PHYTOTRON AND FIELD PERFORMANCE OF TARO [*Colocasia Esculenta* (L.) Schott] LANDRACES FROM UMBUMBULU

RORISANG `MAPHOKA MARE

BSc. Agric. (Lesotho)

Submitted in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

(CROP SCIENCE)

in the

School of Agricultural Sciences and Agribusiness

Faculty of Science and Agriculture

University of KwaZulu-Natal

Pietermaritzburg

Republic of South Africa

December 2006

DECLARATION

I, Rorisang `Maphoka Mare, certify that the research work reported in this thesis is my original work, except where acknowledged. I also declare that the results have not been submitted in any form, for any degree or diploma, to any other university. The research work was carried out at the University of KwaZulu-Natal.

....

R.`M. Mare

....

Professor Albert T. Modi

(Supervisor)

ACKNOWLEDGEMENTS

I am indebted to and would like to give many thanks to the following people and organisations who made this research possible:

- My supervisor, Professor Albert Modi for securing financial support, his supervision, encouragement and guidance throughout the study period.

-PlantBio for financial support.

- Ezemvelo Farmers` Organisation (EFO) farmers for their cooperation and time during the workshops.

-Mrs Nxele for providing land for field experiment.

-The academic and technical staff, and students of the Agricultural Plant Sciences for their help and sound advice on subjects related to the study.

-My parents, sisters, my husband Tumelo, my sons Mpho and Ts`epo for their love, patience and unwavering support, without which I would not be where I am today.

-And above all, The Almighty God who makes all things possible.

ABSTRACT

The taro landraces that are most preferred by farmers from Umbumbulu, KwaZulu-Natal were identified through focus group discussions with farmers. Farmers ranked taro landraces on the basis of preference as determined by economic value, social significance, ecological importance and food characteristics. Using pairwise ranking, the farmers` preference of taro landraces across all locations was found to be in the following order: Dumbe-dumbe, Mgingqeni, Pitshi and Dumbe-lomfula. Dumbe-dumbe was identified as the currently actively cultivated taro whereas Mgingqeni was regarded as a less desirable cultivated taro. Pitshi was regarded as an antiquated landrace and Dumbe-lomfula was generally regarded as a taro type of no economic, social or food value that grew on river banks as a wild species.

Glasshouse and field studies were conducted to determine the effects of temperature and growing location [Pietermaritzburg (UKZN) and Umbumbulu] on emergence, plant growth and yield of taro. Starch and mineral composition of taro corms were determined in harvest-mature corms. Effects of three day/night temperature levels (22/12°C, 27/17°C and 33/23°C) were examined on the growth of four taro landraces Dumbe-dumbe, Mgingqeni, Pitshi and Dumbe-lomfula. Pitshi-omhlophe, an ecotype of Pitshi for which there was a limited amount of planting material, was also included in the glasshouse studies. The farmers stated that the normal growing season for the economically important landraces, Dumbe-dumbe and Mgingqeni, was six months, but in this study plants were grown in glasshouses for nine months, and in the field, for seven months before the attainment of harvest maturity.

Emergence was determined daily for glasshouse experiment until all plants had emerged and it was determined monthly for the field experiment. Leaf number, plant height and leaf area were measured every month to determine growth and development, while number of corms and fresh corm weight were used at harvest to determine yield. For all landraces, time to emergence increased significantly with decrease in temperature from 33/23°C to 27/17°C, but it increased significantly for only *Dumbe-dumbe* and *Mgingqeni*

from 27/17°C to 22/12°C. *Mgingqeni* showed the shortest time to emergence, whereas, *Pitshi* showed the longest delay in emergence. The locations were not significantly different in emergence. *Mgingqeni* displayed the highest emergence in UKZN (91.4%), whereas, *Dumbe-dumbe* displayed the highest emergence (95.5%) and *Dumbe-lomfula* displayed the lowest emergence (55.9%) in Umbumbulu. Leaf number was highest for *Pitshi-omhlophe*, in glasshouse experiment due to its tendency to produce multiple shoots compared with the other landraces. Plant height increased with increase in temperature for all landraces except for *Pitshi*, for which height decreased with an increase in temperature. Leaf area was greatest for *Dumbe-lomfula* at all temperatures and lowest for *Pitshi* at both 22/12°C and 27/17°C. Leaf number was highest for *Mgingqeni* and lowest for *Dumbe-lomfula* at both sites, although it was significantly lower only for *Dumbe-lomfula* in UKZN. Plant height and leaf area were significantly highest for *Dumbe-lomfula* at both sites. The highest total number of corms per plant was shown by *Pitshi-omhlophe* at 22/12°C. Total fresh corm weight was highest for *Dumbe-lomfula* at 27/17°C and lowest for *Pitshi* at 22/22 °C. The field experiment results showed Pitshi and Dumbe-lomfula with significantly higher total fresh corm weight in UKZN compared with Umbumbulu.

Corms were analysed for mineral elements and starch. There were significant differences in starch content between temperatures ($P = 0.017$) and taro landraces ($P = 0.025$). There was also a significant interaction of temperatures and landrace ($P = 0.002$). Starch content increased with temperature for all landraces except for *Pitshi-omhlophe* and *Dumbe-lomfula* which showed a decrease at 27/17°C. There were significant differences in corm mineral content between temperatures, locations and landraces ($P < 005$).

It is concluded that the chemical composition of taro corms is influenced by growth temperature and the location (site) where the crop is grown. The results of this study also indicated that taro plant growth is enhanced by high temperatures (33/23°C). High temperatures are, however, associated with short leaf area duration and subsequently low yield. The findings of this study may also be useful in determining taro quality for processing.

TABLE OF CONTENTS

DECLARATION....i

ACKNOWLEDGEMENTS....ii

ABSTRACT....iii

TABLE OF CONTENTS....v

LIST OF TABLES....ix

LIST OF FIGURES....xii

LIST OF APPENDICES....xv

1. GENERAL INTRODUCTION....1

2. LITERATURE REVIEW....4

2.1 Introduction....4

2.1.1 Food security importance....4

2.1.2 Socio-cultural importance....5

2.1.3 Taro as a cash crop....6

2.2 Characteristics of taro....7

2.2.1 Botany and ecology....7

2.2.1.1 Classification and ecology....7

2.2.1.2 Origin and distribution....8

2.2.1.3 Morphology and anatomy....9

2.2.1.4 Growth cycle....10

2.2.1.5 Ecology and physiology....11

2.2.1.6 Composition and utilisation....13

2.2.1.7 Availability and utilization in South Africa....15

2.2.1.8 Justification and study objectives..16

3. A SURVEY OF TARO LANDRACES: PRODUCTION AND

UTILISATION BY SUBSISTENCE FARMERS IN UMBUMBULU..............17

3.1 Introduction..17

3.1.1 Germplasm collection..17

3.1.2 Taro production in Umbumbulu...18

3.2 Methodology...19

3.2.1 Identification of sites, key informants and germplasm collection..........19

3.2.2 Communication tools...20

3.3 Results and discussion..21

3.3.1 Farmers` knowledge of taro landraces...21

3.3.2 Description of taro landraces by farmers..23

3.3.3 Taro landrace planting preference...35

3.3.4 Utilisation of taro landraces by Umbumbulu farmers..............................39

3.3.5 Agronomic practices...41

3.3.6 Taro cropping calendar..42

3.4 Conclusions and future directions..45

4. PHYTOTRON STUDIES ON THE EFFECTS OF TEMPERATURE ON TARO GROWTH, YIELD, STARCH AND MINERAL CONTENT..........................47

4.1 Introduction..47

4.1.1 Seedling emergence..49

4.1.2 Leaf number...49

4.1.3 Plant height...50

4.1.4 Leaf area...50

4.1.5 Yield...52

4.1.6 Starch and mineral content..53

4.2 Materials and methods...54

4.2.1 Planting material...54

4.2.2 Experimental treatments and design...55

4.2.3 Crop management..56

4.2.4 Data collection...57

4.2.5 Starch and chemical analysis...58

4.2.6 Statistical analysis..58

4.3 Results and discussion...58

4.3.1 Seedling emergence...58

4.3.2 Leaf number...60

4.3.3 Plant height..62

4.3.4 Leaf area..64

4.3.5 Yield..68

4.3.5.1. Fresh corm weight...68

4.3.5.2 Number of corms...69

4.3.6 Starch content..72

4.3.7 Mineral content....73

4.3.8 Conclusion....78

5. FIELD STUDIES ON TARO GROWTH AND YIELD....79

5.1 Introduction....79

5.2 Materials and methods....80

5.2.1 Planting material....80

5.2.2 Description of planting sites....80

5.2.3 Planting and crop management....82

5.2.4 Data collection....82

5.2.5 Starch and chemical analysis....82

5.2.6 Statistical analysis....83

5.3 Results and discussion....83

5.3.1 Seedling emergence....83

5.3.2 Leaf number....86

5.3.3 Plant height....89

5.3.4 Leaf area....91

5.3.5 Yield....94

5.3.5.1 Fresh corm weight....94

5.3.5.2 Number of corms....94

5.3.6 Starch and mineral content....97

6. GENERAL DISCUSSION AND CONCLUSIONS....101

REFERENCES....105

APPENDICES....117

LIST OF TABLES

Table 2.1 Production, yield and area for taro in 1998 5

Table 2.2 Nutritional information of the fresh taro corm..15

Table 3.1 Number of farmers interviewed at Umbumbulu locations........................19

Table 3.2 Descriptors used by farmers in characterization of taro landraces................21

Table 3.3 Number of male (M) and female (F) farmers who knew 1, 2, 3, 4 or 5 taro landraces..22

Table 3.4 Taro landraces as named and known by farmers at different locations..........23

Table 3.5 Leaf colour of different taro landraces as characterized by farmers at different locations..25

Table 3.6 Leaf size of different taro landraces as characterized by farmers at different locations..26

Table 3.7 Petiole leaf junction colour of different taro landraces as characterized by farmers at different locations..27

Table 3.8 Corm shape of different taro landraces as characterized by farmers at different locations..28

Table 3.9 Corm size of different taro landraces as characterized by farmers at different locations..29

Table 3.10 Petiole corm junction colour of different taro landraces as characterized by farmers at different locations..30

Table 3.11 Yield of different taro landraces as characterized by farmers at different locations..31

Table 3.12 Taste of different taro landraces as characterized by farmers at different locations. 32

Table 3.13 Cooking time of different taro landraces as characterized by farmers at different locations. 33

Table 3.14 Sliminess of different taro landraces as characterized by farmers at different locations..34

Table 3.15 Pair-wise ranking of taro landraces for planting preference produced with Ezigeni farmers. 36

Table 3.16 Pair-wise ranking of taro landraces for planting preference produced with Upper Ogagwini farmers..36

Table 3.17 Pair-wise ranking of taro landraces for planting preference produced with Lower Ogagwini farmers..37

Table 3.18 Pair-wise ranking of taro landraces for planting preference produced with Rhwayi farmers..37

Table 3.19 Pair-wise ranking of taro landraces for planting preference produced with Eziphambathini farmers. 38

Table 3.20 Pair-wise ranking of taro landraces for planting preference produced with Msholozi farmers. 38

Table 3.21 Pair-wise ranking of taro landraces for planting preference produced with Ezimwini farmers. 39

Table 3.22 Taro cropping calendar for different locations in Umbumbulu....................44

Table 4.1 Physical and chemical analysis of soil from UKZN farm used in glasshouse experiment..56

Table 4.2 Number of harvested corms classified (graded) according to the fresh mass (g)..71

Table 4.3 Mineral composition of taro landraces (Dumbe-dumbe (D), Mgingqeni (M), Pitshi (P), Pitshi emhlophe (Pw) and Dumbe lomfula (R) grown under different temperatures..77

Table 5.1 Physical and chemical analysis of soil from UKZN and Umbumbulu sites. ...80

Table 5.2 Number of harvested corms graded according to the fresh mass (g).............96

Table 5.3 Starch and mineral content of four taro landraces cultivated at UKZN and Umbumbulu [Dumbe-dumbe (D), Mgingqeni (M), Pitshi (P) and Dumbe-lomfula (R)]..100

LIST OF FIGURES

Figure 3.1 A farmer collecting volunteer taro germplasm from her field....................20

Figure 3.2 Utilisation of taro landraces by Umbumbulu farmers...............................41

Figure 4.1 Corms of taro landraces (named) used as planting material 55

Figure 4.2 Portable LI-COR, LI-3000 leaf area meter..57

Figure 4.3 Mean seedling emergence of taro landraces at different alternating (day/night) temperatures 59

Figure 4.4 Mean seedling emergence of taro landraces at different temperatures..........60

Figure 4.5 Mean leaf number of taro landraces over nine months at different temperatures...61

Figure 4.6 Mean plant height of taro landraces over nine months at different temperatures...63

Figure 4.7 Mean leaf area of taro landraces over nine months at different temperatures 66

Figure 4.8 Change in leaf number, plant height and leaf area of taro landraces grown under three temperatures regimes..67

Figure 4.9 Fresh corm weight of the taro landraces at different temperatures..............68

Figure 4.10 Mean number of corms of taro landraces at different temperatures...69

Figure 4.11 Corm starch content of taro landraces at different temperatures...72

Figure 5.1 Temperature (a) and rainfall (b) distribution at UKZN and Umbumbulu. 81

Figure 5.2 Taro seedling emergence at UKZN...84

Figure 5.3 Taro seedling emergence at Umbumbulu..84

Figure 5.4 Effect of site on taro landraces` final seedling emergence........................85

Figure 5.5 Taro crop damaged by hail in UKZN field trial....................................86

Figure 5.6 Change in leaf number of taro landraces (inset) grown at UKZN 87

Figure 5.7 Change in leaf number of taro landraces (inset) grown at Umbumbulu...88

Figure 5.8 Average leaf number of taro landraces over the experimental period at different sites 88

Figure 5.9 Change in plant height of taro landraces grown at UKZN.........................90

Figure 5.10 Change in plant height of taro landraces grown at Umbumbulu................90

Figure 5.11 Average plant height of taro landraces over the experimental period at different sites...91

Figure 5.12 Change in leaf area of taro landraces grown at UKZN...........................92

Figure 5.13 Change in leaf area of taro landraces grown at Umbumbulu...................93

Figure 5.14 Average leaf area of taro landraces over the experimental period at different sites 93

Figure 5.15 Fresh corm weight of the taro landraces at different sites.......................94

Figure 5.16 Average number of corms of taro landraces across sites.........................95

LIST OF APPENDICES

APPENDIX 4.1 Analysis of variance of seedling emergence, plant growth and yield...117

APPENDIX 4.2 Analysis of variance of starch and mineral content of taro................119

APPENDIX 5.1 Plan of experimental field trial showing plot numbers [1, 2, ...48], taro landraces [Dumbe-dumbe (D), Mgingqeni (M), Pitshi (P) and Dumbe-lomfula (R)] and replications [r_1, r_2, r_3 and r_4]..123

APPENDIX 5.2 Analysis of variance of seedling emergence, plant growth and yield...125

APPENDIX 5.3 Analysis of variance of starch and mineral content of taro................128

CHAPTER 1

GENERAL INTRODUCTION

Taro is an important tropical and subtropical crop grown for its starchy corms. It is the most widely cultivated species because, essentially, it does not require a large area and its planting material is relatively easy to obtain and maintain (VINNING, 2003). Therefore, taro is an appropriate crop for small-scale farmers who produce crops with little access to essential resources (SHANGE, 2004). The taro industry provides meaningful employment to a large number of people, mostly in the rural areas. In tropical countries where taro is a major crop, taro is significant as a provider of food security, as a focus of socio-cultural attention, as a cash crop and as a vehicle for rural development (ONWUEME, 1999). Food made of taro is used to honour guests and in sacred ceremonies (TSITSIRINGOS, 2002). Taro is also recommended for gastric patients and its flour is considered good baby food (SALUNKHE & KADAM, 1998).

In Asia and Oceania taro is considered a prestige crop, and the crop of choice for royalty, gift giving, traditional feasting, and the fulfilment of social obligations (TSITSIRINGOS, 2002). It also features prominently in the folklore and oral traditions of many cultures (TSITSIRINGOS, 2002). Various parts of the taro plant are used in traditional medicine practice. As if to highlight the importance of taro in the countries, both Samoa and Tonga each have a depiction of taro as the main feature on one of their currency coins. Outside Oceania, it is unlikely that taro is given such a glorified place in any other part of the world. The socio-cultural attachment to taro has meant that taro itself has become a totem of cultural identification. People of Pacific Island origin continue to consume taro wherever they live in the world to maintain links with their culture. This cultural attachment to taro has spawned a lucrative taro export market to ethnic Pacific Islanders living in Australia, New Zealand and western North America (ONWUEME, 1999).

While a lot of taro is produced and consumed on a subsistence basis, quite a considerable amount is produced as a cash crop. Also, surpluses from the subsistence production manage to find their way to the market, thereby playing a role in poverty alleviation (ONWUEME, 1999).

The effectiveness of the taro cash crop system is therefore dependent on an adequate marketing structure (ONWUEME, 1999), connecting suppliers to consumers via strong supply chains and major awareness campaigns and education of consumers to properly appreciate the very special qualities of taro as well as significant improvement in the efficiencies of production (DANIELS, 2005).

Unfortunately, very few of the taro producing countries have such structures. Fiji, Hawaii and Cook Islands are examples of where efforts have been made to establish such structures, and quite a few farmers make reasonable money as taro producers (ONWUEME, 1999). In South Africa, marketing structures are in place for Umbumbulu subsistence farmers who are certified to supply taro to Woolworths (THAMAGA-CHITJA *et al.*, 2005).

Despite the importance and good qualities of taro in the lives of the rural farmers, scientific research on taro environmental requirements for growth has not been conducted in South Africa. Research done in other countries, like Hawaii shows that among environmental requirements, temperature is the most important factor affecting taro growth and yield (MIYASAKI *et al.*, 2003). It is therefore important to examine the influence of temperature on the local landraces with the view of better understanding of its effects on growth and hence yield.

The objective of this study was to determine the effect of temperature, under controlled environment conditions and production site on emergence, growth and yield of taro. The chemical composition of taro corms, in response to growth environment was determined, with a focus on starch and mineral elements. The study was undertaken at two provenances, Pietermaritzburg and Umbumbulu, both in KwaZulu-Natal during the 2005-2006 season. Glasshouse experiments were undertaken, simultaneously as the field experiments, at the University of KwaZulu-Natal, Pietermaritzburg. The field and glasshouse experiments were established following a social study of taro landraces in the rural area of Umbumbulu. The social study was used to identify and collect taro landrace germplasm found in Umbumbulu, with the assistance of local farmers.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The term taro is used to refer to *Colocasia esculenta* (L.) Schott. It should not be confused with the related aroid *Xanthosoma* spp., which is called tannia. In many parts of the Asia and Pacific region, the name for tannia is a modification or qualification of the name for taro. In Papua New Guinea for example, taro is called "taro tru" while tannia is called "taro singapo". In Tonga, taro is called "talo Tonga" while tannia is called "talo Futuna". In some of the world literature, taro and tannia are collectively called cocoyams, while in a place like Malaysia, the local name for taro (keladi) also applies to all the other edible aroids (ONWUEME,1999). In South Africa, especially in KwaZulu-Natal taro is called amadumbe (idumbe = singular), which is a Zulu name referring to the swollen underground stem (SHANGE, 2004).

2.1.1 Food security importance

Taro is one of the important tuber crops grown in Africa and Asia (SALUNKHE & KADAM, 1998). Taro is a starch crop and a staple food in many tropical countries (VAN WYK, 2005). It is accepted that, according to the Food and Agriculture Organisation of the United Nations (FAO) data, taro production in Africa and Asia dwarfs that of the Pacific (VINNING, 2003). Table 2.1 shows that in 1998, 4.452 million tonnes of taro were produced in Africa on an area of 876 thousand hectares and this accounted for about 68% of the world`s production and about 82% of the world's area under the crop. This makes Africa the leading producer of taro in the whole world. Asia produced about half and Oceania about one tenth of Africa's production.

Table 2.1 Production, yield and area for taro in 1998. Note: Only the leading producers are indicated (ONWUEME, 1999).

	Production (1000 t)	Yield (t ha^{-1})	Area (1000 ha)
World	**6586**	**6.2**	**1070**
Africa	**4452**	**5.1**	**876**
Asia	**1819**	**12.6**	**144**
China	1387	16.8	82
Japan	255	11.6	22
Philippines	118	3.4	35
Thailand	54	11.0	5
Oceania	**283**	**6.2**	**46**
Papua New Guinea	160	5.2	31
W. Samoa	37	6.2	6
Solomon Islands	28	21.9	1
Tonga	27	6.4	4
Fiji	21	14.7	1

Production statistics, however, do not reflect the relative importance of taro in each of the countries. This is mainly because of distortion by land mass and population factors. China, for example, still manages to produce substantial quantities of taro which is a minor crop as compared to rice, because of the large land mass involved. A much better gauge of the importance of taro/ tannia in each nation's food basket comes from examining the percentage of total dietary calories that each person derives from taro/ tannia (ONWUEME, 1999).

2.1.2 Socio-cultural importance

Taro was probably the main staple food in Africa before the arrival of sweet potatoes (*Ipomoea batatas*). Particularly large specimens of taro are grown in special places and with special care. This food is used to honour guests and in sacred ceremonies. Taro is served at feasts (TSITSIRINGOS, 2002). Taro is also recommended for gastric patients and its flour is considered good baby food (SALUNKHE & KADAM, 1998).

In Asia and Oceania taro is considered a prestige crop, and the crop of choice for royalty, gift giving, traditional feasting, and the fulfilment of social obligations. It also features prominently in the folklore and oral traditions of many cultures. Various parts of the taro plant are used in traditional medicine practice. As if to highlight the importance of taro in the countries, both Samoa and Tonga each have a depiction of taro as the main feature on one of their currency coins. Outside Oceania, it is unlikely that taro is given such a glorified place in any other part of the world. The socio-cultural attachment to taro has meant that taro itself has become a totem of cultural identification. People of Pacific Island origin continue to consume taro wherever they live in the world to maintain links with their culture. This cultural attachment to taro has spawned a lucrative taro export market to ethnic Pacific Islanders living in Australia, New Zealand and western North America (ONWUEME, 1999).

2.1.3 Taro as a cash crop

While a lot of taro is produced and consumed on a subsistence basis, quite a considerable amount is produced as a cash crop. Also surpluses from the subsistence production manage to find their way to market, thereby playing a role in poverty alleviation (ONWUEME, 1999). The taro corm is a very awkward market commodity. This is due to its bulkiness and high moisture content. It is fragile and easily bruised. It is perishable and can only store for a few days at ambient temperatures. Yet most of taro marketing takes place in the form of the fresh corm. The effectiveness of the taro cash crop system is therefore dependent on an adequate marketing structure (ONWUEME, 1999), connecting suppliers to consumers via strong supply chains and major awareness campaigns and education of consumers to properly appreciate the very special qualities of taro as well as significant improvement in the efficiencies of production (DANIELS, 2005).

Unfortunately, very few of the producing countries have such structures. Fiji, Hawaii, and Cook Islands are examples of where efforts have been made to establish such structures, and quite a few farmers make reasonable money as taro producers (ONWUEME, 1999). In South Africa, marketing structures are in place for only Umbumbulu subsistence farmers who are certified to supply taro to Woolworths Food (THAMAGA-CHITJA *et al.*, 2005). The taro industry provides meaningful employment to a large number of people, mostly in the rural areas. Taro is significant as a provider of food security, as a focus of socio-cultural attention, as a cash crop and as a vehicle for rural development (ONWUEME, 1999).

2.2 Characteristics of taro

2.2.1 Botany and ecology

2.2.1.1 Classification and ecology

Taro, *Colocasia esculenta* (L.) Schott. is one of the few edible species in the genus Colocasia within the sub-family Colocasioideae (EZUMAH,1972) . It is the most widely cultivated species because, essentially, it does not require a large area and planting material is relatively easy to obtain and maintain (VINNING, 2003). It belongs to the order Arales, whose members are referred to as aroids. Within the order Arales, taro is classified as a member of monocotyledonous family Araceae (HENRY, 2001; VAN WYK, 2005), commonly known as Arum family. This family includes about 100 genera and 1500 widely distributed species (MERLIN, 1982; VINNING, 2003), most of which are adapted to tropical or subtropical environments (MERLIN, 1982). There is considerable confusion in the taxonomy of the genus *Colocasia* due to a long history of vegetative propagation. The cultivated taro species is classified as *Colocasia esculenta*, but the species is considered to be allogamous and polymorphic (IVANCIC *et al.*, 2003). There are at least two botanical varieties of taro (PURSEGLOVE, 1972):

i) *Colocasia esculenta* (L.) Schott var. *esculenta* and

ii) *Colocasia esculenta* (L.) Schott var. *antiquorum* (Schott) Hubbard & Rehder which is synonymous with C. *esculenta* var. *globulifera* Engl.& Krause.

Colocasia esculenta var. *esculenta* is characterised by a large cylindrical central corm and very few cormels. This variety is agronomically known as the dasheen type. Colocasia *esculenta* var. *antiquorum* has a small globular central corm with several relatively large cormels arising from the corm. This variety is agronomically known as the eddoe type (PURSEGLOVE, 1972; LEBOT & ARADHYA, 1991). Hundreds of taro cultivars are grown throughout the world. Corm, cormel or shoot characteristics together with agronomic or culinary behaviour are used to distinguish these cultivars. Taro may be grown under both flooded and dryland conditions. Growing taro under flooded soil conditions prevents use of heavy machinery and hence production becomes laborious (EZUMAH, 1972).

2.2.1.2 Origin and distribution

Various lines of ethno-botanical evidence indicate that taro originated in South Central Asia, probably in India or the Malay Peninsula with wild forms existing in various parts of South Eastern Asia (PURSEGLOVE, 1972; MERLIN, 1982). For example, MERLIN (1982) stated "its speciation has been postulated as occurring in "Indo Malaysia" by de Candolle (1886), in "Indonesia" by Engler and Krause (1920), in "India" by Burkill (1935), Vavilov (1949), and Chang (1958), in the "East Indies" by Degener (1945), in " Southeast Asia" by Sauer (1952) and in "Malaysia" by Keleny (1962) and Good (1964)". Taro may have been distributed to South East Asia, China, Japan and the Pacific Islands. From Asia it was distributed to Arabia and the Mediterranean (ONWUEME, 1999). It has been suggested that the eddoe type of taro was developed and selected from cultivated taro in China and Japan several centuries ago, and it was later introduced to the West Indies and other parts of the world (PURSEGLOVE, 1972). VAN VYK (2005) suggested that taro was brought to Africa and the New World by Spanish and Portuguese explorers. Taro was introduced to South Africa before the arrival of Europeans (GERSTNER,1938) and it is likely that it was introduced through Malagasy (SHANGE, 2004) because yams were also reported to have been introduced from Indonesia to Africa via Malagasy (COURSEY, 1976).

2.2.1.3 Morphology and anatomy

Taro is a robust (VAN WYK, 2005) perennial herbaceous plant (PLUCKNETT *et al.*, 1970; EZUMAH, 1972) which grows to a height of 0.5 m to 2 m (EZUMAH, 1972). The leaves are large and heart shaped with peltate leaf blades (ONWUEME, 1999; VAN WYK, 2005). These leaves effectively constitute the only part of the plant that is visible above ground. They determine the plant's height in the field (ONWUEME, 1999). Leaf blades are borne at the top of long petioles (EZUMAH, 1972; VAN WYK, 2005) arising as clusters or whorls from compact corms (EZUMAH, 1972). The petiole is thickest at its base, and thinner towards its attachment to the lamina. Internally, the petiole is spongy in texture, and has numerous air spaces which presumably facilitate gaseous exchange when the plant is grown in swampy or flooded conditions. For most taro types, the attachment of the petiole to the lamina is peltate, meaning that the petiole is attached, not at the edge of the lamina, but at some point in the middle. The lamina of taro is 20-50 cm long, oblong-ovate, with the basal lobes rounded. It is entire (not serrated), glabrous, and thick. Three main veins radiate from the point of attachment of the petiole, one going to the apex, and one to each of the two basal lamina lobes. Some prominent veins arise from the three main veins, but the overall leaf venation is reticulate (net-veined) (ONWUEME, 1999).

The corms are cylindrical or spherical (about 15 to 18 cm in diameter) and starchy (PLUCKNETT *et al.*, 1970; ONWUEME, 1978; STRAUSS, 1983). The plant consists of a central corm (lying just below the soil surface) from which leaves grow upwards, roots grow downwards, while cormels, daughter corms and runners (stolons) grow laterally. The root system is fibrous and lies mainly in the top one meter of soil (ONWUEME, 1999).

Occasionally in the field, some taro plants are observed to produce runners. These structures grow horizontally along the surface of the soil for some distance, rooting down at intervals to give rise to new erect plants (ONWUEME, 1999).

The plant rarely flowers naturally (VAN WYK, 2005), but flowering can be artificially promoted by application of gibberellic acid. The inflorescence arises from the leaf axils, or from the centre of the cluster of unexpanded leaves. Each plant may bear more than one inflorescence. The inflorescence is made up of a short peduncle, a spadix, and spathe. The spadix is botanically a spike, with a fleshy central axis to which the small sessile flowers are attached. The spadix is 6-14 cm long, with female flowers at the base, male flowers towards the tip, and sterile flowers in between, in the region compressed by the neck of the spathe. The extreme tip of the spadix has no flowers at all, and is called the sterile appendage (ONWUEME, 1999).

The spathe is a large yellowish bract, about 20 cm long, which sheathes the spadix. The lower part of the spathe wraps tightly around the spadix and completely occludes the female flowers from view. The top portion of the spadix is rolled inward at the apex, but is open on one side to reveal the male flowers on the spadix. The top and bottom portions of the spadix are separated by a narrow neck region, corresponding to the region of the sterile flowers on the spadix (ONWUEME, 1999).

Pollination in taro is probably accomplished by flies. Fruit set and seed production occur only occasionally under natural conditions. Fruits, when produced, occur at the lower part of the spadix. Each fruit is a berry measuring 3-5 mm in diameter and containing numerous seeds. Each seed has a hard testa, and contains an endosperm in addition to the embryo (ONWUEME, 1999).

2.2.1.4 Growth cycle

Taro survives from year to year by means of the corms and cormels (ONWUEME, 1999). The root forms and grows rapidly immediately after planting, followed by rapid growth of the shoot. Shoot growth and total shoot dry weight show a rapid decline at about six months after planting. At this time, there is 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. Throughout the season, there is a rapid turnover of leaves; new ones are continually unfurling from the centre of the whorl of leaves, as the oldest ones below die off (ONWUEME, 1999).

Corms form at about three months after planting, cormel formation follows soon afterwards in cultivars that produce appreciable cormels. By the sixth month when shoot growth declines, the corm and cormels become the main sink and grow very rapidly. As the adverse (dry) season sets in, the decline of the shoot accelerates, until the shoot finally dies back. The corm and cormels permit the plant to survive through the adverse season. If they are not harvested, they will sprout and give rise to new plants at the onset of the next favourable season. Where there is no adverse season, the shoot may fail to die back, and instead persist and continue growth for several years (ONWUEME, 1999).

The growth and development of taro has been studied by various workers throughout the season. For example, CHING (1970), cited by JOHNSTON *et al.*, (1997) found that after about six months of growth, there was a decline in shoot growth, characterised by a decline in leaf number, leaf area, petiole length and plant height. REYNOLDS (1977), on the other hand, described 5 main growth stages for taro, and determined that corm yield was proportional to shoot mass and leaf area at 21 weeks. One feature of the taro plant is that there is a high turnover of leaves during the season (ONWUEME, 1978), however, quantification of this turnover has rarely been provided (e.g CAESAR, 1980; JOHNSTON *et al.*, 1997).

2.2.1.5 Ecology and physiology

Taro can grow in a wide range of sites from dry uplands to wetlands with soils that remain saturated for prolonged periods (DE LA PENA, 1983). Taro plants have a high requirement for moisture for their production, due to their large transpiring surfaces. Normally, rainfall or irrigation of 1500 - 2000 mm is required for optimum yields (ONWUEME, 1999) but taro grows best with rainfall of 2500 mm year^{-1} or more (PURSEGLOVE, 1972). Taro thrives best under very wet or flooded conditions

(ONWUEME, 1999) because it prefers abundant water supply and can withstand water logging (SALUNKHE & KADAM, 1998). Dry conditions result in reduced corm yields. Corms produced under dry conditions also tend to have a dumb-bell shape; the constrictions reflect periods of reduced growth during drought (ONWUEME, 1999).

Taro will not grow in a cooler climate where frost is a problem, but will grow even in a sub tropical climate where the temperature averages around 20°C (SALUNKHE & KADAM, 1998). It requires an average daily temperature above 21°C for normal production (ONWUEME, 1999) and it will grow best with temperatures of 20 - 27°C (PURSEGLOVE, 1972). It cannot tolerate frosty conditions, partly because of its temperature sensitivity. Taro is essentially a lowland crop. Yields at high altitudes tend to be poor. In Papua New Guinea, for example, the maximum elevation for taro cultivation is 2700 m (ONWUEME, 1999; SLONE, 2001).

It is emersed along moist, shaded lake and river shorelines and tolerates intense sunlight to deep shade (NYMAN & ARDITTI, 1985). The highest yields for taro are obtained under full intensity sunlight. However, taro appears to be more shade-tolerant than most other crops. This means that reasonable yields can be obtained even in shade conditions where other crops might fail completely. This is a particularly important characteristic which enables taro to fit into unique intercropping systems with tree crops and other crops. Daylight also affects the growth and development of taro. The formation of corms/cormels is promoted by short-day conditions, while flowering is promoted by long-day conditions (ONWUEME, 1999).

Taro does best in soils with a pH of about 5.5-6.5 (SALUNKHE & KADAM, 1998). It is able to form beneficial associations with vesicular-arbuscular mycorrhizae, which therefore facilitate nutrient absorption (ONWUEME, 1999). One particularly useful characteristic of taro is that some cultivars are able to tolerate salinity. Indeed, in Japan and Egypt, taro has been used satisfactorily as a first crop in the reclamation of saline soils (KAY, 1973). This definitely opens up the possibility for the use of taro to exploit some difficult ecology where other crops might fail.

Reproduction is primarily vegetative. Seed production is thought to be uncommon, seeds and seedlings have low viability (NYMAN & ARDITTI, 1985). Flowering and seed set in taro are relatively rare under natural conditions. Most plants complete their field life without flowering at all, and some cultivars have never been known to flower. For many years, this characteristic was a great hindrance to taro improvement through cross pollination. However, the problem was solved when it was discovered that gibberellic acid (GA) could promote flowering in taro (WILSON, 1979). Plants treated with 15000 ppm GA when they are at 3-5 leaf stage in the field have been shown to flower (ALVAREZ & HAHN, 1986).

2.2.1.6 Composition and utilisation

The main economic parts of the taro plant are the corms and cormels, as well as the leaves (ONWUEME, 1999; VINNING, 2003). The corm is an excellent source of carbohydrates, but it is low in fat and protein, and the taro leaves contain sizebale amounts of carotene and potassium (LAMBERT, 1982; HANSON & IMAMUDDIN, 1983; BRADBURY & HOLLOWAY, 1988) (Table 2.2). The tubers of tropical plants belonging to the family *Araceae* store a high starch concentration ranging between 22 and 40% (DELPEUCH *et al.*, 1978; RASHID & DAUNICHT, 1979; TRECHE & GUION, 1980; AGBOR EGBE & RICKARD, 1990). According to HIZUKURU *et al.*, (1970); MUHRBECK & TELLIER (1991) and NIELSEN *et al.*, (1994) root and tuber crops contain 16–24% carbohydrate. Table 2.2 shows that taro corms are good sources of carbohydrates (19g 100g $^{-1}$ edible portion) and potassium (514 mg 100g $^{-1}$ edible portion). TU *et al.*, (1979), cited by MODI (2004) indicated that taro contains 70-80% starch. ONWUEME (1994) confirms that by stating that fresh taro corm contains 13- 29% carbohydrate which is 77.9% starch. VINNING (2003), on the other hand stated that taro corms can contain up to 35% starch. The corm of taro is an excellent source of energy and fibre; and a good source of calcium and iron when eaten regularly (AREGHEORE & PERERA, 2003; VAN WYK, 2005). VAN WYK (2005) also suggested that taro is a good source of phosphorus and vitamin C, and that it has a high energy value of 107 kcal 100g $^{-1}$.

The starch is about 80% amylopectin with 22 glucose units per molecule and 20% amylose with 490 glucose units per molecule. The starch grains are small and therefore easily digestible (ONWUEME, 1999; VAN WYK, 2005), making taro suitable as a specialty food for allergic infants and persons with alimentary disorders (ONWUEME, 1999), and for those allergic to cereal starch and those sensitive to animal milk (VINNING, 2003). Taro starch digestibility is as high as 98% (VINNING, 2003). The smallness of the starch grains makes taro less suitable as a source of industrial starch (ONWUEME, 1999). Taro starch granules vary from 1.0 – 6.5 micrometers and as such they have a potential role as an additive to render plastics bio-degradable (VINNING, 2003) and hence taro starch is used in plastic grocery bags to improve biodegradability (LLAMAS, 2003). Protein content can range from 1.0 – 4.5 %. Taro displays allelopathic characteristics (PERDALES & DINGAL, 1988) and contains an irritant calcium oxalate crystals that can deliver a mild sting or even a severe rash (GREENWELL, 1947; VINNING, 2003). This represent 0.1-0.4% of the fresh weight and the acridity causes an itchy reaction in the mouth and throat of humans if consumed without thorough preparation (AREGHEORE & PERERA, 2003). Nearly all taros are cooked to eliminate the irritation before eating (HUTTON, 2004). Taro corms can be cooked with the skin on or off (VINNING, 2003).

Table 2.2 Nutritional information of the fresh taro corm (VINNING, 2003).

Component	**100g^{-1} edible portion**
Edible portion (%)	81
Energy (cal)	85
Protein(g)	2.5
Fat (g)	0.2
Carbohydrate (g)	19
Calcium (mg)	32
Potassium (mg)	514
Iron (mg)	0.8
Thiamine (mg)	0.18
Riboflavin (mg)	0.04
Niacin (mg)	0.9
Vitamin A (IU)	Trace

The nutritional composition of root crops have been reported to be influenced, among other factors, by species and climate (HUANG *et al.*, 2006). Growing condition and temperature have been reported to influence phosphorus content of root and tuber crops (HIZUKURU *et al.*, 1970; MUHRBECK & TELLIER, 1991; NIELSEN *et al.*, 1994).

2.2.1.7 Availability and utilisation in South Africa

Taro is mainly a KwaZulu-Natal coast and hinterland traditional crop (MODI, 2004), hence the Zulu name amadumbe. Taro is an important staple crop in the subtropical coastal area of South Africa, 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).

Most taro production in South Africa is consumed as subsistence food on the farms (SHANGE, 2004). A small proportion finds its way to the market. MODI (2003) stated that only Umbumbulu farmers marketed it. The crop is underutilized as only corms are used for food and cooking of leaves is not considered a standard practice and it is mainly associated with impoverished families. Taro is also fed to children because it helps with digestive problems and supplements iron (SHANGE, 2004).

2.2.1.7 Justification and study objectives

To test the hypothesis that emergence, growth and development, corm yield and nutrient composition of taro [*Colocasia esculenta* (L.) Schott] are affected by temperature and site, this study was designed to examine five taro landraces (Dumbe-dumbe, Mgingqeni, Pitshi, Pitshi-omhlophe and Dumbe-lomfula) under greenhouse and four taro landraces (Dumbe-dumbe, Mgingqeni, Pitshi and Dumbe-lomfula) under field conditions.

The objectives of the study were to:

1) Identify taro landraces that are found in Umbumbulu, KwaZulu Natal.
2) Assess the influence of temperature on emergence, growth, yield, starch and mineral content of those taro landraces that are preferred by farmers in Umbumbulu.
3) Assess the effect of planting site (location) on emergence, growth, yield, starch and mineral content of those taro landraces that are preferred by farmers in Umbumbulu.

CHAPTER 3

A SURVEY OF TARO LANDRACES: PRODUCTION AND UTILISATION BY SUBSISTENCE FARMERS IN UMBUMBULU

3.1 Introduction

Technologies generated to improve farmers' needs must emanate from integration studies of the natural and socio-economic circumstances that influence their farming systems and control their responses to alternative technologies. The type of crop farmers grow is influenced by many factors (e.g. environmental requirements, characteristics, and uses of the crop). By conducting multidisciplinary research and analysing the farmers' knowledge, important feedback can be obtained and this information can be incorporated into research decisions that are conducive to the development of technologies adapted to farmers' needs and resources.

Descriptions of research methodologies attuned to actual conditions of small-scale farmers in the developing world are available (PRETTY *et al.*, 1995; MILLIGAN, 2003). These methodologies emerged in response to critics of internationally funded rural development, who charged that in the past, programmes lacked an understanding of the ecological and socio-economic milieu in which they operated, excluded the small farmers as both collaborators and beneficiaries, and ineptly promoted inappropriate technologies.

This study was designed to allow farmer-participation in identification of taro landraces found in Umbumbulu, their characteristics, uses, production practices and collection of taro germplasm that will assist in identifying research decisions that are conducive to the development of technologies adapted to farmers' needs and resources.

3.1.1 Germplasm collection

Germplasm has been collected and exchanged for many centuries. Initially, explorations were aimed at finding appropriate species and local "varieties" for cultivation

(CHRISTINCK *et al.*, 2006). Usually, germplasm explorations were undertaken by scientists, with the intention of collecting the widest possible range of genetic diversity of a crop or wild species, based on geographical distribution, observation of morphological traits, agroclimatic data, soil conditions and population genetic considerations (MARSHALL & BROWN, 1975; WITCOMBE & GILANI, 1979). Landraces are sometimes preferred by farmers for quality aspects (DHAMOTHARAN *et al.*, 1997). Thus, a new interest has arisen to use traditional landraces. Involving farmers in the collecting of germplasm could avoid unnecessary cost of evaluation, because some of the information required might already be known among the present users. Given these considerations, communication methods based on participatory rural appraisal (PRA) approaches are tested and adapted for use during collections. The objective is not only to document the farmers' knowledge together with each sample, but also to actively involve the farmers in the identification of landraces and representative samples to be collected (CHRISTINCK *et al.*, 2006).

3.1.2 Taro production in Umbumbulu

Umbumbulu is a serene rural area in the South of Durban (PLANTBIO, 2005), with mean annual rainfall of 956 mm per annum, broken or rolling terrain, altitude range of 394-779 m, slope either steep (more than 12%) or moderate (5-10%) and widespread extent of cultivation (more than 50%). Soils are mainly loam and only a small percentage (3%) of farmers plant on sandy soil and 20% plant on sandy loam soil. Farmers own small land (1 ha or less) and this has serious implications for food security (SHANGE, 2004). The planting time extends from August to October in KwaZulu-Natal (WESTHUYZEN, 1967). At Umbumbulu, the majority of farmers produce taro under dryland conditions, with much smaller proportions producing under wetland only or wetland and dryland conditions (SHANGE, 2004). In South Africa, upland taro grown under dryland conditions is harvested after six to eight months during April and May (WESTHUYZEN, 1967; YOUNG, 1992). According to MODI (2003) more than 80% of farmers at Umbumbulu practice organic farming, and the reasons are lack of resources, food security and better crop performance. Farmers occasionally intercrop taro with maize and beans. Crop rotation of taro was a standard practice among small scale farmers, and maize and dry beans are used in rotation. Downy mildew in taro was reported by 12% of Umbumbulu farmers but it was not responsible for major reduction in yield. Millipedes were the most frequently cited pests in taro (SHANGE, 2004).

3.2 Methodology

3.2.1 Identification of sites, key informants and germplasm collection

Prior to collecting, seven locations of Umbumbulu district were defined as target areas. This was mainly because subsistence farmers in these locations are members of the Ezemvelo Farmers` Organisation (EFO) that will deal more directly with matters of farm management and marketing of taro among other organic, traditional and indigenous vegetables they supply to Woolworths Foods. The farmers in Umbumbulu are currently fully certified. They sell taro to a supermarket chain, Woolworths in South Africa (THAMAGA-CHITJA *et al.*, 2005). These locations were Ezigeni, Upper Ogagwini, Lower Ogagwini, Rhwayi, Eziphambathini, Msholozi and Ezimwini. Table 3.1 shows the number and gender of farmers by location who were interviewed at each of the seven locations. One hundred and nine (109) farmers participated in the study. Most of the interviewees (about 84%) were women. This may have been due to the fact that men work in cities while women remain at home to take care of domestic duties, especially in the rural areas.

Table 3.1 Number of farmers interviewed at Umbumbulu locations.

Location	**Male**	**Female**	***Total***
Ezigeni	2	16	**18**
Upper Ogagwini	3	16	**19**
Lower Ogagwini	4	15	**19**
Rhwayi	3	13	**16**
Eziphambathini	2	15	**17**
Msholozi	1	6	**7**
Ezimwini	2	11	**13**
Total	**17**	**92**	**109**

One day workshops were held in each of the seven locations. The farmers were informed about the purpose of the workshops and that samples would be collected. The farmers were also asked to give a general description of their landraces, and whether they were different from other local landraces. From each identified landrace, a sample was randomly selected from the farmers` fields (Figure 3.1). The information on farmers` knowledge of taro landraces, description of the landraces, which landraces farmers preferred to plant, uses and reasons for the farmers to grow these landraces, agricultural practices, as well as taro cropping calendar were recorded.

Figure 3.1 A farmer collecting volunteer taro germplasm from her field.

3.2.2 Communication tools

Semi structured interviews were used for discussions with the farmers' groups. The conversations were open, but some pre-determined questions were always asked during the workshops to allow comparsion of responses from different locations. Unexpected topics raised by the farmers themselves were also discussed, and the questions were purposely asked in a way to encourage new and unexpected points. An important element of PRA methods is visual sharing of the matters discussed. Farmers gave descriptions of those traits of their taro landraces which they considered to be important and they were also encouraged to show the crop in the field. Descriptors that were used to characterize landraces are listed in Table 3.2. Additionally, pair-wise ranking was also used to determine preferences for landraces.

Table 3.2 Descriptors used by farmers in characterization of taro landraces.

Characteristic	Abbreviation
Leaf colour	LC
Leaf size	LS
Petiole leaf junction colour	PLJC
Corm shape	CSH
Corm size	CS
Petiole corm junction colour	PCJC
Yield	Y
Taste	T
Cooking time	CT
Cooked corm sliminess	CCS

3.3 Results and discussion

3.3.1 Farmers knowledge of taro landraces

The numbers of farmers who knew a certain number of taro landraces were recorded (Table 3.3). About 4% of the farmers across locations knew only 2 landraces, about 40% knew 3 landraces, about 7% knew 4 landraces while about 19% knew 5 landraces. Farmers from Lower Ogagwini knew a maximum of 5 landraces individually even though they knew 7 landraces collectively. The names of taro landraces known and named by farmers at different locations are indicated in Table 3.4. The first letter in the codes used in Table 3.4 represents the different names of landraces as given by farmers (D – Dumbe-dumbe, M – Mgingqeni, P – Pitshi, R – Dumbe-lomfula, F – Dumbe-elimbali, I - Intebe) while the last letter represents the locations where the landraces were known (e – Ezigeni, u – Upper Ogagwini, o – Lower Ogagwini, r – Rhwayi, p –

Eziphambathini, m – Msholozi and z – Ezimwini. Where there are three letters, the middle letter represents the other characteristic like height or colour, that were used by farmers to differentiate the landraces (s – short, t – tall, w – white and r – red).

Table 3.3 Number of male (M) and female (F) farmers who knew 1, 2, 3, 4 or 5 taro landraces. Note: No one knew more than 6 taro landraces.

Location	*Number of known taro landraces*									
	1		2		3		4		5	
	Gender									
	M	F	M	F	M	F	M	F	M	F
Ezigeni	0	0	0	0	0	0	2	15	0	1
Upper Ogagwini	0	0	0	0	0	0	0	0	3	16
Lower Ogagwini	0	0	0	0	4	14	0	0	0	1
Rhwayi	0	0	1	2	2	10	0	1	0	0
Eziphambathini	0	0	0	1	2	8	0	6	0	0
Msholozi	0	0	0	0	0	4	1	2	0	0
Ezimwini	0	0	0	0	0	0	2	11	0	0
Total per gender	**0**	**0**	**1**	**3**	**8**	**36**	**5**	**35**	**3**	**18**
Total	**0**		**4**		**44**		**40**		**21**	

Table 3.4 Taro landraces as named and known by farmers at different locations.

Location	Names of taro landraces known by farmers	Code
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	De
	Mgingqeni or Dumbe-elimhlophe	Me
	Pitshi	Pe
	Dumbe-lomfula	Re
	Dumbe-elimbali	Fe
Upper Ogagwini	Dumbe-dumbe	Du
	Mgingqeni	Mu
	Pitshi-omfushane	Psu
	Pitshi-omude	Ptu
	Dumbe-lomfula	Ru
Lower Ogagwini	Dumbe-dumbe omhlophe	Dwo
	Pitshi or Pitshana-omhlophe	Pwo
	Mgingqeni	Mo
	Inkomfe or Dumbe-lomfula	Ro
	Dumbe-dumbe obomvu	Dro
	Pitshana-obomvu	Pro
	Intebe	Io
Rhwayi	Dumbe-dumbe	Dr
	Mgingqeni	Mr
	Pitshi	Pr
	Dumbe-lomfula or Dumbe-njani	Rr
Eziphambathini	Mgingqeni	Mp
	Dumbe-dumbe	Dp
	Pitshi	Pp
	Dumbe-lomfula or Uzaza or Dumbe-njani	Rp
Msholozi	Dumbe-elibomvu	Dm
	Mgingqeni or Dumbe-elimhlophe	Mm
	Pitshi or Dumbe lesiZulu	Pm
	Dumbe-lomfula or Dumbe-njani	Rm
Ezimwini	Pitshi	Pz
	Dumbe-dumbe	Dz
	Dumbe-elimhlophe	Dwz
	Dumbe-lomfula	Rz

3.3.2 Description of taro landraces by farmers

Morphological characters exhibited large variability. Leaf colour ranged from light green (8), light green with light veins (4), green (2), intense green (3), dark green (9), dark green with red veins (3), dark green with purple brown veins (1), purple or green (1), light purple (1), and very dark purple (1) (Table 3.5). Leaf size ranged from small (3), slightly small (1), large (13), very large (6) and the remaining ten were not classified (Table 3.6). Petiole leaf junction colour ranged from light (6), white (5), light green (2), reddish (3), red (3), dark (1) purple (10) and dark purple (3) (Table 3.7).

Corm shape ranged from elongated (2), roundish (5), round to oblong (3), oblong (2), long (3), long with nodes (2), very long (1), long and thick (3), long and thin (1), straight short (1), fingerlike (3) and 2 were not classified (Table 3.8). Corm size ranged from very small (1), small (11), normal (2), medium (1), large (12), very large (1), long and thick (2) and 3 were not classified (Table 3.9). Petiole corm junction colour ranged from light (7), white (9), pink (1), pink or light (1), reddish (4), purple (8), dark (1) and dark purple (2) (Table 3.10). Yield ranged from poor (4), good (5), very good (4), very good to excellent (1), excellent (7), overproduces (1), and 11 were not classified (Table 3.11).

Taste ranged from bitter (1), bad, but good in winter (1), not great (1), not so good (2), great but bitter when half cooked (1), good (6), good, best in winter (2) very good (7), excellent (4), 8 were not classified (Table 3.12). Cooking time ranges from ± 30 minutes (11), > 8 hours (10), cooking time for 2 was not known since they are not edible and they are never cooked and 10 were not classified (Table 3.13). Corm sliminess when cooked ranged from dry (13), slimy (12), not dry, not slimy (3), 2 were not applicable because they are not edible so they are not cooked and 3 were not classified (Table 3.14).

Table 3.5 Leaf colour of different taro landraces as characterized by farmers at different locations.

Location	**Landrace**	**Description**
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	Intense green
	Mgingqeni or Dumbe-elimhlophe	Light green
	Pitshi	Like Dumbe-dumbe but not as deep green
	Dumbe-lomfula	Green as Dumbe-dumbe
	Dumbe-elimbali	Purple or green
Upper Ogagwini	Dumbe-dumbe	Dark green with red veins
	Mgingqeni	Light green with light veins
	Pitshi-omfushane	Light green with light veins
	Pitshi-omude	Light green with light veins
	Dumbe-lomfula	Dark green with red veins
Lower Ogagwini	Dumbe-dumbe omhlophe	Light green
	Pitshi or Pitshana-omhlophe	Light green
	Mgingqeni	Light green with light veins
	Inkomfe or Dumbe-lomfula	Dark green
	Dumbe-dumbe obomvu	Dark green
	Pitshana-obomvu	Dark green with reddish veins
	Intebe	Light green
Rhwayi	Dumbe-dumbe	Dark green
	Mgingqeni	Light green
	Pitshi	Dark green
	Dumbe-lomfula or Dumbe-njani	Dark green with purple brown veins
Eziphambathini	Mgingqeni	Light green
	Dumbe-dumbe	Dark green
	Pitshi	Light green like Mgingqeni
	Dumbe-lomfula or Uzaza or Dumbe-njani	Very dark purple
Msholozi	Dumbe-elibomvu	Dark green
	Mgingqeni or Dumbe-elimhlophe	Light purple
	Pitshi or Dumbe lesiZulu	Green between Dumbe-elibomvu and Mgingqeni
	Dumbe-lomfula or Dumbe-njani	Dark green
Ezimwini	Pitshi	Dark green
	Dumbe-dumbe	Green
	Dumbe-elimhlophe	Light green
	Dumbe-lomfula	Dark green

Table 3.6 Leaf size of different taro landraces as characterized by farmers at different locations. Note: - means that no comment was given.

Location	Landrace	Description
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	-
	Mgingqeni or Dumbe-elimhlophe	-
	Pitshi	-
	Dumbe-lomfula	Very large
	Dumbe-elimbali	-
Upper Ogagwini	Dumbe-dumbe	Large
	Mgingqeni	Small
	Pitshi-omfushane	Small
	Pitshi-omude	Small
	Dumbe-lomfula	Very large
Lower Ogagwini	Dumbe-dumbe omhlophe	Large
	Pitshi or Pitshana-omhlophe	-
	Mgingqeni	-
	Inkomfe or Dumbe-lomfula	-
	Dumbe-dumbe obomvu	-
	Pitshana obomvu	-
	Intebe	-
Rhwayi	Dumbe-dumbe	Large
	Mgingqeni	Large
	Pitshi	Large
	Dumbe-lomfula or Dumbe-njani	Very large
Eziphambathini	Mgingqeni	Large
	Dumbe-dumbe	Large
	Pitshi	Large
	Dumbe-lomfula or Uzaza or Dumbe-njani	Very large
Msholozi	Dumbe-elibomvu	Large depends on environment
	Mgingqeni or Dumbe-elimhlophe	Large depends on environment
	Pitshi or Dumbe lesiZulu	Large depends on environment
	Dumbe-lomfula or Dumbe-njani	Very large
Ezimwini	Pitshi	Slightly small
	Dumbe-dumbe	Large
	Dumbe-elimhlophe	Large
	Dumbe-lomfula	Very large

Table 3.7 Petiole leaf junction colour of different taro landraces as characterized by farmers at different locations.

Location	Landrace	Description
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	Red
	Mgingqeni or Dumbe-elimhlophe	Light green
	Pitshi	Red
	Dumbe-lomfula	Red
	Dumbe-elimbali	Purple
Upper Ogagwini	Dumbe-dumbe	Purple
	Mgingqeni	White
	Pitshi-omfushane	White
	Pitshi-omude	White
	Dumbe-lomfula	Dark
Lower Ogagwini	Dumbe-dumbe omhlophe	Light
	Pitshi or Pitshana-omhlophe	White
	Mgingqeni	White
	Inkomfe or Dumbe-lomfula	Reddish
	Dumbe-dumbe obomvu	Reddish
	Pitshana-obomvu	Reddish
	Intebe	Light green
Rhwayi	Dumbe-dumbe	Purple
	Mgingqeni	Light
	Pitshi	Purple
	Dumbe-lomfula or Dumbe-njani	Dark purple
Eziphambathini	Mgingqeni	Light
	Dumbe-dumbe	Purple
	Pitshi	Light
	Dumbe-lomfula or Uzaza or Dumde-njani	Purple
Msholozi	Dumbe-elibomvu	Purple
	Mgingqeni or Dumbe-elimhlophe	Light
	Pitshi or Dumbe lesiZulu	Purple
	Dumbe-lomfula or Dumbe-njani	Dark purple
Ezimwini	Pitshi	Purple
	Dumbe-dumbe	Purple
	Dumbe-elimhlophe	Light
	Dumbe-lomfula	Dark purple

Table 3.8 Corm shape of different taro landraces as characterized by farmers at different locations. Note: - means that no comment was given.

Location	Landrace	Description
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	Elongated
	Mgingqeni or Dumbe-elimhlophe	Round
	Pitshi	Long with nodes
	Dumbe-lomfula	Very long
	Dumbe-elimbali	Long with nodes
Upper Ogagwini	Dumbe-dumbe	Oblong normal shape
	Mgingqeni	Roundish
	Pitshi-omfushane	Straight long
	Pitshi-omude	Straight short
	Dumbe-lomfula	Long and thick
Lower Ogagwini	Dumbe-dumbe omhlophe	-
	Pitshi or Pitshana-omhlophe	-
	Mgingqeni	-
	Inkomfe or Dumbe-lomfula	Elongated
	Dumbe-dumbe obomvu	Roundish
	Pitshana-obomvu	-
	Intebe	-
Rhwayi	Dumbe-dumbe	Oblong
	Mgingqeni	Roundish oblong
	Pitshi	Long thin
	Dumbe-lomfula or Dumbe-njani	Long and thick
Eziphambathini	Mgingqeni	Roundish
	Dumbe-dumbe	Oblong
	Pitshi	Fingerlike
	Dumbe-lomfula or Uzaza or Dumbe-njani	Long
Msholozi	Dumbe-elibomvu	Round to oblong
	Mgingqeni or Dumbe-elimhlophe	Roundish
	Pitshi or Dumbe lesiZulu	Fingerlike
	Dumbe-lomfula or Dumbe-njani	Long and thick
Ezimwini	Pitshi	Fingerlike
	Dumbe-dumbe	Oblong
	Dumbe-elimhlophe	Roundish to oblong
	Dumbe-lomfula	Long

Table 3.9 Corm size of different taro landraces as characterized by farmers at different locations. Note: - means that no comment was given.

Location	Landrace	Description
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	Large
	Mgingqeni or Dumbe-elimhlophe	Smaller than Dumbe-dumbe
	Pitshi	Small
	Dumbe-lomfula	Very long and large
	Dumbe-elimbali	Large main corm, cormels same size as Pitshi
Upper Ogagwini	Dumbe-dumbe	Normal, depends on environment
	Mgingqeni	Normal, depends on environment
	Pitshi-omfushane	Small
	Pitshi-omude	Small
	Dumbe-lomfula	Very large
Lower Ogagwini	Dumbe-dumbe omhlophe	-
	Pitshi or Pitshana-omhlophe	Small
	Mgingqeni	-
	Inkomfe or Dumbe-lomfula	Large and long
	Dumbe-dumbe obomvu	-
	Pitshana-obomvu	Small
	Intebe	Small
Rhwayi	Dumbe-dumbe	Large, depending on environment
	Mgingqeni	Smaller than Dumbe-dumbe, depends on environment
	Pitshi	Very small
	Dumbe-lomfula or Dumbe-njani	Long and thick
Eziphambathini	Mgingqeni	Large
	Dumbe-dumbe	Large
	Pitshi	Small
	Dumbe-lomfula or Uzaza or Dumbe-njani	Large (thick)
Msholozi	Dumbe-elibomvu	Large
	Mgingqeni or Dumbe-elimhlophe	Large but smaller than Dumbe-elibomvu
	Pitshi or Dumbe lesiZulu	Small
	Dumbe-lomfula or Dumbe-njani	Large
Ezimwini	Pitshi	Small
	Dumbe-dumbe	Medium
	Dumbe-elimhlophe	Large
	Dumbe-lomfula	Long and thick

Table 3.10 Petiole corm junction colour of different taro landraces as characterized by farmers at different locations.

Location	Landrace	Description
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	Reddish
	Mgingqeni or Dumbe-elimhlophe	White
	Pitshi	White
	Dumbe-lomfula	White
	Dumbe-elimbali	White
Upper Ogagwini	Dumbe-dumbe	Purple
	Mgingqeni	Light
	Pitshi-omfushane	Light
	Pitshi-omude	Light
	Dumbe-lomfula	Dark
Lower Ogagwini	Dumbe-dumbe omhlophe	White
	Pitshi or Pitshana-omhlophe	White
	Mgingqeni	White
	Inkomfe or Dumbe-lomfula	Reddish
	Dumbe-dumbe obomvu	Reddish
	Pitshana-obomvu	Reddish
	Intebe	White
Rhwayi	Dumbe-dumbe	Purple
	Mgingqeni	White
	Pitshi	Purple
	Dumbe-lomfula or Dumbe-njani	Dark purple
Eziphambathini	Mgingqeni	Light
	Dumbe-dumbe	Purple
	Pitshi	Light
	Dumbe-lomfula or Uzaza or Dumbe-njani	Purple
Msholozi	Dumbe-elibomvu	Pink
	Mgingqeni or Dumbe-elimhlophe	Light
	Pitshi or Dumbe lesiZulu	Pink or light
	Dumbe-lomfula or Dumbe-njani	Purple
Ezimwini	Pitshi	Purplish
	Dumbe-dumbe	Purplish
	Dumbe-elimhlophe	Light
	Dumbe-lomfula	Dark purple

Table 3.11 Yield of different taro landraces as characterized by farmers at different locations. Note: - means that no comment was given.

Location	**Landrace**	**Description**
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	Good
	Mgingqeni or Dumbe-elimhlophe	Excellent
	Pitshi	Higher than Dumbe-dumbe and Mgingqeni
	Dumbe-lomfula	Excellent like Mgingqeni
	Dumbe-elimbali	Not harvested because it is not edible
Upper Ogagwini	Dumbe-dumbe	Good, depends on environment
	Mgingqeni	Very good to excellent
	Pitshi-omfushane	Excellent
	Pitshi-omude	Excellent
	Dumbe-lomfula	Poor
Lower Ogagwini	Dumbe-dumbe omhlophe	-
	Pitshi or Pitshana-omhlophe	-
	Mgingqeni	Overproduces
	Inkomfe or Dumbe-lomfula	-
	Dumbe-dumbe obomvu	-
	Pitshana-obomvu	-
	Intebe	-
Rhwayi	Dumbe-dumbe	Good
	Mgingqeni	Very good
	Pitshi	Excellent
	Dumbe-lomfula or Dumbe njani	Poor
Eziphambathini	Mgingqeni	Very good
	Dumbe-dumbe	Good
	Pitshi	Excellent
	Dumbe-lomfula or Uzaza or Dumbe-njani	Poor
Msholozi	Dumbe-elibomvu	Good
	Mgingqeni or Dumbe-elimhlophe	Very good
	Pitshi or Dumbe lesiZulu	Very good
	Dumbe-lomfula or Dumbe-njani	Poor
Ezimwini	Pitshi	-
	Dumbe-dumbe	-
	Dumbe-elimhlophe	-
	Dumbe-lomfula	-

Table 3.12 Taste of different taro landraces as characterized by farmers at different locations. Note: - means that no comment was given.

Location	Landrace	Description
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	Excellent
	Mgingqeni or Dumbe-elimhlophe	Not great
	Pitshi	Great but bitter when half cooked
	Dumbe-lomfula	Good
	Dumbe-elimbali	Not edible
Upper Ogagwini	Dumbe-dumbe	Good
	Mgingqeni	Not good, almost bad, good in Winter
	Pitshi-omfushane	Very good
	Pitshi-omude	Very good
	Dumbe-lomfula	Good
Lower Ogagwini	Dumbe-dumbe omhlophe	-
	Pitshi or Pitshana-omhlophe	-
	Mgingqeni	Great in Winter
	Inkomfe or Dumbe-lomfula	-
	Dumbe-dumbe obomvu	-
	Pitshana-obomvu	-
	Intebe	Bitter
Rhwayi	Dumbe-dumbe	Excellent
	Mgingqeni	Good
	Pitshi	Very good
	Dumbe-lomfula or Dumbe-njani	Very good
Eziphambathini	Mgingqeni	Good
	Dumbe-dumbe	Very good
	Pitshi	Excellent
	Dumbe-lomfula or Uzaza or Dumbe-njani	Not so good
Msholozi	Dumbe-elibomvu	Very good
	Mgingqeni or Dumbe-elimhlophe	Good, best in Winter
	Pitshi or Dumbe lesiZulu	Not well known
	Dumbe-lomfula or Dumbe-njani	Not well known
Ezimwini	Pitshi	Excellent
	Dumbe-dumbe	Very good
	Dumbe-elimhlophe	Good
	Dumbe-lomfula	Not so good

Table 3.13 Cooking time of different taro landraces as characterized by farmers at different locations. Note: - means that no comment was given.

Location	Landrace	Description
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	± 30 minutes
	Mgingqeni or Dumbe-elimhlophe	± 30 minutes
	Pitshi	> 8 hours
	Dumbe-lomfula	> 8 hours
	Dumbe-elimbali	Not known
Upper Ogagwini	Dumbe-dumbe	± 30 minutes
	Mgingqeni	± 30 minutes
	Pitshi-omfushane	> 8 hours, until it turns red
	Pitshi-omude	> 8 hours, until it turns red
	Dumbe-lomfula	> 8 hours
Lower Ogagwini	Dumbe-dumbe omhlophe	± 30 minutes
	Pitshi or Pitshana-omhlophe	-
	Mgingqeni	-
	Inkomfe or Dumbe-lomfula	-
	Dumbe-dumbe obomvu	-
	Pitshana-obomvu	-
	Intebe	-
Rhwayi	Dumbe-dumbe	-
	Mgingqeni	-
	Pitshi	-
	Dumbe-lomfula or Dumbe-njani	-
Eziphambathini	Mgingqeni	± 30 minutes
	Dumbe-dumbe	± 30 minutes
	Pitshi	> 8 hours
	Dumbe-lomfula or Uzaza or Dumbe-njani	> 8 hours
Msholozi	Dumbe-elibomvu	± 30 minutes
	Mgingqeni or Dumbe-elimhlophe	± 30 minutes
	Pitshi or Dumbe lesiZulu	> 8 hours
	Dumbe-lomfula or Dumbe-njani	Not known
Ezimwini	Pitshi	> 8 hours
	Dumbe-dumbe	± 30 minutes
	Dumbe-elimhlophe	± 30 minutes
	Dumbe-lomfula	> 8 hours

Table 3.14 Sliminess of different taro landraces as characterized by farmers at different locations. Note: - means that no comment was given.

Location	Landrace	Description
Ezigeni	Dumbe-dumbe or Dumbe-elibomvu	Dry
	Mgingqeni or Dumbe-elimhlophe	Slimy
	Pitshi	Between Dumbe-dumbe and Mgingqeni but more like Dumbe-dumbe
	Dumbe-lomfula	Dry
	Dumbe-elimbali	N/A
Upper Ogagwini	Dumbe-dumbe	Dry
	Mgingqeni	Slimy
	Pitshi-omfushane	Not dry, not slimy
	Pitshi-omude	Not dry, not slimy
	Dumbe-lomfula	Dry
Lower Ogagwini	Dumbe-dumbe omhlophe	Slimy
	Pitshi or Pitshana-omhlophe	-
	Mgingqeni	Slimy
	Inkomfe or Dumbe-lomfula	-
	Dumbe-dumbe obomvu	Dry
	Pitshana-obomvu	Dry
	Intebe	-
Rhwayi	Dumbe-dumbe	Dry
	Mgingqeni	Slimy
	Pitshi	Slimy
	Dumbe-lomfula or Dumbe-njani	Dry
Eziphambathini	Mgingqeni	Slimy
	Dumbe-dumbe	Dry
	Pitshi	Slimy
	Dumbe-lomfula or Uzaza or Dumbe-njani	Dry
Msholozi	Dumbe-elibomvu	Dry
	Mgingqeni or Dumbe-elimhlophe	Slimy, better in Winter
	Pitshi or Dumbe lesiZulu	Slimy
	Dumbe-lomfula or Dumbe-njani	Not known
Ezimwini	Pitshi	Slimy
	Dumbe-dumbe	Dry
	Dumbe-elimhlophe	Slimy
	Dumbe-lomfula	Dry

3.3.3 Taro landrace planting preference

According to the knowledge of the farmers at locations where the taro landraces were identified, the following were cultivated types: Dumbe-dumbe, Mgingqeni, Pitshi, Dumbe-dumbe obomvu, Pitshana-obomvu, Pitshi-omfushane, Pitshi-omude and Dumbe-elimhlophe; only Dumbe-lomfula was known to be wild by all farmers across all locations. Dumbe-elimbali was indicated as cultivated by 6% and wild by 94% of farmers at Ezigeni which was the only location where it was known. Intebe on the other hand was indicated as wild by 11% of farmers who were the only ones who knew it at Lower Ogagwini.

Farmers seemed to prefer to plant other taro landraces more than others. Pair-wise ranking of taro landraces at each location was performed to determine their relative importances, and reasons were given for their preference (Tables 3.15 – 3.21). The ranking of each attribute in Tables 3.15-3.21 was scored and reasons for preferential ranking given by the farmers. See Table 3.4 for explanation of codes for the ranked attributes. Looking at the landraces that were common to all locations, Dumbe-dumbe was generally the best preffered taro landrace followed by Mgingqeni, Pitshi and Dumbe-lomfula respectively. The reasons that seemed to make a landrace more preferred were culture, income generation and food; and the preference of corms to be used for culture, income generation and food was determined by the characteristics of corms like taste, cooking time, and sliminess.

Table 3.15 Pair-wise ranking of taro landraces for planting preference produced with Ezigeni farmers.

	De	Me	Pe	Re	Fe	Score	Reasons
De	X	De	De	De	De	4	It is used for food (corms and leaves), income generation and culture.
Me		X	Me	Me	Me	3	It is also used for food (corms and leaves), income generation and culture but leaves are bitter.
Pe			X	Pe	Pe	2	It is used for food (corms and leaves) though leaves are bitter and for plant protection.
Re				X	Re	1	It is known by only 6% of the interviewed farmers in Ezigeni.
Fe					X	0	It is only used as an ornament.

Table 3.16 Pair-wise ranking of taro landraces for planting preference produced with Upper Ogagwini farmers.

	Du	Mu	P_{Su}	P_{Tu}	Ro	Score	Reasons
Du	X	Du	Du	Du	Du	4	It is the best in income generating. It is also used for food (corms and leaves), medicinal use and in cultural activities.
Mu		X	P_{Su}	P_{Tu}	Mu	1	It is only used for food (corms and leaves).
P_{Su}			X	P_{Su}	P_{Su}	3	Corms and leaves are used for food. It is also used for plant protection. Corms are longer than those of P_{Tu}.
P_{Tu}				X	P_{Tu}	2	Corms and leaves are used for food. It is also used for plant protection.
Ru					X	0	Corms and leaves are used for food. It is also used for medicinal purposes. And it is wild.

Table 3.17 Pair-wise ranking of taro landraces for planting preference produced with Lower Ogagwini farmers.

	Dwo	Pwo	Mo	Ro	Dro	Pro	Io	Score	Reasons
Dwo	X	Dwo	Dwo	Dwo	Dwo	Dwo	Dwo	6	Corms and leaves are used for food. It is also used for plant protection, income generation and medicinal purposes.
Pwo		X	Pwo	Pwo	Dro	Pro	Pwo	2	Only corms are eaten and also used for plant protection
Mo			X	Mo	Dro	Pro	Mo	2	Only corms are eaten and also used for crop protection and for medicinal purposes to a lesser extent.
Ro				X	Dro	Pro	Io	0	Corms and leaves are used for food by some people.
Dro					X	Dro	Dro	5	Corms and leaves are used for food. It is also used for plant protection, income generation and medicinal purposes.
Pro						X	Pro	4	Only corms are eaten and also used for plant protection
Io							X	1	Only leaves are eaten and some farmers use it for plant protection.

Table 3.18 Pair-wise ranking of taro landraces for planting preference produced with Rhwayi farmers.

	Dr	Mr	Pr	Rr	Score	Reasons
Dr	X	Dr	Dr	Dr	3	Corms and leaves are used as food. It is also used for income generation, in cultural activities and for medicinal use.
Mr		X	Mr	Mr	2	Corms and leaves are used for food. Some but not all farmers use it to generate income. It is also used in cultural activities.
Pr			X	Pr	1	Corms and leaves are used for food and some farmers use it for plant protection.
Rr				X	0	It is not used that much for food and income generation. It is mostly used for plant protection and to a lesser extent for medicinal use.

Table 3.19 Pair-wise ranking of taro landraces for planting preference produced with Eziphambathini farmers.

	Mp	**Dp**	**Pp**	**Rp**	**Score**	**Reasons**
Mp	X	Dp	Mp	Mp	2	Only corms are used for food, half of the farmers use it to generate income and some use it in cultural activities.
Dp		X	Dp	Dp	3	It is used by all for food (both corms and leaves), income generation and in cultural activities.
Pp			X	Pp	1	Corms and leaves are used for food and some farmers use it for plant protection.
Rp				X	0	Both corms and leaves are used for food. It is also used for plant protection and some farmers use it for medicinal use but it is not preferred since it is not cultivated.

Table 3.20 Pair-wise ranking of taro landraces for planting preference produced with Msholozi farmers.

	Dm	**Mm**	**Pm**	**Rm**	**Score**	**Reasons**
Dm	X	Dm	Dm	Dm	3	It is used for food (corms and leaves), income generation and in cultural activities.
Mm		X	Mm	Mm	2	Only corms are eaten and some but not all farmers use it for income generation, plant protection and in cultural activities.
Pm			X	Pm	1	Apart from corms being used for food, it has no other use.
Rm				X	0	Corms and leaves are used to a lesser extend for food.

Table 3.21 Pair-wise ranking of taro landraces for planting preference produced with Ezimwini farmers.

	Pz	Dz	Dwz	Rz	Score	Reasons
Pz	X	Dz	Pz	Pz	2	Only corms are used for food and it is also used for plant protection.
Dz		X	Dz	Dz	3	Corms and leaves are used for food and it is also used for income generation, plant protection, medicinal use and in cultural activities.
Dwz			X	Dwz	1	Corms and leaves are used for food and it is also used for plant protection but not preferred over Pz because of slimy corms and because Pz have a better taste.
Rz				X	0	It is mainly used for plant protection and half of the interviewed farmers use its corms and leaves for food.

3.3.4 Utilisation of taro landraces by Umbumbulu farmers

Farmers in Umbumbulu produce different taro landraces for various reasons (Figure 3.2). All the farmers interviewed produced Dumbe-dumbe for corms and leaves as food, income generation and cultural activities; and this made the landrace the most planted and popular taro landrace. Dumbe–dumbe was cited as the best type for income generation and cultural activities; and others are only used for these purposes if it is not available. Twenty-nine percent (29 %) of the respondents used Dumbe-dumbe for plant protection and only 18% used it for medicinal purposes.

The second preferred landrace was Mgingqeni, of which corms were used by 88% of the interviewed farmers and leaves were used by 49% as food. Only 29% marketed Mgingqeni, 69% used it for cultural activities, 20% for plant protection and 1% for medicinal properties. Mgingqeni was followed by Pitshi, which was used by 83% and 47% of the respondents for corms and leaves as food respectively. Pitshi was less preferred for income generation, not used at all for cultural activities and 52% of the respondents used it for plant protection to chase away moles.

Dumbe-lomfula was used by 49% for corms as food, 62% for leaves as food, 15% for income generation, 27% for plant protection and 20% for medicinal purposes. Eighty four percent of farmers who used Dumbe-lomfula`s leaves as food cited it as the best of all in being used as green vegetable. Dumbe-elimbali was used only as an ornament by 1% of the farmers and that made it the less popular and less preferred taro type. Seventeen percent of the farmers used Dumbe-dumbe obomvu for food (both corms and leaves), income generation, culture and plant protection. These 17% were all farmers at Lower Ogagwini and it was the only location where the landrace was named. Further discussions, however, revealed that Dumbe-dumbe obomvu is synonymous with Dumbe-dumbe.

Pitshana-obomvu was used for food (corms only) and plant protection by 17% of farmers also from Lower Ogagwini since it was the only location where the landrace was also named. Intebe was also named only at Lower Ogagwini and all farmers at the location (17% of farmers from all locations) used it as green vegetable (leaves only) and 10% of farmers at the location (2% of farmers from all seven locations) used it for plant protection. Pitshi-omfushane and Pitshi-omude were both used for food (corms and leaves) and plant protection by all farmers at Upper Ogagwini (17% of farmers from all locations). Dumbe-elimhlophe (synonymous with Mgingqeni) was also used for food (corms and leaves) and plant protection by all farmers at Ezimwini which is 12% of all farmers interviewed.

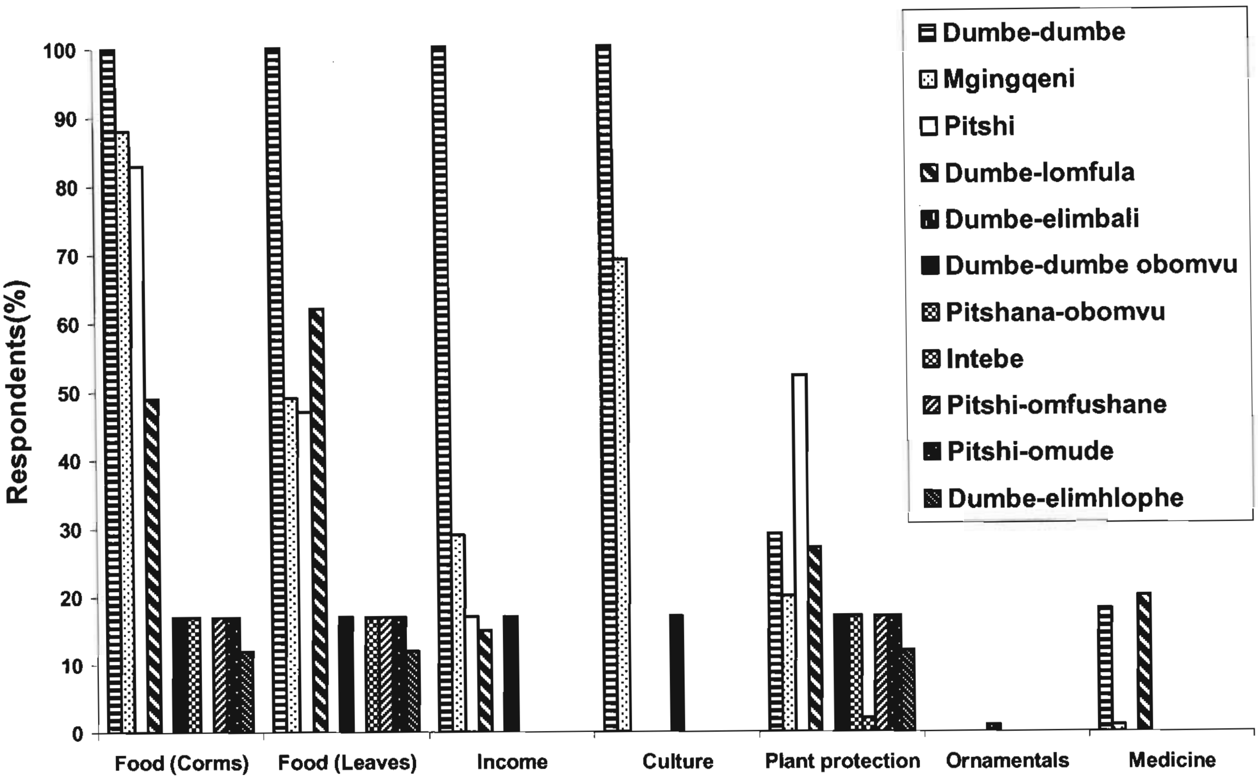

Figure 3.2 Utilisation of taro landraces by Umbumbulu farmers.

3.3.5. Agronomic practices

The farmers interviewed stated that they all practice crop rotation and organic manuring. They reported to rotate their taro with sweet potatoes, beans, maize, potatoes and peanuts. The reasons they gave for rotating their taro with these crops were to improve soil fertility and structure, increase yield, prevent built up of diseases and pests and to control soil erosion. The other reason was that they have learned crop rotation from their forefathers.

Organic manuring was practiced because it was cheap, and also to improve soil quality and fertility and hence increase yield. The other reasons were that they are organic farmers and organic taro had good taste. Inorganically fertilized taro reportedly becomes slimy and soft, and does not have long shelf life. The farmers also thought that it is traditional to use organic manure. Eighty percent of farmers at Eziphambathini (13% of farmers across locations) reported that they did not even know chemical fertilizer until 2-5 years ago.

Ninety three percent (93%) of farmers interviewed practised intercropping to improve soil fertility and hence increase yield, to obtain a variety of food from one piece of land because of limited land and to take advantage of different growing seasons of different crops. Short season crops like maize and beans are used. The other reason for farmers to use maize in intercropping was that maize roots prevent soil erosion by holding loose soil. Taro was either planted with beans and maize in alternating rows or sometimes in alternating plants within rows; or taro would be planted, then after its emergence beans or maize would be planted between rows. The 7% of farmers that did not practice intercropping were from Eziphambathini.

Farmers at Ezigeni (17% of interviewed farmers) reported to have come across corm rot, especially in monoculture. The same farmers also cited moles as the pests of taro and that Pitshi was used as a crop protection measure to chase away moles. Warthhog was reported to be a serious taro pest by farmers at Eziphambathini (16% of interviewed farmers). Downy mildew was reported by 17% of interviewed farmers, which was all farmers at Lower Ogagwini, and to prevent the disease dampness was avoided by storing corms in a cool, dry place before planting and mature decomposed organic matter was used for planting. Millipedes were cited as taro pests by 72% of farmers. These farmers were all farmers at Upper Ogagwini, Lower Ogagwini, Rhwayi, Eziphambathini and Msholozi. Only farmers at Lower Ogagwini reported hand picking and crop rotation as the measures they used to control millipedes. Fifty four percent of the farmers did not know any taro diseases and they were farmers at Upper Ogagwini, Rhwayi, Eziphambathini and Msholozi.

3.3.6. Taro cropping calendar

Table 3.22 shows a list of taro cropping activities and months when farmers are involved in the different activities. Farmers begin to prepare their soil for planting in August to

October at Ezigeni. Soil preparation begins in July to September at the following locations: Rhwayi, Eziphambathini, Msholozi and Ezimwini, and October at Upper and Lower Ogagwini. Planting starts as soon as soil preparation is done and extends to November at Ezigeni, Ezimwini and Eziphambathini, but the farmers from Eziphambathini indicated September as the best time for planting.

Farmers start weeding in November at Ezigeni, August at Upper Ogagwini, September at Rhwayi, Eziphambathini, Msholozi and Ezimwini, and mid September at Lower Ogagwini. This activity is carried out until December to March depending on the location. The following activity is harvesting, which occurs concurrently with marketing and extends beyond marketing in Eziphambathini and Msholozi. And this is in line with what WESTHUYZEN (1967) and YOUNG (1992) stated, that in South Africa, upland taro grown under dryland conditions is harvested after seven to eight months.

Table 3.22 Taro cropping calendar for different locations in Umbumbulu.

		Months											
Location	**Activity**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Ezigeni	**Cultivation**								X	X	X		
	Planting								X	X	X	X	
	Weeding	X	X									X	X
	Harvesting			X	X	X	X	X					
	Marketing			X	X	X	X	X					
Upper Ogagwini	**Cultivation**							X	X	X	X		
	Planting							X	X	X	X		
	Weeding								X	X	X	X	X
	Harvesting		X	X	X	X	X	X					
	Marketing		X	X	X	X	X	X					
Lower Ogagwini	**Cultivation**							X	X	X	X		
	Planting							X	X	X	X*		
	Weeding	X								*X	X	X	X
	Harvesting		X	X	X	X	X	X					
	Marketing		X	X	X	X	X	X	X				
Rhwayi	**Cultivation**							X	X	X			
	Planting	X						X	X	X	X	X	X
	Weeding	X	X	X						X	X	X	X
	Harvesting			X	X	X	X	X	X				
	Marketing			X	X	X	X	X	X				
Eziphambathini	**Cultivation**							X	X	X			
	Planting								X	X	X	X	
	Weeding	X	X							X	X	X	X
	Harvesting			X	X	X	X	X	X				
	Marketing				X	X	X	X					
Msholozi	**Cultivation**							X	X	X			
	Planting							*X	X	X	X		
	Weeding									X	X	X	X
	Harvesting			X	X	X	X	X	X	X			
	Marketing			X	X	X	X	X	X*				
Ezimwini	**Cultivation**							X	X	X			
	Planting							X	X	X	X	X	
	Weeding									X	X	X	X
	Harvesting			X	X	X	X	X	X				
	Marketing			X	X	X	X	X	X				

* indicates that activities begin or end mid-month.

3.4 Conclusions and future directions

Subsistence farmers at Umbumbulu know a maximum of five taro landraces. Even though the names of these types are sometimes different depending on different locations, morphological characteristics and utilization by farmers indicate that the landraces might be the same landraces. The other factor that might bring the difference are the environmental conditions under which they grow.

Farmers produce different taro landraces for different reasons. Dumbe-dumbe is mainly produced for food, marketing and culture. Other landraces may be used for these purposes if there is a shortage in the production of Dumbe-dumbe but they are not preferred. Leaves of taro are not marketed, only corms are used to generate income. Mgingqeni and Pitshi are mainly used for home consumption. Although Dumbe-lomfula is not planted, it has food security potential because its corms are edible, and it was cited by farmers as usable as a green leafy vegetable despite it being wild. And its large corms and leaves can provide a considerable, abundant supply of food.

Millipedes, moles, warthogs, downy mildew and corm rot were the only pests and diseases of taro cited by the farmers. However, no chemical control measures were known or used by the farmers. Hand picking, crop rotation, use of maturely decomposed organic matter and avoiding dampness by storing corms in a cool, dry place before planting were the standard crop protection measures.

The findings of this study showed that there are several taro landraces in Umbumbulu. The landraces can be grouped into four, namely Dumbe-dumbe (also known as Dumbe-dumbe obomvu or Dumbe-elibomvu), Mgingqeni (also known as Dumbe-elimhlophe or Dumbe-dumbe omhlophe), Pitshi (variously referred to as Pitshana-obomvu, Pitshi-omhlophe, omude, omfushane, Dumbe lesiZulu, perhaps to identify its ecotypes) and Dumbe-lomfula (also known as Dumbe-njani, Uzaza or Inkomfe). Discussions with Umbumbulu farmers revealed that there is a significant amount of traditional knowledge about taro, but there is no evidence of knowledge about the agronomical aspects of the crop. Therefore, it was proposed that experiments be conducted on taro landraces that were identified as more commonly available and potentially useful to the farmers, to determine agronomic performance at Umbumbulu and Pietermaritzburg. Since temperature has been shown to be an important factor in taro production elsewhere in the world (MIYASAKI *et al.*, 2003), it was of interest to also conduct a controlled environment study to determine the effects of temperatures representative of cool, warm and hot climates on taro growth, yield and chemical composition. These field and controlled environment studies are reported next, in chapters four and five of this dissertation.

CHAPTER 4

PHYTOTRON STUDIES ON THE EFFECTS OF TEMPERATURE ON TARO GROWTH, YIELD, STARCH AND MINERAL CONTENT

4.1 Introduction

All stages of crop development are sensitive to temperature and the sensitivity differs with phenological stages, being stronger at sowing to emergence phase. Temperature is the main factor controlling the rate of crop development (BAZZAZ & SOMBROEK, 1996) and the most important factor affecting taro growth (LU *et al.*, 2001). Higher temperatures speed annual crops through their developmental phases (WOLFE, unpublished). Development generally accelerates as temperature increases, a phenomenon that is often described as a linear function of daily average temperature. The growing degree day concept is a common example of a linear model of developmental response to temperature. A non-linear model is needed to describe development when a crop is exposed to extreme temperature stress (BAZZAZ & SOMBROEK, 1996). The rate of reaction increases gradually, reaches maximum and declines very fast as temperature increases above the optimum. Crop growth is reduced by stresses of high and low temperatures that develop when air temperature is above or below the optimum (SINGH *et al.*, 1998).

Most plant processes related to growth and yield are highly temperature dependent (WOLFE, unpublished). There are two ways in which temperature affects plants at the canopy level. Firstly higher temperatures increase transpiration by changing the vapour pressure deficit (VPD) at the leaf surface, and secondly the higher canopy temperature may lead to an accelerated ageing of the foliage and a shortening of the growing season (BAZZAZ & SOMBROEK, 1996) which result in lower yields. This was also confirmed by MUCHOW *et al.*, (1990) and SINCLAIR & GARDNER (1998) who stated that temperature has a great influence on the duration of the growing season. It determines the length of the crop growth period, either by influencing the length of the crop growth stages, or by ending crop growth through temperature extremes. Commonly, as temperatures increase, the time required to progress through each developmental stage in the plant life cycle is decreased (MUCHOW *et al.*, 1990; SINCLAIR & GARDNER, 1998). Therefore, higher dry weight accumulation and yields are associated with cool temperatures that lengthen the season depending on the crop (SINCLAIR & GARDNER, 1998).

The duration of a physiological process usually decreases with rise in temperature to a minimum at an optimum temperature, and increases with further rise in temperature above the optimum (SQUIRE, 1990). Photosynthesis and respiration of plants and microbes increase with temperature (BAZZAZ & SOMBROEK, 1996). High temperature appears to restrict or inhibit protein synthesis, but probably also affects other cellular processes (SQUIRE, 1990).

Productivity of wheat and other crop species falls markedly at high temperatures above optimum. All genotypes are sensitive to temperature at one stage or another. Temperature sensitivity, however, varies greatly with genotype (BAZZAZ & SOMBROEK, 1996). An optimum temperature range for maximum yield for any one crop can be identified. The optimum growth temperature frequently corresponds to the optimum temperature for photosynthesis (WOLFE, unpublished).

Yield response to leaf area is primarily a function of light interception (SINGH *et al.*, 1998; ZIEMS *et al.*, 2006). The greater the leaf area, the greater the radiation absorption, the greater the possible production of photosynthates and hence the greater yield (ANDERSON, 1967). In the tropics, high temperature decreased the duration of growth and grain yield, despite high levels of radiation (MUCHOW *et al.*, 1990). Plant production is driven by photosynthesis. Interception of photosynthetically active radiation (PAR, 400 – 700 nm) is one of the key elements in the system. High yields can be realized among others by maximizing the extent and duration of radiation interception. Whether leaf area is optimal for photosynthesis in a particular environment is reciprocally linked with development and properties of individual leaves, including their longevity (LOOMIS & AMTHOR, 1999).

4.1.1 Seedling emergence

Time to emergence depends much on sowing depth as deep sowing increases the thermal duration of a percentile of the population and reduces the fraction of the population that emerges. Moreover, the increase in thermal duration is greater for the more slowly developing individuals, so the spread of thermal time between the first and the last seeds to emerge increases (SQUIRE, 1990).

Shoot emergence was more rapid when *Zephyra elegans* plants were grown at a day/night temperature combination of 15/10 °C (22.2 days) or 20/15 °C (24.3 days) than at 25/20 °C (48.6 days). High temperatures also delayed the emergence of non-dormant corms planted during summer, and reduced their emergence (LU *et al.*, 2001).

4.1.2 Leaf number

Temperature affected both the rate and pattern of development of sugar beet. The number of unfolded leaves increased linearly with time (TERRY, 1968). Moreover, the rate at which leaves were produced by the apex depended on temperature in sugar beet. It increased with time up to about three weeks and then began to decrease. At 15°C the rate of leaf production was initially slow but continued to increase throughout and in the second half of the experimental period rates of leaf production were greater than those at 25°C. The rate of unfolding of leaves was nearly constant and was faster at 25 than at 15°C (TERRY, 1970). Over years of experimental work, it has been observed that high temperatures in summer accelerates the senescence of *Z. elegans* plants (YANEZ *et al.*, 2005), decreasing the longevity of leaves. A senescence period of decreasing root and shoot growth with continued increase in corm size during six to nine months after planting has also been observed in taro (MIYASAKI *et al.*, 2003). Whether the amount of leaf area is optimal for photosynthesis in a particular environment is reciprocally linked with development and properties of individual leaves, including their longevity (LOOMIS & AMTHOR, 1999).

4.1.3 Plant height

The rate of expansion of most stems is strongly affected by temperature (SQUIRE, 1990). Cool conditions slows the rate of growth compared to warm conditions in wheat, cool temperature slows the rate of protein synthesis and thereby growth. As leaves live longer, have assimilation rates only slightly lower, and respire relatively less in cool than warm conditions, the growth rate per unit of accumulated temperature may be larger in cool conditions (LAWLOR *et al.*, 1988). On the other hand, even though 25°C was required for effective breaking of dormancy with *Z. elegans*, lower temperatures were better for its growth and development. High temperatures negatively affected growth of *Z. elegans* (YANEZ *et al.*, 2005).

4.1.4 Leaf area

Leaf area is a valuable index in identifying taro growth and development (EZUMAH, 1972). It determines radiation interception, water and energy exchange and therefore considered the most important single determinant of dry matter accumulation and yield in taro (SATOU *et al.*, 1978, 1988; JACOBS & CHAND, 1992; CHAN *et al.*, 1995, 1998, DE JESUS *et al.*, 2001).

The fraction of solar radiation reaching the earth`s surface and intercepted by a leaf canopy is dependent on the extent of the leaf surface area. In turn, canopy leaf area depends on the number and size of leaves, both of which are influenced by environment and plant genetics. Temperature is one of the environmental factors that can greatly affect leaf size (SINCLAIR & GARDNER, 1998). The efficiency of crop production is defined in thermodynamics terms as the ratio of energy output (carbohydrate) to energy input (solar radiation). Temperature is one of the main climatic constraints on efficiency of crop production (MONTEITH & MOSS, 1977). Not surprisingly, the growth rate of many plant systems increases with increasing leaf area. Because leaf canopy increases asymptotically with leaf area index, an asymptotic increase in crop growth rate with increasing leaf area index has been observed (SINCLAIR & GARDNER, 1998). The decreased area of individual leaves means that the canopy leaf area index is decreased and light interception is decreased. Leaf area development can be restricted by direct damage from insects, diseases and hail. Leaf photosynthetic activity and radiation use efficiency can be decreased by factors such as extreme temperatures and diseases. (SINCLAIR & GARDNER, 1998).

Total production of dry matter by potatoes is strongly correlated with interception of radiation, and the crop forms carbohydrate at about 1.4 g MJ^{-1} solar energy, equivalent to 2.4% efficiency. The amount of light intercepted during the growing season and the efficiency with which intercepted light is used may be used to analyse crop growth. The amount intercepted is dependant on the seasonal distribution of leaf area which, in turn is dependant on temperature (MONTEITH & MOSS, 1977).

When roots have access to adequate water, the leaves of many temperate crop plants assimilate CO_2 at a maximum rate when tissue temperature is between 20 and 30°C. The maximum photosynthesis rate in bright light does not decrease much when temperature is lowered from 20 to about 10°C but approaches zero when temperature is between 0 and 5°C. For tropical plants, the optimum temperature for photosynthesis is between 30 and 40°C, but photosynthesis rates approach zero between 10 and 15°C (MONTEITH & MOSS, 1977).

The effect of temperature on development rate of taro has been described using a thermal-time concept, which assumes that phenological development is constant per degree of temperature between a base temperature and an upper threshold temperature, above and below where the development rate is zero (LU *et al.*, 2001). The primary factor governing taro growth rate is temperature (CHAN *et al.*, 1998). Temperature strongly affects the rate of expansion of leaves of most crops (SQUIRE, 1990). Temperature also has an important effect on the length of time for which stands in moist conditions maintain a canopy with sufficient leaf area to cover most of the ground. Ground cover is present for the shortest time at the optimum temperature (usually 30 – 35°C), and for the longest time at the lowest temperature (SQUIRE, 1990). Leaves remain green longer at a lower temperature. This effect of temperature can be very large, for example, leaves of cassava in the altitude trial in Columbia remained on the plant for two months at 28°C and five months at 20°C. The influence of temperature on senescence is probably indirect, in that the senescence coincides with another development event, itself controlled by temperature. Sometimes senescence increases with the movement of nutrients from the leaf to the fruiting structures. Senescence also occurs in some species when the light falling on the leaf is reduced to a critical level by shading from newer leaves, as in cassava (SQUIRE, 1990).

Leaf area within each layer followed a quadratic relationship with temperature in potato. The largest areas were between 16.6 and 22.1°C. Quantity of leaf area before harvest caused canopy maximum gross photosynthetic rates to be higher at 14/10, 17/12, and 20/15°C temperatures than at 23/18, 28/23, and 34/29°C in potato and to declined as successive canopy layers were removed, primarily due to decreases in canopy light interception. These results indicate that the relative proportion of main- or axillary-stem leaves are not as important for potato canopy modeling considerations as is the need to simulate the correct quantity of leaf area (FLEISHER *et al.*, 2006). The increase of total leaf area with time was sigmoid in sugar beet (TERRY, 1968). Leaf area at first increases exponentially, but later its rate of growth decreases to zero and leaf area reaches a maximum. During senescence leaf area may decrease. Although leaves unfolded more slowly at 15°C, they attained greater growth rates and sizes than at 25 °C (TERRY, 1970). Plant leaf area increased faster in warm conditions than cool conditions in wheat (LAWLOR *et al.*, 1988). Leaves developed up to max canopy then leaf growth and leaf area declined in taro (SIVAN, 1982). Tuber and total dry matter increase linearly with increasing cumulative leaf area index up to 10 and thereafter tubers deteriorate (SHIH & SNYDER, 1984). The percentage dry matter and corm yield are reduced significantly where leaf area is reduced (CABLE *et al.*, 1988).

4.1.5 Yield

In Columbia, cassava grew at 20, 24 and 28°C. As temperature rose, the canopy expanded faster and intercepted more solar radiation over the season, but also required an increasingly greater proportion of the dry matter. For a genotype that was not vegetatively vigorous, the yield of tubers increased with rise in temperature from 20 to 28°C – the extra dry matter from the faster canopy expansion at higher temperature was much more than the increased requirement by the shoots. For, another, very vigorous cultivar, tuber yield was greater at 20°C (three times that of the less vigorous), but decreased to very small values at higher temperatures. For this vigorous genotype, the extra dry matter produced at higher temperature was very much less the increased requirement by the shoots. In fact, at the higher temperature, the new dry matter was little more than required to sustain shoot growth. Low temperature increased partitioning for tubers by reducing the expansion rate of the shoot system and thereby the sink (SQUIRE, 1990).

The number of tubers in potato is determined by tuber formation which in turn is affected among others by temperature. Low temperature can shift tuber formation to earlier time and increase the number of tubers per plant (LIAN *et al.*, 2004). The size of the tubers in potato is determined by its growth speed and the length of growth time (LIAN *et al.*, 2004). The most suitable temperature for potato tuber to increase size and weight is in the range of 16-20°C. Above 30°C and additional short of water cause stop of tuber expansion, and may form a malformed tuber (LIAN *et al.*, 2004). According to YI (1995) as cited by LIAN *et al.*, (2004), low temperatures especially low night temperatures are most important for increasing tuber size and weight. TIMLIN *et al.*, (2006) found that end-of-season tuber mass decreased with increasing temperature above 24°C. In addition to yield differences, high defoliation reduced number and weight of large (65–100 mm diameter) tubers and increased the number of small tubers (47–64 mm diameter) (ZIEMS *et al.*, 2006). The prolonged grain filling period at low temperatures coupled with constant rates of filling at all temperatures resulted in single mature grain dry weight being highest at the lowest temperature in pearl millet (FUSSELL *et al.*, 1980).

4.1.6 Starch and mineral content

The nutritional value is the main concern when a crop is being considered as a food source. Due to the emphasis placed on the nutritional value of food by consumers, a great need exists for information on the nutritional contents of root crops. The high starch content of most root crops is considered an excellent energy source, but they are marginal to poor sources of protein (DAVIDSON *et al.*, 1979; BRADBURY, 1988). Root crops contain a wide variety of minerals and trace elements, including relatively substantial quantities of iron and calcium, as well as potassium and magnesium (HUANG *et al.*, 2000; BHANDARI *et al.*, 2003; ENGLBERGER *et al.*, 2003).

Taro tubers store a high starch concentration that ranges between 22 to 40%. According to VINNING (2003) taro corms can contain up to 35% starch. In potato tubers, high temperature led to an inhibition of starch synthesis. Increasing the temperature from 23°C or 25°C up to 37°C led to increased respiration and decreased starch synthesis (GEIGENBERGER *et al.*, 1998). This decreased starch synthesis at elevated temperatures could be caused by a direct inhibition of starch biosynthetic enzymes in the plastid (i.e. increased heat-stress susceptibility or thermolability of enzyme activities) and/or a decrease in the levels of precursors caused by increased respiration or decreased sucrose mobilization (GEIGENBERGER *et al.*, 1998). High temperatures caused inhibition of potato tuber growth and increased sucrose levels in the tubers as well as in the leaves, indicating a block of sucrose breakdown and starch synthesis in the tubers (WOLF *et al.*, 1991; MIDMORE & PRANGE, 1992). MOHABIR & JOHN (1988) demonstrated a sharp temperature optimum for starch synthesis at approximately 21.5°C. Starch synthesis was reduced by 50% when temperature was increased to 30°C. There is evidence that the reduced carbon import into potato tubers at high temperature is attributable to reduced sucrose mobilization in the tuber itself, and not just to a shortage of photosynthate supply (KRAUS & MARSCHNER, 1984; MOHABIR & JOHN, 1988; WOLF *et al.*, 1991).

4.2 Materials and methods

4.2.1 Planting material

Full corms of the five taro landraces, Dumbe-dumbe, Mgingqeni, Pitshi, Pitshi-omhlophe and Dumbe-lomfula were used as planting material (Figure 4.1). The corms were obtained in 2005 from subsistence farmers who are members of the Ezemvelo Farmers' Organisation (EFO) in the Umbumbulu district, KwaZulu-Natal, South Africa.

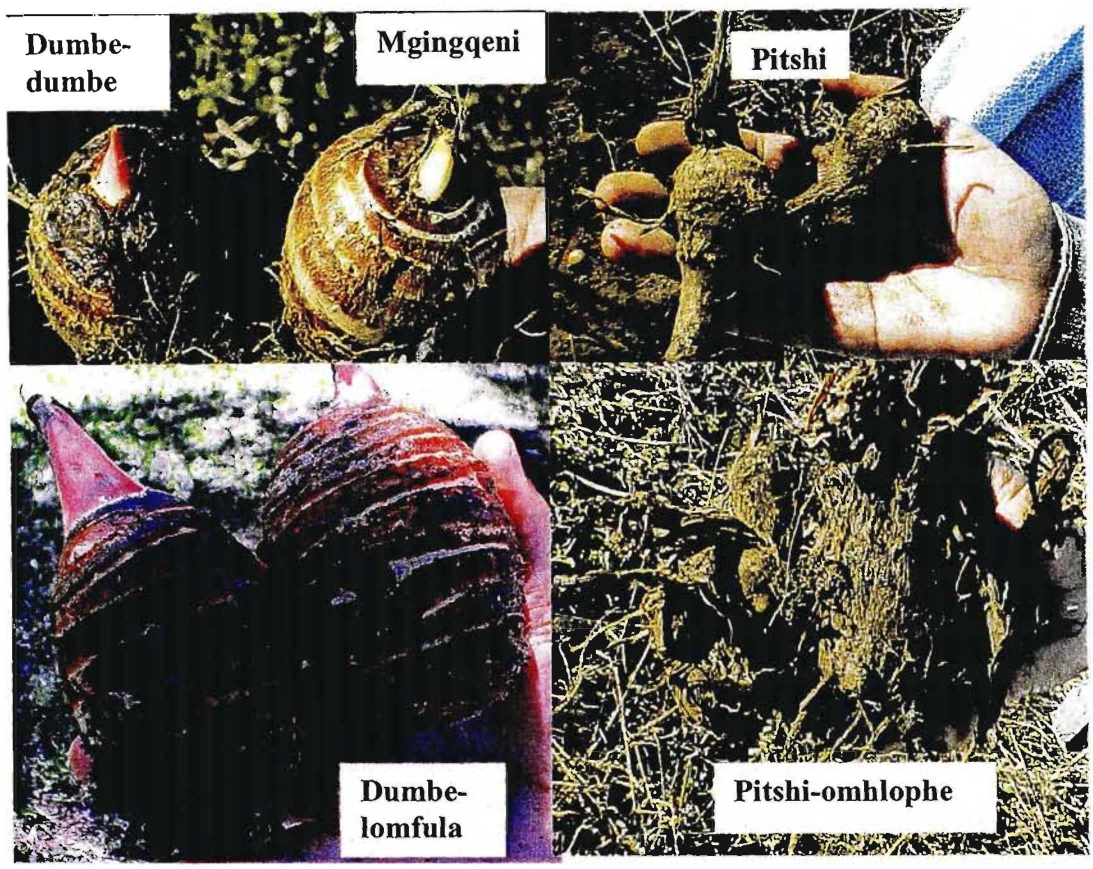

Figure 4.1 Corms of taro landraces (named) used as planting material.

Corm size for the taro landraces vary between and within a landrace (Figure 4.1). For the purposes of this study, the corms selected for planting were purposely selected to be in the following size ranges (corm $^{-1}$): 40 – 60 g for Dumbe-dumbe and Mgingqeni, 60 – 80 g for Dumbe-lomfula and 20 - 40g for Pitshi (both types).

4.2.2 Experimental treatments and design

Plants were grown in three 4.5 x 4.0 m^2 day-lit glasshouses with the same photoperiod of 12 h set at different temperatures: 22°C day and 12°C night temperature (22/12°C), 27°C day and 17°C night temperature (27/17°C), and 33°C day and 23°C night temperature

(33/23°C) at CERU (Controlled Environment Research Unit) at the University of KwaZulu-Natal during the nine months experimental period from September 2005 to June 2006. A total of sixty 25 litre pots, containing soil from Ukulinga [University of KwaZulu-Natal (UKZN) farm] were used in completely randomised design (CRD) with the three temperatures and five taro landraces. Each landrace was replicated four times and one corm was planted per pot. Table 4.1 shows the physical and chemical analysis of the soil used in the glasshouse experiment.

Table 4.1 Physical and chemical analysis of soil from UKZN farm used in glasshouse experiment. Soil analysis was conducted at the KwaZulu-Natal Department of Agricultural Soil Science Laboratories, Cedara.

Soil characteristic	
Sample density g ml^{-1}	1.1
P mg L^{-1}	20
K mg L^{-1}	243
Ca mg L^{-1}	1304
Mg mg L^{-1}	296
Exch. Acidity cmol L^{-1}	0.15
Total cations cmol L^{-1}	9.71
Acid saturation %	2
pH (KCl)	4.33
Zn mg L^{-1}	7.1
Mn mg L^{-1}	31
Cu mg L^{-1}	8.77
NIRS organic carbon %	2.5
NIRS clay %	40.9

4.2.3 Crop management

Pots were watered manually (1 litre per pot) once a week until the fith leaf stage when the watering regime was changed to three times a week. Aviguard, vertmic, metasystox, cypermethrin and chronyrifis were used whenever the need arose for control of aphids. The pesticides were used alternately to prevent the aphids from building up resistance. Weeds were removed by hand whenever they appeared. Corms were harvested at 80% leaf senescence.

4.2.4 Data collection

Growth and development measurements made on taro were days to emergence, leaf number, plant height, leaf area, and fresh corm yield. Emergence was determined daily and the number of days to emergence was calculated. Leaf number was recorded by counting the total number of fully unfolded leaves for each plant per pot, including the green leaves of suckers. Plant height was measured as the distance from the soil surface to the highest point of the highest erect standing leaf using a 3 m graded tape. Leaf area was measured non-destructively by tracing all fully folded green leaves, including the green leaves of suckers, on white paper (80 g m^{-2}), cutting the traced leaf shapes and then using the portable leaf area meter (LI-COR, LI-3000) (Figure 4.2). Leaf number, plant height and leaf area were measured once every month, started one month after planting.

Fresh corm yield was recorded by counting the total number of corms per plant and weighing the total fresh corm mass per plant. The corms were also weighed individually and graded into sizes according to the fresh mass of corm (Table 4.2).

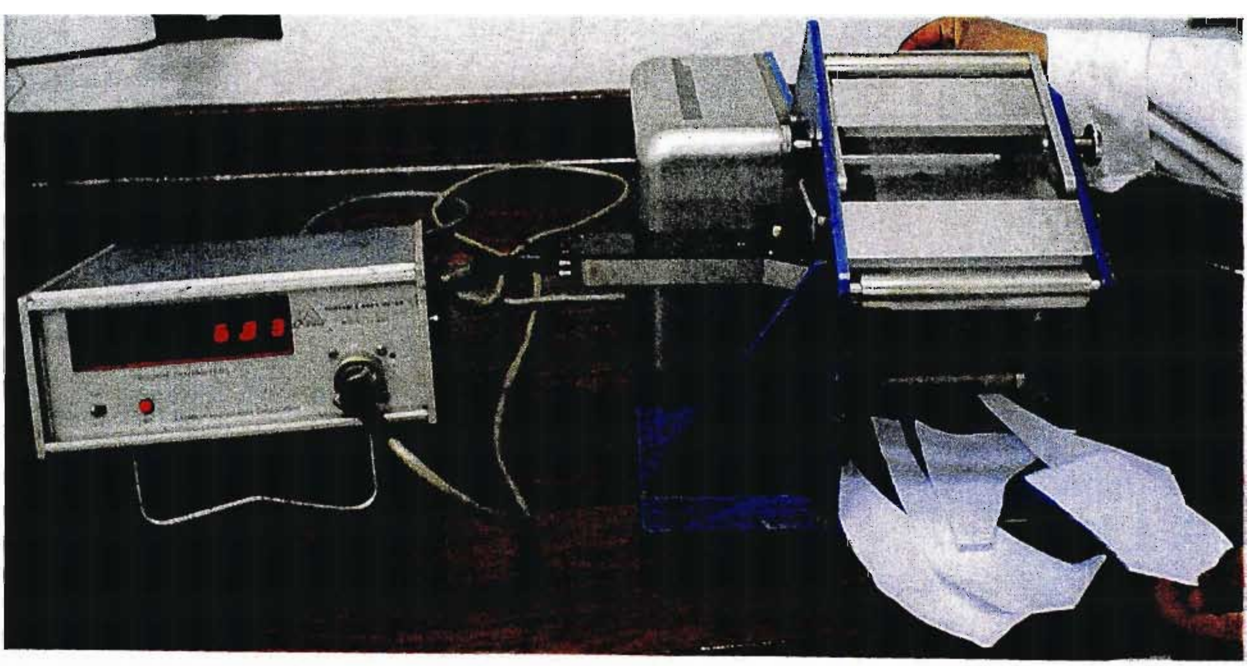

Figure 4.2 Portable LI-COR, LI-3000 leaf area meter.

4.2.5 Starch and mineral analysis

Following yield determination, corms were stored in a cold room (5°C). After two weeks of storage, the corms were peeled using a potato peeler, sliced, freeze-dried and ground fine for starch and mineral element determinations. Starch was analysed using methods of MARAIS *et al.*, (1966) modified by RASMUSSEN & HENRY (1990). The analysis 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. Carbon, sulphur and nitrogen were run on a LECO CNS instrument calibrated with an imported sample and checked against known standard samples.

4.2.6 Statistical analysis

All data were subjected to analysis of variance using the ANOVA procedure of the GenStat package version 7.1 (Rothamsted Experimental Station, UK). The least significant difference ($LSD_{0.05}$) test was used to compare individual means where necessary.

4.3 Results and discussion

4.3.1 Seedling emergence

There was a significant difference between temperatures with respect to seedling emergence ($P< 0.001$) (Appendix 4.1A). High temperature (33/23°C) showed the lowest number of days to seedling emergence compared with the other temperatures (Figure 4.3). Seedling emergence at 22/12°C was delayed. Seedling emergence time was shortest at 33/23°C followed by 27/17°C and 22/12°C respectively (Figure 4.3). Time to seedling emergence increased with decrease in temperature for all landraces, likely because seed corms at lower temperature had slower reserve mobilisation due to lower respiration or due to low thermal heat units (BURTON & BAZZAZ, 1991). Seedling emergence time at

22/12°C was not significantly different from that at 27/17°C, but both temperatures were significantly different from 33/23°C in seedling emergence time (LSD = 4.6). These findings confirm what BURTON & BAZZAZ (1991) also found, that low temperatures (5, 10, 15 and 20°C) delayed emergence of tree seedlings but are in contrast with findings of LU *et al.*, (2001) who found that high temperatures delayed emergence of non-dormant corms and reduced their emergence when taro corms were planted in January and March compared to July and September.

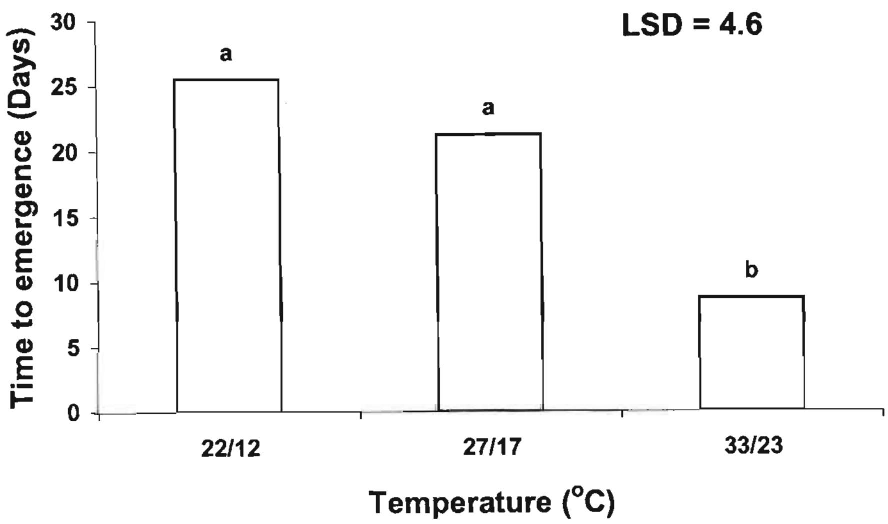

Figure 4.3 Mean seedling emergence of taro landraces at different alternating (day/night) temperatures. Means or bars with the same letters are not significantly different.

There was a significant difference in the number of days to seedling emergence between landraces ($P < 0.001$) (Appendix 4.1 A). Seedling emergence varied considerably among the landraces (Figure 4.4). Mgingqeni took the shortest time to emergence but it was not significantly shorter than Dumbe-dumbe and Dumbe-lomfula. The longest time to seedling emergence was taken by Pitshi which was significantly longer than that taken by all the other landraces except Pitshi-omhlophe. Pitshi-omhlophe on the other hand was not significantly different from Dumbe-lomfula but significantly different from Mgingqeni and Dumbe-dumbe (LSD = 5.9). The difference in time to emergence between taro landraces might have been because the increase in thermal duration was greater for the more slowly developing individuals, so the spread of thermal time between the first and the last to emerge increased (SQUIRE, 1990).

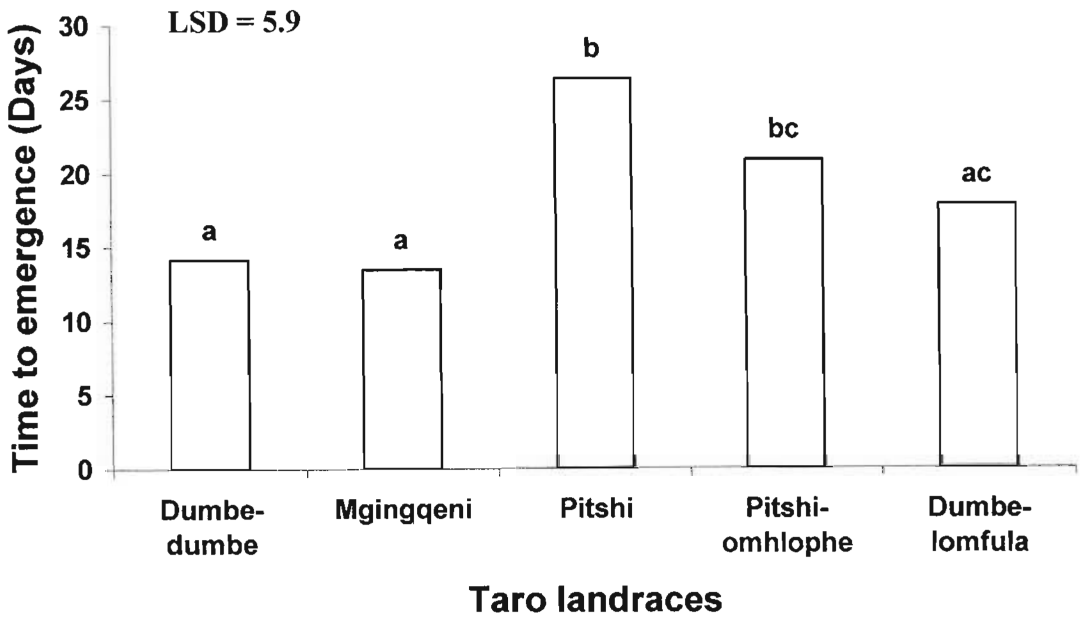

Figure 4.4 Mean seedling emergence of taro landraces at different temperatures. Means or bars with the same letters are not significantly different.

4.3.2 Leaf number

The interaction between temperature and landrace was significant for leaf number ($P < 0.001$) (Appendix 4.1B).The significantly highest number of leaves was obtained at 33/23°C for Pitshi-omhlophe while the significantly lowest was obtained at 27/17°C for Pitshi (LSD = 1.4) (Figure 4.5). The highest number of leaves at 33/27°C might have been because of the high suckering of plants, greater rates of leaf production and rapid unfolding of leaves (TERRY, 1970) at this temperature compared with the other temperatures. The lowest temperatures (22/12°C) might have maintained the higher number of leaves than 27/17°C because of accelerated senescence of plants decreasing the longevity of leaves at 27/17°C (YANEZ *et al.*, 2005).

The average leaf number over nine months for Pitshi-omhlophe and Dumbe-lomfula increased with increase in temperature though the increase was not significant for both landraces and temperature increases (Figure 4.5). The remaining three landraces followed a different trend of having significantly lowest number of leaves at 27/17°C followed by 22/12°C and 33/23°C, respectively which were not significantly different from each other. Pitshi-omhlophe had significantly higher number of leaves at 33/23°C than at lower temperatures, and the lower temperatures were not significantly different from each other. At 22/12°C, Dumbe-dumbe had significantly higher number of leaves than Pitshi-omhlophe and Dumbe-lomfula, but it was not significantly different from Mgingqeni and Pitshi. Pitshi-omhlophe had significantly higher number of leaves than Mgingqeni, Pitshi and Dumbe-lomfula but it was not significantly different from Dumbe-dumbe at 27/17°C. At 33/23°C Pitshi-omhlophe had the highest number of leaves but it was not significantly different from Pitshi and Dumbe-dumbe. The difference in the leaf number of different landraces might have been brought by the fact that some landraces produced more suckers than others while others did not produce any suckers.

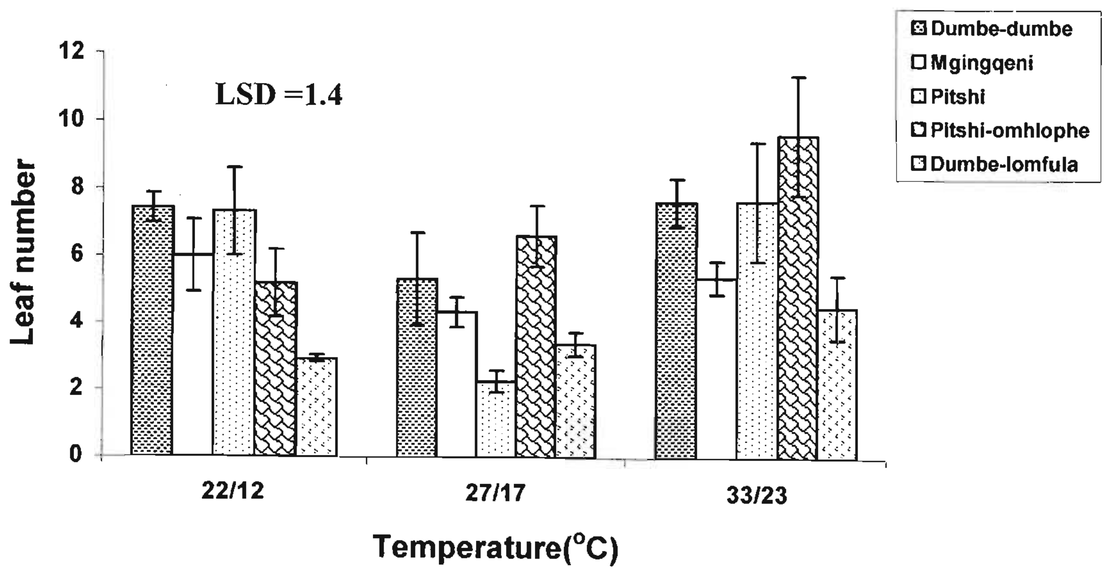

Figure 4.5 Mean leaf number of taro landraces over nine months at different temperatures.

Number of leaves generally increased at first for all landraces at all temperatures and started to decrease earlier at high temperature. At 22/12°C, maximum number of leaves was reached at nine months after sowing (Figure 8). Mgingqeni initially had the highest number of leaves for the first month, Dumbe- dumbe took over until six and half months when Pitshi became the highest until the end of the growing period. Dumbe-lomfula generally had the lowest number of leaves throughout the duration of the experiment, and was significantly lower for the last five months of the experiment. Temperature increase from 22/12°C to 27/17°C increased the number of leaves for Pitshi-omhlophe and decreased it for Pitshi from four months, making Pitshi-omhlophe the highest and Pitshi the lowest in leaf number. Pitshi reached maximum number of leaves at six months, Pitshi-omhlophe at seven months, Dumbe-dumbe at eight months and Mgingqeni and Dumbe-lomfula at nine months. At 33/23°C, Pitshi generally had the highest number of leaves, reaching maximum at six months. Dumbe-lomfula had lowest number of leaves.

Pitshi-omhlophe might have had the highest number of leaves due to its tendency to produce more suckers at high temperatures. The maximum number of leaves might have been reached earlier at high temperatures because of decreased longevity of leaves at high temperature (YANEZ *et al.*, 2005), accelerated ageing of the foliage and a shortening of the growing season resulting in early translocation of assimilates from the leaves to the corms (BAZZAZ & SOMBROEK, 1996).

4.3.3 Plant height

The interaction between temperature and landrace was significant for plant height ($P < 0.001$) (Appendix 4.1 C). Temperature had a significant positive impact on the plant height of taro landraces (Figure 4.6). The highest plant height was obtained at 33/23°C while the lowest was obtained at 22/12°C. All the temperatures were significantly different from each other. This finding confirmed the statement made by SQUIRE (1990) that the rate of expansion of most stems is strongly affected by temperature and

LAWLOR *et al.*, (1988) finding that cool conditions slowed the rate of plant growth compared to warm conditions by slowing the rate of protein synthesis.

Dumbe-lomfula was significantly taller than the other four landraces. This was probably because assimilates were more concentrated in plant growth rather than in initiation of new leaves as is the case in suckering landraces. The shortest was Pitshi, although it was not significantly shorter than Dumbe- dumbe.

Dumbe-dumbe and Mgingqeni followed the same trend of significantly tallest plants at high temperature and significantly shortest plants at low temperature over nine months (Figure 4.6). Pitshi-omhlophe and Dumbe-lomfula displayed a different trend with tallest plants at 27/17°C followed by 33/23°C and 22/12°C respectively although Dumbe-lomfula at 22/12°C and 33/23°C were not significantly different. Pitshi-omhlophe at 27/17°C was not significantly taller than at 33/23°C which was also not significantly different from the same landrace at 22/12°C. Pitshi on the other hand was significantly taller at 33/23°C than at the lower temperatures, which were not significantly different from each other (LSD = 4.6).

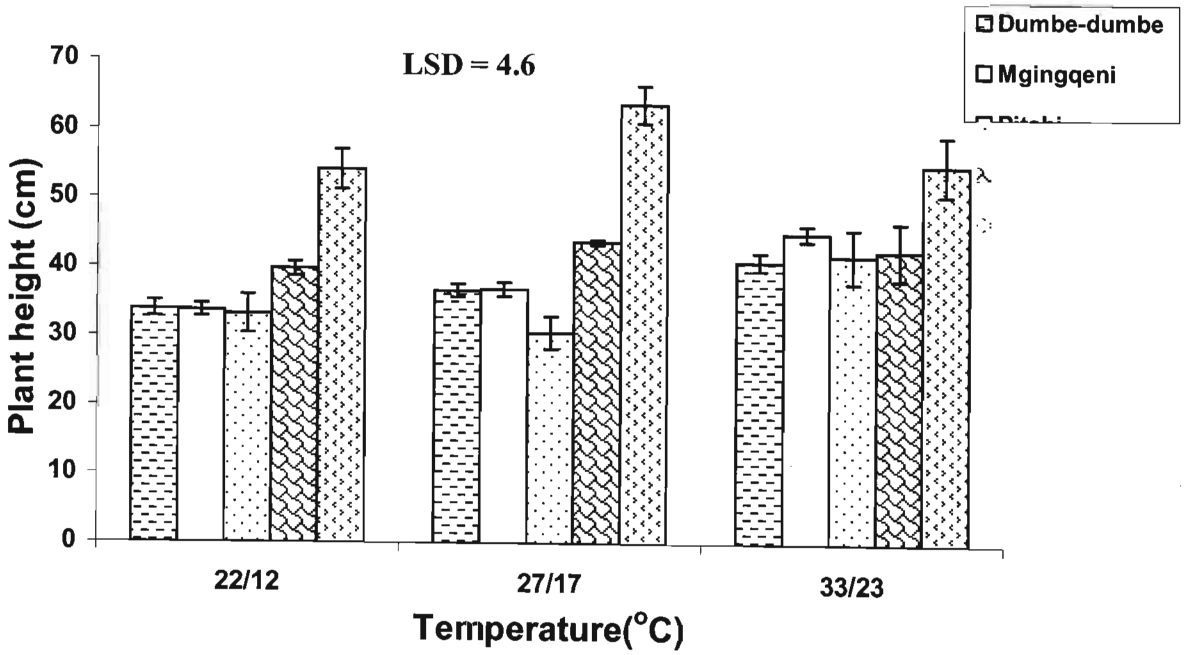

Figure 4.6 Mean plant height of taro landraces over nine months at different temperatures.

Height for all taro landraces growing at 22/12°C followed the same trend of increasing with time except that at four months after sowing, there was a general decrease in the plant height (Figure 4.8). The landraces reached maximum plant height at six months after sowing at both 22/12°C and 27/17°C conditions, with the exception of Dumbe-lomfula which reached the peak at eight months and was generally the tallest from two and half months throughout the duration of the experiment. The longer time that was taken by Dumbe-lomfula to reach the peak was due to the difference in the length of growing season required by different landraces. At 22/12°C, Pitshi-omhlophe was the tallest for the first two months followed by Dumbe-dumbe while Pitshi was the shortest from three months followed by Mgingqeni, Dumbe-dumbe and Pitshi respectively. Pitshi-omhlophe was significantly taller than Pitshi, Mgingqeni and Dumbe-dumbe and had been in that order from seven months to nine months at 22/12°C. At 27/17°C Pitshi was the shortest for the first five months, while Pitshi-omhlophe was the second tallest after Dumbe-lomfula from two and half months months to the end of the experimental period.

The peak was reached earlier at 33/23°C than in the lower temperatures, at two months for Dumbe-dumbe, three months for Mgingqeni, Pitshi-omhlophe and Dumbe-lomfula and four months for Pitshi. This might have been due to the shortened growing season at high temperatures. The plant height declined for all landraces after reaching the peak and then increased again for Dumbe-dumbe, Pitshi and Dumbe-lomfula at nine months. Dumbe-lomfula was the tallest for all months and Dumbe-dumbe was generally the shortest.

4.3.4 Leaf area

There was significant difference between taro landraces, but there was no significant difference between temperatures. The interaction of landrace and temperature was significant for leaf area ($P < 0.001$) (Appendix 4.1D).

Average leaf area over nine months was highest for Dumbe-lomfula at all temperatures with 27/17°C significantly higher than 22/12°C and 33/23°C, which were not significantly different from each other (Figure 4.7). Pitshi had the lowest leaf area at 22/12°C but it was not significantly lower than Pitshi-omhlophe, which was also not significantly lower than Dumbe-dumbe and Mgingqeni (LSD = 1.8). Mgingqeni was also not significantly different from Dumbe-lomfula while Dumbe-dumbe had significantly lower leaf area than Dumbe-lomfula.

At 27/17°C Pitshi had significantly low leaf area followed by Mgingqeni and Dumbe-dumbe respectively, which were not significantly different from each other. Dumbe-lomfula had significantly highest leaf area followed by Pitshi-omhlophe which itself was not significantly higher than Dumbe-dumbe.

Dumbe-dumbe had the lowest leaf area at 33/23°C followed by Pitshi-omhlophe and Pitshi, respectively which were not significantly higher than Dumbe-dumbe. Mgingqeni and Pitshi`s leaf area were not significantly lower than Dumbe-lomfula.

Leaf area followed the same trend for all landraces at 22/12°C and 27/17°C for the first four months and reached maximum with the exception of Pitshi-omhlophe that reached maximum at six months at 22/12°C and at five months at 27/17°C (Figure 8). Leaf area declined generally after reaching maximum to the end of the experimental period with Dumbe-dumbe increasing slightly at eight months, and Mgingqeni and Pitshi-omhlophe at nine months at 22/12°C. At 27/17°C, Dumbe-lomfula also increased leaf area at seven and nine months, Dumbe-dumbe increased at seven months and Mgingqeni increased steadily up to nine months. Leaf area at 33/23°C reached maximum at two months for Mgingqeni and Dumbe-dumbe, at three months for Pitshi-omhlophe and Dumbe-lomfula and at six months for Pitshi, after which the trend was not clear. This might be on account of rapid leaf appearance, growth and senescence of leaves at high temperature. Leaf area change did not show a clear trend from four months at 33/23°C, making identification of a precise pattern very difficult. Dumbe-lomfula acquired the highest leaf area at all temperatures with Mgingqeni showing the highest leaf area for the first month at all temperatures while Pitshi had the highest leaf area for the fifth month and sixth month at 33/23°C. Pitshi generally had the lowest leaf area throughout its growth at both 22/12°C and 27/17°C. The highest leaf area was displayed by Mgingqeni and Dumbe-lomfula until Dumbe-lomfula took over at two and half months at 33/23°C. Mgingqeni had the highest leaf area at five months, whereas Pitshi-omhlophe had the lowest leaf area at this stage. Mgingqeni demonstrated the significantly lower leaf area at seven months at 33/23°C.

One would expect the yield to be high for Dumbe-lomfula because it displayed large leaf area, because leaf area is an important index in identifying plant growth and development. Leaf area is also related to light interception, transpiration, and photosynthesis, hence, it is considered the most important determinant of dry matter accumulation and yield in taro (SATOU *et al.*, 1978, 1988; JACOBS & CHAND, 1992; CHAN *et al.*, 1995, 1998).

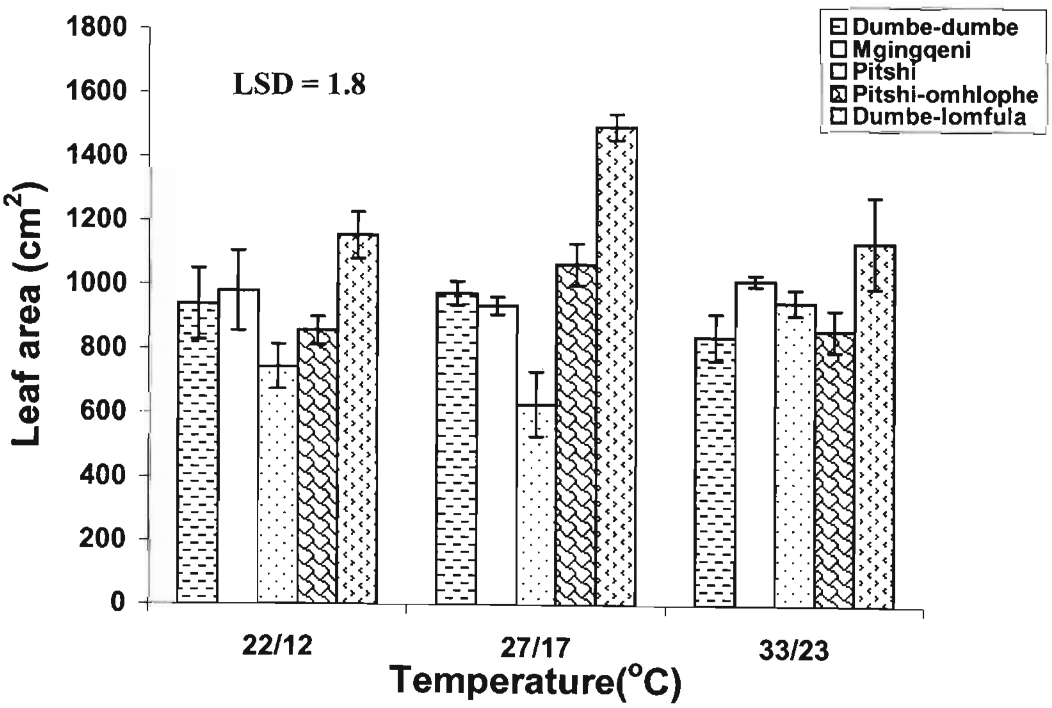

Figure 4.7 Mean leaf area of taro landraces over nine months at different temperatures.

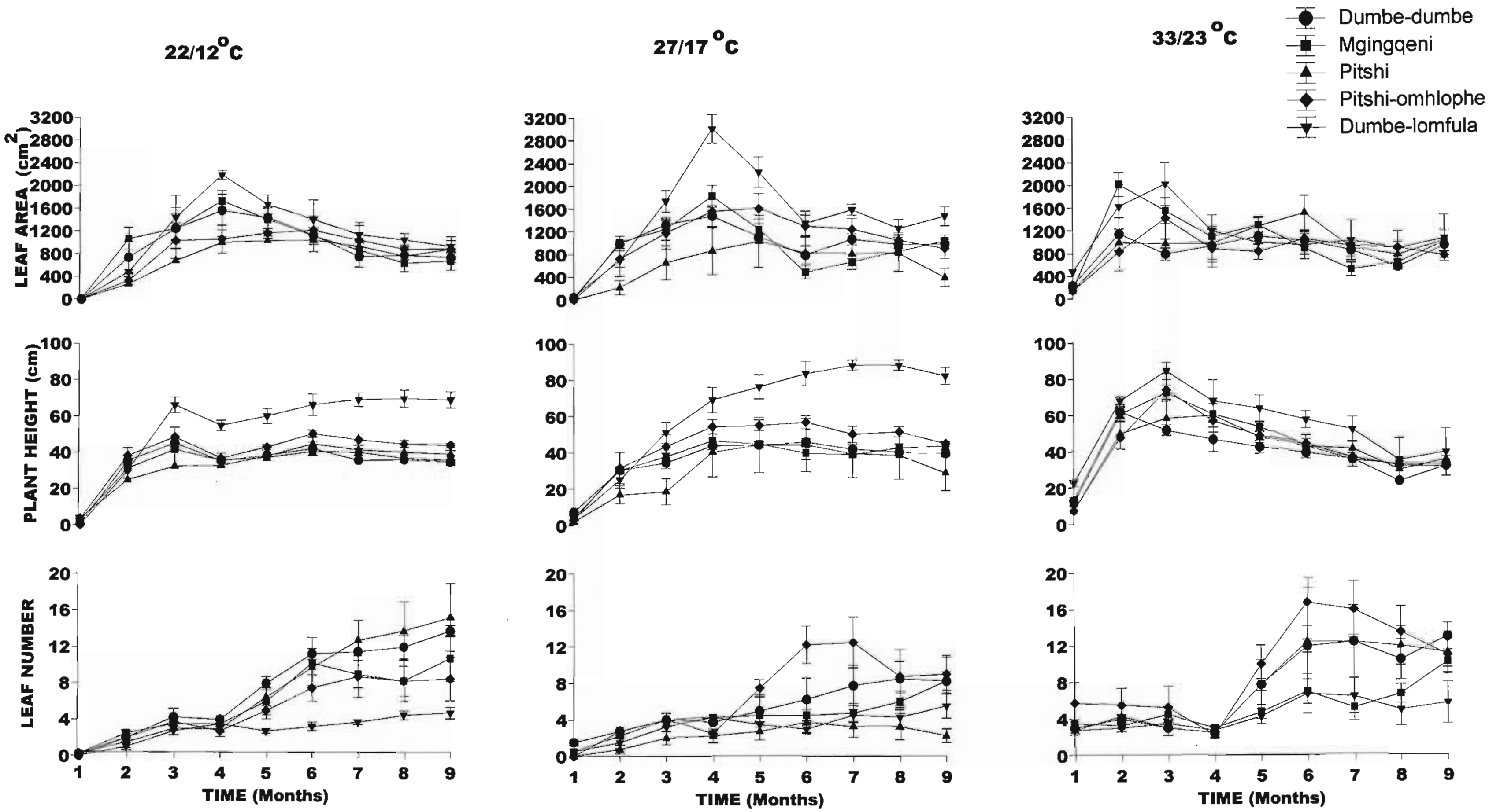

Figure 4.8 Change in leaf number, plant height and leaf area of taro landraces grown under three temperatures regimes.

4.3.5 Yield

4.3.5.1. Fresh corm mass

There was significant difference in fresh corm mass between temperatures (P = 0.044) (Appendix 4.1E), but no significant difference between taro landraces and the interaction of the two factors. The temperature of 27/17°C had significantly higher fresh corm weight than 33/23°C, but it was not significantly higher than 22/12°C (Figure 4.9). Fresh corm mass at 33/23°C was not significantly different from that at 22/12°C (LSD = 77.7). The 33/23°C temperature had the lowest fresh corm mass, and this is in consistent with AWAN (1964) and BURTON (1989) who found that in potato yield is limited by high temperatures, and BURTON (1989), who reported the optimum temperature for tuber growth to be 22°C. The reduction in yield at high temperatures could have been the result of increased photorespiration and inhibition of net photosynthesis in the leaves (BERRY & BJÖRKMAN, 1980). FARRAR & WILLIAMS (1991) and WOLF *et al.*, (1990) reported that increased respiration rates caused a considerable loss of photosynthates in growing sinks such as roots and potato tubers.

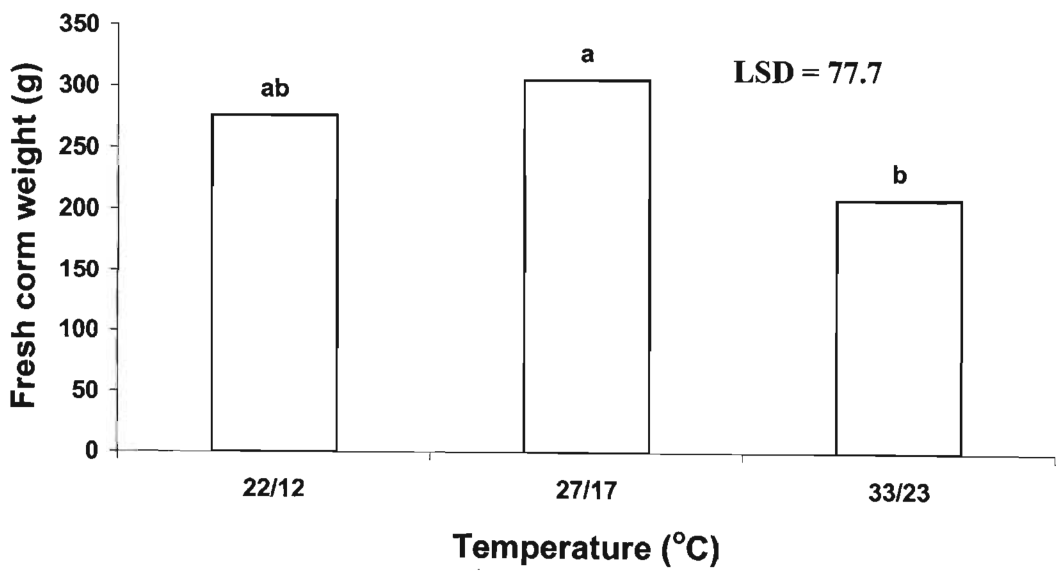

Figure 4.9 Fresh corm weight of the taro landraces at different temperatures. Means or bars with the same letters are not significantly different.

4.3.5.2 Number of corms

There was significant difference in the number of corms between landraces ($P<0.001$) (Appendix 4.1F). Pitshi-omhlophe had the highest number of corms, although it was not significantly higher than that of Dumbe-dumbe and Pitshi. Dumbe-lomfula had significantly lower number of corms than all the other landraces (Figure 4.10). Dumbe-dumbe, Mgingqeni and Pitshi were not significantly different in relation to the number of corms (LSD = 4.8). The difference between landraces may have been due to genotype differences.

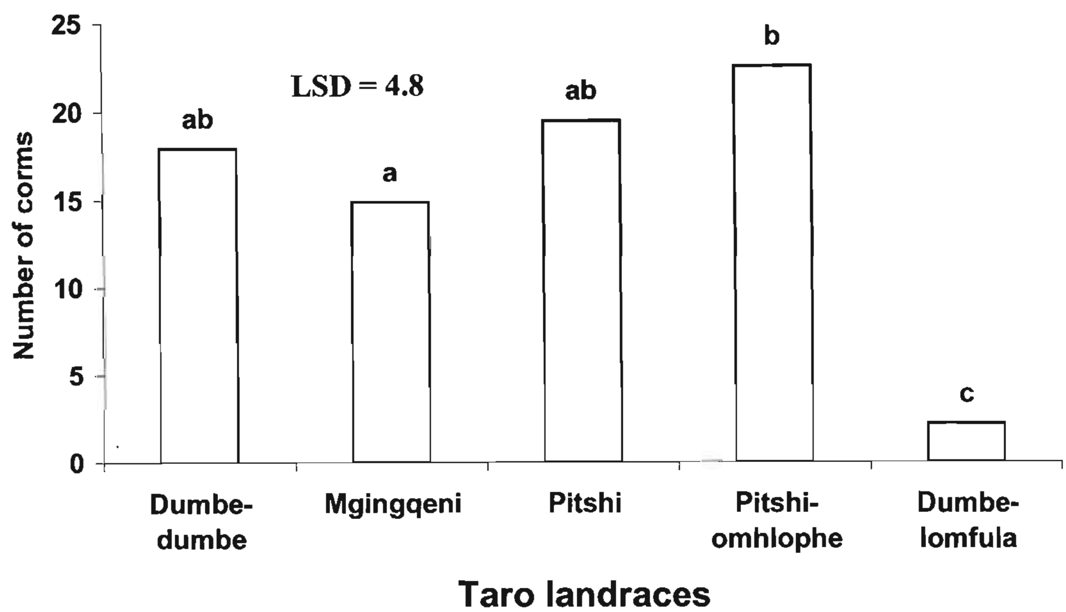

Figure 4.10 Mean number of corms of taro landraces at different temperatures. Means or bars with the same letters are not significantly different.

Table 4.2 shows the distribution of number of corms graded according to the fresh mass, that were harvested from the five taro landraces grown under different temperatures. A large percentage of the harvested corms weighed less than 20 g. The highest percentage of corms weighing less than 20 g each was obtained with Dumbe-dumbe at 33/23°C (91%) and the lowest was Dumbe-lomfula with 17% at both 22/12°C and 27/17°C. Dumbe-dumbe and Mgingqeni had the highest number of corms weighing less than 20 g at 33/23°C (91% and 80%) followed by 27/17°C (67% and 69%) and 22/12°C (62% and

53%) respectively. Pitshi and Pitshi-omhlophe on the other hand had the highest number of corms less than 20 g at 27/17°C (84% for both) followed by 22/12°C (82% for Pitshi) and 33/23°C (79% and 73% for Pitshi and Pitshi-omhlophe respectively) and 22/12°C (68% for Pitshi-omhlophe). Dumbe-lomfula though had the lowest percentage of corms of marketable size (> 40 g) had the lowest total number of corms, six corms at 22/12°C and 27/17°C and eight corms at 33/23°C .

Table 4.2 Number of harvested corms classified (graded) according to the fresh mass (g).

	22/12°C					27/17°C					33/23°C				
Weight ranges (g)	D	M	P	Pw	R	D	M	P	Pw	R	D	M	P	Pw	R
<20	11 ± 3.39	8.5 ± 0.85	16.5 ± 2.66	18.75 ± 3.06	1 ± 0^1	15 ± 3.61^3	12 ± 0.81	15.33 ± 3.5^3	20.5 ± 4.74	1 ± 0^1	19 ± 2.55	12 ± 0.71	21.25 ± 7.97	18.5 ± 2.1	2 ± 0^3
21-40	3.5 ± 0.65	4 ± 0.35	1.67 ± 0.67^3	5 ± 0^3	*	4.25 ± 0.75	3.5 ± 0.65	1 ± 0^2	3 ± 0^1	1 ± 0^1	1 ± 0^2	1 ± 0^2	1.5 ± 0.5^2	4 ± 3^2	2 ± 0^1
41-60	1.33 ± 0.33^3	1 ± 0^1	1 ± 0^1	2 ± 0^1	*	1.25 ± 0.25	1 ± 0^3	1 ± 0^1	1.5 ± 0.5^2	*	1 ± 0	1 ± 0^2	2 ± 0^1	1 ± 0^1	1 ± 0^1
61-80	1 ± 0^1	1.33 ± 0.33^3	*	*	1 ± 0^2	1 ± 0^1	1 ± 0^3	*	*	*	*	1 ± 0^3	1 ± 0^1	*	*
81-100	1 ± 0^1	*	*	*	*	1 ± 0^1	*	*	*	*	*	*	*	1 ± 0^1	*
101-120	*	1 ± 0^1	1 ± 0^1	*	*	*	*	*	1 ± 0^1	*	*	*	1 ± 0^1	1 ± 0^1	*
121-140	*	*	*	*	1 ± 0^1	*	*	*	*	1 ± 0^1	*	*	*	*	1 ± 0^1
141-160	*	*	*	1 ± 0^1		*	*	*	*	*	*	*	*	*	1 ± 0^1
161-180	*	*	*		1 ± 0^1	*	*	1 ± 0^1	*	*	*	*	*	*	*
181-200	*	*	*			*	*	*	*	1 ± 0^1	*	*	*	*	*
201-220	*	*	*			*	*	*	1 ± 0^1	*	*	*	*	*	*
241-260	*	*	*		1 ± 0^1	*	*	*	*	*	*	*	*	*	*
321-340	*	*	*			*	*	*	*	*	*	*	*	*	1 ± 0^1
341-360	*	*	*	1 ± 0^1		*	*	*	*	*	*	*	*	*	*
441-460	*	*	*		1 ± 0^1	*	*	*	*	*	*	*	*	*	*
481-500	*	*	*			*	*	*	*	1 ± 0^1	*	*	*	*	*
661-680	*	*	*			*	*	*	*	1 ± 0^1	*	*	*	*	*

The superscript numbers indicate the number of replications involved. * indicates that there was no yield.

4.3.6 Starch content

The interaction between temperature and landrace was significant, with respect to corm starch content (P = 0.002) (Appendix 4.2A). Mgingqeni had significantly high starch content at 33/23°C followed by Pitshi-omhlophe and Pitshi, respectively, which were not significantly different from each other (LSD = 20.25). Dumbe-dumbe and Dumbe-lomfula had the same starch content, which was not significantly different from Pitshi. The trend was different at both 22/12°C and 27/17°C.

Starch content in Mgingqeni increased with an increase in temperature (Figure 4.11). A different trend was displayed by Pitshi and Dumbe-lomfula with a high starch content at 22/12°C followed by 33/23°C and 27/17°C, respectively. Dumbe-dumbe had the highest corm starch at 27/17°C, followed by 22/12°C and 33/23°C, respectively. Pitshi-omhlophe had the lowest starch content at 27/17°C and highest at 33/23°C.

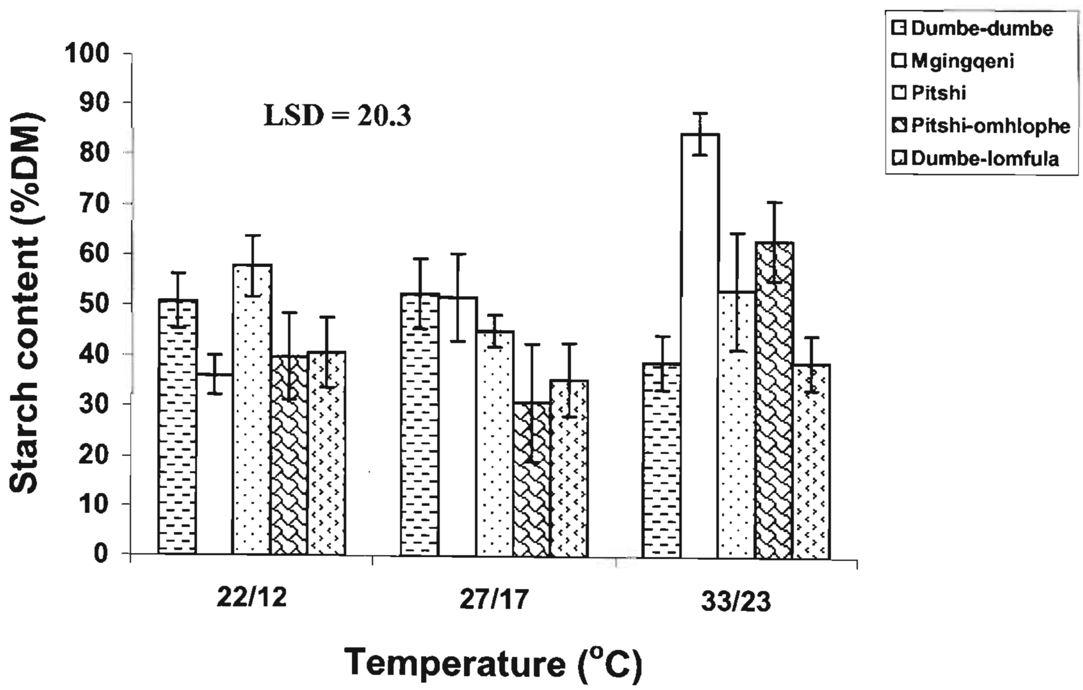

Figure 4.11 Corm starch content of taro landraces at different temperatures.

4.3.7 Mineral content

The interaction between temperature and landrace were significant for the mineral content of corms except for carbon (C) and aluminium (Al) as indicated in Appendix 4.2 B - N. Temperature influenced the carbon (C) content of corms significantly (Appendix 4.2 B). Aluminium (Al) content showed no significant difference between temperature and landrace. Table 4.2 shows the chemical content of corms of different landraces which were grown under different temperatures.

Corm carbon content was highest for Dumbe-dumbe at 22/12°C, although it was only significantly higher than C content for Dumbe-lomfula at 33/23°C (Table 4.2). Corm carbon content ranged from 39.69 – 42.64% dry matter for all the landraces across temperatures. Carbon content was lowest at 33/23°C for all landraces with the exception of Dumbe-dumbe, which was lowest at 27/17°C. The low C content at 33/23°C might be due to the reduced carbon import into corms at high temperature that is attributable to reduced sucrose mobilization as is the case in potato tubers, and not just to a shortage of photosynthate supply (KRAUS & MARSCHNER, 1984; MOHABIR & JOHN, 1988; WOLF *et al.*, 1991).

Corm sulphur content ranged from 0.06% dry matter for Dumbe-lomfula at 27/17°C to 0.27% for Dumbe-dumbe at 33/23°C (Table 4.2). Sulphur content increased with increase in temperature for all landraces except for Dumbe-lomfula that decreased with increase in temperature from 22/12°C to 27/17°C. The S content increase was only significant from 27/17°C to 33/23°C for all landraces. Pitshi-omhlophe showed the highest S content at 22/12°C followed by Mgingqeni and Pitshi which showed the same S content, Dumbe-dumbe and Dumbe-lomfula respectively. At 27/17°C, Mgingqeni was the highest in S content followed by Pitshi, Dumbe-dumbe, Pitshi-omhlophe and Dumbe-lomfula respectively. Pitshi and Pitshi-omhlophe had lowest S content at 33/23°C followed by Mgingqeni, Dumbe-lomfula and Dumbe-dumbe.

Corm nitrogen content ranged from 0.68 to 3.06% dry matter. It increased with temperature for all landraces except for Pitshi and Pitshi-omhlophe which did not show an increase from 22/12°C to 27/17°C. The nitrogen content for Dumbe-lomfula was the highest at 33/23°C followed by 22/12°C and 27/17°C, respectively. The N content increase was only significant from 27/17°C to 33/23°C for all landraces. Mgingqeni had the highest N content at 22/12°C followed by Pitshi-omhlophe, Dumbe-dumbe, Dumbe-lomfula and Pitshi respectively. The trend was the same at 27/17°C, except that the N content for Pitshi-omhlophe was lower than that of Dumbe-dumbe. A completely different trend was shown at 33/23°C, where Dumbe-dumbe had the highest N content followed by Mgingqeni, Dumbe-lomfula, Pitshi and Pitshi-omhlophe, respectively (Table 4.2).

Corm calcium content ranged from 0.05 to 0.60% dry matter. An increase in temperature caused an increase in Ca content for all landraces with an exception of Pitshi and Dumbe-dumbe which decreased with increase in temperature from 22/12°C to 27/17°C. The increase was only significant for Dumbe-lomfula from 27/17°C to 33/23°C. Dumbe-lomfula showed the highest Ca content at all temperatures followed by Pitshi-omhlophe. The lowest Ca content was shown by Dumbe-dumbe at 27/17°C.

Corm magnesium content ranged from 0.12 to 0.360% dry matter. Temperature increase caused a decrease in Mg content for Dumbe-dumbe, Mgingqeni and Pitshi from 22/12°C to 27/17°C though the increase was not significant. Magnesium content increased with increase in temperature for all landraces from 27/17°C to 33/23°C. Dumbe-lomfula demonstrated the highest Mg content at all temperatures while Pitshi-omhlophe, Dumbe-dumbe and Mgingqeni at 22/12°C, 27/17°C and 33/23°C, respectively, showed the lowest Mg content.

Corm potassium content ranged from 1.61 to 3.10% dry matter. An increase in temperature resulted in an increase in K content for Dumbe-dumbe, Mgingqeni and Pitshi from 22/12°C to 27/17°C. Potassium content increased with increase in temperature for Dumbe-dumbe, Pitshi, Pitshi-omhlophe and Dumbe-lomfula from 27/17°C and 33/23°C.

The highest K content was displayed by Mgingqeni at both 22/12°C and 27/17°C, and Dumbe-lomfula at 33/23°C.

Corm sodium content ranged from 174 to 1305 mg kg $^{-1}$ dry matter. Temperature increase increased Na content for Dumbe-dumbe, Pitshi, Pitshi-omhlophe and Dumbe-lomfula from 22/12°C to 27/17°C and Mgingqeni, Pitshi and Pitshi-omhlophe from 27/17°C to 33/23°C, although the increase was significant only for Pitshi from 27/17°C to 33/23°C. The highest Na content was obtained by Mgingqeni, Dumbe-lomfula and Pitshi at 22/12°C, 27/17°C, and 33/23°C, respectively, while the lowest was obtained by Pitshi-omhlophe, Mgingqeni and Dumbe-dumbe at 22/12°C, 27/17°C, and 33/23°C respectively.

Corm zinc content ranged from 13.8 to 309 mg kg $^{-1}$ dry matter. A decrease of temperature from 27/17°C to 22/12°C caused an increase of Zn content for all landraces with an exception of Dumbe-lomfula and Zn content increased with increase in temperature from 27/17°C to 33/23°C. Dumbe-lomfula had the highest Zn content at all temperatures while Pitshi-omhlophe was highest at both 22/12°C and 33/23°C and Pitshi was highest at 27/17°C.

Corm copper content ranged from 7.5 mg kg $^{-1}$ dry matter for Pitshi-omhlophe at 22/12°C to 23.9 mg kg $^{-1}$ dry matter for Dumbe-lomfula at 33/23°C. Temperature had a positive effect on the Cu content of all landraces. Pitshi had the highest Cu content at 22/12°C while Pitshi-omhlophe had the lowest at 22/12°C as well as at 33/23°C. At 27/17°C, Mgingqeni displayed the highest and Dumbe-dumbe the lowest Cu content.

Corm manganese content ranged from 8 mg kg $^{-1}$ for Pitshi at 27/17°C to 28 mg kg $^{-1}$ for Dumbe-lomfula at 22/12°C. There was a significant decrease in Mn content for all landraces except Pitshi-omhlophe from 22/12°C to 27/17°C, whereas there was an increase in Mn content for all landraces except Dumbe-lomfula from 27/17°C to 33/23°C. At 27/17°C, Pitshi-omhlophe had the highest Mn content (12.8 mg kg $^{-1}$) while Dumbe-dumbe had the highest Mn content at 33/23°C (14.8 mg kg $^{-1}$). At 33/23°C the lowest Mn content was obtained in Pitshi-omhlophe (11.5 mg kg^{-1}), while at 22/12°C the lowest Mn content was obtained in Pitshi (9.8 mg kg^{-1}).

The range of corm Fe content was from 13.5 mg kg^{-1} dry matter for Pitshi and Pitshi-omhlophe at 22/12°C to 59.5 mg kg^{-1} for Dumbe-dumbe at 33/23°C. Iron content increased with temperature for all landraces. Dumbe-lomfula had the highest Fe content at 22/12°C and 27/17°C followed by Dumbe-dumbe, Mgingqeni and Pitshi and or Pitshi-omhlophe (they were similar), respectively. At 33/23°C, Dumbe-dumbe showed the highest Fe content, followed by Dumbe-lomfula, Mgingqeni, Pitshi and Pitshi-omhlophe, respectively.

Corm phosphorus content ranged from 0.3 mg kg^{-1} dry matter for Pitshi at 22/12°C to 0.9 mg kg^{-1} for Dumbe-lomfula at 33/23°C. Phosphorus content increased with temperature, except for Dumbe-lomfula from 22/12°C to 27/17°C, although the increase was not significant. Temperature significantly improved phosphorus content from 27/17°C to 33/23°C.

Table 4.3 Mineral composition of taro landraces (Dumbe-dumbe (D), Mgingqeni (M), Pitshi (P), Pitshi emhlophe (Pw) and Dumbe-lomfula (R) grown under different temperatures.

		22/12°C					27/17°C					33/23°C				
Mineral	LSD(0.05)	D	M	P	Pw	R	D	M	P	Pw	R	D	M	P	Pw	R
C (%)	1.78	42.64 **acde**	41.89 **abcde**	42.22 **acde**	41.9 **abcde**	42.45 **acde**	40.17 **bcef**	41.76 **cde**	42.59 **de**	41.25 **ef**	41.38 **ef**	41.20 **ef**	41.59 **e**	40.95 **ef**	41.52 **e**	39.69 **f**
S (%)	0.03	0.07 **acde**	0.08 **abcde**	0.08 **abcde**	0.08 **abcde**	0.06 **ade**	0.08 **abcde**	0.11 **bcd**	0.10 **cd**	0.08 **de**	0.06 **e**	0.27 **f**	0.20 **g**	0.16 **g**	0.16 **g**	0.20 **g**
N (%)	0.44	0.82 **a**	0.98 **ab**	0.68 **a**	0.87 **ab**	0.77 **a**	1.11 **ab**	1.28 **be**	0.68 **a**	0.87 **ab**	0.75 **a**	3.06 **c**	2.39 **d**	1.70 **e**	1.66 **e**	2.28 **d**
Ca (%)	0.14	0.08 **abcd**	0.08 **abcd**	0.09 **abcd**	0.10 **abcd**	0.16 **abcd**	0.05 **ac**	0.06 **acd**	0.06 **acd**	0.11 **abcd**	0.20 **bcd**	0.16 **abcd**	0.12 **cd**	0.15 **cd**	0.19 **d**	0.60 **e**
Mg (%)	0.04	0.13 **abe**	0.14 **abe**	0.13 **abe**	0.12 **a**	0.15 **abe**	0.12 **a**	0.13 **ae**	0.13 **abe**	0.13 **abe**	0.17 **bde**	0.22 **cd**	0.15 **abde**	0.19 **de**	0.17 **e**	0.36 **f**
K (%)	0.55	1.68 **acdfgi**	2.24 **bcdefghi**	1.61 **acg**	2.02 **cdefghi**	2.17 **defghi**	2.20 **defghi**	2.34 **efghi**	2.17 **fghi**	1.88 **ghi**	1.84 **ghi**	2.32 **hi**	2.24 **hi**	2.23 **i**	2.22 **i**	3.1 **j**
Na (mg kg^{-1})	447.2	240 **a**	334 **a**	192 **a**	190 **a**	323 **a**	266 **a**	261 **a**	270 **a**	294 **a**	495 **a**	174 **a**	489 **a**	1305 **b**	381 **a**	214 **a**
Zn (mg kg^{-1})	85.9	43 **abd**	30.5 **ab**	36.5 **ab**	22.5 **ab**	107.2 **acd**	21.2 **ab**	23.2 **ab**	13.8 **b**	21.5 **ab**	135.5 **cd**	125.5 **de**	60.8 **abcd**	42.5 **abe**	27.2 **ab**	309 **f**
Cu (mg kg^{-1})	3.5	9.5 **abd**	10.5 **abde**	10.6 **abde**	7.5 **a**	9.4 **ab**	10.1 **abde**	12.8 **bcde**	10.4 **abde**	10.6 **abde**	12.1 **bcde**	14.2 **cde**	12.9 **de**	13.2 **e**	10.8 **abcde**	23.9 **f**
Mn(mg kg^{-1})	6.5	28 **a**	22.5 **abd**	16.25 **bcdfghij**	11.5 **cdefghij**	17.5 **dfgi**	9.8 **efghij**	9.5 **efghij**	8 **efhij**	12.8 **fghij**	12 **fghij**	14.8 **ghij**	11 **hij**	9.8 **hij**	13.8 **ij**	10.5 **j**
Fe (mg kg^{-1})	11.0	18.5 **abef**	17.3 **abef**	13.5 **af**	13.5 **af**	22.8 **abef**	22.5 **abef**	20.3 **abef**	14.8 **af**	16.5 **abf**	26.5 **bef**	59.5 **cg**	40.8 **dg**	28.0 **ef**	21.8 **f**	49.0 **g**
P (%)	0.13	0.27 **ad**	0.31 **abcd**	0.26 **ad**	0.27 **ad**	0.32 **abcd**	0.42 **bcd**	0.44 **cdf**	0.35 **d**	0.31 **abcd**	0.31 **d**	0.81 **e**	0.63 **f**	0.56 **f**	0.34 **d**	0.92 **e**
Al (mg kg^{-1})	47.1	8.5 **a**	9.2 **a**	3.3 **a**	5.2 **a**	3.0 **a**	18.2 **ab**	47.0 **ab**	64.7 **b**	1.5 **a**	5.5 **a**	8.5 **a**	14.2 **a**	9.2 **a**	5.5 **a**	3.0 **a**

Values in the same row followed by similar letters are not significantly different by the LSD test (0.05).

4.3.8 Conclusion

This study confirmed the previous findings that low temperatures delay seedling emergence (BURTON & BAZZAZ, 1991), crop growth is reduced by stresses of high and low temperatures that develop when air temperature is above or below the optimum (SINGH *et al.*, 1998), and that temperature sensitivity, however, varies greatly with genotype (BAZZAZ & SOMBROEK, 1996). The study also provided evidence that taro is an important staple food because it contains high amounts of starch (carbohydrates) and a significant amount of mineral nutrients. The variation in levels of starch and minerals observed among the landraces and temperatures may offer some meaningful information for future studies to determine the quality of taro corms for food consumption and industrial processing.

CHAPTER 5

FIELD STUDIES ON TARO GROWTH AND YIELD

5.1 Introduction

Taro is adapted to moist environments and can be grown under rainfed or irrigated upland (i.e., nonflooded) as well as flooded conditions (PLUCKNETT *et al.*, 1970). Under upland conditions in Hawaii, Western Samoa, or Fiji, it is a 9 to 11 months crop (REYNOLDS, 1977; SIVAN, 1982) and only corms are harvested due to the small size of the cormels (MIYASAKA *et al.*, 2003). According to ONWUEME (1999), time from planting to harvest ranges from 5-12 months for dryland taro depending on the cultivar and the prevailing conditions during the season; while according to MIYASAKA *et al.*, (2003), taro can be harvested between 6 and 13 months, due to its indeterminant growth, depending on incidence of pests, soil and weather conditions that could cause early maturation. In South Africa, upland taro grown under dryland (upland) conditions can be harvested as early as 6 months after planting, and the corms can keep good harvest quality in the soil for a few months after that (WESTHUZEN 1967; YOUNG, 1992). At Umbumbulu, the majority of farmers produce taro under dryland conditions (SHANGE, 2004). The rainfed nature of dryland taro cultivation means that the time of planting is critical. Planting is usually done at the onset of the rainy season, and the rainy season itself must last long enough (6-9 months) to enable the taro crop to mature. For dryland taro, maturity for harvest is signalled by a decline in the height of the plants and senescence of the leaves (ONWUEME, 1999).

There is a need for an understanding of how taro growth, yield, starch and mineral composition are influenced by production site. The objective of this study was to determine the agronomic performance (emergence, plant growth and yield) and corm quality (starch and mineral composition) of taro landraces identified by local farmers at Umbumbulu district, KwaZulu-Natal. It was of interest to identify the performance of each landraces for further studies into its potential for cultivation/ commercialisation.

5.2 Materials and methods

5.2.1 Planting material

Full corms of the four taro landraces, namely, Dumbe-dumbe, Mgingqeni, Pitshi and Dumbe lomfula that were used as planting material were donated by subsistence farmers who are members of the Ezemvelo Farmers Organisation (EFO) in the Umbumbulu district, KwaZulu-Natal, South Africa. See section 4.2.1 for more details about planting material.

5.2.2 Description of planting sites

Two sites were selected for the study at two locations: UKZN (University of KwaZulu-Natal, Pietermaritzburg) and Umbumbulu (landrace provenance). Umbumbulu has a mean annual rainfall of 956 mm and altitude range of 394-779 m. UKZN has a mean annual rainfall of 913.6 mm and altitude of 613 m. Table 5.1 shows the soil properties of both sites, analysed just before planting for the present study. Figure 5.1 shows distribution of temperature and rainfall at both locations.

Table 5.1 Physical and chemical analysis of soil from UKZN and Umbumbulu sites. (Soil analysis was conducted at the KwaZulu-Natal Department of Agricultural Soil Science Laboratories, Cedara).

Soil characteristic	*UKZN*	*Umbumbulu*
Sample density g ml^{-1}	1.1	0.97
P mg L^{-1}	20	5
K mg L^{-1}	243	72
Ca mg L^{-1}	1304	439
Mg mg L^{-1}	296	131
Exch. Acidity cmol L^{-1}	0.15	2.21
Total cations cmol L^{-1}	9.71	5.66
Acid saturation %	2	39
pH (KCl)	4.33	4.00
Zn mg L^{-1}	7.1	4.8
Mn mg L^{-1}	31	4
Cu mg L^{-1}	8.77	3.9
NIRS organic carbon %	2.5	3.0
NIRS clay %	40.9	50

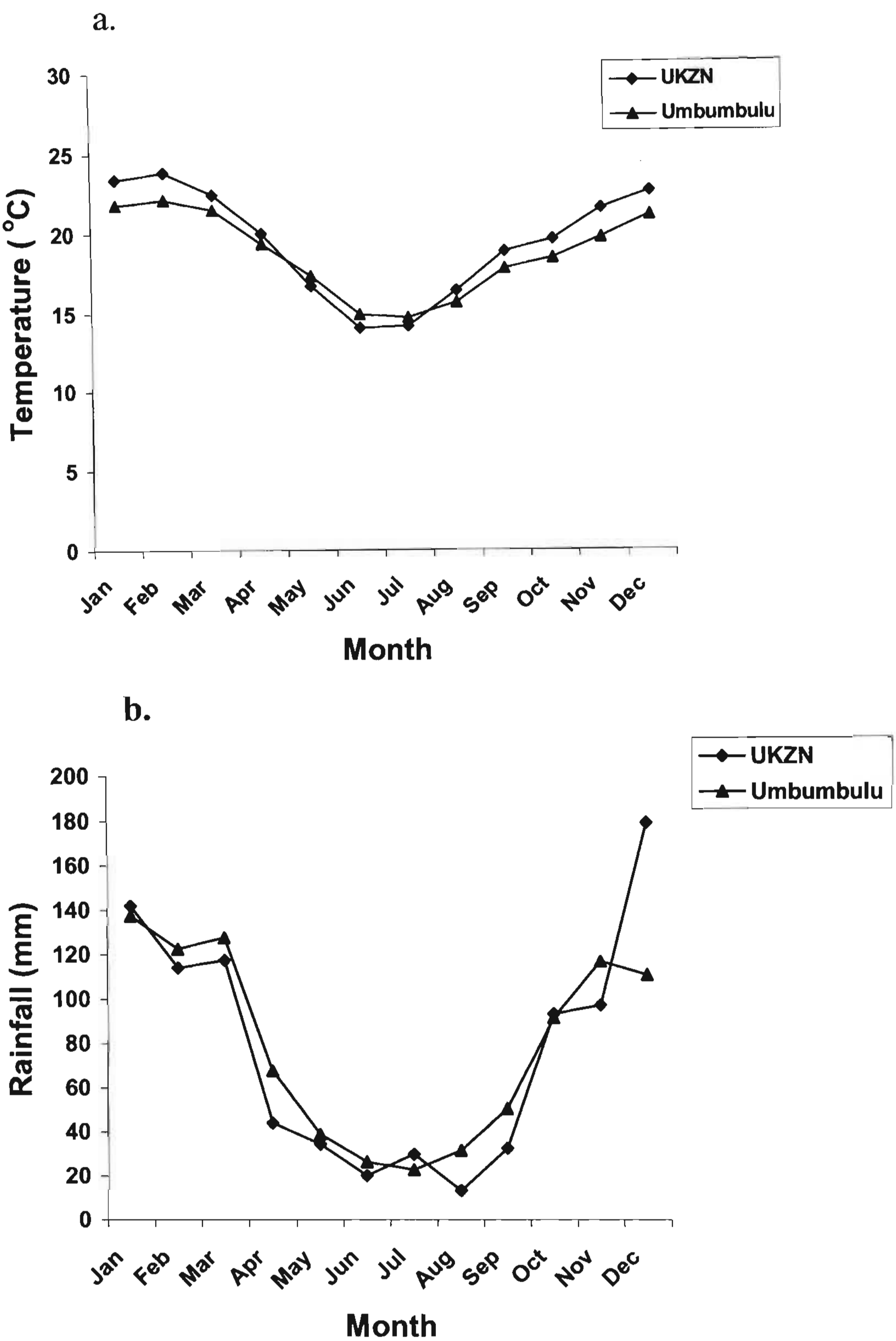

Figure 5.1 Temperature (a) and rainfall (b) distribution at UKZN and Umbumbulu. Data are means over a period of 10 years to 2000.

5.2.3 Planting and crop management

Planting was done by opening holes with hand hoes, putting seed corms and covering with soil in November 2005. No organic manure was used during planting. Weeds were removed by hand-hoe, whenever they appeared. Harvesting was done by hand-hoe. No chemical disease or pest control measures were used.

5.2.4 Data collection

The variables that were determined were emergence, leaf number, plant height, leaf area and fresh corm yield. The number of plants that had emerged per plot was counted and emergence percentages calculated monthly, from one month after planting until no change was observed. Leaf number was recorded by counting all green, unfolded leaves including the green leaves of suckers. Plant height was measured as the distance from the soil surface to the highest point of the highest erect standing leaf using a 3 m graded tape. Leaf area was measured nondestructively by tracing all the green, unfolded leaves, including the green leaves of suckers on paper, cutting the traced leaf shapes and then using the portable area meter (LI-COR,LI-3000) to measure the area. The number of leaves, plant height and leaf area were measured monthly one month after planting on four inner most leaves and averages were then calculated. Fresh corm yield was recorded by weighing the total fresh corm weight per plant and counting the number of corms per plant. The corms were also weighed individually and graded into sizes by mass (Table 5.2).

5.2.5 Starch and chemical analysis

Following yield determination, corms were stored in a cold room (5°C). After two weeks of storage, the corms were peeled using a potato peeler, sliced, freeze-dried and ground fine for starch and mineral element determinations. Starch was analysed using methods of MARAIS *et al.*, (1966) modified by RASMUSSEN & HENRY (1990). The analysis 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. Carbon, sulphur and nitrogen were run on a LECO CNS instrument calibrated with an imported sample and checked against known standard samples.

5.2.6 Statistical analysis

Treatments consisted of four taro landraces (Dumbe-dumbe, Mgingqeni, Pitshi and Dumbe-lomfula). The experiment was arranged at each site as a randomized complete block design with four treatments (taro landraces) and three blocks. Spacing of plants was 0.5 by 0.5 m. Plot size was 2.25 m^2 containing, 16 plants per plot. Plots were replicated 4 times within the blocks (Appendix 5.1). The sampling unit was consitituted by the four middle plants. All data were subjected to analysis of variance using the ANOVA procedure of the GenStat package version 7.1 Rothamsted Experimental Station, UK. The least significant difference ($LSD_{0.05}$) test was used to compare individual means where necessary.

5.3 Results and discussion

5.3.1 Seedling emergence

There were significant differences between taro landraces with respect to seedling emergence ($P < 0.001$) (Appendix 5 2 A (a). Dumbe-lomfula had significantly lowest seedling emergence at both sites. At UKZN, Mgingqeni had significantly highest seedling emergence from the first month to the end followed by Pitshi and Dumbe-dumbe, respectively, which were not significantly different from each other and from Dumbe-lomfula at the second and the third month (Figure 5.2). Dumbe-dumbe had significantly highest emergence at Umbumbulu from the first month followed by Mgingqeni and Pitshi, respectively, for the first two months, which were not different from each other. Pitshi had higher seedling emergence than Mgingqeni at the third month though the difference was not significant (Figure 5.3).

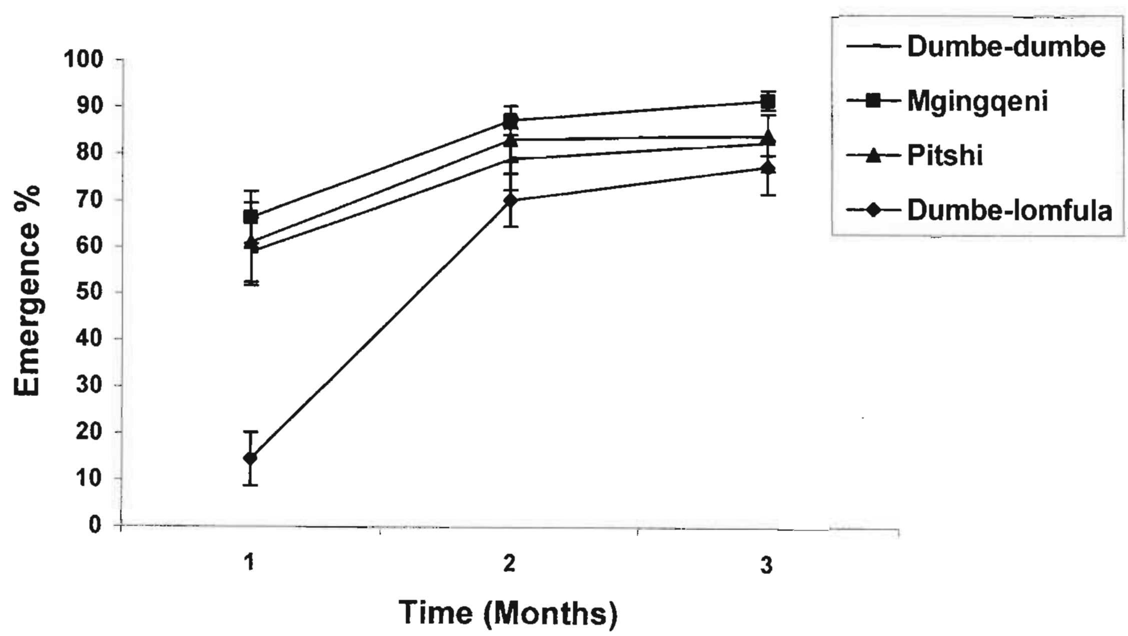

Figure 5.2 Taro seedling emergence at UKZN.

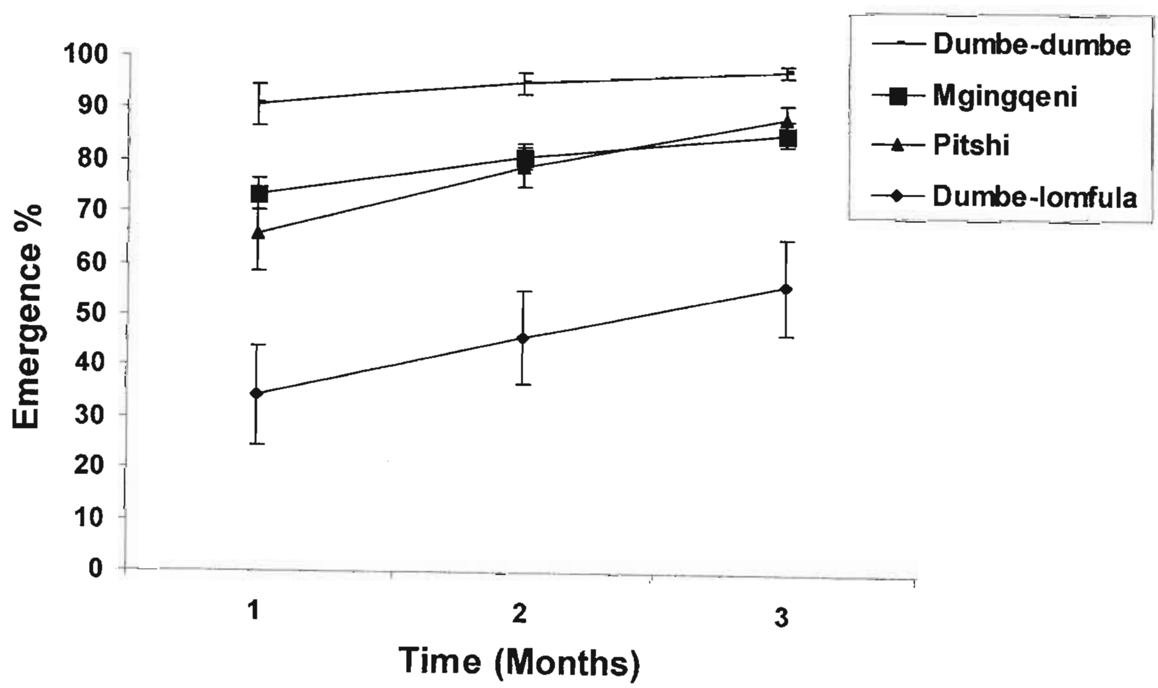

Figure 5.3 Taro seedling emergence at Umbumbulu.

The interaction of landrace and site was significant (P = 0.003) in final seedling emergence but there was no difference between the two sites (Appendix 5.2 A). Average final emergence for taro landraces is shown in Figure 5.4.

At UKZN, Dumbe-dumbe was not significantly different from the other three landraces in final seedling emergence (LSD = 13.8). Mgingqeni had significantly higher final seedling emergence than Dumbe-lomfula. At Umbumbulu Dumbe-dumbe displayed the significantly highest final seedling emergence. Mgingqeni and Pitshi were not significantly different from each other. Dumbe-lomfula displayed significantly lowest final seedling emergence at Umbumbulu, and it displayed significantly different final seedling emergence between the sites, with UKZN having the highest final seedling emergence. Dumbe-dumbe also showed significantly highest final seedling emergence at Umbumbulu.

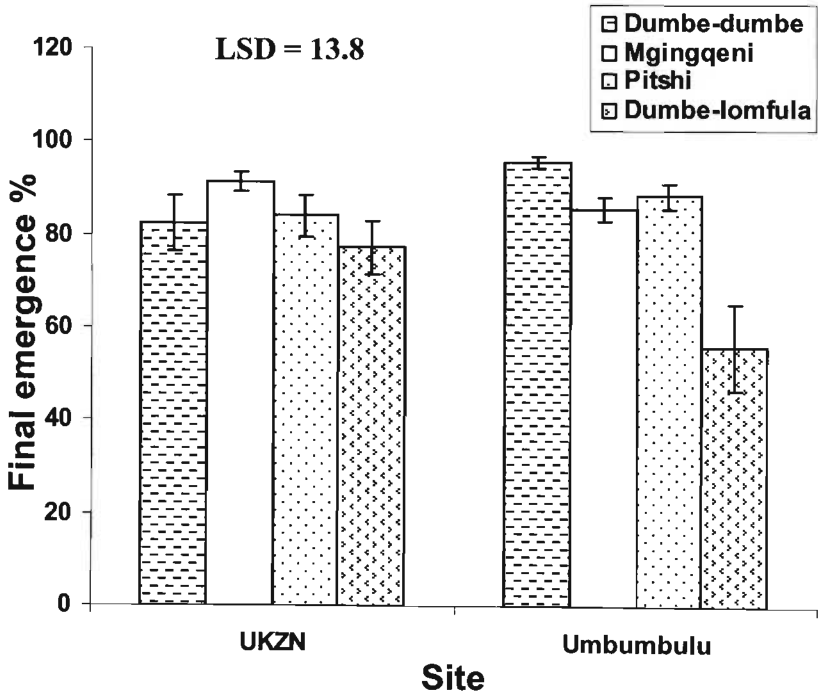

Figure 5.4 Effect of site on taro landraces` final seedling emergence.

5.3.2 Leaf number

The crop at UKZN site was destroyed by hail (Figure 5.5) before the data could be collected for the seventh month, so the leaf number data is missing for the last month. There was significant interaction between site, landrace and time for the leaf number ($P < 0.001$) (Appendix 5.2 B). The highest leaf number was obtained at UKZN (LSD = 0.3). Mgingqeni displayed the highest number of leaves followed by Pitshi and Dumbe-dumbe, respectively, which were not significantly different from each other in leaf number (LSD = 0.4). Dumbe-lomfula on the other hand had significantly lowest leaf number.

Figure 5.5 Taro crop damaged by hail at the UKZN field trial.

The leaf number showed the same trend for all taro landraces of increasing until a peak was reached, and then declined to the end of the experimental period at both sites, with the exception of Dumbe-lomfula, which showed an increase at the sixth month. The leaf number peak was reached early during the third month at Umbumbulu as compared to the fourth month at UKZN (Figures 5.6 and 5.7). Dumbe-lomfula had significantly lowest leaf number from the second to the fifth month at UKZN, and at Umbumbulu it had a significantly lowest leaf number only for the first month. At Umbumbulu, Mgingqeni, which had significantly highest leaf number during the second and third months, also had significantly lowest leaf number during the sixth month. The average leaf number of taro landraces over the experimental period was not different for Dumbe-dumbe, Mgingqeni and Pitshi for the UKZN site. Dumbe-lomfula showed the lowest average leaf number but was not different from Dumbe-dumbe. At Umbumbulu, there was no difference between all taro landraces in average leaf number. There was also no difference between all landraces at both sites in relation to average leaf number (LSD = 0.63) (Figure 5.8).

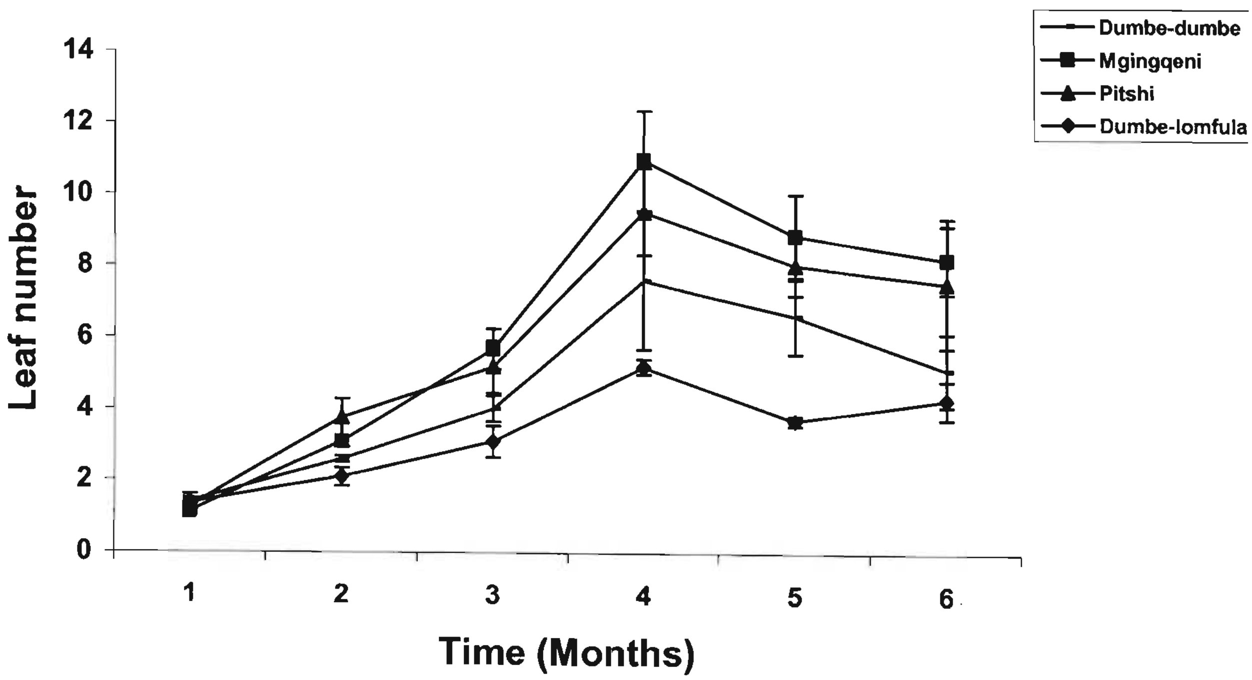

Figure 5.6 Change in leaf number of taro landraces (inset) grown at UKZN.

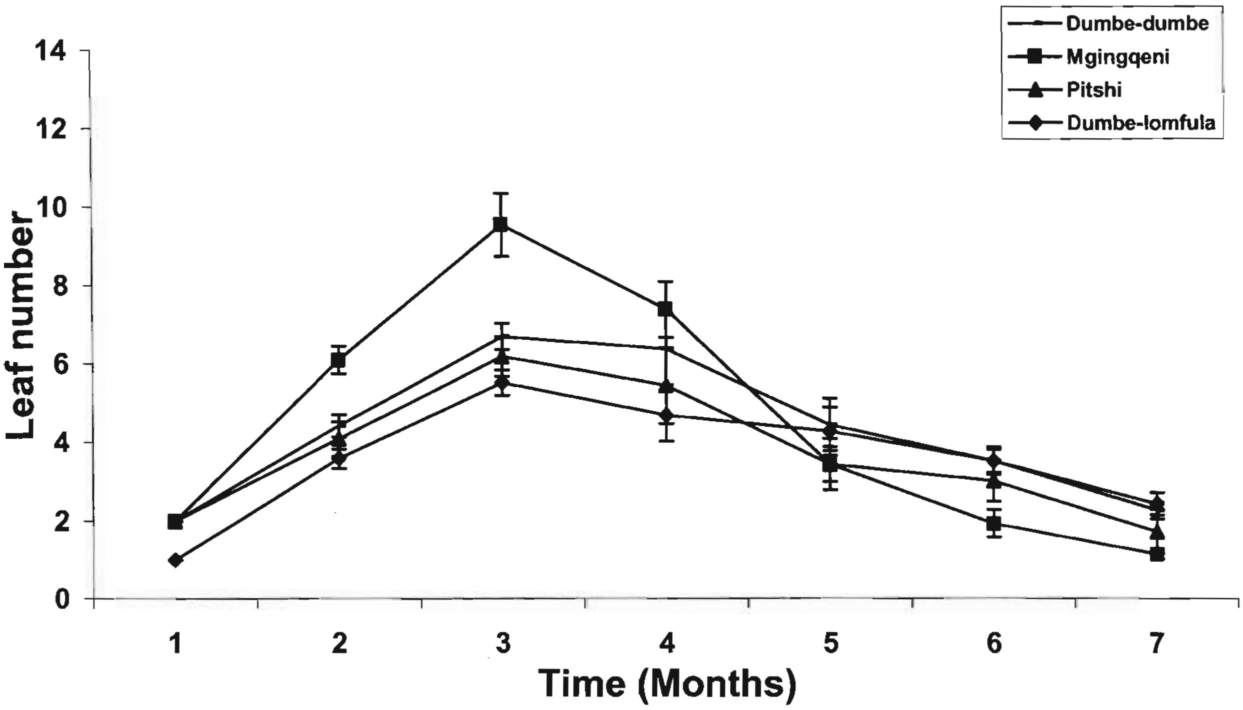

Figure 5.7 Change in leaf number of taro landraces (inset) grown at Umbumbulu.

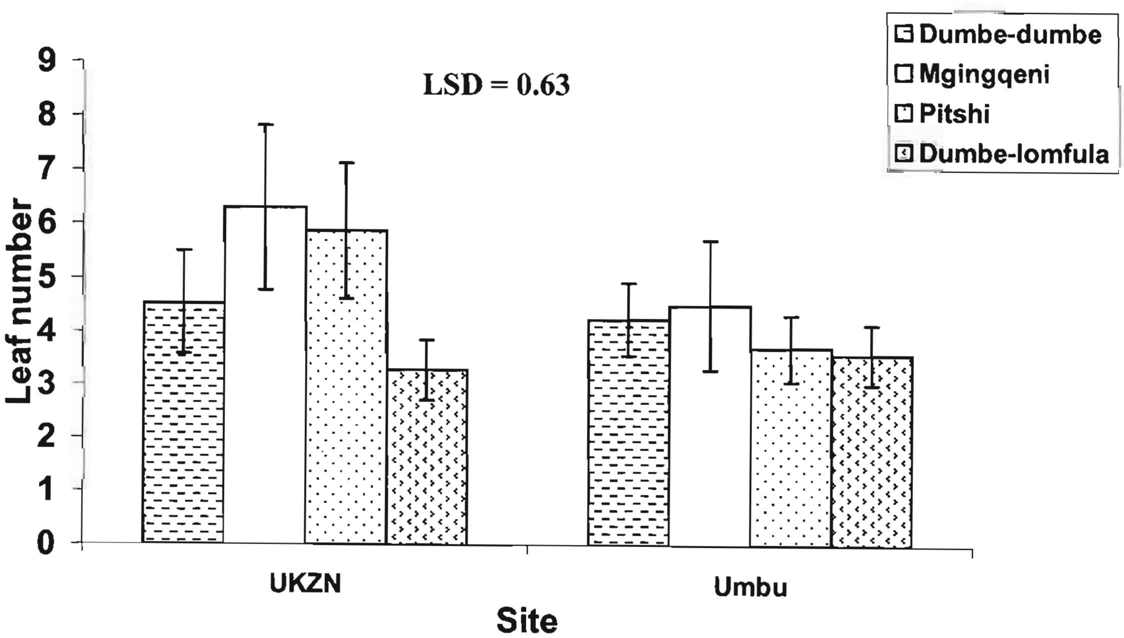

Figure 5.8 Average leaf number of taro landraces over the experimental period at different sites.

5.3.3 Plant height

There was a significant interaction between site, landrace and time for plant height ($P < 0.001$) (Appendix 5.2 C). Dumbe-lomfula had the significantly highest plant height followed by Pitshi, Dumbe-dumbe and Mgingqeni which were not significantly different from one another (LSD = 2.3). The results showed that the tallest taro landrace had the smallest number of leaves and the shortest landrace had the largest number of leaves. This might be because the short landraces produced more suckers and assimilates produced in taller landraces were more concentrated in the growth of the plant and not in producing more suckers and leaves.

All taro landraces displayed the same trend of increasing until they reached a maximum and then declined. Plant height peak was reached at the same time (fourth month) by all landraces at both UKZN and Umbumbulu, except for Dumbe-lomfula at Umbumbulu, which reached the peak during the sixth month (Figures 5.9 and 5.10). Dumbe-lomfula had a significantly highest plant height from the first month at UKZN and second month at Umbumbulu to the end of the experimental period. The other landraces were not different from each other in plant height throughout the experimental period at both sites, except during the first month, where Dumbe-dumbe was taller than Mgingqeni and Pitshi, and the second month, where Dumbe-dumbe was second tallest after Dumbe-lomfula followed by Mgingqeni and Pitshi, respectively.

Dumbe-lomfula was the tallest at both UKZN and Umbumbulu trials, on average, over the experimental period, and there was no difference in the average height of Dumbe-lomfula between the two sites. There was also no difference in average height between the other three taro landraces (Dumbe-dumbe, Mgingqeni and Pitshi) within and between sites (LSD = 3.2) (Figure 5.11).

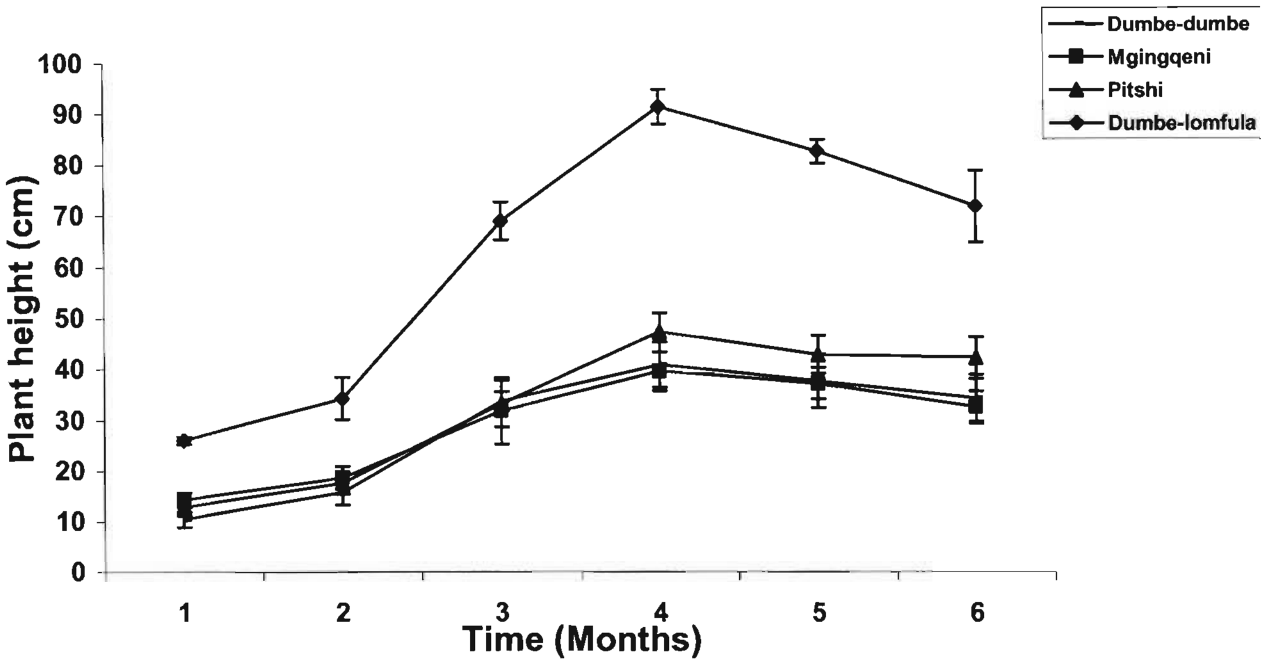

Figure 5.9 Change in plant height of taro landraces grown at UKZN.

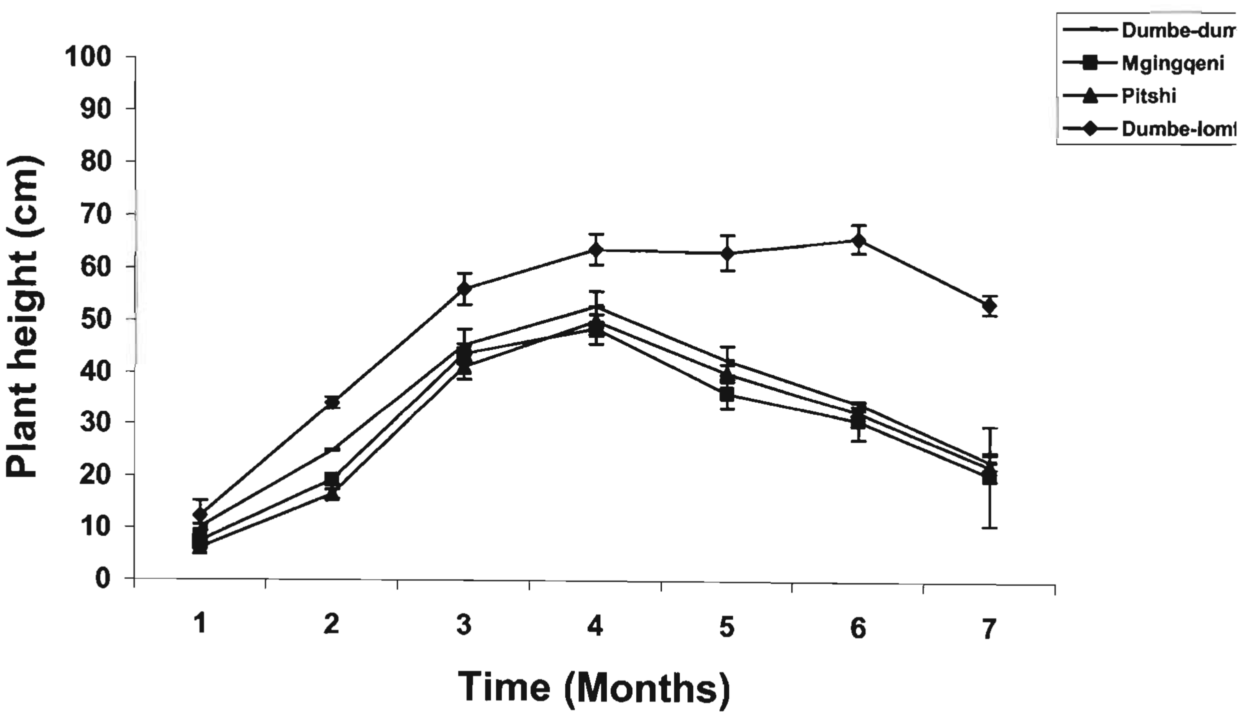

Figure 5.10 Change in plant height of taro landraces grown at Umbumbulu.

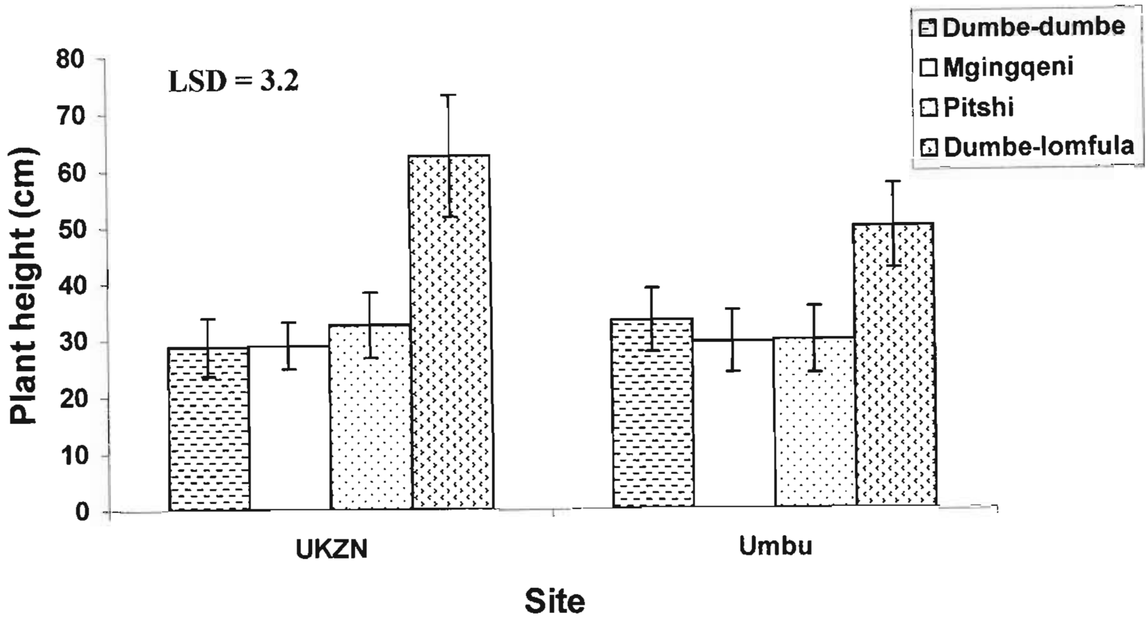

Figure 5.11 Average plant height of taro landraces over the experimental period at different sites.

5.3.4 Leaf area

There was a significant interaction for leaf area between site and landrace (P = < 0.001), but there was no significant interaction between site, landrace and time (Appendix 5.2 D). Leaf area was significantly high for Dumbe-lomfula at both sites (LSD = 183.5). UKZN has significantly high leaf area for Dumbe-lomfula only, the other landraces were not different from the same landraces at Umbumbulu (Figure 5.14).

Leaf area for all landraces increased until it reached the peak at four months and then declined to the end of the experimental period at both UKZN and Umbumbulu. At UKZN, Dumbe-lomfula had a significantly highest leaf area from the first month throughout the experiment, but at Umbumbulu it displayed the significantly high leaf area from four month onward (Figure 5.12 and 5.13). The lowest leaf area was displayed by Dumbe-dumbe in UKZN from two months to the end of the experiment, although the leaf area was not significantly different from that of Mgingqeni and Pitshi.

Average leaf area of Dumbe-lomfula was significantly higher than that of all the other taro landraces at both sites, and UKZN had a significantly higher average leaf area than Umbumbulu over the experimental period. The other three taro landraces were not significantly different from one another in relation to average leaf area over the experimental period within and between sites. Dumbe-lomfula might be expected to have the highest yield since it displayed the highest leaf area because leaf area is considered as a valuable index in identifying plant growth and development. It is also related to light interception, transpiration, and photosynthesis and thus considered the most important single determinant of dry matter accumulation and yield in taro (SATOU *et al.*, 1978, 1988; JACOBS & CHAND, 1992; CHAN *et al.*, 1995, 1998).

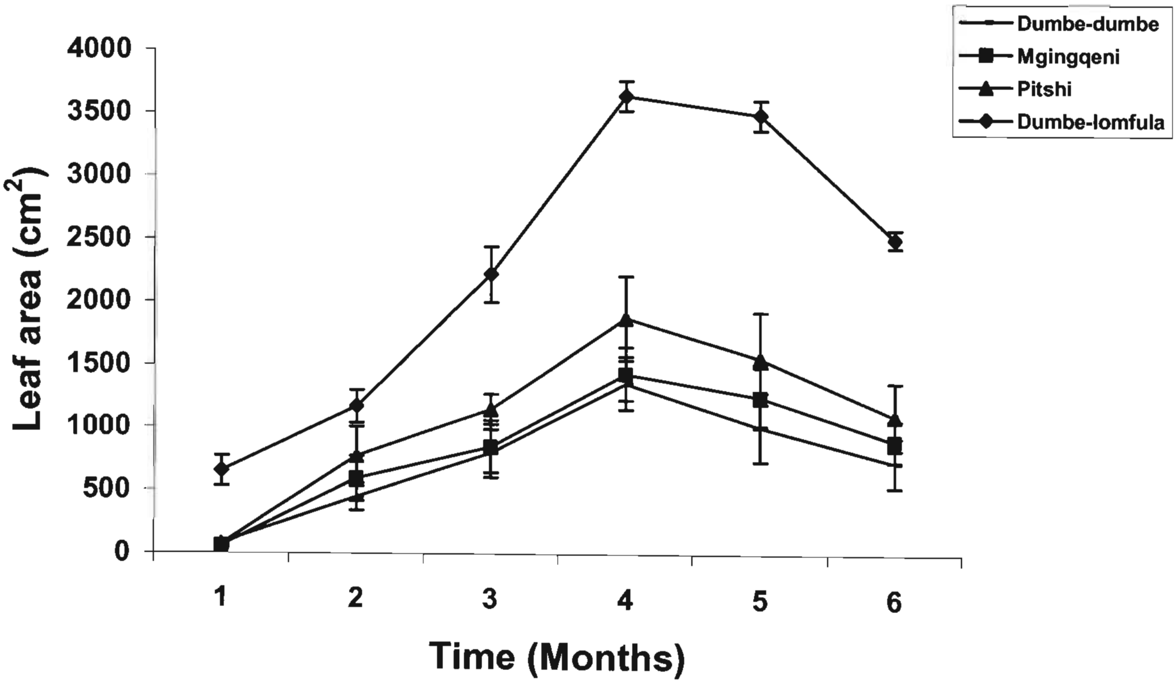

Figure 5.12 Change in leaf area of taro landraces grown at UKZN.

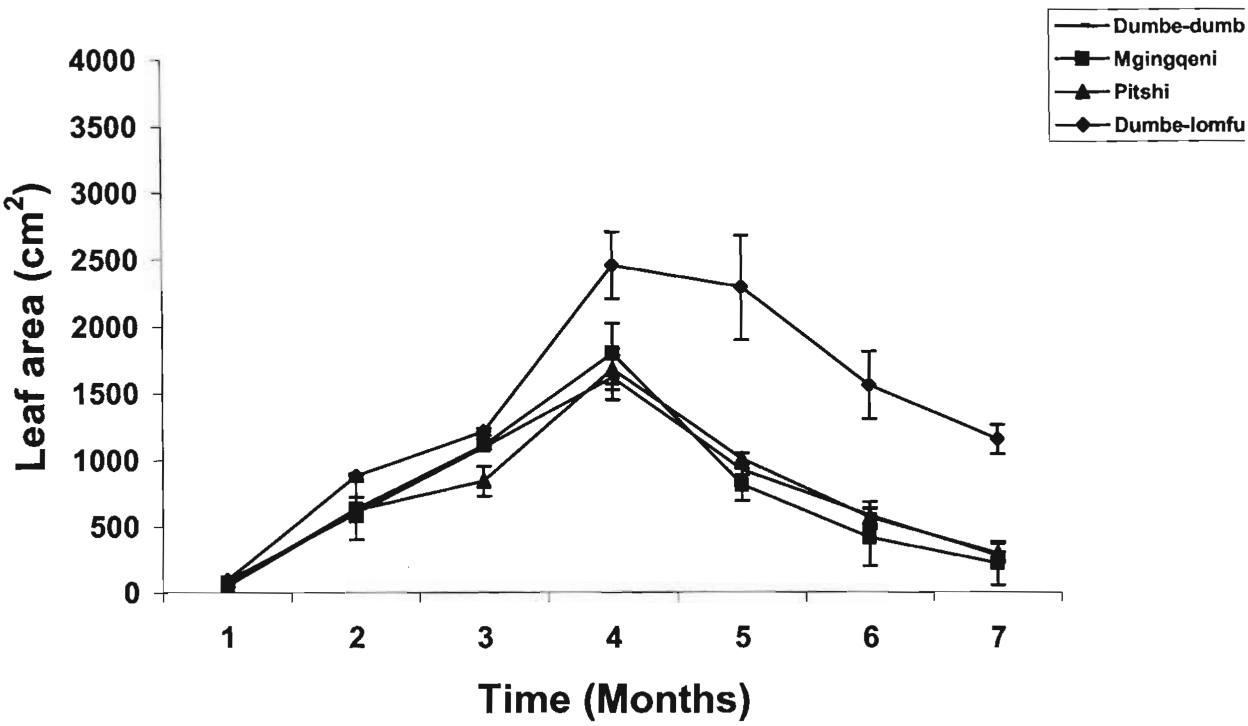

Figure 5.13 Change in leaf area of taro landraces grown at Umbumbulu.

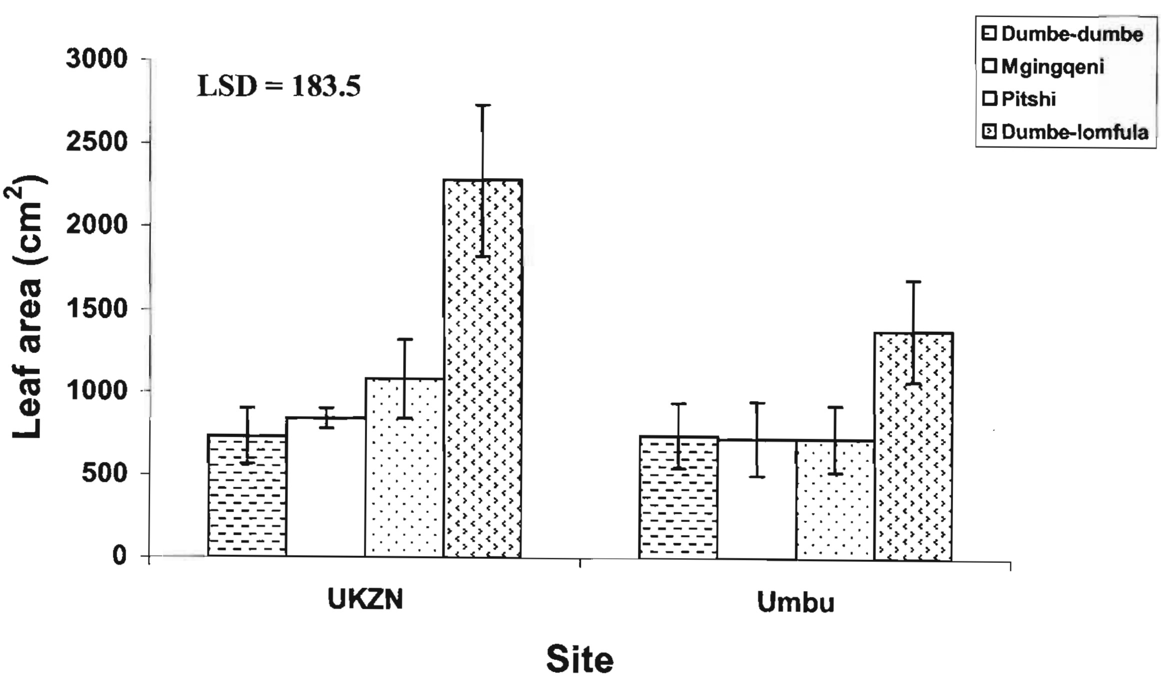

Figure 5.14 Average leaf area of taro landraces over the experimental period at different sites.

5.3.5 Yield

5.3.5.1 Fresh corm weight

There was a significant difference in fresh corm weight between sites (P = 0.036) (Appendix 5.2 E). UKZN had the highest fresh corm weight of 932 g compared with Umbumbulu, with 749 g (LSD = 17.9) (Figure 5.15). This might be the result of higher P, K, Ca, Mg, Zn, Mn, Cu, sample density, total cations and temperature, which might have also resulted in the higher leaf area at the UKZN site than at Umbumbulu site. The higher yield of the site that had the high leaf area confirms what was stated that leaf area is the most important single determinant of dry matter accumulation and yield in taro (SATOU *et al.*, 1978, 1988; JACOBS & CHAND, 1992; CHAN *et al.*, 1995, 1998).

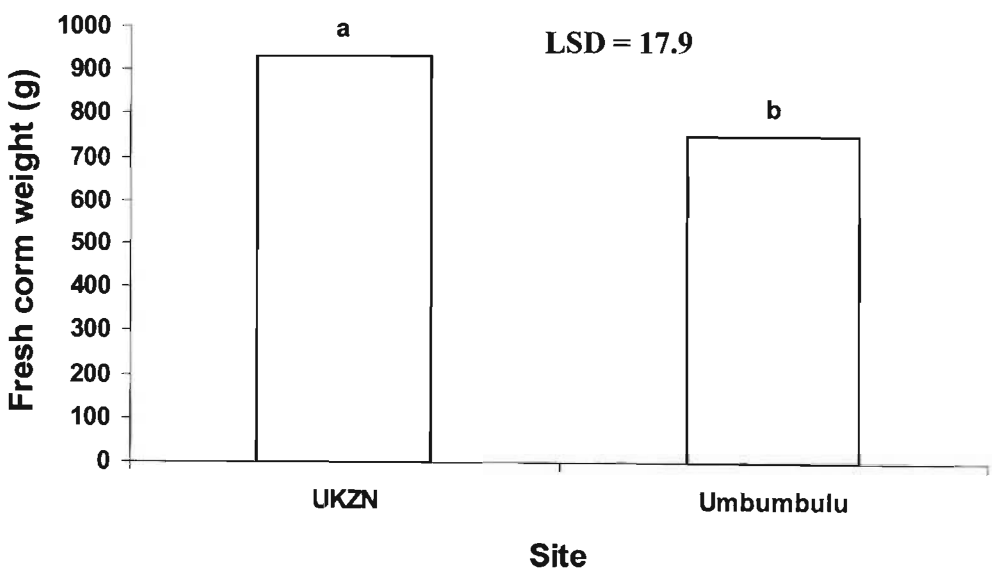

Figure 5.15 Fresh corm weight of the taro landraces at different sites. Means or bars with the same letters are not significantly different.

5.3.5.2 Number of corms

There was a significant difference in the number of corms between taro landraces (P < 0.001) (Appendix 5.2 F). Pitshi had the significantly highest number of corms followed by Mgingqeni, Dumbe-dumbe and Dumbe-lomfula, respectively (LSD = 9.35) (Figure

5.16). All taro landraces, with the exception of Dumbe-dumbe at Umbumbulu, showed that the highest percentage of harvested corms weighed less than 20 g $corm^{-1}$. Although Pitshi had the highest number of corms, about 82% of the corms harvested from the Umbumbulu site weighed less than 20 g each, whereas about 61% from UKZN site weighed less than 20 g. Dumbe-dumbe at Umbumbulu displayed higher percentage (about 27%) of harvested corms in the range of 21 - 40 g and 24% in the range 41 – 60 g as compared to other ranges.

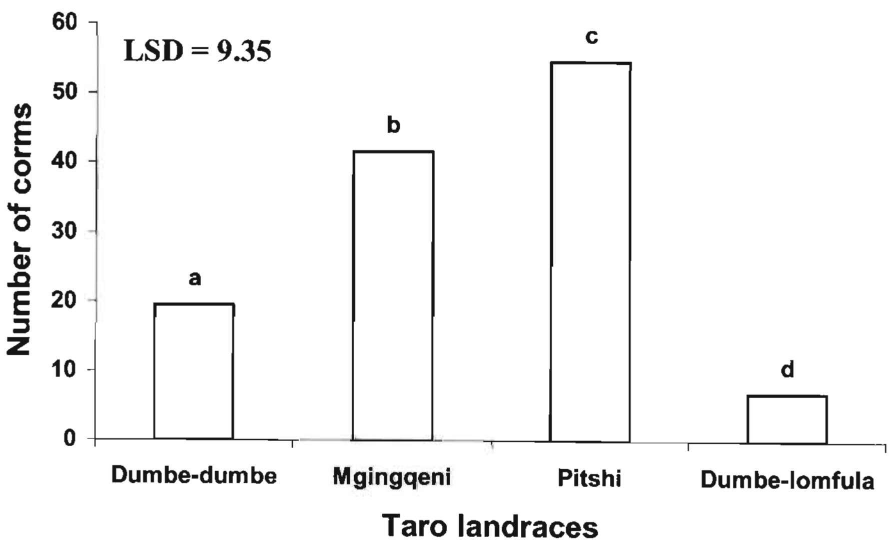

Figure 5.16 Average number of corms of taro landraces across sites. Means or bars with the same letters are not significantly different.

Table 5.2 Number of harvested corms graded according to the fresh mass (g).

	UMBUMBULU				UKZN			
Weight ranges (g)	D	M	P	R	D	M	P	R
<20	3.17 ± 0.53	19.67 ± 2.37	49.92 ± 7.51	1 ± 0	9.2 ± 0.84	25.5 ± 3.99	36.78 ± 6.63	5.56 ± 3.82
21-40	5.92 ± 0.91	12.42 ± 1.32	0.08 ± 0.92	1.5 ± 0.22	8.38 ± 1.36	14.6 ± 2.17	13.78 ± 2	3.13 ± 0.67
41-60	5.18 ± 0.48	4. 1 ± 0.89	2.25 ± 0.45	1.67 ± 0.33	3 ± 0.78	5.25 ± 1.46	4 ± 1.32	1 ± 0
61-80	2.8 ± 0.36	1.63 ± 0.32	1.67 ± 0.33	1.4 ± 0.25	2.33 ± 0.56	1.71 ± 0.29	2 ± 0.41	1.2 ± 0.2
81-100	1.67 ± 0.24	1 ± 0	*	1 ± 0	2 ± 0.58	1 ± 0	1.2 ± 0.2	1.75 ± 0.25
101-120	1.25 ± 0.25	1 ± 0	1 ± 0	1.5 ± 0.29	1.5 ± 0.5	1 ± 0	1 ± 0	1 ± 0
121-140	2 ± 0	1 ± 0	*	1.4 ± 0.25	1 ± 0	*	*	1 ± 0
141-160	*	1 ± 0	*	1 ± 0	*	*	1 ± 0	1.33 ± 0.33
161-180	*	*	*	1.33 ± 0.33	*	*	1 ± 0	1 ± 0
181-200	*	*	*	1 ± 0	*	*	*	1 ± 02
201-220	*	*	*	1 ± 0	*	*	*	1 ± 0
221-240	*	*	*	1 ± 0	*	1 ± 0	1 ± 0	1.5 ± 0.5
241-260	*	*	*	1 ± 0	*	*	*	1.5 ± 0.5
261-280	*	*	*	1 ± 0	*	*	*	*
281-300	*	*	*	*	*	*	*	1 ± 0
301-320	*	*	*	1 ± 0	*	*	*	1 ± 0
321-340	*	*	*	1 ± 0	*	*	*	1 ± 0
341-360	*	*	*	1 ± 0	*	*	*	1 ± 0
401-420	*	*	*	1 ± 0	*	*	*	1 ± 0
461-480	*	*	*	*	*	*	*	1 ± 0
661-680	*	*	*	*	*	*	*	1 ± 0

* indicates that there was no yield.

5.3.6 Starch and mineral content

The results of starch and mineral analysis are presented in Table 5.3. Site had significant effect on the starch content (P = 0.022), K content (P = 0.004), Na content (P = 0.001) and C, N, S, Mg, Mn, Cu, P and Zn content (P < 0.001) (Appendix 5.3 A-N) of the four taro landraces with UKZN showing significantly higher starch, sulphur, nitrogen, magnesium, potassium, zinc, copper, manganese and phosphorus content than Umbumbulu. The high magnesium, potassium, zinc, copper, manganese and phosphorus content in taro corms from UKZN might have been as a result of the higher mineral quantities in the soil (Table 5.1). Umbumbulu displayed higher carbon and sodium content than UKZN. The higher carbon content in taro corms from Umbumbulu might have also been obtained from the higher organic carbon in the soil. There were no significant differences in calcium, iron and aluminium content between the sites despite the higher calcium content in the soil.

Landrace also brought significant difference in C content (P = 0.044), Fe content (P = 0.025), Al (P = 0.038), starch, N, Ca, Cu, Mg, Mn, P and Zn content (P < 0.001) (Appendix 5.4 A-N). Dumbe-dumbe had the highest carbon content (42.18% dry matter) compared with the other landraces, although it was not significantly different from Mgingqeni (41.98 %) (LSD = 0.5) (Table 5.3). Iron and calcium content were highest for Dumbe-lomfula, followed by Pitshi, Mgingqeni and Dumbe-dumbe respectively, whereas nitrogen, magnesium and zinc content were highest for Dumbe-lomfula followed by Dumbe-dumbe, Pitshi and Mgingqeni respectively. Pitshi displayed the highest starch content (68.5%), which was not significantly higher than Dumbe-dumbe (64.7%) and Mgingqeni (66.2%) but significantly higher than Dumbe-lomfula (48.3%) (LSD = 10.04). Dumbe-lomfula showed the highest copper, manganese and phosphorus content, while Dumbe-dumbe, Mgingqeni and Pitshi showed lowest copper, manganese and phosphorus content respectively. Aluminium content was significantly high for Mgingqeni (17.8mg kg^{-1} dry matter), although it was not significantly higher than that of Pitshi. Dumbe-dumbe had the lowest Al content that was not significantly lower than that of Dumbe-lomfula and Pitshi.

There was a significant difference between the interaction of site and landrace in starch content ($P = 0.039$), N content ($P = 0.017$) and Mg, Zn, Cu, Mn, and P content (($P < 0.001$) (Appendix 5.4 A, D, F, I, J, K and M). Starch content was highest for Pitshi (79.4%) and lowest for Dumbe-lomfula (44.6%), both at UKZN and both were significantly different from starch content shown by Dumbe-dumbe and Mgingqeni at Umbumbulu. Dumbe-lomfula had significantly lower starch content compared with the other landraces at UKZN, but the others were not significantly different from each other (LSD = 14.19). At Umbumbulu, there was no significant difference in starch content between all taro landraces. Although they were not significantly different, all taro landraces at UKZN had higher starch content than the same landraces at Umbumbulu with the exception of Dumbe-lomfula, which had a lower starch content at UKZN (Table 5.3). Only Pitshi had a significantly higher starch content at UKZN.

The highest nitrogen content was shown by Dumbe-lomfula from UKZN followed by Pitshi, Dumbe-dumbe and Mgingqeni from the same site which had significantly lower nitrogen content than Dumbe-lomfula, but a significantly higher nitrogen content than Dumbe-dumbe, Mgingqeni and Pitshi from Umbumbulu (Table 5.3). Copper content was significantly highest for Dumbe-lomfula from UKZN followed by the same landrace from Umbumbulu, which had a significantly higher copper content than Dumbe-dumbe and Pitshi from the same site. The highest magnesium content was displayed by Dumbe-lomfula (0.28%) at UKZN, while Pitshi from Umbumbulu had the lowest magnesium content of 0.09%. Dumbe-lomfula at UKZN showed a significantly higher manganese and phosphorus content than the other landraces, and all landraces at Umbumbulu which were not significantly different from each other. Zinc content was highest for Dumbe-lomfula from UKZN and lowest for Pitshi from Umbumbulu. The remaining landraces from both sites were not significantly different in zinc content.

The results showed that potassium was the most abundant mineral and ranged from 1.8 to 2.2 mg kg^{-1} for Dumbe-dumbe at Umbumbulu and Pitshi at UKZN, respectively. The landraces from UKZN showed higher potassium content compared with the same landraces at Umbumbulu.

The response of leaf area, fresh corm weight and number of corms harvested from each plant at the two sites suggested that growth environment plays an important role in taro production. The slightly higher temperature at UKZN, compared with Umbumbulu might have also resulted in the higher leaf area and higher fresh corm weight at that site. The results of starch and mineral analysis provided evidence that taro is potentially an important food source, because it contains high amounts of carbohydrates and is an excellent energy supplier. Umbumbulu and UKZN production of taro showed significant differences in the starch and mineral content. The variation in levels of starch and minerals observed between sites and landraces may offer some meaningful information for choice of sites to cultivate taro in KwaZulu-Natal or South Africa.

Table 5.3 Starch and mineral content of four taro landraces cultivated at UKZN and Umbumbulu [Dumbe-dumbe (D), Mgingqeni (M), Pitshi (P) and Dumbe-lomfula (R)].

Nutrients	**LSD**	**Umbumbulu**				**UKZN**			
		D	**M**	**P**	**R**	**D**	**M**	**P**	**R**
Starch (% DM)	14.19	61.7**abc**	59.7**abc**	57.5**abe**	51.9**ae**	67.7**bcd**	72.6**cd**	79.4**d**	44.6**e**
Carbon (%)	0.75	42.48**a**	42.12**a**	42.37**a**	41.77**a**	41.87**a**	41.08**b**	41.59**b**	41.16**b**
Sulphur (%)	0.01	0.10**a**	0.11**b**	0.10**a**	0.10**a**	0.13**c**	0.13**c**	0.13**c**	0.14**d**
Nitrogen (%)	0.33	1.31**ab**	1.25**a**	1.24**a**	1.61**bd**	1.94**c**	1.86**cd**	2.00**c**	2.91**e**
Calcium (%)	0.07	0.04**a**	0.06**a**	0.06**a**	0.35**b**	0.04**a**	0.04**a**	0.08**a**	0.44**c**
Magnesium (%)	0.03	0.10**ac**	0.10**ac**	0.09**a**	0.18**b**	0.12**c**	0.09**a**	0.12**c**	0.28**d**
Potassium (%)	0.27	1.80**a**	2.03**abd**	1.85**a**	2.05**abd**	1.96**abd**	2.18**bcd**	2.24**cd**	2.14**d**
Sodium (mg kg^{-1})	185.8	276**ab**	273**ab**	249**ab**	308**a**	143**ab**	164**ab**	93**b**	125**ab**
Zinc (mg kg^{-1})	25	13.7**ab**	14.8**ab**	9.3**a**	31.4**ab**	35.3**ab**	22.7**ab**	37**b**	196.7**c**
Copper (mg kg^{-1})	2.1	5.4**a**	7.2**acd**	6.4**ac**	10.8**bde**	8.1**cde**	9.2**de**	9.3**e**	19.4**f**
Manganese (mg kg^{-1})	53.7	10.8**a**	17**a**	15.5**a**	31**a**	47.4**a**	31.9**a**	43.8**a**	257.8**b**
Iron (mg kg^{-1})	24.5	14.9**acd**	22.3**acd**	32**abcd**	53**bd**	19.7**cd**	19.4**cd**	18.7**cd**	31.2**d**
Phosphorus (%)	0.05	0.23**ab**	0.22**ab**	0.19**a**	0.23**ab**	0.26**b**	0.21**a**	0.23**ab**	0.41**c**
Aluminium (mg kg^{-1})	13.4	8.3**abc**	14.9**abc**	16.3**ac**	12.6**abc**	1.7**b**	21.4**c**	2.6**ab**	2.6**ab**

Values in the same row followed by similar letters are not significantly different by the LSD test (0.05).

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSIONS

The survey conducted in this study revealed that the not all the subsistence farmers at Umbumbulu know all taro landraces existing in their area, and those who do generally know the popular landraces (Dumbe-dumbe and Mgingqeni). It was found that the same landrace may be known by a different name in different localities or more than one name may be used, with one locality preferring one name over another name. For example, Dumbe-dumbe is also known by its descriptive (petiole colour, especially shoot bud – Figure 4.1) name, Dumbe-elibomvu. The characteristics of the landraces that were used to describe taro landraces confirmed that some mentioned landraces could not be classified separately. Farmers' preferences for landrace cultivation were influenced by social, economic and ecological factors. The importance of a landrace depended on the use of the landrace by farmers. Marketing, food and culture, which were determined by taste, cooking time and sliminess among other characteristics were the main uses that determined the importance and therefore the preference of a landrace. The known landraces at Umbumbulu, in order of general preference, were Dumbe-dumbe, Mgingqeni, Pitshi and Dumbe-lomfula, respectively. It is interesting to note that Mgingqeni is actively being selected out of cultivation, because it has a poorer food quality than Dumbe-dumbe, but it yields better than Dumbe-dumbe; Pitshi is disregarded in cultivation, because its corms are too small and take too long to cook; Dumbe-lomfula is not a cultivated landrace, but it is edible when cooked.

The importance of these taro landraces to Umbumbulu farmers requires sound knowledge of the environmental requirements of the landraces. Both controlled environment and field studies are of great importance in providing a clear understanding of the landraces relating to interaction of the environment and main physiological processes that determine economic yield and composition of the landraces. The phytotron and field studies, reported herein, provided an insight into the agronomic qualities of the Umbumbulu landraces of taro. However, the data from these studies are general, in that they do not offer opportunities to determine input requirements and thus to recommend management practices for the taro landraces. Future studies on response to fertiliser, and other cultural practices are therefore, warranted. The major finding of this study, with respect to taro management is that taro production is influenced by temperature and possibly other environmental conditions at a production site. This finding was shown by the phytotron results, which revealed that cool environments reduce taro yield; hot environments increase growth, but do not improve yield over warm environments. It was shown in this study that corm chemical composition (starch and minerals) is influenced by growth temperature.

The results of this study about the effect of temperature on taro growth and development confirmed previous studies elsewhere in the world (LU *et al.*, 2001). The results also showed that all stages are sensitive to temperature and that the sensitivity differs with phenological stages, being more severe at sowing to emergence phase (BAZZAZ & SOMBROEK, 1996). The shorter time to emergence taken by all taro landraces at 33/23°C than at 22/12°C and 27/17°C explained that seed corms reserves were mobilized through accelerated respiration (BURTON & BAZZAZ, 1991) and that high temperatures enhanced seedling emergence of taro. The longer time to emergence taken by Mgingqeni relative to Dumbe-dumbe, Dumbe-lomfula, Pitshi-omhlophe and Pitshi explains that the increase in thermal duration was greater for more slowly developing individuals, so the spread of thermal time between the first and the last to emerge increased (SQUIRE, 1990). It is important to note that the present study did not measure thermal time, hence its determination for taro growth would be a useful future study.

The enhanced leaf number and leaf area at 33/23°C, which was characterised by early senescence, compared with 22/12°C and 27/17°C indicated that taro development accelerates as temperature increases leading to an accelerated ageing of the foliage and a shortening of the growing season (BAZZAZ & SOMBROEK, 1996). Plant leaf area increased faster at 33/23°C than 22/12°C and 27/17°C. Leaves developed up to maximum canopy then leaf growth and leaf area declined as leaves senesced earlier at high temperature. The faster leaf appearance and expansion at 33/23°C compared to 22/12°C and 27/17°C shown by this study are supported by previous studies that temperature strongly affects the rate of initiation and expansion of most leaves (SQUIRE, 1990). Cool conditions slowed the rate of growth compared with warm conditions. The shorter leaf life duration displayed at 33/23°C compared to 22/12°C and 27/17°C shows that leaves remains green longer at lower temperatures. This phenomenon had a yield advantage at warm temperatures over hot temperatures, but it did not help to increase the yield at cool tempeartures (LAWLOR *et al.*, 1988). The leaf area peak was reached at a later time in cooler temperatures when assimilates were translocated into the sink as senescence increases with the movement of nutrients from the leaf to the fruiting structures. Senescence also occurs in some species when the light intercepted by the leaves is reduced to a critical level by shading from newer leaves, as in cassava (SQUIRE, 1990). This was probably the case with Pitshi-omhlophe that displayed high number of leaves and leaf area but lower yields.

Dumbe-lomfula generally showed the lowest number of leaves and the highest leaf area at all temperatures and sites but it did not display the highest yield. This was in contrast with what was reported earlier that leaf area is the most important single determinant of dry matter accumulation and yield in taro (SATOU *et al.*, 1978, 1988; JACOBS & CHAND, 1992; CHAN *et al.*, 1995, 1998, DE JESUS *et al.*, 2001). This might have been because yield response to leaf area is primarily a function of light interception (SINGH *et al.*, 1998; ZIEMS *et al.*, 2006). Although it was expected that the greater the leaf area, the greater the radiation absorption, the greater the possible production of photosynthates and hence, the greater the yield (ANDERSON, 1967), whether leaf area is optimal for photosynthesis in a particular environment is reciprocally linked with development and properties of individual leaves, including their longevity (LOOMIS & AMTHOR, 1999) and the variability of taro landraces due to genotype. The findings of this study were also in line with what SQUIRE (1990) found, that for vigorous genotypes, the extra dry matter produced at higher temperatures was very much less than the increased requirement by the shoots. In fact, at the higher temperature, the new dry matter was little more than required to sustain shoot growth. Low temperature increased partitioning for tubers by reducing the expansion rate of the shoot system and thereby the sink (SQUIRE, 1990).

The success of this study in identifying redundant taro landraces in Umbumbulu is significant for agriculture. The identified landraces can now be examined closely for agronomic performance, in widespread and longterm cultuivar trials in the province and the country. The landraces could also be submitted for germplasm preservation at the national institutes such as the ARC and the national genebank. Molecular biology studies could be undertaken to determine genetic differences of the landraces and to identify genes for agronomic performance and other uses for humanity.

REFERENCES

AGBOR EGBE, T. & RICKARD, J. 1990. Evaluation of the chemical composition of fresh and stored edible aroids. Journal of the Science of Food and Agriculture 53: 487–495.

ALVAREZ, M.N. & HAHN, S.K. 1986. Seed production in sweet potato, yam and cocoyam at IITA. In: J.H. Cock (Ed.). The proceedings of the global workshop on root and tuber crops propagation. CIAT, Cali, Colombia.

ANDERSON, M.C. 1967. Photon flux, chlorophyll content, and photosynthesis under natural conditions. Ecology 48: 1050.1053.

AREGHEORE, E.M. & PERERA, D. 2003. Dry matter, nutrient composition and palatability / acridity of eight exotic cultivars of cocoyams-taro (*Colocasia esculenta*) in Samoa. Plant Foods for Human Nutrition 58: 1-8.

AWAN, A.B. 1964. Influence of mulch on soil moisture, soil temperature and yield of potatoes. American Potato Journal 41: 337-339.

BAZZAZ, F. & 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.

BERRY, J. & BJÖRKMAN, O. 1980. Photosynthetic response and adaptation to temperature in higher plants. Annual Review of Plant Physiology 31: 491-543.

BHANDARI, M.R., KASAI, T. & KAWATA, J. 2003. Nutritional evaluation of wild yam (*Dioscorea* spp.) tubers of Nepal. Food Chemistry 82: 619–623.

BRADBURY, J.H. 1988. The chemical composition of tropical root crops. Asean Food Journal 4: 3–13.

BRADBURY, & HOLLOWAY, 1988. Chemistry of tropical root crops. ACIAR, Canberra.

BURTON, W.G. 1989. The potato, Third Edition, Longman Scientific and Technical, Harlow, UK.

BURTON, P.J. & BAZZAZ, F.A. 1991. Tree seedling emergence on interactive temperature and moisture gradients and in patches of old field vegetation. American Journal of Botany 78(1): 131-149.

CABLE, W.J., BRAUNE, H.J., KAN, S.K & AUKUSO, O. 1988. Effects of leaf harvesting on growth, corm yield and quality of taro, *Colocasia sp*., at Laloanea, Western Samoa. Tropical Root and Tuber Crops Newsletter18: 16.

CAESAR, K. 1980. Growth and development of *Xanthosoma* and *Colocasia* under different light and water supply conditions. Field Crops Research 3: 235-44.

CHAN, L.F., LU, C.T. & 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.

CHAN, L.F., LU, H.Y., LU, C.T. & LAI, C.H. 1995. Relationship between leaf area and dry biomass production in wetland taro. Journal of Agricultural Research of China 44:59–71.

CHING, K.W. 1970. Development of starch, protein, leaf and corm in *Colocasia esculenta.* In: 'Tropical Root and Tubers Crops Tomorrow'. Proceedings of the 2nd International Symposium on Tropical Root and Tuber Crops 1: 143-146.

CHRISTINCK, A., VOM BROCKE, K., KSHIRSAGAR, K.G., WELTZIEN, E & BRAMEL-COX, P.J. 2006. Participatory methods for collecting germplasm: Experiences with farmers in Rajasthan, India. Plant Genetic Resources Newsletter121: 1-9.

COURSEY, D.G. 1976. Yams, *Dioscorea* spp. (Dioscoreaceae). In: N.W.SIMMONDS & COURSEY, D.G. (eds.). Evolution of crop plants. Longman, London.

DANIELS, J. 2005. Taro – Tapping the full potential of a minor Australian crop. Acta Horticulturae 694: 295-299.

DAVIDSON, S., PASSMORE, R., BROCK, J.F. & TRUSWELL, A.S. 1979. Human nutrition and dietetics. Churchill Livingstone, Edinburg.

DE JESUS, W.C. Jr., DO VALE, F.X.R. COELHO R.R & COSTA, L.C. 2001. Comparison of two methods for estimating leaf area index on common bean. Agronomy Journal 93: 989-991.

DE LA PENA, R.S. 1983. Agronomy. In: J.K. WANG (ed.) A review of *Colocasia esculenta* and its potentials. University of Hawaii Press, Honolulu.

DELPEUCH, F., FAVIER, J. & CHARBONNIERE, R. 1978. Characteristics of starches from tropical food plants. Annales de Technlogie Agricole 27: 809–812.

DHAMOTHARAN, M., WELTZIEN, E. R., WHITAKER, M.L., RATTUNDE, H.W.F., ANDERS, M.M., TIAGI, L.C., MANGA, V.K., & VYAS, K.L. 1997. Seed management strategies of farmers in western Rajasthan in their social and environmental contexts: results from a workshop using new communication techniques for a dialogue between farmers and scientists. 5-8 February 1996, Digadi village, Jodhpur district, Rajasthan, India. Integrated Systems Project Progress Report no. 9. ICRISAT Patancheru 502324, Andhra Pradesh, India.

ENGLBERGER, L., AALBERSBERG, W., RAVI, P., BONNIN, E., MARKS, G.C., FITZGERALD, M.H. & ELYMORE, J. 2003. Further analyses on Micronesian banana, taro, breadfruit and other foods for provitamin A carotenoids and minerals. Journal of Food Composition and Analysis 16: 219–236.

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.

FARRAR, J.F. & WILLIAMS, J.M. 1991. The effects of increased atmospheric carbon dioxide and temperature on carbon partitioning, sink-source relations and partitioning. Plant, Cell and Environment 14: 813-830.

FLEISHER, D.H., TIMLIN, D.J., & REDDY, V.R. 2006 Temperature influence on potato leaf and branch distribution and on canopy photosynthetic rate. Agronomy Journal 98: 1442-1452.

FUSSELL, L.K., PEARSON, C.J. & NORMAN, M.J.T. 1980. Effect of temperature during various growth stage on grain development and yield of *Pennisetum americanum.* Journal of Experimental Botany 31 (121): 621-633.

GEIGENBERGER, P., GEIGER, M. & STITT, M. 1998. High-temperature perturbation of starch synthesis is attributable to inhibition of ADP-glucose pyrophosphorylase by decreased levels of glycerate-3-phosphate in growing potato tubers. Plant Physiology 117: 1307-1316.

GERSTNER, J. 1938. Preliminary checklist of Zulu names of plants, Bantu Studies, Johannesburg.

GREENWELL, A. 1947. Taro with special reflections to its culture and use. Economic Botany 1: 276-289.

HANSON, J. & IMAMUDDIN, H. 1983. Germination and seed storage behaviour of seeds of *Colocasia gigantean* Hook.f. Proceedings of the Sixth Symposium of the International Society for Tropical Root Crops, Peru.

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

HIZUKURU, S., TABATA, S. & NIKUNI, Z. 1970. Studies on starch phosphates. Part I. Estimation of glucose-6-phosphate residues in starch and the presence of other bound phosphate(s). Stärke 22: 338–343.

HUANG, A.S., TITCHENAL, C.A. & MEILLEUR, B.A. 2000. Nutrient composition of taro corms and breadfruit. Journal of Food Composition and Analysis 13:859–864.

HUANG, C.C., CHEN, W.C. & WANG, C.C.R. 2006. Comparison of Taiwan paddy- and upland-cultivated taro (*Colocasia esculenta* L.) cultivars for nutritive values. Food Chemistry 102: 250-256.

HUTTON, W. 2004. Handy pocket guide to Asian vegetables. Tuttle Publishing, Tokyo, Japan.

IVANCIC, A., QUERO-GARCIA, J. & 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.

JACOBS, B.C. & CHAND, V. 1992. Large headsetts and improved cultivar enhance growth and development of taro [*Colocasia esculenta* (L.) Schott] during establishment. Journal of Agronomy and Crop Science 168:119–127.

JOHNSTON, M., ONWUEME, I.C., DOWLING, A.L. & RODONI, B. C. 1997. Comparison of suckering, leaf and corm characteristics and taro grown from tissue culture and conventional planting material. Australian Journal of Experimental Agriculture 37: 469-75.

KAY, D.E. 1973. Crop and product digest 2. Root Crops. Tropical Products Institute, London.

KRAUS, A. & MARSCHNER, H. 1984. Growth rate and carbohydrate metabolism of potato tubers exposed to high temperatures. Potato Research 27: 297-303.

LAMBERT, M. 1982. Taro cultivation in the South Pacific. South Pacific Commission, Noumea, New Caledonia.

LAWLOR, D.W., BOYLE, F.A., KEYS, A.J., KENDALL, A.C. & YOUNG, A.T. 1988. Nitrate nutrition and temperature effects on wheat: A synthesis of plant growth and nitrogen uptake in relation to metabolic and physiological processes. Journal of Experimental Botany 39 (200): 329-343.

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

LIAN, M.M., YI M.F., JUN, C.Y. & LIN, Y.Z. 2004. Research progress on cultivation physiology of potato in China. Proceedings of the Fifth World Potato Congress. China.

LLAMAS, K.A. 2003. Tropical flowering plants: A guide to identification and cultivation. Timber Press, Portland, Cambridge.

LOOMIS, R.S. & AMTHOR, J.S. 1999. Yield potential, plant assimilatory capacity, and metabolic efficiencies. Crop Science 39:1584-1596.

LU, H.Y., LU, C.T., CHAN, L.F. & WEI, M.L. 2001. Seasonal variation in linear increase of taro harvest index explained by growing degree days. Agronomy Journal 93:1136-1141.

MARAIS, J.P., DEWIT, L.L. & QUICKE, G.V. 1966. A critical examination of the Nelson Somogyi method for the determination of reducing sugars. Analytical Biochemistry 15: 373-381.

MARSHALL, D.R. & BROWN, A.H.D. 1975. Optimum sampling strategies in genetic conservation. In: O.H. FRANKEL & J.G. HAWKES, (Eds.) Crop genetic resources today and tomorrow. Cambridge University Press, USA.

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

MIDMORE, D.J. & PRANGE, R.K. 1992. Growth responses of two *Solanum* species to contrasting temperatures and irradiance levels. Annals of Botany 69: 13-20.

MILLIGAN, A. 2003. Participatory learning and action notes. IIED, London.

MIYASAKI, S.C., OGOSHI, R.M., TSUJI, G.Y & 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. 2004 . Short-term preservation of maize landrace seed and taro propagules using indigenous storage methods. South African Journal of Botany 70(1): 16-23.

MOHABIR, G. & JOHN, P. 1988. Effect of temperature on starch synthesis in potato tuber tissue and in amyloplasts. Plant Physiology 88: 1222-1228.

MONTEITH, J.L. & MOSS, C.J. 1977. Climate and efficiency of crop production in Britain. Philosophical Transactions of the Royal Society 281:277-294.

MUCHOW, R.C., SINCLAIR, T.R. & BENNETT, J.M. 1990. Temperature and solar radiation effects on potential maize yield across locations. Agronomy Journal 82: 338-343.

MUHRBECK, P. & TELLIER, C. 1991. Determination of the phosphorylation of starch from native potato varieties by 31P-NMR. Stärke 46: 25–27.

NIELSEN, T.H., WISCHMAN, B., ENEROLDSEN, K. & MOLLER, B.J. 1994. Starch phosphorylation in potato tubers proceeds concurrently with de novo biosynthesis of starch. Plant Physiology 105: 111–117.

NYMAN, L. P. & ARDITTI, J. 1985. Germination of taro seeds. Ariodeana 8(3):83-88.

ONWUEME, I.C. 1978. The tropical tuber crops: Yams, cassava, sweet potato, and cocoyams. John Wiley. Chichester.

ONWUEME, I.C. 1994. Tropical root and tuber crops - Production, perspectives and future prospects. FAO Plant Production & Protection Paper 126. FAO, Rome.

ONWUEME, I. C. 1999. Taro cultivation in Asia and the Pacific. FAO RAP Publication: 16.

PERDALES, J. R. & DINGAL, A. G. 1988. An allelopathic factor in taro residues. Tropical Agriculture (Trinidad) 65(1):21-24.

PLANTBIO 2005. PlantBio's involvement at Umbumbulu. PlantBio Trust Newsletter 1:1-2.

PLUCKNETT, D.L., DE LA PENA, R.S. & OBRERO, F. 1970. Taro (*Colocasia esculenta*), A Review. Field Crop Abstracts 23: 413-426.

PRETTY, J.N., GUIJT, I., SCOONES, I. & THOMPSON, J. 1995. A trainer's guide for participatory learning and action. IIED, London.

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

RASHID, M. & DAUNICHT, H. 1979. Chemical composition of nine edible aroid cultivars of Bangladesh. Scientia Horticulturae 10: 1217–1234.

RASMUSSEN, T. S. & HENRY, R. J. 1990. Starch determination in horticultural plant material by an enzymiccolorimetric procedure. Journal of Food and Agricultural Science 52:159-70.

REYNOLDS, S.G. 1977. A study of the growth period of the taro plant (*Colocasia esculenta* (L.) Schott cv. Niue) in Western Samoa. Technical Paper for Regional Meeting on the Production of Root Crops, South Pacific Commission No.174, Noumea.

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

SATOU, T., KAWAI, M. & FUKUYAMA, T. 1978. Studies on matter production of taro plant (*Colocasia esculenta* Schott). Japanese Journal of Crop Science 47:425-430.

SATOU, T., MIYAUCHI, E. & SUGIMOTO, H. 1988. Studies on matter production of taro plant (*Colocasia esculenta* Schott). Japanese Journal of Crop Science 57:305–310.

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.

SHIH, S.F & SNYDER, G.H 1984. Leaf area index and dry biomass of taro. Agronomy Journal 76:750-752.

SINCLAIR, T.R. & GARDNER, F.P. 1998. Principles of ecology in plant production. CAB International, USA.

SINGH, U., MATTHEWS, R.B., GRIFFIN, T.S., RITCHIE, J.T., HUNT, L.A. & R. GOENAGA, R. 1998. Modeling growth and development of root and tuber crops.In: G.Y. Tsuji, G. Hoogenboom, and P.K. Thorton (ed.) Understanding options for agricultural production. Kluwer Academic Press, Dordrecht, The Netherlands.

SIVAN, P. S. 1982. Growth and development of taro (*Colocasia esculenta*) under dryland conditions in Fiji. Fifth International symposium on Tropical Root and tuber crop*s:* 637-646.

SLONE, H.T. 2001. One thousand one Papua New Guienian nights: Folktales from Wantok Newspapers :Volume 2. Masalai Press, USA.

SQUIRE, G.R. 1990. The physiology of tropical crop production. CAB International, Wallingford, UK.

STRAUSS, M.S. 1983. Anatomy and morphology of Taro *Colocasia esculenta* (L.) Schoott. In: J.K.Wang (ed) Taro a review of Colocasia esculenta and its potentials. University of Hawaii Press, Honolulu.

TERRY, N. 1968. Developmental physiology of sugar beet. I. The influence of light and temperature on growth. University of Nottingham School of Agriculture. Sutton Bonington, Loughborough.

TERRY, N. 1970. Developmental physiology of sugar-beet. II. Effects of temperature and nitrogen supply on the growth, soluble carbohydrate content and nitrogen content of leaves and roots. Journal of Experimental Botany. 21 (67): 477-96.

THAMAGA-CHITJA , J.M., HENDRIKS, S.L., MODI, A.T. & NSAHLAI, I.V. 2005. The agro-ecological potential for organic farming by small holder farmers in KwaZulu-Natal. Project Brief No.8. Food Security Programme. University of KwaZulu-Natal, Pietermaritzburg.

TIMLIN, D., RAHMAN, S.M.L., BAKER, J., REDDY, V.R., FLEISHER, D. & QUEBEDEAUX, B. 2006. Whole plant photosynthesis, development, and carbon partitioning in potato as a function of temperature. Agronomy Journal 98:1195-1203.

TRECHE, S. & GUION, P. 1980. The nutritional potential of some tropical tuber crops in the Cameroon. I. Influence of maturity of harvest. Agronomie Tropicale 34: 127–137.

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

TU, C.C., NIP, W.K. & NAKAYAMA, T.O.M. 1979. Starch and flour from taro. In: Plucknett D.L. (ed). Small scale processing and storage of tropical root crops. Westview Press, Boulder, Colorado, USA.

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.

WESTHUYZEN, J.J.N. 1967. Madumbis, Extension Office, Port Shepstone. Reprint from "Farming in South Africa".

WILSON, J.E. 1979. Promotion of flowering and production of seed in cocoyam, *Xanthosoma* and *Colocasia*. Proceedings of the fifth symposium on international Soc. Tropical Root Crops. Manila.

WITCOMBE, J.R. & GILANI, M.M. 1979. Variation in cereals from the Himalayas and the optimum strategy for sampling germplasm. Journal of Applied Ecology 16:633-640.

WOLF, S., MARANI, A. & RUDICH, J. 1990. Effect of temperature and photoperiod on assimilate partitioning in potato plants. Annals of Botany 64: 241-247.

WOLF, S. MARANI, A & RUDICH, J. 1991. Effect of temperature on carbohydrate metabolism in potato plants. Journal of Experimental Botany 42: 619-625.

WOLFE, D.W. (undated). Potential impact of climate change on agriculture and food supply. Cornell University.

YANEZ, P., OHNO, H. & OHKAWA, K. 2005. Temperature effects on corm dormancy and growth of *Zephyra elegans* D.Don. Scientia Horticulturae 105 (1): 127-138.

YOUNG, B.W. 1992. Vegetable production: Madumbies. Horticultural Advisory notes. Cedara Agricultural Development Institute, Pietermaritzburg, South Africa.

ZIEMS, J.R., ZECHMANN, B.J., HOBACK, W.W., WALLACE, J.C., MADSEN, R.A., HUNT, T.E. & HIGLEY, L.G. 2006. Yield response of indeterminate potato (*Solanum tuberosum* L.) to simulated insect defoliation. Agronomy Journal 98:1435-1441.

APPENDIX 4.1 Analysis of variance of seedling emergence, plant growth and yield.

A. Variate: Number_of_days_to_emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	203.65	67.88	1.32	
Replication.*Units* stratum					
Temperature	2	3066.10	1533.05	29.73	<.001
Landrace	4	1325.10	331.27	6.42	<.001
Temperature.Landrace	8	235.90	29.49	0.57	0.795
Residual	42	2166.10	51.57		
Total	59	6996.85			

B. Variate: Leaf_number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	99.976	33.325	3.74	
Replication.*Units* stratum					
Temperature	2	587.100	293.550	32.91	<.001
Landrace	4	845.841	211.460	23.70	<.001
Time	8	4509.467	563.683	63.19	<.001
Temperature.Landrace	8	636.215	79.527	8.91	<.001
Temperature.Time	16	429.733	26.858	3.01	<.001
Landrace.Time	32	757.626	23.676	2.65	<.001
Temperature.Landrace.Time	64	522.619	8.166	0.92	0.660
Residual	402	3586.274	8.921		
Total	539	11974.850			

C. Variate: Plant_height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	2749.6	916.5	9.12	
Replication.*Units* stratum					
Temperature	2	3026.4	1513.2	15.05	<.001
Landrace	4	34619.2	8654.8	86.09	<.001
Time	8	94958.5	11869.8	118.07	<.001
Temperature.Landrace	8	4800.3	600.0	5.97	<.001
Temperature.Time	16	35940.1	2246.3	22.34	<.001
Landrace.Time	32	10703.7	334.5	3.33	<.001
Temperature.Landrace.Time	64	7110.0	111.1	1.11	0.282
Residual	402	40414.6	100.5		
Total	539	234322.6			

D.Variate: Leaf_area

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	3414403.	1138134.	7.44	
Replication.*Units* stratum					
Temperature	2	679421.	339711.	2.22	0.110
Landrace	4	13775479.	3443870.	22.52	<.001
Time	8	72397553.	9049694.	59.18	<.001
Temperature.Landrace	8	5650091.	706261.	4.62	<.001
Temperature.Time	16	15573448.	973340.	6.37	<.001
Landrace.Time	32	15104635.	472020.	3.09	<.001
Temperature.Landrace.Time	64	10733815.	167716.	1.10	0.296
Residual	402	61470663.	152912.		
Total	539	198799508.			

E.Variate: Fresh_corm_weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	12558.	4186.	0.28	
Replication.*Units* stratum					
Temperature	2	100121.	50061.	3.38	0.044
Landrace	4	86861.	21715.	1.47	0.230
Temperature.Landrace	8	63711.	7964.	0.54	0.821
Residual	42	622005.	14810.		
Total	59	885257.			

F.Variate: Number_of_corms

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	203.24	67.75	1.99	
Replication.*Units* stratum					
Temperature	2	23.85	11.92	0.35	0.707
Landrace	4	2962.65	740.66	21.71	<.001
Temperature.Landrace	8	121.89	15.24	0.45	0.886
Residual	42	1432.81	34.11		
Total	59	4744.43			

APPENDIX 4.2 Analysis of variance of starch and mineral content of taro

A. Variate: Starch

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	1083.7	361.2	1.79	
Replication.*Units* stratum					
Temperature	2	1806.0	903.0	4.48	0.017
Landrace	4	2501.3	625.3	3.11	0.025
Temperature.Landrace	8	5995.5	749.4	3.72	0.002
Residual	42	8457.6	201.4		
Total	59	19844.1			

B. Variate: Carbon

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	9.727	3.242	2.08	
Replication.*Units* stratum					
Temperature	2	15.557	7.778	4.98	0.011
Landrace	4	4.415	1.104	0.71	0.592
Temperature.Landrace	8	19.361	2.420	1.55	0.170
Residual	42	65.606	1.562		
Total	59	114.665			

C. Variate: Sulphur

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.0011267	0.0003756	0.63	
Replication.*Units* stratum					
Temperature	2	0.1880033	0.0940017	156.84	<.001
Landrace	4	0.0100400	0.0025100	4.19	0.006
Temperature.Landrace	8	0.0241300	0.0030163	5.03	<.001
Residual	42	0.0251733	0.0005994		
Total	59	0.2484733			

D. Variate: Nitrogen

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.11750	0.03917	0.41	
Replication.*Units* stratum					
Temperature	2	22.98541	11.49270	120.90	<.001
Landrace	4	2.90204	0.72551	7.63	<.001
Temperature.Landrace	8	3.29791	0.41224	4.34	<.001
Residual	42	3.99263	0.09506		
Total	59	33.29548			

E. Variate: Calcium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.030538	0.010179	1.14	
Replication.*Units* stratum					
Temperature	2	0.285310	0.142655	15.95	<.001
Landrace	4	0.471677	0.117919	13.18	<.001
Temperature.Landrace	8	0.268023	0.033503	3.74	0.002
Residual	42	0.375737	0.008946		
Total	59	1.431285			

F. Variate: Magnesium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.0029667	0.0009889	1.06	
Replication.*Units* stratum					
Temperature	2	0.0902233	0.0451117	48.35	<.001
Landrace	4	0.0603333	0.0150833	16.17	<.001
Temperature.Landrace	8	0.0539267	0.0067408	7.23	<.001
Residual	42	0.0391833	0.0009329		
Total	59	0.2466333			

G. Variate: Potassium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.0640	0.0213	0.14	
Replication.*Units* stratum					
Temperature	2	2.4634	1.2317	8.25	<.001
Landrace	4	1.2891	0.3223	2.16	0.090
Temperature.Landrace	8	3.0912	0.3864	2.59	0.021
Residual	42	6.2691	0.1493		
Total	59	13.1768			

H. Variate: Sodium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	402384.	134128.	1.20	
Replication.*Units* stratum					
Temperature	2	719093.	359546.	3.22	0.050
Landrace	4	906879.	226720.	2.03	0.108
Temperature.Landrace	8	2727085.	340886.	3.05	0.009
Residual	42	4696950.	111832.		
Total	59	9452390.			

I. Variate: Zinc

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	22895.	7632.	2.11	
Replication.*Units* stratum					
Temperature	2	60990.	30495.	8.41	<.001
Landrace	4	212190.	53048.	14.63	<.001
Temperature.Landrace	8	63758.	7970.	2.20	0.047
Residual	42	152246.	3625.		
Total	59	512080.			

J. Variate: Copper

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	4.418	1.473	0.25	
Replication.*Units* stratum					
Temperature	2	318.582	159.291	27.26	<.001
Landrace	4	192.871	48.218	8.25	<.001
Temperature.Landrace	8	271.244	33.906	5.80	<.001
Residual	42	245.435	5.844		
Total	59	1032.550			

K. Variate: Manganese

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	180.33	60.11	2.93	
Replication.*Units* stratum					
Temperature	2	872.03	436.02	21.26	<.001
Landrace	4	258.67	64.67	3.15	0.024
Temperature.Landrace	8	514.13	64.27	3.13	0.007
Residual	42	861.17	20.50		
Total	59	2686.33			

L. Variate: Iron

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	363.40	121.13	2.03	
Replication.*Units* stratum					
Temperature	2	6081.42	3040.71	51.02	<.001
Landrace	4	2763.28	690.82	11.59	<.001
Temperature.Landrace	8	1582.95	197.87	3.32	0.005
Residual	42	2503.36	59.60		
Total	59	13294.41			

M. Variate: Phosphorus

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.059073	0.019691	2.44	
Replication.*Units* stratum					
Temperature	2	1.516000	0.758000	94.02	<.001
Landrace	4	0.365550	0.091387	11.33	<.001
Temperature.Landrace	8	0.517250	0.064656	8.02	<.001
Residual	42	0.338627	0.008063		
Total	59	2.796500			

N. Variate: Aluminium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	1860.	620.	0.57	
Replication.*Units* stratum					
Temperature	2	5610.	2805.	2.58	0.088
Landrace	4	5216.	1304.	1.20	0.325
Temperature.Landrace	8	7254.	907.	0.83	0.578
Residual	42	45659.	1087.		
Total	59	65599.			

APPENDIX 5.1 Plan of experimental field trial showing plot numbers [1, 2, …48], taro landraces [Dumbe-dumbe (D), Mgingqeni (M), Pitshi (P) and Dumbe-lomfula (R)] and replications [r_1, r_2, r_3 and r_4]

1 Dr_1	2 Mr_1	3 Pr_1	4 Dr_2	5 Pr_2	6 Mr_2	7 Rr_1	8 Dr_3	
0.5m								**BLOCK 1**
9 Rr_2	10 Rr_3	11 Mr_3	12 Pr_3	13 Rr_4	14 Dr_4	15 Mr_4	16 Pr_4	
17 Pr_1	18 Mr_1	19 Dr_1	20 Mr_2	21 Pr_2	22 Rr_1	23 Pr_3	24 Dr_2	
								BLOCK 2
25 Mr_3	26 Dr_3	27 Mr_4	28 Pr_4	29 Rr_2	30 Pr_5	31 Rr_3	32 Pr_6	
33 Rr_1	34 Pr_1	35 Rr_2	36 Rr_3	37 Dr_1	38 Mr_1	39 Mr_2	40 Rr_4	
								BLOCK 3
41 Dr_2	42 Rr_5	43 Pr_2	44 Dr_3	45 Mr_3	46 Dr_4	46 Dr_4	48 Mr_4	

Subplot size = 1.5 m X 1.5 m; Inter-row spacing = 0.5 m; Intra-row spacing = 0.5 m; Spacing between blocks = 0.5 m; Planted 16 plants $plot^{-1}$ and data taken from 4 inner most plants.

APPENDIX 5.2 Analysis of variance of seedling emergence, plant growth and yield.

A. (a) Variate: Seedling emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	2844.3	948.1	2.56	
Block stratum	2	3898.2	1949.1	5.27	
Replication.Block.*Units* stratum					
Site	1	684.5	684.5	1.85	0.175
Landrace	3	53105.8	17701.9	47.89	<.001
Time	2	32145.6	16072.8	43.48	<.001
Site.Landrace	3	8650.9	2883.6	7.80	<.001
Site.Time	2	5993.8	2996.9	8.11	<.001
Landrace.Time	6	5917.7	986.3	2.67	0.016
Site.Landrace.Time	6	3361.0	560.2	1.52	0.173
Residual	259	95738.0	369.6		
Total	287	212339.8			

A. (b) Variate: Final emergence percentage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	819.8	273.2	0.94	
Block stratum	2	743.3	371.7	1.28	
Replication.Block.*Units* stratum					
Site	1	96.0	96.0	0.33	0.566
Landrace	3	8589.4	2863.1	9.89	<.001
Site.Landrace	3	4298.6	1432.9	4.95	0.003
Residual	83	24036.9	289.6		
Total	95	38584.0			

B. Variate: Leaf_number

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	7.732	2.577	0.60	
Block stratum	2	14.021	7.011	1.64	
Replication.Block.*Units* stratum					
Site	1	64.588	64.588	15.13	<.001
Landrace	3	298.845	99.615	23.34	<.001
Time	6	2264.462	377.410	88.44	<.001
Site.Landrace	3	145.580	48.527	11.37	<.001
Site.Time	5(1)	737.737	147.547	34.57	<.001
Landrace.Time	18	208.395	11.577	2.71	<.001
Site.Landrace.Time	15(3)	210.327	14.022	3.29	<.001
Residual	543(68)	2317.283	4.268		
Total	599(72)	5871.300			

C. Variate: Plant_height

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	1153.5	384.5	3.36	
Block stratum	2	2420.4	1210.2	10.59	
Replication.Block.*Units* stratum					
Site	1	417.4	417.4	3.65	0.057
Landrace	3	85835.8	28611.9	250.31	<.001
Time	6	129946.9	21657.8	189.47	<.001
Site.Landrace	3	8182.8	2727.6	23.86	<.001
Site.Time	5(1)	2617.5	523.5	4.58	<.001
Landrace.Time	18	14505.5	805.9	7.05	<.001
Site.Landrace.Time	15(3)	4631.6	308.8	2.70	<.001
Residual	550(61)	62867.5	114.3		
Total	606(65)	288197.9			

D.Variate: Leaf_area

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	803453.	267818.	0.73	
Block stratum	2	51609.	25805.	0.07	
Replication.Block.*Units* stratum					
Site	1	13645091.	13645091.	37.22	<.001
Landrace	3	138383226.	46127742.	125.83	<.001
Time	6	209260608.	34876768.	95.14	<.001
Site.Landrace	3	22061138.	7353713.	20.06	<.001
Site.Time	5(1)	5422945.	1084589.	2.96	0.012
Landrace.Time	18	33599832.	1866657.	5.09	<.001
Site.Landrace.Time	15(3)	4597944.	306530.	0.84	0.637
Residual	543(68)	199057996.	366589.		
Total	599(72)	584543072.			

E.Variate: Fresh_corm_weight

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	144642.	48214.	0.27	
Block stratum	2	320096.	160048.	0.91	
Replication.Block.*Units* stratum					
Site	1	806380.	806380.	4.56	0.036
Landrace	3	798266.	266089.	1.51	0.220
Site.Landrace	3	1175764.	391921.	2.22	0.093
Residual	77(6)	13610937.	176765.		
Total	89(6)	16594853.			

F.Variate: Number_of_corms

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	706.1	235.4	0.89	
Block stratum	2	87.2	43.6	0.16	
Replication.Block.*Units* stratum					
Site	1	128.3	128.3	0.48	0.488
Landrace	3	33106.2	11035.4	41.69	<.001
Site.Landrace	3	852.8	284.3	1.07	0.365
Residual	77(6)	20380.2	264.7		
Total	89(6)	53484.5			

APPENDIX 5.3 Analysis of variance of starch and mineral content of taro

A.Variate: Starch

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	180.8	60.3	0.20	
Block stratum	2	836.9	418.5	1.37	
Replication.Block.*Units* stratum					
Site	1	1666.8	1666.8	5.47	0.022
Landrace	3	6105.5	2035.2	6.68	<.001
Site.Landrace	3	2682.6	894.2	2.94	0.039
Residual	76(7)	23152.7	304.6		
Total	88(7)	33436.2			

B.Variate: Carbon

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	5.5986	1.8662	2.21	
Block stratum	2	1.0321	0.5160	0.61	
Replication.Block.*Units* stratum					
Site	1	14.6204	14.6204	17.30	<.001
Landrace	3	7.1620	2.3873	2.83	0.044
Site.Landrace	3	0.6308	0.2103	0.25	0.862
Residual	76(7)	64.2185	0.8450		
Total	88(7)	92.0238			

C.Variate: Sulphur

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.0005407	0.0001802	0.70	
Block stratum	2	0.0021149	0.0010574	4.11	
Replication.Block.*Units* stratum					
Site	1	0.0235779	0.0235779	91.68	<.001
Landrace	3	0.0003311	0.0001104	0.43	0.733
Site.Landrace	3	0.0017721	0.0005907	2.30	0.084
Residual	76(7)	0.0195462	0.0002572		
Total	88(7)	0.0466022			

D.Variate: Nitrogen

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.9140	0.3047	1.81	
Block stratum	2	1.2542	0.6271	3.72	
Replication.Block.*Units* stratum					
Site	1	16.6824	16.6824	99.06	<.001
Landrace	3	7.7183	2.5728	15.28	<.001
Site.Landrace	3	1.8193	0.6064	3.60	0.017
Residual	76(7)	12.7986	0.1684		
Total	88(7)	40.6744			

E.Variate: Calcium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.017556	0.005852	0.88	
Block stratum	2	0.080462	0.040231	6.07	
Replication.Block.*Units* stratum					
Site	1	0.015057	0.015057	2.27	0.136
Landrace	3	2.089256	0.696419	105.12	<.001
Site.Landrace	3	0.035760	0.011920	1.80	0.154
Residual	76(7)	0.503512	0.006625		
Total	88(7)	2.674112			

F.Variate: Magnesium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.009911	0.003304	2.82	
Block stratum	2	0.008417	0.004208	3.60	
Replication.Block.*Units* stratum					
Site	1	0.035511	0.035511	30.34	<.001
Landrace	3	0.283935	0.094645	80.87	<.001
Site.Landrace	3	0.035826	0.011942	10.20	<.001
Residual	76(7)	0.088945	0.001170		
Total	88(7)	0.455575			

G.Variate: Potassium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	1.0049	0.3350	2.95	
Block stratum	2	0.1013	0.0506	0.45	
Replication.Block.*Units* stratum					
Site	1	0.9900	0.9900	8.72	0.004
Landrace	3	0.7127	0.2376	2.09	0.108
Site.Landrace	3	0.3199	0.1066	0.94	0.426
Residual	76(7)	8.6251	0.1135		
Total	88(7)	11.5153			

H.Variate: Sodium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	1477873.	492624.	9.43	
Block stratum	2	10140.	5070.	0.10	
Replication.Block.*Units* stratum					
Site	1	596603.	596603.	11.42	0.001
Landrace	3	40548.	13516.	0.26	0.855
Site.Landrace	3	11760.	3920.	0.08	0.973
Residual	76(7)	3970073.	52238.		
Total	88(7)	5936229.			

I.Variate: Zinc

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	10642.4	3547.5	3.76	
Block stratum	2	3850.2	1925.1	2.04	
Replication.Block.*Units* stratum					
Site	1	74914.9	74914.9	79.33	<.001
Landrace	3	152001.3	50667.1	53.65	<.001
Site.Landrace	3	97076.7	32358.9	34.27	<.001
Residual	76(7)	71768.1	944.3		
Total	88(7)	406778.5			

J.Variate: Copper

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	46.160	15.387	2.22	
Block stratum	2	79.402	39.701	5.72	
Replication.Block.*Units* stratum					
Site	1	394.959	394.959	56.86	<.001
Landrace	3	1042.080	347.360	50.01	<.001
Site.Landrace	3	167.052	55.684	8.02	<.001
Residual	76(7)	527.869	6.946		
Total	88(7)	2240.596			

K.Variate: Manganese

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	23298.	7766.	1.78	
Block stratum	2	19106.	9553.	2.19	
Replication.Block.*Units* stratum					
Site	1	141727.	141727.	32.46	<.001
Landrace	3	244727.	81576.	18.68	<.001
Site.Landrace	3	181422.	60474.	13.85	<.001
Residual	76(7)	331833.	4366.		
Total	88(7)	934366.			

L.Variate: Iron

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	3010.5	1003.5	1.10	
Block stratum	2	169.1	84.5	0.09	
Replication.Block.*Units* stratum					
Site	1	1772.3	1772.3	1.95	0.167
Landrace	3	8969.8	2989.9	3.29	0.025
Site.Landrace	3	2214.2	738.1	0.81	0.492
Residual	76(7)	69136.2	909.7		
Total	88(7)	84492.1			

M.Variate: Phosphorus

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	0.027238	0.009079	2.64	
Block stratum	2	0.050700	0.025350	7.38	
Replication.Block.*Units* stratum					
Site	1	0.095577	0.095577	27.82	<.001
Landrace	3	0.166673	0.055558	16.17	<.001
Site.Landrace	3	0.117088	0.039029	11.36	<.001
Residual	76(7)	0.261118	0.003436		
Total	88(7)	0.701112			

N.Variate: Aluminium

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	3960.8	1320.3	4.86	
Block stratum	2	272.9	136.5	0.50	
Replication.Block.*Units* stratum					
Site	1	1059.3	1059.3	3.90	0.052
Landrace	3	2407.4	802.5	2.95	0.038
Site.Landrace	3	1374.6	458.2	1.69	0.177
Residual	76(7)	20648.5	271.7		
Total	88(7)	28860.4			