PERFORMANCE OF ELITE PIGEONPEA (*Cajanus cajan*) VARIETIES IN LIMPOPO PROVINCE

BY

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DEDICATION

With gratitude to God, this study is dedicated to my parents Phillemon and Machuene Matlala, who gave me the gift and the privilege to be at university to further my studies. Sincere gratitude also goes out to my siblings Motlakgomo, Khomotso, Phuti, Ramokome, Phasha, Hairice and Mokgadi, as well as to my son Phenyo, my nephew Koena and my nieces Tumisho, Blessing and Bokamoso who have always stood by me and kept me in their thoughts and prayers throughout my endeavours.

DECLARATION

I declare that the research report hereby submitted to the University of Limpopo, for the degree of Master of Science in Agriculture (Agronomy) has not been submitted previously by me or anybody for a degree at this or any other university. Also, this is my work in design and in execution, and related materials contained herein had been duly acknowledged.

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Matlala M.V   Date

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ABSTRACT

Pigeonpea (*cajanus cajan* [L] Millsp.) is a legume crop which is grown mainly in the Semi-Arid Tropical (SAT) regions and it is mostly cultivated for its edible seeds. It has been identified as a possible substitute crop which can be bought by all people and it can also provide an acceptable amount of nutrition and protein in particular as it is not an expensive source of protein when compared to animal protein. Its ability to tolerate drought and fix atmospheric nitrogen makes it suitable for marginal areas with low rainfall and poor fertility. However, it remains one of the underutilized crops due to limited research on the crop's diversification and adaptation. Smallholder farmers in the Limpopo Province cultivate landraces pigeonpea varieties that are characterized by late maturity, low grain yield and are sensitive to photoperiod and this makes it difficult for the cultivars to flower early and produce reasonable yield. The objectives of the study were to evaluate the nitrogen fixation, yield and yield components of exotic elite pigeonpea genotypes. The experiment was conducted at the University of Limpopo Experimental farm (Syferkuil) in Mankweng during the 2017/18 growing seasons. The trial was carried out in a Randomized Complete Block Design (RCBD) consisting of three replications. A total of 18 elite pigeonpea breeding lines obtained from ICRISAT in Kenya were planted at an inter-row and intra-row spacing of 1m and 0.5m respectively, in a row of 5m length with an alley way of 2m between the blocks. The standard management practices for pigeonpea were used for weed and insect control. The agronomic data collected included the number of days to first and 50% flowering, the number of days to 90% maturity, canopy width (m), plant height (m), peduncle length (m), number of primary branches, number of pods per plant, pod length (cm), hundred seed weight (g), calcium content, sodium content, magnesium content, phosphorus content, potassium content, iron content, zinc content, proportion of legume N derived from the fixation of atmospheric N_2 (%Ndfa), amount of nitrogen fixed and the grain yield ($kg.ha^{-1}$). The generated data was subjected to an analysis of variance using the Statistix 10.0 software. The Least Significance Difference (LSD) was used to separate the means that showed significant differences at an alpha level of 0.05. The results revealed significant differences in nearly all the pigeonpea variables (pod length, number of seed per pod, nutrient elements and the number of primary branches). Across genotypes, the number of days to 50% flowering ranged from 95 to 130 days, while the number of days to 90% maturity ranged from 172 to

220 days, with variety ICEAP 01154-2 being the earliest to flower and mature. Tall plants were observed by variety ICEAP 01541 (2.01m) followed by ICEAP 00902 (1.99m) and ICEAP 00850 (1.90m). Breeding line ICEAP 00673-1 recorded long peduncles with a mean of 0.94m. The number of pods per plant had a range between 56 and 482, while the pod length varied from 2.03 to 8.82cm. Variety ICEAP 00673-1 exhibited the highest number of pods per plant and with longest pods. The 100 seed weight varied from 9.43 to 16.97g among the genotypes. The higher calcium amount was observed in verities ICEAP 00979-1 with an average of 556 mg/L and the highest iron content was observed in ICEAP 01172-2 (14 mg/L). The potassium content ranged between 24 mg/L to 110 mg/L, with the variety ICEAP 00540 having the highest and the variety ICEAP 00850 having the lowest content. The sodium content ranged from 15 to 85.1 mg/L, with the variety ICEAP 01154-2 being the highest and the variety ICEAP 01147-1 having the lowest sodium content. The highest magnesium content was observed in ICEAP 00673-1 (141 mg/L). The phosphorus content ranged from 24.5 to 3.77 mg/L and the highest zinc content was observed in ICEAP 01541 and in ICEAP 00979-1 that had an average of 2.36 and 2.26 mg/L, respectively. The amount of nitrogen fixed from all the varieties ranged from 73.547 to 154.254 $kg.ha^{-1}$. The grain yield among the genotypes ranged from 89.24 to 785.29 $kg.ha^{-1}$. The top yielding varieties were ICEAP 01159 and ICEAP 00557 with grain yields of 785.29 and 661.51 $kg.ha^{-1}$. ICEAP 01159 and ICEAP 00557 are the varieties that produced the highest grain yields and they are recommended for cultivation and breeding purposes.

Key words: *Cajanus cajan; breeding lines; maturity; nitrogen fixation and grain yield.*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

The pigeonpea (*Cajanus cajan* [L] Millsp.) is a legume crop belonging to the *Fabaceae* family, and it is grown mainly in the Semi-Arid Tropical (SAT) regions. The crop is mostly cultivated for its edible seeds. The pigeonpea is a fast growing, hardy, widely adaptable, drought-resistant and a perennial shrub that lives around one to 5 years. The crop can reach a height of approximately 1-4 meters, and it is a multipurpose legume crop that provides food, fodder and wood for small-scale farmers. The pigeonpea is among the beneficial crops that were introduced to South African agriculture which can be used to diversify the legume-base cropping system of the country. With an average of 21.5% protein on the dry weight basis, it is an essential source of protein to about 20% of the world's population (Odeny, 2006; Matthews & Saxena, 2001). The crop is also rich in carbohydrates and it is also useful for mineral elements such as calcium, phosphorus and magnesium (Morake *et al*., 2002). Therefore, the pigeonpea has been identified as a possible protein substitute crop which can be bought by all people and provide an acceptable amount of nutrition because it is cheaper when compared to animal protein.

The pigeonpea originated from India (Moryon, 1976) and it is grown in over 4 million hectares in tropical and sub-tropical areas in the world (Matthews & Saxena, 2001). India is still the largest producer of pigeonpea with three million tons produced per annum, which is equivalent to 70% of the world's total production. The pigeonpea yields can reach up to 2 ton.ha^{-1} (Chauhan, 1990). However, there are many constraints to the crop's production which have resulted in low yields of approximately 600 to 700 kg.ha^{-1} (Chauhan, 1990; Ministry of Agriculture and Food Security, 2007). The constraints include but are not limited to diseases, pests, as well as agronomic and abiotic factors. The pigeonpea has the ability to survive and give good economic returns when planted under dryland conditions. Being a legume crop, its root nodules enrich the soil by adding about 40kg of nitrogen per hectare. It can be planted commercially, because its production requires low farming inputs. It is a drought-tolerant crop and can therefore, be planted under dryland production conditions.

As a result of it being drought resistant, the crop can be considered to be of utmost importance for food security in regions where rainfall is unreliable and in areas where droughts are prone to occur. However, it remains one of the underutilised crops with limited research on its diversification and adaptation. The problem is that in most countries where the crop has been cultivated, the yields are low due to drought, pests and diseases as well as due to low seed quality. Several germplasm accessions have been introduced at the University of Limpopo. However, the germplasms that were introduced have not been evaluated in the Limpopo Province. The introduction of this crop in the rural areas will help to alleviate poverty by providing a source of food. In South Africa, pigeonpea is not grown as a field crop but as shade plants in home gardens, where only a few long rows are planted.

1.2 Problem statement

The pigeonpea is a grain legume crop grown in tropical and subtropical countries where it provides a cheap and rich source of protein (Gwata & Siambi, 2009). The pigeonpea is among the beneficial crops introduced to South African agriculture in order to diversify the country's legume based-cropping system. In India, pigeonpea is cultivated as an important companion and staple crop, because it fixes nitrogen and uses its deep root system to bring up minerals from the horizons that are inaccessible to other crops. The crop is drought tolerant (Kumar *et al*., 2011), which makes it a suitable for dry areas such as the Limpopo Province. The productivity of pigeonpea depends on the availability of good and improved seeds. The pigeonpea varieties that are cultivated in South Africa are landraces and photosensitives (Asiwe, 2016). The crop varieties that are cultivated in South Africa flower when the daylength is reduced, that is around the end of March, April or May which is at the beginning of winter. This predisposes them to be likely damaged at the pod stage by early frost. The yield produced by the pigeonpea varieties that are cultivated in South African is very low, therefore there is a need to introduce and evaluate exotic germplasm varieties that are not only daylength insensitive, but they are also high yielding and early maturing. This research evaluated the performance of exotic germplasm pigeonpea varieties in the Limpopo Province.

1.3 Hypotheses

i. The yield performance of the different pigeonpea varieties in the Limpopo province will not differ.
ii. The assessment of nitrogen fixation on exotic elite pigeonpea varieties will not differ.

1.4 Rationale of the study

The pigeonpea has been identified as one of the possible substitute crops which provides an acceptable amount of nutrition because it is a cheap and rich source of protein. The crop improves soil quality and fertility when used as green manure which can substitute the use of up to 40kg of nitrogen fertilisers per hectare in the soil. Pigeonpea is capable of bringing minerals from deeper soil horizons to the soil surface and it can also improve soil aeration (Makelo, 2011). The pigeonpea stems can be used as; firewood for cooking and they can also be utilised for roof thatching and for making baskets in rural areas (Agyare *et al*., 2002). South Africa, particularly the Limpopo Province, is a semi-arid region characterized by marginal soil, low erratic rainfall or uneven rainfall distribution and this results in reduced crop yields (Mpandeli *et al*., 2015). Therefore, the introduction of improved early maturing pigeonpea varieties that are daylength insensitive and high yielding to smallholder farmers will increase their productivity. Introducing pigeonpea to Limpopo farmers will be valuable as the crop will grow well and produce satisfactory yields under limited rainfall and low soil fertility. The crop is also very nutritious, therefore it will improve family nutrition.

1.5 Purpose of the study

1.5.1 Aim

To enhance the availability of well adapted pigeonpea varieties and improve the productivity of pigeonpea in the Limpopo Province.

1.5.2 Objectives:

i. To evaluate the yield and the yield components of exotic elite pigeonpea genotypes in the Limpopo Province, South Africa.
ii. To assess the nitrogen fixing ability of pigeonpea varieties.

CHAPTER 2

LITERATURE REVIEW

2.1. Description of pigeonpea

The pigeonpea is a perennial shrub that is grown for its edible pods and seeds. The crop is a highly branched shrub with a woody base, as well as slender stems and trifoliate leaves. The plant's leaflets are oblong or elliptical in shape and the leaves are alternate and they are arranged spirally on the stems (Saxena *et al*., 2008). The plant usually produces yellow flowers but they can also be yellow with streaks of purple or red. The flowers are produced on racemes of 5–10 flowers. The seed pods are flat and are either straight or sickle shaped and measure between 5–9cm in length. Each pod can contain between two and nine seeds which can be white, cream, brown, yellow, purple, black or mottled with any combination of these colors. The pigeonpea can reach between 4–5m in height and it is usually grown as an annual crop that is harvested after one season. It may also be referred to as the red gram or the congo pea and it originates from India. The crop has a life span of up to five years (Ong & Daniel, 1990). Although the pigeonpea ranks sixth in area and production in comparison to other grain legumes such as beans, peas and chickpeas, it is used in more diverse ways than any other legume. Besides its primary use as food, it can also be used as forage, fodder and fuel. Recent findings further show its importance in soil conservation along the highways and mountain slopes, particularly against the soil erosion caused by wind and water (Nene & Sheila, 1990; Saxena, 1996).

2.2. The origin and distribution of pigeonpea

Most of the evidence points to India as the place where pigeonpea originated because of the presence of several wild relatives, the large diversity of the crop gene pool, ample linguistic evidence, a few archaeological remains, and its wide usage in daily cuisine (van der Maesen, 1990). The diversity of the crop in India is much larger than in Africa, and this made Vavilov in 1951 to list pigeonpea as being of Indian origin (van der Maesen, 1990). However, it spread quite early to the rest of the world. India and Myanmar account for 16 related wild species, one of which, *C. cajanifolius*, could be considered as a progenitor (van der Maesen, 1990). Many authors including Purseglove (1968) considered Eastern Africa as the centre of origin, as pigeonpea seems to grow in the wild in Africa (van der Maesen, 1990). The scarce, but often cited, archaeological evidence of one seed in an ancient Egyptian tomb, and the wild occurrences in Africa, further favoured the speculation that pigeonpea had an African origin. However, Africa harbors only one close wild relative of pigeonpea, which is the *C. kerstingii* (van der Maesen, 1990).

Pigeonpea is widely grown on the Indian subcontinent. It is also grown in Southeast Asia, Africa and in America. There is a substantial area under pigeonpea production in Kenya, Malawi, Mozambique, Tanzania and Uganda in Africa, as well as in the Dominican Republic and in Puerto Rico in Central America. In most other countries, pigeonpea is grown in small areas and as a backyard crop (Nene & Sheila, 1990). India has dominated the production of pigeonpea (91.3% of world production) during the last decade (Muller *et al*., 1990). The other countries with a notable pigeonpea production are Malawi (3.5%), Eastern Africa (2.6%), Nepal and Myanmar in Asia (1.5%) as well as the Americas (1.1%) (Muller *et al*., 1990).

2.3. Importance of pigeonpea

The most important usage of pigeonpea in Eastern Africa, Southern Africa, Latin America and Asia is for human consumption (Turnbull, 1986). Nutritionally, pigeonpea contains more minerals, that is ten times more fat, five times more vitamin A and three times more vitamin C than ordinary peas and other food legumes such as cowpeas and chickpeas (Makelo, 2011) (Table 2.1). It is also a good source of vitamin B and carbohydrates (Duhan *et al*., 2002). The crop also contains amino acids which form 1% of cotyledons and the embryo of pigeonpea (Saxena *et al*., 2008). The major minerals in pigeonpea are calcium, potassium, magnesium, sodium and zinc (Morake *et al*., 2002). The protein content of the pigeonpea grain ranges between 18 and 26%, with some wild types having 30% and above protein content. The crop also yields more energy, protein and beta-carotene ha^{-1} than other important pulse crops (Muller *et al*., 1990). The World Health Organization (WHO) recommends 0.75 g of protein daily for each kg of body weight in order to meet the needs of most of the general world population (Shils *et al*., 1994; Garrison & Somer, 1995).

Table 2.1: WHO recommended daily intake of protein for populations in Africa

Population group	Protein (g)	Population group	Protein (g)
Adult man (55 kg)		Children Below 1 year	14
Sedentary	31	1 – 3 years	16
Active	31	4 – 6 years	20
Very Active	31	7 – 9 years	25
Adult Woman (47 kg)		Boys 10 – 19 years	30
Sedentary	24	Girls 10 – 19 years	29
Active	24		
Very Active	24		
Pregnant	33		
Lactating	41		

Source: Latham (1979)

The seed husks and the pod walls of pigeonpea are commonly fed to cattle and the green leaves are used as fodder. After the pods are harvested, the plants are often left in the field for cattle to graze on the new green leaves such plants produce (Nene & Sheila, 1990; Shiying *et al*., 2001). The pigeonpea is not only used as fodder for domestic animals (Shiying *et al*., 2001; Arya *et al*., 2002), but it also has the potential to fill the late summer/fall (off-season) gap in forage availability (Arnold, 2002).

The pigeonpea as a legume, improves soil fertility through biological nitrogen fixation. It is also reported to contribute approximately 40kg N ha^{-1} (Kumar *et al*., 2011). The leaf fall at maturity not only adds to the organic matter in the soil, but it also provides additional nitrogen. This also benefits subsequent cereal crops when grown in the rotation with maize and sorghum (Sakala, 1992; Arya *et al*., 2002). The deep root system of pigeonpea is reported to break plough pans, thus improving the soil structure (Nene & Sheila, 1990). The deep rooting system also enables the plant to be drought-tolerant (Nene & Sheila, 1990; Johansen, 2003) and among the legumes, pigeonpea has a relatively high level of dehydration tolerance (Johansen, 2003). The extensive ground cover provided by pigeonpea prevents wind and water soil erosion, and it also encourages infiltration, minimizes sedimentation as well as smothers weeds (Nene & Sheila, 1990).

The pigeonpea is a perennial crop, but it is most often cultivated as an annual crop. As a result of the long maturity period of the pigeonpea, the landraces and the traditional cultivars are almost always grown as intercrops or in mixed cropping systems with shorter-duration crops. In Africa, the pigeonpea is commonly intercropped with maize, sorghum, cowpeas and cassava (Nene & Sheila, 1990). The mixed cropping systems have advantages to the farmer, especially in optimizing land utilization.

The pigeonpea is one of the crops that contributes significantly to fire wood for many households. The dry stems of the pigeonpea can be used as firewood (Chatarvedi *et al*., 2001; Shiying *et al*., 2001). Ten ton.ha^{-1} of dry sticks can routinely be obtained from the pigeonpea to serve as fire wood (Nene & Sheila, 1990). In an agroforestry trial at Bunda College in Malawi, Edje (1984) reported that at the end of the second year, the pigeonpea crop grown at 5000, 10000 and 20000 plants ha^{-1} produced 10.1, 11.7 and 12.5 ton.ha^{-1} of fuel wood, respectively. Faris and Singh (1990) reported that 57.6 t ha^{-1} fire wood in Colombia and 51 ton.ha^{-1} in Western Australia were harvested in two cuttings within one year. After eight months in India, an actual wood yield of 32 t ha-1 was obtained in one cutting. In India, the pigeonpea sticks are also used to make field fences, huts, and baskets (Nene& Sheila, 1990).

The pigeonpea has many traditional medicinal uses. The dry roots, leaves, flowers, and seeds are used in different countries to treat a wide range of skin ailments as well as other sicknesses that include but are not limited to the skin, liver, lungs, and the kidney (Nene & Sheila, 1990). The roots are used to treat febrile diseases and to relieve fever. They can also be used to constrict tissue for controlling bleeding and for destroying internal worms. The leaves can be used to treat jaundice, trauma, cough, burn infections and bedsores (Shiying *et al*., 2001). The crop has many other potential uses, one of which is serving as an important host for the scale insect that produces sticklac (Nene & Sheila, 1990). High yields of up to 750 kg ha-1 of sticklac of superior quality have been reported (Shiying *et al*., 2001). Lac is processed into shellac, which is used as a dye for wool, silk, leather goods and synthetic dyes. It is used in medicine as a hepatoprotective and in antiobesity drugs. Shellac is also used in several industrial applications such as surface coatings, textiles, printing, cosmetics, pharmaceuticals and adhesives.

2.4. Production of pigeonpea in South Africa

The pigeonpea is not a field crop in South Africa. It is grown either as single plants or as a hedge in or around the home gardens mainly in the Kwazulu-Natal, Limpopo and the Mpumalanga Provinces. Migrant workers from Mozambique and Malawi may have introduced these plants into the eastern provinces (Mpumalanga) and the Indian immigrants might have introduced them to the coastal Kwazulu-Natal. Intercropping with sugarcane proved unsuccessful in Kazulu-Natal and this could be attributed to the long-duration types used (Gwata & Shimelis, 2013). A report by the Department of Agriculture and Land Administration in Mpumalanga (2003) stated that pigeonpea in the Kwazulu-Natal region yield according to their duration type where the extra-short, short, medium and long duration varieties 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 to the compared cultivated varieties in Malawi, that had 2.7 to 3 tons per hectare.

2.5. Major cropping systems

The pigeonpea plants can adapt to a wide range of soil types from stones to heavy clays provided there is no standing water on the soil surface. The crop can tolerate salinity and alkalinity but not excessive acidity, that is pH below 5.0. The pigeonpea is grown in a wide range of cropping systems. The long-duration (9-10 months) types sown around the longest day of the year, are always grown as a mixed crop or intercrop with one or more other species. The medium-duration (6-7 months) types are also sown as either a mixed crop or intercrop with cereals and legumes. This type of production system is prevalent in lower latitudes of southern and central India (Saxena *et al*., 1998).

Farmers prefer to intercrop medium and long-duration varieties with faster growing cereals because there is very little competition between the crops. The short-duration pigeonpea are not well adapted to intercropping. Despite the slow above ground growth, the pigeonpea plant sends out a deep tap-root which allows the plant to exploit the moisture reserves that are underground. The short-duration varieties do not have such a deep rooting system, but they are also very hardy. Both the long-and medium-duration types when intercropped result in the better utilization of resources and in higher combined yields than if the crops are grown separately. These production systems provide stability and food security to smallholder dryland farmers. Saxena *et al*., (1998) found that a combination of 75% maize and 25% pigeonpea had an 8% advantage in Land Equivalent Ratio (LER) compared to sole cropping. For vegetable purposes, the pigeonpea is often cultivated as a sole crop.

2.6. Effect of environmental factors on pigeonpea

The pigeonpea is mostly cultivated in tropical and sub-tropical environments between 30 °N and 30 °S latitude (Jones, 2002). 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 environments (Jones, 2002). It also grows well in an environment with rainfall ranging between 400 and 750mm per annum and where there is less than 600mm annual rainfall in dry areas. The pigeonpea prefers moist conditions for the first two months and drier conditions during the flowering and harvesting stages (DAFF, 2009). Factors such as droughts and easily erodible soils with poor water holding capacity affect the 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 they can give some grain yield during the dry period, which is a rare phenomenon in many legumes. The ability of pigeonpea to withstand severe drought better than many legumes is due to their deep roots and to the osmotic adjustment in their leaves (Odeny, 2006).

Pigeonpea grow well in temperatures between 18 and 29°C. The crop is very sensitive to waterlogging and frost (DAFF, 2009). Pigeonpea are grown in rainfall areas and in day length environments of 11 to 14 hours and large differences in temperature are noticed due to the variations in different altitude and latitude (Silim *et al*., 2007). Environmental factors are also known to have an important influence on the crop's rate of development from sowing to flowering, depending on the month of planting (Warrington, 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 another constraint affecting pigeonpea 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 to the temperature. Plant height, vegetative biomass, phenology and grain yield are the crop parameters that are mostly affected by such conditions. When a cultivar takes time to flower and mature, it increases terminal drought which often occurs in Southern Africa (Gwata & Shimelis, 2013). The photoperiod and the temperature's effects on flowering and plant canopy development in pigeonpea make agronomists choose cultivars that adapt and perform well in specific climatic conditions (Silim *et al*., 2007).

2.7. Photosensitivity of pigeonpea

The sensitivity of pigeonpea to photoperiod has played an important role in determining its growth and characteristics. The phenological responses of this crop are influenced by photoperiod and temperature as these have played a major role in the evolution of the various crop production systems that have been established (Turnbull, 1986). The photoperiod sensitive reaction of pigeonpea germplasm is not only linked to flowering but it is also linked to the amount of biomass produced (Wallis *et al.,* 1981). The traditional pigeonpea cultivars and landraces are highly sensitive to the photoperiod, which limits their adaptation to up to 30°N and S. The sowing of photoperiod sensitive types near the shortest day of the year generally leads to the physiological dwarfing of plants (Spence & Williams, 1972). In early maturing genetic materials under natural day lengths at Patancheru (17°N), up to four seed-to-seed generations can be achieved within a calendar year (Saxena, 1996). This is in contrast with the late maturing types that would require the use of an environment controlled facility in order to provide extended day lengths and high temperatures in achieving a similar rapid generation turnover.

2.8. Nitrogen fixation

Nitrogen (N) is an important and essential plant nutrient for plant growth and development and its deficiency has become a problem in agriculture (Kahindi *et al*., 2008; Egbe & Anyam, 2011; Egbe *et al*., 2013). Pigeonpea have the ability to fix up to 235 kg/ha of N and produce more nitrogen per unit area from plant biomass than most of the legumes (Egbe & Anyam, 2011). Nitrogen fixation differs with the duration types where by longer duration genotypes can fix up to 200kg nitrogen per ha over a period of 40 weeks and early maturing varieties can fix 40kg of nitrogen per ha and it is further reported by Murwa (2013) that the leaf drop alone can contribute up to 40g of nitrogen.

According to Mapfumo *et al.* (1999), short duration pigeonpea fix from 6 to 43kg per ha and the long duration has from 18 to 183kg per ha. The biological nitrogen fixation from nodules is very important for growth and the yield of legumes and the 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 it also reduces soil fertility problems (Kahindi *et al*., 2008).

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

2.9. Important attributes of to be measured when assessing the agronomic performance of pigeonpea

According to Gwata and Siambi (2009) and Kumar *et al*. (2011), the following are the relevant variables to be measured when assessing the agronomic performance of pigeonpea.

2.9.1. Flowering

The inflorescence is a raceme which contains up to ten flowers per panicle and usually two flowers open at a time on a single inflorescence (Sharma & Green, 1980). Flowering is acropetal (in the direction of apex), both within the raceme and on the branch. A single plant can hold up to 915 racemes. The terminal or auxiliary raceme is usually 4-12 cm long. In most of the long duration genotypes, the racemes are grouped together at the end of branches, while in early, medium and indeterminate genotypes, the racemes are distributed along the branches (Sharma & Green, 1980).

The flowers are bisexual, zygomorphic and are predominantly yellow (Sundaraj & Thulasidas, 1980). More flowers are seen on the top of the peduncle. Small flowers, normally about 2cm in length are borne on thin, hairy pedicels. The flower size is very small in wild species and it is correlated to seed size (Sharma & Green, 1980). The calyx is gamosepalous with five lobes. The corolla is zygomorphic and the petals are imbricate. The largest, auricled and erect petal form the standard; two lateral, obliquely obovate and incurved clawed petals known as the wings. The two innermost obtuse, incurved and boat shaped petals are fused to form the keel in order to protect the stigma and the style. The standard and the wings are generally bright yellow in colour, whereas the keel is greenish yellow. A lot of variation in petal colour can be observed in the germplasm collections. The androecium has 10 stamens bunched into two groups (diadelphous) of nine and a single free stamen that is attached at the base of androecium. The grouped filaments are fused at the base and they cover the gynaecium, while the upper part is free and bears uniform anthers of about 1mm in length. The six filaments are long, while the remaining four stamens including the free posterior have short filaments which are supposed to encourage self-fertilization (Bahadur & Rao, 1981). The dorsifixed anthers consisting of two halves are pale yellow to yellow in colour. The placement of subsessile, dorsoventrally flattened and densely hairy ovary is superior. The long, filliform and the glabrous style of the gynaecium bears a thick, incurved and capitate stigma. The short stalked glandular ovary is unilocular and monocarpellary, bearing 2-9 ovules with marginal placenta.

2.9.2. Pod and seed size

The pod size is highly variable. The vegetable types have long pods with 4-7 seeds per pod. Depending on the genotype, 2-7 seeds develop in each pod. The seeds are produced in separate locules and the pod may be highly constricted in certain genotypes thereby giving a beaded appearance. The pod colour varies from green to dark purple and it has varying degrees of brownish or purplish streaks. The pod is generally pubescent with varying degrees of simple or glandular hairs. Pod shattering at maturity is uncommon in cultivated varieties as it is an undesirable trait for grain harvest. In pigeonpea, the seed and the pod size are generally correlated. The large podded genotypes have relatively large immature and dry seed sizes. In some vegetable type lines, the immature seed size is large but their dry seed size reduces rapidly with maturity. The number of ovules in a pod varies from two to nine, but all the ovules do not develop to their full size due to ovule abortion. The exact reason for ovule abortion is not fully understood but there appears to be some sort of blockage in food translocation, due to insect damage or fungal infection and this blockage restricts or stops the process of ovule development inside the pods (Gwata & Siambi, 2009).

2.9.3. Plant type

The plant type in pigeonpea also has considerable variations. Besides its growth habit (determinate/non-determinate), the nature of branching plays an important role in determining the plant type. Some of the varieties are erect and compact with narrow branching while in others the angle of branches is open thereby giving the appearance of semi-spread or spreading plants. Similarly, a considerable variation is observed for plant height. In conventional germplasm, these two characters have a considerable range with a strong environmental effect, depending on the planting time. Cultivated pigeonpea types are mainly recognized as compact or spreading. However, a range of intermediate types with varying degrees of spread are also common. The dominance of the erect growth habit over the spreading type was observed by Shaw (1931). D'Cruz and Deokar (1970) report that a single dominant gene controlled the spreading habit and that the erect types are homozygous recessive. D'Cruz *et al*. (1971) observe that the branching habit is governed by three duplicate complementary factors. Marekar (1982) reports that the close branching habit is controlled by one basic and two inhibitory complementary genes. The positive associations of yield with plant height, plant spread and the number of primary and secondary branches suggests that spreading, tall, indeterminate types have an advantage. Nevertheless, the tall compact and spreading types are widely grown, perhaps because they are ideal for intercropping.

2.9.4. Pod colour

Saxena *et al*. (1983) studied the effect of pod color on the important organoleptic properties of vegetable pigeonpea. They found that the seed from pods with a purple color had poor texture, flavor and taste but after cooking such differences disappeared. This study concluded that pod color does not play an important role in determining the organoleptic properties of vegetable pigeonpea. In a survey conducted in the Gujarat state of India where immature pigeonpea seed is a popular vegetable, it was observed that in spite of the extensive cultivation of a green podded pigeonpea variety, the rural consumers preferred cultivars that had purple streaks on the pod surface. On the contrary, the city consumers preferred fresh pods that were green in color. In another consumer survey conducted by Yadavendra and Patel (1983), the cultivar with green colored pods was found to be the best because it had good taste and it was easy to shell.

2.9.5. Seed

The germplasm of pigeonpea shows a variety of seed colour (white, creamy white, silvery, fawn, dark purple which appear as black, pink, red to purple, straw, brown) with or without specks and blotches of different shades. The 100 gram seed weight varies considerably from five to 22g in germplasm materials. The 100 seed weight of short duration cultivated varieties are low (generally 6-8 grams) when compared to long duration varieties (9-13 g). The seed weight of medium duration varieties lie between early and late maturing varieties. The 100 seed weight of vegetable types may reach up to 22g. The seeds do not show dormancy and germination is hypogeal (Saxena *et al*., 1983).

2.9.6. 90% Physiological maturity

Maturity duration is a very important factor that determines the adaptation of varieties to different agro-climatic areas and cropping systems (Matthews & Saxena, 2001). The field duration of pigeonpea is controlled by the temperature and sensitivity to photoperiod (Orr *et al*., 2013). Pigeonpea have been classified into four major duration groups as shown in Table 2.2 below.

Table 2.2: Duration types of pigeonpea and their maturity days

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

(Matthews and Saxena, 2001).

Extra-short-duration

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

Short-duration

The short-duration varieties are photoperiod insensitive and can be grown in frost-free areas (Matthews & Saxena, 2001). Flowering in short-duration genotypes is less sensitive to the photoperiod and they can flower and mature in the short summer (Kimani, 2001). The short duration groups are more susceptible to pests and are mostly grown by commercial farmers with resources and production inputs because of their high maintenance (Joshi *et al*., 2003). In the last three decades, breeders have developed a large number of short duration large seeded, high yielding types of peagopea (Sharma *et al.,* 2011). The short duration genotypes develop a smaller root system than the long-duration genotypes (Singh & Oswalt, 1992).

Medium-duration

The medium-duration varieties are mostly intercropped and are grown in areas with warm temperatures as they are more often unsuitable for long duration varieties. The medium duration varieties' maturity is delayed in areas that are away from the equator, for example in Malawi and Mozambique (Silim, 2005). The medium duration types are photoperiod sensitive and they always flower during the short-day periods (Matthews & Saxena, 2001). Most of the medium duration varieties are indeterminate varieties which flower within 110 days and mature within 160 days (Jones *et al*., 2002). The medium duration varieties have been developed through breeding and selection. Although these cultivars have shown good adaptation across the different agro-ecological zones, they perform best at medium altitudes with 600 to 1 500m and with mean temperatures of 23 to 25°C and a rainfall of 400-1500 mm over two seasons (Snapp, 2003). There are now improved varieties of medium duration pigeonpea in India, Myanmar, Kenya, Northern Tanzania and Uganda (Joshi *et al*., 2003).

Long-duration

Long duration varieties are mostly intercropped and are grown in low-latitude and high-elevation areas near the equator but they are also grown in areas away from the equator provided there are warm temperatures during the vegetative stage and cool temperatures during the reproductive stage (Silim, 2000). The long duration varieties are also photoperiod sensitive and flower in short days (Matthews & Saxena, 2001). In short rainy season areas, the long duration pigeonpea reserve soil moisture before the crop matures and in areas where there is little variation in temperature or day length, the crop will often not flower when it has reached 12 months or when it is gone beyond that due to the sudden change in temperature from warmer to cooler temperature (Jones, 2002). In areas which are 1 400 m above sea level, the insensitivity to cool temperatures allows the crop to mature early (Silim, 2005).

2.10. Production constraints on pigeonpea

The pigeonpea yields can reach up to 2 $t.ha^{-1}$ (Chauhan, 1990). However, there are many constraints limiting the actual production; these constraints have resulted in low yields of about 600 to 700 kg ha^{-1} (Chauhan, 1990). The constraints include but are not limited to diseases, insect pests, agronomic and abiotic factors.

2.10.1. Disease and insect pests

The incidence of diseases is a major cause of unstable yields of pigeonpea, particularly in intensively managed systems (Chauhan, 1990). The pigeonpea are attacked by more than 210 pathogens (Nene & Sheila, 1990). These include fungi, bacteria, viruses, nematodes and mycoplasma-like organisms. Fortunately, only a few of these pathogens cause economic losses (Kannaiyan *et al*., 1984). The pigeonpea is a host to over 200 species of insects (Reed & Lateef, 1990). Some of these insects cause sufficient crop losses to be regarded as major pests, but the majority are seldom abundant to cause much damage, or are of sporadic or localized importance, and may be regarded as minor pests. Pod damage can greatly reduce crop yield (Chauhan, 1990).

Diseases are major constraints to pigeonpea production (Subrahmanyam *et al*., 1992). Most diseases are of relatively minor importance, but fusarium wilt, caused *by F. udum*, is the most common and destructive disease of pigeonpea (Changaya-Banda, 1997; Hillocks *et al*., 2000; Gwata *et al*., 2006), and it can cause yield losses as high as 50-100% in susceptible cultivars (Soko, 1992). The disease is more prevalent in the southern region where most of the pigeonpea are grown. The disease is favoured by a continuous cropping system with minimal crop rotation and the use of susceptible cultivars. Though dependent on the stage at which the plants wilt, yield loss can approach 100% when the wilt occurs at the pre-pod stage (Reddy *et al*., 1990).

The diversity in the range of pigeonpea insect pests is a challenge to plant breeders, Insects are found chewing or sucking on pigeonpea plants from when they are at the seedling stage to the harvest stage, and no part of the plant is immune to attack. The pod-damaging insects, pod borer (*helicoverpa armigera hub*), pod borer (*maruca vitrata*), larvae of blue butterfly (*lampides boeticus* L. and the *catochrysops strado Fab*.), plume moth (exelastis atomosa wals.), thrips (*megalurothrips uitatus bagnall*), blister beetles (*Mylbris pustulata* thunberg), pod fly (*melanagromyza obtusa malloch*.) and the sucking bugs (*nezara viridula* L.), are the most important pests on this crop. The pod damage can greatly reduce the crop yield, as the pigeonpea's potential to compensate for pod damage is limited. The diversity in the range of pigeonpea pests is a challenge to plant breeders. Currently, a few pest tolerant cultivars have been developed in India but they are susceptible to wilt (Singh *et al*., 1990).

2.10.2. Limited use of high-yielding varieties

A low realized productivity in pigeonpea remains one of the major. In East and South African countries (Tanzania, Kenya, South Africa, Uganda, Rwanda, Burundi, Malawi and South Sudan), the yield of green pods varies from 1 000 to 5 000 kg.ha^{-1} and that of dry grain may reach 2 500 kg.ha^{-1} in pure stands with improved cultivars. The present regional yields are about 800 kg/ha under intercropping systems which is much lower than the realizable yield potential. Although several improved varieties are now available, the adoption is limited and most of the farmers grow traditional landraces that are prone to soilborne fungal diseases and the grain yields are of low quality (Høgh-Jensen *et al*. 2007). Alternatively, the short-duration varieties are much more susceptible to insect pest attacks, thereby necessitating the use of insecticides, which most East and South African farmers cannot afford (Jones *et al*., 2002). However, the recent trend was on the cultivation of medium-duration varieties that can fit very well into existing cropping systems. More breeding efforts are needed to focus on developing farmer- and market-preferred genotypes with a high yield, fusarium wilt resistance and good pest-tolerance.

2.10.3. Shortage of improved seed

Access to improved seeds and markets is particularly limited in sub-Saharan Africa (ICRISAT, 2009). Inadequate supply of the breeder seeds by the public sector (Rao *et al*., 2012), limited involvement of the private sector (Jones *et al*., 2002) and the non-existence of the commercial pigeonpea seed markets (Tripp, 2000) are the major challenges facing the pigeonpea seed industry in South Africa. In addition, the lack of access to quality seeds (Abate & Orr, 2012) and poor extension services significantly contribute to the poor adoption of the improved pigeonpea seeds in South Africa.

2.10.4. Lack of human resource capacity

In East and Southern African countries, all the major producers of pigeonpea have limited capacity to carry out effective research and development on pigeonpea, as they have traditionally received less attention than cereals and cash crops (Abate & Orr 2012). Information from the Uganda National Agricultural Research Organization (NARO) revealed that currently there is only one scientist who is actively involved in pigeonpea breeding. The same applies to Malawi where only one pigeonpea breeder and one agronomist within the national programme are working (Abate *et al*., 2012). There is also still a huge gap in the scientific capacity that was left by retired scientists, due to the failure by the national governments to continue hiring and supporting agricultural scientists for a long time (Beintema & Stads 2006). For instance, in Tanzania, the situation is most extreme at the Ilonga Agricultural Research Institute, a country pigeonpea mandate, where most of the posts for senior research officers are vacant (Coulson & Diyamett 2012).

2.11. Genetic improvement of pigeonpea

Genetic improvement has been an important contributor to the enormous advances in productivity that have been achieved over the past 50 years in plants that are of agricultural importance. Relatively, a few genetic studies of pigeonpea agronomic traits have been conducted. Basic information on the genetics of yield and related traits such as maturity, pods per plant and seed size, which are essential to determine the most efficient breeding approaches for genetically improving the yield potential of the crop, have not been widely reported (Byth *et* al. 1981).

Breeding the pigeonpea is a challenge because the objectives and the methods that are chosen in the breeding programme depend on the nature and the magnitude of the genetic variation, the reproductive behaviour, usage, adaptation to the environments and the cropping systems involving the crop. A high stable yield with acceptable grain quality, is the major breeding objective. A stable yield is sought by incorporating resistance to biotic stresses such as diseases (wilt, sterility mosaic, *phytophthora blight*), pests, and abiotic stresses (waterlogging, drought, acidity, and salinity) (Singh *et al*., 1990). It is essential to breed for a range of resistances to pathogenic organisms in order to reduce the need for chemical controls to a minimum and thus lower production costs and increase the nutritional value of agricultural products (Byth *et* al., 1981).

Other objectives have focused on breeding pigeonpea for specific production systems and special traits such as the suitability for vegetable products and fodder, high protein content for the animal feed industry, suitability for processing for canning; the milling quality for split peas and market preferences (Singh *et al*., 1990). Short and extra short-duration, short-statured pigeonpea with comparatively low sensitivity to photoperiod and temperature interactions, have been bred by ICRISAT. Medium and long-duration pigeonpea are principally grown as intercrops with tall cereals (maize, sorghum, and millets), and a variety of other crops. However, the selection for competitiveness and high productivity from early generations in mixed cropping systems is not practical (Singh *et al*., 1990) because selections at early generations are done in pure stands instead of in interrows. Breeding research and the development of pigeonpea is considered more difficult due to various crop-specific traits. The most important pigeonpea specific trait is its natural partial outcrossing that directly impacts its breeding and selection efficiency. Therefore, before launching a pigeonpea improvement program, one must understand the nature and potential effects of special traits on breeding outputs (Perera *et al.,* 2001). ICRISAT has developed a lot of improved germplasm for global exploitation. However, such elite germplasm needs to be tested for specific adaptation and relevance, which forms one of the objectives of this study.

CHAPTER 3

MATERIALS AND METHOD

3.1. Description of study area

The study was conducted at Syferkuil University Farm (23°50' S; 29°40' E) in the Limpopo Province of South Africa in the Capricorn district. The climate of the area is classified as semi-arid. Soils at this farm are formed in situ on basalt, sandstone and biotic gneiss and they possess inherent poor fertility and are locally classified as Hutton (WRB, 2006). The annual average rainfall for the area is between 401 to 500mm. The annual average minimum and maximum temperatures are 10°C and 25°C (50 and 77°F), respectively.

3.2. Research design, treatments and procedures

The land was ploughed and harrowed using a tractor in order to ensure that there was a good seed bed. A total of 18 early maturing pigeonpea genotypes obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Kenya were planted on 07 December 2017. The trial was laid out using Randomized Complete Block Design (RCBD) with three replications. The plot size was 4m x 18m ($72m^2$) and the plant spacing was 1m x 0.5m with an alley way of 2m between the blocks.

Herbicides, Roundup (Isopropylamine salt of glyphosate) and dual (S-metalachlor) at a rate of 3 $L.ha^{-1}$ and 0.5 $L.ha^{-1}$ respectively were used to control weeds in the field using a knapsack sprayer. Manual weeding was done subsequently when necessary. Insecticide karate (Lambda-cyhalothrin) at the rate of 1 $L.ha^{-1}$ was applied to control insects at the flowering stage until pod maturity. Supplementary irrigation was applied when needed during the seedling establishment stage. Planting was done during the first week of December 2017 when rainfall was still stable. During the cropping season temperature, rainfall and relative humidity data were obtained monthly from the nearest weather station.

Table 3.1: List of the elite pigeonpea breeding lines used in the study

	Name of variety	Coat colour	Coat texture
1	ICEAP 01147	Cream white	Smooth
2	ICEAP 01147-1	Cream white	Smooth
3	ICEAP 00673-1	Cream white	Rough
4	ICEAP 00557	Cream white	Smooth
5	ICEAP 01150-1	Cream white	Rough
6	KAT 60-8	Cream white	Wrinkled
7	ICEAP 00850	Brown	Wrinkled
8	ICEAP 01172-2	Cream white	Rough
9	ICEAP 00902	Brown	Smooth
10	ICEAP 00068	Cream white	Wrinkled
11	ICEAP 01541	Cream white	Rough
12	ICEAP 01159	Cream white	Smooth
13	ICEAP 00540	Brown	Rough
14	ICEAP 00554	Cream white	Wrinkled
15	ICEAP 01154-2	Cream white	Wrinkled
16	ICEAP 00979-1	Brown	Smooth
17	ICEAP 01179	Cream white	Wrinkled
18	ICEAP 00911	Cream white	Rough

3.3. Data collection

3.3.1. Data collection for objective 1

i. Date of first flower on 18 pigeonpea varieties

This was determined by counting the number of days from the date of planting to the first date when the first flower appeared.

ii. Fifty percent (50%) flowering on 18 pigeonpea varieties

This was determined by counting the number of days from the date of planting to the date when 50% of the population flowered.

iii. Days of 90% maturity on 18 pigeonpea varieties

This was determined by counting the number of days taken from the date of planting to the date of 90% maturity.

iv. Plant height of 18 pigeonpea varieties

This was measured from the ground surface to the tip of the growing point using a meter rule over five randomly selected plants at maturity stage and it was recorded in metres.

v. Canopy width of 18 pigeonpea varieties

This was measured from the outer edges of each row (swath) using a meter rule and it was recorded in metres.

vi. Peduncle length of 18 pigeonpea varieties

This was measured from the base of the peduncle to its tip using a meter rule and it averaged over five randomly selected plants and it was recorded in metres.

vii. Pod length of 18 pigeonpea varieties

The length of five randomly selected pods per plot were measured using a ruler and the average length per pod was expressed in centimetres.

viii. Number of pods per plant of 18 pigeonpea varieties

The number of pods per plant was determined by counting the fully developed pods from five plants and then the average was calculated.

ix. Number of seeds per pod of 18 pigeonpea varieties

The total number of seeds in each pod were counted and averaged over five pods.

x. Number of primary branches per plant of 18 pigeonpea varieties

This was counted from five tagged plants and the average was calculated.

xi. The mass of 100 seeds of 18 pigeonpea varieties

A total of a 100 randomly selected good seeds were counted and weighed in grams using a digital scale.

xii. Grain yield of 18 pigeonpea varieties

Sun-dried pods were harvested from the net area and they were threshed manually from each net plot, the seeds were then weighed using an electronic weighing balance and then they were converted to a kilogram per hectare ($kg.ha^{-1}$).

3.3.2. Data collection for objective 2

15N/14N isotopic analysis and biological nitrogen fixation of 18 pigeonpea varieties

The isotopic ratio of 15N/14N and the concentration of N in plant organs and whole plants were determined at the University of Limpopo's LATS Station Laboratory. Dried plant samples were digested in an acid solution with a PerkinElmer Titan MPS. The amount of 5.0mL of HNO_3, and 3.0 mL of H_2O_2 were added into the mixture, then it was shaken carefully for ten minutes before it was heated in a microwave with the following program;

Table 3.2: Temperature Program

Step	Target Temp [^{0}C]	Pressure Max [bar]	Ramp time [min]	Hold time [min]	Power [%]*
1	150	30	10	5	50
2	190	35	5	15	80
3	50	35	1	10	0
4	-	-	-	-	-
5	-	-	-	-	-

The isotopic composition (15N) was measured as the difference in the number of atoms of 15N to 14N in atmospheric N_2 using the formula below:

$$\delta^{15}N = \frac{(15N/14N)sample - (15N/14N)atm}{(15N/14N)atm} \ x\ 1000$$

Where, $(15N/14N)_{sample}$ = Legume and

$(15N/14N)_{atm}$ = Standard

The proportion of legume N was derived from the fixation of atmospheric N_2 (%Ndfa) and it was estimated as:

$$\%Ndfa = \frac{(\delta15NReference\ plant - \delta15NLegume)}{(\delta15NReference\ plant - B)} \ x\ 100$$

The reference plant and the legume were the grass species and the pigeonpea grown in the field respectively. The name of the grass species used in this study was common thatching grass (*hyparrhenia hirta* (L.) Stapf), which grows naturally around the Limpopo Province. *Hyparrhenia hirta* is recognized by its hard basal tussock, rough narrow leaves and a scanty panicle of pairs of white villous racemes which do not deflex (bend downwards). Whereas, B is the 15N natural abundance of test legume deriving all of its N nutrition from N_2. The lowest $\delta^{15}N$ for each legume was used as the B value (Hansen & Vinther, 2001; Riffkin *et al*., 1999).

The amount of N-fixed was calculated as:

N-fixed = %Ndfa x legume biomass N ($kg.ha^{-1}$).

3.4. Data analysis

Data generated from this study was subjected to Analysis Of Variance (ANOVA) in order to determine whether there are any significant differences between the treatment means using STATISTIX Version 10 software. The Least Significance Difference (LSD) was used to separate the means that showed significant differences at an alpha level of 0.05.

CHAPTER 4
RESULTS AND DISCUSSION

4.1. Weather results during the 2017/18 season at the University of Limpopo Experimental Farm (UL Farm)

The trial was planted on 07 December 2018 when the rainfall was stable and the temperature was high. During the December and January 2017/18 season, the rainfall was considerably high with an average of 42.17mm and 53.34mm and it was coupled with temperatures of between 23 - 27 ^{0}C (Figure 4.1). The adequate rainfall especially after planting promoted crop establishment and a reduced crop failure. The rainfall continued to increase in February to 90.17mm even though the temperature decreased a bit to 20.51^{0}C. The high rainfall during the vegetative stage accelerated vegetative growth which led to a high number of primary branches and pods per plant. However, during the month of March, there was a reduction in rainfall until April (32 - 9.65mm) but the temperature was a bit high (24.66 - 25.39^{0}C). Furthermore, towards the end of the season (April – May), there was a steady decline of rainfall distribution coupled with high temperatures (Figure 4.1). The weather from the entire season was decent as it resulted in the good performance of the varieties on the agronomic yield components.

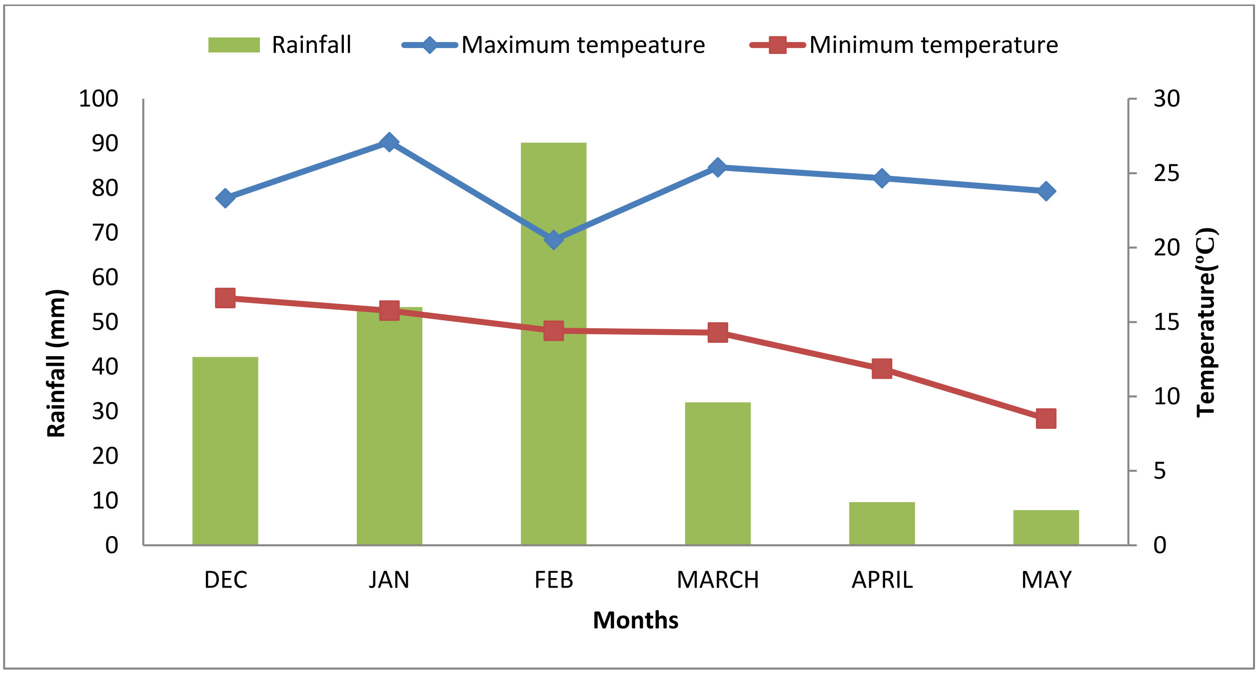

Figure 4.1: Monthly rainfall and temperatures for the 2017/18 season at the UL Farm.

4.2. Performance of 18 pigeonpea varieties at the University of Limpopo Experimental Farm (UL Farm)

4.2.1. Number of days to first flowering of 18 pigeonpea varieties

The timing of flowering is one of the most widely investigated aspects of the phenology of plant life-cycles (Herrera, 1995). The analysis indicated significant differences ($P \leq 0.05$) among pigeonpea varieties with respect to the number of days to first flowering (Table 4.2.1). Varieties (ICEAP 01159, KAT 60-8 and ICEAP 00902) attained first flowering earlier at 91 days after planting (Figure 4.2). Temperature is definitely the dominant component that affected flowering and maturity (Wallace *et al*., 1995). Marfo and Hall (1992) suggest that the combination of high temperatures and long days can slow down or inhibit floral bud development, thus resulting in a few flowers being produced in grain legumes. Their results were also supported by Wien and Summerfield (1984) who mention that warmer temperatures hasten the appearance of flowers in day-length sensitive genotypes. Most of the varieties produced their first flowers within 91 to 100 days when the temperature was still stable in March (Figure 4.1).

However, some varieties (ICEAP 00673-1, ICEAP 00979-1 and ICEAP 00540) produced their first flowers later at between 101 to 112 days (Figure 4.2). A decrease in temperature at the end March to April (Figure 4.1) is the main reason for increasing the days to the flowering of pigeonpea cultivars. The differences in flowering concluded that cultivars differ in their phonological response to temperature and their sensitivity to photoperiod. They also differ according to their association or reaction to environment conditions. The more the cultivar was sensitive to the photoperiod, the more flowering was delayed. Flowering is triggered by short days (Jeuffroy & Ney, 2007). Long day make flowering response to be on critical photoperiod and flowering is delayed (Silim *et al*., 2007).

Table 4.1: Analysis of variance for number of days to first flowering of 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	919.47	54.0864		
Variety	17	1354.59	79.6876	2.0359	0.0434*
Error	34	745.41	39.2321		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and * significant at (P≤0.05).

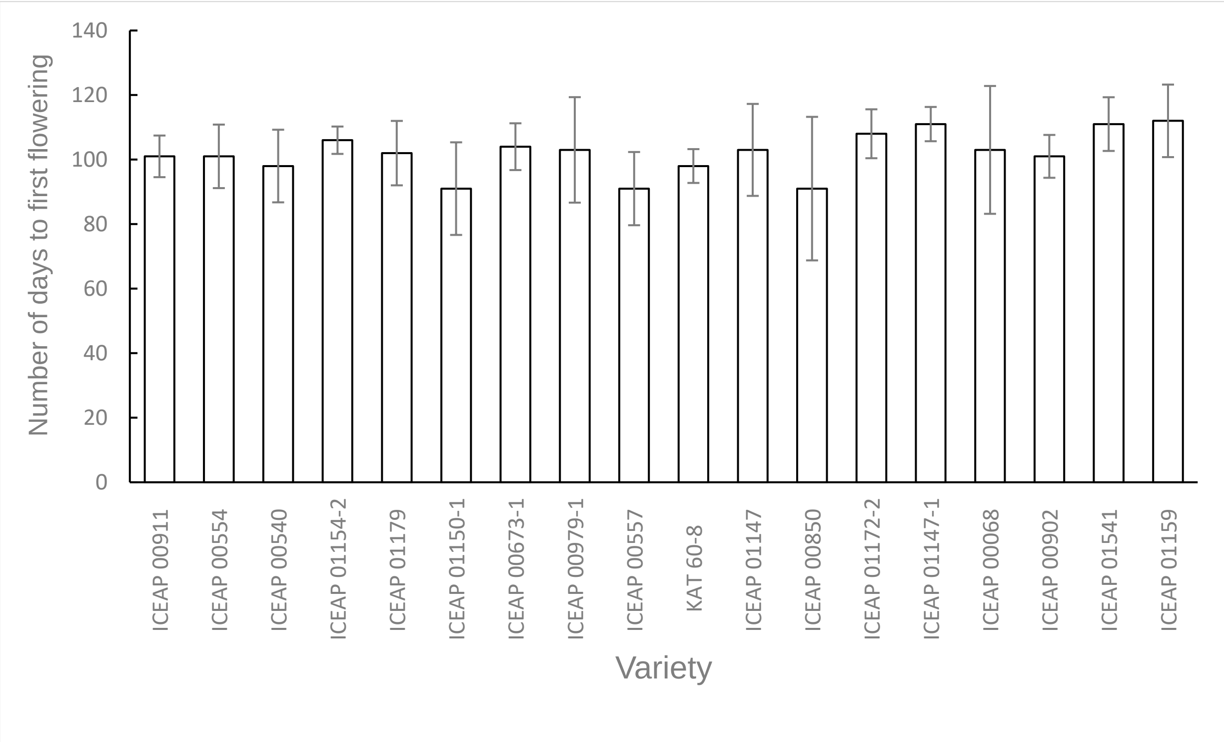

Figure 4.2: Number of days to first flowering of 18 pigeonpea varieties

4.2.2. Number of days to 50% flowering of 18 pigeonpea varieties

The analysis of the number of days to 50% flowering indicated significant differences (P ≤ 0.05) among the pigeonpea varieties (Table 4.2). The minimum days to 50% flowering was reached by ICEAP 01172-2 at 95 days and the longest days to 50% flowering was reached by ICEAP 00540 at 116 days (Figure 4.3). The variation in number of days to 50% flowering was due to the varietal characteristics. A similar outcome was observed by Khaki (2014) who reported significant differences on pigeonpea due to the varietal characteristics under different seasons. Most of the varieties attained 50% flowering within 101 to 110 days which resulted in huge variations due to their varietal characteristics. This is supported by the work done by Deshmuk and Mate (2013) who reported significant differences among pigeonpea due to genetic variability.

The varieties (ICEAP 01159, ICEAP 01172-2 and ICEAP 01541) that attained 50% flowering earlier at 95 to 100 days were when the temperature was still stable around mid-March (Figure 4.1), which led them to produce their first flowers early and hasten their 50% flowering. The longer days to 50% flowering were observed by three varieties (ICEAP 00540, ICEAP 00979-1 and ICEAP 00673-1) at 110 to 116 days (Figure 4.3) which may be due to the cool temperatures during the day which were prevalent during end-March to early April (Figure 4.1). These agree with previous findings by Slim *et al*. (2007). These authors reported that cool temperature lengthens flowering while elevated temperature shortens the duration of flowering.

Table 4.2: Analysis of variance for number of days to 50% flowering of 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	1457,04	85.708		
Variety	17	986,04	58.002	2.011	0.0484*
Error	34	556.62	33.875		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P= Probability * significant at (P≤0.05).

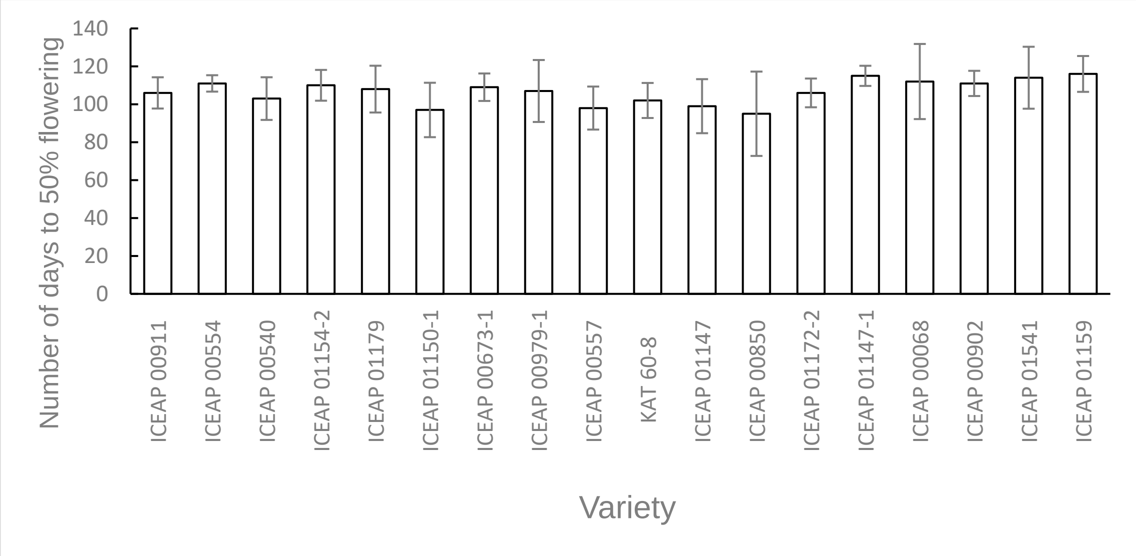

Figure 4.3: Number of days to 50% flowering of 18 pigeonpea varieties

4.2.3. Number of days to 90% physiological maturity of 18 pigeonpea varieties

The analysis showed significant differences ($P \leq 0.0484$) between pigeonpea varieties with respect to the days to 90% physiological maturity (Table 4.2.3). Variety (ICEAP 01154-2) exhibited the shortest number of days to 90% physiological maturity which was recorded at 172 days after planting (Figure 4.4). The variety ICEAP 00540 took longer to reach 90% physiological maturity which was in 212 days followed by ICEAP 00911 and ICEAP 00979-1 which took 211 and 210 days to reach 90% physiological maturity. The differences in 90% physiological maturity among varieties were due to varietal characteristics. The findings of Deshmuk and Mate (2013) agree with previous statements which support the variations in number of days to 90% physiological maturity among pigeonpea varieties due to the genetic makeup. Similar results were reported by Slim *et al*. (2007).

Dwarf varieties like the ICEAP 01154-2 matured early due to their short vegetative growth whereas taller varieties like the ICEAP 00540 matured late because they continued to grow indeterminately until they reached physiological maturity. This is in line with the outcomes of Ojwang (2015) who reports the differences in physiological maturity due to genetic makeup. Most varieties including (ICEAP 00673-1, ICEAP 00068, KAT 60-8 and ICEAP 00557) had average days of 90% physiological maturity that fell between 190 to 209 days (Figure 4.4). Grain legumes such as pigeonpea are perennial in nature as long as there is available moisture, this can increase or extend the maturity of some of the varieties. These varieties also had the longest maturity period of between 190 to 212 days and they were regarded as late maturing cultivars when compared to variety (ICEAP 01154-2) which matured at 172 days. The reason for the variety (ICEAP 01154-2) to reach 90% physiological maturity early is because it had the shortest number of days to 50% flowering and this is why it attained its physiological maturity earlier while ICEAP 00540 attained its physiological maturity late. This is in line with the findings of Hluyako (2015) who reported that early flowering results in early maturity whereas late flowering results in late physiological maturity. Within the population, there is enough variation in the number of days to maturity thereby indicating opportunities for selection and the improvement of the crop.

Table 4.3: Analysis of variance for number of days to 90% physiological maturity

Source of variation	**DF**	**SS**	**MS**	**F**	**P**
Rep	2	1069,27	62,8981		
Variety	17	1065.850	62.69705	2.001	0.0484*
Error	34	601.201	31.6142		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and * significant at (P≤0.05).

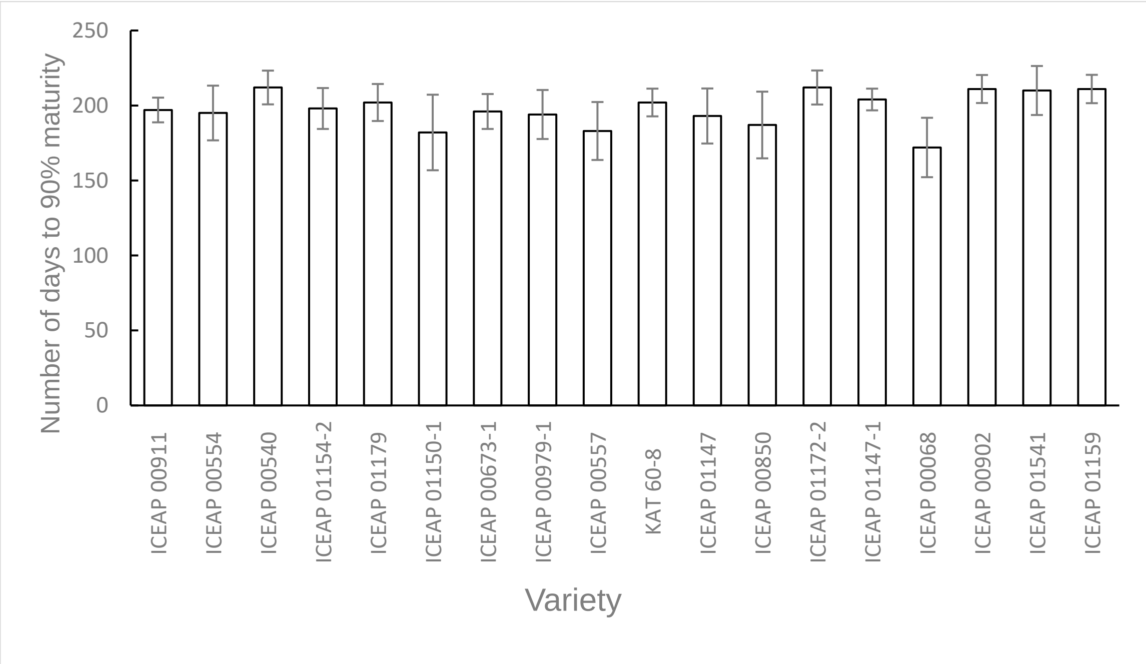

Figure 4.4: Number of days to 90% physiological maturity of 18 pigeonpea varieties

Table 4.4: Mean of yield components: Days to first flowering of 18 pigeonpea varieties

Variety	Variable	(Days)	
	first flowering	50% flowering	90% physiological maturity
ICEAP 01147	101^{ab}	106^{ab}	197^{ab}
ICEAP 01147-1	101^{ab}	105^{ab}	195^{abc}
ICEAP 00673-1	98^{bc}	103^{bc}	194^{abc}
ICEAP 00557	106^{ab}	110^{ab}	198^{ab}
ICEAP 01150-1	102^{ab}	108^{ab}	202^{ab}
KAT 60-8	91^{c}	97^{c}	182^{bc}
ICEAP 00850	104^{ab}	109^{ab}	196^{ab}
ICEAP 01172-2	103^{ab}	107^{ab}	194^{ab}
ICEAP 00902	91^{c}	98^{c}	183^{bc}
ICEAP 00068	98^{bc}	102^{abc}	202^{ab}
ICEAP 01541	103^{ab}	99^{bc}	193^{ab}
ICEAP 01159	91^{c}	95^{c}	187^{bc}
ICEAP 00540	108^{ab}	111^{ab}	212^{a}
ICEAP 00554	111^{a}	115^{a}	204^{ab}
ICEAP 01154-2	103^{ab}	112^{a}	172^{c}
ICEAP 00979-1	101^{ab}	111^{ab}	211^{a}
ICEAP 01179	111^{a}	114^{a}	210^{a}
ICEAP 00911	112^{a}	116^{a}	211^{a}
Grand mean	102.08	110	199
SEM	0.6933	0.7976	1.7988

Means followed by the same letters in each column does not differ significantly at $P \leq 0.05$
SEM= Standard error of means.

4.2.4. Plant height of 18 pigeonpea varieties

Plant height showed the significance difference ($P \leq 0.0455$) among the tested 18 genotypes. The plant height ranged between 0.60m (ICEAP 00540) and 2.01m (ICEAP 01541) (Figure 4.4). The highest plant observed was under ICEAP 01541, ICEAP 00902 and ICEAP 00850 with a mean height of 2.01, 1.99 and 1.90 m, respectively (Figure 4.5). The reason for the above varieties to achieve taller plant height may be attributed to the higher moisture availability during the vegetative stage and the stable temperature around March and April (Figure 4.1). This agrees with what was reported by Nagraj *et al*. (2016) who states that an adequate rainfall at a critical stage especially during flowering results in higher plants on pigeonpea genotypes. The taller plants observed in the long and medium duration types than the short duration genotypes in this study agreed with the findings of Egbe (2005), which state that the short duration genotypes of pigeonpea had shorter plants than the medium and late-maturing genotypes in both sole and inter-cropping systems. Reddy (1990) observed that the late-maturing (long-duration) varieties are generally tall because of their prolonged vegetative phase, while the short-duration (early-maturing) varieties are comparatively short in stature due to their short vegetative growth phase. This is also evidenced by Hluyako (2015) who explained that the increase in plant height was associated with longer days to flower due to the prolonged vegetative phase.

The lower plant height in this study was recorded by ICEAP 00540, ICEAP 00068 and ICEAP 01150-1 with a mean of 0.60 m, 0.61 and 0.63 cm, respectively (Figure 4.5). The variation in height on 18 pigeonpea varieties may be due to the different genetic makeup of the varieties. Egbe (2005) reported that plant height is known to be affected by maturity duration, genetic, photoperiod and by the environment. The pigeonpea genotypes in this work were generally tall, probably due to the influence of exposure to long-day conditions during March and April (Figure 4.1). The previous statement was also supported by Reddy (1990) who explained that plant height could be substantially increased through the prolongation of the vegetative phase by exposure to the long-day situations, especially in a crop that exhibits indeterminacy as the pigeonpea.

Table 4.5: Analysis of variance for plant height of 18 pigeonpea varieties

Source of variation	**DF**	**SS**	**MS**	**F**	**P**
Rep	2	6,75712	0,39748		
Variety	17	4,41393	0.2596	2.663	0.0455*
Error	34	1,85880	0.09748		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and * significant at ($P \leq 0.05$).

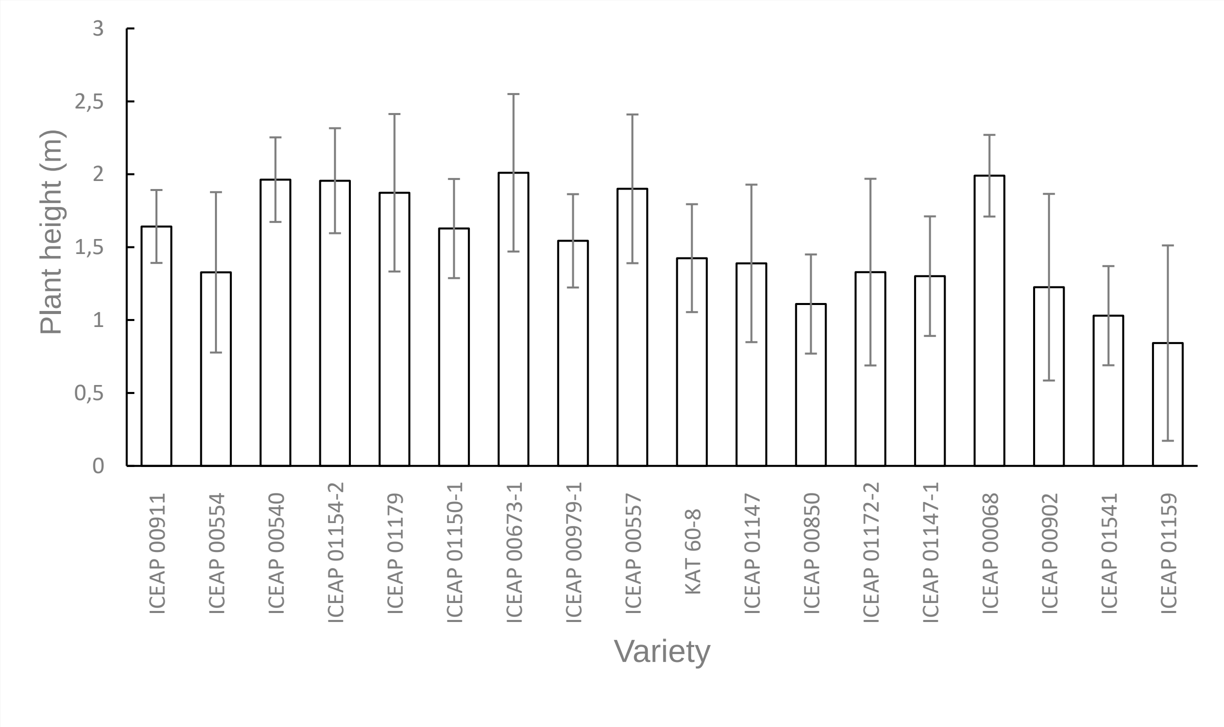

Figure 4.5: Plant height of 18 pigeonpea varieties

4.2.5. Canopy width of 18 pigeonpea varieties

Highly significant differences ($P \leq 0.05$) were observed among the tested 18 genotypes in respective to canopy width. The widest canopy cover was observed on the varieties ICEAP 01159 and ICEAP 00911 at the average width of 1.11 and 1.10m respectively. The narrowest canopy cover was attained by ICEAP 01150-1 (0.43m) followed by ICEAP 00902 (0.44m) (Figure 4.6). The canopy width differs with respect to plant types. When pigeonpea varieties have large canopy width, it does not necessarily mean that they have high height. Most of the varieties with wider canopy in this study were those of trailing types and they have the tendency of spreading on the ground and covering it up when they grow.

Biradar *et al.* (2010) reported that the canopy cover is important as it assists in the conservation of soil moisture by reducing evaporation due to reduced soil temperatures in the canopies and suppressing weed growth, thus reducing the competition that might be exerted by the weeds on growth and yields. Most varieties including ICEAP 00673-1, ICEAP 00068, KAT 60-8 and ICEAP 00557 had average canopy width that fell between 0.64 to 0.95m and they were spreading on the ground (Figure 4.6). It has been reported in other studies on cowpeas that cultivars that are the spreading types are more suitable to be used in areas with soil erosion problems (Aremu *et al.,* 2007). They can also be used for moisture conservation in the soil in areas with insufficient water irrigation. Islam and Fakir (2007) explained that canopy structure, canopy spreading and a degree of branching influences most of the yield components such as the number of pods per plant. Ndiso *et al*. (2017) mentioned that the genotypes that produce the widest canopy and high biomass on legumes tend to have low seed yield, therefore the farmers need to know which genotype is best suited for their production.

Table 4.6 : Analysis of variance for canopy width of 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	1,82269	0,10722		
Variety	17	1,23799	0.0728	2.0289	0.0464*
Error	34	0,67049	0.03588		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability, ns= not significant and * significant at (P≤0.05).

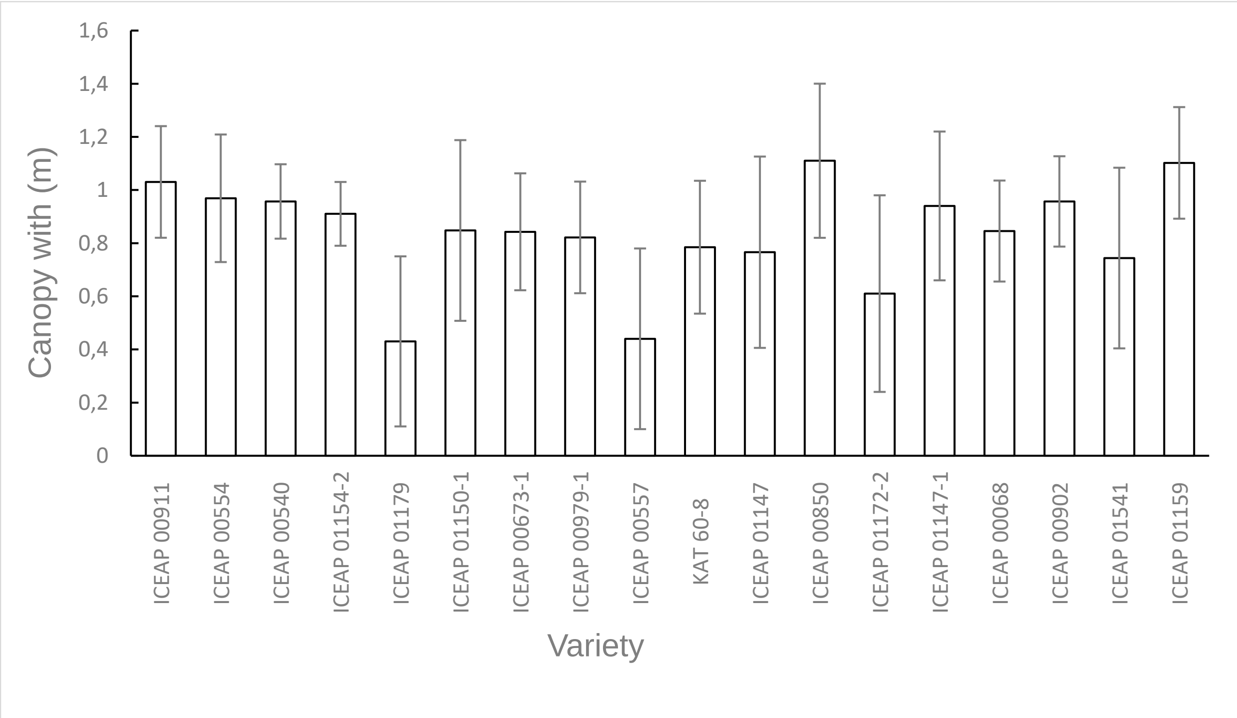

Figure 4.6: Canopy width of 18 pigeonpea varieties

4.2.6. Number of primary branches of 18 pigeonpea varieties

The pigeonpea varieties showed no significant (P ≥ 0.05) differences for a number of primary branches. The number of primary branches in pigeonpea ranged from six to 15. The high number of primary branches (15) that were observed were from three varieties (ICEAP 01147, ICEAP 00557 and ICEAP 00554) during the season. The highest primary branches that were observed were attributed to a high rainfall during February and March (Figure.41). This agrees with what was reported by Nagraj *et al*. (2016) who stated that the adequate rainfall at a critical stage especially during flowering promotes more number of branches per plant on pigeonpea genotypes.

The following genotypes; ICEAP 00673-1, ICEAP 00068, ICEAP 00554 and ICEAP 00557 which produce flowers for a long period of time had more branches (both primary and secondary). This result is in contrast to that of Dasbak *et al.* (2012) and Sharma *et al.* (1981), who found that the medium maturing genotypes produced a higher grain yield than the early and late flowering genotypes. The varieties ICEAP 00979-1, ICEAP 01179 and ICEAP 00911 obtained a lower number of primary branches (6) because they had a shorter vegetative period and the other reason may be due to the lack of moisture during the production period. An increase in the number of primary branches, secondary branches, number of pods per plant and plant height would result in an increased seed yield per plant (Mwanamwenge *et a*l., 1999). This was also supported by Rani and Reddy (2000) who reported that an increase in yield is attributed to more branches, more pods per plant and a good harvest index. Santosh and Madrap (2007) reported that the primary branches and the 100-gram weight had a direct positive effect on the seed yield. Hence, the simultaneous selection based on these characters could lead to improved yield.

Table 4.7: Analysis of variance for number of primary branches of 18 pigeonpea varieties.

Source of variation	DF	SS	MS	F	P
Rep	2	212,634	12,5079		
Variety	17	253,051	14.8852	1.3918	$0,4142^{ns}$
Error	34	203,199	10.6946		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05)

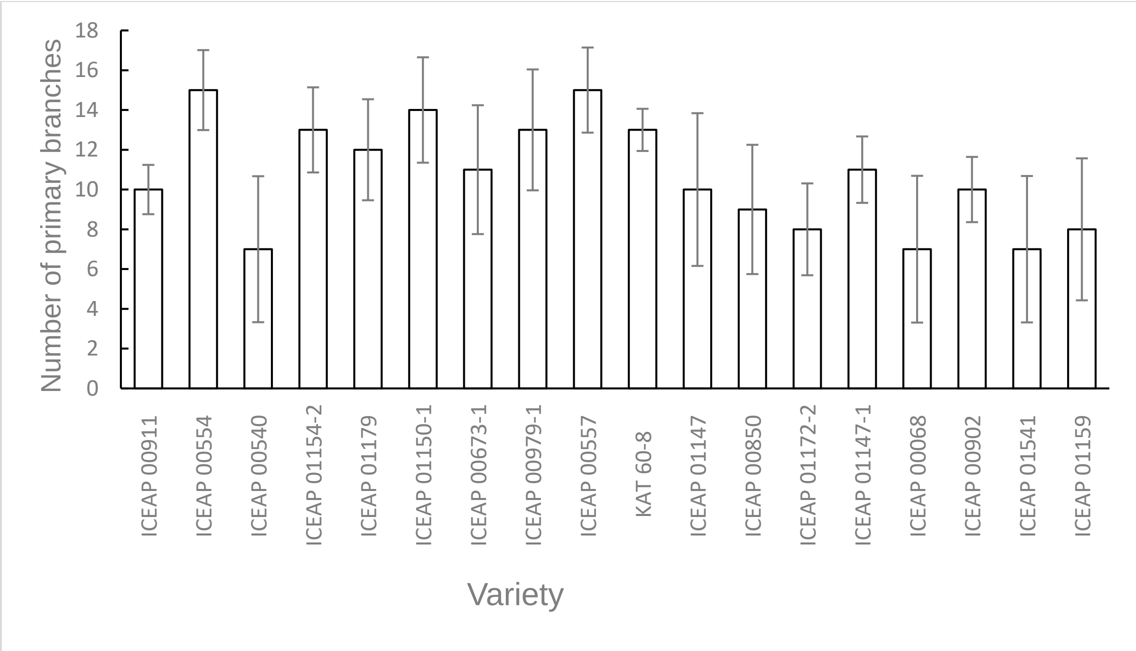

Figure 4.7: Number of primary branches of 18 pigeonpea varieties

Table 4.8: Mean of yield components on plant height, canopy width and number of primary branches of 18 pigeonpea varieties

Variety	Variable		
	Plant height (m)	**Canopy width (m)**	**Number of Primary branches**
ICEAP 01147	1.6419[a]	1.0304[a]	15[a]
ICEAP 01147-1	1.3273[ab]	0.9689[b]	14[a]
ICEAP 00673-1	1.9630[abc]	0.9570[b]	13[a]
ICEAP 00557	1.9557[abc]	0.9103[ab]	13[a]
ICEAP 01150-1	1.8730[abc]	0.4304[c]	12[a]
KAT 60-8	1.6277[b]	0.8478[ab]	12[a]
ICEAP 00850	2.01[a]	0.8428[ab]	11[a]
ICEAP 01172-2	1.5435[bc]	0.8217[ab]	11[a]
ICEAP 00902	1.90[b]	0.4401[c]	10[a]
ICEAP 00068	1.4246[ab]	0.7848[b]	10[a]
ICEAP 01541	1.3887[bc]	0.7659[b]	10[a]
ICEAP 01159	1.11[bc]	1.1102[b]	9[ab]
ICEAP 00540	1.3289[ab]	0.6102[c]	8[ab]
ICEAP 00554	1.3013[bc]	0.9401[ab]	8[ab]
ICEAP 01154-2	1.99[a]	0.8456[ab]	8[ab]
ICEAP 00979-1	1.2255[bc]	0.9571[ab]	7[ab]
ICEAP 01179	1.0302[bc]	0,7440[bc]	7[ab]
ICEAP 00911	0.8421[c]	1,1021[a]	6[ab]
Grand mean	1.6122	0,9029	8.5117
SEM	2.7369	2.1504	0.9904

Means followed by the same letters in each column does not differ significantly at P ≤ 0.05.
Standard error of means (SEM)

4.2.7. Length of primary branches of 18 pigeonpea varieties

The length of primary branches determines the position of the pods on the plant and thus becomes an important character with respect to harvesting of pigeonpea. This is because mature pods are normally held on the branch, which reflects the position of pods on the plant. The branching pattern in pigeonpea depends on genotype, habitat, and spacing of the plants. Wider spacing may form a bush and at narrow spacing may remain compact and upright. For agronomic purposes, pigeonpea plants can be grouped as compact (erect), semi-spreading (semi-erect), and spreading types. Pigeonpea genotypes in this work were categorised as semi-erect.

Although the analysis showed no significant differences ($P \geq 0.05$) on length of primary branch among the different pigeonpea varieties (Table 4.2.10), low was detected within experiments. The results of the evaluation of the length of primary showed that the varieties had length ranging from 0.45 to 0.94 m (Figure 4.8). The variety ICEAP 00540 had the shortest branching length, followed by KAT 60-8, ICEAP 00557 and ICEAP 00554 and ten more varieties with an average length ranging from 0.65 to 0.82 m, while ICEAP 00673-1 was the top variety with length of 0.94 m (Figure 4.8). Pandey and Ngarm (1985) stated that for easy harvesting, the length of primary branch should be intermediate and above the canopy to hold the pods above the canopy to enhance easy visibility and also help to attract sun light for photosynthesis. However, the accessions observed on variety (ICEAP 00673-1) with extra-long branches may easily be lodged by strong winds causing other problems such as rotting and rodent attack. Variation in length of primary branches on pigeonpea may be attributed to maturity duration and environment and also to different genetic makeup of the varieties. From the pooled data, length of primary branches of pigeonpea genotypes in this work were generally taller, probably due to influence of exposure to long-day conditions of March and April (Figure 4.1) and synchronous supply of plant nutrients throughout the growth period. The previous statement was also supported by Reddy (1990) who explained that length of primary branches could be substantially increased through prolongation of the vegetative phase by exposure to the long-day situations. The results observed also confirm significant diversity in length of primary branches which is also important for breeding purpose.

Table 4.9: Analysis of variance for length of primary branches of 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	0,32131	0,01890		
Variety	17	0.29794	0.01752	0.3231	0,9699^{ns}
Error	34	1.03000	0.05421		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05).

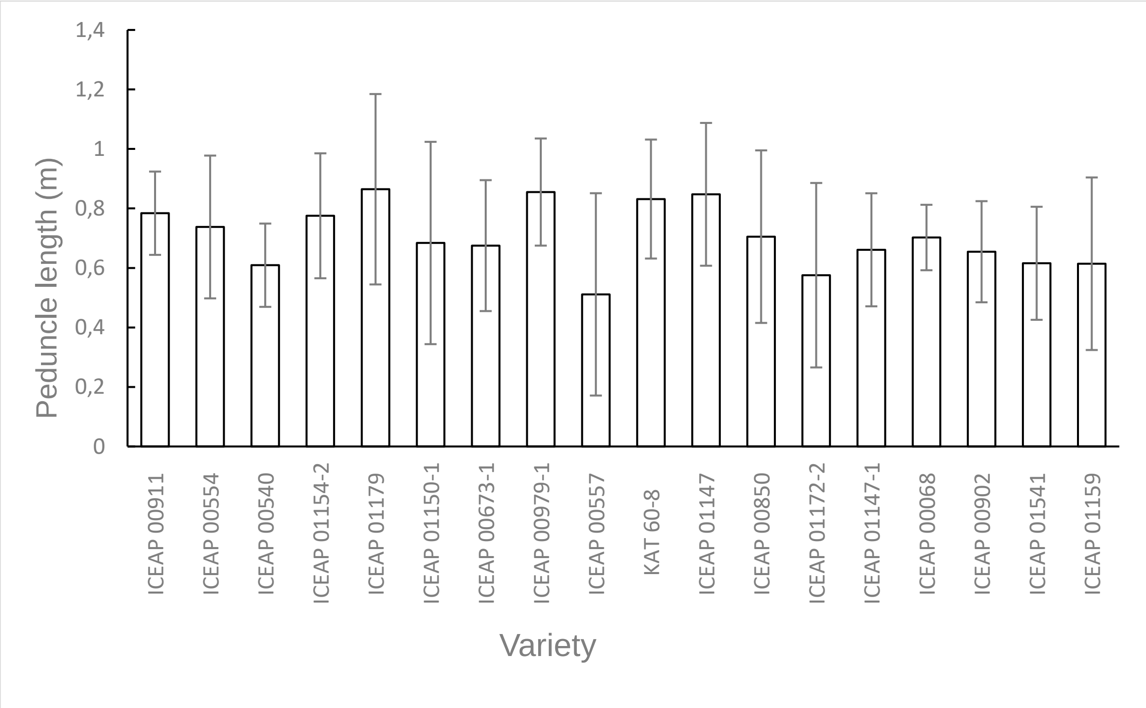

Figure 4.8: Length of primary branches of 18 pigeonpea varieties

4.2.8. Number of pods per plant of 18 pigeonpea varieties

The analysis indicated significant differences (P ≤ 0.05) among pigeonpea varieties with respect to the number of pods per plant (Table 4.10). The differences in pod numbers among the cultivars were recorded. This suggests that different cultivars may produce greater number of pods depending on the seasons and locations thereby indicating that the production of pigeonpea pods may be greater under certain environmental (temperature and rainfall) and genetic factors (cultivar variations). The variation in the number of pods per plant arose due to the differences in the genetic characteristics of the varieties and the response to other growth factors. These observations agree with the findings of Cheboi *et al*. (2016) who recorded differences in the number of pods per plant due to genetic makeup.

The lower number of pods per plant were recorded for ICEAP 00540, ICEAP 00979-1 and ICEAP 01150-1 with a mean of 56, 64 and 76, respectively (Figure 4.9) which may be due to a reduced rainfall in April and May (Figure 4.1). Under reduced rainfall, the number of pods per plant may be reduced due to flower abortion. The reduced number of pods per plant under rain-fed condition (limited rainfall) was thought to be due to flower abortion during the main flowering and pod abortion during the period of rapid development after flowering (Kamel & Abbas, 2012; Patel & Mehta, 2001). Similarly, the low moisture content in the soil during drought affects the anthesis stage due to the lack of adequate water in plants, which thereby causes a drastic reduction in the yield and in the yield components (Saleem *et al*., 2005). In other studies, the significant ($P \leq 0.05$) and positive correlations between the number of pods per plant and the seed yield have been reported by Kumar and Hirochika (2001) on cowpeas (*Vigna ungiculata*), Sawargoankar *et al*., (2011), Baskaran and Muthiah (2007), and Kamel and Abass (2012) on chickpeas (*Cicer arietinum*). It has been postulated that the yield reduction is attributed to a drop in the pod numbers per plant, seeds per pod and seed mass or weight. Saleem *et al*., (2005), also noted a high significant difference in pods per plant in the chickpea cultivars as a result of irrigation. This is similar to findings by Turnbull (1986) who reported that flower abortion increases at high constant temperatures, thereby leading to low pod sets. The highest numbers of pods per plant that were observed were ICEAP 01159, ICEAP 00850 and KAT 60-8 with a mean of 629, 510 and 495, respectively (Figure 4.9). This implies that the varieties were stable in grain production despite the variation in weather conditions during the season.

Table 4.10 : Analysis of variance for number of pods per plant on 18 pigeonpea varieties.

Source of variation	**DF**	**SS**	**MS**	**F**	**P**
Rep	2	296168	17421.6		
Variety	17	289364	17021.4	2.002	0.0464*
Error	34	161518	8500.9		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and * significant at ($P \leq 0.05$).

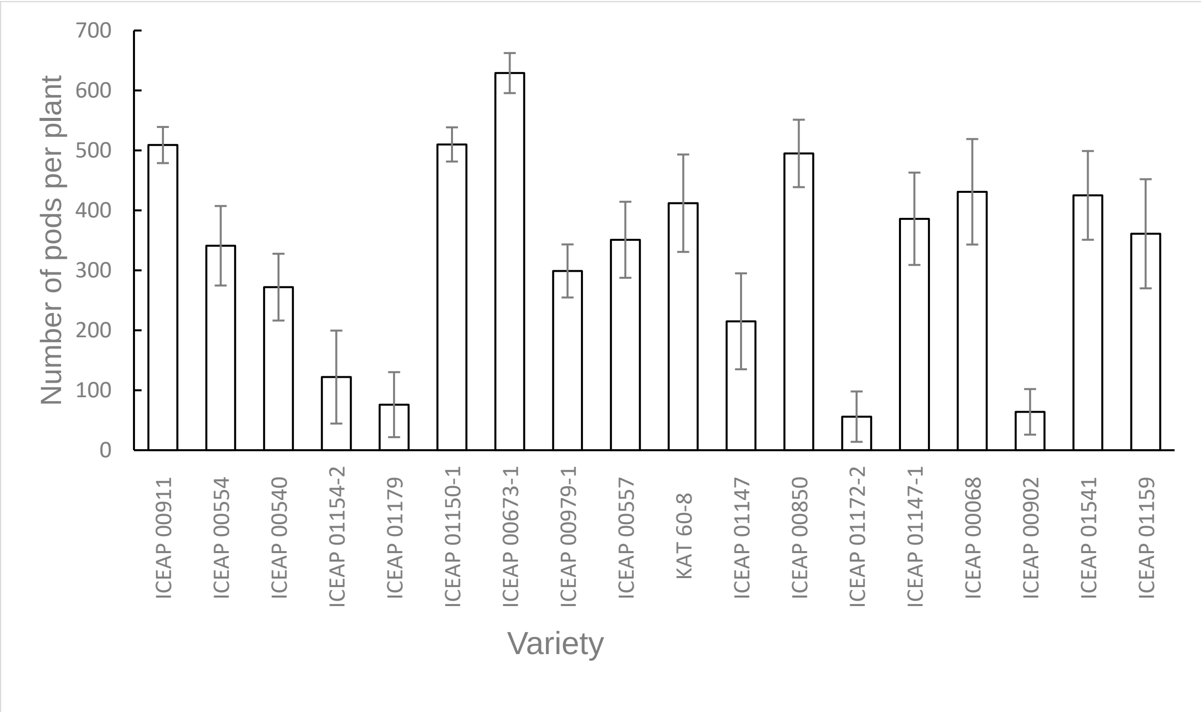

Figure 4.9: Number of pods per plant of 18 pigeonpea varieties

4.2.9. Number of seeds per pod of 18 pigeonpea varieties

Although the analysis showed that there were no significant differences ($P \geq 0.05$) on the number of seeds per pod among the different pigeonpea varieties (Table 4.11), the low variation in the number of seeds per pod was detected within the experiments. This suggests that the genetic variation in seed numbers among the cultivars that were tested may not be great or this may not be an important criterion for grain yield when compared to seed weight. In other leguminous crops, the significant ($P \leq 0.05$) differences among the cultivars for seed numbers per pod have also been reported by RozRokh *et al.,* (2009) on chickpeas. It was observed that the chickpea plants with a higher number of pods per plant resulted in higher competition for assimilates, consequently leading to a lower number and a smaller size of seeds.

In this research study, the number of seeds per pod was positively correlated to the pod length and the mass of 100 seeds for crops that were harvested during the crop season (Table 4.2.29). The researcher can postulate that the increases in pod length may result in a greater number of ovules which could have enhanced seed weight as a result of adequate space for seed growth and expansion. In other studies, Udensi and Ikpeme (2012) as well as Baskaran and Muthiah, (2007) documented similar results in pigeonpea. The low number of seeds per pod may perhaps be attributed to water supplementation during crop growth. An increase in water applications (irrigation frequency) has been shown to increase the number of seeds per pod and the mass of 100 seeds in French beans (*Phaseolus vulgaris*) and bush beans (Ahlawat & Sharma, 1989; Mozumder *et al*., 2005). The average number of seeds per pod ranged from one to six. Most of the varieties including ICEAP 00850, KAT 60-8, ICEAP 01147-1, ICEAP 01179 and ICEAP 00911 had the greatest number of seeds (6) and also had identical seeds per pod at crop season, while ICEAP 00557, ICEAP 01147-1 and ICEAP 00911 had the least mean number of seeds per pod (2) (Figure 4.10). Similar findings were observed by Ojwang (2015) who reported no significant difference on the number of seed per pod among the pigeonpea genotypes.

Table 4.11: Analysis of variance for number of seed per pod of 18 pigeonpea varieties.

Source of variation	DF	SS	MS	F	P
Rep	2	32.8991	1,93524		
Variety	17	28.9825	1.70485	1.052	0. 4736^{ns}
Error	34	30.7675	1.61934		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05).

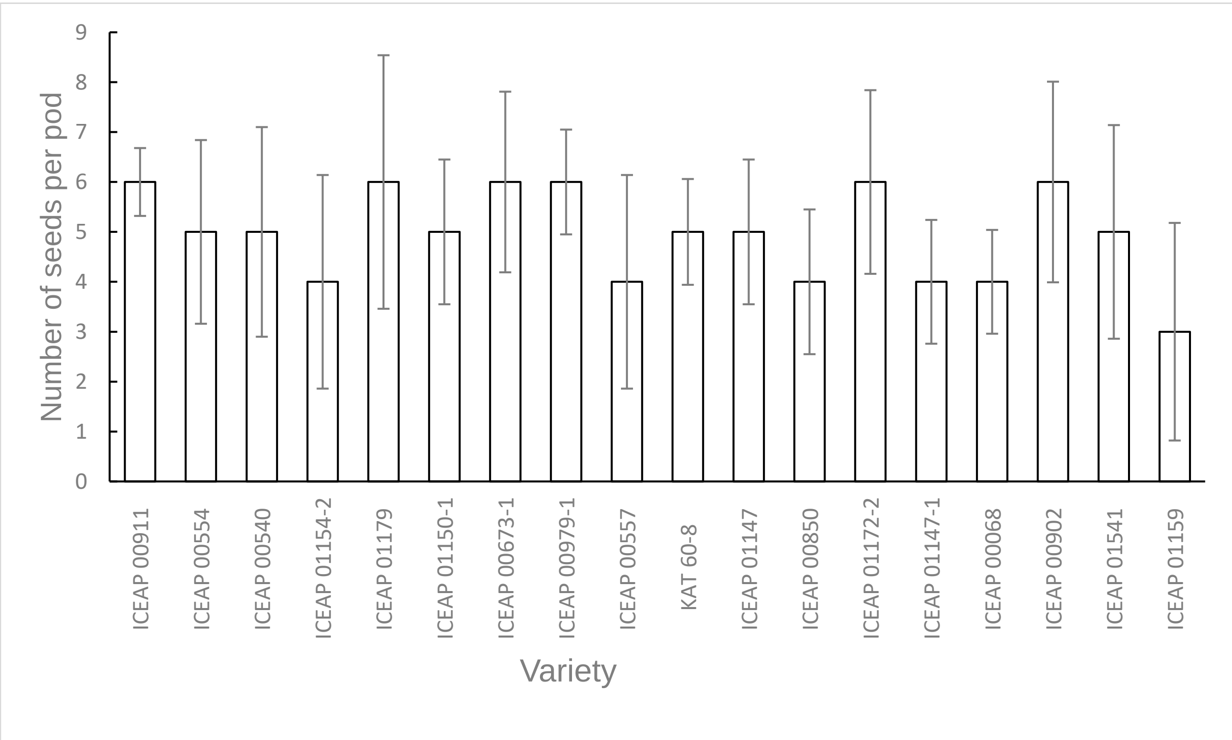

Figure 4.10: Number of seeds per pod of 18 pigeonpea varieties

4.2.10. Pod length of 18 pigeonpea varieties

The analysis indicated no significant differences (P ≥ 0.05) among the pigeonpea varieties with respect to the number of pod length (Table 4.12). For vegetable purposes, generally large pods are preferred as they are attractive and relatively shelled easily. Although the number of seeds per pod in the germplasm ranges from between two and six, on average, the optimum seed number per pod is easily marketed at between five and seven. In pigeonpea, seed and pod size are invariably correlated with large podded types having large immature as well as dry seeds. On the contrary, in some vegetable type lines, the immature seeds are large, but their size reduces gradually with approaching maturity. Saxena (2008) observed that in the long podded genotypes, all the ovules did not develop properly to their full size due to ovule abortion. The exact reason for the loss of ovules is not fully understood but there appears to be some sort of blockage in the supply of carbohydrates and other vital nutrients resulting in their pre-mature cessation.

The average pod length ranged from between 2.03 to 8.82cm (Figure 4.11). Most of the cultivars including ICEAP 00673-1, ICEAP 01147-1, ICEAP 01541, ICEAP 01179 and ICEAP 00557 had the longer pod length (8.34 - 8.72 cm), while ICEAP 00540, ICEAP 00979-1 and ICEAP 00068 had the shorter pod length (2.02 – 3.62cm), respectively. In other studies, Sharma *et al*. (2010) recorded longer pods under intercropping in which the superior performance of intercrop plots suggest that there was lower competition for resources both aboveground and belowground.

Table 4. 12: Analysis of variance for pod length of 18 pigeonpea varieties

Source of variation	**DF**	**SS**	**MS**	**F**	**P**
Rep	2	63.7192	3.74819		
Variety	17	42.4147	2.4947	1.0526	0,4642^{ns}
Error	34	45,1578	2.3797		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05)

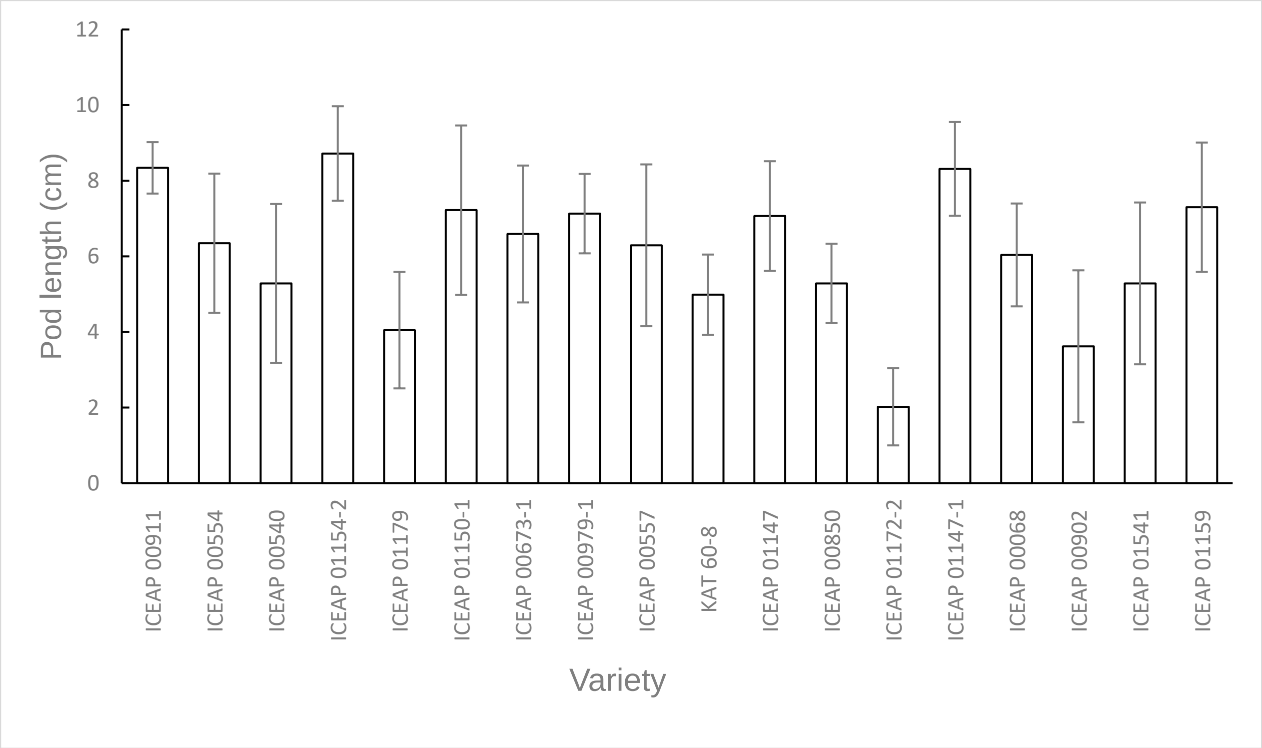

Figure 4.11: Pod length of 18 pigeonpea varieties

Table 4.13: Mean of yield components on peduncle height (m), number of pods per plant and number of seed per pod of 18 pigeonpea varieties

Variety	Variable		
	Length of primary branches (m).	Pod length (cm)	Number of seed per pod
ICEAP 01147	0.784[a]	8.34[a]	6[a]
ICEAP 01147-1	0.7377[a]	6.348[ab]	5[a]
ICEAP 00673-1	0.6092[a] b	5.2844[ab]	5[a]
ICEAP 00557	0.7753[a]	8.72[a]	4[a]
ICEAP 01150-1	0.8646[a]	4.0480[b]	6[a]
KAT 60-8	0.6839[ab]	7.2214[ab]	5[a]
ICEAP 00850	0.6751[ab]	6.5909[ab]	6[a]
ICEAP 01172-2	0.8551[a]	7.1294[ab]	6[a]
ICEAP 00902	0.5112[ab]	6.2914[ab]	4[a]
ICEAP 00068	0.8316[a]	4.9870[b]	5[a]
ICEAP 01541	0.8475 [a]	7.0655[ab]	5[a]
ICEAP 01159	0.7052 [a]	5.2844[ab]	4[a]
ICEAP 00540	0.5756 [a]	2.02[b]	6[a]
ICEAP 00554	0.661[ab]	8.3120[a]	4[a]
ICEAP 01154-2	0.7023[a]	6.0376[ab]	4[a]
ICEAP 00979-1	0.6545[ab]	3.62[b]	6[a]
ICEAP 01179	0.6157[ab]	5.2844[ab]	5[a]
ICEAP 00911	0.6142[ab]	7.2994[ab]	3[a]
Grand mean	0.6837	6.4122	4,9753
SEM	0.3933	0.1648	0.1542

Means followed by the same letters in each column does not differ significantly at P≤0.05. SEM= Standard error of means

4.2.11. Hundred Seed weight of 18 pigeonpea varieties

Highly significant differences (P ≤ 0.05) were observed on the mass of 100 seeds (Table 4.14). The variation in seed mass recorded for cultivars was ranging from 9.43 to 16.97g (Figure 4.12). This suggests that there are inherent differences among cultivars and they may be attributed to the genetic variation of cultivars. The cultivar ICEAP 00540 had the lowest seed mass with an average of 9.43g, followed by ICEAP 00979-1 with an average of 9.84g respectively (Figure 4.12). The reason of the cultivars to attain lower mass may be due to limited soil moisture during the cropping season. Patel and Mehta (2001) observed a significant (P ≤ 0.05) lower mass of 100 seeds of pigeonpea grown under rain-fed conditions. They attributed the low yield to moisture stress (inadequate water), which affected the translocation of photosynthetic products from the leaves to the grain, thereby resulting in small grain weight.

Most of the cultivars including ICEAP 00911, ICEAP 01150-1, ICEAP 00557 and ICEAP 00902 attained an average mass of 10.54 to 14.93 g respectively, while seven cultivars including, ICEAP 00540, ICEAP 00979-1 and KAT 60-8 obtained the higher seed mass of 15.03 to 16.93 g (Figure 4.12). The high seed mass that was recorded could have been a result of the water application effect rather than the temperature effect. Although Patel and Mehta (2001) observed that high mean temperatures favour pod growth and an increase in seed size, the researchers noted greater seed mass (weight) at the University of Limpopo Farm which was occurring while the temperature was 25.39^0C and 24.66^0C around April and May (Figure 4.1) during the grain filling period. Therefore, this may also be attributed to the temperature effect. The mass of 100 seeds was positively and significantly ($P \leq 0.05$) correlated to the vegetative growth of the crop, but it negatively correlated with other yield components such as pod length and the number of seeds per pod. In other studies, a positive correlation between seed mass and seed yield in lentils (*Lens culinaris*) has been reported (Dixit, 2005). Santosh and Madrap (2007) reported that the primary branches and a 100-seed weight had a direct positive effect on the seed yield. Hence, the simultaneous selection based on these characters could lead to improved yield.

Table 4.14: Analysis of variance for hundred seed weight of 18 pigeonpea varieties.

Source of variation	**DF**	**SS**	**MS**	**F**	**P**
Rep	2	62.2701	3.66294		
Variety	17	47.9294	3.99411	3.00	0.0105*
Error	34	31.9204	1.33002		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and * significant at ($P \leq 0.05$).

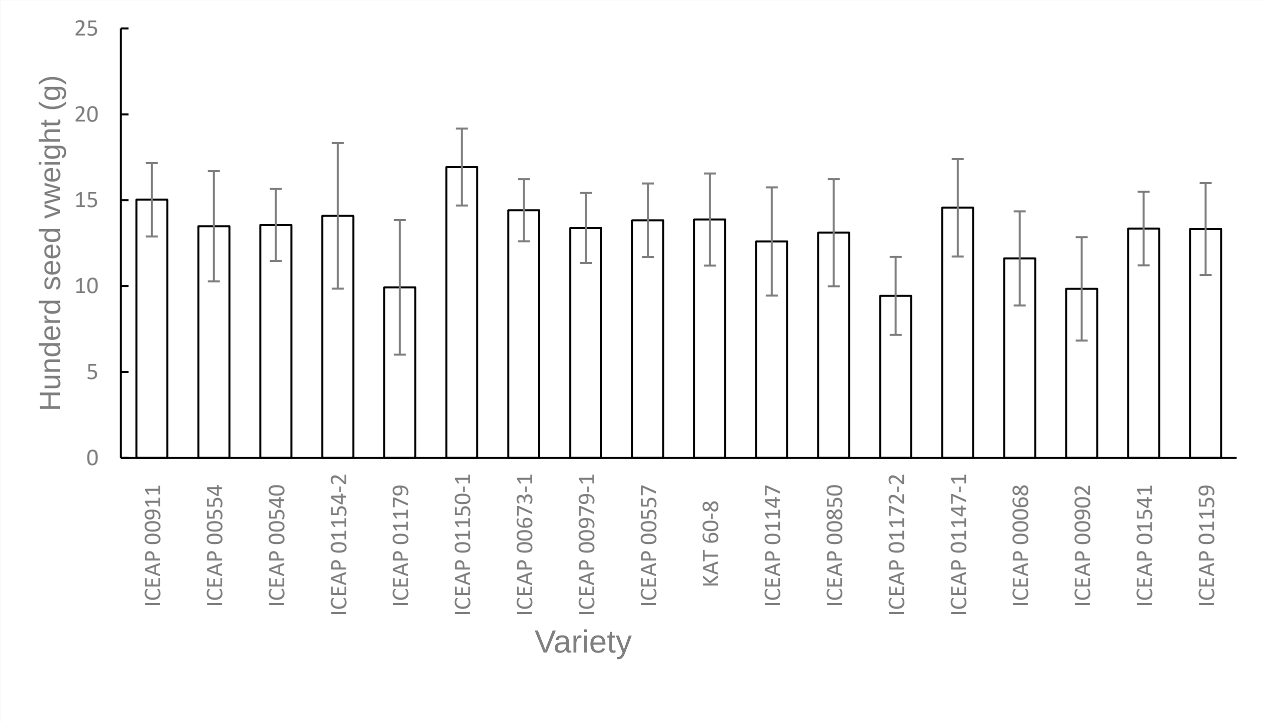

Figure 4.12: Hundred Seed weight of 18 pigeonpea varieties

4.2.12. Calcium (Ca) content of 18 pigeonpea varieties

Calcium is the most important plentiful mineral found in the human body which helps in maintaining strong bones and teeth, prevents blood clotting, neurotransmission, muscular movements, hormonal activities and maintaining a normal heartbeat (U.S. National Library of General Medicine). The analysis showed no significant differences ($P \geq 0.05$) among pigeonpea varieties with respect to calcium content (Table 4.15). Among the pigeonpea genotypes, the calcium content ranged between 45.4mg/L to 556mg/L. The higher calcium amount was observed by varieties ICEAP 00979-1, ICEAP 00673-1, ICEAP 01172-2 and ICEAP 01147-1 with an average of 556, 490, 444 and 420mg/L respectively (Figure 4.13). A lower calcium content was found on the varieties ICEAP 00902, KAT 60-8, ICEAP 00557 and ICEAP 01541 with an average of 45.4, 54.6, 77 and 81.3mg/L, respectively. Similar reports on higher calcium content in pigeonpea were given by Saxena *et al*. (2010) and Patil *et al.* (2015) who reviewed "Vegetable Pigeonpea - a High Protein Food for all Ages". Most of the varieties resulted in a higher calcium content due to the accumulation of calcium in the seed coat during seed maturation (Cabanne & Doneche, 2003).

Table 4.15: Analysis of variance of Calcium content in 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	214476	12616.2		
Variety	17	216148	18012.4	2.0289	0.2437^{ns}
Error	34	314266	13094.4		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05).

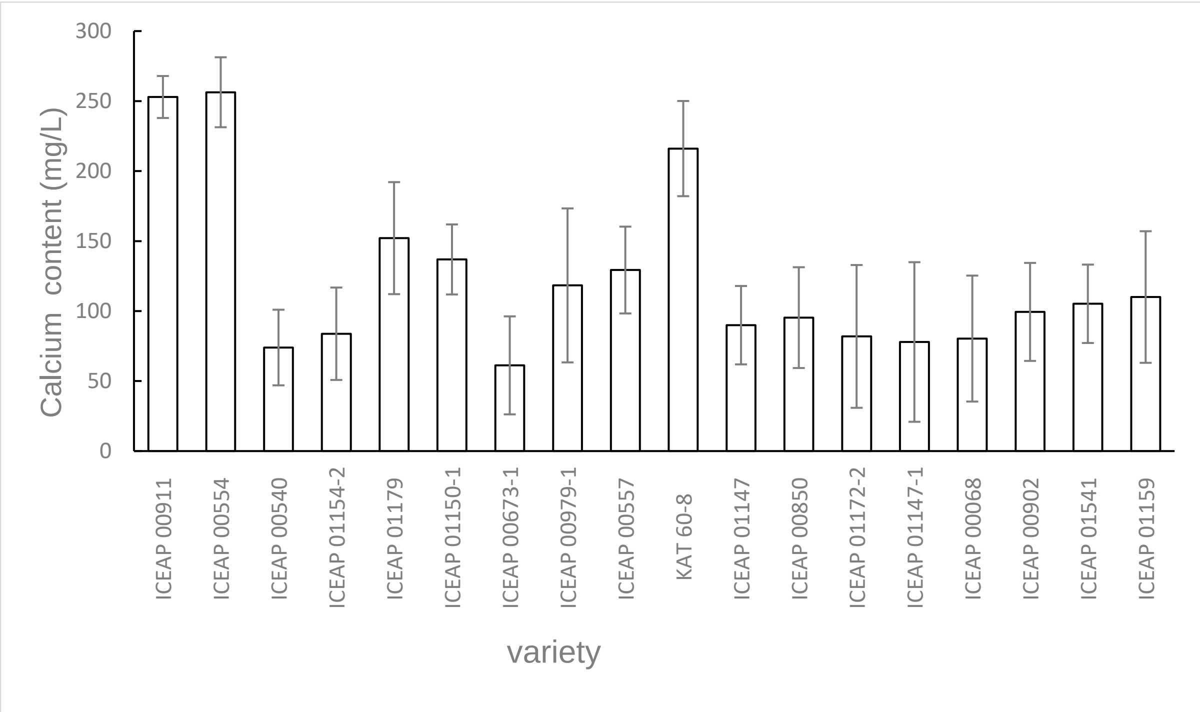

Figure 4.13: Calcium (Ca) content in 18 pigeonpea varieties

4.2.13. Iron (Fe) content of 18 pigeonpea varieties

Iron is an essential mineral as it is needed for haemoglobin synthesis and its deficiency causes iron-deficiency anaemia which is a common problem in women and children (Latham, 1979). The analysis showed no significant differences (P ≥ 0.05) among pigeonpea varieties with respect to iron content (Table 4.16). In the pigeonpea genotypes, the iron content ranged between 3.72mg/L to 14 Calcium (Ca) content. The highest iron content was observed by ICEAP 01172-2 (14 mg/L) and the lowest iron content was found in ICEAP 00850 (3.72mg/L). The other varieties that attained higher

Fe content were ICEAP 01147, ICEAP 00540 and ICEAP 00911 with an average of 10.2mg/L, 9.94mg/L and 9.92mg/L, while the lower Fe content was observed under ICEAP 01159, ICEAP 01172-2 and ICEAP 01147 with an average of 3.76, 3.97 and 4.21mg/L, respectively (Figure 4.14). The grand mean values were 5.74mg/L, respectively (Table 4.2.5.1). Similar results were reported by Saxena *et al*. (2010). The increase in iron may be due to the fact that the simple amino acids and simple sugars are converted to complex substances such as iron, protein and starch respectively during maturation (Geervani & Umadevi, 1989).

Table 4.16: Analysis of variance of iron content in 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	95.848	5.63810		
Variety	17	26.950	2.24584	0.39	0.9536^{ns}
Error	34	137.875	5.74477		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05).

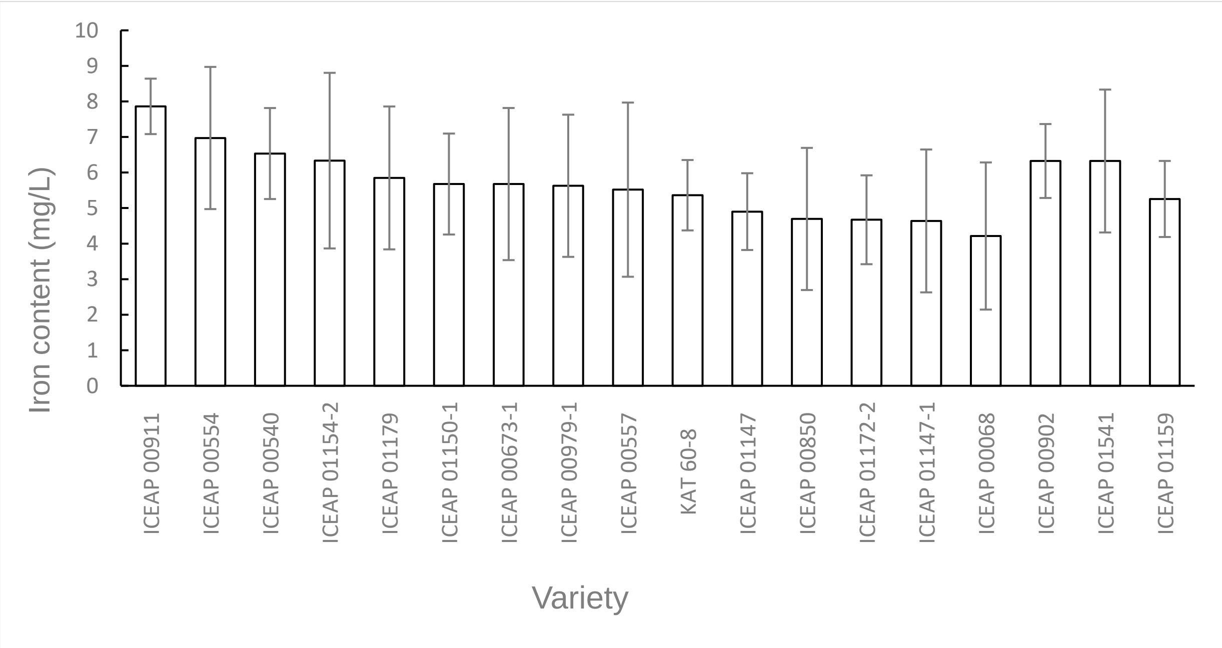

Figure 4.14: Iron (Fe) content in 18 pigeonpea varieties

4.2.14. Potassium (K) content of 18 pigeonpea varieties

Potassium is an essential nutrient, it is the most abundant cation in intracellular fluid, and it plays a key role in maintaining cell function, particularly in excitable cells such as in the muscles and in the nerves. Since potassium is a major intracellular ion, it is widely distributed in foods once it is derived from living tissues. The potassium concentration is higher in fruits and vegetables than in cereals and meat (FAO, 2008). The analysis showed no significant differences (P ≥ 0.05) among the pigeonpea varieties with respect to potassium content (Table 4.2.18). In the pigeonpea genotypes, the potassium content ranged between 24 mg/L to 110 mg/L. The highest potassium content was observed in ICEAP 00540 (110 mg/L) and the lowest potassium content was found in ICEAP 00850 (24 mg/L). The other varieties that attained a higher K content were ICEAP 00673-1, ICEAP 01172-2 and ICEAP 00850 with an average of 94 mg/L, 82.6 mg/L and 76.4 mg/L respectively, while the lower potassium content was observed in ICEAP 00068, ICEAP 01154-2 and in ICEAP 00911 with an average of 26.7 mg/L, 31 mg/L and 32 mg/L respectively (Figure 4.15).

Table 4.17: Analysis of variance of potassium content in 18 pigeonpea varieties.

Source of variation	DF	SS	MS	F	P
Rep	2	11256.7	662.158		
Variety	17	9293.1	774.422	1.05	0.4413^{ns}
Error	34	17743.2	739.300		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05).

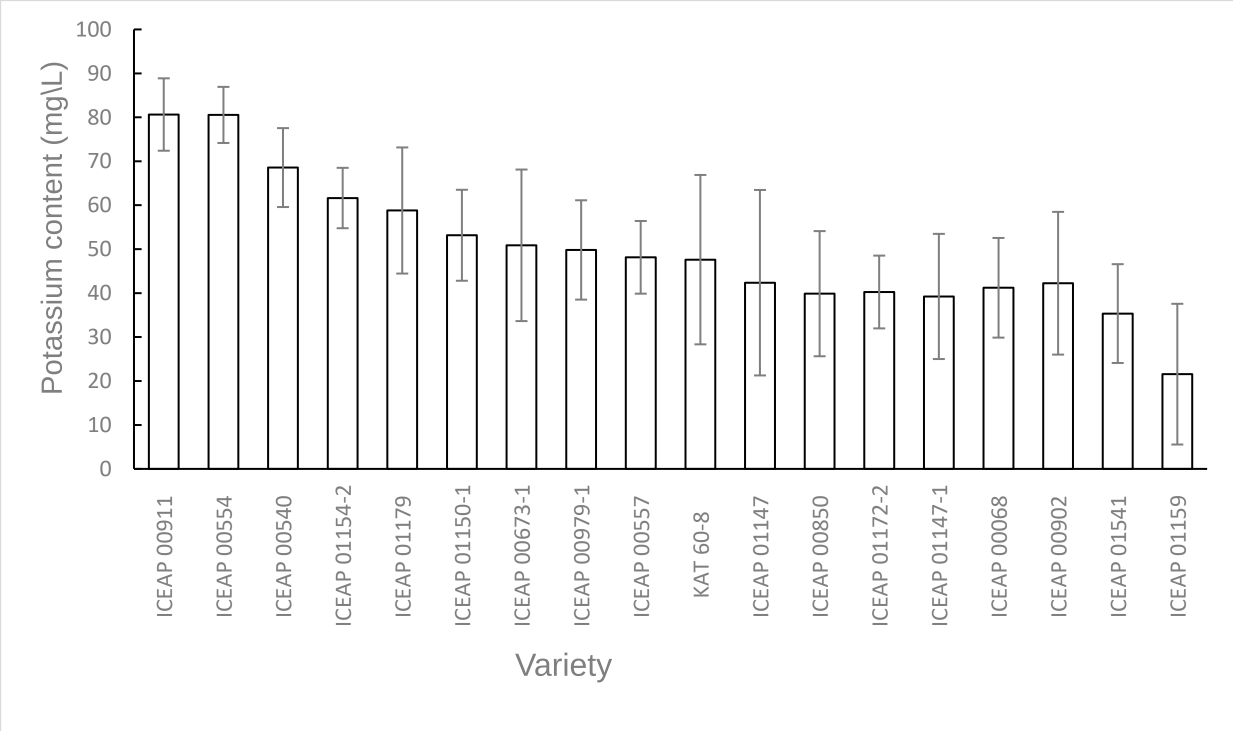

Figure 4.15: Potassium content in 18 pigeonpea varieties

Table 4.18: Mean of mineral contents: Calcium, Iron and Potassium of 18 varieties

Variety	Mineral		
	Calcium (mg/L)	Iron (mg/L)	Potassium (mg/L)
ICEAP 01147	252.92[a]	7.8612[a]	80.637[a]
ICEAP 01147-1	256.31[a]	6.9714[a]	80.547[a]
ICEAP 00673-1	73.96[ab]	6.5346[a]	68.566[ab]
ICEAP 00557	83.81[ab]	6.3346[a]	61.637[ab]
ICEAP 01150-1	152.10[ab]	5.8486[a]	58.798[ab]
KAT 60-8	136.89[ab]	5.6761[a]	53.164[ab]
ICEAP 00850	61.23[ab]	5.6761[a]	50.877[ab]
ICEAP 01172-2	118.35[ab]	5.6277[a]	49.819[ab]
ICEAP 00902	129.32[ab]	5.5181[a]	48.144[ab]
ICEAP 00068	216.06[ab]	5.3622[a]	47.615[ab]
ICEAP 01541	89.925[ab]	4.9005[a]	42.368[ab]
ICEAP 01159	95.321[a]	4.6938[a]	39.870[ab]
ICEAP 00540	81.901a[b]	4.6714[a]	40.254[ab]
ICEAP 00554	77.919[ab]	4.6386[a]	39.242[ab]
ICEAP 01154-2	80.354[ab]	4.2142[a]	41.215[ab]
ICEAP 00979-1	99.410[ab]	6.3241[a]	42.248[ab]
ICEAP 01179	105.21[b]	6.3240[a]	35.344[ab]
ICEAP 00911	110.03[b]	5.2564[a]	21.559[b]
Grand mean	159.93	5.7414	54.123
SEM	2.064	0.974	3.4325

Means followed by the same letters in each column does not differ significantly at P≤0.05.
SEM= Standard error of means.

4.2.15. Magnesium (Mg) content of 18 pigeonpea varieties

Magnesium is important for bone formation. It helps assimilate calcium into the bone and plays a role in activating vitamin D in the kidneys. Optimal magnesium intake is associated with greater bone density, improved bone crystal formation and a lower risk of osteoporosis in women after menopause (Latham, 1979). The analysis showed no significant differences (P ≥ 0.05) among pigeonpea varieties with respect to Magnesium content (Table 4.2. 20). In the pigeonpea genotypes, magnesium content ranged between 27.2 mg/L to 141 mg/L. The highest magnesium content was observed in ICEAP 00673-1 (141 mg/L) and the lowest mg content was found in ICEAP 00902 (27.2 mg/L). The other varieties that attained a higher mg content were ICEAP 01154-2, ICEAP 00540 and ICEAP 01147-1 with an average of 107, 98.8 and 85.5 mg/L respectively, while the lower magnesium content was observed in ICEAP 00557, ICEAP 01154-2 and ICEAP 01541 with an average of 31.3, 32 and 39 mg/L, respectively (Figure 4.16). The grand mean values were 59.213 mg/L, respectively (Table 4.2.22).

Table 4.19: Analysis of variance of Magnesium content in 18 pigeonpea varieties

Source of variation	**DF**	**SS**	**MS**	**F**	**P**
Rep	2	16756.7	985.686		
Variety	17	11633.6	969.463	1.07	0.4238^{ns}
Error	34	21720.8	905.035		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05).

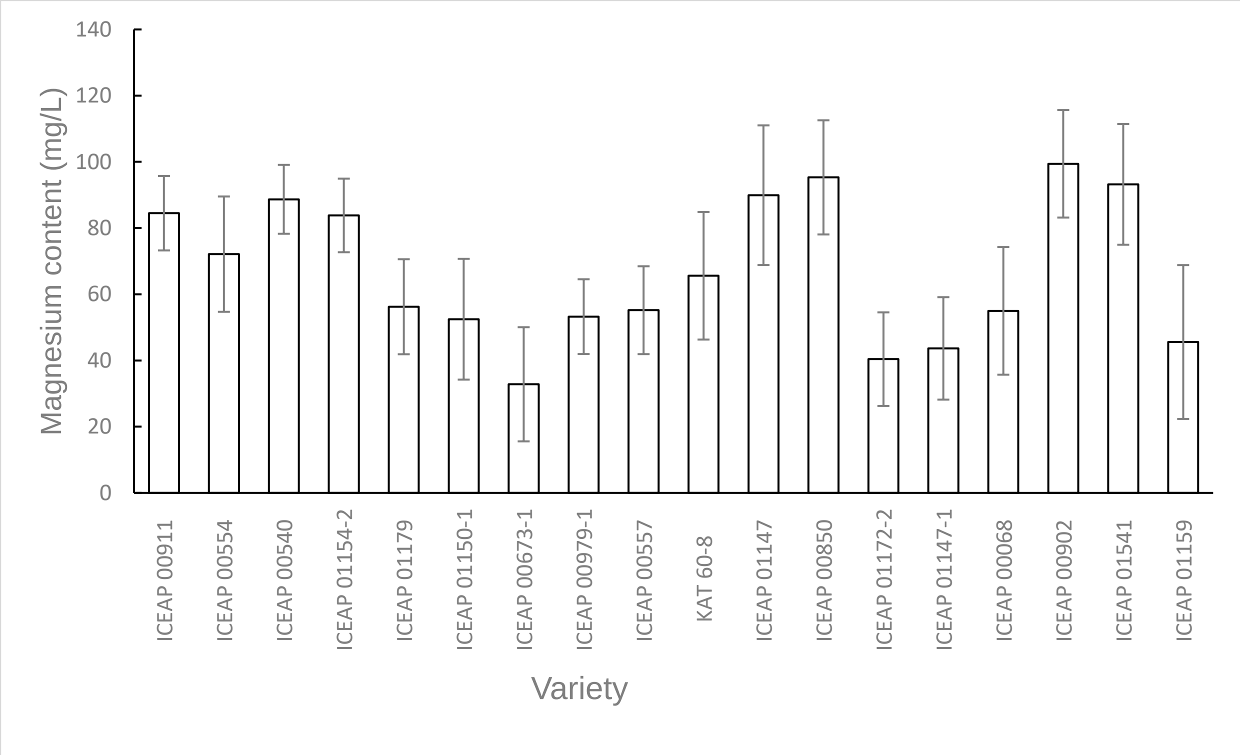

Figure 4.16: Magnesium content of 18 pigeonpea varieties

4.2.16. Sodium (Na) content of 18 pigeonpea varieties

Sodium is found mainly in body fluids. It plays a major role in maintaining the blood volume and blood pressure by attracting and holding water. Sodium is also important in cellular osmotic pressure (the passage of fluids in and out of the cells) and in transmitting nerve impulses (Latham, 1979). Although the analysis showed no significant differences ($P \geq 0.05$) on sodium content among the different pigeonpea varieties (Table 4.2.21), a low variation was detected within the tested varieties. The results of the evaluation of the sodium content showed that the varieties had sodium content ranging from 15 to 85.1 mg/L. The variety ICEAP 01147-1 had the lowest sodium content, followed by ICEAP 00068, ICEAP 00540 and ICEAP 00673-1 with an average of 13.1, 15, 17.5 and 19.4 mg/L respectively, while ICEAP 01154-2 and ICEAP 01172-2 were the top varieties that produced a higher sodium content with an average of 85.1and 77.7 mg/L, respectively (Figure 4.17).

Table 4.20: Analysis of variance of sodium content in 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	12408.6	729.920		
Variety	17	2569.5	214.128	0.74	0.6978^{ns}
Error	34	6913.2	288.052		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05).

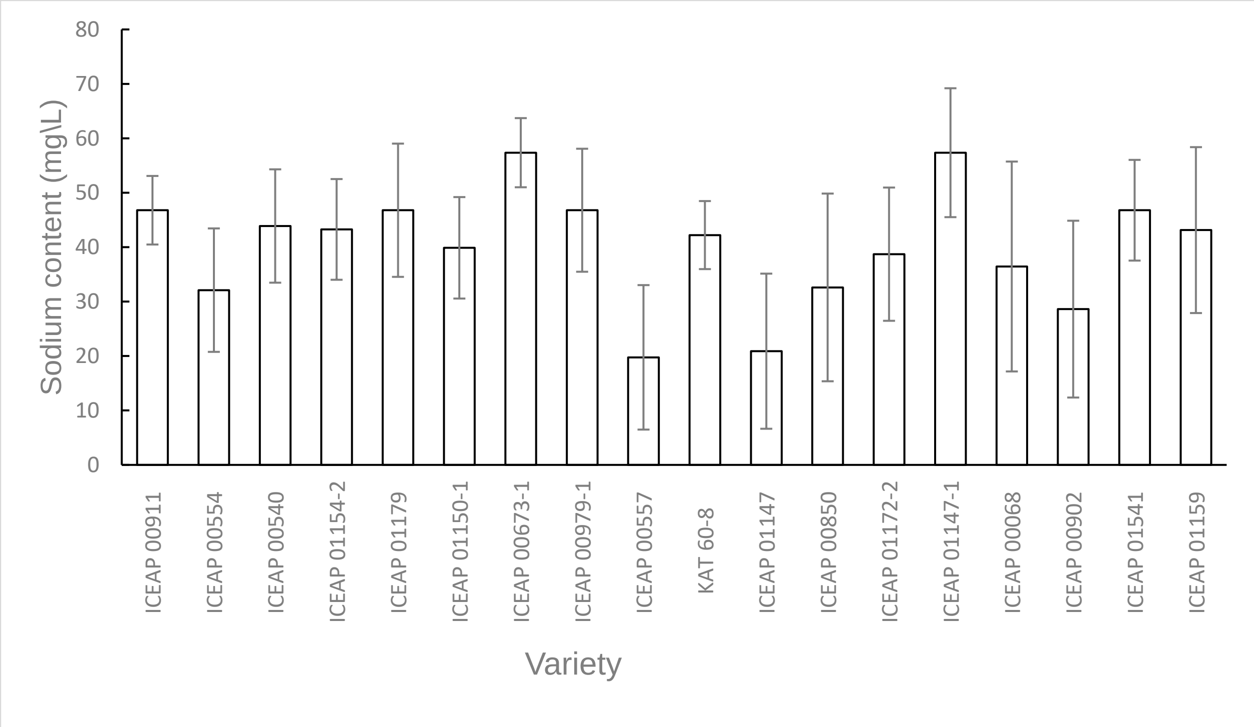

Figure 4.17: Sodium content of 18 pigeonpea varieties

4.2.17. Phosphorus (P) content of 18 pigeonpea varieties

As the second most abundant mineral in the body, phosphorus works with calcium to help build strong bones and teeth. It also plays an important role in energy metabolism, and it also helps to filter out waste in the kidneys, while promoting the growth, maintenance and repair of all tissues and cells (Latham, 1979). Although the analysis showed no significant differences (P ≥ 0.05) on phosphorus content among the different pigeonpea varieties (Table 4.2.21), a low variation was detected within the tested varieties. In the pigeonpea genotypes, the phosphorus content ranged between 3.77 mg/L to 24.5 mg/L. The highest phosphorus content was observed in ICEAP 00911 (24.5 mg/L) and the lowest was found in ICEAP 01147 (3.77 mg/L). The other varieties that attained higher phosphorus content were KAT 60-8, ICEAP 01541 and

ICEAP 00554 with an average of 20.7, 20, and 19.7 mg/L respectively, while the lower phosphorus content was observed in ICEAP 01159, ICEAP 01154-2 and ICEAP 00673-1 with an average of 4, 4.12 and 4.96 mg/L, respectively (Figure 4.18). The grand mean values were 11.235 mg/L, respectively (Table 4.21). The overall nutritional status is that the genotypes showed a higher amount of phosphorus.

Table 4.21: Analysis of variance for phosphorus content in 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	555.471	32.6748		
Variety	17	357.433	29.7861	0.89	0.5671^{ns}
Error	34	801.918	33.4132		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05).

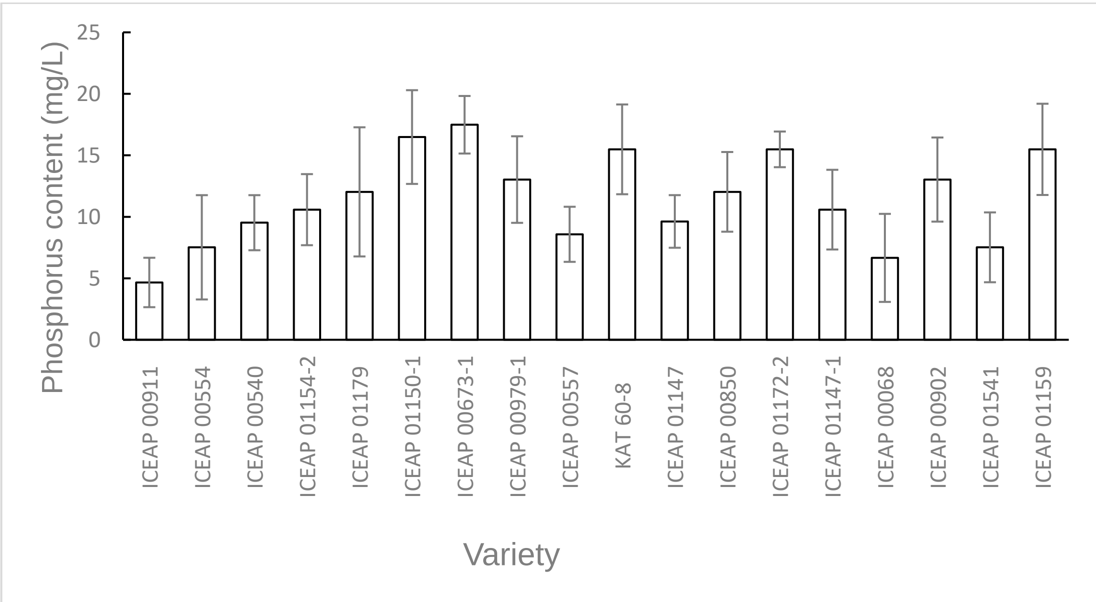

Figure 4.18: Phosphorus content of 18 pigeonpea varieties

Table 4.22 : Mean of mineral contents of magnesium, sodium and phosphorus in 18 pigeonpea varieties

Variety	Variable		
	Magnesium (mg/L)	Sodium (mg/L)	Phosphorus (mg/L)
ICEAP 01147	84.491[ab]	46.784[ab]	4.660[b]
ICEAP 01147-1	72.121[ab]	32.105[ab]	7.519[ab]
ICEAP 00673-1	88.682[ab]	43.887[ab]	9.520[ab]
ICEAP 00557	83.812[ab]	43.261[ab]	10.581[ab]
ICEAP 01150-1	56.241[ab]	46.784[ab]	12.028[ab]
KAT 60-8	52.455[ab]	39.878[ab]	16.485[a]
ICEAP 00850	32.814[b]	57.356[a]	17.485[a]
ICEAP 01172-2	53.245[ab]	46.784[ab]	13.028[ab]
ICEAP 00902	55.193[ab]	19.758[b]	8.577[ab]
ICEAP 00068	65.590[ab]	42.217[ab]	15.485[ab]
ICEAP 01541	89.925[ab]	20.887[b]	9.622[ab]
ICEAP 01159	95.321[a]	32.603[ab]	12.028[ab]
ICEAP 00540	40.405[b]	38.711[ab]	15.485[ab]
ICEAP 00554	43.652[b]	57.356[a]	10.581[ab]
ICEAP 01154-2	54.983[ab]	36.447[ab]	6.660[b]
ICEAP 00979-1	99.410[a]	28.617[ab]	13.028[ab]
ICEAP 01179	93.190[a]	46.784 [ab]	7.519[ab]
ICEAP 00911	45.570[b]	43.134[ab]	15.485[ab]
Grand mean	59.213	38.827	11.235
SEM	3.236	6.511	0.464

Means followed by the same letters in each column does not differ significantly at P≤0.05. SEM= Standard error of means.

4.2.18. Zinc (Zn) content of 18 pigeonpea varieties

Zinc is an important trace mineral that is needed for, the body's immune system, cell division, wound healing and for the sense of smell and taste. The analysis showed no significant differences (P ≥ 0.05) on zinc content among the different pigeonpea varieties (Table 4.2.23). The pigeonpea genotypes had zinc content that ranged between 0.738 mg/L to 2.36 mg/L. The highest zinc content was observed in ICEAP 01541 and ICEAP 00979-1 (2.36 and 2.26 mg/L) and the lowest zinc content was found in ICEAP 00540 and ICEAP 00068 (0.738 and 0.777mg/L) (Figure 4.19). The mean values were 0.9347 mg/L (Table 4.2.26). The overall nutritional composition is mentioned in Table 4.2.26. The overall nutritional status is that the genotypes showed a higher amount of zinc. Similar results were reported by Saxena *et al*. (2010) and Patil *et al*. (2015). The reason for other varieties that had higher amounts of minerals viz., iron and zinc, may be due to the fact that the seeds contain enzymes in the living state and they prevent nutrient losses in the green seeds (Salunkhe *et al*., 1985).

Table 4.23: Analysis of variance for zinc of 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	3.95237	0.23249		
Variety	17	4.05470	0.33789	1.76	0.1149^{ns}
Error	34	4.60319	0.19180		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability and NS= not significant at (P≤0.05).

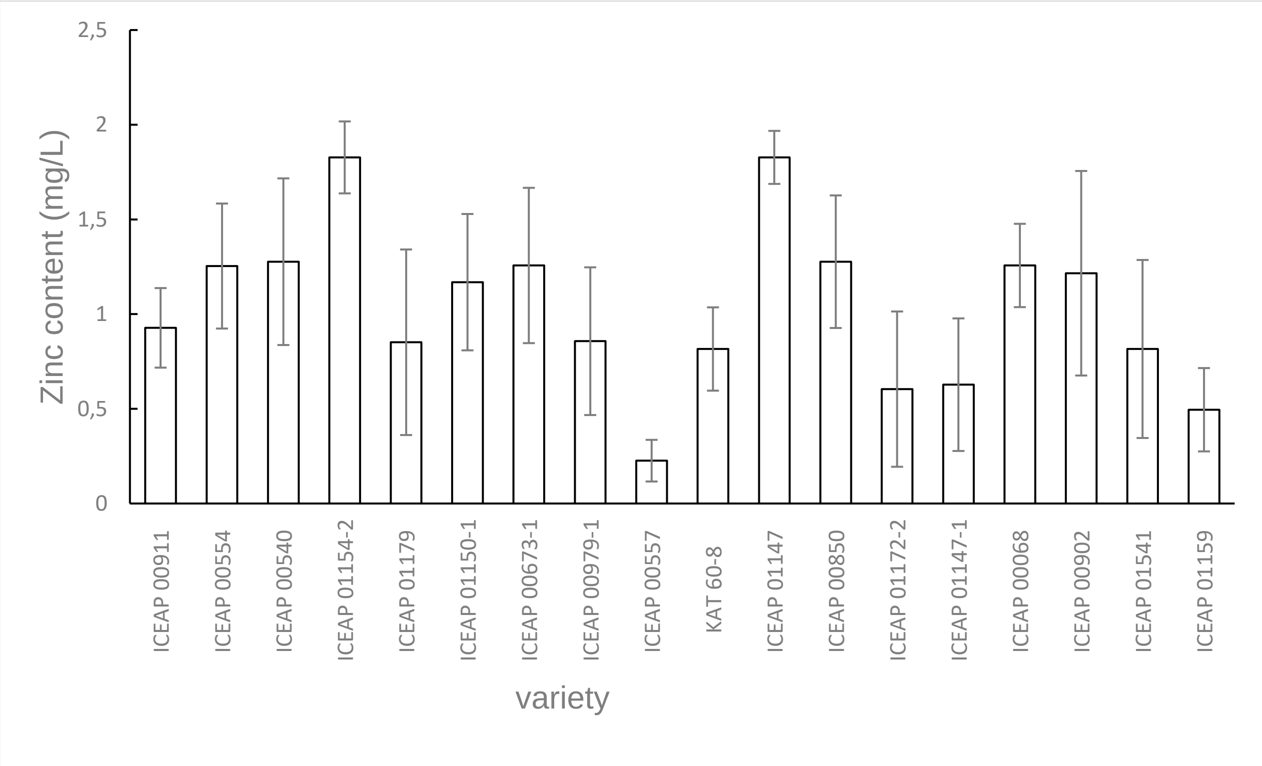

Figure 4.19: Zinc content of 18 pigeonpea varieties

4.2.19. The proportion of legume nitrogen derived from the fixation of atmospheric N_2 (%Ndfa) of 18 pigeonpea varieties

Highly significant differences (P≤0.05) were observed on the proportion of the legume nitrogen derived from the fixation of atmospheric N_2 (%Ndfa) among the pigeonpea varieties (Table 4.2.24). The pigeonpea varieties which contained much nitrogen were ICEAP 00911, ICEAP 01150-1 and ICEAP 01179 at the proportion of 73.676 and 63.199% (Figure 4.20). Mapfumo *et al*. (1999) stated that the fixed nitrogen is related to biomass whereby smaller amounts of fixed nitrogen are the results of lower biomass productivity. On average, among other varieties, ICEAP 00902, ICEAP 01541 and ICEAP 00068 were able to produce less amounts of nitrogen at the proportion of 12.999, 29.244 and 33.771% (Figure 4.20). The variation in the proportion of legume nitrogen was derived from the fixation of atmospheric nitrogen and it may be due to the varietal characteristics of the varieties. The reason for some varieties containing less nitrogen may be due to less duration types with respect to vegetative growth whereby long duration genotypes can produce a large amount of nitrogen.

Table 4.24: Analysis of variance for proportion of legume nitrogen derived from the fixation of atmospheric N2 (%Ndfa) of 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	7531.66	443.039		
Variety	17	9323.99	548.47	2.223	0.0279*
Error	34	4687.68	246.7205		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability, NS= not significant and * significant at ($P \leq 0.05$)

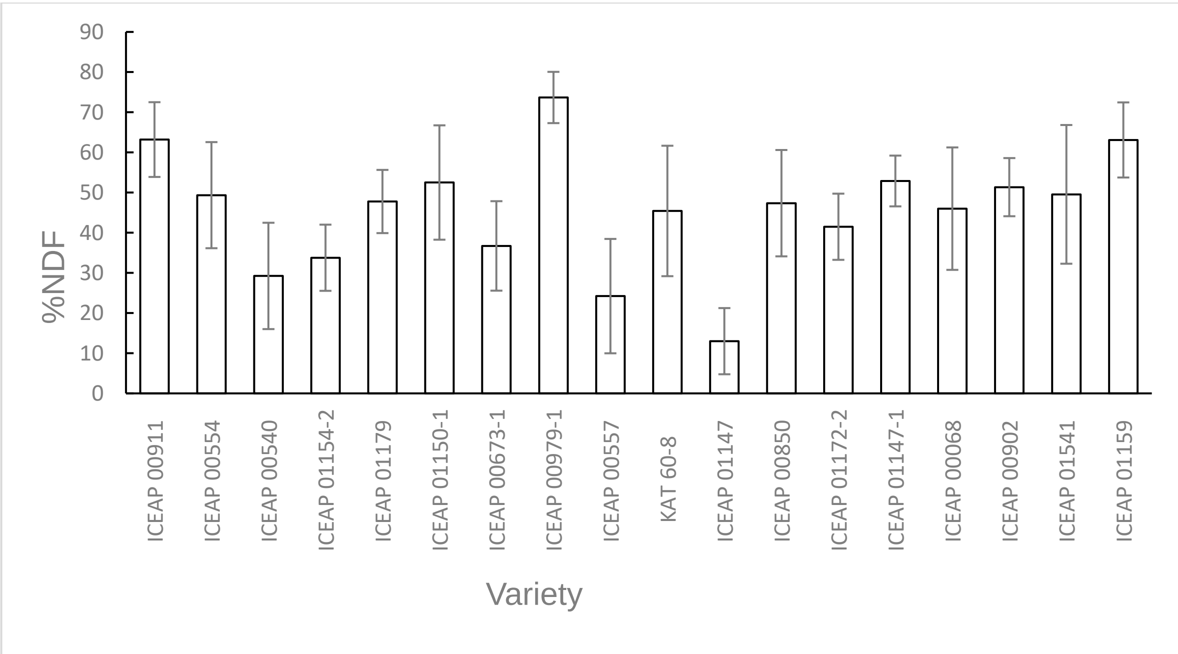

Figure 4.20: The proportion of legume nitrogen derived from the fixation of atmospheric N2 (%Ndfa) of 18 pigeonpea varieties

4.2.20. The amount of nitrogen fixed on 18 pigeonpea varieties

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 & Anyam, 2011; Egbe *et al.,* 2013). It has been stated in the literature review (Chapter 2) that pigeonpea have the ability to fix 235 $kg.ha^{-1}$ of N and produce more nitrogen per unit area from plant biomass than most of the legumes (Egbe & Anyam, 2011). The analysis showed significant differences ($P \leq 0.05$) among pigeonpea varieties in terms of nitrogen fixation (Table 4.2.25). Most of the varieties were able to fix a certain amount of nitrogen. ICEAP 01154-2 was able to fix the highest amount of nitrogen among the varieties which was 154.254 $kg.ha^{-1}$, and ICEAP 01541 fixed less nitrogen than all the all varieties which was 73.547 $kg.ha^{-1}$ (Figure 4.21). The variation in the amount of nitrogen that was fixed was due to the varietal characteristics of the varieties. Nitrogen fixation differs with duration types whereby long duration genotypes can fix up to 200kg of nitrogen per hectare over a period of 40 weeks and the early maturing varieties fix 40kg of nitrogen per hectare. It is further reported by Murwa (2013) that the leaf drop alone can contribute up to 40g of nitrogen. The varieties ICEAP 00673-1, ICEAP 00557 and ICEAP 00902 that reached their 90% physiological maturity later within 200 to 220 days were able to attain a large amount of nitrogen of 151.145, 148.14 and 134.25 $kg.ha^{-1}$, respectively. According to Mapfumo *et al*. (1999), the short duration pigeonpea fixes less nitrogen per hectare and the long duration fixes more nitrogen per hectare, this may be the reason of the results indicating less nitrogen (73.547 and 81.255 $kg.ha^{-1}$) in early maturing varieties (ICEAP 01541 and ICEAP 00540) (Figure 4.21). Biological nitrogen fixation is very important in sustaining crop productivity and it reduces soil fertility problems (Kahindi *et al*., 2008). This is why nitrogen becomes an important character to be tested with respect to the production and the performance of pigeonpea.

Table 4.25: Analysis of variance of proportion of nitrogen fixed on 18 pigeonpea varieties

Source of variation	DF	SS	MS	F	P
Rep	2	2.510E+09	1.476E+08		
Variety	17	2.318E+09	1.677E+08	3.96	0.0059*
Error	34	1.892E+09	9.657E+07		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares,
P = Probability, NS= not significant and * significant at (P≤0.05).

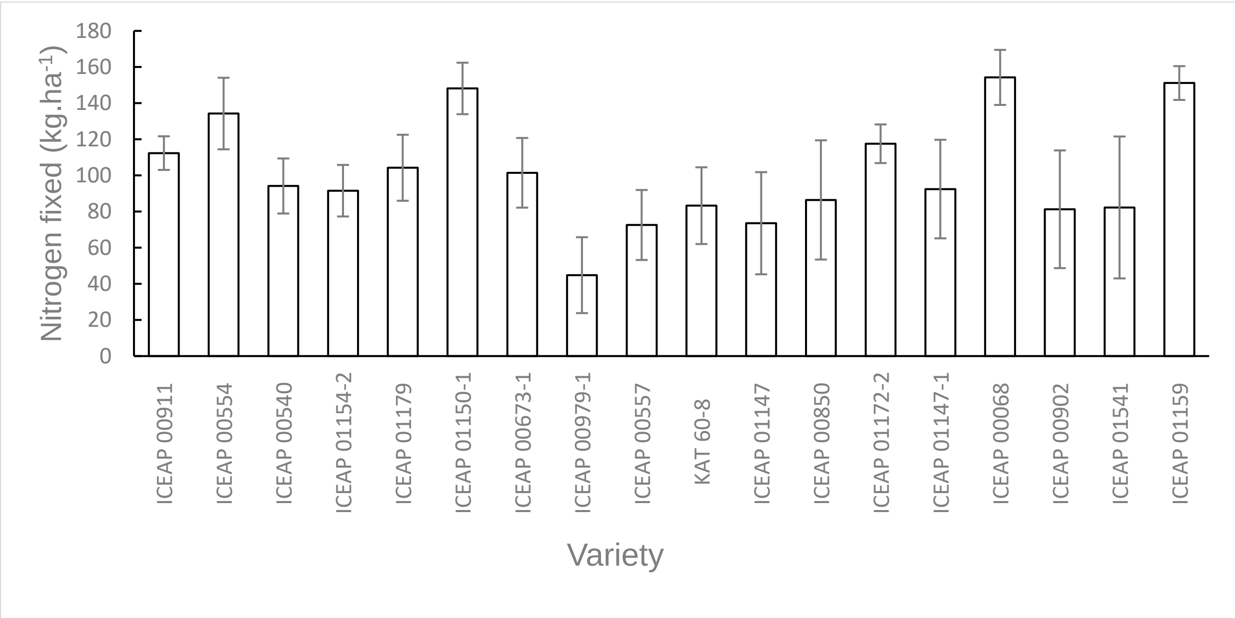

Figure 4.21: The amount of nitrogen fixed in 18 pigeonpea varieties

Table 4.26: Mean of mineral contents of zinc, proportion of legume nitrogen derived from the fixation of atmospheric and the amount of nitrogen fixed in 18 varieties

Variety	Nutrient		
	Zinc (mg/L)	%Ndfa	N-fixed
ICEAP 01147	0.9275[ab]	63.199[ab]	112.34[ab]
ICEAP 01147-1	1.2539[a]	49.354[ab]	134.25[ab]
ICEAP 00673-1	1.2769[a]	29.244[bc]	94.14[bc]
ICEAP 00557	1.8276[a]	33.771[bc]	91.54[bc]
ICEAP 01150-1	0.8515[ab]	47.776[ab]	104.24[ab]
KAT 60-8	1.1688[a]	52.504[ab]	148.14[a]
ICEAP 00850	1.2569[a]	36.715[bc]	101.44[ab]
ICEAP 01172-2	0.8572[ab]	73.676[a]	44.785[c]
ICEAP 00902	0.2262[b]	24.220[c]	72.554[bc]
ICEAP 00068	0.8159[ab]	45.419[ab]	83.254[bc]
ICEAP 01541	1.8276[a]	12.999[c]	73.54b[c]
ICEAP 01159	1.2769[a]	47.360[ab]	86.425[bc]
ICEAP 00540	0.6040[b]	41.489[ab]	117.524[ab]
ICEAP 00554	0.6275[b]	52.885[ab]	92.442[bc]
ICEAP 01154-2	1.2569[a]	45.999[ab]	154.254[a]
ICEAP 00979-1	1.2159[a]	51.347[ab]	81.255[bc]
ICEAP 01179	0.8159[bc]	49.553[ab]	82.257[bc]
ICEAP 00911	0.4952[b]	63.102[ab]	151.145[a]
Grand mean	0.9347	42.014	96.196
SEM	0.064	2.062	2.321

Means followed by the same letters in each column does not differ significantly at P≤0.05. SEM= Standard error of means

4.2.21. Grain yields of 18 pigeonpea varieties

The analysis indicated significant differences (P ≤ 0.05) among pigeonpea varieties with respect to grain yield (Table 4.27). The differences in the yields among the pigeonpea varieties were probably because of the genetic makeup of the varieties. This is also highlighted by Sujatha and Babalad (2018) who reported significant differences due to genetic characteristics. A similar significant variation in yields among pigeonpea varieties was reported by Manivel *et al*. (2012).

The top yielders of pigeonpea varieties were ICEAP 01172-2 (785.29 kg.ha^{-1}), ICEAP 00557 (661.51 kg.ha^{-1}), KAT 60-8 (593.47 kg.ha^{-1}), ICEAP 01159 (529.03 kg.ha^{-1}), and ICEAP 00902 (526.93 kg.ha^{-1}) (Figure 4.22). The increases in grain yield may be attributed to all of the combinations of the yield components as well as the environmental factors (greater rainfall). The effects of supplementary irrigation on grain yield have been previously reported by Khourgami *et al*., (2012) on lentils, and Anwar *et al*., (2003) in chickpeas where grain yield and pods per plant increased to 17% and 48%, respectively; subsequent to water supplementation. Khourgami (2012) observed a 1,559.9kg/ha while Oweis *et al.,* (2004) indicated that under full irrigation, the yield in chickpeas increased by 65%, while Zhang *et al*., (2000) observed a 100% increase compared to rain-fed chickpeas. Similar results have been observed by Zhang *et al*., (2000) on lentils and chickpeas while Felix, (2009) observed a 39% increase in the yield of beans (*phaseolus vulgaris*). Elevated temperatures may also be a constraint to pigeonpea yields as well as to other leguminous crops. In this experiment, the mean temperatures were moderate and therefore they had minimal impact on the yield and on the yield components.

Although, some varieties (ICEAP 00540, ICEAP 00979-1 and ICEAP 00911) showed a declined grain yield (Figure 4.22), this may be due to the lack of moisture and delayed flowering. Gwata and Silim, (2009), Upadhayaya *et al*., (2006) and *Snapp et al*., (2003), observed that the delay in flowering and maturity leads to increased susceptibility to terminal drought, thereby reducing the yields. These results are in close conformity with previous findings by Sarika *et al*. (2013) who reported that low rainfall during the anthesis stage caused drastic reduction of pods per plant, in the seeds per pod as well as in the yields. This has also been reported by Berhe *et al*., (1998) in faba beans. An increased plant height also increased the number of pods per plant during ratoon. The negative association between the seed per pod and the immature pods per plant in bush beans has been reported by Yorgancilar *et al*., (2001) who observed that the number of seeds per pod was negatively and significantly associated with the number of immature pods per plant and the 100 seed weight on bunch beans varieties.

Table 4.27: Analysis of variance of grain yield among 18 pigeonpea varieties

Source of variation	**DF**	**SS**	**MS**	**F**	**P**
Rep	2	500542	29443,6		
Variety	17	683816	40224.5	2.007	0.0434*
Error	34	380756	20039,8		
Total	53				

DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares, P = Probability, NS= not significant and * significant at (P≤0.05).

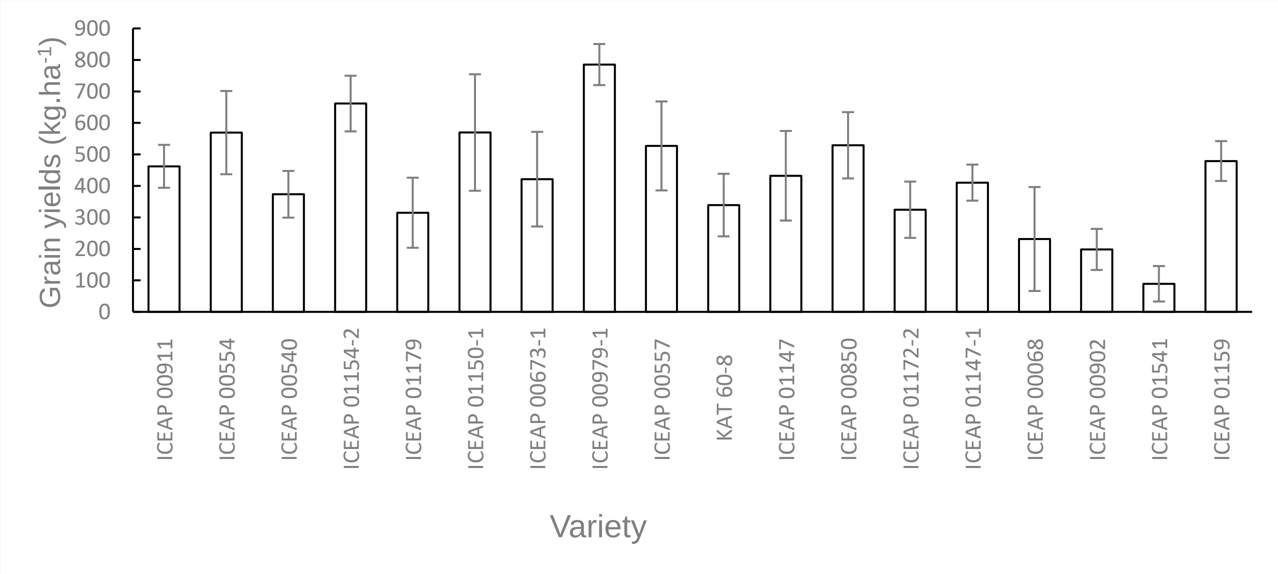

Figure 4.22: Analysis of variance of grain yield among 18 pigeonpea varieties

Table 4.28: Mean of pigeonpea yield components, peduncle height, number of pods per plant and number of seeds per pod of 18 pigeonpea varieties

Variety	**Variable**		
	Pod per plant	**Hundred seed weight (g)**	**Grain yields (kg.ha^{-1})**
ICEAP 01147	509^{ab}	15.03^{ab}	462.21^{b}
ICEAP 01147-1	341^{abc}	13.488^{bc}	569.24^{ab}
ICEAP 00673-1	272^{c}	13.560^{abc}	373.36^{ab}
ICEAP 00557	122^{bcd}	14.093^{abc}	661.51^{a}
ICEAP 01150-1	76^{d}	9.932^{d}	314.79^{ab}
KAT 60-8	510^{ab}	16.93^{a}	593.47^{ab}
ICEAP 00850	629^{a}	14.420^{ab}	421.38^{a}
ICEAP 01172-2	299^{bc}	13.386^{bc}	785.29^{a}
ICEAP 00902	351^{bc}	13.833^{abc}	526.93^{b}
ICEAP 00068	412^{b}	13.874^{abc}	339.18^{ab}
ICEAP 01541	215^{cd}	12.600^{bcd}	432.214^{b}
ICEAP 01159	495^{b}	13.111^{bc}	529.03^{ab}
ICEAP 00540	56^{d}	9.43^{d}	324.31^{abc}
ICEAP 00554	386^{abc}	14.562^{abc}	410.38^{abc}
ICEAP 01154-2	431^{abc}	11.614^{cd}	231.35^{abc}
ICEAP 00979-1	64^{d}	9.84^{d}	198.32^{c}
ICEAP 01179	425^{b}	13.350^{bc}	89.24^{c}
ICEAP 00911	361^{bc}	13.325^{bc}	478.94^{ab}
Grand mean	294,14	13,479	347,23
SEM	20.806	0.4245	117.43

Means followed by the same letters in each column does not differ significantly at P≤0.05.
SEM= Standard error of means.

4.2.22. The correlation coefficient of 18 pigeonpea varieties

The results of the correlation analysis were presented in Table 4.29. Plant height had a significant and positive association with the number of pods per plant, the number of primary branches, the amount of nitrogen fixed and the grain yields, however it had a negative association with the number of days to 90% maturity (Table 4.29). Reddy (1990) observed that the short-duration (early-maturing) varieties are comparatively short in stature due to their short vegetative growth phase, while the late-maturing (long-duration) varieties are generally tall, because of their prolonged vegetative phase. This may be the reason why plant height was negatively correlated to the number of days to 90% maturity. The number of pods per plant was significant and it positively correlated with the grain yields and the number of primary branches and the amount of nitrogen fixed, however it had a negative association with the number of days to 90% maturity (Table 3.4). Rani and Reddy (2000) reported that an increase in the yield is attributed to an increased number of branches, as well as in the number of pods per plant and the harvest index.

Grain yields were found to be significantly and positively correlated with the number of primary branches, the number of pods per plant and the number of days to 90% maturity (Table 4.2.29). Kumar and Hirochika (2001) also reported significant ($P \leq 0.05$) and positive correlations between the grain yield and the number of pods per plant. Mwanamwenge *et al*. (1999) reported that an increase in the number of primary branches, in the number of pods per plant and in plant height would result in an increased seed yield per plant. A significant positive correlation was observed between an amount of nitrogen fixed, number of primary branches, plant height, number of days to 90% maturity and in the grain yield (Table 4.2.29). The reason for the positive correlation between the number of days to 90% maturity, nitrogen fixation and grain yield may be because of late maturing varieties that have prolonged the vegetative phase which fixes more nitrogen per hectare and results in an increase in the number of pods per plant which attributes to an increase in the grain yield. Hence, a simultaneous selection based on these characters could lead to an improved yield.

Table 4.29: Correlation coefficient between different characters in 18 pigeonpea varieties

	Plant height	Number of pods per plant	Grain yield	Number of primary branches	Number of days to 90% maturity	Amount of nitrogen fixed
Plant height	1					
Number of pods per plant	0,5263	1				
Grain yield	0,5851	0,6575	1			
Number of primary branches	0,5839	0,4137	0,5740	1		
Number of days to 90% maturity	-0,2173	-0,1906	0,2243	0,1362	1	
Amount of nitrogen fixed	0.6174	0.5488	0.6152	0.5386	0.6352	1

CHAPTER 5
SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. Summary

Pigeonpea have been identified as the possible substitute crop which can be bought by all people and provide an acceptable amount of nutrition and protein. Their ability to tolerate drought and fix atmospheric nitrogen makes them suitable for marginal areas with low rainfall and poor fertility. Significant differences existed in most measured parameters such as in the number of days to first flowering, days to 50% flowering and 90% maturity, plant height, canopy width number of primary branches as well as in the yield and yield components among the evaluated pigeonpea varieties. The null hypothesis of the study was therefore rejected as the yield performance of 18 pigeonpea varieties differed. The parameters such as days to 50% flowering and 90% maturity, plant height, pods per plant and grain yield were influenced by determinacy, temperature and rainfall distribution. Three pigeonpea varieties (ICEAP 01159, KAT 60-8 and ICEAP 00902) were regarded as early in terms of flowering and maturity when compared to ICEAP 00540, ICEAP 00979-1 and ICEAP 00673-1. The early varieties took <100 days whereas the others took 110-116 days. There were highly significant differences regarding the number of days to 50% flowering and 90% maturity. These variations were due to that the varieties were exposed to different climatic conditions (temperature and rainfall) and determinacy. During the season, most of the varieties flowered early with a mean of less than 110 days. Tall plants were observed for variety ICEAP 01541, followed by ICEAP 00850 and ICEAP 00850 with a mean height of 2.01, 1.89 and 1.90m, respectively. Variety ICEAP 00673-1 produced longer peduncles when compared to all the other varieties. The highest number of pods per plant were recorded for ICEAP 01159, followed by ICEAP 00850 and KAT 60-8 with a mean height of 482, 434 and 435, respectively. ICEAP 00557 produced long pods, and it was followed by ICEAP 00673-1, ICEAP 01147-1 and ICEAP 01541.

There was low variation in respect of the number of seeds per pod. Most of the cultivars including ICEAP 00850, KAT 60-8, ICEAP 01147-1, ICEAP 01179 and ICEAP 00911 had six seeds in their pods. There was no significant difference among genotypes for all the mineral elements. The null hypothesis of the study was therefore accepted as the mineral elements of 18 pigeonpea varieties did not differ. The varieties were able to fix a variable amount of nitrogen from 73.547 to 154.254kg.ha^{-1}. ICEAP 01172-2 was the best variety in nitrogen fixation. Significant differences were observed for the mass of hundred seeds. ICEAP 00540, ICEAP 00979-1 and KAT 60-8 had a larger amount of seed weight simply because their seeds were bigger compared to other varieties which had smaller seeds. The grain yields have been proved to be influenced by yield parameters such as pods per plant, pod length and the number of seeds per pod. The top yielder pigeonpea varieties were ICEAP 01172-2 (785.29kg.ha^{-1}), ICEAP 00557 (661.51kg.ha^{-1}), KAT 60-8 (593.47kg.ha^{-1}), ICEAP 01159 (529.03kg.ha^{-1}), and ICEAP 00902 (526.93kg.ha^{-1}).

5.2. Conclusion and Recommendations

Although there are many important measured genotypic and phenotypic parameters which included plant height, days to 50 % flowering and 90 % to maturity, the number of pods per plant, amount of nitrogen fixed, 100 seed weight, they are not as important as grain yield. The study characterised all the above mentioned variables with an aim of answering the problem in Chapter 1 which was related to a low yield of pigeonpea varieties in South Africa and the objective of selecting high yielding varieties for crop improvement through breeding. Among all the varieties, ICEAP 01172-2, ICEAP 00557, KAT 60-8, ICEAP 01159 and ICEAP 00902 were selected as the promising varieties because of their early maturity and high yield. These were the varieties with high yield potential and fixed high nitrogen, and they are recommended for adoption by farmers.

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