AGRONOMIC CHARACTERIZATION AND EVALUATION OF PIGEON PEA LANDRACES IN KWAZULU-NATAL PROVINCE OF SOUTH AFRICA

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DECLARATION

I, Lindah London Hluyako, certify that the material reported in this thesis represents my original work, except where acknowledged. I further declare that these results have not otherwise been submitted in any form for any degree or diploma to any university. The work does not contain any other people's information or data such as graphs, tables and pictures unless acknowledged to be found or sourced from other researchers.

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This thesis is dedicated to my late parents, Mariah Betty Shabangu-Hluyako and Zwelonke Lucas Hluyako.

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GENERAL ABSTRACT

Pigeon pea (*Cajanus cajan* [L] Millsp.) is multipurpose legume crop that provides food fodder and wood for small- scale farmers. However, it remains one of the underutilised crops with limited research needed for the crop diversification and adaptation. The problem is that in most countries where the crop has been cultivated yields low due to drought, pests and diseases as well as low seed quality, therefore research on the crop in South Africa especially in KwaZulu-Natal have not been done. The study focused on agronomic characterization of pigeon pea landraces in rain-fed conditions of KwaZulu-Natal province as pigeon pea is a crop with potential to eliminate protein malnutrition and contribute to food security in Sub-Saharan Africa.

Seeds of six pigeon pea landraces were collected from Hluhluwe in KwaZulu-Natal, South Africa and characterised in cream white, dark brown, white with black, cream white with brown, light brown with brown and light brown landrace. The study was conducted in Makhathini Research Station in Jozini, KwaZulu-Natal and Newlands East Permaculture Centre in Durban where six landraces of pigeon pea were planted in each site in 4 rows of 4 m^2 plot is 50 cm rows apart spaced at 30 cm. The experimental design used was randomised complete block design with 18 plots of 4 m^2. The parameters measured were standard seed germination, seed emergence, plant height, leaf Area Index, chlorophyll content index, days to 50% flowering, days to 75% physiological maturity and yield and yield components which were pod mass per plant, pods per plant, seeds per pod, grain yield per hectare, above ground biomass and harvest index.

Results of chapter 3 showed significant differences at ($P < 0.05$) and the highest germination percentage was achieved by light brown with brown with 100 % germination. There were also significant differences among the landraces with respect to leaf area index in Makhathini Research Station, days to 50% flowering and days to 75% physiological maturity. Significant differences were also observed among landraces in terms of yield and yield components which included 100 seed weight and seeds per pod. There were no much differences in morphological characters of the crop such as leaf colour, stem colour, flower colour, streak pattern, pod colour,

growth habit and flowering pattern. Cream white took maximum days to 50 % flowering in Makhathini which was 165 days, and 208 days to reach 75 % physiological maturity while the same landrace took 201 days to 50 % flowering in Newlands which was also the maximum days to reach flowering.

Results of principal component analysis (PCA) in chapter 4 showed that Makhathini Research Station was defined by time to 50 % flowering, plant height at week 20, chlorophyll content, leaf area index, yield and yield components (pod mass, harvest index and grain yield) and Newlands was defined by fixed nitrogen at vegetative and flowering stage as well as seed emergence. Results revealed that the yield was related to two parameters which were harvest index and pod mass in Makhathini Research Station. Grain yield in tons per ha was also significant positive correlated with pod mass (0.84) and harvest index (0.76). Correlation results also revealed that biomass was the major influence to fixed nitrogen at maturity (0.86). Negative correlations also existed between germination percentage and seeds per pod (-0.52), seed emergence and harvest index (-0.50). Significant negative correlation also existed between harvest index and biomass (-0.76).

The results for the two analyses (principal component analysis and correlation coefficient) clearly indicated that grain yield was influenced or contributed by pod mass and harvest index in Makhathini Research Station and pod mass and harvest index should be considered as parameters for selecting high yielding pigeon pea landraces. In conclusion, the agronomic characterisation of the crop will be useful in selecting traits which are important and enhance the yield of landraces through breeding programs and may be beneficial to farmers on pigeon pea growing conditions and cultivation practices as well as selecting landrace based on its performance.

CHAPTER 1: GENERAL INTRODUCTION

1.1. Introduction

Nutrition is an important basic need for human health (Vadivel and Janardhanan, 2005). However, according to the Global Food Security index (2012), countries in the Sub-Saharan Africa and South East Asia are the most food and nutrient insecure. This indicates that food and nutrition security is still an unfilled dream in the region including South Africa. In South Africa, 2.8 million households with an estimation of 11.5 million people are vulnerable to food and nutrient insecurities. Statistics shows that about 72 % of those vulnerable to food insecurity are predominantly poor people (DAFF, 2012; Fanzo, 2012). The national food security policy released in 2002 has a vision for South Africa, where everyone has a right to sufficient, safe and nutritious food (Department of Agriculture, 2002).

In recent years, there has been a continuous and increasing demand for nutritional foods rich in proteins, vitamins and essential minerals. This demand has put too much pressure on animal foods as sources of proteins. The high demand for proteins has spurred the need for alternative sources including pulses, because a nutritious and varied diet is a critical means by which good human health can be maintained. As a result, several underutilised crops with the potential to reduce food insecurity have been introduced in South Africa (Akibode and Maredia, 2011; Modi, 2013).

Pigeon pea (*Cajanus cajan* [L] Millsp.) is among beneficial crops introduced to South African agriculture which can be used to diversify legume base of the country. With an average of 21.5% protein on dry weight basis, pigeon pea is a major source of protein to about 20% of the world population (Odeny, 2006; Matthews and Saxena, 2010). The crop is also rich in carbohydrates and useful mineral elements such as calcium, phosphorus and magnesium (Morake et al., 2000). Therefore, pigeon pea has been identified as a possible substitute crop which can be bought by all people and provide an acceptable amount of nutrition and protein in particular because it is not expensive source of protein than animal protein. However, pigeon pea is an underutilised introduced crop species in South Africa that has not been developed to full potential in the country. The crop originated in India (Ladizinsky and Hamel, 1979) and is grown in over 4 million hectares in tropical and sub-tropical areas of the world (Matthews and

Saxena, 2000). India is still the largest producer with 3 million tons of pigeon peas produced per annum, which is equivalent to 70% of the world total production.

Although the crop has been introduced successfully in Southern Africa, very low yields have been identified as a major problem for its production in the region (Snapp, 2003). Compared to the average yield potential of between 1.5 and 2.5 tons per hectare observed in India, Khakhi (2014) found that in Uganda the production of the crop is as low as 0.45 tons per hectare. Similarly, in Kenya, Makelo (2011) reported that pigeon pea landraces produced an average of 0.40 tons per hectare. In Nigeria, Egbe and Vange (2008) reported an average pigeon pea yield of 0.7 tons per hectare for four consecutive years, since 2004.

In South Africa, the crop is not a field crop but is mainly planted in home gardens mostly in Limpopo, Mpumalanga and KwaZulu-Natal. A report by Department of Agriculture and Land Administration in Mpumalanga (2003) stated that pigeon pea in this region yields according to its duration type where extra-short, short, medium and long duration yielded 1.83, 1.91, 1.69 and 1.35 tons per hectare, respectively. A study conducted by Gwata and Shimelis (2013) revealed that an average yield of 0.5 and 1.01 tons per hectare obtained for different landraces is still low when compared cultivated varieties in Malawi, with 2.7 to 3 tons per hectare.

Low yields of pigeon pea in Sub-Saharan Africa have been attributed to climate and environmental conditions which are different from India which is the country of origin. In India the crop is planted in low latitude between 14 °N and 28 °N than in Southern Africa with 30 °N and 35 °N (Singh and Oswalt, 1992; Robertson et al., 2001). This makes pigeon pea difficult to adapt to Sub-Saharan Africa which is characterised by high latitude than in India. The differences in latitude affect growth variables such as plant height, biomass, phenology and grain yield. This is because pigeon pea is highly sensitive to photoperiod (Gwata and Siambi, 2009). The crop is mostly planted in areas receiving a mean annual rainfall of 600 to 1400 mm in India (Sadarna et al., 2010) which is higher than the annual rainfall of 400 to 750 mm occurring in South Africa (DAFF, 2009). The temperature required for cultivation of pigeon pea in India is 26 to 30 °C during the rainy season between June to October and 17 to 22 °C during November to March season (Sadarna et al., 2010). In South Africa, the crop is planted in areas with temperatures ranging between 18 to 29 °C (DAFF, 2009). The rainfall and temperature differences between South Africa and India may explain the differences in yields reported earlier. Poor production practices such as low plant densities, low soil fertility and insufficient weeding are other constraints contributing to low pigeon pea yields because no known practices have been developed in Southern Africa. Low yields are also a result of pests, diseases, low soil fertility, drought and lack of quality seeds (Odeny, 2006). The crop is mostly grown from landraces by small scale farmers in South Africa also contributing to reduced yields.

Although pigeon pea can adapt well under drought conditions there is a great variability of different genotypes for yield under the drought conditions (Deshmukh and Mate, 2013). Pigeon pea yields are decreased by pests and diseases. Insect pests such as pod boring Lepidoptera and pod sucking bugs reduce yields by more than 10% (Mutegi and Zingore, 2012). Fusarium wilt, sterility mosaic disease, leaf spot and powdery mildew are diseases of economic concern in relation to pigeon pea production (Makelo, 2011). Most soils are poor in Africa which are often acidic, with low nitrogen, phosphorus and potassium content (Mutegi and Zingore, 2012). Low soil fertility, soils with poor water holding capacity and easily erodible soils are contributing to low productivity and food insecurity in Southern and Eastern Africa (Njira et al., 2013; Odeny, 2006). Most of the work on pigeon pea research has been on crop potential yield and adaptation has been mostly done in India. Those studies helped in identifying high yielding and low yielding genotypes are modified through breeding in India and very limited results report work from African countries. Although significant amount of research has been reported on the crop around the world, there has been no published research on agronomic characterisation of pigeon pea in South Africa, especially in KwaZulu-Natal.

The crop is grown by smallholder farmers in many countries in Eastern and Southern Africa including Kenya, Malawi, Mozambique and Tanzania, where it is intercropped with maize, sorghum or cassava. In these cropping systems farmers grow traditional, long duration landraces which takes 9 to 10 months to mature with grain yields of 0.4 tons per ha. The problem of low yield in the region affects small-holder farmers who grow the crop to produce food with limited resources (Saxena et al., 2010). Farmers are reluctant to invest in the crop by buying fertilisers because they have limited resources and the return may be uncertain due to the risks in environments under which they grow the crop. As a result, resource-poor small scale farmers end up growing genotypes which are susceptible to fungal diseases and low grain yield. Although new pigeon pea genotypes from breeding programmes have been developed in Southern Africa for improved yield, good grain quality and adaption to drought and low soil fertility, knowledge of agronomic and physiological performance under South African conditions is still lacking (Hogh-Jensen et al., 2007). The lack of agronomic and yield characteristics of pigeon pea genotypes in South Africa impacts the productivity of small scale farmers with limited resources. It also affects the poor rural people who cannot afford to buy animal proteins because animal protein is beyond the reach in some countries where their primary protein supply comes from plant-based products (Saxena et al., 2010).

One of the reasons for low yields in Southern Africa is because the crop originated wholly within the tropical latitudes in India, demonstrating a need to develop genotypes that can grow and yield better in areas outside the centre of origin. However, there is no information reporting performance and characterisation of different genotypes under climatic conditions of KwaZulu-Natal. This warrants the need for research towards understanding agronomic and physiological responses of pigeon pea landraces under climatic zones of the province. The study will characterise the different pigeon pea landraces grown in the two sites with a goal of identifying the best genotype in terms of agronomic and yield characteristics. Understanding the cause of genotype by environment interactions is important in selecting genotypes with the best adaptation and that can give stable yields. Those landraces will be recommended to farmers and the agronomic characteristic will be used to assist breeders in identifying useful traits in order to create desired genotype (progeny) which yield better, resistant to diseases and pests as well as to drought and which adapts well and give stable yield under unfavourable conditions. The agronomic characterisation of the crop in the two experimental sites which is Jozini and Durban will aid farmers on basic crop production practises (adaptation and climate) of such crop in South Africa especially in KwaZulu-Natal conditions.

1.2. Aims and objectives

The overall aim of the study is to characterise agronomic performance of 6 pigeon pea landraces. The specific objective of the study is to compare agronomic (yield) performance of six pigeon pea landraces grown in two climatic zones of KwaZulu-Natal, South Africa.

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CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Legumes are nutritious foods which are a good substitute for animal proteins (Adebowale and Maliki, 2011). Dry beans, peas, soya beans, groundnuts, chick peas, pigeon peas, lintels, mung beans and cowpeas are among some of the most consumed legume crops in the world. Legumes are regarded as important supplements of cereal-based foods and cheap sources of proteins (Ramakrisna et al., 2006; Pratap and Kumar, 2011). With very high protein content, legumes are of high importance in eliminating protein malnutrition. Among other important characteristics, legume plants also have the ability to a symbiotic association with rhizobia which fix atmospheric nitrogen (N) into plant available N. Nitrogen fixation from this association reduces the use of synthesised nitrogen fertilisers (Apata and Ologhobo, 1993; Pratap and Kumar, 2011).

Pigeon pea (*Cajanus cajan* [L.] Millsp.) is among important legume crops in agricultural systems. The crop originated in India (Makelo, 2011) and is currently the sixth most important legume food crop in the world (Varshney, et al., 2011). The crop is mostly grown in India, Myammar, Nepal, Kenya, Malawi, Uganda and Tanzania (Swindale, 1987; Singh et al., 2005; Lin-Qi et al., 2014). Pigeon pea provides food and fuel to many people in the developing countries and is a good source of protein (Ishikawa et al., 2002; Egbe and Kalu, 2009). It has been cultivated for more than 3500 years in semi-arid and arid areas. This legume crop plays a significant role in ensuring nutritional food security and elimination of poverty among poor people in many countries of Asia and Africa (Lin-Qi et al., 2014). It has been regarded as one of the most important grain legumes due to its ability to withstand biotic and abiotic stresses in India (Singh et al., 2005). Despite the significance of pigeon pea in providing protein rich food in vegetarian diet, its productivity in many producing areas in Africa remained low. This is mainly due to several biotic and abiotic constraints the crop is exposed to in environments of Africa. Recent climatic change conditions are expected to make this situation worse in coming future (Varshney et al., 2011).

In the African continent, pigeon pea is mostly grown by small holder farmers for home consumption and to generate income by selling harvested grains in informal markets (Saxena et al., 2008). In Southern and Eastern Africa, pigeon pea is grown under rain-fed conditions with least inputs because it adapts well and give reasonable yields under droughty conditions and poor soils (Matthews and Saxena, 2000; Saxena et al., 2010). Pigeon pea is divided into four duration types which are extra-short, short, medium and long duration cultivars. Some of this pigeon pea types are sensitive to photoperiod (Gwata and Shimelis, 2013). This review is outlining the pigeon pea morphology, characterisation, types of pigeon pea based on duration and its adaption. It further explains the importance of the crop as well as suitable environment for adaption through discussion of environmental factors affecting the crop and its importance in food security.

2.2. Taxonomy of pigeon pea

Pigeon pea has many wild relatives belonging to six genera, including *Cajanus*, *Dunbaria*, *Flemingia*, *Paracalyx*, *Rhynchosia* and *Eriosema* (Lakshmi et al., 2000). All six genera are grouped under the sub-tribe Cajaninae of the tribe Phaseoleae and the family of the Leguminosae (Makelo, 2011). The first scientific name used for pigeon pea was *Abor trifolia indica*. The name was given by Bauhin and Cherla between 1650 and 1651 and binomial nomenclature to pigeon pea was given by Linnaeus Cajanus indicus (Smart, 1990). According to international rules of botanical classification of the crop, the name for pigeon pea was then concluded to be *Cajanus cajan* (Singh et al., 2005).

Pigeon pea is an annual shrub (Figure 2.1) that is usually 1 to 2 meters in height but can grow up to 5 meters tall (Mula and Saxena, 2010). Its stem is woody at the base with deep tap root system and its canopy is usually erect and branching (Singh and Oswalt, 1992; Singh et al., 2005). It has trifoliate leaves with oblong lanceolate leaflets (Figure 2.2) of about 5 to 10 cm long and 2 to 4 cm wide. Petioles are 2 to 3 mm while the stipules are 2 to 3 mm long. The flowers are usually yellow but may also be purple or red in colour (Figure 2.3). The corolla is about 20 to 25 mm with flag of 18 to 20 mm wide and the calyx is 10 to 12 mm long (Mula and Saxena, 2010).

Figure 2.1: Typical pigeon pea plants with pods (Saxena et al., 2010).

Figure 2.2: Leaf shape of typical pigeon pea plant (Reddy et al., 2012).

A B

Figure 2.3: Different flower colours of pigeon pea (A) red and (B) yellow (Mallikarjunaet al., 2011).

The pods are usually 5 to 9 cm long and 12 to 13 mm wide, flat and with red, green or brown colour (Figure 2.4) with 2 to 9 seeds in it (Mula and Saxena, 2010). The husks bear deep oblique furrows underlining the septa between the seeds (Singh et al., 2005). The crop has a life span of up to 5 years and its reproduction is 60% autogamous and mostly diploid with some tetraploid. The pods of most pigeon pea plants are oblong, straight or sickle-shaped. Most seeds are oval with purple, black and brown colour (Baryeh and Mangope, 2002).

A B

Figure 2.4: Green (A) and red (B) vegetable type of pigeon pea pods (Saxena et al., 2010).

The development of lateral roots occurs as soon as the primary leaves begin to unfold. The roots continue to accumulate dry matter and produce laterals throughout the growth of plant until either harvested or killed by diseases. When conditions are favourable for the growth of the crop, the roots may grow to a depth of 3m. Tall varieties produce longer and deeper penetrating roots whereas spreading types produce more spreading and dense root systems (Singh et al., 2005). The deep root system allows extraction of moisture from deep layers of the soil and makes the crop to produce more biomass (Odeny, 2006). The deep root system allows the crop to grow well under semi-arid conditions with 635mm annual rainfall (Baryeh and Mangope, 2002).

2.3. Uses of pigeon pea

2.3.1. Nutrition

The most important usage of pigeon pea in Eastern Africa, Southern Africa, Latin America and Asia is for human consumption (Reddy, 2001). Nutritionally, pigeon pea contains more minerals, ten times more fat, five times more vitamin A and three times more vitamin C than ordinary peas and other food legumes such as cowpea and chickpea (Makelo, 2011). It is also a good source of vitamins B and carbohydrates (Duhan et al., 2002). The crop also contains amino acids which form 1% of cotyledons and embryo of pigeon pea as shown in Table 2.1 (Saxena et al., 2008). Major minerals in pigeon pea are calcium, potassium, Magnesium, sodium and zinc (Morake et al., 2000). Protein content of the pigeon pea grain ranges between 18 and 26% with some wild types having protein content of 30% and above (Makelo, 2011).

When the crop is used as source of food, the grains are cooked without removing the seed coat, which takes long time (3 to 4 hours) to cook (Matthews and Saxena, 2000). In some instances, the seed coat is removed to quicken the cooking process (Matthews and Saxena, 2000). The reason for slow cooking is because the seed coat is rich in fibre and thicker than most of legumes seed coat with very low digestibility (Fasoyiro et al., 2005). The seed coat also has anti-nutritional factors such as phytates, oxalates and saponins which make important nutritional parameters unavailable for absorption by human body (Adebowale and Maliki, 2011).

Table 2.1: Nutrients content of mature pigeon pea seed (Saxena et al., 2008).

Constituent	Whole seed	Cotyledons	Embryo	Seed coat
Carbohydrates (%)	64.2	66.7	31.0	58.7
Protein (%)	20.5	22.2	49.6	4.9
Fat (%)	3.8	4.4	13.5	0.3
Fibre (%)	5.0	0.4	1.4	31.9
Ash (%)	4.2	4.2	6.0	3.5
Lysine[1]	6.8	7.1	7.0	3.9
Threonine[1]	3.8	4.3	4.7	2.5
Methionine[1]	1.0	1.2	1.4	0.7
Cystine[1]	1.2	1.3	1.7	-
Calcium[2]	296	176	400	917
Iron[2]	6.7	6.1	13.0	9.5
Thiamine[2]	0.6	0.4	-	-
Riboflavin[2]	0.2	0.3	-	-
Niacin[2]	3.1	2.2	-	-

1: g 100^{-1} g protein

2: mg 100^{-1}g dry matter

A B

Figure 2.5: Collection of (A) brown pigeon pea seeds and (B) red vegetable type pigeon pea seeds (Saxena et al., 2010).

2.3.2. Animal feed or fodder

Indian farmers have used pigeon pea plants as animal feed for more than 100 years where after crop harvest, vegetative plant material is left in the field for grazing (Roder et al., 2008). Dry pigeon pea leaves are used as fodder and the threshing from crop used as feed for dairy cattle (Matthews and Saxena, 2000). About 9% of available by-products from the seed is consumed as animal and poultry feed (Joshi et al., 2001). According to Makelo (2011) the fodder of the crop has been an important factor in increasing weight of animals consuming the fodder.

2.3.3. Conservation and fuel use

Pigeon pea improves soil quality and fertility when used as green manure which can substitute the use of 40 kg nitrogen fertilisers per ha in the soil. Pigeon pea is capable of bringing minerals from deeper soil horizons to the soil surface and improving soil aeration (Makelo, 2011). The plant stems are used as firewood for cooking, roof thatching and making baskets (Agyare et al., 2002). Dry stems of pigeon pea are an important source of fuel in rural India and produces about 10 to 12 tons per ha of dry woods (Matthews and Saxena, 2000; Joshi et al., 2001).

2.3.4. Medicinal value

Pigeon pea flowers are used for treating bronchitis, coughs and pneumonia (Saxena et al., 2010). Pigeon pea seeds and grains are used to treat disorders of the skin, liver, lungs and kidney (Matthews and Saxena, 2000). Pigeon pea flowers are also boiled for treating upper respiratory infections and pain (Saxena et al., 2010). Fresh seeds are believed to help problems of urinary systems in males while immature seeds are recommended for treatment of kidney problems (Saxena et al., 2010).

2.4. Characterisation of pigeon pea genotypes

Pigeon pea can be classified as cultivars, varieties, genotypes and landraces. Landrace is defined as local variety with an ability to withstand biotic and abiotic factors which results in high yield and intermediate yield levels under low inputs (Sinefu, 2011). It is also defined as a mixture of genotypes with high diverse population (Sinefu, 2011). Characterisation of pigeon pea landraces can be divided into four categories which are morphological, botanical, agronomical and biochemical characters (Syamuyoba, 2002). Selection of useful traits is important in achieving the breeding objective whereby some research has been conducted to characterise genotypes and inbred lines of the pigeon pea and provide basic information for breeding of such crop (Olawuyi et al., 2003). According to Khaki et al. (2012), characterization of germplasm is one of the trustworthy ways of uncovering genetic variations in traits that influence yield and resistance to pest and diseases. Agronomical characterisation gives information on traits of a certain genotype. It is also defined as the scoring of characters that can be easily detected and have high hereditability (Syamuyoba, 2002).

Khaki et al. (2012) also stated that, agronomical characterisation aims at evaluating and comparing agronomic performance. Some research on collection and characterization has been done in Malawi and Uganda where 54 pigeon pea landraces were evaluated for flowering and maturity as well as crop yield analysis. Agronomic evaluation of pigeon pea landraces aid in knowing the adaptation of the crop in different agro-ecological area it is used to classify the crop into four duration types which are extra early, early, medium and late duration (Manyasa et al., 2009). According to Hamid et al. (2011), the agronomical characterization also aims at exploring and fitting the genotypes in intercropping system in Bangladesh where 23 genotypes were intercropped with rice. Some genotypes adapted but yielded low only short duration had high yield in those conditions.

2.5. Classification of pigeon pea duration types

Maturity duration is a very important factor that determines adaptation of varieties to different agro-climatic areas and cropping systems (Matthews and Saxena, 2000). Field duration of pigeon pea is controlled by temperature and sensitivity to photoperiod (Orr et al., 2013). Pigeon peas have been classified into four major duration groups as shown in Table 2.2 below.

Table 2.2: Duration types of pigeon pea and their maturity days (Matthews and Saxena, 2000).

Duration group	Approximate days to maturity
1. Extra-short-duration (XSD)	<100 days
2. Short-duration (SD)	100-150
3. Medium-duration (MD)	151-180
4. Long-duration (LD)	>180

2.5.1. Extra-short-duration

Extra short duration pigeon pea is the type of pigeon pea which takes less than 100 days from planting to flowering. Its growth or maturity maybe delayed by cooler temperatures from 94 days at 23 °C to 175 days at 18 °C. Delayed maturity reduces yield of late season drought stress and interferes with planting another crop in a rotation system (Snapp, 2003). Research conducted by International Crops Research Institute for the Semi-arid Tropics (ICRISAT) found that extra-short duration pigeon pea showed little increase in yield with increase in population from 8 to 60 plants per m^2 in tropical environment in India. XSD pigeon pea types commonly have optimum population in subtropical environments and high biomass production (Dahiya et al., 2002). Although currently available XSD is always intercropped with rice and wheat (Snapp et al., 2003) or in crop rotation with wheat but the genotypes are usually characterised by low yield sensitivity due to drought and low temperatures (Dahiya et al., 2002). XSD duration pigeon pea genotypes such as ICPL 90011 developed by ICRISAT escape drought and are less sensitive to photoperiod than traditional varieties with longer growth cycles (Silim et al., 2007).

2.5.2. Short-duration

Short-duration varieties are photoperiod insensitive and can be grown in frost-free areas (Matthews and Saxena, 2000). Flowering in SD genotypes is less sensitive to photoperiod and they can flower and mature in the short summer (Kimani, 2001). The SD group are more susceptible to pests and are mostly grown by commercial farmers with resources and production inputs because of its high maintenance (Joshi et al., 2001). In the last three decades, breeders have developed a large number of short duration, large seeded, high yielding types and disease resistant (Sharma et al., 2006). Short duration genotypes develop a smaller root system than long-duration genotypes (Singh and Oswalt, 1992).

2.5.3. Medium-duration

Medium-duration varieties are mostly intercropped and grown in areas with warm temperatures which are more often unsuitable for LD varieties. MD varieties maturity is delayed in areas away from the equator e.g. Malawi and Mozambique (Silim, 2000). Medium duration types are photoperiod sensitive and they always flower during short-day periods (Matthews and Saxena, 2000). Most of the MD varieties are indeterminate varieties which flower within 110 days and mature within 160 days (Jones, 2002). MD varieties have been developed through breeding and selection. Although these cultivars have shown good adaptation across different agro-ecological zones but they perform best at medium altitudes with 600 to 1500 m and with mean temperatures of 23 to 25 °C and rainfall of 400-1500 mm over two seasons (Snapp, 2003). There are now improved varieties of MD in India and Myanmar, Kenya, Northern Tanzania and Uganda on-farm trials where in some areas farmers are already growing them in their farms (Joshi et al., 2001).

2.5.4. Long-duration

Long duration varieties are mostly intercropped and grown in low-latitude and high-elevation areas near the equator but also in areas away from the equator provided they are warm temperatures are during the vegetative stage and cool during the reproductive stage (Silim, 2000). The LD varieties are also photoperiod sensitive and flower in short days (Matthews and Saxena, 2000). In short rain season areas, LD pigeon pea reserve soil moisture before the crop matures and in areas where there is little variation in temperature or day length and the crop will often not flower when it has reached 12 months or gone beyond that due to sudden change in temperature form warmer to cooler temperature (Jones, 2002). In areas which are 1400 m above sea level, insensitivity to cool temperature allows the crop to mature early (Silim, 2000).

2.6. Impact of pigeon pea on food security

Nutrition is a most important basic need, being a major determinant of health (Vadivel and Janardhanan, 2005). Protein malnutrition is an important nutritional problem in developing world (Butt and Batool, 2010) and it has spread among poor developing and under-developed countries since animal protein is expensive and their primary protein supply comes from plant-based products. Amongst these, pigeon pea is an important food legume that can be grown to eliminate the problem of protein malnutrition among poor people which is a problem in Sub-Saharan Africa (Saxena et al., 2010). Pigeon pea is rich in starch, protein, calcium, manganese, crude fibre, fat, trace elements and minerals (Saxena et al., 2010).

The crop has been recommended for a balanced diet with cereals especially to fill in the nutritional gap for proteins amongst the poor section in developing economies that cannot afford animal proteins. Various nutritional development programs are facing a challenge to meet protein demand and growing of pigeon pea both as annual crop or perennial plant in homestead or commercial can solve the issue of such protein malnutrition and food insecurity (Saxena et al., 2010). The challenge to farmers is that there is no commercial market where farmers can purchase improved pigeon pea seeds. Farmers save pigeon pea seeds for next planting season and some farmers buy grain from local market to use as seeds. This makes the production of pigeon pea seed challenging and consumption of such crop limited due to traditional cultivars with low yield and low quality (Snapp et al., 2003). In Africa, there have never been any government price controls on pigeon pea because the crop was never considered important for national food security (Jones, 2002). The intercropping of the crop with maize in Eastern and Southern Africa has proven to play an important role in high production, consumption and cash income in households (Hogh-Jensen et al., 2006).

2.7 Effect of environmental factors on pigeon pea

Pigeon pea is mostly cultivated in tropical and sub-tropical environments between 30 °N and 30 °S latitude (Jones, 2002; Sharma, 2008). It is a short-day plant whereby flowering is delayed by longer days (Botcha et al., 2013). The crop grows well in hot and dry environment (Jones, 2002). It grows well in an environment with rainfall ranging between 400 and 750 mm per annum and less than 600 mm annual rainfall in dry areas. Pigeon pea prefers moist conditions for the first two months and drier conditions during flowering and harvesting (DAFF, 2009).

Factors such as droughts and easily erodible soils with poor water holding capacity affect production of the crop (Odeny, 2006). Drought is one of the most important environmental constraints limiting crop productivity in the tropics. Most pigeon pea cultivars are drought-resistant and can give some grain yield during dry period, a rare phenomenon in many legumes. The ability of pigeon pea to withstand severe drought better than many legumes is due to its deep roots and osmotic adjustment in the leaves (Odeny, 2007).

The crop grows well in temperatures between 18 and 29 °C. The crop is very sensitive to waterlogging and frost (DAFF, 2009). The crop is grown in rainfall areas and in day length environment of 11 to 14 hours and large differences in temperature are noticed due to variations in different altitude and latitude (Silim et al., 2007). Environmental factors are also known to have an important influence on the rate of development from sowing to flowering depending on the month of planting (Warrington et al., 1985). The crop grows best in well-drained soils and will not survive waterlogged conditions in a pH range of 4.5 to 8.4 (Sheahan, 2012). Photoperiodic sensitivity is other constraint affecting pigeon pea production (Makelo, 2011). When the crop is grown in high latitude areas of more than 10° away from the equator it is sensitive to photoperiod and temperature. Plant height, vegetative biomass, phenology and grain yield are the crop parameters that are most affected by such condition. When a cultivar takes time to flower and mature it increases terminal drought which often occurs in Southern Africa (Gwata and Shimelis, 2013). The photoperiod and temperature effects on flowering and plant canopy development in pigeon pea make agronomists to choose cultivars that adapt and perform well to specific climatic conditions (Silim et al., 2005).

2.8. Nitrogen fixation

Nitrogen (N) is an important and essential plant nutrient for plant growth and development whereby its deficiency has become a problem in agriculture (Kahindi et al., 2008; Egbe and Anyam, 2011; Egbe et al., 2013). Pigeon pea has the ability to fix 235 kg/ha of N and produce more nitrogen per unit area from plant biomass than most of the legumes (Egbe and Anyam, 2011). Nitrogen fixation differs with duration types where by LD genotypes can fix up to 200 kg nitrogen per ha over a period of 40 weeks and early maturing varieties fix 40 kg nitrogen per ha and it is further reported by Murwa (2013) that leaf drop alone can contribute up to 40 g of nitrogen. According to Mapfumo et al. (1999) short duration pigeon pea fixes from 6 to 43 kg per ha and long duration from 18 to 183 kg per ha. Biological nitrogen fixation from nodule is very important for growth and yield of legumes and crop yield often remains low if the legumes do not have nodules in their roots (Dinh et al., 2013). Biological nitrogen fixation is also very important in sustaining crop productivity and reduces soil fertility problems (Kahindi et al., 2008).

Symbiotic association between a legume and rhizobia is essential for effective nitrate-fixation. N contribution from symbiotic Nitrate-fixation is important in Africa, whereby nitrogen is one of the most limiting nutrients for plant growth and crop yield (Murwa, 2013). Biological nitrogen fixation is important in intercropping system when nitrogen fertilizer is limited in the soil and organic matter status of that soil is low (Egbe, 2007). It is the only means which supply nitrogen to the plants in addition to valuable grain yield in poor-resource small scale farmers (Egbe et al., 2009). Intercropping of legume and non-legume crops is important in nitrogen fixation and the transfer of nitrogen by legume to the other crop which is an important nutrient circulation in an agricultural ecosystem (Olujobi and Oyun, 2012). According to Egbe and Egbo (2011), intercropping of cowpea and maize in West Africa has shown to reduce urea application by 50 % whereby cowpea fixes about 64 to 134 kg nitrogen per ha which can also be used by the following cereal crop in a crop rotation system.

2.9. Conclusions

Most available literature has regarded grain legumes as an important human nutrition in several parts of the world which provides proteins to vegetarian and population which cannot afford animal proteins. Among the grain legumes pigeon pea is a nutritious legume which substitutes animal proteins. Although the crop is stated to be very nutritious and contains high protein content as well as other nutrients but it is still the underutilised crop with potential to contribute to food security. The crop is known to be cultivated in more than seven countries of Africa and some countries of Asia but the production of traditional landraces has been decreased by climate change and environmental factors such as drought, pests and diseases and low fertility are major factors which contribute to low yield of about 0.4-1.0 tons per ha.

Low yields of the crop in many countries of Sub-Saharan Africa have been attributed to differences in climate and environmental conditions of the crop's country of origin and the countries in the Sub Saharan Africa. These factors are both abiotic and biotic which include temperature, photoperiod, rainfall, altitude and altitude differences, pests and diseases, drought and low quality seeds. Climate change has also placed a major effect on the production of such crop where a sudden change in rainfall and temperature may affect the pod fill and results in low yields. Although pigeon pea is regarded as a drought resistant crop, but drought has decreased its production in many countries of the region. Low yield in association with drought has caused reduction of crop growth and development together with decrease in photosynthesis rate, chlorophyll content and slow vegetative growth.

Poor adaptation of the crop to certain climatic conditions has been a factor contributing towards low yield due to the unknown agronomic practices of the crop to that specific area. In South Africa, the crop has been planted mostly by small scale farmers and rural people in their home gardens. Agronomic characterisation has to research and identify genotype with high yield potential which will aid farmers to adopt and produce the crop to fight the food insecurity and protein malnutrition among poor people. Breeders will be aided by the agronomic characterisation in order to genetically improve the crop's traits such as yield and resistance to pests and adaptation to adverse conditions.

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CHAPTER 3:
AGRONOMIC CHARACTERISATION: GROWTH, DEVELOPMENT AND YIELD PERFORMANCE OF PIGEON PEA LANDRACES UNDER RAIN-FED CONDITIONS

Abstract

Agronomic characterisation of pigeon pea landraces is very important in knowing the adaptation of the crop in different agro-ecological areas and for yield potential purposes. The aim of this study was agronomic characterisation of important traits or characters of pigeon pea landraces in KwaZulu-Natal climatic conditions. Seeds of six pigeon pea landraces were collected from Tshaneni, Mkuze in KwaZulu-Natal province and planted in Makhathini Research Station in Jozini and Newlands East Permaculture Centre in Durban, both in KwaZulu-Natal province,. The experiments were planned in December 2014 and February 2015 in Makhathini and Newlands, respectively. Results showed that there were no much differences in morphological characters of the crop such as leaf colour, stem colour, flower colour, streak pattern, pod colour, growth habit and flowering pattern. In terms of plant height mean, light brown had the highest height of 160.3 cm in Makhathini and white with black landrace was the highest in Newlands which had the height of 103.2 cm. Maximum days to 50 % flowering was reached by cream white in Makhathini with 165 days and 208 days to reach 75 % physiological maturity while the same landrace took 201.3 days to 50 % flowering in Newlands. Dark brown landrace flowered with 150 days in Makhathini and reached physiological maturity earlier than all the landraces after 185 days after planting whereas the earliest to flower in Newlands was light brown to flower within 106 days after planting though it did not reach maturity due to seed abortion after pod setting. Seed abortion in Newlands was due to low temperatures and short day length during June to July. These results indicate that long duration pigeon pea must be planted in spring to escape cool or low temperatures.

3.1. Introduction

Pigeon pea (*Cajanus cajan L.*) is an important grain legume in Eastern and Southern Africa, Asia and Central America. In Africa it is mostly grown by subsistence farmers in the semi-arid areas due to its drought tolerance (Khaki, 2014). The crop is consumed as dried beans or vegetable peas (Lin-Qi et al., 2014). Pigeon pea is a nutritious high protein crop with high digestible protein (68%), low fat and sodium with no cholesterol and rich in fibre. The crop is grown in many other countries because of its multiple uses as a source of food, feed, fuel and fertilizer (Wilson et al., 2012). The crop is a major food legume and is being grown as an intercrop with cereals and as a sole crop in Eastern and Southern Africa.

In South Africa and other Southern and Eastern African countries the crop has been cultivated from landraces which showed great variability in yield. Landraces of pigeon pea has been associated with low yields in countries where it was grown. The average yields of pigeon pea landraces are as low as 250 to 450 kg/ha and some takes time to mature (Khaki, 2014). The yield of the crop is also affected by salinity and drought stress (Kaydan and Yagmur, 2008). Low yields have also been associated with poor seed quality in terms of germination and emergence, which often lead to poor crop establishment (Zondi, 2012). Low yields of pigeon pea in Sub-Saharan Africa have been attributed to climate and environmental conditions which are different from the country of origin (Singh and Oswalt, 1992). This also makes pigeon pea difficult to adapt to Sub-Saharan Africa which is characterised by high latitude than in India the country of origin. The differences in latitude affect plant height, biomass, phenology and grain yield (Gwata and Siambi, 2009). The problem of low yield in the region affects small-holder farmers who grow the crop to produce food with limited resources (Saxena et al., 2010).

One of the reasons for low yields in Southern Africa is because the crop originated in the tropical latitudes of India, demonstrating a need to develop genotypes that can grow and yield better in areas outside the centre of origin. However, there is no information reporting performance and characteristics of different genotypes grown under climatic conditions of KwaZulu-Natal. Therefore, there is a need for research towards understanding agronomic and physiological responses of pigeon pea landraces under climatic zones of the province. Most of the work on pigeon pea research has been on crop yield and adaptation which has been done mostly in India. Such research has helped in identifying high yielding genotypes and low yielding genotypes have been modified through breeding in India, however there is very limited research work from African countries. Although significant amount of research has been reported on the crop around the world, there has been no published work on agronomic characterisation of pigeon pea in South Africa, especially in KwaZulu-Natal.

Yield for pigeon pea has remained low in past years leaving hunger to poor people who cannot afford to buy animal protein. Therefore, the aim of this study was to characterise the phenotypic and genotypic traits of pigeon pea landraces in identifying landrace(s) with high yield potential to increase and maximise pigeon pea production. It further gathered information on agronomic practices of pigeon pea production in South Africa especially in different climatic zones of KwaZulu-Natal province. The agronomic characterisation of the crop will be useful to farmers on basic crop production practises (agronomic practices) in South Africa especially in KwaZulu-Natal.

3.2. Material and Methods

3.2.1. Plant material and seed characterisation

The seeds of pigeon pea landraces were obtained from small-scale farmers in Hluhluwe (28.0189° S, 32.2675° E), KwaZulu-Natal, South Africa. Six landraces used in this study were categorised based on seed coat colour as dark brown (DB), light brown (LB), white with black (WBL), light brown with brown (LBB), cream white with brown (CWB) and cream white (CW).

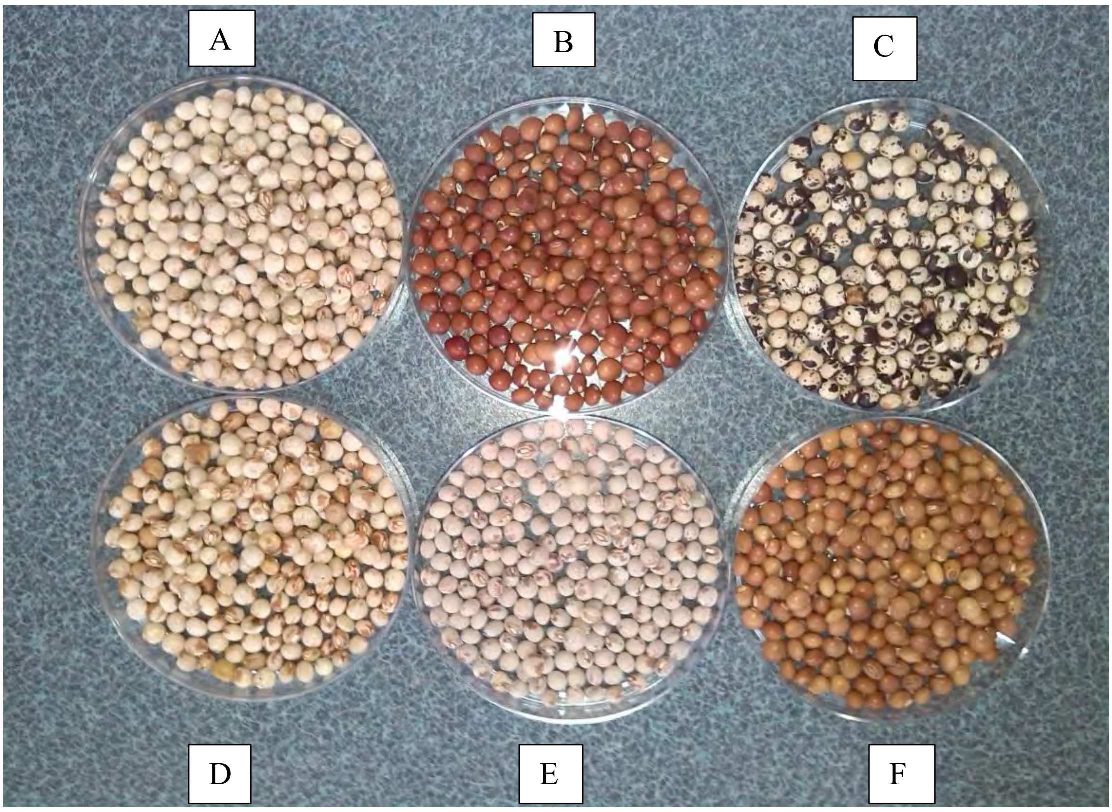

Figure 3.1: Seed coat colour of different pigeon pea landraces, (A) cream white, (B) dark brown, (C) white with black, (D) cream white with brown, (E) light brown with brown and (F) light brown.

3.2.2. Field experiment

Field experiments were conducted during 2014/15 growing season in two experimental sites which were Makhathini Research Station in Jozini, KwaZulu-Natal, South Africa (27,430° S, 32,067° E) and Newlands East Permaculture Centre in Durban, South Africa (29,53°S; 31,03°E). Both sites were rain-fed. The soil types were sandy clay and silt clay loam soils for Makhathini and Newlands, respectively. Before planting, five soil samples were collected in each site at a depth of 30 cm. The soil samples were then combined and sent for soil chemical and physical properties analysis at Cedara Analytical laboratory of the KwaZulu-Natal Department of Agriculture and Rural Development. Important soil chemical and physical properties tests are represented by Table 3.1.

Table 3.1: Soil chemical and physical properties per ha of Makhathini and Newlands.

Chemical properties	Makhathini	Newlands
N %	0.11	0.34
P mg/kg	12.50	6.63
pH (KCl)	4.85	5.07
Organic carbon %	0.80	2.75
Physical properties		
Clay %	20.00	30.50
Fine silt %	7.00	15.00
Sand %	72.50	53.00
Texture	Sandy Clay	Sandy clay loam

3.2.3. Climate

Jozini is located in the Northern part of KwaZulu-Natal with a mean rainfall of 296.20 mm during the growing season (December to August) and the mean maximum temperature of 25.84 °C and minimum temperature was 17.03 °C. Durban is located in the Eastern part of KwaZulu-Natal with a mean rainfall of 316.20 mm during the season (February to August). The mean maximum temperature was 26.06 °C and minimum temperature was 15.32 °C Rainfall and temperatures were recorded during the 2014/15 growing season in Jozini and Durban. Monthly rainfall for Makhathini and Newlands are represented by Table 3.2 below.

Table 3.2: Monthly rainfall in mm during 2014/15 season in Makhathini and Newlands.

Months	Makhathini	Newlands
December	58.0	-
January	50.6	-
February	97.2	86.6
March	56.0	97.8
April	20.2	10.2
May	0.0	0.2
June	0.0	1.6
July	14.2	119.8
August	0.0	0.0
Total	**296.2**	**316.2**

3.2.4. Experimental design

In the two experimental sites, each experiment was conducted using randomised complete block design consisting of 3 replications. The experiment consisted of 18 plots in three blocks. The plots were 4 m^2 each with a space of one metre from each plot. The plant population for the pigeon pea was 66 666 plants per ha with a spacing of 50 cm between the four rows per plot and 30 cm in rows. The field experiment at Makhathini was planted on the 13^{th} of December 2014 whilst Newlands was planted on the 03^{rd} of February. Two seeds per hole were sown manually then thinned to one plant 2 weeks after planting.

3.2.5. Fertiliser application

Fertilizer was applied based on the results of soil analysis whereby nitrogen at the rate of 80 kg ha^{-1} was applied in the form of Urea (46%) and Phosphorus of 20 kg ha^{-1} in the form of Single super phosphate (10.3%). The fertilisers were broadcasted at rate of 20 kg and 80 kg per ha Single super phosphate and Urea per plot respectively. Weeds were manually controlled two times throughout the whole experiment using hand hoes after the plants were 4 weeks old and 3 months old in the two sites.

3.2.6. Data collection

The germination test was used to evaluate the germination capacity of the seeds. 25 seeds of each landrace were arranged in rows and germinated in double paper towels moistened with water. The paper towels were tied in both sides with elastic bands and put in sealed plastic bags. Seeds of each landrace were replicated three times. The plastic bags were then put in a germination chamber with the delivery air temperature of 25 °C. Daily measurements of germinated seed were taken for 7 days by counting the number germinated seeds. Plant height was measured monthly using a measuring tape from soil surface to the apical tip of the plant. Three representative plants were sampled in a net plot. Leaf area was measured using the LAI2200 Canopy Analyser (LI-COR, Inc. USA & Canada). Chlorophyll content was measured to check the ability of the leaf to photosynthesize. The chlorophyll content was measured from three representative plants using chlorophyll content meter (CCM-200 *PLUS*, Opti-Sciences, USA). Morphological traits such as leaf colour, leaf shape, stem thickness, growth habit, flower colour, flowering pattern, streak colour, pod colour, pod shape, pod construction, seed coat colour, seed shape, seed eye colour were observed and recorded.

Days to 50 % flowering, flowering pattern, flower colour, flower or petal streak, streak colour and raceme colour were recorded. The days to 50 % flowering was recorded after counting half of the plants per plot which has flowered, flowering pattern through observing the position where the plant has borne its flowers and state whether it is determinate, semi-determinate or indeterminate. Flower colour was also recorded. Flower or petal streak was also recorded as either low, medium or dense. Days to physiological maturity were monitored and recorded. This was determined when 75% of the pods change colour from green to brown. Above ground biomass was obtained after weighing the fresh and dry mass after harvesting the above parts of the plant. Grain yield was recorded after harvesting the two middle rows and weighing total seed mass after threshing. Nitrogen difference was done by taking samples in plants at vegetative, flowering and maturity stage on each plot and also by sampling the non-nitrogen fixing species.

3.2.7. Data analysis

The data was subjected to analysis of variance (ANOVA) using GenStat® Version 14 (VSN International, UK). Differences between the treatment means were separated using turkey test and least significant differences (LSD) at 5 % level of significance.

3.3. Results

3.3.1 Seed germination

There were highly significant differences ($P < 0.001$) among pigeon pea landraces with respect to the percentage of seeds geminated as showed in Figure 3.2. There were also highly significant differences ($P < 0.001$) with respect to germination over time. Landrace and days had high significant differences ($P < 0.001$), the interaction between landraces and days was also significant ($P < 0.001$). On average, pigeon pea seeds were slow to germinate in the first 2 days. On day 3 dark brown performed best with 33.20 % seeds germinated followed by cream white with 26.25 % seeds and white with black with 21.20 % seeds germinated. On day 4 dark brown continued to perform best with 58.68 % seeds germinated followed by light brown with brown landrace with 53.32 % and white with black with 49.32 % although there was no much different between the white with black with light brown which germinated 48.00 % seeds on the very same day. On the 6th day there were significant differences ($P < 0.05$) between landrace on seed germination whereby light brown with brown performed best with 98.68 % seed germination followed by cream white with brown with 93.32 % seed germination and white with black with 90.68 %.

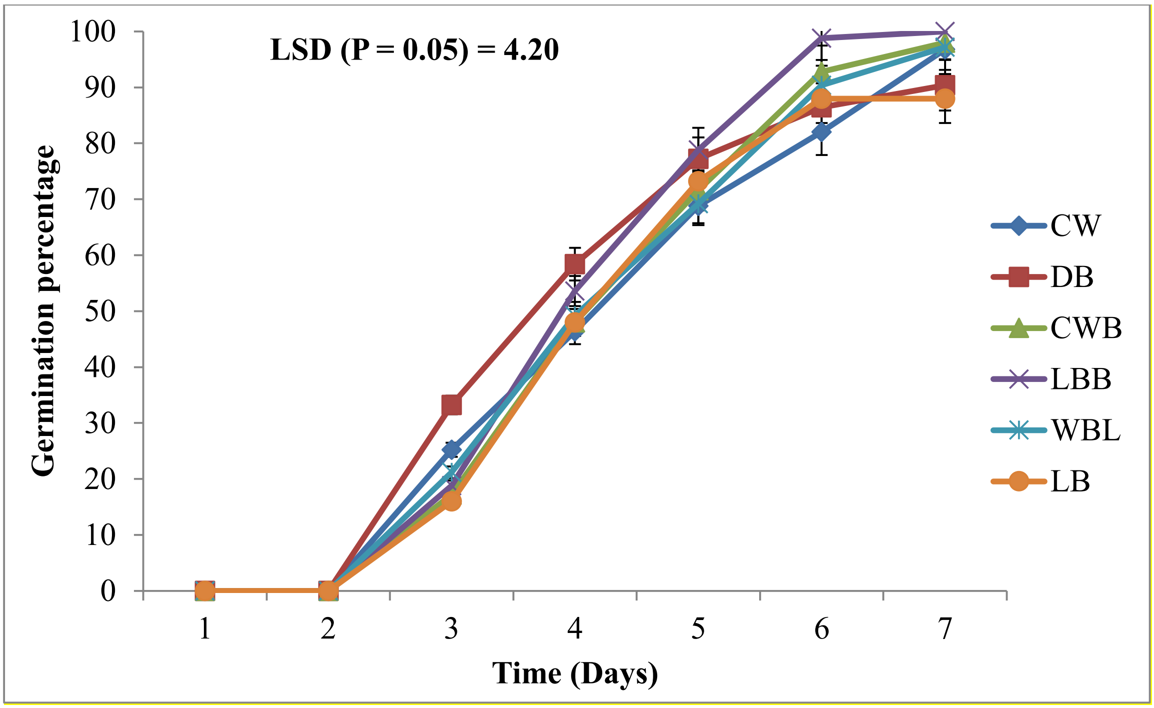

Figure 3.2: Germination percentages of pigeon pea landraces over time.

Based on means for the landraces on the final day light brown with brown performed best with (100%) seed germination, followed by cream white with brown with (98.70%) seed germination. White with black and cream white with (97.33%), light brown landrace had (88%). seed germination

3.3.2. Seed emergence

There were no significant differences ($P > 0.05$) between pigeon pea landraces with respect to final seed emergence in Makhathini as shown in Figure 3.3 although there are many seeds that emerged from dark brown landrace than the others (84.72%) followed by light brown with 80.93%, Light brown with brown (79.33 %), cream white with 76.77 % and cream white with 75.15 % as well as white with black which had less seed emergence (73.89%).

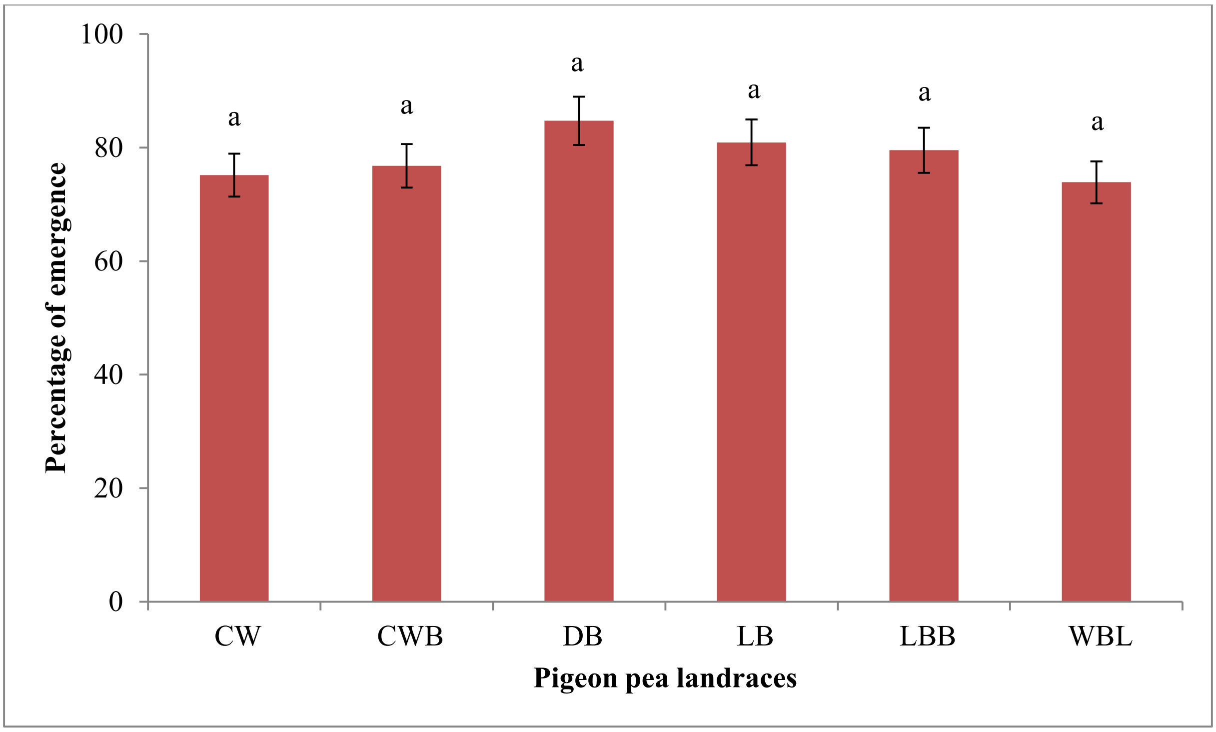

Figure 3.3: Final seed emergence of pigeon pea in Makhathini and Newlands after 4 weeks.

There were no significant differences (P > 0.05) between pigeon pea landraces with respect to seed emergence (Figure 3.4) although light brown landrace performed better (100%) than the others. It was then followed by cream white with 97.22 % seed emergence, cream white with brown with 92.77 seed emergence, dark brown with 91.67% seed emergence, white with black with 88.85 % seed emergence and light brown with brown with 84.70 % seed emergence. Seed germinated better in Newlands than in Makhathini Research Station.

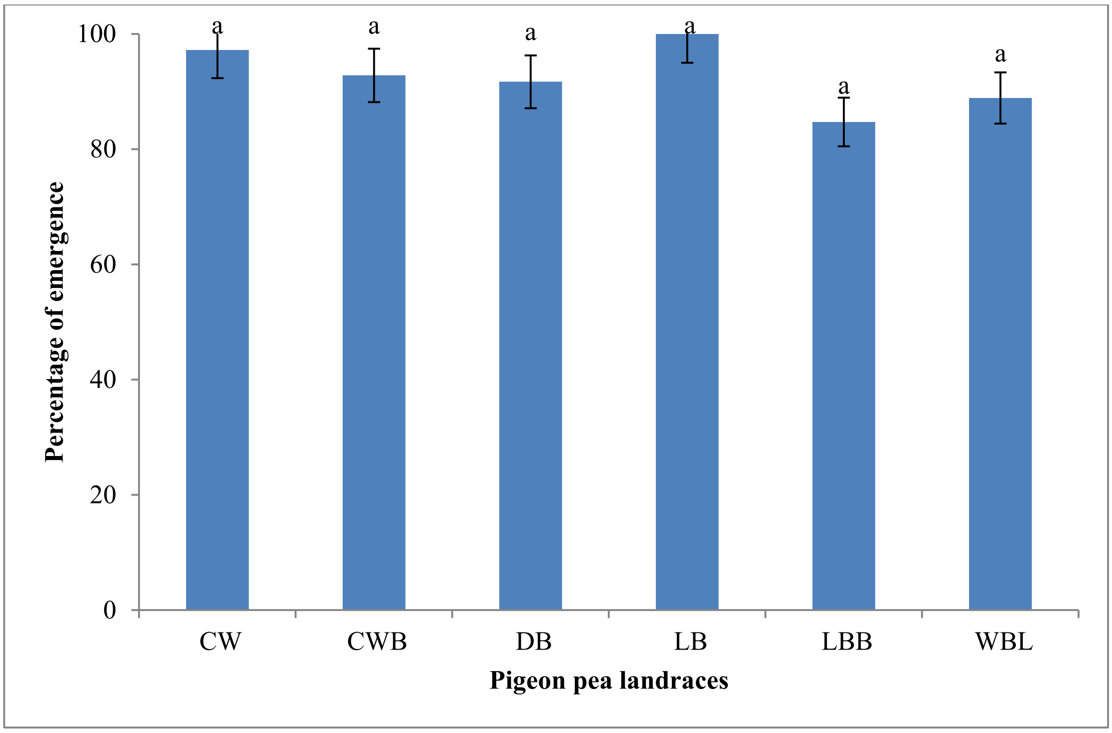

Figure 3.4: Final seed emergence of pigeon pea in Makhathini and Newlands after 4 weeks.

3.3.3. Leaf area index (LAI)

The interaction of landrace and weeks had no significant differences (P > 0.05) but there were highly significant differences (P < 0.001) between pigeon pea landraces and weeks with respect to LAI in Makhathini. Figure 3.5 showed that in week 4 white with black had a highest LAI among all the landraces with the LAI of 1.54 followed by dark brown with the LAI of 1.53, light brown with brown with the LAI of 1.39, cream white with the LAI of 1.33, cream white with brown with the LAI of 1.06, and lastly light brown with the LAI of 1.01. On week 8, dark brown landrace had the highest LAI of 2.21 followed by light brown with brown with a LAI of 1.82, white with black with the LAI of 1.73, light brown with the LAI of 1.71, cream white with the LAI of 1.65 and cream white with brown with the LAI of 1.43. On week 16, dark brown landrace had the highest LAI of 2.84 followed by white with black with the leaf area index of 2.79, light brown with the LAI of 2.73, cream white with the LAI of 2.72, light brown with brown with the LAI of 2.47 and lastly cream white with brown with the LAI of 2.24. During 20 weeks after planting dark brown landrace had the highest LAI of 3.210 followed by white with black with the LAI 2.92, cream white had LAI of 2.89, light brown had LAI of 2.89, light brown with brown had 2.85 and the landrace with the lowest LAI was cream white with brown with the LAI of 2.83. On average, for all pigeon pea landraces the mean LAI was the highest in dark brown landrace with 2.44 followed by white with black with LAI of 2.24, cream white with the LAI of 2.15, light brown with brown with the LAI of 2.13 and cream white with brown with LAI of 1.89.

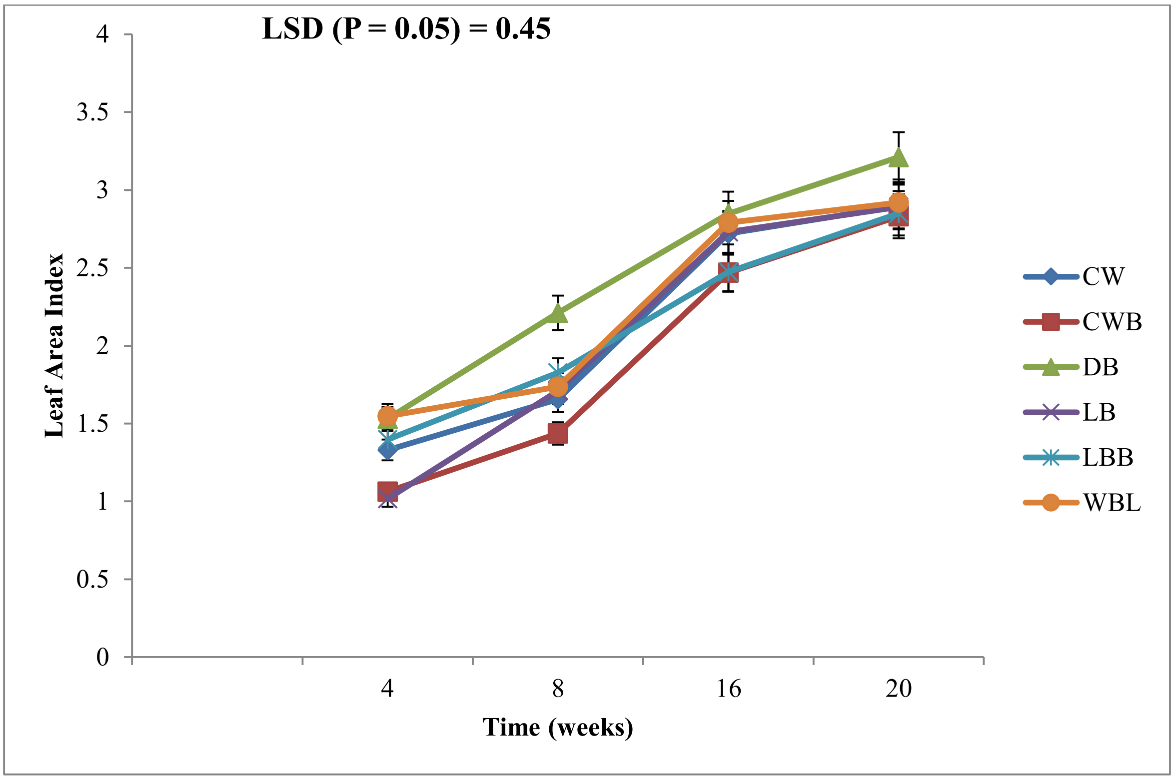

Figure 3.5: LAI of pigeon pea landraces in Makhathini.

The interaction between landrace and weeks in Newlands had no significant effect on LAI (P > 0.05). There were no significant differences (P > 0.05) between pigeon pea landraces with respect to LAI in Newlands but there were high significant differences (P < 0.001) between weeks. In Figure 43.6 in white with black had a highest LAI among all the landraces with the leaf index of 1.49 followed by dark brown with a LAI of 1.42, cream white with LAI of 1.283, cream white with brown with LAI of 1.24, light brown with LAI of 1.14 in week 4. The landrace with the lowest LAI is light brown with brown with the LAI of 1.13. On the 8th week cream white had a highest LAI among all the landraces with the LAI of 1.97 followed by white with black with LAI of 1.79, dark brown with LAI of 1.73, light brown with the LAI of 1.66, cream white with brown with LAI of 1.41. The LAI on the 8th week was achieved by light brown with brown which had a LAI of 1.40. On the 16th week dark brown landrace had the highest LAI of 2.91 followed by cream with brown with the LAI of 2.91, white with black LAI of 2.90, cream white with the LAI of 2.74, light brown with LAI of 2.70 and the lowest LAI was achieved by light brown with brown with LAI of 2.63. During flowering white with black had a highest LAI among all the landraces with the leaf index of 2.85 followed by cream white with brown with the LAI of 2.83, light brown with brown with LAI of 2.81, cream white with LAI of 2.79, light brown with LAI of 2.71 and dark brown with the lowest LAI of 2.71 in Newlands East Permaculture centre, Durban.

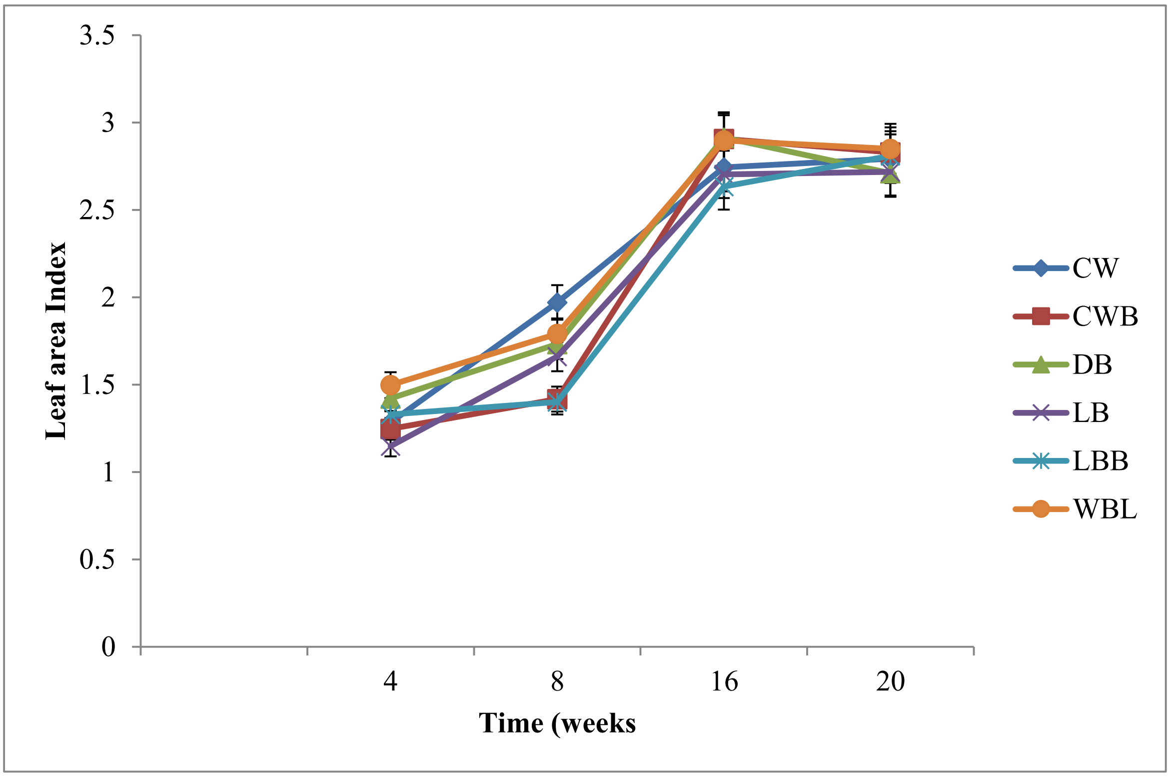

Figure 3.6: Differences in leaf area index of pigeon pea landraces in Newlands.

On average, for all pigeon pea landraces, the mean LAI was the highest in white with black landrace with 2.26 followed by cream white with LAI of 2.19, dark brown landrace with LAI of 2.19, cream white with brown with LAI of 2.10, light brown with LAI of 2.06 and lastly light brown with brown which had the lowest LAI of 1.99.

3.3.4. Plant height

Although there were no significant differences ($P > 0.05$) between the interaction of landraces and weeks in Makhathini, there were significant differences ($P < 0.05$) between pigeon pea landraces and weeks with respect to plant height in Jozini. On week 4, light brown had the highest plant height among the landraces with the plant height of 43.57 cm followed by light brown with brown with the plant height 38.77 cm, cream white with 38.57, dark brown with a height of 38.03, white with black landrace with plant height of 36.10 cm and the landrace lastly cream white with brown had a plant height of 32.43 cm (Figure 3.7).

On week 24, on last measurement day, white with black had 295.70 cm followed by with 294.70 cm and dark brown with 293.30 cm and the shortest landrace on week 24 was cream white with brown with 289.71 cm. On average, for all landraces light brown had the highest height of 186.80 cm followed by white with black with 185.10 cm and dark brown with the height of 1584.70 cm cream white had height of 181.60 cm, cream white with brown with 173.20 cm and light brown with brown had 172.60 which was the shortest among all landraces in Makhathini.

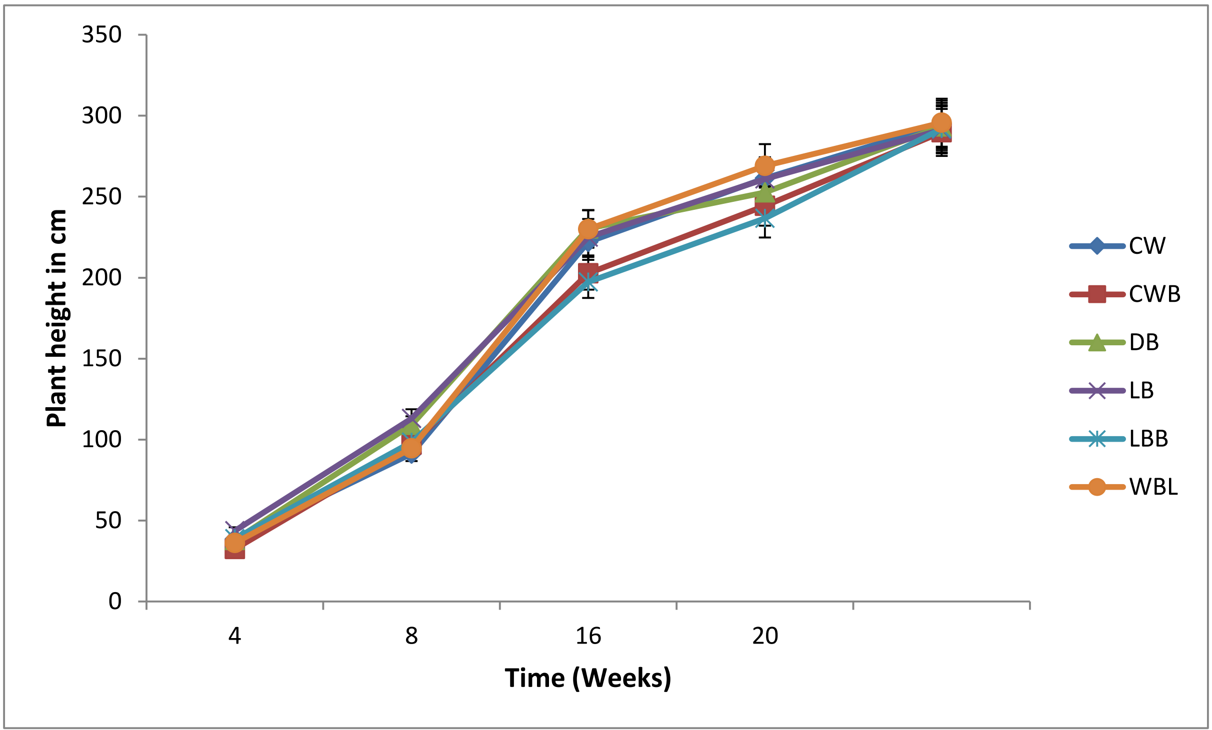

Figure 3.7: Plant height of pigeon pea landraces over weeks in Makhathini.

In Figure 3.8, there were no significant differences (P > 0.05) between the interaction of landraces and weeks in Newlands. There were slightly significant differences (P < 0.05) between pigeon pea landraces with respect to plant height in Newlands and weeks also had high significant differences (P < 0.001). On week 4, white with black had a highest height of 29.83 followed by light brown with the height of 38.93, dark brown with the height of 37.97 and light brown with brown with 35.33, cream white 34.20 and cream white with brown with 33.13 cm.

In week 24 after planting, the light brown was the highest height of all landraces with height of 161.60 cm followed by white with black with 161.00 cm, cream white with 155.67 cm and the shortest of them all was light brown with brown with 142.01 cm. On average, for all landraces white with black had the highest height of 114.71 cm followed by light brown with the height of 112.33 cm followed by dark brown with the height of 109.02 cm, cream white with 107.20 cm and the shortest landrace was light brown with brown with 103.91 cm.

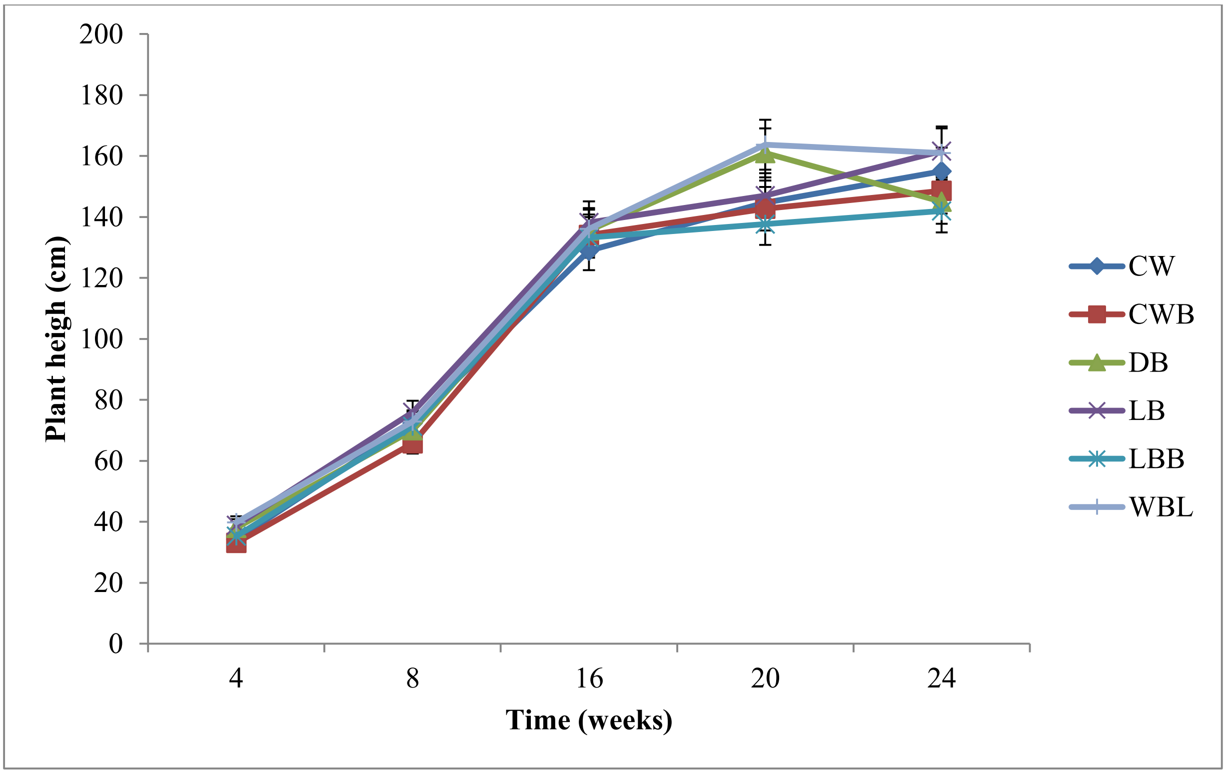

Figure 3.8: Differences in plant height of pigeon pea landraces in Newlands.

3.3.5. Chlorophyll content

There were no significant differences ($P > 0.05$) between the interaction of pigeon pea landraces and weeks after planting with respect to chlorophyll content in Makhathini. During flowering or week 24 which was the last week to record chlorophyll content, dark brown had the highest chlorophyll content of 24.90 followed by white with black with the chlorophyll content of 24.80. The landrace with the lowest chlorophyll content was cream white with brown with the chlorophyll content of 23.03 (Figure 3.9). On average, for all landraces, the mean highest chlorophyll content was achieved by cream white landrace with the chlorophyll content index of 24.19 followed by light brown with the chlorophyll content of 24.06, cream white with chlorophyll content of 24.06. The lowest chlorophyll content was attained by dark brown with brown in Makhathini with chlorophyll content index of 23.12.

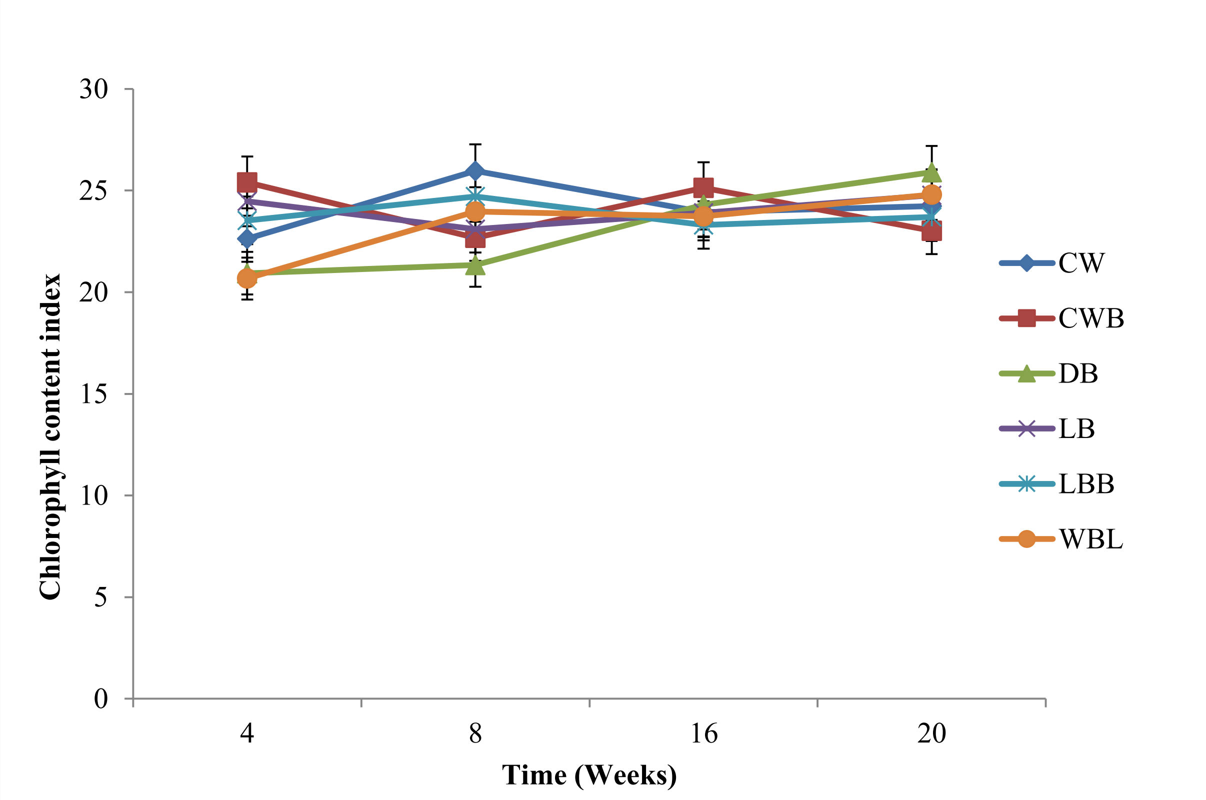

Figure 3.9: Chlorophyll content of pigeon pea landraces in Makhathini.

There were no significant differences (P > 0.05) between the interaction between pigeon pea landraces and weeks after planting with respect to chlorophyll content in Newlands. During flowering or week 24 which was the last week to record chlorophyll content, dark brown had the highest chlorophyll content of 25.57 followed by light brown with chlorophyll content of 25.13 and cream white with brown with the chlorophyll content of 24.60. The cream white landrace recorded least chlorophyll content index of 22.27 during the 20th week. On average, for all landraces the mean highest chlorophyll content was achieved cream white with brown achieved highest chlorophyll 24.47 followed by white with black and light brown with 24.42 and 24.17 respectively. Cream white recorded least chlorophyll content. The results of both sites in respect to chlorophyll content found that there were no significant differences (P > 0.05) among the interaction of landraces weeks and sites as well as for landrace, weeks and sites. No significant differences (P > 0.05) between the interaction of landrace and weeks, interaction of landraces and sites and weeks and sites. Even though there was no significant differences (P > 0.05) found between the interaction of landrace, weeks and sites the cream white with brown landrace had the highest chlorophyll content of 24.27 followed by light brown with 24.11 and white with black with 23.85. The landrace with the lowest chlorophyll content in both sites was dark brown with 23.46.

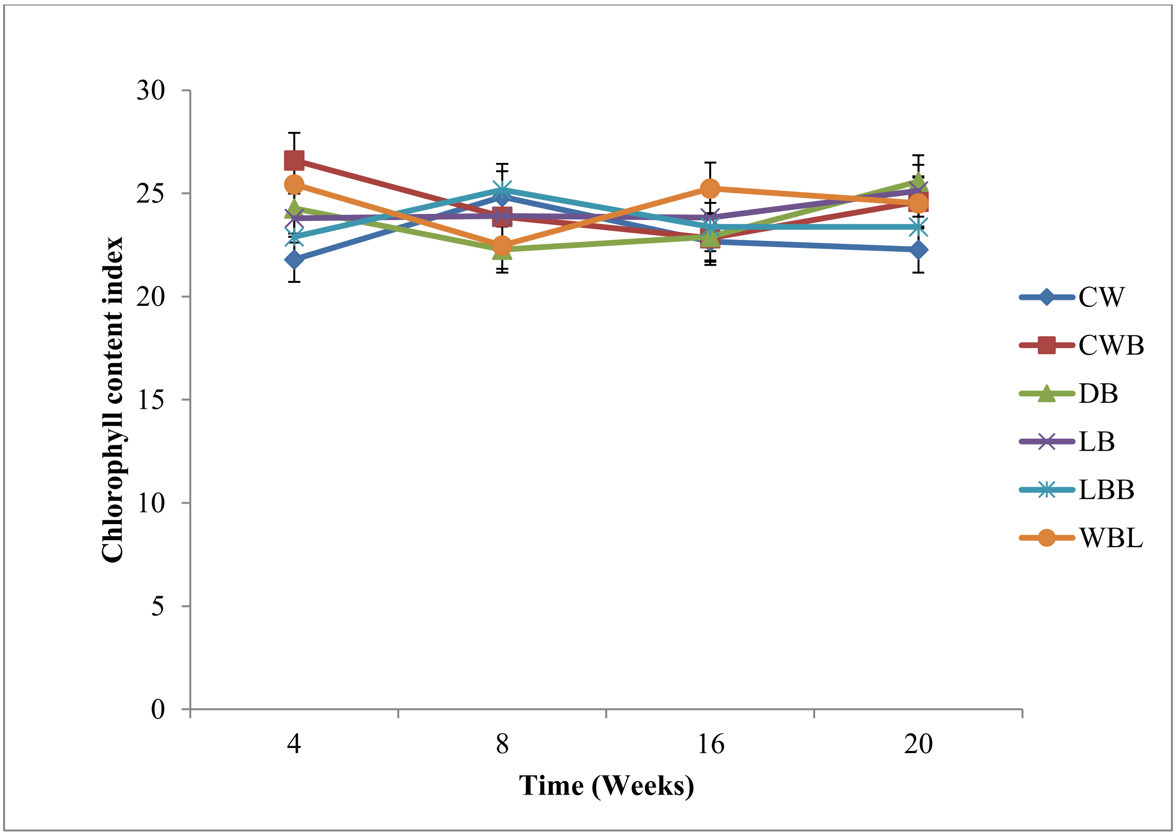

Figure 3.10: Mean differences of chlorophyll content of pigeon pea landraces in Newlands.

3.3.6. Number of days 50% flowering and 75 % to physiological maturity

There were highly significant differences ($P < 0.001$) between pigeon pea landraces with respect to days to 50 % flowering in Makhathini Research Station. Cream white reached the maximum days to flower at 168 days followed by cream white with brown landrace which reached 167 days. Light brown with brown reached 50 % flowering in 165 days. The minimum days to 50% flowering was reached by dark brown landrace at 150 days. Flower colour was yellow and the streak pattern of the flowers was medium for all landraces. There was no streak colour in all the landraces with yellow colour except white with black which had the purple streak. Flowering pattern was indeterminate whereby flowers were borne in auxiliary buds of all branches of the plants.

There were highly significant differences ($P < 0.001$) between pigeon pea landraces with respect to days flowering in Newlands permaculture centre. Cream white reached the maximum days to flower which was 201.30 days followed by cream white with brown landrace which reached 195.00 days. Dark brown reached 50 % flowering in 110.00 days. The minimum days to 50% flowering was reached by light brown landrace at 106.00 days. Flower colour was yellow for all landraces and the streak pattern of the flowers was medium. There was no streak colour in all the landraces with yellow colour except white with black which had the purple streak. Flowering pattern was indeterminate whereby flowers were borne in auxiliary buds of all branches of the plants. Overall there were highly significant differences ($P < 0.001$) between the landraces and growing sites and the interaction of landrace and site had high significant differences ($P < 0.001$) as well. The landrace with longest days to reach 50 % flowering was achieved by cream white and cream white with brown with 201.30 and 195.00 days after planting in Newlands, respectively.

There were highly significant differences ($P < 0.001$) between pigeon pea landraces with respect days to physiological maturity in Makhathini Research Station. Cream white reached the maximum days to 75 % physiological maturity which was 208.7 days followed by cream white black landrace which reached 207.70 days. Light brown with brown and light brown reached physiological maturity after 199.70 and 197.33 days after planting, respectively. Early maturing landrace was dark brown which reached maturity after 185.00 days after planting. Landrace did not mature in Newlands due to seed abortion after the pods has set. Data of days to 50 % flowering, flowering components and maturity were represented in Table 3.3, 3.4 and 3.5, respectively.

Table 3.3: Flowering components at 50 % flowering stage in Makhathini and Newlands.

Landrace	**Flower colour**	**Streak pattern**	**Streak colour**	**Flowering pattern**
Light brown with brown	Yellow	Medium	None	Indeterminate
Light brown	Yellow	Medium	None	Indeterminate
Cream white	Yellow	Medium	None	Indeterminate
Cream white with brown	Yellow	Medium	None	Indeterminate
White with black	Purple	Medium	Purple	Indeterminate
Dark brown	Yellow	Medium	None	Indeterminate

Table 3.4: Days to 50 % flowering and 75 % physiological maturity in Makhathini.

Landrace	**50 % flowering**	**75 % maturity**
Light brown with brown	165.00bc	199.70bc
Light brown	155.00ab	197.30b
Cream white	168.00c	208.70bc
Cream white with brown	167.00c	207.70c
White with black	160.00abc	191.30ab
Dark brown	150.00a	185.00a
Mean	160.80	198.20
CV %	2.40	1.60
LSD	7.08	5.84

Table 3.5: Days to 50 % flowering and 75 % physiological maturity in Newlands.

Landrace	50 % flowering	75 % maturity
Light brown with brown	140.10b	NM
Light brown	106.00a	NM
Cream white	201.30c	NM
Cream white with brown	195.00c	NM
White with black	139.33b	NM
Dark brown	110.00a	NM
Mean	148.60	
CV %	3.40	
LSD	9.32	

NM= Never reached maturity due to seed abortion.

3.3.7. Morphological parameters

Morphological parameters of pigeon pea were observed and recorded. The morphological parameters were shown in Table 3.6 to 3.8.

Table 3.6: Morphological parameters of pigeon pea **vegetative growth** in Makhathini and Newlands.

Landrace	Leaf colour	Leaf shape	Stem colour	Growth habit	Stem thickness	Leaf hairiness
LBB	Green	Ovate	Green	Spreading	Thick	Glabrous
LB	Green	Ovate	Green	Spreading	Thick	Glabrous
CWB	Green	Ovate	Green	Spreading	Thick	Glabrous
CW	Green	Ovate	Green	Spreading	Thick	Glabrous
WBL	Green	Ovate	Green	Spreading	Thick	Glabrous
DB	Green	Ovate	Green	Spreading	Thick	Glabrous

Table 3.7: Morphological traits of pigeon pea pods in Makhathini Research Station at physiological maturity.

Landrace	Pod form	Pod hairiness	Pod constriction	Pod waxiness	Pod colour	Pod size
LBB	Flat	Sparse	Slight	Present	Green	Large
LB	Flat	Sparse	Slight	Present	Green	Large
CWB	Flat	Sparse	Slight	Present	Green	Large
CW	Flat	Sparse	Slight	Present	Green	Large
WBL	Flat	Sparse	Slight	Present	Green	Large
DB	Flat	Sparse	Slight	Present	Green	Large

Table 3.8: Morphological traits of pigeon pea **seeds** in Makhathini Research Station at physiological maturity.

Landrace	Seed colour pattern	Seed eye width	Seed eye colour	Seed shape	Seed size	Seed coat colour
LBB	Mottled	Medium	White	Globular	Very large	Light brown with brown
LB	Plain	Medium	White	Globular	Very large	Light brown
CWB	Mottled	Medium	White	Globular	Very large	Cream white with brown
CW	Mottled	Medium	White	Globular	Very large	Cream white
WBL	Speckled	Medium	White	Globular	Very large	White with black
DB	Plain	Medium	White	Globular	Very large	Dark brown

3.3.8. Yield and yield components

There were no significant differences (P > 0.05) among pigeon pea landraces in terms of pods per plant in Makhathini Research Station but cream white with brown had the highest number of pods per plant among the landraces with 133.30, followed by light brown with 118.00 pods per plant. Dark brown with brown had 114.00 had an average of 114.00 pods per plant. The landrace with the least pods per plant was light brown with brown with 98.70 pods per plant. There were slightly significant differences (P < 0.05) among pigeon pea landraces in terms of seeds per pod in Makhathini Research Station whereby dark brown had an average 5.6 seeds per pods while white with black cream white with brown, light brown and cream white had an average of 5 seeds per pods. Light brown with brown had the lowest average seed per pod which was 4.8 seeds.

There were slightly significant differences (P < 0.05) among pigeon pea landraces in terms of 100 seeds mass in Makhathini Research Station whereby dark brown had the highest average grams of 100 seed weight which was 16 g followed by white with black with an average of 15.10 g. The lowest weight was achieved by light brown with brown with the mean of 14.10 g. There were no significant differences (P > 0.05) among pigeon pea landraces in terms of fresh weight in Makhathini Research Station whereby white with black had the highest average grams of pod mass per plant which was 126.70 g followed light brown by with average of 125.70 g. Dark brown had the mean of 118.00 g and the lowest weight was achieved by light cream white with the mean of 88.30 g.

There were no significant differences (P > 0.05) among pigeon pea landraces in terms of grain yield of the landraces in tons per hectare in Makhathini Research Station though dark brown yielded more than all the other landraces with the average yield of 1.40 tons per hectare followed by white with black and light brown landrace both with average yield of 1.30 tons per hectare. Cream white had the lowest yield among all the landraces with 1.00 tons per hectare. There were no significant differences (P > 0.05) among pigeon pea landraces in terms of above ground biomass in Makhathini Research Station though cream white yielded more than all the other landraces with the average biomass yield of 6.46 tons per ha followed by dark brown with and white with black landrace with 5.34 tons per ha and 5.32 tons per ha, respectively. Light brown had the lowest above ground biomass among all the landraces which was 4.99 tons per ha.

There were no significant differences (P > 0.05) among pigeon pea landraces when harvest index is compared in Makhathini Research Station. Even though there was no statistical differences, dark brown had harvest index percentages more than all the other landraces with the average of 13.90 % followed by light brown and white with black landrace with 11.80 % and 11.70 %, respectively. Cream white with brown had the lowest harvest index percentage among all the landraces which was 5.90 %. Yield and yield components are represented in Table 3.9.

Table 3.9: Yield and yield components of pigeon pea landraces in Makhathini 75% physiological maturity.

Landrace	Pods per plant	Seeds per pod	100 seed weight	Pod mass per plant (g)	Grain yield (t/ha)	Above ground Biomass (t/ha)	Harvest Index (%)
LBB	98.70a	4.83a	14.10a	95.70a	1.16a	5.14a	10.50a
LB	118.00a	5.00ab	14.40ab	125.70a	1.36a	4.99a	11.80a
CWB	133.30a	5.00ab	14.60ab	107.30a	1.22a	5.00a	10.50a
CW	112.70a	5.00ab	14.70ab	88.30a	1.06a	6.46a	5.90a
WBL	103.00a	5.00ab	15.10ab	126.70a	1.37a	5.32a	11.70a
DB	114.00a	5.67b	16.00b	118.30a	1.49a	5.34a	13.90a
Mean	113.28	5.08	14.81	110	1.27	5.37	10.7
CV	25	4.80	4.10	20.70	19.60	23.50	42.00
LSD (P=0.05	51.6	0.13	1.11	41.5	0.45	1.03	8.22

3.3.9. Nitrogen Fixation

3.3.9.1. Plant tissue nitrogen fixation

There were no significant differences (P > 0.05) among pigeon pea landraces in terms of nitrogen fixation during vegetative stage (16 weeks after planting) in Makhathini. No significant differences (P > 0.05) were observed during flowering in Makhathini but light brown with brown had the highest kg for nitrogen fixation which was 211.60 kg followed by dark brown with 208.60 kg. Light brown and cream white with brown had 199.10 kg and

191.50 kg nitrogen fixation levels. At this stage, white with black was able to fix 172.80 kg nitrogen in the soil.

Although there were no significant differences (P > 0.05) among pigeon pea landraces in terms of nitrogen fixation during vegetative stage (16 weeks after planting) in Newlands, cream white with brown landrace was able to fix the highest nitrogen among the landraces which was 35.85 kg. White with black landrace fixed 35.75 kg nitrogen and light brown fixed 33.03 kg per ha and light brown with brown fixed less nitrogen than all the landraces during this stage which was 25.00 kg per ha. During flowering stage no significant differences (P > 0.05) were observed for nitrogen fixation in Newlands. White with black continued to fix more nitrogen than any other landrace whereby it fixed 233.90 kg per ha followed by cream white with brown with 222.60 kg per ha, dark brown with 220.40 kg per ha. Light brown with brown fixed 209.10 kg per ha which was the least kg achieved by the landraces at this stage.

3.3.9.2. Leaf litter nitrogen differences

Although there were no significant differences (P > 0.05) observed in Makhathini at physiological maturity in terms of data collected for leaf litter, dark brown had the highest kg for nitrogen fixation which was 263.20 kg per ha followed by cream white with 233.10 kg. White with black and light brown had 199.90 kg and 184.70 kg nitrogen fixation levels, respectively. Overall performance for landraces at different stages of development, there were no significant difference (P > 0.05) among landraces in terms of leaf litter in Makhathini Research Station. On average, for all the stages of development, dark brown performed more than all the landraces whereby it fixed 167.90 kg per ha followed by cream white with 143.50 kg per ha, cream white with brown performed least with 117.60 kg per ha nitrogen fixed. In Newlands, landraces and the interaction of landraces and stages of development had no significant differences (P > 0.05) and (P > 0.05), respectively. On average, white with black had 134.80 kg per ha which fixed the highest nitrogen, followed by cream white with brown with 130.20 kg per ha, light brown with brown fixed 117.50 kg per ha of nitrogen which fixed least nitrogen among the landraces. Table 3.10 and 3.11 below shows the nitrogen fixation of pigeon pea landraces at different stages of the development.

Table 3.10: Nitrogen fixation of pigeon pea landraces in Makhathini at different stages of development.

Landrace	N at vegetative (16 weeks)	N at Flowering	N at maturity (leaf litter)	Average
LBB	7.38a	211.60a	172.90a	130.60a
LB	17.14a	199.10a	184.70a	133.70a
CWB	18.65a	191.50a	142.70a	117.60a
CW	14.02a	183.50a	233.10a	143.50a
WBL	12.83a	172.80a	199.90a	128.50a
DB	3.37a	208.60a	263.20a	167.90a
Mean	12.23	194.51	199.41	136.96
CV %	80.00	28.00	34.70	76.60
LSD (P=0.05)	40.37	99.00	126.10	99.50

Table 3.11: Nitrogen fixation of pigeon pea landraces in Newlands Permaculture Centre at different stages of development.

Landrace	Vegetative	Flowering	Average
LBB	25.00a	210.00a	117.50a
LB	33.03a	209.10a	121.10a
CWB	35.85a	222.60a	130.20a
CW	26.90a	209.40a	118.20a
WBL	35.75a	233.90a	134.80a
DB	31.06a	220.40a	127.40a
Mean	31.26	188.36	124.86
CV %	21.40	22.70	130.40
LSD (P=0.05)	5.47	90.00	88.30

3.4. Discussion

Germination continued slowly during the first two days for all the pigeon pea seeds of different landraces. Variation in germination between landraces started to show by the third day. At seventh day all landraces showed their differences in germinating. Significant differences (P <

0 .001) among the landraces have been influenced by seed colour which has been reported by Ochuodho and Modi (2013) that it plays an important role in seed dormancy and germination and seed coat and structure is known to influence germination. Ochuodho and Modi (2013) further explained that differences in germination are attributed to biochemical reactions in the embryo whereby high rate of germination is due to increase in biochemical reaction taking place in the embryo.

The differences in germination are also explained by Khatun et al. (2009) whereby he states that if the seeds are harvested after physiological maturity, physiological changes in seed may lead to formation of hard seeds in legume crops and early harvested seeds will be immature and poorly developed and results in poor germination, vigour, viability and also storability. Although Ahirwar (2012) concluded that seed germination variability among cultivars is affected by seed size and weight but on this study this was not observed. Further justification on seed size is evidenced by Ying et al. (2014) that in seed germination large seeds perform better than small seeds but these depends on the environmental conditions whereby in winter large seed do not do so. Botcha et al. (2013) reported that variation in germination is due to temperature and environmental factors whereby higher temperatures favours seed germination than cooler and lower temperatures.

No significant differences ($P > 0.05$) found in respect to seed emergence in Makhathini. Seed emergence is influenced by water content of the soil, seed quality, soil type and environment (Mabhaudhi, 2009). According to Sinefu (2011), seed bed conditions and insufficient soil moisture are factors affecting seed emergence. The pigeon pea reacted the same in Makhathini Research station due to same soil type and environmental conditions which were soil moisture content, rainfall, surface temperature and atmospheric temperature during seed emergence and reaction of landraces to uniform soil fertility as same amount of fertiliser was applied prior sowing. Sinefu (2011) further explained that differences in emergence is influenced by seed colour whereby dark seeds emerge better than light coloured seeds due to the fact that they are vigorous than light seeds as it is the case in this study. However, this was not the case in Makhathini Research Station. The same trend of no significant differences ($P > 0.05$) was observed in Newlands East Permaculture Centre. Landraces reacted the same to cooler to warmer temperature, soil moisture and soil temperature as well as soil condition and fertility in that site.

Significant differences ($P < 0.001$) were observed among landraces for leaf area index in Makhathini. According Jeuffroy and Ney (2007) leaf area depends on cell number and cell size and it changes with time due to cell division and cell expansion. The differences in terms of LAI among landraces were due to the ability of landrace to increase in leaf size in a canopy, nature of canopy, structure canopy size, canopy position and the shape of the plant. Leaf expansion between landraces was not the same whereby some landraces produced branches and leaves at early stages than the others. When the plant continue to grow in structure and size with expansion of leaves and stem elongation the leaf area index increases Other factors which contributed to LAI were light and energy capture in leaves whereby long hours of day length and good interception of radiation in the leaves of the canopy led to high leaf area index (Garcia et al., 2012). Differences were also attributed by interception of light among landraces which was not uniform due to the position of the plant and the structure of the plant. Significant differences of landrace and weeks were due to the large variation of plant height week after week which was because of continuous branch and leaf development (Robertson et al., 2001).

In Newlands East Permaculture centre, plant growth in terms of height has been slowly growing due to low temperatures and that slowed down the crop growth which led to lower leaf area index. This was also influenced by the stress due to drought during the month of May and June. Soil conditions also played a role in contributing to lower leaf area index because soil was stony which also limited plant root to penetrate and grow and reproduce well. There was an increase in leaf area index at different growth stages of the landraces. Setiyono et al. (2012) found that leaf area index is influenced by biomass which simple mean that when the plant biomass accumulates or increase, LAI also increases during different stages of development except when plant reaches physiological maturity due to leaf litter and leaf oldness.

Significant differences ($P < 0.05$) were observed among landraces for plant height in Makhathini. Plant height is known to be affected by maturity duration, photoperiod and environment and increases by exposure of plant to long day (Egbe and Vange, 2008). Significant differences among the different landraces maybe attributed to maturity, photoperiod and environment (Egbe and Vange, 2008). Plants had different height in Makhathini due to sensitivity to photoperiod among landraces whereby they reacted differently and exposure to long day condition and temperature sensitivity among landraces. This is evidenced by Robertson (2001), that genotypic differences are influenced by the temperature in terms of plant height. Maturity period has also influenced plant height in Makhathini whereby plant continue to grow vertical until they are physiological matured. No significant difference was observed in Newlands East in terms of plant height among landraces. Plant reacted the same to the rainfall, temperature and soil moisture. Soil had impermeable layer whereby plant roots were limited when growing. Plants were stressed due to unavailability of water during vegetative growth and development stage. Reduced plant height in Newlands than the potential plant height of pigeon pea was due to the delay in sowing or in planting (Rani and Reddy, 2010).

Early flowering has an influence on yield (Ncube et al., 2002). There were high significant differences ($P < 0.001$) in Makhathini among landraces with regards to flowering. Earliest landrace to flower was dark brown within 150 days followed by light brown with 155 days to flower. Days to 50 % flowering and 75 % maturity are positively correlated (Egbe and Vange, 2008). Differences in flowering in Makhathini was observed and concluded that cultivars differ in their phonological response to temperature and their sensitivity to photoperiod as well as to their association or reaction to environment conditions of the site. The more the landrace was sensitive to photoperiod the more flowering was delayed. Flowering is triggered by short days (Jeuffroy and Ney, 1997). Long day makes flowering response to be on critical photoperiod and flowering is delayed (Silim et al., 2007).

There were high significant differences ($P < 0.001$) in Newlands where landraces flowered early especially light brown at 106 days after planting, followed by dark brown at 110 days after flowering. There were great differences between flowering of all the four landraces which were dark brown, light brown, light brown with brown and white with black with flowering of cream white and cream white with brown which flowered after 201.30 and 196. 50 days after planting, respectively. Days to flowering of those two landraces were close to physiological maturity of light brown with brown and light brown landrace which reached their maturity at 199.70 and 197.30 days after planting respectively. The delay of flowering of the two landraces (cream white and cream white with brown) was due to lower or cooler temperatures in the middle of the growing season (May to July) accompanied by short photo-period. According to Omanga et al. (1995), the period before first flower appears varies among pigeon pea cultivars and with location and season. Robertson et al. (2001) also stated that flowering is delayed in longer days than short days because the crop is a short day plant. This concurs with the rate of flowering of four landraces in Newlands flowered before Makhathini. Differences in days to 50 % flowering were also influenced by cooler temperatures in Newlands East Permaculture

Centre. Early maturing cultivars are insensitive to photoperiod and late maturing are sensitive (Singh, 2012) as it also known that short duration cultivars are less sensitive to photoperiod and long duration are more sensitive so as early flowering genotype are less sensitive than late flowering (Carberry et al, 2001). This is because when it flowers late it reaches ceiling photoperiod which is reached when maximum days are taken to flower (Silim et al., 2007). Cool temperatures lengthen flowering while warm temperatures shorten the duration of flowering (Silim, et al., 2007). This applied in Newlands where there temperatures were low during May to June where cream white and cream white with brown did not flower with relatively all the landraces. These two genotypes or landraces differences in flowering indicated that the adaptation to the area where the seeds were collected (Hluhluwe, KwaZulu-Natal) and where planted (Newlands) were different in environmental conditions such as temperature and soil type. Silim et al. (2007) also stated that the optimum temperature for early flowering is 18 °C for late duration type.

Differences in physiological maturity among landraces in Makhathini were observed. Delay in physiological maturity to some landraces was due to sensitivity in phenology where it also affects grain yield and the reaction of each landrace to environmental conditions such as temperature and photoperiod as well as moisture utilisation. It can be concluded that landraces such as light brown with brown, light brown and white with black were sensitive to photoperiod as a result they flowered and matured late. Newlands East permaculture centre landraces did not reach physiological maturity because of seed abortion caused by low temperatures during June and July.

Increase in yield is attributed to more number of branches, number of pods per plant and harvest index (Rani and Reddy, 2000). Grain yield is known to be affected by photoperiod and low temperature. Many measured yield variables had no significant differences among landraces at maturity in Makhathini, only seed per pods and 100 seed weight had significant difference among the landraces. The differences in seeds per pod and 100 seed weight were attributed to genetic characteristics or genetic make-up of the landraces whereby seeds per pod, pod mass and pod length is said to be not influenced by environmental conditions and growth traits (Singh, 2012). The significant differences in those yield components are further explained by Islam and Fakir (2007) that canopy structure, canopy spreading and degree of branching influences most of the yield components such as number of pods per plant. The significant differences were also due to reaction of different landraces in temperature and photoperiod even though 100 seed weight and seeds per pods are not major determinant of grain yield. 100 seed weight in dark brown and white with black landrace was high because it has bigger seeds than the other landraces. No significant differences ($P > 0.05$) were observed in nitrogen fixation among landraces although changes were observed during different stages of development whereby nitrogen fixation increased from vegetative stage to flowering state in Makhathini Research Station then decreased at 75 % physiological maturity. Mapfumo et al. (1999) stated that nitrogen fixed is related to biomass whereby smaller amount of fixed nitrogen are a results of lower biomass productivity. On average, among all landraces, dark brown and light brown landraces fixed more kg of nitrogen in Makhathini Research Station. Dark brown and white with black fixed high nitrogen in Newlands East Permaculture Centre on average of vegetative and flowering stage.

3.5. Conclusions

Although there are many important measured genotypic and phenotypic parameters which included plant height, leaf area index, seed emergence, chlorophyll content, flowering components (flower colour and flowering pattern), days to 50 % flowering and 75 % to maturity, they are not important as grain yield. The study characterised all the above mentioned variables with an aim of answering the problem in chapter 1 whereby it was related to low yield of landraces in most countries of the continent and an objective of selecting high yielding landrace (s) for crop improvement through breeding. The average yield for all the landraces planted in Makhathini was 1.27 tons per ha. Although there were no significant differences between grain yield among landraces but dark brown landrace performed best yielding 1.49 tons per ha followed by white with black and light brown yielding 1.37 and 1.36 tons per ha, respectively. These were the landraces with high yield potential and fixed high nitrogen in Makhathini and can be recommended to be adopted by farmers through their yield performance and ability to fix high nitrogen.

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CHAPTER 4:
AGRONOMIC CHARACTERISATION AND EVALUATION OF PIGEON GENOTYPES USING MULTIVARIATE STATISTICAL ANALYSIS

Abstract

This research focused on analysis of various pigeon pea parameters using principal component analysis and correlation coefficients for identifying yield contributing parameters in pigeon pea landraces. Seeds of six landraces of pigeon pea were sown in a randomized complete block design replicated 3 times in both Makhathini Research Station in Jozini and Newlands Permaculture Centre in Durban. Results of principal component showed that Makhathini was defined by time to 50 % flowering, plant height at week 20, chlorophyll content, leaf area index, yield and yield components (pod mass, harvest index and grain yield). In Newlands, they were defined by fixed nitrogen at vegetative and flowering stage as well as seed emergence. Light brown landrace was the landrace associated or related to grain yield, harvest index and pod mass than any other landraces. Results revealed that yield was related to two parameters which were harvest index and pod mass in Makhathini. Correlation analysis was also used on estimating yield contributing parameters. Correlation results revealed that there were significant positive correlations between seed emergence percentage and fixed nitrogen at maturity (0.62). Grain yield in tons per ha was also significant positive correlation with pod mass (0.84) and harvest index (0.76). Correlation results also revealed that biomass was the major influence to fixed nitrogen at maturity (0.86). Negative correlations also existed between germination percentage and seeds per pod (-0.52), seed emergence and harvest index (-0.50). Large significant negative correlation existed between harvest index and biomass (-0.76). The results of the two analyses (principal component analysis and correlation coefficient) clearly indicate that grain yield was influenced by pod mass and harvest index in Makhathini. Pod mass and harvest index should be considered as parameters for selecting high yielding pigeon pea landraces.

4.1. Introduction

Pigeon pea (*Cajanus cajan L.*) is an important grain legume crop grown for its multiple uses as a source of food, animal feed, fuel, and source of nitrogen (Khaki, 2013; Wilson et al., 2012). Pigeon pea has been identified as a possible substitute crop which can be bought by all people and provide an acceptable amount of nutrition and protein in particular because it is not expensive. Many varieties of pigeon pea are low in yields (0.5 - 1.0 t ha^{-1}) due to cultivation of traditional culitvars (landraces) (Ladizinsky and Hamel, 1979; Egbe et al., 2013). According to Das and Fakir (2010), indeterminate type which are most grown by farmers have low grain yield which is due to failing of the crop to adapt well and there is lack of characterisation of the crop.

Although the crop has not been planted as a commercial field crop in South Africa, its low grain yield of between 0.5 and 1.0 tons per ha has been reported in Limpopo, KwaZulu-Natal and Mpumalanga (Department of Agriculture, 2003; Snapp et al., 2003; Gwata and Shimelis, 2013). Although several studies have identified photoperiod as a factor affecting growth and flowering of pigeon pea, other environmental factors are believed to contribute to low yields. However, there is a lack of information in the literature reporting specific factors reducing yields of pigeon pea in South Africa. There is also a lack of knowledge on agronomic characterisation of the crop in South Africa. Furthermore, results of studies reporting research related to the crop yield are based on data subjected to normal statistical analysis techniques. These statistical methods are not sufficient to discriminate genotypes, especially when characterisation is based on more than one trait of interest. Therefore, multivariate analyses are advantageous in a way that they distinguish systematic from non-systematic variation. These statistical or chemometric methods also summarise the data and reveal the mapping structure in a graph such as linear regression and non-linear regression.

Multivariate data analysis consists of methods to analyse data sets with more than one variable (Abdi, 2003). Multivariate analysis has been used mostly in summarizing, analysing and describing variation in many crop genotypes (Makinde and Ariyo, 2010). It is also important in different fields which are bioinformatics, psychology, finance education, science and many more (Copeland and Raymer, 2012) and is a way of analysing large and complex data and has ability to detect correlations (Nguyen et al., 2014). Multivariate analysis is important in analysing two-way matrices which are genotype x environment interaction (Alberts, 2004).

Multivariate analysis include several techniques such as principal component analysis (PCA), principal coordinate's analysis, factor analysis, regression analysis, discriminant analysis, etc. These methods aim at transforming the data from one set of coordinate axes to other axes especially in a continuous data. These classification techniques involve grouping similar entities in clusters and are effective for summarizing redundancy in the data (Alberts, 2004). Many statistical analysis are not accurate when it comes to analysing large set of data, therefore the objective of this study was to characterise the agronomic traits of pigeon using multivariate statistical analysis such as PCA, which simplifies the complex data by transforming the number of correlated variables into a smaller number which is principal component (Ajmal et al., 2013). It is also important in comparing characteristics of different genotypes (Magwaza et al., 2014). This study also aimed at analysing the pigeon pea traits or characters using correlations analysis which determines simple relationship among traits.

4.2. Materials and methods

4.2.1. Plant material and seed characterisation

The seeds of pigeon pea landraces were obtained from small-scale farmers in Tshaneni, Mkuze in KwaZulu-Natal, South Africa. Six landraces used in this study were categorised based on seed coat colour as dark brown (DB), light brown (LB), white with black (WBL), light brown with brown (LBB), cream white with brown (CWB) and cream white (CW).

4.2.2. Field experiment

Field experiments were conducted during 2014/15 growing season in two experimental sites which were Makhathini Research Station in Jozini, KwaZulu-Natal, South Africa (27,430° S, 32,067° E) and Newlands East Agricultural Permaculture Centre in Durban, South Africa (29,53°S; 31,03°E) under rain-fed conditions. The soil types were sandy clay and silt clay loam soils in Makhathini Research Station and Agricultural Permaculture Centre, respectively. Five soil samples were collected in each site at the depth of 30 cm before planting. The soil sample were then combined and sent for soil chemical and physical properties at Cedara Analytical Laboratory of the Department of Agriculture and Rural Development in KwaZulu-Natal.

4.2.3. Data collection

Daily measurements of germinated seeds were taken by counting the number of germinated seeds each day and recorded daily for 7 days as the final germination day. Seedling emergence was taken in the field and recorded 4 weeks after planting in Newlands and Makhathini. Plant height was measured from soil surface to the apical tip of the plant. Measuring tape was used for measuring plant height. This was measured from four weeks to the physiological maturity of the crop. Three plant representatives were sampled in a net plot for such measurement whereby the measurements of plant height was taken in an interval of 4 weeks in both experimental sites. Leaf area was measured using the LAI2200 Canopy Analyser (LI-COR, Inc. USA & Canada). Measurements were done in both experimental sites which were Makhathini and Newlands in an interval of 4 weeks. The chlorophyll content was measured using chlorophyll content meter (CCM-200 *PLUS*, Opti-Sciences, USA). Three plants were sampled in a net plot whereby each second leaf from each plant was chosen for the sample. Morphological traits such as leaf colour, leaf hairiness, leaf shape, stem thickness, growth habit, flower colour, flowering pattern, streak colour, pod colour, pod shape, pod construction, seed coat colour, seed shape, seed eye colour were observed and recorded

At 50 % flowering most parameters were observed and recorded and some were measured. Day to the 50 % flowering, flowering pattern, flower colour, flower or petal streak, streak colour and raceme colour were among the physiological parameters measured. The days to 50 % flowering was recorded after counting half of the plants per plot which has flowered, flowering pattern through observing the position where the plant has borne its flowers and state whether it is determinate, semi-determinate or indeterminate. Flower colour was observed in all the plants and recorded whether red, yellow or purple. Flower or petal streak was also observed and stated whether it is low, medium or dense and its colour by checking the colour on the petal. Days to physiological maturity were monitored and recorded. This was determined when 75% of the pods changed colour from green to brown. Above ground biomass, grain yield, 100 seed weight, pod per plant seeds per pot, pod length, pod colour, seed colour and harvest index. Above ground biomass was obtained after weighing the fresh and dry mass after harvesting the above parts of the plant in exclusion of roots. Grain yield was obtained and recorded after harvesting the net plot and weighing the mass of dry pods which was determined by total seed mass after threshing. Nitrogen difference in pigeon pea was done by taking samples in plants at flowering and maturity on each plot and also by sampling the non-nitrogen fixing species. Samples were also collected when leaves have littered to obtain the nitrogen which will be transferred by the decaying leaves to the soil.

4.2.4. Data analysis

Data collected in this study was subjected to multivariate statistical analyses, including principal component analysis and Pearson's correlation. PCA was perfumed on an Unscrambler Software (Version 10.3, CamoSoftware, AS, Norway). PCA was used to identify the main associations or contributions to grain yield in different landraces and their distribution pattern. The scores which describe the response of genotypes to a certain environment, bi-plot and correlation loadings describing order of interaction of genotype and the measured parameters were determined. Correlation coefficient was also done using matrix correlation table in Microsoft excel (Microsoft. 2010, USA).

4.3. Results

4.3.1. Makhathini Research Station

When multiple variables of pigeon pea were subjected to principal component analysis, obtained scores and loadings showed a clear separation or clustering of landraces based on their physiological parameters. The first two principal components contributed 66% to the observed mapping, with PC1 and PC2, respectively contributing 42 and 24 % to this clustering. A bi-plot clearly demonstrated the parameters distribution which was clustered into four different groups. The results of correlation loadings of the PCA on PC-1 (42 %) and PC-2 (24 %) in Figure 4.2 show distribution among the physiological parameters measured. Figure 4.3 further showed that seed emergence, pods per plant, seeds per pod, days to 50 % flowering and days to maturity and fixed nitrogen at flowering had a strong influence on LBB, DB and CW landraces in Makhathini. LB was mostly associated with above biomass and fixed nitrogen at maturity. Dark brown was mostly associated with seed emergence, seeds per pod and pods per plant while cream white was associated with 100 seed weight in Makhathini.

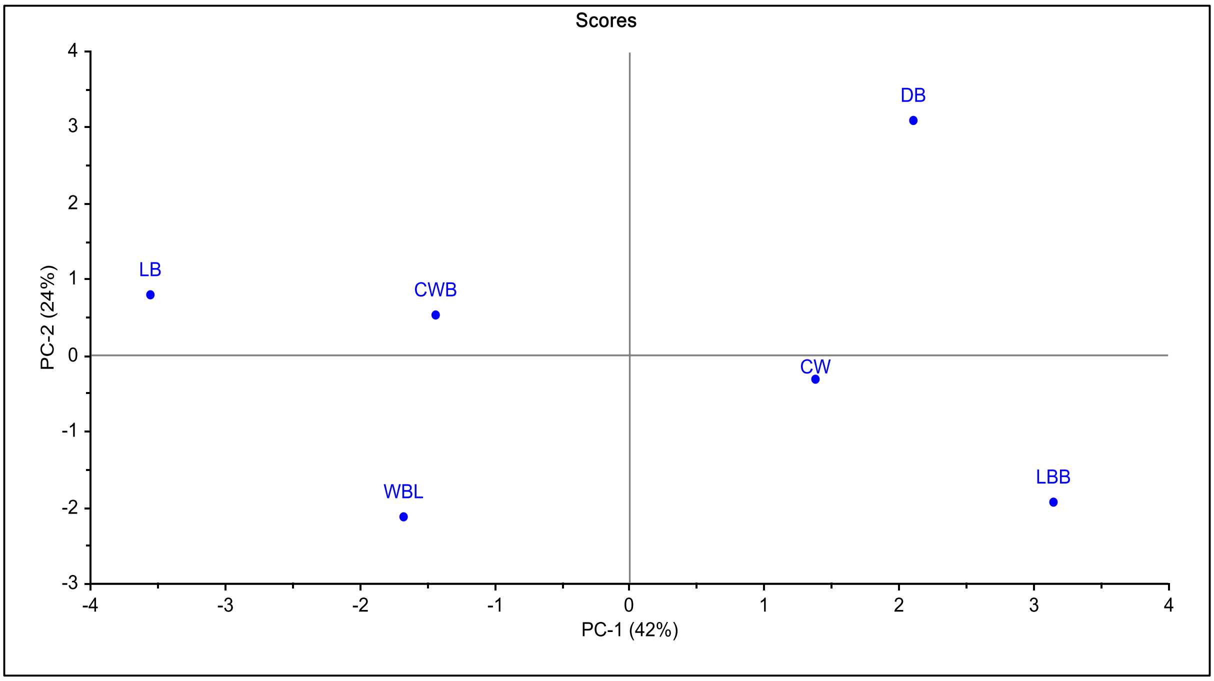

Figure 4.1: Principal component analysis scores of landrace distribution in Makhathini. (CW) cream white, (DB) dark brown, (WBL) white with black, (CWB) cream white with brown, (LBB) light brown with brown and (LB) light brown.

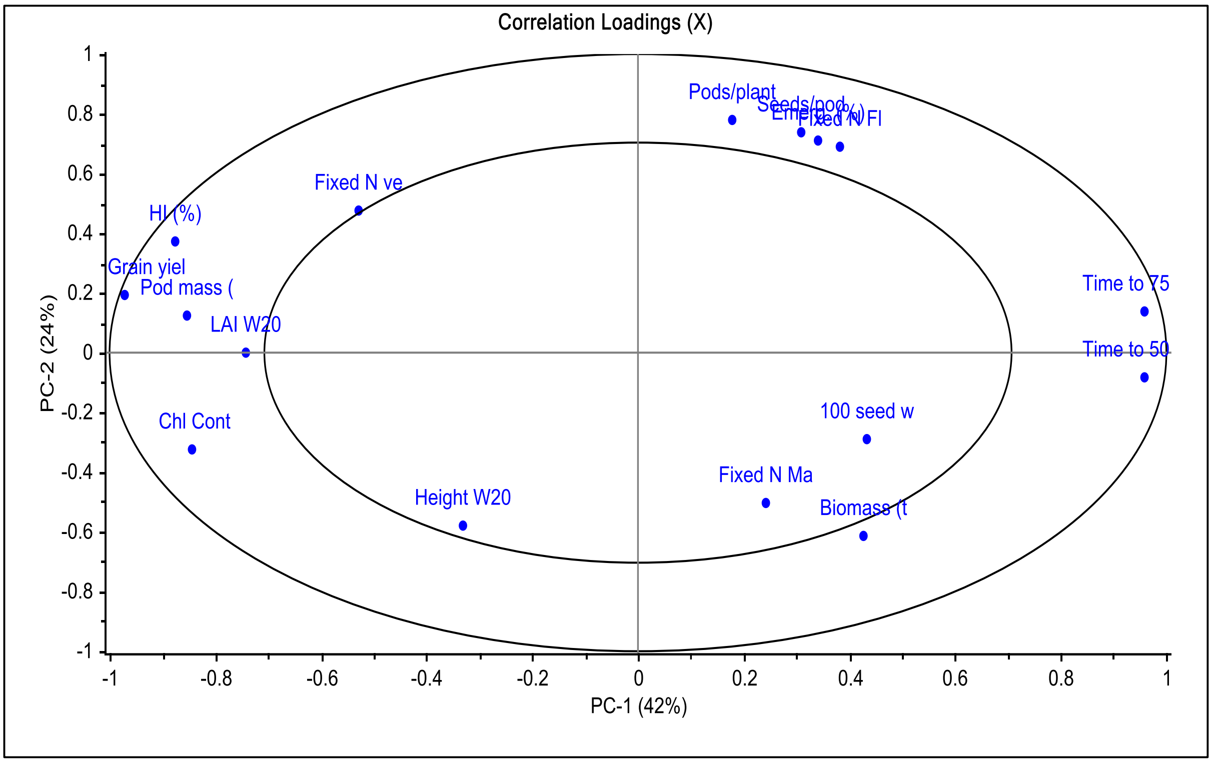

Figure 4.2: PCA correlations loading of parameter distribution in Makhathini

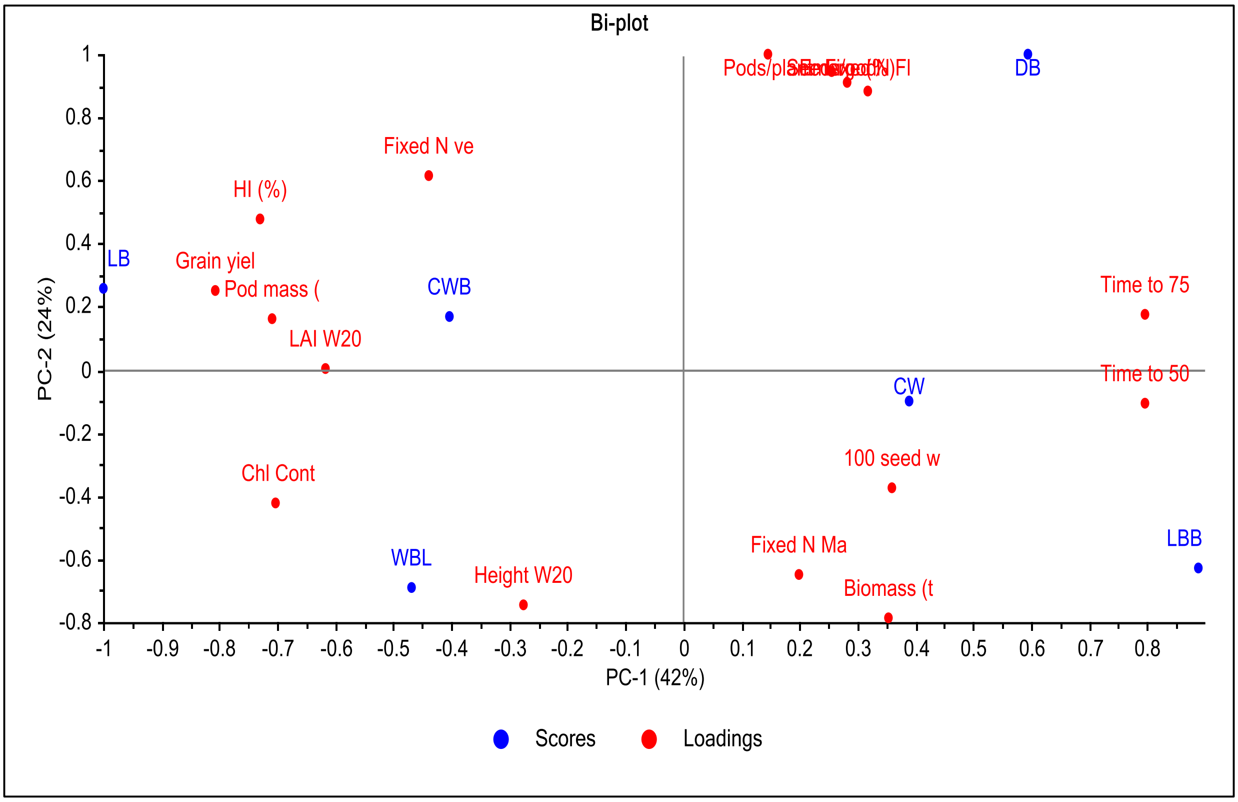

Figure 4.3: Principal component analysis bi-plot of landrace distribution and parameters in Makhathini. (CW) cream white, (DB) dark brown, (WBL) white with black, (CWB) cream white with brown, (LBB) light brown with brown and (LB) light brown.

Cream white, white with black and light brown were further explained by harvest index, grain yield, pod mass, leaf area index and chlorophyll content as well as plant height. According to bi-plot in Figure 4.3 light brown is defined by grain yield, harvest index and pod mass while white with black landrace is mostly associated with plant height in Makhathini.

4.3.2. Newlands permaculture centre

Results of the PCA scores and loadings in PC1 (42 %) and PC2 (25 %) of Figure 4.4 and 4.5 showed a clear separation or clustering of the landraces with their physiological parameters. The scores shown in a PCA in Figure 4.4 shows the distribution of the separation of landraces and Figure 4.5 shows the separation of the parameters measured in Newlands. Bi-plot in figure 4.6 clearly demonstrated the parameters distribution which was clustered into four parts of all the landraces. The results of correlation loadings of the PCA on PC1 (42%) and PC2 (25%) in Figure 4. shows that among the physiological parameters measured, seed emergence, pods per plant and seeds per pod had a strong influence on light brown with brown, dark brown and cream white landraces in Newlands.

In Figure 4.6, dark brown was mostly associated with seed emergence and leaf area index. There was no parameter measured that clearly defined cream white landrace in Newlands among all the parameters. It was also the same with cream white with brown which had no parameter defining it. Light brown landrace was associated to chlorophyll content whereby white with black was mostly associated with plant height. Fixed nitrogen at vegetative stage and fixed nitrogen at flowering did not influence any landrace among the landraces in Newlands.

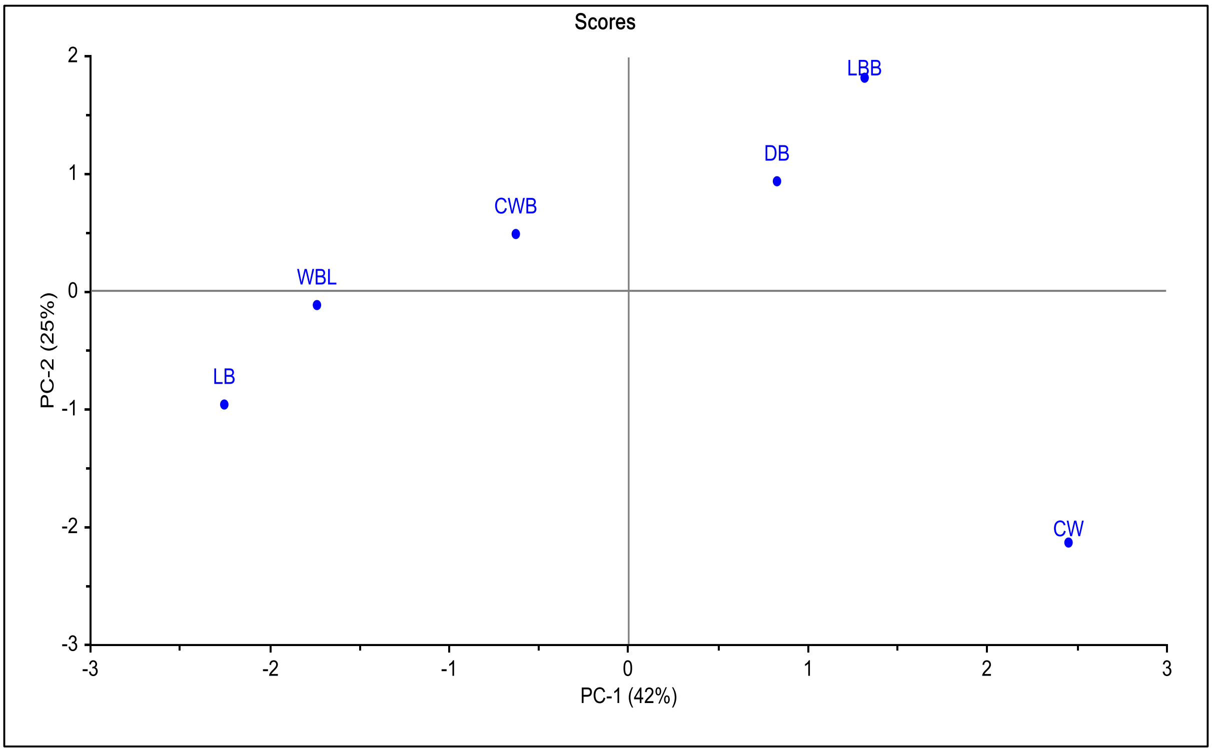

Figure 4.4: PCA scores landrace distribution in Newlands. Principal component analysis scores of landrace distribution in Newlands. (CW) cream white, (DB) dark brown, (WBL) white with black, (CWB) cream white with brown, (LBB) light brown with brown and (LB) light brown.

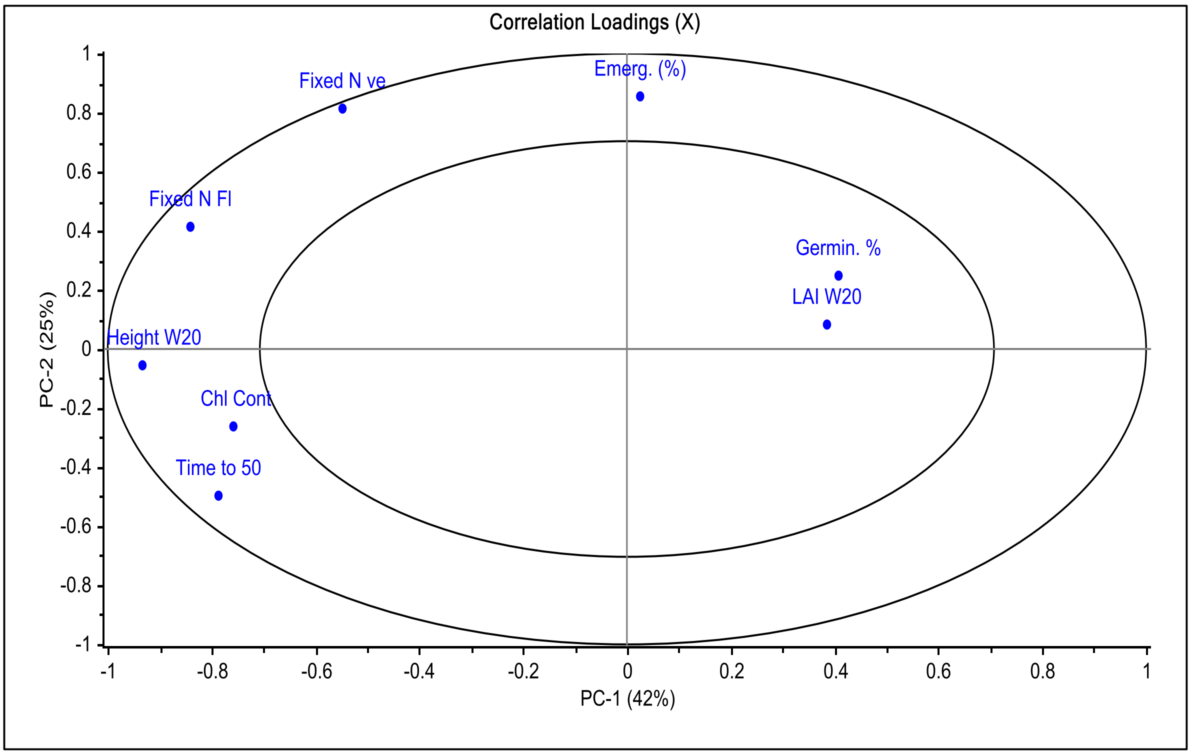

Figure 4.5: PCA correlation loadings of parameter separation in Newlands.

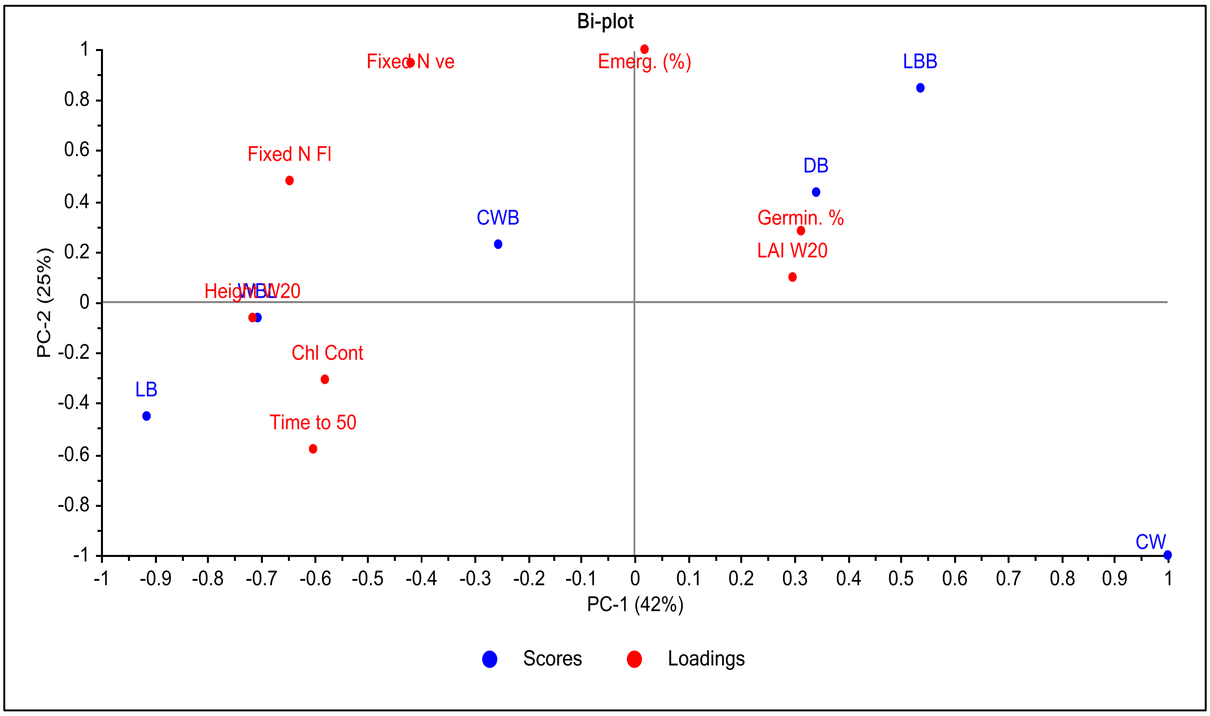

Figure 4.6: Principal component analysis bi-plot of landrace distribution and parameters defining them in Newlands. (CW) cream white, (DB) dark brown, (WBL) white with black, (CWB) cream white with brown, (LBB) light brown with brown and (LB) light brown.

4.3.3. Genotype x environment interaction

The results of the PCA scores in Figure 4.7, 4.8, 4.9 showed that the two environments or sites are separated with their parameters measured contributing to their separation and landraces. Figure 4.7 showed the separation of the two sites which were Newlands and Makhathini. Correlation loadings show the distribution of parameters measured (Figure 4.8). In Figure 4.9 which is the bi-plot showed the results of distribution and the relationship of the landraces with the parameters measured in both Makhathini and Newlands. Makhathini Research Station was defined by time to 50 % flowering, plant height at week 20, chlorophyll content, leaf area index, yield and yield components (pod mass, harvest index and grain yield) and Newlands was greatly defined by fixed nitrogen at vegetative and flowering stage as well as seed emergence. Light brown landrace was the landrace associated or related to grain yield, harvest index and pod mass than any other landraces. Light brown with brown was related time 75 % maturity and germination whereby cream white is related to biomass, fixed nitrogen at maturity and 100 seed weight. Dark brown was associated with seed emergence and fixed nitrogen at flowering. White with black landrace was defined by seeds per pod and pod per plant as well as plant height. Cream white was associated with leaf area index. According to the bi-plot in Figure 4.9 no landrace was associated with time to 50% flowering and chlorophyll content.

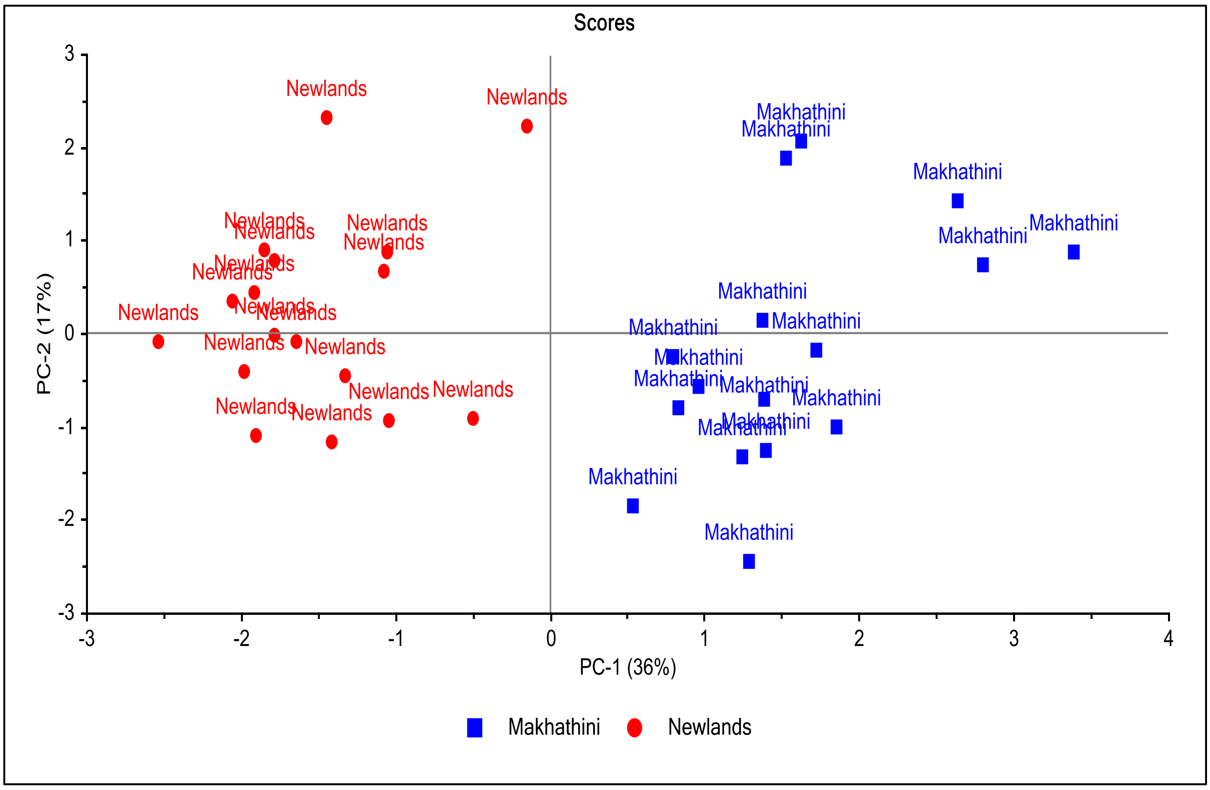

Figure 4.7: Principal component analysis scores of environment or experimental site distribution.

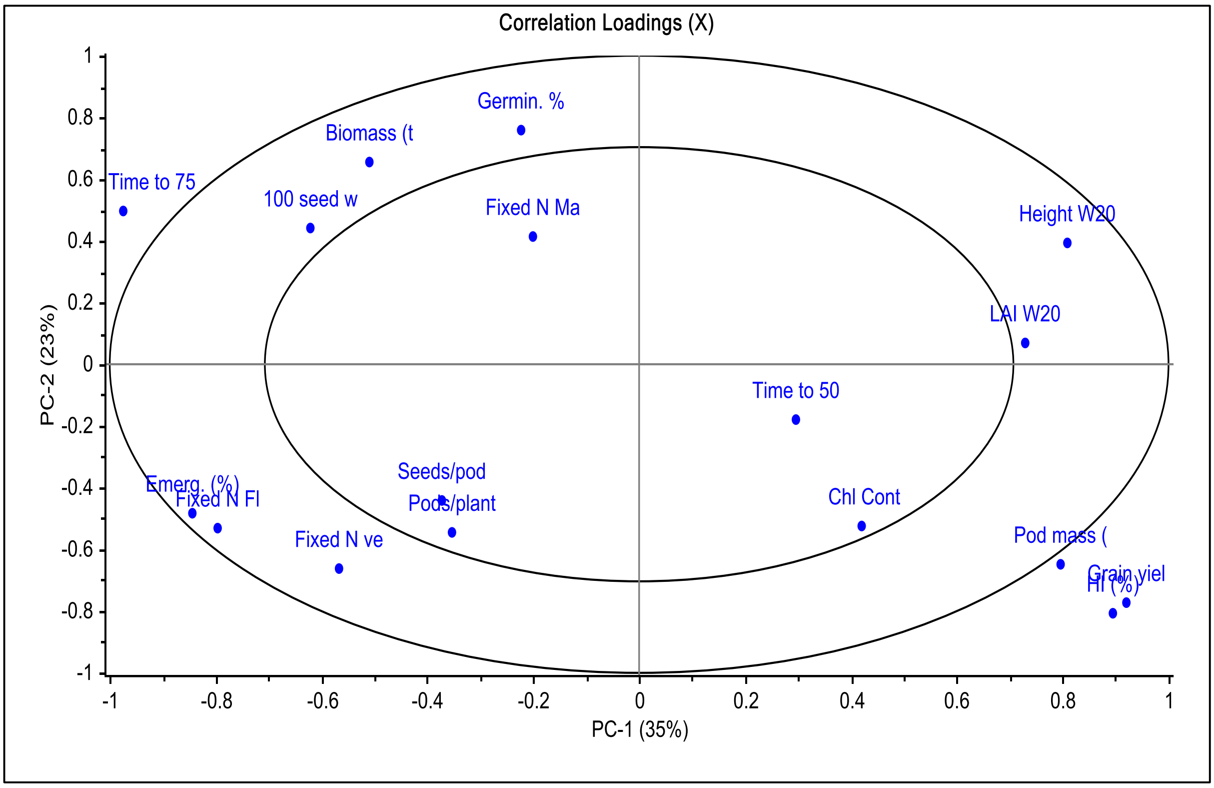

Figure 4.8: PCA correlation loadings of parameter distribution in Makhathini and Newlands.

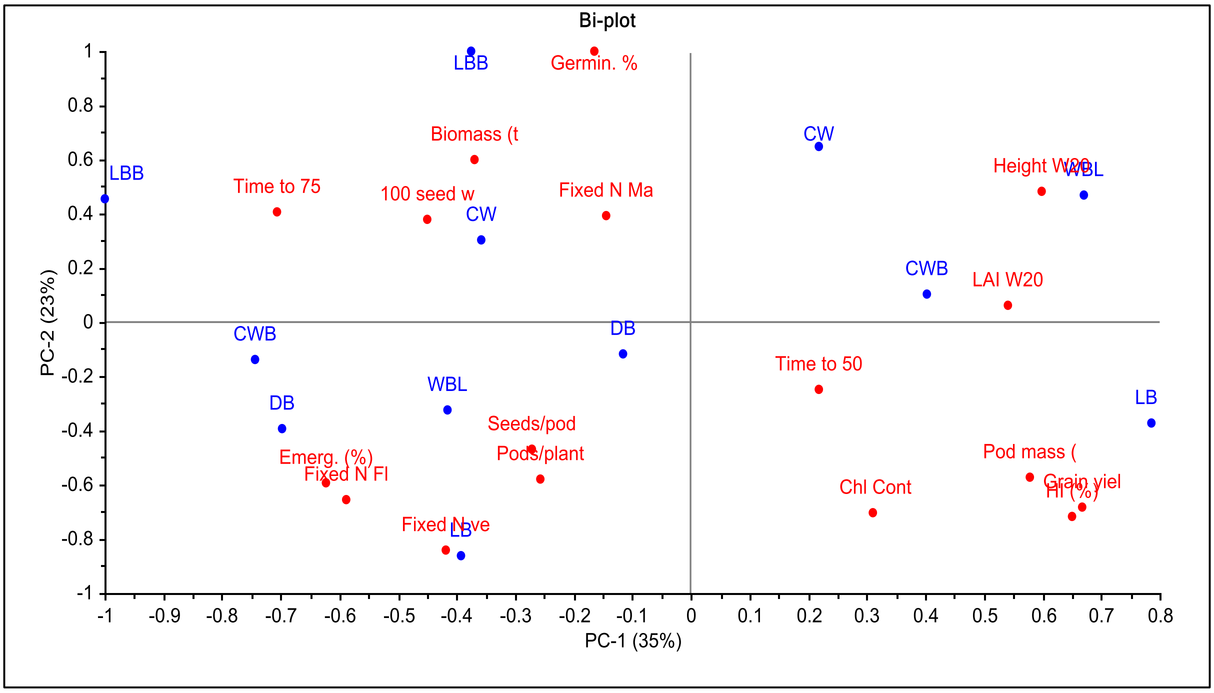

Figure 4.9: Principal component analysis bi-plot of landrace distribution and paramters in Makhathini and Newlands. (CW) cream white, (DB) dark brown, (WBL) white with black, (CWB) cream white with brown, (LBB) light brown with brown and (LB) light brown.

4.3.4. Correlations coefficient of parameters of pigeon pea landraces

Seed germination and seeds per pod had negative correlation with each other whereby the higher or an increase in seed germination per landrace posed a decrease in seeds per pod.

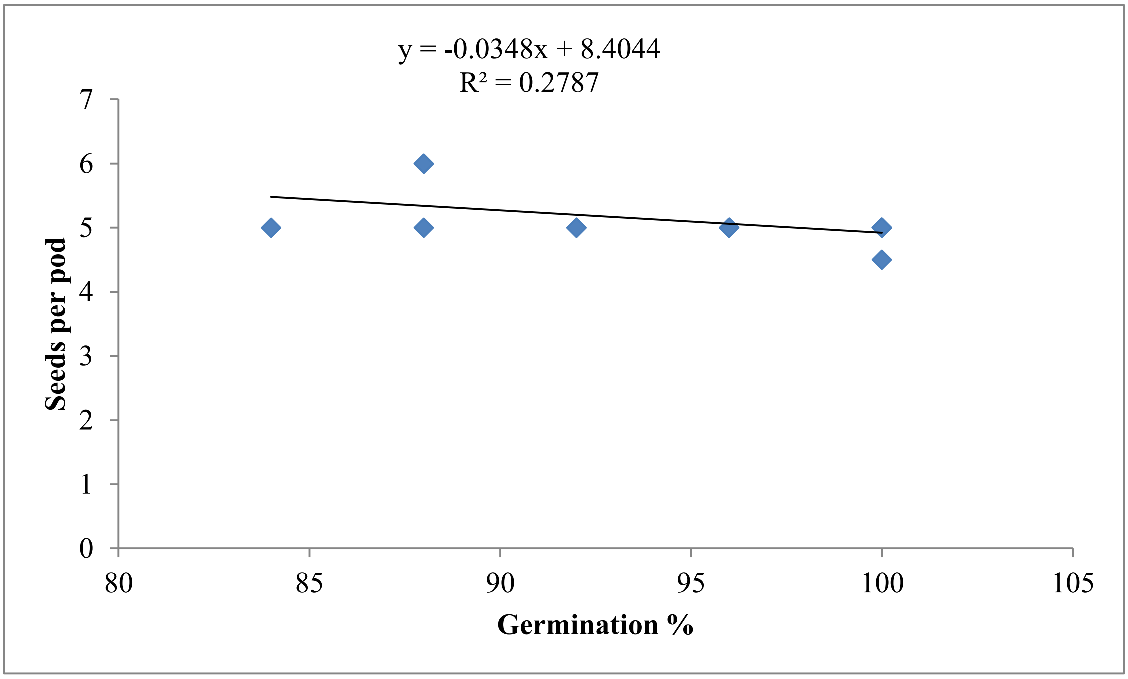

Figure 4.10: Scatter plot of correlation between seed germination % and seeds per pod in landraces.

There was no relationship between either the increase or the decrease of seed germination percentage with the number of seeds per pods which further explains that seeds per pod is not related or correlated with seed germination. The results of the scatter plot in Figure 4.11 revealed that there was a strong negative correlation between the seed emergence and harvest index whereby the higher the seed emergence had influence in the decrease of harvest index among pigeon pea landraces in Makhathini. In relation to seed emergence there is strong positive relationship between the seed emergence and biomass. There was another positive correlation between seed emergence and amount of fixed nitrogen at physiological maturity per hectare.

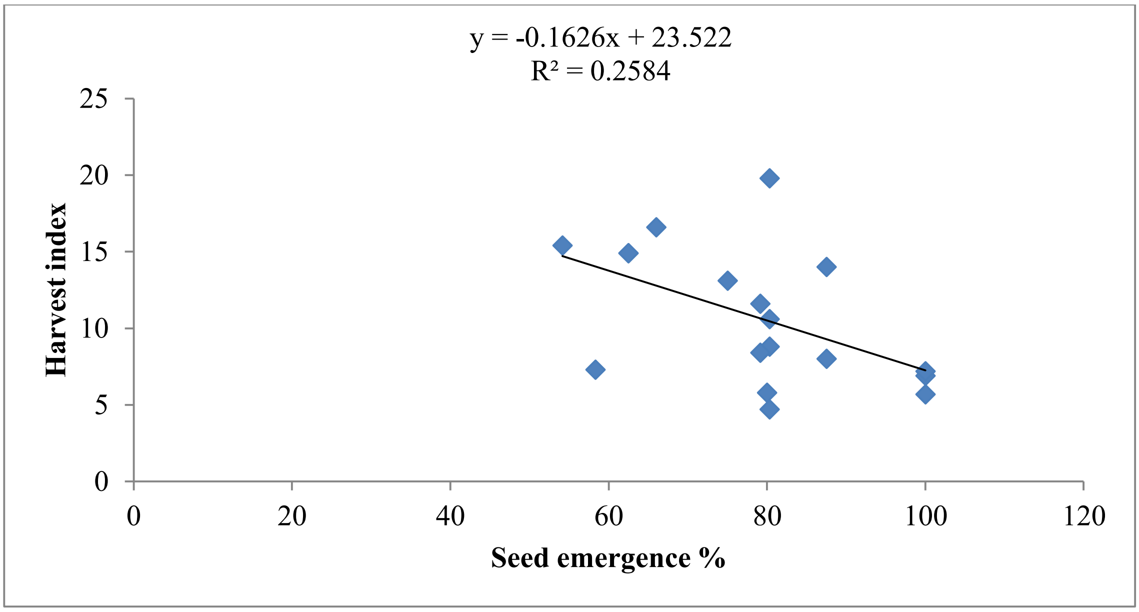

Figure 4.11: Scatter plot of correlation between seed emergence % and harvest index of pigeon pea landraces in Makhathini.

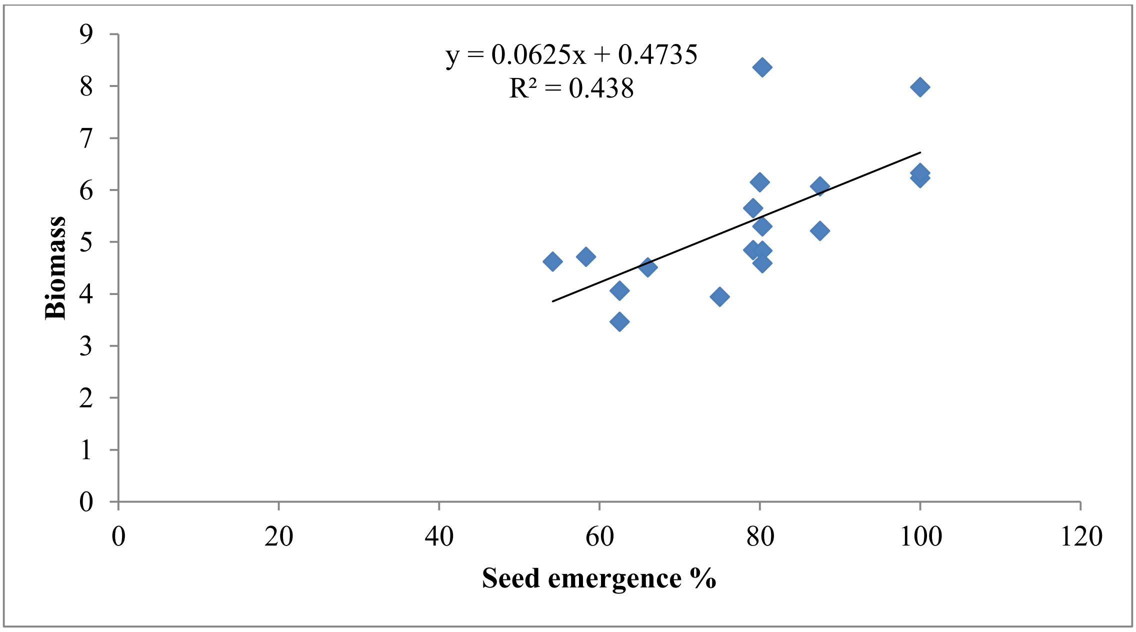

Figure 4.12: Scatter plot of correlation between seed emergence % and above ground biomass in pigeon pea landraces in Makhathini.

LAI had strong negative correlation with time or days to 50 % flowering whereby an increase in LAI at week 20 among the landraces was associated with earlier days to flower. This can also be explained by lower leaf area index which is associated with many days to flowering whereby LAI decrease with longest days to flower in pigeon pea landraces in Makhathini.

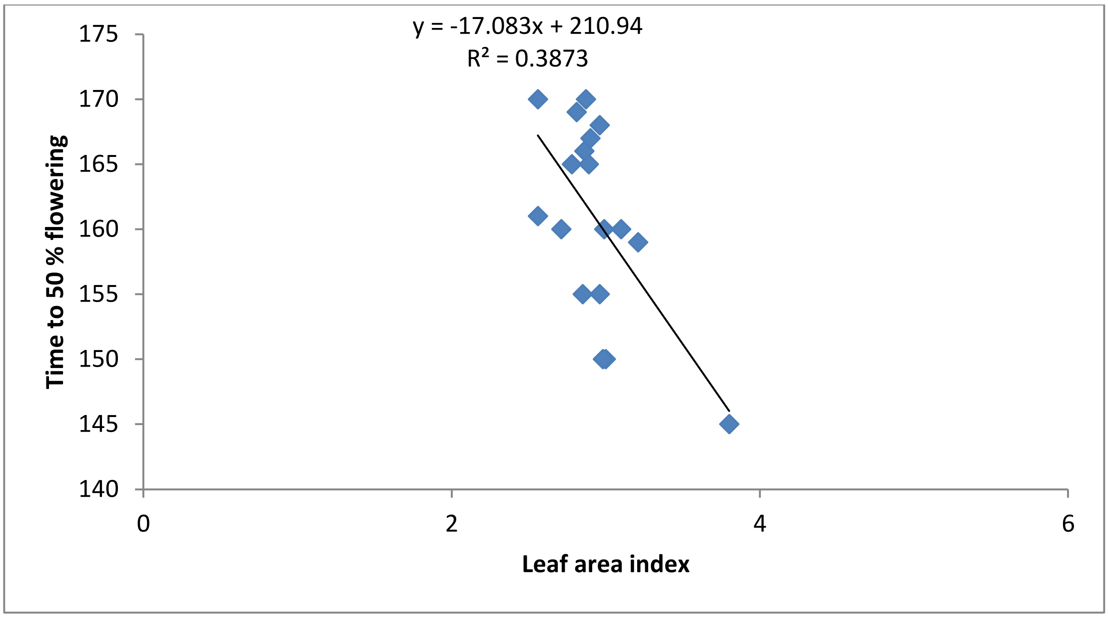

Figure 4.13: Scatter plot of correlation between seed leaf area index and time to 50 % flowering in pigeon pea landraces.

There was a strong positive correlation between time to 50 % flowering and time to 75 % maturity. Results revealed that early flowering was related to early maturity in Makhathini Research Station. This was evidenced in Figure 4.14 whereby landraces flowered in 145 days took 183 days to mature as well as when they take 170 days to flower they mature at 208 days.

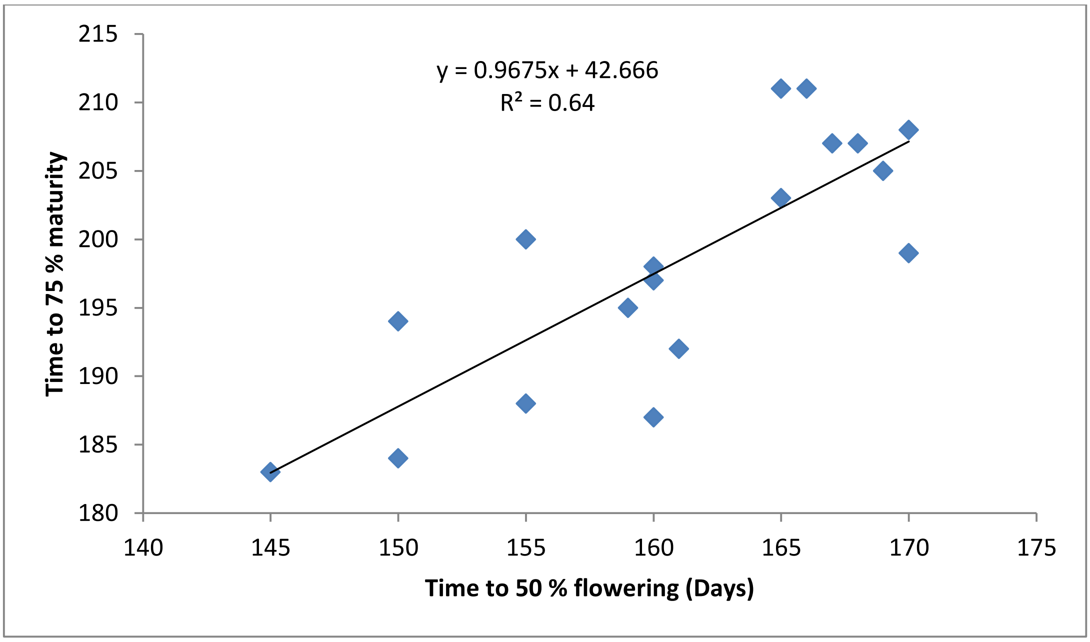

Figure 4.14: Scatter plot of correlation between time to 50 % flowering and time to 75 % physiological maturity in pigeon pea landraces.

Pod mass of pigeon pea landraces had an influence on grain yield whereby there was a strong positive correlation between the two. When the pod mass of the landraces increase the grain yield increases as well which further explained the association between the two parameters in Makhathini as shown in Figure 4.15. Results in Figure 4.16 revealed that nitrogen fixation at maturity depended on above ground biomass whereby when the above ground biomass increases it also increases the amount of fixed nitrogen at maturity in Makhathini Research station. It can be concluded that high biomass could be an indication of high nitrogen fixation. In Newlands research station among all the variables measured, only two parameters had correlation, the plant height at week 20 and time to 50 % flowering (Figure 4.17). Flowering in Newlands was influenced by the height of the plant. The landraces with shorter height tend to flower earlier than the taller ones.

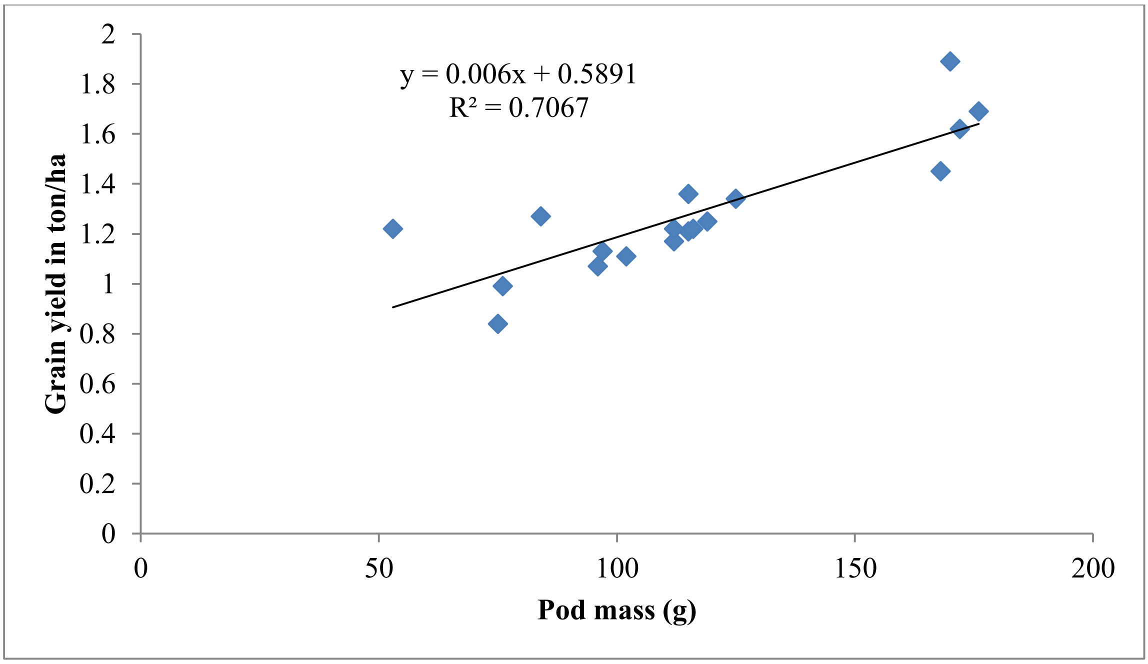

Figure 4.15: Scatter plot of correlation between pod mass in grams and grain yield in ton/ha of pigeon pea landraces.

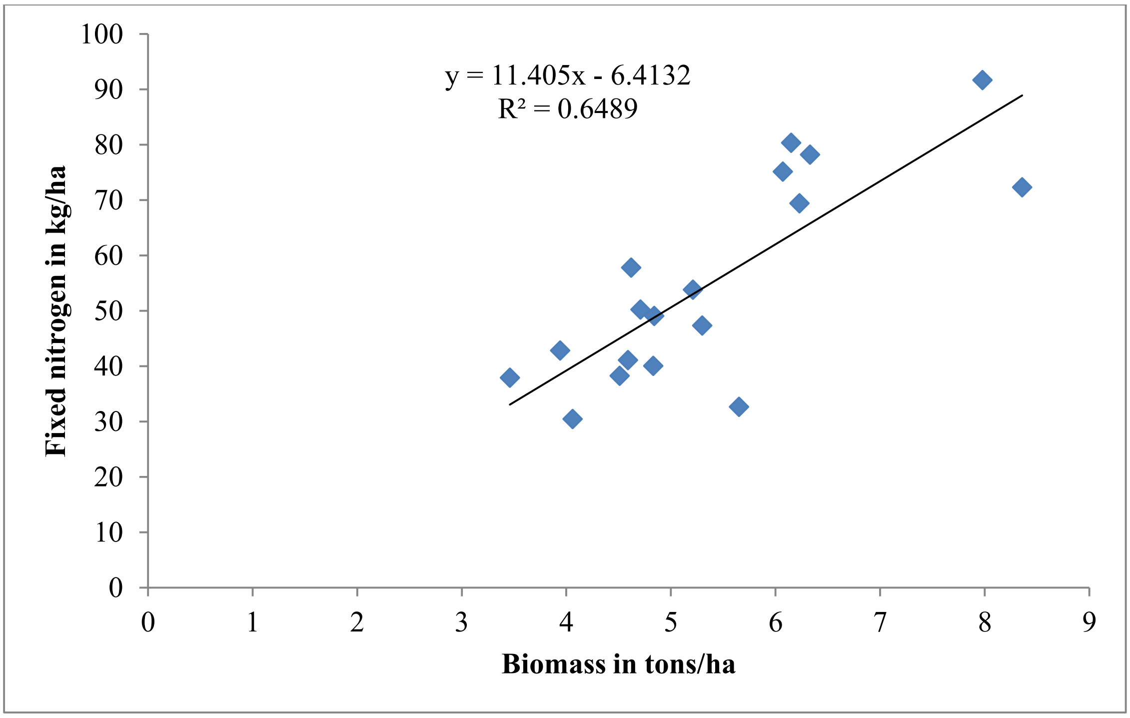

Figure 4.16: Scatter plot of correlation of above ground biomass and fixed nitrogen of pigeon pea landraces in Makhathini.

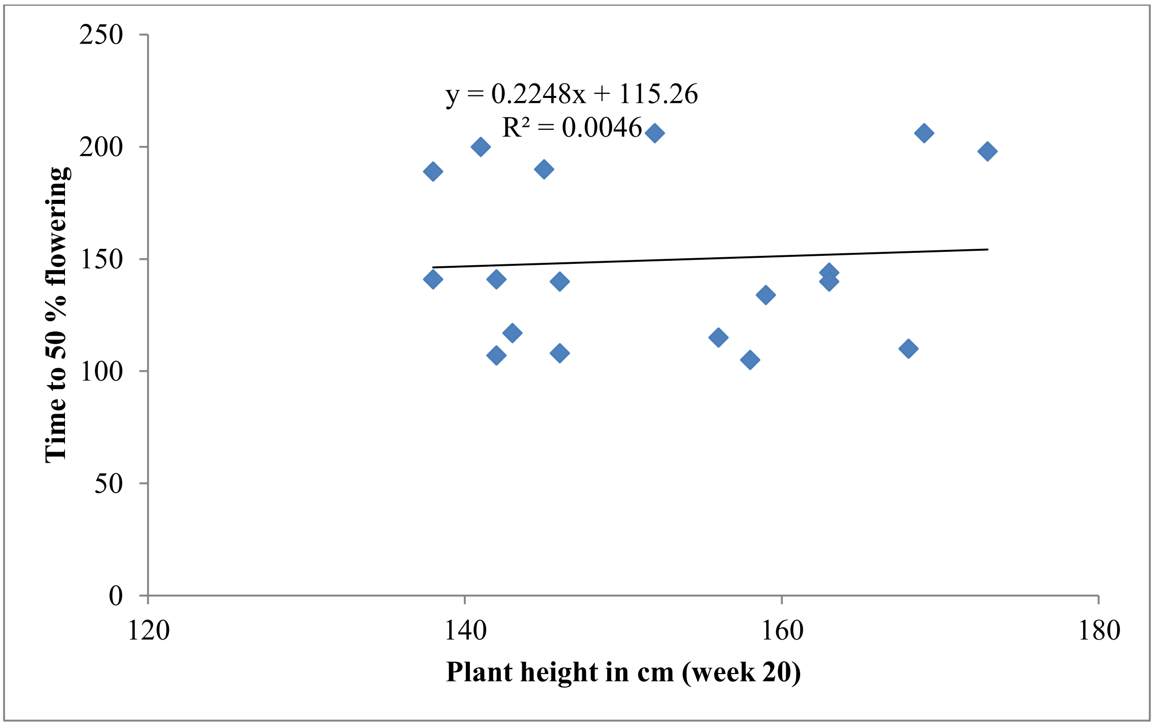

Figure 4.17: Scatter plot of correlation of plant at weeks 20 and time to 50 % flowering of pigeon pea landraces in Newlands.

4.4. Discussion

Results of PCA showed the clustering of pigeon pea landraces and their parameters influencing them. Some parameter defined a certain environment whilst some on the other hand defined the six landraces evaluated in this study. It was clear from the results that Makhathini Research Station was defined by time to 50 % flowering, plant height at week 20, chlorophyll content, leaf area index, yield and yield components (pod mass, harvest index and grain yield). Newlands was greatly defined by fixed nitrogen at vegetative and flowering stage as well as seed emergence. It was deduced that light brown landrace was the landrace associated or related to grain yield, harvest index and pod mass than any other landrace.

The basic relationships between traits were expressed by correlation coefficient analysis dividing the independent and dependent variables and their importance (Rasaei et al., 2011). There were significant variation among the traits measured which were seed germination, seed emergence, plant height, days to 50 % flowering, 75 % flowering and yield components with results revealing positive and negative correlation coefficient. Although previous research on correlation analysis found quantitative traits such as number of seeds per pod and number of pods per plant to be directly correlation with grain yield (Rasaei et al., 2011), correlation coefficient in this study indicated that grain yield had no strong positive association or correlation with days to 50 % flowering, days to maturity, 100 seed weight, pod per plant and seed per pod. Pod mass and harvest index were parameters contributing to yield of pigeon pea landraces. Grain yield showed positive association with pod mass and harvest index. The two parameters are desirable in plant breeding because it facilitates the selecting process of important and yielding landraces (Vange and Egbe, 2009).

According to variables concerning seed emergence, there was negative correlation between the seed emergence and harvest index. Seed emergence had positive correlation to biomass with a strong correlation existing between the two variables. One of the variables to influence biomass was seed emergence. Genotypic variables such as days to 50 % flowering, 75 % flowering, fixed nitrogen at all stages of development which includes vegetative, flowering and maturity as well as biomass, pods per plant and better seed germination were the variables which never contributed to grain yield of any landrace. Days to 50 % flowering and 75 % maturity are known to be positively related (Egbe and Vange, 2008). Time to 50 % flowering is known to influence time to 75 % maturity as it was the case in the study. Above ground biomass was significantly correlated with fixed nitrogen at maturity than fixed nitrogen at vegetative and flowering stage which had no correlation with biomass.

LAI at week 20 was negatively correlated with time to 50 % flowering. Although other traits such as chlorophyll content and plant height had no strong positive correlation and influence on other traits of landraces in Makhathini, plant height had a positive correlation and influence in determining the time required for a landrace to flower. The increase in plant height was greatly associated with longer days to flower in Newlands. When ranking the variables measured and their influence on an important variable which was grain yield, pod mass had strong positive correlation (0.84) followed by harvest index (0.76). Strong positive correlation of biomass and fixed nitrogen at maturity (0.80) existed. The least correlation was the negative correlation of harvest index and biomass which was -0.74 and a negative correlation of harvest index and fixed nitrogen at maturity which was -0.66 also existed.

Seed yield is the results of association of several plant growth components which helps in modifying other traits directly or indirectly. Genotypic and phenotypic correlation provides a measure association among different characters and also helps in identifying the traits in selection program (Yerimani et al., 2013). The positive correlation of major yield traits will be important in breeding although it will be difficult in selection of the best trait for a certain cultivar (Udensi and Ikpeme, 2012). The choice of breeding method for qualitative traits improvement depends on genetic variability in separating genetic material and gene action of a cultivar (Yerimani et al., 2013).

4.5. Conclusions

The study aimed at correlating variables which influences each other. Correlations between germination percentage and seed per pods, biomass and harvest index, leaf area index and time to 50 % flowering and seed emergence and harvest index were negative correlated. Positive correlations existed between 50 % flowering and days to maturity as well as biomass and nitrogen fixed at maturity. All these correlations were not related to grain yield as the main aim of the study was to identify traits or parameters related to grain yield. It is then concluded that grain yield in Makhathini is influenced by pod mass and harvest index which strongly positively correlated with the grain yield. According to the results of the PCA and correlation coefficient, pod mass and harvest index have to be considered as an indicator when selecting pigeon pea landrace (s) on grain yield basis.

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CHAPTER 5:
GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1. Discussion

The development of more yielding pigeon pea genotypes or landraces from South Africa will be important in eliminating food security threats for poor rural people with protein malnutrition. The crop is mostly grown under rain-fed conditions around the world. Drought and uneven distribution of rainfall are the major constraints that reduce the yield potential of the crop. Although drought and insufficient water due to climate change are major constraints to the production of the crop, genetic improvement is required to improve its yield and adaptation to such conditions. As pigeon pea remains one of the underutilised crops in Africa its improvement may result in recommending it as the potential source of proteins and other nutrients. The general aim of the study was to characterise pigeon pea landraces in two sites of KwaZulu-Natal, with respect to growth, development and yield responses to their environmental sites under rain-fed conditions. The findings of the study will be used to promote pigeon diversity and cultivation under the best suitable conditions

The results revealed differences in early growth, vegetative growth and reproductive growth responses of pigeon pea in the two locations (Makhathini and Newlands). Environmental conditions such as surface temperature, soil temperature, atmospheric temperature, rainfall, day length, soil moisture and photoperiod had an effect on the growth and development of pigeon pea. Makhathini was characterised by warmer temperatures and long or days whilst Newlands had warmer temperatures during summer and cooler temperatures during winter.

According to Silim et al. (2007) XSD and SD pigeon pea are insensitive to photoperiod, long days and warm temperatures during growth and development. The sensitivity to photoperiod is more severe in LD pigeon pea and mostly affects morphological traits which are plant height, biomass and grain yield being mostly affected. Seed germination and seed emergence were influenced by seed coat colour which has been reported to play an important role in the process. Harvesting stage also influences germination of pigeon pea, early harvested seeds result in immature seeds, this promotes poor seed germination. Biochemical reactions such as water uptake by a seed played a role in higher germination of light brown with brown than other landraces. Seed emergence proved to be affected by soil water content, seed quality, soil temperature and soil type as well as environment conditions (Mabhaudhi, 2009). Although there were no significant differences in seed emergence, it was hypothesised by Sinefu (2011) that dark coloured seeds emerge better than light coloured seeds as it is the case with dark brown, light brown and light brown with brown landraces which emerged more than the other landraces in Makathini.

According to Gwata and Siambi (2009), pigeon pea grown in high latitude areas above 10° sensitivity to temperature and photoperiod affect the vegetative and reproductive growth. It was further stated that the ability of landrace to increase in leaf size is affected by canopy, nature of canopy, structure canopy size, canopy position and the shape of the plant, radiation interception and these factors contributed on the differences in LAI of Makhathini. Slow growth of leaf area, and branching due to stress and impermeable soil in Newlands had no effect in leaf area development and LAI.

Slow growth of plant height in Newlands Permaculture centre was related to cooler temperatures and insufficient moisture during the vegetative growth. Sandy clay loam with impermeable layers which limit plant roots to penetrate also contributed to the slow growth of plant height than the potential plant height of the crop which is 2 to 3 metres. Higher plant height is known to be affected by maturity duration whereby long duration landraces have higher plant height than short and medium duration. Plants were taller in warm temperature than in cooler temperature. Uniformity in chlorophyll content of the different landraces evaluated was attributed to the genetic make-up as well as the location where the seeds were collected (Hluhluwe, KwaZulu-Natal). Reduction in chlorophyll content in Newlands was due to stress and insufficient water with minimization of light absorption by chloroplasts as evidenced by Mashilo (2013).

When pigeon pea plant flowers early, it results in high yield than when they flower late. Although statistically there were no differences in yield of all the pigeon pea landraces but according to Ncube et al. (2002), early flowering results in early maturity and high grain yield. DB landrace flowered early in this study and matured early and has more grain yield than other landraces. It was also the case with cream white landrace which flowered late (168 days) and had lowest grain yield which was 1.06 tons per ha. Days to flower and days to maturity are always related where by when the plant flowers early it is most likely to mature early as well.

Flowering was also delayed by short days than long days in warmer temperatures. Cool temperatures triggered flowering which often delayed flowering of cream white and cream white with brown landraces by two months in Newlands. Biomass accumulation in terms of increase in number of branches which also influences pod number per plant has a direct influence on yield. Yield was influenced by physiological maturity and flowering whereby landrace which flowered and matured early was most likely to have higher yield than the others. Singh (2012) explained that grain yield was not influenced by pod length and number of seeds per plant. In Makhathini pod length, number of seeds per pod and pod mass was possible influenced by genetic make- up of the plant. Seed weight also contributes to grain yield whereby larger seeds contribute to many kg per ha than small seeds. Even though dark brown, light brown and white with brown generally had higher in nitrogen fixation, it did not differ statistically. This was influenced by high weight of above ground biomass in other pigeon pea landraces.

It was deduced on the results of multivariate analysis PCA and correlation coefficient that pigeon pea yield and other parameters were positively or negative correlated. Results of correlation efficient concluded that pigeon pea grain yield was mostly associated with pod mass and harvest index as it was also the case with the results of principal component analysis. Principal component analysis segregated each site with the parameters defining it. This provided reliable information on the nature and direction of identifying characters which might be a useful indication of high yield which were pod mas and harvest index.

5.2. Conclusion

Significant differences existed with respect to most parameters measured such as seed emergence, seed germination, leaf area index, days to flower and days to maturity as well as yield and yield components among the studied landraces. Seed germination and seed emergence were influenced by temperature, harvesting period and soil conditions. Seed emergence in some cases was also influenced by seed coat colour (darker seeds have higher emergence whilst lighter seeds have lower emergence). Parameters such as plant height, flowering and days to physiological maturity were associated with photoperiod, temperature and rainfall distribution. Yield has been proved to be affected by flowering and maturity where high yield corresponded with early flowering and early maturing. Seeds per pod, 100 seed and pod mass are known to be influenced by genetic-base or genetic make-up in pigeon pea whereas high weight of 100 seed is caused by landrace with bigger seeds than the others.

Results of nitrogen fixation varied from each stage of plant development. The results indicated that nitrogen fixation by the pigeon pea landraces increases from vegetative to flowering stage then decreases at maturity stage. The mean of fixed N for vegetative stage at both Makhathini and Newlands were 12.33 kg per ha and 31.26, respectively. At flowering stage, the fixed nitrogen content had an average of 194.51 and 188.36 in Makhathini and Newlands, respectively. At maturity, the leaf litter nitrogen fixation was 199.41 per ha on average.

In conclusion, all the landraces characterised in this study were found to be long duration landraces which took more than 180 days to reach physiological maturity. On average, all landraces flowered within 160.8 days in Makhathini and 148.60 in Newlands. Additionally, landraces took 198.20 days to reach maturity in Makhathini. Grain yield of pigeon pea was proved to be influenced by pod mass and harvest index in Makhathini. This was deduced after correlating pod mass and grain yield which were strong correlated. Yield components such as pods per plant, seeds per pods were not strongly correlated to grain yield in Makhathini. Pod mass and harvest index could be used in selecting the high yielding and performing landrace(s) for further crop improvement in breeding program.

5.3. Recommendations

- ✓ Agronomic characterisation of pigeon pea in KwaZulu-Natal provided a reliable knowledge and information on pigeon pea adaptation in both Makhathini and Newlands. Dark brown, light brown and white with black landrace have to be recommended because of their high yield potential and high nitrogen fixing ability.
- ✓ Multivariate analysis and correlation coefficient provided information on identifying useful indicators of grain yield which were pod mass and harvest index.
- ✓ The study must be expanded by another season in the near future although significant amount of data were obtained but it had limited information on yield response to different locations because of landraces in Newlands failing to reach maturity.
- ✓ The study characterised long duration pigeon pea landraces, therefore future research should to be focused on characterising short duration and medium duration pigeon pea and evaluate its yield potential in KwaZulu-Natal.

- ✓ Future research should also focus on genetics and breeding programs to enhance the yield of long duration pigeon pea.
- ✓ Pigeon pea must be used in integrated cropping systems (sole, intercropping or crop rotation) to evaluate its yield performance and its benefit on other crops.
- ✓ The three landraces were high grain yielders (dark brown, white with black and light brown) and can be recommended for agro-forestry.

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