York pp. 479–490.

Nadler, A. and Heuer, B. 1995. Effect of saline irrigation and water deficit on tuber quality. *Potato Research* 38: 119–123.

Pal, S., Bhattacharya, A., Konar, A., Mazumdar, A. and Das, A.K. 2008. Chemical composition of potato at harvest and after cold storage. *International Journal of Vegetable Science* 14 (2): 162-176.

Pavlista, A.D. 1997. , Potato types: Their characteristics and uses. *The American Biology Teacher* 59: 26–34.

Proietti, S., Moscatello, S., Battistelli, A., Mauromicale, G. and Ierna, A. 2005. Quality of early potato in Sicily as affected by cultivar, sowing time and irrigation. *Acta Horticulturae* 684: 171-177.

Rasmussen, T.S. and Henry, R.J. 1990. Starch determination in horticultural plant material by an enzymic colorimetric procedure. *Journal of Food and Agricultural Science* 52:159-70.

Rivero, R.C., Rodriquez, E.R and Romero, C.D. 2003. Effects of current storage conditions on nutrient retention in several varieties of potatoes from Tenerife. *Food Chemistry* 80: 445-450.

Shan, L., Sattelmacher, B., Kutzmutz, E., Mühling, K. H. and Dittert, K. 2004. Influence of nitrogen nutrition on tuber quality of potato with special reference to the pathway of nitrate transport into tubers. *Journal of Plant Nutrition* 27 (2): 341-350.

Sharma, U.C. and Arora, B.R. 1988. Effect of applied nutrients on the starch, proteins and sugars in potatoes. Food Chemistry 30 (4): 313-317.

Smith, O. 1987. Potato chips. In: W. Talburt and O. Smith, Editors, *Potato processing*, Van Nostrand Reinhold Company Inc, New York.

Sowokinos, J.S. 1990. Stress-induced alterations in carbohydrate metabolism. In: Vayda, ME, Park WD (eds) The molecular and cellular biology of the potato. CAB International, Wallingford, UK, pp 137–158.

Williams, R.O. and Cobb, A.H. 1993. The relationship between storage temperature, reconditioning and tuber storage. *Potato Research* 36: 373-392.

Wiltshire, J.J.J. and Cobb, A.H. 1996. A review of the physiology of potato tuber dormancy. *Annual Applied Biology* 129: 553-569.

Wolf, S., Marani, A. and Rudich, J. 1991. Effect of temperature on carbohydrate metabolism in potato plants. *Journal of Experimental Botany* 42: 619-625.

Wong Yen Cheong, J.K.C and Govinden, N. 1998. Quality of potato during storage at three temperatures. AMAS 1998. Food and Agricultural Research Council, Réduit, Mauritius.

Yosuke, M., Yaptenco, K.F., Tomohiro, N., Toshiro, S., Hiroaki, S., Shinji, M. and Katsumi, T. 2000. Property changes in potato tubers (*Solanum tuberosum* L.) during cold storage at 0 and 10^{o}C. *Food Preservation Science* 26 (3): 153-160.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

Taro quality for crisping includes yield, chemical composition and storability of corms (Eskin, 1989; Kader and Rolle, 2004; Carputo *et al*., 2005; Gebhardt *et al*., 2005; O`Keefe *et al*., 2005). Taro cultivars that combine high corm yield with good chemical composition and storability are required for processing. Yield and chemical composition are affected by genotype, planting date and fertilisation (Casa *et al*., 2005; Martin *et al*., 2005; Proietti *et al*. (2005); Mazid, 1993) while storability is influenced by storage temperature and packaging method (Kay, 1987; Brown *et al*., 1990; Yosuke *et al*., 2000). Findings reported in Chapter 3 of this study support this and indicate that the number of cormels plant^{-1} and fresh cormel mass plant^{-1} were negatively affected by delayed planting at both sites and positively affected by fertilisation at Umbumbulu only. All three taro cultivars performed best in terms of the number of cormels plant^{-1} when they were planted in October at both sites, with *Dumbe-dumbe* and *Mgingqeni* also performing best when planted in November at Ukulinga (Fig. 3.17 and 3.18). The cultivars showed differences in the number of cormels plant^{-1} when planted early in the season and the differences became less or disappeared completely when planting was delayed further. Yield varies among cultivars (Babaji *et al*., 2009). *Dumbe-dumbe* yielded less cormels followed by *Mgingqeni* and *Pitshi* respectively when they were planted in October, but for November planting *Mgingqeni* and *Pitshi* were not different from each other at both sites (Fig. 3.17 and 3.18). Fresh cormel mass plant^{-1} was best for all cultivars when planted in October with *Dumbe-dumbe* also performing best when planted in November at Ukulinga (Fig. 3.29). Application of Gromor Accelerator® enhanced the number of cormels plant^{-1} and fresh cormel mass plant^{-1}, especially when planting was done in October at Umbumbulu (Fig. 3.19 and 3.30). Fertiliser application enhanced the number of cormels plant^{-1} for all cultivars though number of cormels plant^{-1} was increased for *Mgingqeni* and *Pitshi* when 160 N kg ha^{-1} of the fertiliser was applied, whereas for *Dumbe-dumbe* the increase was observed with addition of 320 N kg ha^{-1} of the fertiliser (Fig. 3.20).

The high yielding in response to early planting dates may be attributed to earlier emergence (Table 3.5 and Fig. 3.6) and vigorous leaf growth (Figs. 3.8, 3.9, 3.14, 3.15

and 3.16) which were due to adequate rainfall and temperature (Table 3.1) during planting, vegetative growth and corm initiation stage of taro (Sangakkara, 1993; Lu *et al*., 2001; Miyasaka *et al*. 2003; Scheffer *et al.*, 2005). Tubers of about 50-350 g in weight are preferred because they produce the crisp of the right size and pass through the processing line with less need for hand trimming (Panhwar, 2005). *Dumbe-dumbe* yielded less and more fresh cormel mass plant^{-1} than both *Mgingqeni* and *Pitshi* when cultivars were planted in October and November, respectively (Fig. 3.29) but higher number of cormels in the usable size category (Table 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7 and 7.8). *Mgingqeni* and *Pitshi* might have produced significantly higher fresh cormel mass plant^{-1} and number of cormels plant^{-1}, but the cormels were too small for crisping (Fig. 3.21, 3.22, 3.23, 3.24, 3.25, 3.26, 3.27 and 3.28).

Dry matter content of taro was negatively affected by application of fertiliser. It has been established that excessive nitrogen fertilisation reduces dry matter allocated to the corms in taro (Manrique, 1994). This was evident at Ukulinga where the decrease in dry matter content was more pronounced when 320 N kg ha^{-1} of Gromor Accelerator® was applied (Fig. 4.1). Dry matter content was positively affected by delaying planting date. Dry matter was optimum for November and December plantings for *Dumbe-dumbe*, December and January plantings for *Mgingqeni* and December planting for *Pitshi* (Fig. 4.2). And when it decreased again it decreased to initial levels realised in October. It can also be postulated that application of fertiliser did not affect dry matter content at Umbumbulu. Dry matter content yielded by all planting dates, fertiliser rates and cultivars (Figs. 4.1 and 4.2) was above the minimum acceptable for crisping (Smith., 1987; Kita, 2002; Panhwar, 2005).

The response of specific gravity to planting date was reported to be variable depending on cultivar (Mohamed, 1985). This was evident with decreasing specific gravity as planting date was delayed for *Dumbe-dumbe* but increasing for *Mgingqeni* while with no effect for *Pitshi* at Ukulinga (Fig.4.3). However, at Umbumbulu, it decreased for *Dumbe-dumbe* and *Pitshi* but without effect for *Mgingqeni* (Fig. 4.5). Taro cultivars responded differently at the two experimental sites in respect to specific gravity. They showed no response to fertiliser application when planting was done early in the season at Ukulinga. The later the cultivars were planted the more they responded to fertiliser application. This is displayed in Fig. 4.4 where application of 320 N kg ha^{-1} of the fertiliser decreased and increased specific gravity to levels equivalent to those obtained when no fertiliser was applied at Ukulinga. At Umbumbulu, on the other hand, fertiliser application decreased specific gravity when cultivars were planted in October and applying 320 N kg ha^{-1} of the fertiliser decreased specific gravity when planting was done in December (Fig. 4.6).

Planting date and fertilization had no effect on total protein when planting was done late in the season (Figs. 4.11 and 4.12). Protein and nitrogen contents were increased by late planting while phosphorus, potassium, calcium and copper content were decreased by the delay in planting at Ukulinga. El-Sirafy *et al.* (2008) found application of farm yard manure to increase protein content, as well as nitrogen, phosphorus and potassium content of potato tubers. This was evident at Ukulinga where protein content was increased by application of 160 N kg ha^{-1} Gromor Accelerator, and at Umbumbulu where phosphorus and potassium content was increased by fertiliser application.

The results of this study can be used to determine the usefulness of taro cormels for processing purposes using information that is already in the literature as a basis to create discriminative scores. The arbitrary scoring of taro cultivars (Appendix 7.1) displays *Dumbe-dumbe* planted with 160 N kg ha^{-1} of organic fertiliser in October and 320 N kg ha^{-1} in November at Ukulinga to be the best for crisping. This is due to the highest total scores (5.6) of combination of the crisping quality parameters assessed (Table 7.1 and 7.2). This might also imply that the later *Dumbe-dumbe* is planted the higher amount of fertiliser it requires to be suitable for crisping. Although *Pitshi* shows the moderately high total score (Fig. 7.1, 7.2 and 7.3), it had the smallest number of corms that are suitable for crisping. The high total score is due to the lowest reducing sugar content that was found in *Pitshi* compared to the other cultivars. The number of corms weighing 50-350g, which are suitable for crisping decreased for *Dumbe-dumbe* as planting was delayed (Fig.7.1, 7.2, 7.3 and 7.3).

At Umbumbulu, *Dumbe-dumbe* planted in October with 320 N kg ha^{-1} of fertiliser, shows the highest total score of 5.6 compared to the other combinations of taro cultivar, planting date and fertiliser application rate (Table 7.5, 7.6, 7.7 and 7.8). This makes *Dumbe-dumbe*, 320 N kg ha^{-1} Gromor accelerator and October the best combination for crisping at Umbumbulu.

Table 7.1 Arbitrary scoring of crisping quality of taro cultivars planted in October at Ukulinga.

Taro cultivars	**Gromor Accelerator rate (N kg ha^{-1})**	**Number of cormels weighing 50-350g**	**Dry matter content (Score)**	**Specific gravity (Score)**	**Starch content (Score)**	**Reducing sugars (Score)**	**Total score**
Dumbe-dumbe	0	0.9	1.1	1.0	1.4	0.2	4.6
	160	1.1	1.1	1.1	1.5	0.8	5.6
	320	1.1	1.0	0.7	1.3	0.6	4.7
Mgingqeni	0	0.7	1.0	0.5	1.3	0.7	4.2
	160	0.8	1.0	0.7	1.3	0.8	4.6
	320	1.0	1.0	0.5	1.3	0.9	4.7
Pitshi	0	0.6	1.2	0.9	1.3	1.0	5
	160	0.9	1.1	0.4	1.3	0.9	4.6
	320	0.8	1.0	0.4	1.3	0.7	4.2

Scores are interpreted in appendix 7.1

Table 7.2 Arbitrary scoring of crisping quality of taro cultivars planted in November at Ukulinga.

Taro cultivars	**Gromor Accelerator rate (N kg ha^{-1})**	**Number of cormels weighing 50-350g (Score)**	**Dry matter content (Score)**	**Specific gravity (Score)**	**Starch content (Score)**	**Reducing sugars (Score)**	**Total Score**
Dumbe-dumbe	0	1.2	1.5	0.7	1.5	0.6	5.5
	160	1.3	1.3	0.7	1.5	0.7	5.5
	320	1.6	1.1	0.6	1.5	0.8	5.6
Mgingqeni	0	0.6	1.1	0.7	1.3	0.9	4.6
	160	0.5	1.1	0.7	1.3	0.9	4.5
	320	0.6	1.0	0.7	1.3	0.7	4.3
Pitshi	0	0.6	1.2	0.6	1.3	0.9	4.6
	160	0.6	1.1	1.1	1.3	0.9	5.0
	320	0.5	1.1	0.7	1.3	0.9	4.5

Scores are interpreted in appendix 7.1

Table 7.3 Arbitrary scoring of crisping quality of taro cultivars planted in December at Ukulinga.

Taro cultivars	**Gromor Accelerator rate (N kg ha^{-1})**	**Number of cormels weighing 50-350g (Score)**	**Dry matter content (Score)**	**Specific gravity (Score)**	**Starch content (Score)**	**Reducing sugars (Score)**	**Total Score**
Dumbe-dumbe	0	0.5	1.4	0.8	1.3	0.8	4.8
	160	0.6	1.2	1.2	1.2	0.6	4.8
	320	0.5	1.1	0.5	1.3	0.7	4.1
Mgingqeni	0	0.5	1.2	0.7	1.3	1.0	4.7
	160	0.5	1.2	0.7	1.4	0.5	4.3
	320	0.7	1.2	0.3	1.4	0.6	4.2
Pitshi	0	0.5	1.4	0.7	1.4	0.9	4.9
	160	0.6	1.4	0.7	1.3	0.8	4.8
	320	0.5	1.2	0.7	1.4	0.7	4.5

Scores are interpreted in appendix 7.1

Table 7.4 Arbitrary scoring of crisping quality of taro cultivars planted in January at Ukulinga. Note: * = missing data.

Taro cultivars	**Gromor Accelerator rate (N kg ha^{-1})**	**Number of cormels weighing 50-350g (Score)**	**Dry matter content (Score)**	**Specific gravity (Score)**	**Starch content (Score)**	**Reducing sugars (Score)**	**Total score**
Dumbe-dumbe	0	0.5	1.2	0.5	1.3	0.6	4.1
	160	1.0	1.0	0.0	1.3	0.9	4.2
	320	0.5	1.0	0.7	1.2	0.3	3.7
Mgingqeni	0	0.5	1.2	0.7	1.2	1.0	4.6
	160	0.5	1.2	0.6	1.4	0.8	3.5
	320	*	*	*	*	*	*
Pitshi	0	0.5	1.2	0.8	1.2	0.9	4.6
	160	*	*	*	*	*	*
	320	0.5	1.1	0.9	1.2	0.1	2.8

Scores are interpreten in appendix 7.1

Table 7.5 Arbitrary scoring of crisping quality of taro cultivars planted in October at Umbumbulu.

Taro cultivars	**Gromor Accelerator rate (N kg ha^{-1})**	**Number of cormels weighing 50-350g (Score)**	**Dry matter content (Score)**	**Specific gravity (Score)**	**Starch content (Score)**	**Reducing sugars (Score)**	**Total score**
Dumbe-dumbe	0	0.7	1.2	0.9	1.3	0.7	4.8
	160	1.6	1.2	0.6	1.3	0.7	5.4
	320	1.9	1.1	0.5	1.3	0.8	5.6
Mgingqeni	0	0.7	1.1	1.1	1.2	0.9	5.0
	160	0.9	1.0	0.7	1.3	0.8	4.7
	320	1.1	1.1	0.6	1.3	0.8	4.9
Pitshi	0	0.6	1.1	1.2	1.3	0.6	4.8
	160	0.6	1.1	0.6	1.2	0.7	4.2
	320	0.9	1.0	0.6	1.3	0.6	4.4

Scores are interpreted in appendix 7.1

Table 7.6 Arbitrary scoring of crisping quality of taro cultivars planted in November at Umbumbulu.

Taro cultivars	**Gromor Accelerator rate (N kg ha^{-1})**	**Number of cormels weighing 50-350g (Score)**	**Dry matter content (Score)**	**Specific gravity (Score)**	**Starch content (Score)**	**Reducing sugars (Score)**	**Total score**
Dumbe-dumbe	0	0.5	1.1	0.8	1.3	0.4	5.1
	160	0.8	1.1	0.8	1.4	0.6	4.7
	320	0.8	1.2	0.8	1.4	0.2	4.4
Mgingqeni	0	0.7	1.1	0.8	1.2	0.3	4.1
	160	0.7	1.2	0.7	1.4	1.1	5.1
	320	0.6	1.4	0.8	1.4	0.5	4.7
Pitshi	0	0.6	1.2	0.8	1.4	0.6	4.6
	160	0.6	1.2	0.9	1.3	0.6	4.6
	320	0.8	1.1	0.9	1.3	0.3	4.4

Scores are interpreted in appendix 7.1

Table 7.7 Arbitrary scoring of crisping quality of taro cultivars planted in December at Umbumbulu.

Taro cultivars	Gromor Accelerator rate (N kg ha^{-1})	Number of cormels weighing 50-350g (Score)	Dry matter content (Score)	Specific gravity (Score)	Starch content (Score)	Reducing sugars (Score)	Total score
Dumbe-dumbe	0	0.5	1.1	0.5	1.6	0.8	4.5
	160	0.5	1.1	0.9	1.5	0.8	4.8
	320	0.6	1.1	0.3	1.4	0.6	4.0
Mgingqeni	0	0.5	1.1	0.8	1.4	0.6	4.4
	160	0.5	1.1	0.8	1.4	0.7	4.5
	320	0.5	1.0	0.6	1.5	0.6	4.2
Pitshi	0	0.5	0.9	1.0	1.5	-0.1	2.8
	160	*	*	*	*	*	*
	320	0.5	1.0	-0.2	1.4	0.0	2.7

Scores are interpreted in appendix 7.1

Table 7.8 Arbitrary scoring of crisping quality of taro cultivars planted in January at Umbumbulu. Note: * = missing data.

Taro cultivars	Gromor Accelerator rate (N kg ha^{-1})	Number of cormels weighing 50-350g (Score)	Dry matter content (Score)	Specific Gravity (Score)	Starch Content (Score)	Reducing Sugars (Score)	Total score
Dumbe-dumbe	0	0.5	1.2	0.5	1.5	1.0	4.7
	160	0.5	1.5	0.5	1.7	0.7	4.9
	320	0.5	1.4	0.5	1.3	0.8	4.5
Mgingqeni	0	0.5	1.2	0.9	1.4	1.0	5.0
	160	*	*	*	*	*	*
	320	*	*	*	*	*	*
Pitshi	0	0.5	1.6	0.7	1.5	0.9	5.2
	160	0.8	1.1	0.6	1.3	0.7	4.5
	320	0.5	0.9	0.6	1.3	0.4	3.7

Scores are interpreted in appendix 7.1

It has been reported that the surface morphology of starch granules changes during storage (Cottrell *et al*., 1993). This is supported by findings reported in Chapter 5 that showed that starch granules of *Dumbe-dumbe* and *Pitshi* appeared smooth at harvest and some of *Mgingqeni* appeared smooth while some were rough (Figs 5.1, 5.2 and 5.3) and that they showed signs of indentations, depressions and pitting which deepened with time in storage and ending up in granules breaking into smaller pieces. The severity of the change in surface morphology of starch granules varied between landraces being more pronounced for *Mgingqeni* followed by *Pitshi* and *Dumbe-dumbe* respectively (Fig. 5.4). Alpha amylase activity and sprouting also increased with time in storage with *Dumbe-dumbe* displaying highest alpha amylase activity than *Pitshi* and *Mgingqeni* respectively and *Mgingqeni* displaying highest sprouting than *Pitshi* and *Dumbe-dumbe* respectively. The response of reducing sugars and starch content to planting date and fertilisation was variable depending on landrace. Delayed planting positively affected reducing sugars and negatively affected starch content of *Dumbe-dumbe,* and negatively affected reducing sugars of *Pitshi* at Ukulinga (Fig 6.1). Fertiliser application had no effect on reducing sugars of *Dumbe-dumbe* but negatively affected those of *Mgingqeni* and *Pitshi* at Umbumbulu (Fig. 6.2) Fertilisation decreased starch content of *Pitshi,* delayed planting increased sugar content for *Dumbe-dumbe* and decreased it for *Mgingqeni* and *Pitshi* at Umbumbulu. *Dumbe-dumbe* had higher starch content and higher reducing sugars. Reducing sugars increased and starch content decreased with time and decrease in temperature in storage. Mesh bags had higher starch content while open boxes had higher reducing sugars. *Dumbe-dumbe* had higher starch content and higher reducing sugars.

From the findings of this study it can be recommended that *Dumbe-dumbe* is the best taro cultivar for crisping and the best time to plant it is October with 160 N kg ha^{-1} of organic fertiliser and November with 320 N kg ha^{-1} whereas at Umbumbulu the best time to plant *Dumbe-dumbe* is October with 320 N kg ha^{-1} of the fertiliser. This conclusion needs to be tested in a food processing study. It is also recommended that taro corms be stored at 12^{o}C for two months and at ambient temperature for four months to maintain the acceptable level of reducing sugars for crisp making.

From the agronomic perspective, the results of this study can be used to advise farmers on selection of taro cultivars in terms of planting date, yield performance and possible food processing characteristics.

References

Babaji, B.A., Amans, E.B., Chiezey, U.F., Falak, A.M., Tanimu, B. and Mukhtar, A.A. 2009. Unmarketable tuber yield and other agronomic parameters of four Varieties of Irish potato (*Solanum tuberosum* L.) as influenced by NPK fertilizer rate and type of seed tuber at Samaru, Nigeria. *Asian Journal of Crop Science* 1(1): 26-33.

Brown, J., Mackay, G.R., Bain, H., Griffith, D.W. and Allison, MJ. 1990. The Processing potential of tubers of the cultivated potato, *Solanum tuberosum* L., after storage at low temperature. 2. Sugar concentration. *Potato Research* 33: 219 - 227.

Carputo, D., Aversano, R. and Frusciante, L. 2005. Breeding potato for quality traits. *Acta Horticulturae* 684: 55-64.

Casa, R., Pieruccetti, F., Sgueglia, G. and LoCascio, B. 2005. Potato tuber quality improvement through nitrogen management optimization: Review of methodologies. *Acta Horticulturae* 684: 65-71.

Cottrell, J.E., Duffus, C.M., Mackay, G.R. and Allison, M.J. 1993. Changes in the surface morphology of starch granules of the cultivated potato, *Solanum tuberosum* L. during storage. *Potato Research* 36 (2): 119-125.

El-Sirafy, Z.M., Abbady, K.A., El-Ghamry, A.M and El-Dissoky, R.A. 2008. Potato yield quality, quantity and profitability as affected by soil and foliar potassium application. *Research Journal of Agriculture and Biological Sciences* 4 (6): 912-922.

Eskin, N.A.M. 1989. Quality and preservation of vegetables. CRS Press, Florida, USA.

Gebhardt, C., Menendez, C., Chen, X., Li, L. Schäfer-Pregl, R. and Salamini, F. 2005. *Acta Horticulturae* 684: 85-91.

Kader, A.A. and Rolle, R.S. 2004. The role of post-harvest management in assuring the quality and safety of horticultural produce. FAO Agricultural Services Bulletin 152.

Kay, D.E. 1987. Crop and product digest No. 2 Root crops. 2nd Edition. London: Tropical Development and Research Institute. 380 pp.

Kita, A. 2002. The influence of potato chemical composition on crisp texture. *Food Chemistry* 76 (2): 173-179.

Lu, H.Y., Lu, C.T., Chan, L.F. and Wei, M.L. 2001. Seasonal Variation in linear increase of taro harvest index explained by growing degree days. *Agronomy Journal* 93: 1136-1141.

Manrique, L. A. 1994. Nitrogen requirements of taro. *Journal of plant nutrition* 17(8): 1429-1441.

Martin, R.J., Scheffer, J.J.C., Deo, B. and Halloy, S.R.P. 2005. Effect of planting date on Ulluco yield. *Acta Horticulturae* 670: 181-187.

Mazid, M.A. 1993. Sulfur and nitrogen for sustainable rainfed lowland rice. PhD Thesis, University Philippines at Los Banos. 1-232.

Miyasaka, S.C., Ogoshi, R.M., Tsuji, G.Y. and Kodani, L.S. 2003. Site and planting date effects on taro growth: Comparison with aroid model predictions. *Agronomy Journal* 95: 545–557.

Mohamed, A.I. 1985. Dry matter, protein content and yield of potato as affected by cultivar and planting date in Sudan. *Acta Horticulturae* 158: 139- 141.

O`Keefe, O., Mason, G., Willis, A. and Bell, G. 2005. Commercial taro chip development using agri-chain partnerships: A processing, marketing and financial analysis. RIRDC Publication No 05/144. RIRDC Project No DAQ-296A.

Panhwar, F. 2005. Potato (*Solanum tuberosum* L.) – Cultural practice in Sindh Pakistan. Digitalverlag GmbH, Germany.

Proietti, S., Moscatello, S., Battistelli, A., Mauromicale, G. and Ierna, A. 2005. Quality of early potato in Sicily as affected by cultivar, sowing time and irrigation. *Acta Horticulturae* 684: 171.

Sangakkara, U.R. 1993. Response of sweet potato (*Ipomoea batatas* L.) to different planting times. *Journal of Agronomy and Crop Science* 172 (2): 113 – 118.

Scheffer, J.J.C., Douglas, J.A. and C.M. Triggs, C.M. 2005. Factors affecting the production and quality of Japanese taro cormels. *Acta Horticulturae* 670: 167-172.

Smith, O. 1987. Potato chips. In: W. Talburt and O. Smith, Editors, *Potato processing*, Van Nostrand Reinhold Company Inc, New York , p. 373.

Yosuke, M., Yaptenco, K.F., Tomohiro, N., Toshiro, S., Hiroaki, S., Shinji, M. and Katsumi, T. 2000. Property changes in potato tubers (*Solanum tuberosum* L.) during cold storage at 0 and 10^{o}C. *Food Preservation Science* 26 (3): 153-160.

APPENDICES

Appendix 3.1 Analysis of variance of the growth and yield parameters of taro obtained at Ukulinga.

A. Final_Emergence

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		212.52	106.26	0.39	
Replication.Planting_date stratum						
Planting_date	3		104918.26	34972.75	127.94	<.001
Residual	6		1640.08	273.35	1.18	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		13563.14	6781.57	29.25	<.001
Planting_date.Cultivar	6		4211.67	701.95	3.03	0.036
Residual	16		3709.59	231.85	3.83	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		675.97	337.99	5.58	0.007
Planting_date. Fertiliser	6		661.00	110.17	1.82	0.121
Cultivar. Fertiliser	4		534.26	133.56	2.21	0.087
Planting_date.Cultivar. Fertiliser	11	(1)	2003.58	182.14	3.01	0.006
Residual	38	(10)	2300.44	60.54		
Total	96	(11)	115054.49			

*NB – Numbers in brackets represent missing values.

B. Number of leaves plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		43.88	21.94	1.78	
Replication.Planting_date stratum						
Planting_date	3		1771.82	590.61	47.79	<.001
Residual	6		74.15	12.36	0.80	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		30.64	15.32	0.99	0.395
Planting_date.Cultivar	6		227.27	37.88	2.44	0.072
Residual	16		248.57	15.54	0.97	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		3.67	1.84	0.11	0.892
Planting_date. Fertiliser	6		64.09	10.68	0.67	0.678
Cultivar. Fertiliser	4		27.03	6.76	0.42	0.793
Planting_date.Cultivar. Fertiliser	11	(1)	243.78	22.16	1.38	0.222
Residual	38	(10)	610.27	16.06	0.99	
Replication.Planting_date.Cultivar. Fertiliser.*Units* stratum	268	(56)	4343.69	16.21		
Total	364	(67)	6936.01			

*NB – Numbers in brackets represent missing values.

C. Plant_height plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		556.1	278.0	6.46	
Replication.Planting_date stratum						
Planting_date	3		75101.3	25033.8	581.88	<.001
Residual	6		258.1	43.0	0.36	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		877.0	438.5	3.68	0.048
Planting_date.Cultivar	6		4029.2	671.5	5.64	0.003
Residual	16		1905.3	119.1	1.27	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		450.3	225.1	2.40	0.104
Planting_date. Fertiliser	6		780.5	130.1	1.39	0.244
Cultivar. Fertiliser	4		515.7	128.9	1.38	0.261
Planting_date.Cultivar. Fertiliser	11	(1)	3612.7	328.4	3.50	0.002
Residual	38	(10)	3561.0	93.7	0.25	
Replication.Planting_date.Cultivar. Fertiliser.*Units* stratum						
	275	(49)	102351.8	372.2		
Total	371	(60)	176357.0			

*NB – Numbers in brackets represent missing values.

D. Leaf_area plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		2642233.	1321117.	1.20	
Replication.Planting_date stratum						
Planting_date	3		236956431.	78985477.	71.54	<.001
Residual	6		6624562.	1104094.	1.72	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		400778.	200389.	0.31	0.737
Planting_date.Cultivar	6		12993682.	2165614.	3.37	0.024
Residual	16		10291099.	643194.	0.92	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		3390895.	1695447.	2.42	0.102
Planting_date. Fertiliser	6		7372226.	1228704.	1.76	0.135
Cultivar. Fertiliser	4		4169143.	1042286.	1.49	0.225
Planting_date.Cultivar. Fertiliser	11	(1)	13853417.	1259402.	1.80	0.089
Residual	38	(10)	26600910.	700024.	0.48	
Replication.Planting_date.Cultivar. Fertiliser.*Units* stratum						
	268	(56)	394813217.	1473184.		
Total	364	(67)	661451548.			

*NB – Numbers in brackets represent missing values.

E. Number_of_cormels plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		16.77	8.39	2.62	
Replication.Planting_date stratum						
Planting_date	3		3184.84	1061.61	332.18	<.001
Residual	6		19.18	3.20	0.30	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		487.71	243.86	23.01	<.001
Planting_date.Cultivar	6		361.44	60.24	5.69	0.004
Residual	14	(2)	148.34	10.60	1.04	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		7.78	3.89	0.38	0.686
Planting_date. Fertiliser	6		45.19	7.53	0.74	0.622
Cultivar. Fertiliser	4		15.97	3.99	0.39	0.813
Planting_date.Cultivar. Fertiliser	10	(2)	50.80	5.08	0.50	0.880
Residual	36	(12)	367.17	10.20		
Total	91	(16)	4091.20			

*NB – Numbers in brackets represent missing values.

F. Fresh_cormel_mass plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		11261.	5631.	0.59	
Replication.Planting_date stratum						
Planting_date	3		2182468.	727489.	76.85	<.001
Residual	6		56801.	9467.	1.59	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		5711.	2856.	0.48	0.628
Planting_date.Cultivar	6		154052.	25675.	4.32	0.011
Residual	14	(2)	83158.	5940.	0.69	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		2244.	1122.	0.13	0.878
Planting_date. Fertiliser	6		5611.	935.	0.11	0.995
Cultivar. Fertiliser	4		5044.	1261.	0.15	0.963
Planting_date.Cultivar. Fertiliser	10	(2)	41470.	4147.	0.48	0.890
Residual	36	(12)	309537.	8598.		
Total	91	(16)	2496335.			

*NB – Numbers in brackets represent missing values.

Appendix 3.2 Analysis of variance of the growth and yield parameters of taro obtained at Umbumbulu.

A. Final_emergence

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		92.03	46.01	0.38	
Replication.Planting_date stratum						
Planting_date	3		29461.16	9820.39	80.79	<.001
Residual	6		729.29	121.55	0.61	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		20472.58	10236.29	51.03	<.001
Planting_date.Cultivar	6		34440.91	5740.15	28.62	<.001
Residual	16		3209.50	200.59	2.45	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		134.67	67.33	0.82	0.446
Planting_date. Fertiliser	6		1157.79	192.97	2.36	0.047
Cultivar. Fertiliser	4		403.05	100.76	1.23	0.312
Planting_date.Cultivar. Fertiliser	12		940.71	78.39	0.96	0.502
Residual	43	(5)	3520.62	81.87		
Total	102	(5)	82982.70			

*NB – Numbers in brackets represent missing values.

B. Number of leaves plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.222	0.111	0.01	
Replication.Planting_date stratum						
Planting_date	3		393.426	131.142	10.09	0.009
Residual	6		77.997	12.999	1.67	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		159.406	79.703	10.24	0.001
Planting_date.Cultivar	6		75.521	12.587	1.62	0.206
Residual	16		124.517	7.782	1.41	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		34.811	17.406	3.15	0.053
Planting_date. Fertiliser	6		53.601	8.934	1.62	0.166
Cultivar. Fertiliser	4		11.178	2.795	0.51	0.732
Planting_date.Cultivar. Fertiliser	12		55.234	4.603	0.83	0.617
Residual	43	(5)	237.484	5.523	0.84	
Replication.Planting_date.Cultivar. Fertiliser.*Units* stratum	296	(28)	1940.500	6.556		
Total	398	(33)	3039.674			

*NB – Numbers in brackets represent missing values.

C. Plant_height plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		439.4	219.7	0.46	
Replication.Planting_date stratum						
Planting_date	3		13322.5	4440.8	9.38	0.011
Residual	6		2840.0	473.3	9.33	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		2325.8	1162.9	22.92	<.001
Planting_date.Cultivar	6		6339.2	1056.5	20.83	<.001
Residual	16		811.7	50.7	0.52	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		6018.2	3009.1	31.12	<.001
Planting_date. Fertiliser	6		2289.8	381.6	3.95	0.003
Cultivar. Fertiliser	4		1001.5	250.4	2.59	0.050
Planting_date.Cultivar. Fertiliser	12		984.0	82.0	0.85	0.603
Residual	43	(5)	4157.3	96.7	0.52	
Replication.Planting_date.Cultivar. Fertiliser.*Units* stratum						
	298	(26)	55517.4	186.3		
Total	400	(31)	90981.9			

*NB – Numbers in brackets represent missing values.

D. Leaf area plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		1778821.	889411.	1.31	
Replication.Planting_date stratum						
Planting_date	3		50167969.	16722656.	24.57	<.001
Residual	6		4082934.	680489.	7.83	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		4565423.	2282712.	26.25	<.001
Planting_date.Cultivar	6		5426177.	904363.	10.40	<.001
Residual	16		1391395.	86962.	0.43	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		10517229.	5258614.	25.87	<.001
Planting_date. Fertiliser	6		12067641.	2011273.	9.90	<.001
Cultivar. Fertiliser	4		751431.	187858.	0.92	0.459
Planting_date.Cultivar. Fertiliser	12		2470940.	205912.	1.01	0.454
Residual	43	(5)	8739752.	203250.	0.43	
Replication.Planting_date.Cultivar. Fertiliser.*Units* stratum						
	296	(28)	140898620.	476009.		
Total	398	(33)	235894673.			

*NB – Numbers in brackets represent missing values.

E. Number_of_cormels plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		2.304	1.152	0.37	
Replication.Planting_date stratum						
Planting_date	3		980.186	326.729	105.17	<.001
Residual	6		18.641	3.107	0.67	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		170.859	85.429	18.42	<.001
Planting_date.Cultivar	6		91.333	15.222	3.28	0.034
Residual	13	(3)	60.279	4.637	0.99	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		343.554	171.777	36.77	<.001
Planting_date. Fertiliser	6		330.202	55.034	11.78	<.001
Cultivar. Fertiliser	4		61.932	15.483	3.31	0.020
Planting_date.Cultivar. Fertiliser	9	(3)	45.996	5.111	1.09	0.390
Residual	38	(10)	177.507	4.671		
Total	91	(16)	2205.547			

*NB – Numbers in brackets represent missing values.

F. Fresh_cormel_mass plant^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		8560.	4280.	1.25	
Replication.Planting_date stratum						
Planting_date	3		897200.	299067.	87.37	<.001
Residual	6		20538.	3423.	0.40	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		32393.	16197.	1.89	0.191
Planting_date.Cultivar	6		50544.	8424.	0.98	0.476
Residual	13	(3)	111673.	8590.	3.46	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		208028.	104014.	41.95	<.001
Planting_date. Fertiliser	6		206012.	34335.	13.85	<.001
Cultivar. Fertiliser	4		24176.	6044.	2.44	0.064
Planting_date.Cultivar. Fertiliser	9	(3)	25183.	2798.	1.13	0.367
Residual	38	(10)	94222.	2480.		

Total 91 (16) 1548590.

*NB – Numbers in brackets represent missing values.

Appendix 3.3 Regression analysis of growth and yield parameters

A. Ukulinga

*** Summary of analysis ***

	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	5	726904.	145381.	50.36	<.001
Residual	30	86602.	2887.		
Total	35	813505.	23243.		

Percentage variance accounted for 87.6

*** Estimates of parameters ***

	estimate	s.e.	t(30)	t pr.
Constant	23.4	49.2	0.47	0.638
Emergence	1.016	0.617	1.65	0.110
Number_of_leaves_plant_1	-14.6	10.5	-1.38	0.176
Plant_height_plant_1	2.15	2.62	0.82	0.419
Leaf_area_plant_1	0.0881	0.0646	1.36	0.183
Number_of_corms_plant_1	6.94	3.68	1.89	0.069

*** Accumulated analysis of variance ***

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Emergence	1	600418.	600418.	207.99	<.001
+ Number_of_leaves_plant_1	1	22253.	22253.	7.71	0.009
+ Plant_height_plant_1	1	70195.	70195.	24.32	<.001
+ Leaf_area_plant_1	1	23767.	23767.	8.23	0.007
+ Number_of_corms_plant_1	1	10270.	10270.	3.56	0.069
Residual	30	86602.	2887.		
Total	35	813505.	23243.		

B. Umbumbulu

*** Summary of analysis ***

	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	5	354817.	70963.	17.60	<.001
Residual	30	120947.	4032.		
Total	35	475764.	13593.		

Percentage variance accounted for 70.3

*** Estimates of parameters ***

	estimate	s.e.	t(30)	t pr.
Constant	-72.1	60.6	-1.19	0.243
Emergence	1.283	0.445	2.88	0.007
Leaf_n	3.2	13.4	0.24	0.815
Pt_ht	2.04	2.77	0.74	0.468
Leaf_are	-0.0802	0.0756	-1.06	0.297
Corm_n	21.27	3.33	6.40	<.001

*** Accumulated analysis of variance ***

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Emerge	1	136243.	136243.	33.79	<.001
+ Leaf_n	1	19637.	19637.	4.87	0.035
+ Pt_ht	1	28234.	28234.	7.00	0.013
+ Leaf_area	1	5806.	5806.	1.44	0.239
+ Corm_n	1	164897.	164897.	40.90	<.001
Residual	30	120947.	4032.		
Total	35	475764.	13593.		

Appendix 3.4 Net returns hectare^{-1} of taro in KwaZulu-Natal.

Item	Unit	Quantity	Price/Unit (Zar)	Total (Zar)
Output	kg	8000	7	56000
(A) Variable costs				
Fertiliser	kg	5330	0.4	2132
Transport	km	20	1	20
Total				2152
(B) Labour inputs (Mandays)				
Propagule preparation	MD	2	40	80
Planting	MD	6	40	240
Weeding	MD	6 x 3	40	720
Fertilisation	MD	6	40	240
Harvesting	MD	6	40	240
Cleaning and sorting	MD	6	40	240
Transport to market		20 x 6	1	120
Total				1880
Total costs (TC)				4032
Net returns (NR)				51968
Benefit cost ratio (NR/TC)				12.89 : 1.00

Appendix 4.1 Analysis of variance of dry matter content of taro cormels obtained at Ukulinga.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		31.05	15.53	0.34	
Replication.Planting_date stratum						
Planting_date	3		334.84	111.61	2.43	0.163
Residual	6		275.42	45.90	1.87	
Replication.Planting_date.Cultivar stratum						
cultivar	2		37.65	18.83	0.77	0.484
Planting_date.Cultivar	6		486.33	81.05	3.30	0.031
Residual	14	(2)	344.29	24.59	1.32	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		163.73	81.86	4.39	0.020
Planting_date. Fertiliser	6		115.39	19.23	1.03	0.422
Cultivar. Fertiliser	4		181.45	45.36	2.43	0.065
Planting_date.Cultivar. Fertiliser	10	(2)	163.35	16.33	0.88	0.564
Residual	36	(12)	671.81	18.66		
Total	91	(16)	2492.24			

*NB – Numbers in brackets represent missing values.

Appendix 4.2 Analysis of variance of dry matter content of taro cormels obtained at Umbumbulu.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		164.68	82.34	0.59	
Replication.Planting_date stratum						
Planting_date	3		704.14	234.71	1.67	0.272
Residual	6		844.18	140.70	1.83	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		109.27	54.63	0.71	0.509
Planting_date.Cultivar	6		282.07	47.01	0.61	0.717
Residual	13	(3)	998.53	76.81	1.60	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		8.21	4.11	0.09	0.918
Planting_date. Fertiliser	6		192.03	32.00	0.67	0.677
Cultivar. Fertiliser	4		151.29	37.82	0.79	0.540
Planting_date.Cultivar. Fertiliser	9	(3)	531.13	59.01	1.23	0.307
Residual	38	(10)	1824.36	48.01		
Total	91	(16)	4855.13			

*NB – Numbers in brackets represent missing values.

Appendix 4.3 Analysis of variance of specific gravity of taro cormels obtained at Ukulinga.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.011153	0.005577	0.77	
Replication.Planting_date stratum						
Planting_date	3		0.005959	0.001986	0.27	0.843
Residual	6		0.043556	0.007259	3.01	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.003064	0.001532	0.63	0.545
Planting_date.Cultivar	6		0.104893	0.017482	7.24	0.001
Residual	14	(2)	0.033801	0.002414	0.47	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.000847	0.000423	0.08	0.922
Planting_date. Fertiliser	6		0.099410	0.016568	3.20	0.013
Cultivar. Fertiliser	4		0.018292	0.004573	0.88	0.483
Planting_date.Cultivar. Fertiliser	10	(2)	0.067963	0.006796	1.31	0.261
Residual	36	(12)	0.186307	0.005175		
Total	91	(16)	0.451354			

*NB – Numbers in brackets represent missing values.

Appendix 4.4 Analysis of variance of specific gravity of taro cormels obtained at Umbumbulu.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replications stratum	2		0.006355	0.003177	0.37	
Replication.Planting_date stratum						
Planting_date	3		0.070256	0.023419	2.71	0.138
Residual	6		0.051790	0.008632	2.93	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.032539	0.016269	5.53	0.018
Planting_date.Cultivar	6		0.058566	0.009761	3.32	0.033
Residual	13	(3)	0.038233	0.002941	1.47	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.018817	0.009408	4.71	0.015
Planting_date. Fertiliser	6		0.053055	0.008843	4.43	0.002
Cultivar. Fertiliser	4		0.015109	0.003777	1.89	0.132
Planting_date.Cultivar. Fertiliser	9	(3)	0.008654	0.000962	0.48	0.878
Residual	38	(10)	0.075870	0.001997		
Total	91	(16)	0.311286			

*NB – Numbers in brackets represent missing values.

Appendix 4.5 Analysis of variance of protein content of taro cormels obtained at Ukulinga.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		7.398	3.699	0.94	
Replication.Planting_date stratum						
Planting_date	3		359.798	119.933	30.39	<.001
Residual	6		23.681	3.947	0.91	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.379	0.190	0.04	0.958
Planting_date.Cultivar	6		44.167	7.361	1.69	0.196
Residual	14	(2)	60.949	4.354	1.87	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		17.650	8.825	3.79	0.032
Planting_date. Fertiliser	6		13.316	2.219	0.95	0.471
Cultivar. Fertiliser	4		13.993	3.498	1.50	0.223
Planting_date.Cultivar. Fertiliser	10	(2)	34.178	3.418	1.47	0.194
Residual	35	(13)	81.587	2.331		
Total	90	(17)	502.891			

*NB – Numbers in brackets represent missing values.

Appendix 4.6 Analysis of variance of protein content of taro cormels obtained at Umbumbulu.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		23.366	11.683	3.53	
Replication.Planting_date stratum						
Planting_date	3		56.969	18.990	5.73	0.034
Residual	6		19.882	3.314	1.69	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		103.581	51.790	26.42	<.001
Planting_date.Cultivar	6		77.771	12.962	6.61	0.002
Residual	13	(3)	25.484	1.960	1.43	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		115.946	57.973	42.24	<.001
Planting_date. Fertiliser	6		8.520	1.420	1.03	0.418
Cultivar. Fertiliser	4		5.209	1.302	0.95	0.447
Planting_date.Cultivar. Fertiliser	9	(3)	10.462	1.162	0.85	0.579
Residual	38	(10)	52.160	1.373		
Total	91	(16)	321.166			

*NB – Numbers in brackets represent missing values.

Appendix 4.7 Analysis of variance of total protein of taro cormels obtained at Ukulinga.

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	25.54	12.77	0.60	
Replication.Planting_date stratum					
Planting_date	3	1525.65	508.55	23.83	<.001
Residual	6	128.05	21.34	2.73	
Replication.Planting_date.Cultivar stratum					
Cultivar	2	25.03	12.51	1.60	0.237
Planting_date.Cultivar	6	267.62	44.60	5.70	0.004
Residual	14(2)	109.59	7.83	0.73	
Replication.Planting_date.Cultivar.Fertiliser stratum					
Fertiliser	2	2.77	1.38	0.13	0.879
Planting_date.Fertiliser	6	17.30	2.88	0.27	0.947
Cultivar.Fertiliser	4	26.03	6.51	0.61	0.658
Planting_date.Cultivar.Fertiliser	10(2)	44.41	4.44	0.42	0.929
Residual	35(13)	373.19	10.66		
Total	90(17)	2256.84			

*NB – Numbers in brackets represent missing values.

Appendix 4.8 Analysis of variance of total protein of taro cormels obtained at Umbumbulu.

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	3.215	1.607	0.59	
Replication.Planting_date stratum					
Planting_date	3	350.770	116.923	42.71	<.001
Residual	6	16.425	2.738	0.77	
Replication.Planting_date.Cultivar stratum					
Cultivar	2	17.525	8.762	2.45	0.125
Planting_date.Cultivar	6	25.151	4.192	1.17	0.377
Residual	13(3)	46.411	3.570	2.21	
Replication.Planting_date.Cultivar.Fertiliser stratum					
Fertiliser	2	63.204	31.602	19.53	<.001
Planting_date.Fertiliser	6	74.143	12.357	7.64	<.001
Cultivar.Fertiliser	4	20.936	5.234	3.24	0.022
Planting_date.Cultivar.Fertiliser	9(3)	13.171	1.463	0.90	0.531
Residual	38(10)	61.476	1.618		
Total	91(16)	630.661			

*NB – Numbers in brackets represent missing values.

Appendix 4.9 Analysis of variance of mineral content of taro cormels obtained at Ukulinga.

A. Nitrogen content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.18939	0.09469	0.94	
Replication.Planting_date stratum						
Planting_date	3		9.21082	3.07027	30.39	<.001
Residual	6		0.60623	0.10104	0.91	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.00971	0.00485	0.04	0.958
Planting_date.Cultivar	6		1.13067	0.18845	1.69	0.196
Residual	14	(2)	1.56030	0.11145	1.87	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.45184	0.22592	3.79	0.032
Planting_date. Fertiliser	6		0.34089	0.05681	0.95	0.471
Cultivar. Fertiliser	4		0.35822	0.08956	1.50	0.223
Planting_date.Cultivar. Fertiliser	10	(2)	0.87496	0.08750	1.47	0.194
Residual	35	(13)	2.08864	0.05968		
Total	90	(17)	12.87401			

*NB – Numbers in brackets represent missing values.

B. Phosphorus content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.018861	0.009430	4.70	
Replication.Planting_date stratum						
Planting_date	3		0.125719	0.041906	20.91	0.001
Residual	6		0.012026	0.002004	1.13	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.209736	0.104868	59.36	<.001
Planting_date.Cultivar	6		0.036356	0.006059	3.43	0.027
Residual	14	(2)	0.024734	0.001767	0.71	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.004138	0.002069	0.83	0.445
Planting_date. Fertiliser	6		0.019022	0.003170	1.27	0.297
Cultivar. Fertiliser	4		0.008115	0.002029	0.81	0.526
Planting_date.Cultivar. Fertiliser	10	(2)	0.020734	0.002073	0.83	0.604
Residual	35	(13)	0.087494	0.002500		
Total	90	(17)	0.443503			

*NB – Numbers in brackets represent missing values.

C. Potassium content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.8600	0.4300	5.17	
Replication.Planting_date stratum						
Planting_date	3		11.8562	3.9521	47.49	<.001
Residual	6		0.4993	0.0832	0.90	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.2123	0.1061	1.14	0.347
Planting_date.Cultivar	6		2.4111	0.4019	4.33	0.011
Residual	14	(2)	1.2994	0.0928	0.85	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.3530	0.1765	1.62	0.212
Planting_date. Fertiliser	6		0.5004	0.0834	0.77	0.602
Cultivar. Fertiliser	4		0.1142	0.0286	0.26	0.900
Planting_date.Cultivar. Fertiliser	10	(2)	0.9831	0.0983	0.90	0.541
Residual	35	(13)	3.8113	0.1089		
Total	90	(17)	20.7341			

*NB – Numbers in brackets represent missing values.

D. Calcium content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.0024914	0.0012457	0.70	
Replication.Planting_date stratum						
Planting_date	3		0.0094658	0.0031553	1.76	0.254
Residual	6		0.0107408	0.0017901	1.30	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.0062883	0.0031442	2.28	0.139
Planting_date.Cultivar	6		0.0198132	0.0033022	2.39	0.084
Residual	14	(2)	0.0193182	0.0013799	1.52	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.0011212	0.0005606	0.62	0.545
Planting_date. Fertiliser	6		0.0041626	0.0006938	0.76	0.603
Cultivar. Fertiliser	4		0.0047064	0.0011766	1.30	0.291
Planting_date.Cultivar. Fertiliser	10	(2)	0.0041693	0.0004169	0.46	0.905
Residual	35	(13)	0.0317845	0.0009081		
Total	90	(17)	0.0906615			

*NB – Numbers in brackets represent missing values.

E. Magnesium content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.000263	0.000131	0.17	
Replication.Planting_date stratum						
Planting_date	3		0.003315	0.001105	1.41	0.329
Residual	6		0.004706	0.000784	0.74	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.055776	0.027888	26.27	<.001
Planting_date.Cultivar	6		0.007013	0.001169	1.10	0.409
Residual	14	(2)	0.014863	0.001062	0.96	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.000054	0.000027	0.02	0.976
Planting_date. Fertiliser	6		0.008374	0.001396	1.26	0.300
Cultivar. Fertiliser	4		0.004797	0.001199	1.08	0.379
Planting_date.Cultivar. Fertiliser	10	(2)	0.012960	0.001296	1.17	0.342
Residual	35	(13)	0.038710	0.001106		
Total	90	(17)	0.119213			

*NB – Numbers in brackets represent missing values.

F. Zinc content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		24159.	12080.	14.66	
Replication.Planting_date stratum						
Planting_date	3		12958.	4319.	5.24	0.041
Residual	6		4943.	824.	0.74	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		5962.	2981.	2.67	0.104
Planting_date.Cultivar	6		5269.	878.	0.79	0.596
Residual	14	(2)	15657.	1118.	0.75	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		436.	218.	0.15	0.865
Planting_date. Fertiliser	6		6527.	1088.	0.73	0.631
Cultivar. Fertiliser	4		3393.	848.	0.57	0.689
Planting_date.Cultivar. Fertiliser	10	(2)	13213.	1321.	0.88	0.558
Residual	35	(13)	52402.	1497.		
Total	90	(17)	133872.			

*NB – Numbers in brackets represent missing values.

G. Copper content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		6.298	3.149	0.92	
Replication.Planting_date stratum						
Planting_date	3		31.029	10.343	3.03	0.115
Residual	6		20.498	3.416	0.90	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		1.179	0.590	0.15	0.858
Planting_date.Cultivar	6		55.100	9.183	2.41	0.082
Residual	14	(2)	53.274	3.805	1.54	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.431	0.216	0.09	0.917
Planting_date. Fertiliser	6		22.553	3.759	1.52	0.200
Cultivar. Fertiliser	4		1.976	0.494	0.20	0.937
Planting_date.Cultivar. Fertiliser	10	(2)	29.930	2.993	1.21	0.317
Residual	35	(13)	86.380	2.468		
Total	90	(17)	219.630			

*NB – Numbers in brackets represent missing values.

H. Iron content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		1201.65	600.82	11.90	
Replication.Planting_date stratum						
Planting_date	3		598.80	199.60	3.95	0.072
Residual	6		302.99	50.50	0.39	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		530.28	265.14	2.05	0.166
Planting_date.Cultivar	6		357.56	59.59	0.46	0.826
Residual	14	(2)	1812.82	129.49	1.36	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		28.17	14.08	0.15	0.863
Planting_date. Fertiliser	6		625.61	104.27	1.10	0.384
Cultivar. Fertiliser	4		613.94	153.49	1.61	0.193
Planting_date.Cultivar. Fertiliser	10	(2)	819.44	81.94	0.86	0.576
Residual	35	(13)	3329.11	95.12		

Total 90 (17) 8889.85

*NB – Numbers in brackets represent missing values.

I. Manganese content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		280.72	140.36	1.72	
Replication.Planting_date stratum						
Planting_date	3		554.35	184.78	2.26	0.182
Residual	6		490.42	81.74	6.10	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		86.69	43.35	3.24	0.070
Planting_date.Cultivar	6		272.33	45.39	3.39	0.028
Residual	14	(2)	187.50	13.39	0.75	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		27.73	13.87	0.78	0.468
Planting_date. Fertiliser	6		98.74	16.46	0.92	0.492
Cultivar. Fertiliser	4		104.91	26.23	1.47	0.233
Planting_date.Cultivar. Fertiliser	10	(2)	47.39	4.74	0.27	0.985
Residual	35	(13)	625.62	17.87		
Total	90	(17)	2252.99			

*NB – Numbers in brackets represent missing values.

J. Sodium content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		160692.	80346.	2.19	
Replication.Planting_date stratum						
Planting_date	3		132127.	44042.	1.20	0.387
Residual	6		220145.	36691.	3.05	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		10654.	5327.	0.44	0.651
Planting_date.Cultivar	6		138335.	23056.	1.92	0.148
Residual	14	(2)	168445.	12032.	2.11	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		33976.	16988.	2.97	0.064
Planting_date. Fertiliser	6		76304.	12717.	2.23	0.064
Cultivar. Fertiliser	4		95034.	23758.	4.16	0.007
Planting_date.Cultivar. Fertiliser	10	(2)	116696.	11670.	2.04	0.058
Residual	35	(13)	200014.	5715.		
Total	90	(17)	1006048.			

*NB – Numbers in brackets represent missing values.

Appendix 4.10 Analysis of variance of mineral content of taro cormels obtained at Umbumbulu.

A. Nitrogen content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.59817	0.29909	3.53	
Replication.Planting_date stratum						
Planting_date	3		1.45842	0.48614	5.73	0.034
Residual	6		0.50898	0.08483	1.69	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		2.65167	1.32583	26.42	<.001
Planting_date.Cultivar	6		1.99094	0.33182	6.61	0.002
Residual	13	(3)	0.65240	0.05018	1.43	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		2.96821	1.48410	42.24	<.001
Planting_date. Fertiliser	6		0.21812	0.03635	1.03	0.418
Cultivar. Fertiliser	4		0.13334	0.03334	0.95	0.447
Planting_date.Cultivar. Fertiliser	9	(3)	0.26784	0.02976	0.85	0.579
Residual	38	(10)	1.33529	0.03514		
Total	91	(16)	8.22184			

*NB – Numbers in brackets represent missing values.

B. Phosphorus content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.0025969	0.0012985	0.74	
Replication.Planting_date stratum						
Planting_date	3		0.0048505	0.0016168	0.92	0.487
Residual	6		0.0105881	0.0017647	1.34	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.0057016	0.0028508	2.16	0.155
Planting_date.Cultivar	6		0.0114571	0.0019095	1.45	0.270
Residual	13	(3)	0.0171402	0.0013185	1.41	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.1858619	0.0929309	99.26	<.001
Planting_date. Fertiliser	6		0.0151422	0.0025237	2.70	0.028
Cultivar. Fertiliser	4		0.0009827	0.0002457	0.26	0.900
Planting_date.Cultivar. Fertiliser	9	(3)	0.0231217	0.0025691	2.74	0.014
Residual	38	(10)	0.0355779	0.0009363		
Total	91	(16)	0.2572989			

*NB – Numbers in brackets represent missing values.

C. Potassium content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.0431	0.0215	0.03	
Replication.Planting_date stratum						
Planting_date	3		2.2790	0.7597	0.91	0.488
Residual	6		4.9816	0.8303	8.54	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		2.5927	1.2963	13.34	<.001
Planting_date.Cultivar	6		1.0820	0.1803	1.86	0.165
Residual	13	(3)	1.2636	0.0972	0.86	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		2.5935	1.2968	11.53	<.001
Planting_date. Fertiliser	6		1.2199	0.2033	1.81	0.124
Cultivar. Fertiliser	4		0.3285	0.0821	0.73	0.577
Planting_date.Cultivar. Fertiliser	9	(3)	0.7815	0.0868	0.77	0.642
Residual	38	(10)	4.2730	0.1124		
Total	91	(16)	16.5702			

*NB – Numbers in brackets represent missing values.

D. Calcium content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.0012112	0.0006056	0.34	
Replication.Planting_date stratum						
Planting_date	3		0.0057354	0.0019118	1.07	0.428
Residual	6		0.0106837	0.0017806	1.48	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.0256716	0.0128358	10.67	0.002
Planting_date.Cultivar	6		0.0121805	0.0020301	1.69	0.202
Residual	13	(3)	0.0156414	0.0012032	1.23	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.0036160	0.0018080	1.85	0.171
Planting_date. Fertiliser	6		0.0087116	0.0014519	1.48	0.210
Cultivar. Fertiliser	4		0.0037541	0.0009385	0.96	0.441
Planting_date.Cultivar. Fertiliser	9	(3)	0.0043296	0.0004811	0.49	0.871
Residual	38	(10)	0.0371863	0.0009786		
Total	91	(16)	0.1185250			

*NB – Numbers in brackets represent missing values.

E. Magnesium content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.0018300	0.0009150	2.62	
Replication.Planting_date stratum						
Planting_date	3		0.0047294	0.0015765	4.52	0.055
Residual	6		0.0020936	0.0003489	1.03	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.0015535	0.0007768	2.30	0.140
Planting_date.Cultivar	6		0.0049195	0.0008199	2.43	0.085
Residual	13	(3)	0.0043938	0.0003380	1.73	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		0.0003670	0.0001835	0.94	0.399
Planting_date. Fertiliser	6		0.0026931	0.0004488	2.30	0.054
Cultivar. Fertiliser	4		0.0011338	0.0002834	1.45	0.236
Planting_date.Cultivar. Fertiliser	9	(3)	0.0020468	0.0002274	1.17	0.344
Residual	38	(10)	0.0074167	0.0001952		
Total	91	(16)	0.0279685			

*NB – Numbers in brackets represent missing values.

F. Zinc content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		114.51	57.25	1.28	
Replication.Planting_date stratum						
Planting_date	3		865.45	288.48	6.44	0.026
Residual	6		268.81	44.80	0.57	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		61.02	30.51	0.39	0.688
Planting_date.Cultivar	6		527.63	87.94	1.11	0.408
Residual	13	(3)	1029.95	79.23	1.49	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		394.93	197.46	3.72	0.034
Planting_date. Fertiliser	6		738.10	123.02	2.32	0.053
Cultivar. Fertiliser	4		328.87	82.22	1.55	0.208
Planting_date.Cultivar. Fertiliser	9	(3)	344.54	38.28	0.72	0.687
Residual	38	(10)	2018.23	53.11		
Total	91	(16)	5332.74			

*NB – Numbers in brackets represent missing values.

G. Copper content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		15.539	7.769	2.07	
Replication.Planting_date stratum						
Planting_date	3		7.692	2.564	0.68	0.594
Residual	6		22.539	3.756	1.87	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		174.885	87.442	43.57	<.001
Planting_date.Cultivar	6		17.888	2.981	1.49	0.258
Residual	13	(3)	26.090	2.007	1.96	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		11.890	5.945	5.81	0.006
Planting_date. Fertiliser	6		7.694	1.282	1.25	0.301
Cultivar. Fertiliser	4		11.145	2.786	2.72	0.043
Planting_date.Cultivar. Fertiliser	9	(3)	25.922	2.880	2.82	0.012
Residual	38	(10)	38.857	1.023		
Total	91	(16)	293.257			

*NB – Numbers in brackets represent missing values.

H. Iron content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		5.5	2.7	0.04	
Replication.Planting_date stratum						
Planting_date	3		339.9	113.3	1.45	0.318
Residual	6		467.5	77.9	0.42	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		235.8	117.9	0.63	0.548
Planting_date.Cultivar	6		2530.6	421.8	2.26	0.103
Residual	13	(3)	2430.5	187.0	1.15	
Replication.Planting_date.Cultivar. Fertiliser stratum						
Fertiliser	2		619.7	309.8	1.91	0.162
Planting_date. Fertiliser	6		1454.8	242.5	1.49	0.207
Cultivar.Fertiliser	4		406.3	101.6	0.63	0.647
Planting_date.Cultivar.Fertiliser	9	(3)	1489.2	165.5	1.02	0.443
Residual	38	(10)	6173.0	162.4		
Total	91	(16)	12424.3			

*NB – Numbers in brackets represent missing values.

I. Manganese content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		84.53	42.26	0.44	
Replication.Planting_date stratum						
Planting_date	3		1009.10	336.37	3.54	0.088
Residual	6		570.26	95.04	3.15	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		861.95	430.97	14.31	<.001
Planting_date.Cultivar	6		149.24	24.87	0.83	0.570
Residual	13	(3)	391.66	30.13	0.87	
Replication.Planting_date.Cultivar.Fertiliser stratum						
Fertiliser	2		396.05	198.02	5.71	0.007
Planting_date.Fertiliser	6		561.75	93.63	2.70	0.028
Cultivar.Fertiliser	4		154.53	38.63	1.11	0.364
Planting_date.Cultivar.Fertiliser	9	(3)	170.88	18.99	0.55	0.830
Residual	38	(10)	1317.06	34.66		
Total	91	(16)	5250.61			

*NB – Numbers in brackets represent missing values.

J. Sodium content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		606760.	303380.	0.88	
Replication.Planting_date stratum						
Planting_date	3		1239848.	413283.	1.20	0.386
Residual	6		2063338.	343890.	3.08	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		26045.	13022.	0.12	0.891
Planting_date.Cultivar	6		341054.	56842.	0.51	0.791
Residual	13	(3)	1449369.	111490.	2.05	
Replication.Planting_date.Cultivar.Fertiliser stratum						
Fertiliser	2		108713.	54356.	1.00	0.378
Planting_date.Fertiliser	6		99940.	16657.	0.31	0.930
Cultivar.Fertiliser	4		49778.	12445.	0.23	0.921
Planting_date.Cultivar.Fertiliser	9	(3)	793080.	88120.	1.62	0.145
Residual	38	(10)	2068092.	54423.		
Total	91	(16)	8486333.			

*NB – Numbers in brackets represent missing values.

Appendix 5.1 Analysis of variance of alpha-amylase activity of taro cormels of three taro cultivars (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) stored at 12^{o}C and ambient temperature in three packagings (Polyethylene bag, open box and mesh bag) for four months.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.0072425	0.0036212	3.37	
Replication.Wholeplot stratum						
Storage_temperature	1		0.0073872	0.0073872	6.87	0.120
Residual	2		0.0021500	0.0010750	1.39	
Replication.Wholeplot.Subplot stratum						
Packaging	2		0.0076523	0.0038261	4.94	0.040
Storage_temperature.Packaging	2		0.0080367	0.0040184	5.19	0.036
Residual	8		0.0061906	0.0007738	0.89	
Replication.Wholeplot.Subplot.Subsubplot stratum						
Cultivar	2		0.0118370	0.0059185	6.78	0.005
Storage_temperature.Cultivar	2		0.0233011	0.0116506	13.34	<.001
Packaging.Cultivar	4		0.0033910	0.0008478	0.97	0.442
Storage_temperature.Packaging.Cultivar	4		0.0424579	0.0106145	12.15	<.001
Residual	24		0.0209627	0.0008734	1.29	
Replication.Wholeplot.Subplot.Subsubplot.*Units* stratum						
Sampling_Month	4		0.0933289	0.0233322	34.52	<.001
Storage_temperature.Sampling_Month	4		0.0465050	0.0116263	17.20	<.001
Packaging.Sampling_Month	8		0.0372076	0.0046509	6.88	<.001
Cultivar.Sampling_Month	8		0.0956707	0.0119588	17.69	<.001
Storage_temperature.Packaging.Sampling_Month	7	(1)	0.0423961	0.0060566	8.96	<.001
Storage_temperature.Cultivar.Sampling_Month	8		0.0924113	0.0115514	17.09	<.001
Packaging.Cultivar.Sampling_Month	16		0.0760198	0.0047512	7.03	<.001
Storage_temperature.Packaging.Cultivar.Sampling_Month	5	(11)	0.0428136	0.0085627	12.67	<.001
Residual	120	(24)	0.0811100	0.0006759		
Total	233	(36)	0.6572201			

*NB – Numbers in brackets represent missing values.

Appendix 5.2 Analysis of variance of sprouting of taro cormels of three taro cultivars (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) stored at 12^{o}C and ambient temperature in three packagings (Polyethylene bag, open box and mesh bag) for four months.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	9.40	4.70	0.42	
Replication.Wholeplot stratum					
Temperature	1	11362.09	11362.09	1020.23	<.001
Residual	2	22.27	11.14	0.69	
Replication.Wholeplot.Subplot stratum					
Packaging	2	9531.73	4765.87	294.29	<.001
Temperature.Packaging	2	2092.92	1046.46	64.62	<.001
Residual	8	129.56	16.19	1.12	
Replication.Wholeplot.Subplot.Subsubplot stratum					
Cultivar	2	776.18	388.09	26.72	<.001
Temperature.Cultivar	2	195.24	97.62	6.72	0.005
Packaging.Cultivar	4	3902.56	975.64	67.18	<.001
Temperature.Packaging.Cultivar	4	1091.69	272.92	18.79	<.001
Residual	24	348.52	14.52	1.30	
Replication.Wholeplot.Subplot.Subsubplot.*Units* stratum					
Month	4	77374.28	19343.57	1737.98	<.001
Temperature.Month	4	16682.30	4170.57	374.72	<.001
Packaging.Month	8	15847.03	1980.88	177.98	<.001
Cultivar.Month	8	1254.93	156.87	14.09	<.001
Temperature.Packaging.Month	8	2977.55	372.19	33.44	<.001
Temperature.Cultivar.Month	8	387.15	48.39	4.35	<.001
Packaging.Cultivar.Month	16	5853.95	365.87	32.87	<.001
Temperature.Packaging.Cultivar.Month	16	1886.08	117.88	10.59	<.001
Residual	144	1602.71	11.13		
Total	269	153328.13			

Appendix 6.1 Analysis of variance of reducing sugar content of taro cormels obtained at Ukulinga.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.00918	0.00459	0.34	
Replication.Planting_date stratum						
Planting_date	3		0.09443	0.03148	2.31	0.176
Residual	6		0.08188	0.01365	0.32	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.21542	0.10771	2.55	0.116
Planting_date.Cultivar	6		0.19700	0.03283	0.78	0.601
Residual	13	(3)	0.54847	0.04219	1.70	
Replication.Planting_date.Cultivar.Fertiliser stratum						
Fertiliser	2		0.16537	0.08269	3.34	0.052
Planting_date.Fertiliser	6		0.76659	0.12777	5.15	0.001
Cultivar.Fertiliser	4		0.20524	0.05131	2.07	0.115
Planting_date.Cultivar.Fertiliser	9	(3)	0.14405	0.01601	0.65	0.748
Residual	25	(23)	0.61973	0.02479		
Total	78	(29)	2.13752			

*NB – Numbers in brackets represent missing values.

Appendix 6.2 Analysis of variance of reducing sugar content of taro cormels obtained at Umbumbulu.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.16644	0.08322	1.03	
Replication.Planting_date stratum						
Planting_date	3		1.82616	0.60872	7.55	0.018
Residual	6		0.48351	0.08058	0.53	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		0.27082	0.13541	0.89	0.434
Planting_date.Cultivar	6		1.04569	0.17428	1.15	0.391
Residual	13	(3)	1.97847	0.15219	5.15	
Replication.Planting_date.Cultivar.Fertiliser stratum						
Fertiliser	2		0.00459	0.00229	0.08	0.926
Planting_date.Fertiliser	6		0.24753	0.04125	1.40	0.267
Cultivar.Fertiliser	4		0.05439	0.01360	0.46	0.764
Planting_date.Cultivar.Fertiliser	8	(4)	0.26711	0.03339	1.13	0.388
Residual	19	(29)	0.56167	0.02956		
Total	71	(36)	3.03246			

*NB – Numbers in brackets represent missing values.

Appendix 6.3 Analysis of variance of reducing sugar content of taro cormels of three taro cultivars (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) stored at 12^{o}C and ambient temperature in three packagings (Polyethylene bag, open box and mesh bag) for four months.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.026985	0.013492	4.59	
Replication.Wholeplot stratum						
Temperature	1		0.395134	0.395134	134.35	0.007
Residual	2		0.005882	0.002941	0.31	
Replication.Wholeplot.Subplot stratum						
Packaging	2		0.122810	0.061405	6.48	0.021
Temperature.Packaging	2		0.011125	0.005563	0.59	0.578
Residual	8		0.075764	0.009470	0.98	
Replication.Wholeplot.Subplot.Subsubplot stratum						
Cultivar	2		0.050205	0.025102	2.59	0.096
Temperature.Cultivar	2		0.102922	0.051461	5.31	0.012
Packaging.Cultivar	4		0.126182	0.031545	3.26	0.029
Temperature.Packaging.Cultivar	4		0.179729	0.044932	4.64	0.006
Residual	24		0.232438	0.009685	2.37	
Replication.Wholeplot.Subplot.Subsubplot.*Units* stratum						
Month	3		1.344432	0.448144	109.89	<.001
Temperature.Month	3		0.525417	0.175139	42.95	<.001
Packaging.Month	6		0.111313	0.018552	4.55	<.001
Cultivar.Month	6		0.113996	0.018999	4.66	<.001
Temperature.Packaging.Month	6		0.165271	0.027545	6.75	<.001
Temperature.Cultivar.Month	6		0.065013	0.010836	2.66	0.020
Packaging.Cultivar.Month	12		0.214129	0.017844	4.38	<.001
Temperature.Packaging.Cultivar.Month	8	(4)	0.107757	0.013470	3.30	0.002
Residual	100	(8)	0.407804	0.004078		
Total	203	(12)	3.402170			

*NB – Numbers in brackets represent missing values.

Appendix 6.4 Analysis of variance of starch content of taro cormels obtained at Ukulinga.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		10.29	5.15	0.09	
Replication.Planting_date stratum						
Planting_date	3		246.16	82.05	1.41	0.328
Residual	6		348.76	58.13	2.45	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		98.88	49.44	2.08	0.161
Planting_date.Cultivar	6		580.73	96.79	4.08	0.014
Residual	14	(2)	332.31	23.74	0.58	
Replication.Planting_date.Cultivar.Fertiliser stratum						
Fertiliser	2		2.86	1.43	0.04	0.966
Planting_date.Fertiliser						
	6		100.02	16.67	0.41	0.869
Cultivar.Fertiliser	4		229.59	57.40	1.41	0.252
Planting_date.Cultivar.Fertiliser						
	10	(2)	202.12	20.21	0.49	0.882
Residual	36	(12)	1470.12	40.84		
Total	91	(16)	3154.31			

*NB – Numbers in brackets represent missing values.

Appendix 6.5 Analysis of variance of starch content of taro cormels obtained at Umbumbulu.

Variate: Starch_content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		115.82	57.91	0.61	
Replication.Planting_date stratum						
Planting_date	3		1431.07	477.02	5.02	0.045
Residual	6		570.20	95.03	1.44	
Replication.Planting_date.Cultivar stratum						
Cultivar	2		241.06	120.53	1.83	0.200
Planting_date.Cultivar	6		42.56	7.09	0.11	0.994
Residual	13	(3)	857.52	65.96	1.35	
Replication.Planting_date.Cultivar.Fertiliser stratum						
Fertiliser	2		142.07	71.03	1.46	0.245
Planting_date.Fertiliser						
	6		679.90	113.32	2.33	0.052
Cultivar.Fertiliser	4		749.95	187.49	3.85	0.010
Planting_date.Cultivar.Fertiliser						
	9	(3)	259.15	28.79	0.59	0.796
Residual	38	(10)	1850.62	48.70		
Total	91	(16)	5822.49			

*NB – Numbers in brackets represent missing values.

Appendix 6.6 Analysis of variance of starch content of taro cormels of three taro cultivars (*Dumbe-dumbe*, *Mgingqeni* and *Pitshi*) stored at 12°C and ambient temperature in three packagings (Polyethylene bag, open box and mesh bag) for four months.

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.05075	0.02537	0.53	
Replication.Wholeplot stratum						
Temperature	1		21.09262	21.09262	443.94	0.002
Residual	2		0.09502	0.04751	1.07	
Replication.Wholeplot.Subplot stratum						
Packaging	2		528.39979	264.19989	5950.40	<.001
Temperature.Packaging	2		7.26627	3.63313	81.83	<.001
Residual	8		0.35520	0.04440	0.99	
Replication.Wholeplot.Subplot.Subsubplot stratum						
Cultivar	2		1387.63707	693.81854	15467.41	<.001
Temperature.Cultivar	2		192.28082	96.14041	2143.27	<.001
Packaging.Cultivar	4		119.71358	29.92840	667.20	<.001
Temperature.Packaging.Cultivar	4		107.51135	26.87784	599.19	<.001
Residual	24		1.07656	0.04486	0.82	
Replication.Wholeplot.Subplot.Subsubplot.*Units* stratum						
Month	3		1570.26964	523.42321	9605.13	<.001
Temperature.Month	3		8.79465	2.93155	53.80	<.001
Packaging.Month	6		137.43789	22.90632	420.34	<.001
Cultivar.Month	6		100.61177	16.76863	307.71	<.001
Temperature.Packaging.Month	6		44.51222	7.41870	136.14	<.001
Temperature.Cultivar.Month	5	(1)	23.94719	4.78944	87.89	<.001
Packaging.Cultivar.Month	11	(1)	126.48009	11.49819	211.00	<.001
Temperature.Packaging.Cultivar.Month	6	(6)	23.93457	3.98909	73.20	<.001
Residual	91	(17)	4.95896	0.05449		
Total	190	(25)	3051.94502			

*NB – Numbers in brackets represent missing values.

Appendix 7.1 Arbitrary scores for taro crisping quality parameters

A. Number of cormels plant^{-1} weighing 50-350g

Cormel number ranges	Score
0.00-0.25	0.5
0.26-0.50	0.6
0.51-0.75	0.7
0.76-1.00	0.8
1.01-1.25	0.9
1.26-1.50	1.0
1.51-1.75	1.1
1.76-2.00	1.2
2.01-2.25	1.3
2.26-2.50	1.4
2.51-2.75	1.5
2.76-3.00	1.6
3.01-3.25	1.7
3.26-3.50	1.8
3.51-3.75	1.9

B. Dry matter content

Dry matter content ranges (%)	Scores
17.0-19.9	0.9
20.0-22.9	1.0
23.0-25.9	1.1
26.0-28.9	1.2
29.0-31.9	1.3
32.0-34.9	1.4
35.0-37.9	1.5
38.0-40.9	1.6

C. Specific gravity

Specific gravity ranges	Scores
0.850-0.869	-0.2
0.870-0.889	-0.1
0.890-0.909	0.0
0.910-0.929	0.1
0.930-0.949	0.2
0.950-0.969	0.3
0.970-0.989	0.4
0.990-1.009	0.5
1.010-1.029	0.6
1.030-1.049	0.7
1.050-1.069	0.8
1.070-1.089	0.9
1.090-1.109	1.0
1.110-1.129	1.1
1.130-1.149	1.2

1.150-1.169	1.3

D. Starch content

Starch content ranges (%)	Scores
15.00-19.99	1.0
20.00-24.99	1.1
25.00-29.99	1.2
30.00-34.99	1.3
35.00-39.99	1.4
40.00-44.99	1.5
45.00-49.99	1.6
50.00-54.99	1.7

E. Reducing sugars content

Reducing sugars ranges (%)	Scores
0.860-0.919	-0.1
0.800-0.859	0.0
0.740-0.799	0.1
0.680-0.739	0.2
0.620-0.679	0.3
0.560-0.619	0.4
0.500-0.559	0.5
0.440-0.499	0.6
0.380-0.439	0.7
0.320-0.379	0.8
0.260-0.319	0.9
0.200-0.259	1.0
0.140-0.199	1.1