ENHANCING FOOD SECURITY, NUTRITION AND PRODUCTION EFFICIENCY OF HIGH-YIELDING GRAIN LEGUMES IN SELECTED RURAL COMMUNITIES OF LIMPOPO PROVINCE, SOUTH AFRICA

JAN Asiwe, IB Oluwatayo and DN Asiwe

VOLUME 1:
RESEARCH REPORT AND CAPACITY BUILDING

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Report

to the Water Research Commission

by

JAN Asiwe, IB Oluwatayo and DN Asiwe

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EXECUTIVE SUMMARY

Agriculture is the principal source of livelihood for millions of people in rural and urban communities in Africa. It is the main determinant of food and nutritional security, employment and income, and the prime driver of economic growth. Consequently, poor performance in the agricultural sector affects the performance of nearly all other economic sectors. Agriculture is therefore the hub of economic growth of any country, particularly in Africa. However, agricultural productivity in Africa is lagging behind compared to that of advanced nations. Agricultural productivity has declined from 8% in the 1970s to 3% in 2013. Low agricultural productivity leads to food and nutritional insecurity. It was predicted that Africa's population would double to 1.1 billion between 1997 and 2020. If that was to happen, demand for imported food, especially cereals and legumes, would escalate to over 50 million tonnes annually.

To enhance food and nutritional security, food production must match population growth, which must be driven by technological innovation. Part of this innovation is the development and cultivation of high-yielding, pest-resistant, good-quality and resource use-efficient crop varieties. Breeders develop new varieties, with the expectation that they will be utilised by end-users such as farmers, consumers and processors. However, not all the released varieties are accepted and utilised by the intended end users or beneficiaries. The degree of adoption may vary greatly according to crop species, ecological zone and some other factors, such as quality characteristics and farmer-related preferences. Three micro-level reasons why farmers do not adopt new technologies include awareness (farmers are either not aware of new technologies or they are unaware that the new technologies will provide benefits for them), availability (the technologies are either not available or they are unavailable when needed) and profitability (the technologies are unprofitable to break even). The promotion of grain legumes with good economic and consumer preference traits will not only create more profits, jobs and seeds for sale and consumption, but will also enhance crop diversity, food security and good nutrition.

By 2030, it is projected that the world could confront a water shortage of approximately 40% due to population growth, climate variability and change. In South Africa, irrigated agriculture alone uses more than 60% of surface water. According to a WRC report, the provision of food, water and energy has become increasingly inter-linked, not only from the viewpoint of environmental sustainability, but also from an affordability perspective. One of the ways to enhance sustainable food production, thereby improving food security and nutrition in drought-prone communities in Limpopo, is through the introduction and cultivation of high-yielding, disease- and insect pest-resistant, early-maturing and water use-efficient grain legumes such as cowpea, pigeonpea and Bambara groundnut. Cowpea and early-maturing pigeonpea are versatile crops of note that are globally known to thrive well even under low and erratic rainfall conditions, while cereal crops cannot.

The cardinal objectives of this project were as follows:

- Introduce and promote high-yielding, pest-resistant, early-maturing and water use-efficient grain legumes (cowpea and pigeonpea)
- Promote the transformation of existing cropping practices through the introduction of modern production practices (strip intercropping of legumes with maize)
- Improve the nutritional dietary intake of communities through the introduction of cowpea-based food products (Akara and Moin-moin) and the fortification of their maize-sole diets with cowpea products
- Identify stakeholders in the cowpea value chain (cowpea production and food-processing value addition) and enhance human capital development in the value chain through training and a farmers' school
- Stimulate sustainable development through the improvement of traditional agronomic production practices, the preparation of cowpea diets and the cultivation of resource use-efficient legumes.

In addition, the project also had a capacity-building task to train farmers on agronomic and entrepreneurial skills to empower them to produce these crop, as well as to capacitate four MSc students.

To assess the status of cultural practices, the diversity of crops grown and the daily diet eaten by the farmers in the study areas (Ga-Thaba and Bela-Bela), a pilot survey was conducted among 42 farmers. The essence of the survey was to enable the project team to ascertain whether there was a gap the project could fill. In addition, it aimed to update information on probable new changes from the previous study conducted in the study areas. Results from the survey provided significant information, which indicated that the project had great potential in meeting the needs of farmers, filling the gaps identified during the survey. It would also add value to the livelihoods, cropping systems, food security and nutrition of people in the study areas.

To execute the first two project objectives, field trials were conducted during the 2016 and 2017 growing seasons. The aim of the field trials conducted during the 2016 growing season was to validate and select varieties of cowpea and pigeonpea that were used in the strip intercropping trials. In addition, they also aimed to multiply seed of the varieties for the on-farm farmers' participatory trials. Ten cowpea and 22 pigeonpea varieties, introduced from international agricultural institutes, the International Institute of Tropical Agriculture (IITA)-Nigeria and the International Crops Research Institute for the Semi-arid Tropics (ICRISAT)-Kenya, respectively, were evaluated in the trials. Variables used to make selections were the numbers of days to 50% flowering, maturity yield components, the number of pods per plant, grain yield and seed quality. Our findings showed that varieties of cowpea and pigeonpea responded significantly ($P < 0.05$), differently to the variables. Four cowpea varieties (IT82E-16, IT86D-1010, TVu 13464 and IT97K-499-35), which outperformed the local control variety (Glenda), were selected based on their earliness to maturity and grain yield. Similarly, five varieties of pigeonpea (ICEAP 00661, ICEAP 87091, ICEAP 01101-2, ICEAP 00604 and ICEAP 001284), which combine early maturity and plant type with high grain yield, were selected for intercrop trials.

To execute the second objective, pigeonpea-maize and cowpea-maize strip intercropping trials were conducted during the 2017 growing season in three locations – the University of Limpopo Research Farm (UL-Farm), Ga-Thaba and the Towoomba Agricultural Station, Bela-Bela – under the prevailing erratic atmospheric weather conditions, and insect pressure from army worm at Bela-Bela. Trials at UL-Farm were researcher-managed, while trials at Ga-Thaba and Bela-Bela were farmer-participatory-managed. The trials consisted of five improved pigeonpea varieties (ICEAP 00661, ICEAP 87091, ICEAP 01101-2, ICEAP 00604 and ICEAP 001284) and five improved cowpea varieties (Glenda, IT82E-16, IT86D-1010, TVu 13464 and IT97-499-35). These varieties were tested under strip intercropping with a mixed intercropping as a control check, which is the traditional cropping practice prevalent in Limpopo.

The two trials were set up concurrently in all three locations. Variables used to assess the performance of the trials included number of days to 50% flowering, days to maturity yield components (plant height, plant canopy width, number of pods per plant, 100 seed weight, grain yield, land equivalent ratio (LER) and water use efficiency (WUE).

Our findings showed that significant differences were obtained among pigeonpea varieties in most of the variables measured. The performance of the varieties across locations and cropping systems showed that the top yielders were ICEAP 00604 (668.89 kg ha^{-1}), followed by ICEAP 001284 (591.64 kg ha^{-1}) and ICEAP 001101-2 (562.96 kg ha^{-1}). The lowest yielder was ICEAP 87091 (423.98 kg ha^{-1}). The grain yield of the varieties varied significantly ($P < 0.05$) among locations.

The performance of the locations were in the following order: UL-Farm, Ga-Thaba and Bela-Bela with a grand mean yield of 713.19, 571.84 and 335.79 kg ha^{-1}, respectively. The yields from Bela-Bela were lower than expected due to high temperatures during the flowering and pod set, which affected pod setting and filling.

Strip intercropping performed significantly better (P < 0.05) than mixed intercropping in the three locations, with grand means of 797.63, 600.53 and 422.78 kg ha^{-1}, respectively, for UL-Farm. Ga-Thaba and Bela-Bela.

The maize component of the trial failed at Bela-Bela due to severe infestation by army worm at the silking and tasseling stages. The LER results showed that UL-Farm performed better than Ga-Thaba under strip intercropping with LER values of 2.16 and 1.76, respectively, while for mixed intercropping, the grand mean LER values varied from 0.29 to 0.48, respectively, for UL-Farm and Ga-Thaba. The LER for Bela-Bela was not determined because of the exclusion of maize in the calculation due to severe damage by army worm.

The results of the study also showed that significant interactions were obtained between the varieties and the cropping system and location, which implied that these factors influenced the performance of the varieties differently. The WUE results showed significant variations among the varieties (P < 0.05). The top three varieties for this variable were ICEAP 001101-2 (2.37 kg mm ha^{-1}), ICEAP 001284 (2.16 kg mm ha^{-1}) and ICEAP 00604 (1.84 kg mm ha^{-1}). Cropping system also showed significant variation in water use efficiency. Strip-intercropping performed better than monocropping and mixed intercropping with WUE values of 2.93, 2.40 and 0.60 kg mm ha^{-1}, respectively. Among the locations, results revealed that pigeonpea varieties were more water use efficient at UL-Farm (4.64 kg mm ha^{-1}), followed by Ga-Thaba (1.43 kg mm ha^{-1}). Bela-Bela was the least water use efficient, with 0.91 kg mm ha^{-1}. Among the five varieties evaluated, three of them (ICEAP 001101-2, ICEAP 001284 and ICEAP 00604) were promising top yielders with good maturity indices (early to flower and reach maturity), grain yield, LER and water use efficiency. Farmers selected these varieties for adoption and cultivation.

Results of the study showed significant differences (P < 0.05) among the five cowpea varieties, cropping system and location. Among the five varieties, only TVu 13464 did not perform consistently well across the three locations. The grain yield of the cowpea varieties varied from 511.93-800.89 kg ha^{-1} across cropping systems and locations. The three top performers were IT87K-499-35, IT82E-16 and IT86D-1010, with grain yields of 800.89, 777.30 and 719.04 kg ha^{-1}, respectively. The performance of the locations were in the following order: Ga-Thaba, Bela-Bela and UL-Farm with grand means of 709.44, 691.00 and 641.62 kg ha^{-1}, respectively. Strip intercropping performed significantly better (P < 0.05) than mixed intercropping (traditional intercropping system) in the three locations with grand means of 724.29 and 398.89 kg ha^{-1}, respectively. The LER results showed that UL-Farm performed better than Ga-Thaba under strip intercropping, with LER values of 1.92 and 1.88, respectively, while mixed intercropping values were 0.96 and 1.01, respectively, for UL-Farm and Ga-Thaba.

The LER for Bela-Bela was not determined because of the exclusion of maize in the calculation due to severe damage by army worm. This implies that strip intercropping was superior and can give double the crop yields or financial value of mixed intercropping under the same land area. The WUE result showed significant (P < 0.05) variations among the varieties. The three promising varieties for this variable were IT87K-449-35 (2.53 kg mm ha^{-1}), IT82E-16 (2.35 kg mm ha^{-1}) and IT86D-1010 (2.21 kg mm ha^{-1}). Cropping system also showed significant variation in water use efficiency. Monocropping performed better than strip intercropping and mixed intercropping with WUE values of 2.84, 2.19 and 1.28 kg mm ha^{-1}, respectively. Among the locations, results revealed that cowpea varieties were more water use efficient at Ga-Thaba (2.68 kg mm ha^{-1}), followed by UL-Farm (2.15 kg mm ha^{-1}). Bela-Bela was the least water use efficient (1.45 kg mm ha^{-1}).

Of the five varieties evaluated, IT87K-449-35, IT82E-16 and IT86D-1010 proved promising as top yielders with good maturity indices (early to flower and reach maturity), grain yield, LER and water use efficiency. Farmers selected these varieties for cultivation.

In achieving the third objective, part of this deliverable is contained in Volume 2 of this report. Results of the study showed that 125 farmers were trained on agronomic practices or agronomic operations, as well as how to prepare different cowpea and pigeonpea menus to improve nutrition, dietary diversity and intake. At the end of the project, structured interviews were conducted to assess the impact of the project in terms of the transformation of farmers' cultural practices, the diversity of crops grown and diet, and the daily diet of the farmers in the study areas (Ga-Thaba and Bela-Bela). This was to enable the project team to evaluate the contributions and value addition to the livelihoods of the farmers in the study areas. Fifty farmers were interviewed in both communities using a structured questionnaire. Fifteen of them were from Ga-Thaba and 35 were from Bela-Bela. Results from the study provided significant information indicating that the project was appropriate to meet the needs of the farmers, filling the gaps identified at the commencement of the project. This implied that the project was successfully able to attain the stated objectives and added value to the livelihoods of the farmers in terms of crop diversification, cropping system, food security and dietary diversity in the study areas.

In terms of capacity building, four MSc students who participated in the project received training on the preparation of cowpea menus. They completed their studies and graduated in April 2019.

Cowpea is a drought-tolerant legume, which serves as a staple food for the majority of Africans, alongside maize and other cereals. The crop is regarded as a good source of protein for the rural and urban poor, and plays an important role as a cash crop in some climates. Despite the nutritional benefits of this crop, and its economic importance and welfare-enhancing potential, farmers still do not have sufficient information about the value that can be added to cowpea to get best possible value for money in its production.

The aim of Chapter 5 was to examine economic and marketing efficiency, and to map the cowpea value chain in the Capricorn and Waterberg districts of Limpopo. For economic efficiency, data was collected purposively from 60 smallholder cowpea farmers, while for value chain mapping and marketing efficiency, data was collected from 80 smallholder cowpea farmers. Analytical tools employed include descriptive statistics, data envelopment analysis (DEA), the Tobit regression model, value chain mapping and the binary logistic model. A descriptive analysis of the farmers' socioeconomic characteristics showed that the average age of the farmers was 61 years, with an average income of R1,735.83.

For economic efficiency, the DEA results showed that the technical efficiency scores of cowpea farmers had a mean of 0.9588 with a minimum of 0.7500 and maximum of 1.000. This means that 95% of the farmers were technically efficient. The allocative efficiency score ranged from a minimum of 0.41 and a maximum of 1.000, with a mean of 0.65. The allocative efficiency scores imply that farmers are not utilising inputs efficiently. The economic efficiency scores ranged from a minimum of 0.38 to a maximum of 1.000, with a mean score of 0.62. The implications are that cowpea smallholder farmers are economically inefficient, on average, and that the cost of cowpea production for each farm could be decreased, on average, by approximately 38.2% to obtain the same level of output. The result of the Tobit regression models that were employed to ascertain determinants of economic efficiency revealed age, educational level, primary income source, farm size, method of intercropping, purpose of growing cowpea and source of labour to be significant.

In identifying and defining the participants along the cowpea value chain, a value chain map was constructed to show the different stages cowpea goes through before reaching the final consumer. The results of the marketing efficiency measure revealed that 66% of smallholder cowpea farmers were efficient. Notable determinants of marketing efficiency from the logistic regression model showed that age, household size, years in schooling, years in farming cowpea, income generated from selling cowpea, quantities of cowpea sold and the occupation of the farmers were significant in determining marketing efficiency. Major constraints faced by the farmers were pests, lack of access to formal markets and lack of information on how to process cowpea.

From the foregoing, the study recommends that investment in the capacity building of farmers through education is very important to enhance both economic and marketing efficiency in terms of resource utilisation. The different actors or players in the cowpea value chain should also collaborate for improved linkage along the value chain. Farmers should receive training on adopting new technologies, as this can potentially assist in making their production more efficient.

Results on the sustainable development aspect of the project showed that farmers successfully planted and managed the selected and adopted varieties of cowpea and pigeonpea in their demonstration plots in addition to their private farms or gardens to sustain the production of seeds and cropping practice. They also displayed the mastery of training received during the life cycle of the project. In light of this, results from the farmers' demonstration plots planted in 2017/18 showed that the grain yield of ICEAP 001284 (491.94 kg ha^{-1}) was significantly different and higher than that of ICEAP 001101-2 (345.28 kg ha^{-1}), which was obtained from Ga-Thaba and UL-Farm, Results also showed that yield obtained from Ga-Thaba was significantly higher (611 kg ha^{-1}) than that from UL-Farm (225.00 kg ha^{-1}). The cropping system results showed that strip intercropping (562.92 kg ha^{-1}) performed better than monocropping (461.00 kg ha^{-1}) and mixed intercropping had the lowest yield (231.25 kg ha^{-1}). Grain yield obtained from the two cowpea varieties adopted showed that the yield of IT86D-1010 (623 kg ha^{-1}) was higher than IT82E-16 (527 kg ha^{-1}). The results also indicated that strip intercropping (806 kg ha^{-1}) exerted its superiority over monocropping (676 kg ha^{-1}) and mixed intercropping (243 kg ha^{-1}).

Demonstration trials at Bela-Bela did not establish properly because of a protracted period of high temperature with no rain between December 2017 and January 2018. Supplementary seed increase was carried out at Taung, Ventersdorp and Koster to reduce the risk of crop failure and as a backup. It is important to note that having sufficient seed was one of the greatest challenges that farmers faced. Although farmers generated a lot of seed from their demonstration plots, they could not retain more than 5 kg of seed for the next season's planting because they could not resist the temptation of consuming almost all the seeds that they produced during the season. This implies that an extrogenous seed supply source is critically needed to support and produce seed for the sustainability of the project until the farmers can produce above their home consumption. Commercialisation of the recommended varieties is the way out of this challenge. The upscalling of this project needs the varieties to be commercialised. The commercialisation of the varieties, on the other hand, should be matched with the extensive promotion of menus and recipes so that the demand pull of utilisation will create supply and incentives for farmers to produce.

In sustaining the development of improved agricultural practices, good nutrition and dietary diversity, the results of the study showed that 125 farmers, six agricultural extension agents and students were trained on cowpea and pigeonpea agro-processing and how to prepare different menus, as well as agronomic operations. This is one of the ways to enhance succession planning in the study areas. In addition, four master's degree students were trained on cowpea-related fields as skilled researchers to continue their work on grain legumes.

In conclusion, this study achieved the overall objectives of providing relevant information about the response of introduced cowpea and pigeonpea varieties to cropping systems, different locations, the comparative advantage of strip intercropping over mixed intercropping, as well as the training of farmers and students.

The specific key indicators of innovative end-products achieved by the project were as follows:

- The farmers introduced and adopted three high-yielding pest-resistant and water use efficient cowpea varieties (IT82E-16, IT86D-1010 and IT97K-499-35). These varieties were selected by farmers because they performed better than the local control variety (Glenda).
- The farmers selected three high-yielding pest-resistant and water use efficient pigeonpea varieties (ICEAP 001284 ICEAP 00604 and ICEAP 01101-2) because they performed well in terms of water use efficiency, LER, early maturity and grain yield.

- The farmers introduced and adopted a new intercropping system (strip intercropping) because it performed better than the commonly used traditional mixed intercropping system.
- In the area of human capital development, four MSc students, six technicians and 125 farmers were trained on improved production practices for cowpea and pigeonpea.
- A total of 125 farmers, four MSc students and six technicians were trained on different cowpea and pigeonpea menus and recipes to enhance utilisation, dietary intake and diversity.
- The famers were trained on record-keeping and other farm management techniques for profit making and tracking resources used for sufficient production.

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LIST OF ACRONYMS AND ABBREVIATIONS

AATF	African Agricultural Technology Foundation
ARC	Agricultural Research Concil
ARC-ISCW	Agricultural Research Council-Institute of Soil Climate and Weather
ARC-GCI	Agricultural Research Council-Grain Crops Institute
BFAP	Bureau for Food and Agricultural Policy
CGIAR	Consultative Group on International Agricultural Research
CS	Cropping system
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Data Envelopment Analysis
DFF	Number of days to first flower
DMT	Number of days to maturity
FAO	Foods and Agricultural Organisation
GDP	Gross Domestic Product
HSRC	Human Sciences Research Council
IAEA	International Atomic Energy Agency
ICRISAT	International Crops Research Institute for the Semi-arid Tropics
IITA	International Institute of Tropical Agriculture
L	Location
LER	Land Equivalent Ratio
LSD	Least Significance Difference
ME	Marketing Efficiency
NDP	National Development Plan
NFP	Net Farmers’Price received by farmers
SFA	Stochastic Frontier Approach
StatsSA	Statistics South Africa
TMC	Total Marketing Cost
TMM	Total Marketing Margin
UL-Farm	University of Limpopo Research Farm
V	Variety
WRC	Water Research Commission
WUE	Water Use Efficiency

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CHAPTER 1: GENERAL INTRODUCTION, SCOPE AND OBJECTIVES OF THE STUDY

1.1 GENERAL BACKGROUND OF THE PROJECT

Food production is the largest user of water at the global level, responsible for 80 to 90% of blue water use (FAO, 2013). By 2030, it is projected that the world could confront a water shortage of approximately 40% due to population growth, climate variability and climate change (WRC, 2013). In South Africa, irrigated agriculture alone uses more than 60% of surface water. According to the WRC report, the provision of food, water and energy has become increasingly interlinked, not only from the viewpoint of environmental sustainability, but also from an affordability perspective.

Water, energy and food are inextricably linked. The food production and supply chain is responsible for around 30% of the total global energy demand. The water required for energy production currently stands at about 8% of global water withdrawals. Ample supply of agricultural water is a vital element for sustainable food security and nutrition. Many rural communities in South Africa and Limpopo, in particular, are food insecure and malnourished because of erratic rainfall during the growing season, which has a negative impact on these communities not producing crops for family consumption and income generation.

According to a Human Sciences Research Council (HSRC) survey in 2012, the Eastern Cape, followed by Limpopo, had the highest numbers of citizens experiencing food insecurity. Meanwhile, one of the ways to enhance sustainable food production and thereby enhance food security and nutrition in drought-prone communities in Limpopo is through the introduction and cultivation of high-yielding, disease-resistant and insect pest-resistant, early-maturing and water use efficient grain legumes such as cowpea, pigeonpea and Bambara groundnut. Cowpea and early-maturing pigeonpea are versatile crops of note, which are globally known to thrive well, even under low and erratic rainfall conditions where cereal crops cannot grow (Asiwe, 2007; Asiwe, 2009a; Asiwe, 2009b).

Cowpea (*Vigna unguiculata* (L.) Walp.) and pigeonpea (*Cajanus cajan*) are nutritious multipurpose grain legumes with tremendous potential, especially in rural areas of South Africa. They are perennial crops and allow local farmers to harvest several times (2-3 years) from one single planting as long as there is enough moisture for the ratoons to reflush. This implies that local farmers do not need to buy fresh seeds every planting season. Furthermore, cowpea and pigeonpea are drought tolerant (Fatokun et al., 2004; Asiwe, 2006) and can thrive well under low water stress and soil fertility. Cowpea is an important grain legume with very high potential for production and dietary intake in South Africa. The seeds are rich in protein (24.8%), carbohydrate (63.6%), vitamins and other essential nutrients (Bresani, 1985; Fadupin, 2009; Omenna et al., 2016; Masenya et al., 2014; Asiwe, 2017). It is eaten as dry seeds, green pods and leafy vegetables.

According to Omenna et al. (2016), a study was conducted to investigate the effect of boiling, pressure cooking and germination on the proximate, nutrient, amino acid and anti-nutrient content of cowpea. The results showed that the germinated cowpeas had the highest value of crude protein (22.89%), crude fat (3.81%) and crude fibre (2.10%), followed by raw cowpeas and pressure-cooked cowpeas, while boiled cowpeas had the lowest value. There was a comparable value of ash content in all the samples, except for boiled cowpeas, which had the lowest content. Boiling had significantly higher moisture content than other forms of preparation. The carbohydrate value ranged from 57.21 to 58.13% for germinated cowpeas and boiled cowpeas, respectively, and 59.69 to 59.74% for raw cowpeas and pressure-cooked cowpeas, respectively. The comparable calorific value of germinated cowpeas and boiled cowpeas was significantly higher than that of pressure-cooked cowpeas and raw cowpeas.

The decreasing order of anti-nutrient factors in treated cowpeas is: germinated cowpeas > raw cowpeas > pressure-cooked cowpeas > boiled cowpeas. This result inferred that boiling is an adequate processing for the drastic reduction of the anti-nutrient factors (phytate, tannin, trypsin inhibitor and total phenol) in cowpeas.

Germination increased the amount of methionine, lysine and tryptophan by 10.94, 18.89 and 20.90%, respectively, while pressure cooking and boiling caused mild losses of methionine, lysine and tryptophan. Similarly, germination increased the amount of macro elements (0.0036 mg/kg for sodium, 0.024 mg/kg for potassium, 0.021 mg/kg for calcium, 0.037 mg/kg for phosphorus and 0.022 mg/kg for magnesium), while boiling and pressure cooking decreased the amount of these macro elements compared with the raw sample. Heat treatments (boiling and pressure cooking) recorded decreased level of micro elements (iron, zinc, copper, manganese), while germination increased the micro elements by 4.66, 3.78, 13.85 and 6.38% for iron, zinc, copper and manganese, respectively. Therefore, it could be concluded that the heat treatments (boiling and pressure cooking) significantly reduced the anti-nutrient factors in cowpeas, but germination (sprouting) had excellent nutritional qualities. In many countries in Africa, cowpea is a major food security crop (a versatile candidate crop for the ongoing food security initiative in South Africa (Whitebread et al., 2009; AATF, 2012).

The trading and processing of seeds from cowpea provide a dependable source of livelihood for the poor in both rural and urban areas, thereby creating opportunities for earning a regular income (Giami et al., 2003; Giami, 2005; IITA, 2011). Cowpea snacks and their derivatives are important traditional plant protein-rich menus prepared and sold as foods on the streets in many parts of Africa, and this can help improve the dietary intake of impoverished communities in South Africa. Cowpea can be easily intercropped with many crop species and contributes to soil improvement through nitrogen fixation (Belane et al., 2011). Most of the introduced, improved cowpea varieties mature early and are suitable for drought-prone regions where the duration of the rainfall is less than three months. The introduction and cultivation of improved water use efficient and low input grain legumes in rural communities where erratic rainfall is a major contributory factor to low yield will ameliorate the problem of food insecurity and malnutrition (Asiwe and Adekunle, 2005; De Ronde and Spreeth, 2013; Singh and Ajeigbe, 2007; Asiwe, 2008; Asiwe, 2009a; Asiwe, 2009b; Kutu et al., 2010; Asiwe, 2012; Modi and Mabhaudhi, 2013). Previous work done on cowpea at the WRC includes the screening of cowpea for drought tolerance (Modi and Mabhaudhi, 2013; Modi and Mabhaudhi, 2017) and the nutritional value and water use of African leafy vegetables, including cowpea (Labadarios et al., 2011), for improved livelihoods. Our focus in this research did not duplicate any previous work done at the WRC. This project was not only aimed at enhancing food security and empowering farmers, but also has high potential for upscaling (local and commercial application), especially among the resource poor and vulnerable farmers in the study area and South Africa at large.

According to Pingali (2012), the promotion of the production of cereals occasioned by the green revolution has brought about stagnation in the production and utilisation of grain legumes. However, Modi and Mabhaudhi (2017) reported that the promotion and reinstatement of grain legumes is critical for the attainment of food crop diversity and nutrition in rural communities. According to them, this diversity will translate to food and nutrition security and improve the dietary intake of rural communities. Several scientists (Siddique et al., 2001; Zhang and Li, 2003; Munoz-Perea et al., 2007; Patel et al., 2008; Boshchin and Arnoldi, 2011; Obalum et al., 2011; Mabhaudhi et al., 2013; Akinyele and Shokunbi, 2015), in their various reports and recommendations, also maintained that the production and utilisation of grain legumes should be promoted.

The year 2016 was celebrated as the International Year of Pulses for the promotion of grain legumes. This brought into action all the clarion calls and recommendations made by various scientists for the promotion of legumes. Since 2016, many projects have been suggested, and the call of this proposal is in part fulfilling that critical need.

Alleyne (1977) reported that protein energy malnutrition is a major concern in rural communities. Legumes are generally cheap sources of proteins, micronutrients, vitamins and minerals, and are good complements to starchy diets (Khan, 1987; Asiwe, 2017). Graecub et al. (2015), McDemott at al. (2015) and Shetty (2015) report that one of the ways to enhance food and nutrition security is through crop diversity and productivity. Modi and Mabhuadhl (2017) and Mabhaudhi et al. (2016) maintain that such initiatives should consider limitations posed by water scarcity, recognising the water-food-nutrition-health nexus.

According to them, this includes the promotion of crops that are adapted to dry areas and are nutrient-rich, such as legumes (Chivenge et al., 2015). One of the legumes of note that fits into this consideration is cowpea. The water required for energy production currently stands at about 8% of global water withdrawals. Ample supply of agricultural water is a vital element for sustainable food security and nutrition. Many rural communities in South Africa and Limpopo, in particular, are food insecure and malnourished because of erratic rainfall during the growing season, which has a negative impact on them as they are not producing enough crops for family consumption and the generation of income.

One of the ways to enhance sustainable food production and promote food security and nutrition in drought-prone communities in Limpopo is through the introduction and cultivation of high-yielding, disease- and insect pest-resistant, early-maturing varieties, and water use efficient grain legumes. Cowpea and pigeonpea are versatile crops of note, which are globally known to thrive well under low and erratic rainfall conditions where cereal crops cannot grow, and therefore offer great opportunities for cultivation in such drought-prone areas in South Africa. The promotion of cowpea and pigeonpea in areas with erratic rainfall will not only increase the productivity of the farmers, but will alleviate poverty and malnutrition, and also create employment for all those involved in the value chain in cowpea production.

Intercropping of legumes with cereals is an ancient practice and is important for the development of a sustainable food production system, particularly among smallholder farmers in South Africa (Thobatsi, 2009). Cereal-legume intercropping is commonly practised in South Africa, including in Limpopo, because of the yield advantage, greater stability and lower risks of crop failures that are often associated with monoculture (Sullivan, 2003). Cereal-legume intercropping trials in South Africa have been reported by different authors. These include maize and pigeonpea (Mathews et al., 2001), and maize and dry bean intercropping (Kutu et al., 2010).

In Limpopo, mixed interplanting is a common intercropping practice, where legumes are planted together with cereals without any definite row arrangement. This practice does not optimise plant density, nor does it allow the efficient management of crops using modernised equipment. It hinders farm input application and is also characterised by low yields (Asiwe et al., 2009b). Strip intercropping is a novel practice and involves growing two or more crops together in strips wide enough to permit the separate management of crops, but close enough for the crops to interact (Singh and Ajeigbe, 2007).

This practice has great potential in reducing inter-species competition, allowing the individual management of intercrops and optimising plant density, thereby increasing yields per unit area. However, the performance of improved cowpea and pigeonpea varieties has not been studied in detail under a strip intercropping system with maize in Limpopo. This offers great potential for elite cowpea and pigeonpea varieties to be tested under this cropping system. South Africa, particularly Limpopo, is a semi-arid region, characterised by marginal soil, and low, erratic rainfall distribution. This results in reduced crop yields (Mpandeli et al., 2015). Therefore, introducing improved early-maturing varieties of cowpea and pigeonpea, which are drought-tolerant, in an intercropping system to smallholder farmers will increase their productivity.

In view of the above introduction, the project had the following objectives:

- Introduce and promote the production of new, high-yielding, pest-resistant, water use efficient and resource-efficient grain legumes.
- Promote the transformation of existing cropping practices through the introduction of modern production practices (the strip intercropping of legumes with maize) in communities.

- Improve nutritional dietary intake of the communities through the introduction of cowpea-based food products (akara and moin-moin) and the fortification of their maize-sole diets with cowpea products.
- Identify the stakeholders in the cowpea value chain (cowpea production and food processing value addition) and enhance human capital development in the value chain through training and farmers' schools.
- Stimulate sustainable development through the improvement of traditional agronomic production practices, the preparation of cowpea diets and the cultivation of resource use-efficient legumes.

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CHAPTER 2: PROMOTION OF TRANSFORMATION OF EXISTING CROPPING PRACTICES THROUGH THE INTRODUCTION OF MODERN PRODUCTION PRACTICES (STRIP INTERCROPPING OF LEGUMES WITH MAIZE) IN COMMUNITIES: COWPEA VARIETY VALIDATION TRIAL AND STRIP INTERCROPPING OF COWPEA WITH MAIZE TRIAL

JAN Asiwe and KA Maimela

2.1 PROJECT COMMENCEMENT SURVEY

2.1.1 Introduction

A pilot survey was conducted to assess the status of cultural practices, the diversity of crops grown and diet, and the daily diet eaten among the farmers in the study areas (Ga-Thaba and Bela-Bela). The purpose of this pilot study was to enable the project team to ascertain whether there was any gap that the project could fill. In addition, it would enable the project team to update information on probable new changes from a previous study conducted in the study areas.

In light of this, a pre-project commencement scoping survey was conducted to determine the status of the cropping systems, crops grown, constraints to production and dietary intakes in the communities at the initiation of this project. This would ascertain the potential gaps or needs that the current project would fill in the communities, and the value of the project being conducted. In addition, the survey could determine whether there were changes stemming from the cultural practices of farmers that differed from that which Asiwe et al. (2009b) had reported previously.

2.1.2 Materials and methods

Forty-two farmers were interviewed in both communities; 15 from Ga-Thaba (Capricon District) and 27 from Bela-Bela (Waterberg District).

Capricorn District is divided into five local municipalities: Aganang, Blouberg, Lepelle-Nkumpi, Molemole and Polokwane. Polokwane Local Municipality covers only 3% of Limpopo. However, over 10% of the province's population resides within its boundaries. It serves as the economic hub of the province, with Capricorn District having the highest population density. In Northern Sotho, Polokwane means "place of safety". Ga-Thaba village is a rural community, which falls within the Polokwane Local Municipality. It is situated south-west of Polokwane City, about 70 km from the city. Ga-Thaba is among the poorest areas in Polokwane Local Municipality. The majority of its inhabitants is involved in subsistence agriculture.

Waterberg District Municipality (Figure 5.4) is made up of five local municipalities: Thabazimbi, Bela-Bela, Mookgophong, Lephalale and Mogalakwena. The district covers a total area of about 44 913 km^2. Bela-Bela is the local municipality that was surveyed. The main economic sectors in the district are agriculture, tourism and mining.

A structured questionnaire (Appendix 2) was administered to the farmers.

2.1.3 Results and discussion

Results or responses from the farmers were recorded and the implications of their responses discussed and summarised in Table 2.1.

Table 2.1: Responses obtained from farmers taken from a survey conducted at the end of the project

Respondents	Number of farmers	Implications
Demographics		
Majority above 35 years	42	Retirees, widows, single parents, workers
Cropping practices		
29 (69%) of the respondents practise intercropping	42	Knowledgeable about intercropping
28 (67%) grow cowpea in mixed stands	42	High potential for row cropping
37 (88%) of the farmers plant manually without tractors and practise mixed intercropping	42	Small-scale and mixed intercropping
Constraints		
35 (83%) of farmers indicate that drought was a common occurrence and poses a great limitation to production	42	High potential for WUE legumes, early-maturing cowpea and pigeonpea
38 to 40 (90-95%) of the farmers claimed that insect pests (aphids and weevils) constitute one of the major constraints to production	42	High potential for the introduction of pest-resistant grain legumes
About 40 to 41 (95-97%) of the farmers claimed that grass and broadleaf weeds constitute a great threat to production	42	This implies that efficient weed control practices should be incorporated into the farmers' training programme
30 (71%) of the farmers indicated that lack of storage facilities limits their production	42	Needs granary or silo for storage
42 (100%) of the farmers affirmed that maize is a staple and is most widely grown		High potential for crop diversification
Utilisation and consumption of cowpea		
95% of the farmers stated that they produce legumes solely for consumption	42	This implies that their production is still at a small scale and there is high potential for upscaling through improved production and practices, and the introduction of high-yielding varieties
The majority of the respondents indicated high preferences for seed size (95%), seed colour (90%), early maturity (71%), growth habit (71%), leafy and dual-purpose types (71%)	42	This implies that introducing legume varieties with different morphological and seed attributes is important to meet their needs
40 (95%) of the farmers indicated that they sell their produce at the local markets	42	This indicates that potential market and consumers are available, and they could make more if they can increase their production
Respondents consume cowpea in different forms: 25 (59%) of them consume cowpea as boiled seeds, 40 (90%) of them eat cowpea leaves and 10 (24%) eat cowpea as fresh pods	42	This implies that introducing the legume varieties has great potential in enhancing their dietary intake and diversity
In responding to what constitutes their daily diets, 35 (83%) of the respondents indicated that they take mostly carbohydrates as breakfast, 40 (95%) indicated carbohydrate + vegetables as lunch, while 35 (95%) indicated mostly carbohydrates as dinner. Only 10 (24%)	42	This implies that most of the respondents were on a sole carbohydrate meal daily. This implies that introducting different cowpea protein-rich menus will improve their daily nutrition and diversity.

Respondents	Number of farmers	Implications
of the respondents indicated that they take vegetables.		

2.1.4 Conclusion

The implications drawn from the variables to which the farmers responded in the survey provided significant information that indicated that the project had great potential in meeting the needs of the farmers, filling the gaps identified and adding value to the livelihoods, food security and nutrition of people in the study areas.

2.2 COWPEA VARIETY VALIDATION STUDY

This activity was focused on the evaluation of genetic variation among cowpea lines introduced from IITA, Nigeria for the purpose of selecting candidates to participate in strip intercropping trials and to validate their agronomic traits. Five promising and high-yielding varieties were selected for this purpose.

2.2.1 Introduction

Cowpea (*Vigna unguiculate* (L.) Walp) is a member of the Phaseoleae tribe of the family Fabaceae. There is a lot of controversy surrounding the origin of cowpea. Some literature indicates that cowpea was introduced to the Indian subcontinent from Africa approximately 2,000 to 3,500 years ago, at the same time as the introduction of sorghum and millet, while others state that before 300 BC, cowpea had reached Europe and possibly North Africa from Asia (DAFF, 2011). Some researchers believe that cowpea originated from West Africa because both wild and cultivated species abound in the region, while others believe that it originated from Southern Africa (DAFF, 2011). Whatever its place of origin, the production of cowpea has spread to East and Central Africa, India, Asia, and South and Central America (Eskandari et al., 2009).

2.2.1.1 Importance of cowpea

Cowpea plays a very important role as a source of livelihood for millions of people in the developing world (Timko and Singh, 2008). Cowpea provides nutritious grain and is an inexpensive source of plant protein for rural dwellers, as the protein content of the grain ranges from 23 to 32% (Asiwe, 2017; Hall et al., 2003; Nielson et al., 1993) and the carbohydrate content is 64% (Bressani, 1985). Cowpea has the same nutritional profile as other pulses, as it has a low fat content, and a protein content that is two to four times higher than cereals and tuber crops (Lambot, 2002).

The protein in cowpea seeds is rich in amino acids, lysine and tryptophan when compared to cereal grains, but low in methionine and cysteine when compared to animal proteins (Timko and Singh, 2008). Cowpea seeds are also a rich source of minerals and vitamins (Hall et al., 2003) and have among the highest folic acid and vitamin B content in plants, which is necessary during pregnancy to prevent birth defects in the brain and spine (Timko and Singh, 2008). The protein content of the leaves ranges from 27 to 34% (Tarawali et al., 1997).

The cowpea value chain involves many people who contribute to the development of the commodity in many countries. This value chain includes producers (farmers), transporters, traders of the commodity and those working in local value-adding enterprises (AATF, 2012). A report by the African Agricultural Technology Foundation (AATF) (2012) indicates that many farmers were only surviving on cowpea farming as a business of selling their cowpea harvests enabled them to not only buy supplementary cereal grains such as maize meal or rice, but also inputs for the next season.

Cowpea is also a valuable component of farming systems in regions where soil fertility is low, especially nitrogen (AATF, 2012). This is due to its unique ability to fix atmospheric nitrogen at a higher rate when it is in a symbiotic relationship with the beneficial bacteria (Belane et al., 2011; Singh et al., 2003). Cowpea can withstand extensive ranges of soil pH better than other legumes. Its ability to fix high amounts of nitrogen makes it an efficient main component in crop rotation systems, as it replenishes soil fertility for succeeding cereal crops (Belane et al., 2011). Cowpea can withstand extreme temperatures (AATF, 2012) and tolerate moisture stress (Magloire, 2005) better than many legumes, which even makes it suitable in marginal rainfall areas.

In Southern Africa, cowpea is currently primarily planted for fodder, although it is also used for grain production, green manure and weed control in forestry plantations, and as a cover or anti-erosion crop. The Agricultural Research Council (ARC) (2000) reported that the peduncles of certain cultivars are used for fibre production. These fresh cowpea pods, together with fresh green leaves, are the earliest foods available at the end of the “hungry time” (the time when there is insufficient food for people due to a lack of rainfall) (Eskandari et al*.,* 2009).

2.2.1.2 Global cowpea production perspectives

Cowpea is an important grain legume throughout the world. Small-scale farmers are mostly cowpea producers operating under dryland farming conditions (Asiwe, 2009b). It is estimated that the annual world cowpea crop is grown on 12.5 million hectares, and the total grain production is three million tons, although only a small proportion of this production enters international trade (ICRISAT, 2010). West and Central Africa are the leading cowpea-producing regions in the world. These regions produce 64% of the estimated three million tons of cowpea seed produced annually (Singh and Ajeigbe, 2007).

Nigeria is the world’s leading cowpea-producing country, followed by Brazil. Other cowpea-producing countries in Africa are Burkina Faso, Ghana, Mali and Senegal. The major production countries in the developed world are Brazil, the USA and the West Indies. Only the USA is a substantial producer and exporter (Eskandari et al*.,* 2009). More than 5.4 million tons of dried cowpea are produced worldwide, with Africa producing nearly 5.2 million tons. Nigeria, the largest producer and consumer, accounts for 61% of production in Africa and 58% worldwide (ICRISAT, 2010).

Cowpea production is widely distributed throughout the tropics. However, Central and West Africa account for more than 64% of the area, with about 8 million ha, followed by about 2.4 million ha in Central and South America, 1.3 million ha in Asia and 0.8 million ha in East and Central Africa (Singh and Ajeigbe, 2007). Cowpea can be regarded as the anchor of sustainable farming in semi-arid lands. This applies to West and Central Africa. In these regions, the area of cowpea production extends from Cameroon through to Senegal, lying mainly between 10° N and 15° N, covering the dry savannah (northern Guinea and Sudan savannahs), as well as the Sahel zones (Woodruff et al*.,* 2010).

2.2.1.3 The production of cowpea in South Africa

The Department of Agriculture, Forestry and Fisheries (DAFF) (2011) reported that small-scale farmers achieve cowpea production in South Africa under rainfed farming conditions, but there are no records regarding the size of the area under production and the yields produced. However, Asiwe (2009b) reported that the land area on which farmers produce cowpea ranges from 0.5 to 2.0 hectares per farmer.

The major cowpea-producing areas in South Africa are Limpopo, Mpumalanga, North West and KwaZulu-Natal (DAFF, 2011). A study by Asiwe (2009b) showed that farmers in Limpopo and KwaZulu-Natal grow cowpea for consumption and as a source of income.

Asiwe (2009b) also indicated that, in Limpopo, most of the farmers plant cowpea under mixed planting, while in KwaZulu-Natal, most cowpea is planted using row cropping. Farmers prefer important traits such as seed colour, seed size, growth habit and maturity periods. Maturity periods were reported to be mostly preferred by farmers in Limpopo based on the duration of rainfall. In Limpopo, some farmers choose early maturing varieties in order to escape moisture deficits and frost damage. Farmers who choose late maturing types are more interested in fodder for livestock feeding. On the other hand, farmers in KwaZulu-Natal prefer cowpea varieties based on growth habit (Asiwe, 2009b).

2.2.1.4 Constraints to cowpea production in South Africa

According to Asiwe (2009b), cowpea research and commercial production in South Africa have been abandoned for the last 30 years. Cowpea production is further limited by a shortage of improved varieties or the cultivation of low-yielding, unimproved varieties (Asiwe, 2009b; Moalafi et al., 2010), lack of knowledge of good agronomic practices, the unavailability of good seeds and farmers' low returns (Asiwe, 2009b). A study by Asiwe (2009b) indicated that pest damage, diseases and weeds are among the constraints to cowpea production in South Africa. It was further noted that drought, lack of large markets for farmers' produce, poor pricing and shortage of storage facilities serve as barriers to the increased production of this crop.

Cowpea is susceptible to a wide range of bacterial, fungal and viral diseases and different types of insect pests (Timko et al., 2007). The major insect pests that affect cowpea are aphids (*Aphis craccivora*), thrips (*Megaluro thripssjostedti*) and the Maruca pod borer (*Maruca vitrata*). Parasitic weeds such as *Striga gesnerioides* and *Alectra vogelii* also constitute some of the limitations to cowpea production in Africa (Timko et al*.,* 2007). Asiwe (2009b) reported aphids, thrips, pod-sucking bugs and cowpea weevil as major insect pests in cowpea as well. Among the diseases, viral diseases seemed to affect cowpea the most in South Africa, rather than fungal and bacterial diseases.

Some of the devastating cowpea diseases are bacterial blight*,* cowpea yellow mosaic virus and brown blotch. Bacterial blight is caused by the bacterium *Xanthomonas.* This disease can reduce yield up to 90% and emergence in infected seeds by 67% (Asiwe, 2009b). Cowpea yellow mosaic virus is caused by the yellow mosaic virus. This disease is destructive and can cause yield reduction up to 80-100%. Brown blotch is caused by *Colletotrichum capsica.* This disease is reported by Mark and Channya (2016) to be destructive, causing up to 85% damage. Seed-borne diseases are especially problematic as smallholder farmers use home-grown seeds in the production of the crop.

In South Africa, considerable progress has been made during the past decade in cowpea breeding, and a range of varieties has been developed and introduced. Some were introduced from different parts of the world, combining diverse plant type and maturity with resistance to several diseases, insect pests and parasitic weeds (Asiwe, 2009b); Singh et al., 2003). Despite numerous benefits accruable to cowpea, a lot remains to be done in terms of the agronomic and morphological characterisation of new cultivars for different research purposes. Their characterisation and/or revalidation will enhance the deployment of their traits for utilisation in food security and cropping systems.

It was against this backdrop that 10 elite, high-yielding and pest-resistant cowpea lines were revalidated for their use in a strip intercropping trial in this project. In addition, a revalidation trial was used to multiply seeds needed for the intercropping trials.

2.2.2 Materials and methods

2.2.2.1 Description of the study area

The trial was conducted at UL-Farm (23°53'9.6" S, 29°43'4.8" E) during the 2015/16 season. The soil at Syferkuil is sandy loam. The mean average summer day temperature at Syferkuil varies from 28° to 30° C, and the area receives mean annual rainfall ranging from 400 to 600 mm.

2.2.2.2 Field layout and design

The trial was set up at UL-Farm. The land was prepared using a tractor-mounted disc plough and harrow until a fine seed bed was made. The field was marked into plots for the allocation of treatments (the varieties). Ten cowpea varieties (Photograph 2.1) were planted in January 2015. They were laid in a randomised complete block design with three replications.

2.2.2.3 Agronomic practices

Pre- and post-emergence herbicides (Dual and Roundup) were applied two days after planting and subsequent weed control were effected using Fusilade and Bentazone selective herbicides for both grass and broadleaf weed situations. All the herbicides were applied at three litres of the formulation per hectare, except Dual, which was applied at 0.5 ℓ ha^{-1}. Insect pests, particularly cowpea aphids (Photograph 2.2), defoliators and pod-sucking bugs, were controlled using Karate at the recommended of 1 ℓ ha^{-1}.

2.2.2.4 Data collection

Data was collected on the following agronomic variables: number of days to 50% flowering, number of days to 90% maturity, canopy height and width, grain and fodder yields, as well as 100 seed weight, using the procedures described by Asiwe and Adekunle (2005). The number of days to 50% flowering, number of days to 90% maturity and pods from five plants were sampled randomly and expressed as number of pods per plant. The number of seeds per pod was also determined from five pods. The 100 seed weight was determined by randomly counting 100 good seeds per genotype and weighing them. Grain yields were determined from two middle rows as net plot and converted to kilograms per hectare. Haulm from the net plot was weighed to determine the fodder weight.

Photograph 2.1: Cowpea varietal revalidation trial at mid-flowering, podding stages
Photograph 2.2: Infestation of cowpea aphids on Glenda pods

2.2.2.5 Data analysis

Data was subjected to analysis of variance, using SAS software to determine the performance of the genotypes. Means were separated, using the Duncan Multiple Range Test at the probability level of 5%.

2.2.3 Results and discussion

Table 2.2 shows the means of all the variables taken. The results show that significant difference was observed among the varieties for grain and fodder yields, number of days to maturity, and not for number of days to flower and 100 seed weight. A brief discussion of the results is given below.

Table 2.2 shows that there was significant difference ($P < 0.05$) among the varieties for number of days to maturity, which ranged from 76 to 94 days. Varieties Pan-311, 82D-889, IT07K-299-6 and TVu 13464 matured much earlier than the control variety (Glenda) (Figure 2.1). Kamai et al. (2014) report that days to flowering and days to maturity are always related, because when the plant flowers early, it is most likely to mature early as well. These results are similar to Mafakheri et al. (2017), who find that local cowpea varieties are late to flower and mature. The results of this study corroborate their findings. Six varieties matured significantly earlier than Glenda, which was the local control. These varieties (IT82E-16, TVu 13464, IT82D-889, IT86-1010, IT98k-205-8 and ITO7K-299-6) are promising for selection for the intercrop trial because of their ability to mature early and possibly evade early frost. They also have the ability to complete their life cycles within the rainfall duration of the cropping season.

Table 2.2: Means of variables taken from ten cowpea varieties

Variety	DFF	DMT	Grain (yield per kg/ha)	Fodder (yield per kg/ha)	100 seed weight (g)
IT82E-16	48a	76b	1879.17ab	2172.92bc	13.8a
82D-889	43a	78b	2273.13a	3167.16ab	13.71a
86D-1010	60a	86b	2563.89a	2966.67ab	15.06a
TVu 13464	43a	78b	1996.88ab	1403.13c	12.54a
IT07K-299-6	53a	79b	1014.44c	2541.67ab	16.1a
IT10K-836-4	48a	94a	1286.18bc	2450.00bc	19.8a
IT00K-1263	54a	94a	1539.55b	2871.59ab	22.5a
IT98K-412-13	54a	81b	1260.70bc	2165.12bc	17.5a
IT98K-205-8	51a	81b	1118.29bc	2800.00ab	17.1a
IT835-911	53a	94a	1595.90b	2239.74bc	16.3a
Glenda	50a	94a	1268.87bc	3513.21a	14.6a
P-level	0.25	0.05	0.01	0.01	0.06

DFF = Number of days to first flower

DMT = Number of days to maturity

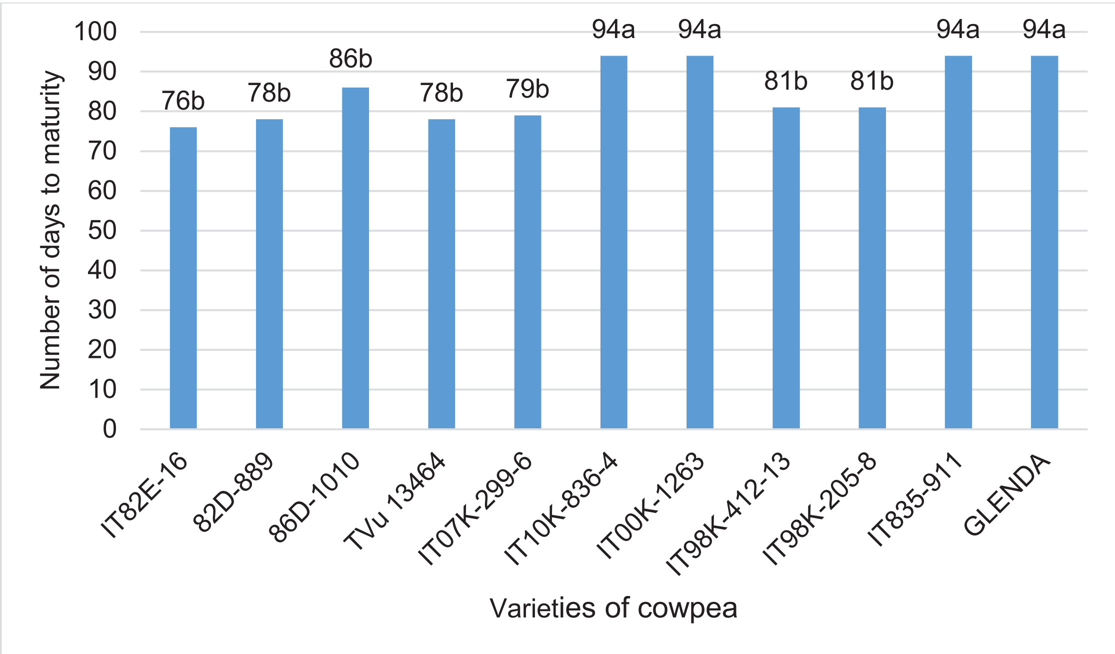

Figure 2.1: Number of days to maturity of ten cowpea varieties

2.2.3.1 Grain and fodder yield

The grain yield of the ten varieties varied significantly (P < 0.05) with a range between 2563.89 kg/ha for IT86D 1010 and 1014.44 kg/ha for IT07K-299-6. Six varieties (IT86D-1010, IT82E-16, IT82D-889, TVu 13464, IT00K-1263 and IT835-911) performed better than Glenda (Figure 2.1). This indicates that there are more grain-yielding cowpea varieties than Glenda. Varieties that combine early maturity with high grain yield were promising targets for selection for the intercropping trial.

For fodder yield, significant difference (P < 0.05, Table 2.3) was observed among the varieties. Glenda exhibited the highest yield, indicating that it is a better fodder variety than the rest (Figure 2.2). These results also show that the maturity period has a significant influence on fodder production. For example, Glenda matured late and produced more fodder. Blümmel et al. (2012) reported that late-maturing cowpea varieties are often used for fodder because they can take advantage of a longer growing season to produce more biomass. However, such varieties are often liable to be damaged by early frost and, consequently, farmers growing them may experience crop failure or lose their expected grain yield for that season.

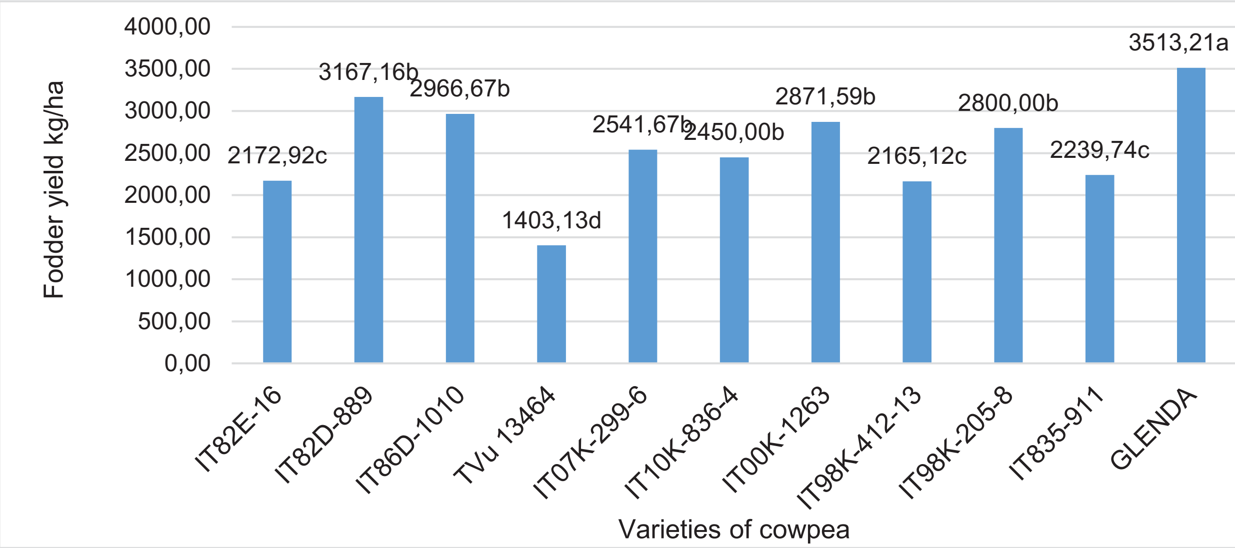

Figure 2.2: Fodder yield of ten cowpea varieties

2.2.3.2 Hundred seed weight

Hundred seed weight did not show any significant difference (P < 0.05) (Table 2.2, Figure 2.3) among the varieties, thus indicating the effect of selection, which must have narrowed their diversity for seed size. Seed size varied from 14 to 23 g per 100 seeds. The majority of the varieties (70%) exhibited sizes (15 to 23 g) greater than Glenda (14.6 per 100 seeds). Ezeaku et al. (2015) also reported that the local variety used in their study exhibited the least 100 seed weight compared to the improved varieties. In their study, they evaluated nine IITA-improved cowpea varieties with a local control and found that the 100 seed weight of the improved varieties varied from 12 to 19 g (with a mean of 14.03 g) compared to 7 to 11 g for the local control The reason for this was because the improved varieties must have been bred and selected for large seed size to meet consumer preference. Most of the cowpea varieties used in this study had large seeds (> 15 g), whereas the control variety, Glenda, exhibited small-sized seeds (< 15.1) based on the classification by Omogui et al. (2006). Drabo et al. (1984) reported that cowpea seed size was highly heritable, but they also indicated that environment could modify seed size.

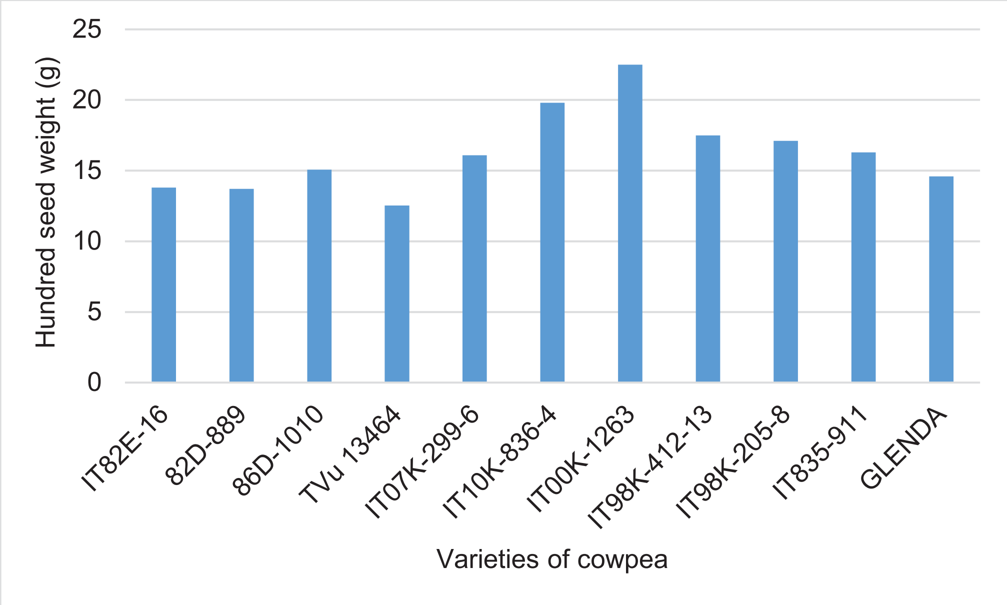

Figure 2.3: Hundred seed weight of ten cowpea varieties

2.2.3 Conclusion

In conclusion, the purpose of the trial was to generate baseline data to make informed decisions about the selection of varieties to participate in the intercropping experiment scheduled for the next growing season. In light of this, varieties that combine early maturity and grain yield would be selected. Varieties selected included IT82E-16, 82D-889, IT86D 1010, TVu 13464 and IT001263.

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2.3 STRIP INTERCROPPING OF COWPEA WITH MAIZE TRIAL

2.3.1 Introduction

Cowpea (*Vigna unguiculata* (L.) Walp) is one of the most ancient crops. It is a protein-rich grain legume that complements staple cereal and starchy tuber crops. It also provides fodder for livestock, improves the soil by fixing nitrogen and benefits households by bringing in cash and a source of income for the family. The sale of cowpea stems and leaves for animal feed during the dry season earns vital household income (ICRISAT, 2010). Cowpea is commonly used as a companion crop in many intercropping systems in sub-Saharan Africa because of its ability to provide fixed atmospheric nitrogen to cereal crops in rotation. For this reason, cowpea is commonly intercropped with cereals, especially maize, sorghum and millet (Woodruff et al., 2010). It is of vital importance in the livelihood of millions of people in the semi-arid regions of West and Central Africa, and is one of the most important grain legumes in sub-Saharan Africa (ICRISAT, 2010). According to Asiwe (2009), South African cowpea production is carried out by smallholder farmers under dryland conditions in Limpopo, Mpumalanga, North West and KwaZulu-Natal.

Globally, maize (*Zea mays* (L.)) is the third-largest planted crop after wheat and rice. It is produced throughout South Africa in diverse environments (Tsubo et al., 2005). Maize grain can be consumed by humans and animals in many communities as it has nutritive value and the highest potential for carbohydrates (Tsubo et al*.,* 2005). It is usually intercropped with legumes to increase carbohydrates. Many smallholder farmers in Limpopo practise the intercropping of maize with legumes due to land scarcity, and to enhance production (Thobatsi, 2009).

Intercropping is the practice of growing two or more crops in close proximity to each other. The most common goal of intercropping is to produce a greater yield on a given piece of land by using resources that would otherwise not be utilised by a single crop (Ayisi et al*.,* 2004). Intercropping is a dominant cropping system practised by smallholder farmers in developing African, Asian and South American countries to better utilise limited resources, especially land. Intercropping maize or grain sorghum (*Sorghum bicolor*) with leguminous species, especially cowpea, common bean (*Phaseolus vulgaris*), groundnuts (*Arachis hypogea*), lablab (*Lablab purpureus*) or Bambara groundnut (*Vigna subterranean*), is a common practice among smallholder farmers in Limpopo (Mpangane, 2001). Strip intercropping is an adaptation of this system to contemporary mechanised agricultural practices. This cropping system allows multiple crops to be grown in narrow adjacent strips that allow interaction between the different crop species, as well as allowing cultural management with modern equipment (Singh and Ajeigbe, 2007).

Strip intercropping is the act of growing two or more crops together in strips wide enough to permit separate crop production, but narrow enough for the crops to interact (Singh and Ajeigbe, 2007). In Limpopo, smallholder farmers practise mixed intercropping, whereby they are broadcasting the seeds of legume crops with cereals with no definite row arrangement. This practice does not optimise plant density, nor does it allow the efficient management of crops using modernised equipment. The practice also hinders the application of farm inputs. However, strip intercropping has the potential of reducing inter-species competition, while simultaneously allowing the individual management of intercrops, and optimising plant density and, consequently, increasing productivity in the smallholder farming sector. Although strip intercropping has all of these benefits (Singh and Ajeigbe, 2007), the performance of grain legume cowpea in a strip intercropping system with maize has not been investigated in the Limpopo environment. Therefore, there was a need to investigate the performance of improved cowpea varieties in a strip intercropping system with maize.

According to Pingali (2012), the promotion of the production of cereals occasioned by the green revolution has brought about stagnation in the production and utilisation of grain legumes. Modi and Mabhaudhi (2017) report that the promotion and reinstatement of grain legumes is critical for the attainment of food crop diversity and nutrition in rural communities.

According to them, this diversity will translate into food and nutrition security and improve the dietary intake of rural communities. In support of their opinions, several scientists (Siddique et al., 2001; Zhang and Li, 2003; Seena and Sridhar, 2005; Munoz-Perea et al., 2007; Patel et al., 2008; Boshchin and Arnoldi, 2011; Obalum et al., 2011; Mabhaudhi et al., 2013; Akinyele and Shokunbi, 2015) have maintained that the production and utilisation of grain legumes should be promoted. The celebration of 2016 as the International Year of Pulses was a good omen for the promotion of grain legumes. Since 2016, many projects have emerged, and the funding of this project by the WRC is, in part, fulfilling that felt need. Alleyne et al. (1977) reported that protein energy malnutrition is a major concern in rural communities. Legumes are generally cheap sources of protein, micronutrients, vitamins and minerals, and are good complements to starchy diets (Khan, 1987). Graeub et al. (2015), McDemott et al. (2015) and Shetty (2015) support the view that one of the ways to enhance food and nutrition security is through crop diversity and productivity. Modi and Mabhaudhi (2017) and Mabhaudhi et al. (2016) maintain that such initiatives should consider limitations posed by water scarcity, recognising the water-food-nutrition-health nexus. According to them, this includes the promotion of crops that are adapted to dry areas and are nutrient rich, such as legumes (Chivenge et al., 2015). One of the legumes of note that fits into this consideration is cowpea.

One of the ways to enhance sustainable food production, and thereby promote food security and nutrition in drought-prone communities in Limpopo, is through the introduction and cultivation of high-yielding, disease- and insect-pest resistant, early-maturing varieties, and water use efficient grain legumes. Cowpea is a versatile crop of note, which is globally known to thrive well under low and erratic rainfall conditions, where cereal crops cannot do so, and therefore offers a great opportunity for cultivation in such drought-prone communities in South Africa. The promotion of cowpea in an intercropping system in areas with erratic rainfall will not only increase farmers' productivity, alleviate the risk of crop failure, and reduce poverty and malnutrition, but also create employment for all involved in the production value chain.

2.3.1.1 Advantages of using cowpea in an intercropping system

In an intercropping system, cowpea is used as a companion crop, and is mostly intercropped with cereal crops such as maize and sorghum (Mead and Riley, 2001). The fast growth and fast-spreading habit of cowpea varieties make it capable of suppressing weeds (Sanginga and Woomer, 2009). Cowpea is a valuable component of farming systems in many areas because of its ability to restore soil fertility for succeeding cereal crops grown in rotation with it (Tarawali et al., 2002). Carsky et al. (2002) reported that early-maturing cowpea varieties can provide the first food from the current harvest sooner than any other crop, thereby shortening the "hungry period" that often occurs just prior to the harvest of the current season's crop in farming communities in the developing world.

2.3.1.2 Importance and utilisation of maize

Maize is one of the most important cereal crops in sub-Saharan Africa and is an important staple food for more than 1.2 billion people in the subregion and Latin America (Sullivan, 2003). Maize is the most important South African grain crop and is produced throughout the country in diverse environments. All parts of the crop can be used for food and non-food products. In industrialised countries, maize is largely used as livestock feed and as a raw material for industrial products (Tsubo et al., 2005). In developed countries, maize is mainly consumed as second-cycle produce, added to meat, eggs and dairy products. In developing countries, maize is consumed directly and serves as a staple diet for some 200 million people. Many people regard maize as a breakfast cereal (Thobatsi, 2009). Maize is also processed into ethanol and starch (Mahapatra, 2011).

2.3.1.3 Maize production

Maize is the staple food for the majority of black people in South Africa. This consumer segment accounts for 94% of white maize meal consumption (Thobatsi, 2009). It is the most important cereal crop produced by resource-poor farmers in Southern Africa (Mpangane, 2001). Approximately 10 to 12 million tons of maize is produced annually in South Africa on more or less 2.5 million hectares of land. Maize is produced by nearly all resource-poor farmers in South Africa in the semi-arid regions and high rainfall provinces (ICRISAT, 2010). Dryland production of maize mainly takes place in the Free State (34%), North West (32%), Mpumalanga (24%), Limpopo (17%) and KwaZulu-Natal (3%) (ICRISAT, 2010). South African maize production is constrained by both biotic and abiotic factors. The economy of maize production in the summer grain areas has deteriorated over the last few decades because the price of maize inputs rose more rapidly than the producer price of maize grain (ARC, 2000).

In Limpopo, most maize producers are small-scale farmers. It is estimated that more than 8,000 commercial maize producers are responsible for the majority of the South African crop, while the rest is produced by thousands of small-scale producers (Thobatsi, 2009). The worldwide production of maize is 785 million tons, with the largest producer, the USA, producing 42%. Nigeria is the largest African producer with nearly 8 million tons, followed by South Africa, which produces 6.5% of worldwide production (DAFF, 2011). Africa imports 28% of its required maize from countries outside the continent (ARC, 2000). Maize accounts for 30 to 50% of low-income household expenditures in Eastern and Southern Africa (ARC, 2000). According to Sullivan (2003), a heavy reliance on maize in the diet can lead to malnutrition, diabetes and diseases related to vitamin deficiency such as night blindness and kwashiorkor. The intercropping of cowpea with maize, which is one of the objectives of this project, using an innovative cropping system (strip intercropping), will reduce the over-dependence of rural communities on exclusive maize diets, and improve their crop and nutrition diversities (Chivenge et al., 2015; Mabhaudhi et al., 2016; Modi and Mabhaudhi, 2017).

2.3.1.4 Constraints in maize production

Many farmers experience constraints to maize production. These constraints are grouped into abiotic and biotic constraints. Drought is a major abiotic constraint affecting maize production. Climate instability has resulted in fluctuations in intra- and inter-annual rainfall levels, and drought has become a recurrent problem in many regions (Marouf et al*.,* 2013). Biotic constraints include field diseases and insects. Farmers have identified a wide range of field insect pests, including army worm, maize stalk borer, cutworm and maize leaf aphid, all of which are detrimental to maize (Tandzi et al*.,* 2015). Importantly, army worms are the major biotic constraint that significantly diminished the 2016 agricultural seasonal cereal production, especially maize production (FAO, 2016). Additionally, major constraints facing farmers are the inadequacy of improved varieties, post-harvest handling challenges, weed infestations, poor soil fertility and the high cost of fertilizers. Therefore, it is necessary to explore more sustainable and affordable ways of increasing crop yields by identifying high-yielding and stable maize varieties that are tolerant to these constraints (Sibiya et al*.,* 2013). The practice of appropriate agricultural systems associated with the utilisation of improved and adapted varieties could significantly increase maize yields (Etoundi and Dia, 2008). Farmers also have to contend with constitutional and economic constraints. Farmers have serious concerns regarding the quality of inputs, low-quality seeds and questionable purity, as well as the inability of farmers to detect these constraints due to a lack of knowledge (Banzige and Meyer, 2002).

2.3.1.5 Intercropping systems

Intercropping is a cropping system of cultivating two or more crops on the same piece of land at the same time (Willey, 1979). It is an old and commonly used cropping practice, which aims at matching crop demands to the available growth resources and labour in an efficient way (Willey, 1979).

Many smallholder farmers in Limpopo practise cereal-legume intercropping. The most utilised intercrops are maize-dry bean, maize-cowpea and maize-lablab. The most common advantage of intercropping is that greater yields are produced on a piece of land by efficiently using the available growth resources, i.e. using a mixture of crops of different rooting ability, canopy structure, light interception, height and nutrient uptake (Eskandari et al*.,* 2009; Kamara et al., 2011; Ewansiha et al., 2015).

Moreover, intercropping improves soil fertility through biological nitrogen fixation with the use of legumes. It increases soil conservation through greater ground cover than sole cropping, asynchrony for reduced pest invasion, and the provision of better lodging resistance for crops susceptible to lodging when grown in monoculture (Zhang and Li, 2003). Intercropping provides insurance against crop failure due to biotic and abiotic factors and against unstable market prices for a given commodity, especially in areas subject to extreme weather conditions such as frost, drought and flood. Furthermore, intercropping offers greater financial stability and distribution of farm labour than sole cropping, which makes the system particularly suitable for small, labour-intensive farms (Fenandez-Aparicio and Sillero*,* 2007).

2.3.1.6 Types of intercropping systems

Intercropping is a cropping system of cultivating two or more crops on the same piece of land at the same time. It is an old and commonly used cropping practice, which aims to match crop demands to the available growth resources and labour in an efficient way (Willey, 1979). As stated above, many smallholder farmers in Limpopo practise cereal-legume intercropping, and the most utilised intercrops are maize-dry bean, maize-cowpea and maize-lablab. The most common advantage of intercropping is greater yields produced on a piece of land by efficiently using the available growth resources, i.e. using a mixture of crops of different rooting ability, canopy structure, light interception, height and nutrient uptake (Eskandari et al*.,* 2009). Many intercropping systems are practised by farmers (Willey, 1979). Some of them are discussed briefly below.

Row cropping

Row intercropping is the practice of growing two or more crops in well-defined rows. In farms growing perennial crops, annual crops such as maize, rice and pineapple are commonly grown as the intercrop between the rows of the main crop (Francis et al*.,* 1986). Row intercropping can be divided into two types: inter-row and intra-row intercropping. This strategy is an efficient way of maximising farmland usage, as it uses vacant spaces, while simultaneously suppressing weed growth during the main crop's juvenile stage. Row intercropping has many advantages, such as wind passages between the inter-rows being enhanced, which increases gas exchange and prevents excessive humidity. Access between the inter-rows facilitates cultivation, weeding and other farm operations, including haulage (Zhang and Li, 2003). As stated above, annual crops such as rice, maize and pineapple are commonly used as intercrops between the rows. Banana, pawpaw, coffee and cacao are commonly grown in multiple rows. The productivity of row intercropping is influenced by the specific combination of crops, their spacing and their planting dates.

Mixed cropping

Mixed cropping – also known as intercropping or co-cultivation – is a type of cropping system that involves planting two or more plants simultaneously in the same field, as shown in Figure 2.4c (Mead and Riley, 2001). In general, the theory is that planting multiple crops at once facilitates crop interaction. Possible benefits of mixed cropping are balancing the input and output of soil nutrients, suppressing weeds, reducing insect pest movement, resisting climate extremes (wet, dry, hot, cold), suppressing plant diseases, increasing overall productivity and using scarce resources for optimum benefit (Mead and Riley, 2001). Mixed cropping has no organised pattern of component crop arrangement, and the density of plants is varied across the field.

Relay intercropping

Relay intercropping is the practice of planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage, but prior to harvesting (Zhang and Li, 2003; Kamara et al., 2011). This helps avoid competition between the main crop and the intercrop. The field is also productive for a longer period, since the relay crop usually continues to grow after the main crop has been harvested (Zhang and Li, 2003). Relay intercropping is possible and useful when the growing season is long enough to grow two crops, or when there are two growing seasons (Lantican, 2001). In maize-bean intercrops, for example, the maize crop is planted first, and when it has been established, the bean crop is planted in between the maize. After the maize has been harvested, the bean crop continues growing and may use the maize as stakes. Soil moisture is used very efficiently and the soil is covered for longer periods, preventing nutrient losses and erosion, and resulting in less competition of water and nutrients (Mucheru-Muna et al*.,* 2010).

Mixed intercropping

Mixed intercropping is the cultivation of two or more crops simultaneously on the same field without any definite row arrangement (Singh and Ajeigbe, 2007). Due to limited land in Limpopo (Ayisi et al., 2004), smallholder farmers are forced to practise mixed intercropping. Examples of the mixed intercropping of annual crops that is practised by smallholder farmers in Limpopo are maize, cowpea, watermelon, groundnuts and squash, where farmers broadcast seeds without row arrangement. This practice does not optimise plant density, and causes problems in performing all the agricultural operations and harvesting of the crops. It also results in a reduction in yield of the component crop, which may occur due to intense competition for growth factors such as light, water and nutrients.

Sullivan (2003) reported that labour requirements in the mixed interplanting system are higher than in the sole cropping system, as multiple crops are planted at the same time or shortly after one another and harvested at different times. Therefore, introducing a new technique such as strip intercropping to smallholder farmers is a useful alternative compared to other intercropping arrangements in this regard, since it allows the efficient management of crops using modernised equipment (Sullivan, 2003). Bambalele (2016) further reports that mixed intercropping is characterised by low yield because legumes are planted together with cereals without any definite row arrangement. This leads to high competition for growth factors, for example, nutrients, light and water. The yields obtainable from mixed intercropping are not constant or reliable because the plant population per unit area in the system is not constant. In some cases, one crop may be clustered more than the other component crop. In some cases, both component crops may be too widely dispersed in such a way that there is no interaction between them.

Strip intercropping

Strip intercropping is the practice of producing two or more crops in narrow strips located across the length of a field (Sullivan, 2003), as shown in Figure 2.4b. The strips are wide enough for each crop to be managed independently, yet narrow enough for each crop to influence the microclimate and yield potential of adjacent crops (Singh and Ajeigbe, 2007). Crops are rotated annually. Strip intercropping use is typically based on agronomic and environmental considerations (Francis et al., 1986). A well-managed strip intercropping system results in higher crop yields and greater profitability than monocropping systems (Kamara et al., 2011; Ewansiha et al., 2015). Environmentally, a well-designed system has greater soil and water conservation potential than most monocropping systems (Francis et al*.,* 1986).

Strip cropping has many advantages. It produces a variety of crops, and the legume improves soil fertility and helps reduce pest and weed problems (Sanginga and Woomer, 2009; Eskandari, 2012). The residues from one strip can also be used as soil cover for the proceeding crop in rotation.

2.3.1.7 Advantages of intercropping

According to Sanginga and Woomer (2009), cereal-legume intercropping plays an important role in subsistence food production in developing countries, especially in areas where water resources are limited. This practice is an attractive strategy for smallholder farmers to increase productivity and intensify land and labour utilisation (Seran and Brintha, 2010). In comparison to pure cropping, the advantages of intercropping in crop production are due to the interaction between components in intercrops and the reduced competition for available environmental resources (Mahapatra, 2011).

The main advantage of intercropping, in contrast to sole crops, is that it is more efficient in the utilisation of available resources for increased productivity (Mucheru-Muna et al*.,* 2010; Kamara et al., 2011; Ewansiha et al., 2015). Yield advantage occurs because growth resources such as light, water and nutrients are better absorbed and converted into crop biomass by the intercrop over time and space, which is occasioned by the difference in competing crops' competitive ability for growth resources (Tsubo et al*.,* 2005, Ewansiha et al., 2015). In comparison to single maize crops, Ghanbari et al*.* (2010) reported that intercropping maize with cowpea has increased light interception, reduced water evaporation and improved conservation of soil moisture.

Intercropping is much less risky than monocropping, considering that if one crop of an intercrop fails, the other component crop(s) may still be harvested. Moreover, farmers may be able to cope with seasonal commodity price variations, which can often destabilise their income. For example, if the market price is more favourable for one crop than for others, farmers are able to benefit from good prices, and may suffer reduced losses due to poor prices paid for the other crops if they grow several crops together. In comparison to monocropping either of the two crops, intercropping maize with beans reduces nutrient declines and raises household incomes, thus insuring against crop failure (Onduru and Du Preez, 2007).

Intercropping systems are able to reduce incidences of pests and diseases. Environmental changes and host plant quality directly affect the host plant's searching behaviour of herbivorous insects, and indirectly affect their developmental rates and interactions with natural enemies. Muli and Saha (2008) reported that the mixed cropping of cowpeas with maize significantly reduces the population density and activity of legume flower bud thrips *(Megalurothrips sjostedti)* compared to sole cowpea crops. Similar results were reported in intercrops of beans, cowpea and maize where the reduced pest incidence has been attributed to the increased populations of natural enemies occasioned by intercropping (Kyamanywa and Tukahirwa, 1988). Black aphid (*Aphis fabae*) infestation of beans was greatly reduced when beans were intercropped with older and taller maize plants, which interfered with aphid colonisation and only small proportions of beans were infested by the aphid (Muoneke et al., 2007).

Legumes enrich soil by fixing the atmospheric nitrogen, changing it from an inorganic form to forms that are available for uptake by plants. The biological fixation of atmospheric nitrogen can replace nitrogen fertilization wholly or partially. When nitrogen fertilizer is limited, biological nitrogen fixation is the major source of nitrogen in legume-cereal mixed cropping systems (Geren et al., 2008). Moreover, because inorganic fertilizers have contributed to environmental damage, such as nitrate pollution, legumes grown in an intercropping system are regarded as an alternative and sustainable way of introducing nitrogen into lower-input agro ecosystems (Fustec et al*.,* 2010).

2.3.1.8 Disadvantages of an intercropping system

Intercropping can lead to poorer yields if the crops are compatible or may actually compete for the same nutrient and water, which may lead to unmanageable conflict. It is possible that neither crops yield enough produce, or that the main crop has reduced yields due to productivity losses during drought periods and high labour inputs in regions where labour is scarce and expensive (Gliessman, 1985).

It is well documented that, in most cases, the main crop in an intercropping system will not produce as high yields as it would in a monoculture system because there is competition among intercropped plants for light, soil nutrients and water (Willey, 1979). This yield reduction may be economically significant if the main crop has a higher market price than the other intercropped plants (Balasubramaniyan and Palaniappan, 2001). Intercropping obviously costs more initially, as more fertilizer and water are required, and harvesting is more complicated.

2.3.1.9 Measurement of productivity in an intercropping system

Land Equivalent Ratio

The intercropping system enables interaction between component crop species. This improves the diversity of an agro ecosystem (Dariush, 2006). According to Thobatsi (2009), increased productivity per unit area and diversity are among the major benefits of an intercropping system. Seran and Brintha (2010) refer to yield as the primary consideration when assessing the potential of an intercropping system. The common index adopted in an intercropping system to measure land productivity is LER. This ratio is used as an important tool to study, evaluate and assess the efficiency of an intercropping system. By definition, LER is the relative land required under a monocultural system to match the yields obtained from an intercropping system or the magnitude of monocropping needed to produce the same yield on the unit area of land in an intercropping system (Mead and Willey, 1980; Federer and Schwager, 1982; Wijesinha et al*.,* 2002).

An advantageous intercropping system is attained with an LER of greater than 1, whereas a disadvantageous intercropping system is attained with an LER of less than 1 (Dariush, 2006). This means that an LER of greater than 1 indicates greater efficiency of land utilisation in an intercropping system. When computing the LER, intercropping yields are divided by the monocropping yields for each crop in the intercropping system and then the two figures are summed (Federer and Schwager, 1982). The formula used to estimate LER is given by LER = $\sum(Ypi/Ymi)$, where Yp represents the yield of individual crops in the intercropping system, and Ym is the yield of the crop in a monocultural system. In the case of maize-cowpea strip intercropping, it will be given as LER = (intercrop maize/sole maize) + (intercrop cowpea/sole cowpea).

Several workers report on the yield advantage of an intercrop system over the sole cropping of the component crops that constitute the intercrop (Addo-Quaye et al., 2011). They report that the intercropping yield is higher than cowpea or maize sole cropping in semi-arid Southern Africa. So, most intercrop treatments both on-station and on-farm had an LER > 1, pointing to the greater land use efficiency of the maize-cowpea intercrop system compared to sole cropping. Furthermore, the LER of an on-station relay intercrop ranged from 1.8 to 2.5, compared with the same planting date intercrop, which ranged from 0.5 to 2.4 in all three seasons.

2.3.1.10 Water use efficiency of cowpea

Soil water content in the root zone is the main determinant of the success of dryland crop production. According to Tambussi et al*.* (2007), water use efficiency refers to the ratio of water used in plant metabolism to water lost by the plant through transpiration. Increases in water use efficiency are commonly cited as a response mechanism of plants to moderate to severe soil water deficits, and has been the focus of many programmes that seek to increase crops' tolerance to drought. However, there are some questions as to the benefits of the increased water use efficiency of plants in agricultural systems, as the processes of increased yield production and decreased transpirational water loss are fundamentally opposed. Farmers can improve crop water use efficiency by using strategies to increase stored soil moisture prior to sowing, and focusing on healthy, early-sown crops with suitably sized canopies that are better able to convert water into grain.

The water use efficiency of grain legumes is affected by the feritity of the soil and biotic stress. Any factor that affects the grain yield will directly affect the WUE value. However, according to Wenhold et al. (2012), the water use efficiency of cowpea may vary from 3 to 6, pigeonpea from 1 to 2 and dry bean from 3 to 6 kg ha mm^{-1}

2.3.2 Materials and methods

2.3.2.1 Description of the study sites

The UL-Farm is located in the Mankweng area in the Capricorn District of Limpopo, at a longitude and latitude of 23°53' 9.6" S, 29°43' 4.8" E. The area is located in the subtropical region of South Africa and the average temperature ranges from 28 to 30 °C. It is characterised by erratic low rainfall, which ranges between 450 and 650 mm per annum, and falls predominantly in the summer. The farm has an average of 170 frost-free days, extending from late October to mid-April. The climate of this area is classified as semi-arid and it has sandy loam soil.

Ga-Thaba village is also located in the Mankweng area in the Capricorn District of Limpopo, at a longitude and latitude of 24°01' 59" S, 29°47' 56" E. The area is characterised by erratic low rainfall, which ranges between 450 and 650 mm per annum, and falls predominantly in the summer. The area has an average of 170 frost-free days extending from late October to mid-April.

Bela-Bela is located in the Waterberg region of Limpopo. The experiment was conducted at three locations: UL-Farm, which was researcher-managed (the trials were planted on 11 January 2017), Ga-Thaba (the trials were planted on 13 January 2017) and Bela-Bela (the trials were planted on 18 January 2017) during the 2016/17 season. The Ga-Thaba and Bela-Bela trials were farmer-participatory-managed.

2.3.2.2 Field layout and design

The trials were laid out in a randomised complete block design in three replications with five cowpea varieties and a maize variety. The varieties were Glenda (control), IT86K-499-35, IT82E-16, IT86D-1010 and TVu-13464, with the maize cultivar being PAN 6479. The maize cultivar was planted at an inter-row spacing of 0.9 m and an intra-row spacing of 0.3 m, with a row length of 4 m. The plot sizes were 5.6 x 4 m, giving approximately six rows of maize and seven rows of cowpea for the monocrop. The intercrop was planted with four rows of cowpea sandwiched between three rows of maize. The planting patterns used for the intercrop and monocrop are shown in Figure 2.4. The intercrops consisted of four rows of cowpea sandwiched between three rows of maize. The monocrop consisted of four rows of cowpea planted at an inter-row spacing of 0.75 m and an intra-row spacing of 0.5 m. This plant pattern was used in the two locations.

The land was prepared using a disc and harrow plough. A mixture of two herbicides, Roundup (with an active ingredient of Glyphosate, N-(phosphonomethyl) glycine) in the form of isopropylamine salt at the recommended rate (240 mℓ per 15 ℓ water = 3 ℓ/ha), and Dual Gold (with an active ingredient of S-metolachlor (chloro-acetanilide) at the rate of 30 mℓ per 15 ℓ water = 0.5 ℓ/ha), was applied using Knapsack to control the weeds before planting. Weeds in the plots were subsequently controlled manually as and when necessary. Karate (lambda-cyhalothrin) and Aphox (pirimicarb) were applied at a rate of 1 ℓ per ha and 500 g per ha, respectively, to control cowpea post-flowering insect pests and aphids, respectively.

2.3.2.3 Data collection on cowpea

Number of days to 50% flowering

The dates of 50% flowering in cowpea were recorded by counting the number of days from the date of planting to the date when 50% of the population in each plot had flowered.

R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_1	R_2	R_3	R_4	R_5	R_6
O	O	O	O	O	O	O	X	X	X	X	X	X
O	O	O	O	O	O	O	X	X	X	X	X	X
O	O	O	O	O	O	O	X	X	X	X	X	X
O	O	O	O	O	O	O	X	X	X	X	X	X

a. Monocropping showing six rows (6 x 0.9 cm) of maize (right) and seven rows (7 x 0.75 cm) of cowpea (left)

R_1	R_2	R_3	R_1	R_2	R_3	R_4	R_1	R2	R3
O	O	O	X	X	X	X	O	O	O
O	O	O	X	X	X	X	O	O	O
O	O	O	X	X	X	X	O	O	O
O	O	O	X	X	X	X	O	O	O

b. Strip intercropping showing four rows (4 x 0.75 cm) of cowpea sandwiched between three rows of maize (1.8 m – 3 m – 1.8 m)

O	O	X	X	O	O	O	X
X	O	X	O	X	O	X	O
O	X	O	X	O	X	O	X
X	O	X	O	X	O	X	X
X	X	O	O	X	O	X	O

c. Mixed intercropping showing a mixture of maize and cowpea

X = cowpea; O = maize, R = row

Figure 2.4: Cowpea intercropping trial plan (monocropping, strip and mixed intercropping)

Photograph 2.3: Cowpea-maize strip intercropping

Photograph 2.4: Cowpea monocropping

Number of days to 90% maturity

Date of maturity was recorded by counting the number of days from the date of emergence to the date at which 90% of the plant population in each plot had attained maturity.

Canopy height and width

Five plants from each plot were sampled randomly at maturity, and their heights measured with a measuring tape. The average was then calculated and recorded. The canopy of two middle rows from each plot was measured at maturity, and the average was calculated and recorded.

Pod length and peduncle length

Five plants were randomly selected from each plot to measure pod length. The pod length was measured from five pods obtained from the five plants, and the average determined. The length of five peduncles from five plants was measured using a measuring tape (ruler). These plants were randomly selected from each plot. An average length per peduncle was determined by finding the average.

Number of pods per plant and grain yield

Five plants from each plot were sampled randomly at maturity, and the number of pods per plant was counted. The average was then calculated and recorded. Four middle rows from each plot in the cowpea intercropping and monocropping plots were harvested. The pods were threshed and weighed using a weighing scale. The weights were recorded and extrapolated on a hectare basis, taking into account the proportion of the area harvested in each plot. Grain yield per plot was calculated from the relationship below. A hundred good seeds were randomly picked from the net plot and used to determine the 100 seed weight using a weighing scale.

Grain yield (kg/ha) = (grain weight (kg) / area harvested (m^2)) ×10,000 m^2

Fodder yield

Haulm from the four rows of each plot in the cowpea intercrop and four net plots from the monocrop plots where grain yield was harvested were sun-dried for a week and weighed using a weighing scale. The weights were recorded and extrapolated on a hectare basis, taking into account the proportion of the area harvested in each plot. Fodder yield per plot was calculated from the relationship below.

Fodder yield (kg/ha) = (fodder weight (kg) / area harvested (m^2)) ×10,000 m^2

Number of days to 50% tasselling and silking

The dates of 50% tasselling in maize were recorded by counting the number of days from the date of planting to the date when 50% of the plant population in each plot had tasselled or silked.

Number of days to 90% maturity

The number of days to maturity was recorded by counting the number of days from the date of emergence to the date at which 90% of the plant population in each plot had attained maturity.

Plant height, cob length and number of cobs per plant

Five plants from each plot were sampled randomly at maturity, and their heights measured with a calibrated measuring tape. The average was then calculated and recorded. Five plants were randomly selected from each plot to measure cob length. The length of five cobs sampled from five plants was measured using a ruler, and the average was determined and recorded. Five plants from each plot were sampled randomly at maturity, and the number of cobs from these plants was counted. The average was then calculated and recorded.

Grain and stover yield

Two middle rows from each plot in the cowpea intercrop were harvested, as well as four net plots from the maize monocrop plots. The cobs were threshed and weighed using a weighing scale. The weights were recorded and extrapolated on a hectare basis, taking into account the proportion of the area harvested in each plot. Grain yield per plot was calculated from the relationship below. Stover from the four rows of each plot in the cowpea intercrop and four net plots from the maize monocrop plots where cobs were harvested were taken and weighed using a weighing scale. The weights were recorded and extrapolated on a hectare basis, taking into account the proportion of the area harvested in each plot. Stover yield per plot was calculated from the relationship below.

Grain yield (kg/ha) = (grain weight (kg) / area harvested (m^2)) ×10,000 m^2

Stover yield

Stover yield (kg/ha) = (fodder weight (kg) / area harvested (m^2)) ×10,000 m^2

To access the intercrop productivity, the following parameter was taken. The LER was calculated from the relative yield of cowpea and maize in the intercrop with their sole treatments, by using the following relationship:

LER (strip intercropping) = (intercrop yield of cowpea / monocrop yield of cowpea) + (intercrop yield of maize / monocrop yield of maize)

LER (mixed intercropping) = (mixed intercrop yield of cowpea / monocrop yield of cowpea) + (mixed intercrop yield of maize / monocrop yield of maize)

- An LER of less than 1 indicates lower productivity of intercropping relative to sole crops.
- An LER of 1 shows no yield difference between intercropping and sole crops.
- An LER greater than 1 shows the yield advantage of intercropping in comparison to sole crops.

Water use efficiency of cowpea

Water use efficiency was measured using the gravimetric method as described by the International Atomic Energy Agency (IAEA) (2008). The soil samples were obtained using metal cylinders. Soil samples from soil depths of 15, 30, 45 and 60 cm were taken using a core sampler, and collected in aluminium soil moisture boxes. These samples were weighed immediately and dried in an oven at 105 °C for 48 hours until a constant weight was obtained. The moisture content is expressed as a percentage. The moisture content in the soil was determined using the relationship below.

Mass basis water content (θ m, g g^{-1}) is θ m = (mass of water / mass of soil solids) = Mw/Md

Where, Md is the mass of the soil after drying, and Mw = Ms – Md, and where Ms is the mass of the soil immediately after it has been sampled. The water use efficiency of crops varies with the amount of rain or moisture used for a given produce and whether the crop produce is fresh weight or dry grain. The water use efficiency of cowpea may vary from 1.0 to 6.0 kg ha mm^{-1} (Babalola, 1980; Beletse et al., 2009; Shiringani and Shimelis, 2011; Wenhold et al., 2012). The water use efficency of pigeonpea may vary from 0.6 to 2.0 kg ha mm^{-1} (FAO, 2011).

Rainfall and temperature data of the experimental stations were obtained from the ARC's Institute of Soil Climate and Weather (ARC-ISWC) in Pretoria as secondary data to determine the water use efficiency.

Data analysis

Data was subjected to an analysis of variance using GenStat VSN 18 to check whether there were differences between the treatments. Differences between means were separated using the least significance difference (LSD). The mean separation was performed at a probability level of 0.05.

2.3.3 Results

The number of days to 50% flowering varied significantly ($P < 0.05$) in the three locations (Ga-Thaba, UL-Farm and Bela-Bela) (Table 2.3). Flowering was earlier at Ga-Thaba and UL-Farm, which were not significantly different from each other, but were significantly different from Bela-Bela, which flowered late. Significant interactions were obtained in all the main effects (variety (V) cropping system (CS), location (L)), as well as the interactions: variety x cropping system (V*CS), variety x location (V*L), cropping system x location (CS*L) and variety x cropping system x location (V*CS*L) (Figure 2.5). Glenda flowered later than the rest of the varieties, while TVu 13463 was the earliest to flower among the varieties. Cropping system results show that strip intercropping flowered earlier than mixed intercropping (Table 2.4).

Table 2.3: Analysis of variance of cowpea growth and yield parameters from all locations (Ga-Thaba, Bela-Bela and UL-Farm)

Parameters	Variety		Cropping system		Location		V*CS		V*L		CS*L		V*CS*L	
	F- value	P- value	F-value	P- value	F- value	P-value	F-value	P- value	F- value	P-value	F-value	P-value	F-value	P-value
50% flowering	22.29	0.0002	13.15	0.0002	408.78	0.0000	10.16	0.0000	6.66	0.0000	3.83	0.0077	1.94	0.0334
90% maturity	4.54	0.0331	10.59	0.0007	61.08	0.0000	3.46	0.0115	3.73	0.0014	8.42	0.0000	0.97	0.4963
Plant height	4.66	0.0309	4.77	0.0202	80.75	0.0000	4.59	0.0027	2.16	0.0432	2.43	0.0574	1.00	0.4699
Pedicle length	4.10	0.0427	1.41	0.2682	9.86	0.0002	2.39	0.0547	4.05	0.0007	1.10	0.3649	1.91	0.0370
Canopy width	13.02	0.0014	1.42	0.2662	204.78	0.0000	9.23	0.0000	3.55	0.0020	1.46	0.2254	1.03	0.4374
Leaf length	2.12	0.1694	8.43	0.0022	2.21	0.1190	0.84	0.5815	0.59	0.7811	2.78	0.0348	0.38	0.9819
Pod length	62.67	0.0000	21.82	0.0000	16.05	0.0000	9.63	0.0000	1.18	0.3260	0.70	0.5977	0.51	0.9336
Number of pods per plant	1.07	0.4315	92.63	0.0000	33.17	0.0000	0.49	0.8503	1.06	0.3999	13.67	0.0000	0.53	0.9218
Grain yield	5.53	0.0196	78.18	0.0000	1.52	0.2267	2.82	0.0287	2.05	0.0552	3.08	0.0226	0.93	0.5407
100 seed weight	23.27	0.0002	3.11	0.0667	0.85	0.4330	8.33	0.0001	1.09	0.3796	2.83	0.0321	0.62	0.8524

CS = cropping system; L = location; V = variety

Table 2.4: Means of cowpea growth and yield parameters taken from varieties, cropping systems and locations (Ga-Thaba, Bela-Bela and UL-Farm) during the 2016/17 growing season

Variety	50% flowering	90% maturity	Plant height (cm)	Peduncle length (cm)	Canopy width (cm)	Leaf length (cm)	Pod length (cm)	Number of pods per plant	Grain yield (kg/ha)	100 seed weight (g)
Glenda	59.15a	91.67a	47.63a	26.44a	50.93a	9.74a	14.37c	15.91a	594.30bc	15.12c
TVu 13464	53.85d	85.78bc	35.30c	20.93b	38.11c	9.70a	12.81d	14.59a	511.93c	14.53c
IT82E-16	55.1cd	83.67bc	40.67bc	22.52ab	41.82bc	11.59a	16.48a	15.11a	777.30a	16.27b
IT86D -1010	55.56c	83.37c	42.78ab	26.48a	44.78b	11.44a	16.15a	15.37a	719.04ab	17.68a
IT86D-499-35	56.96b	88.81ab	44.33ab	25.63a	43.82b	11.30a	15.22b	15.37a	800.89a	18.25a
Grand mean	56.13	86.66	42.14	24.40	43.89	10.76	15.01	15.36	680.69	16.37
Cropping system										
Monocropping	56.84a	87.91a	40.33b	23.44a	43.80a	10.24b	14.27b	11.38b	918.89a	16.27ab
Strip intercropping	56.44a	88.18a	41.93ab	25.31a	44.64a	9.53b	14.82b	12.36b	724.29b	16.03b
Mixed intercropping	55.11b	83.89b	44.16a	24.44a	43.22a	12.49a	15.93a	22.33a	398.89c	16.82a
Location										
UL-Farm	52.33b	93.36a	38.96b	23.13b	38.49b	11.47a	14.69b	11.93c	691.00a	16.63a
Ga-Thaba	52.53b	84.33b	34.67c	27.04a	36.80b	9.73b	14.42b	17.89a	709.44a	16.24a
Bela-Bela	63.53a	82.29b	52.80a	23.02b	56.38a	11.07ab	15.91a	16.24b	641.62a	16.24a

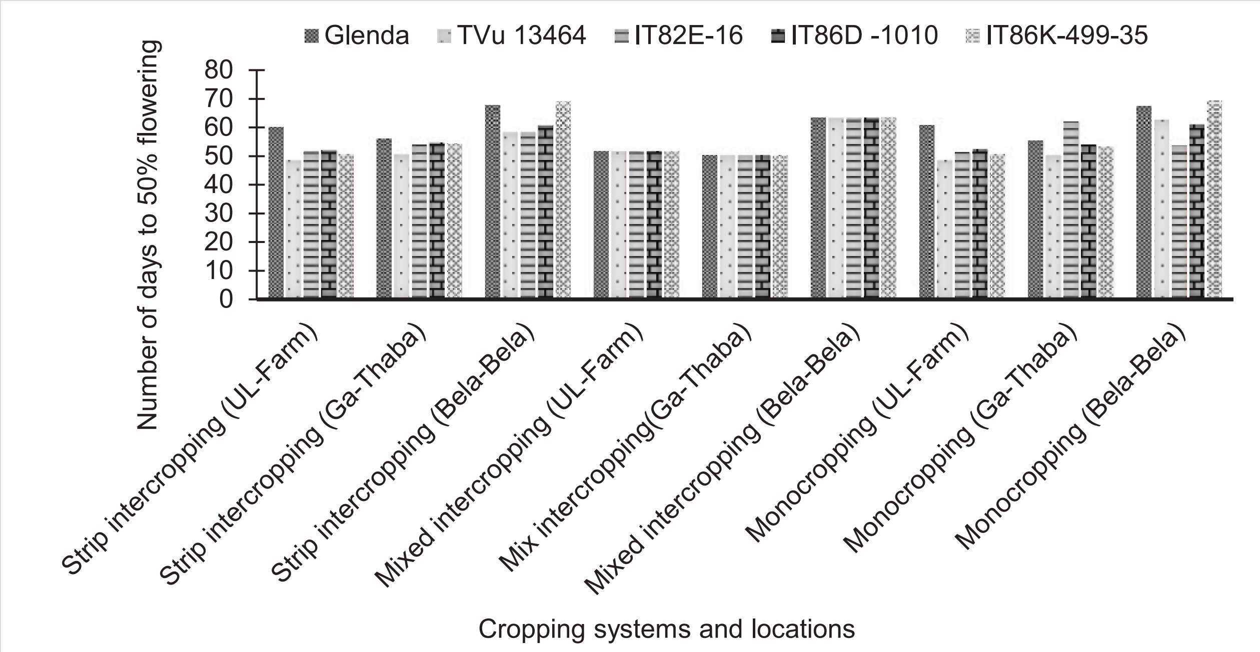

Figure 2.5: Interaction plot between cowpea variety, location and cropping system for the number of days to 50% flowering at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Similarly, the number of days to maturity among the main effects were significant, as well as the interactions of V*CS, V*L and CS*L, except for V*CS*L (Table 2.3, Figure 2.6, Figure 2.7 and Figure 2.8). The varieties matured earlier at Ga-Thaba and Bela-Bela, while they matured late at UL-Farm. Among the varieties, Glenda matured later than the rest (TVu 13464, IT86D-1010, IT82E-16 and IT87K-499-35) (Table 2.4). The results reveal that, among the cropping systems, varieties matured earlier in mixed intercropping than in strip and monocropping.

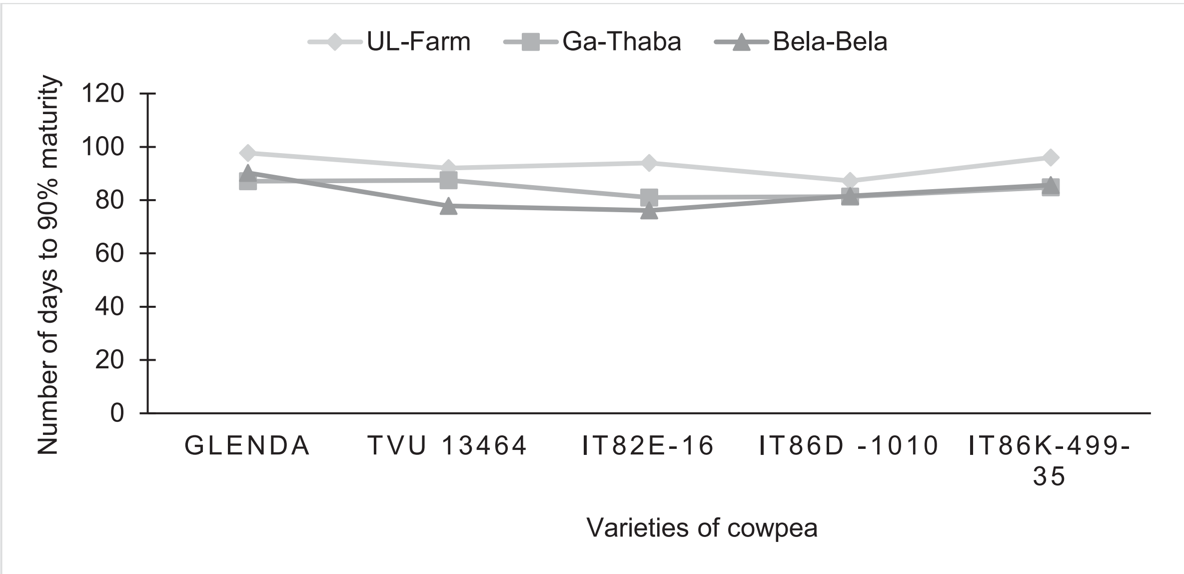

Figure 2.6: Interaction plot between cowpea variety and location for the number of days to 90% maturity at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

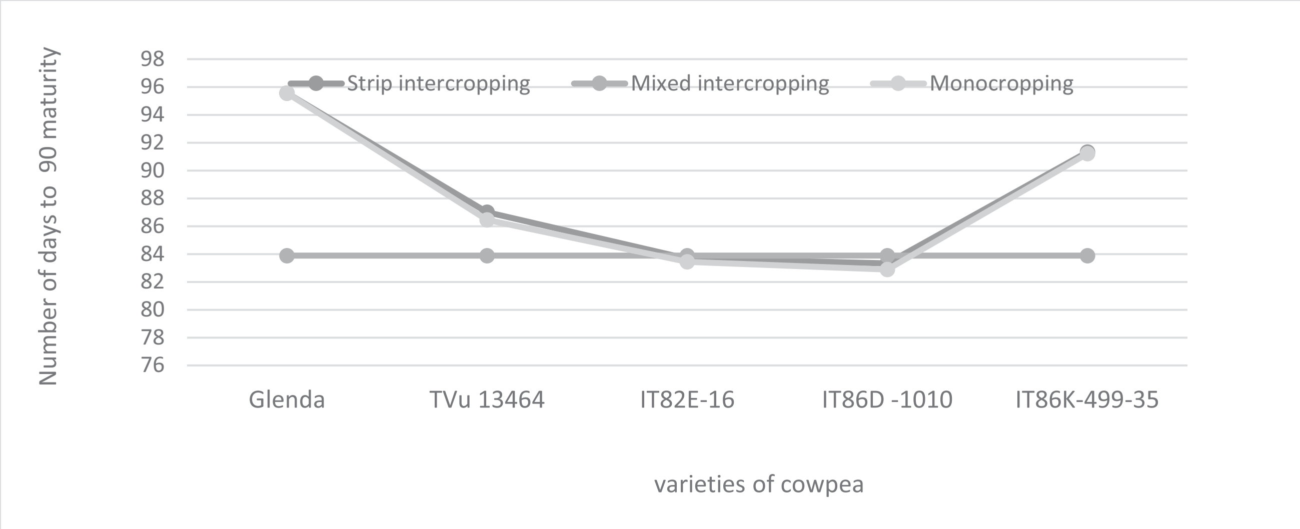

Figure 2.7: Interaction plot between cowpea varieties and cropping system for the number of days to attain 90% maturity at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

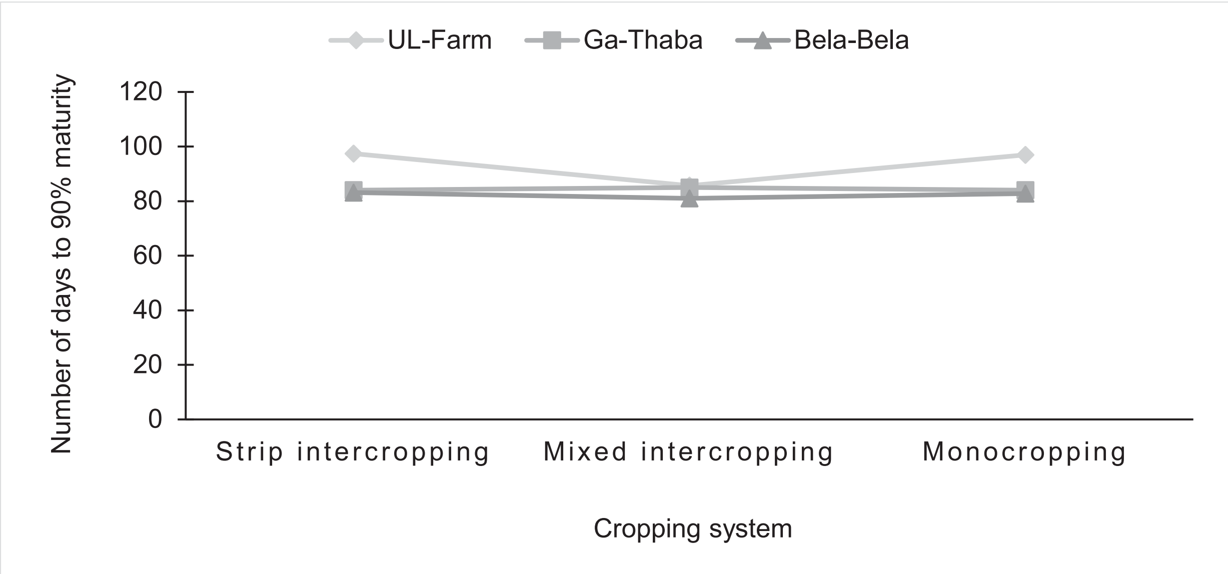

Figure 2.8: Interaction between cropping system and location in the number of days to 90% maturity at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Significant (P < 0.05) differences were observed among the varieties, cropping systems and between locations in plant height. Significant (P < 0.05) interactions were also obtained for V*CS and V*L, except for CS*L and V*CS*L (Table 2.3, Figure 2.9, Figure 2.10 and Figure 2.11). Plant height was highest at Bela-Bela, followed by UL-Farm and it was the lowest at Ga-Thaba. Results show that plant height was highest in mixed intercropping, followed by strip intercropping, the lowest plant height was obtained from monocropping (Table 2.4).

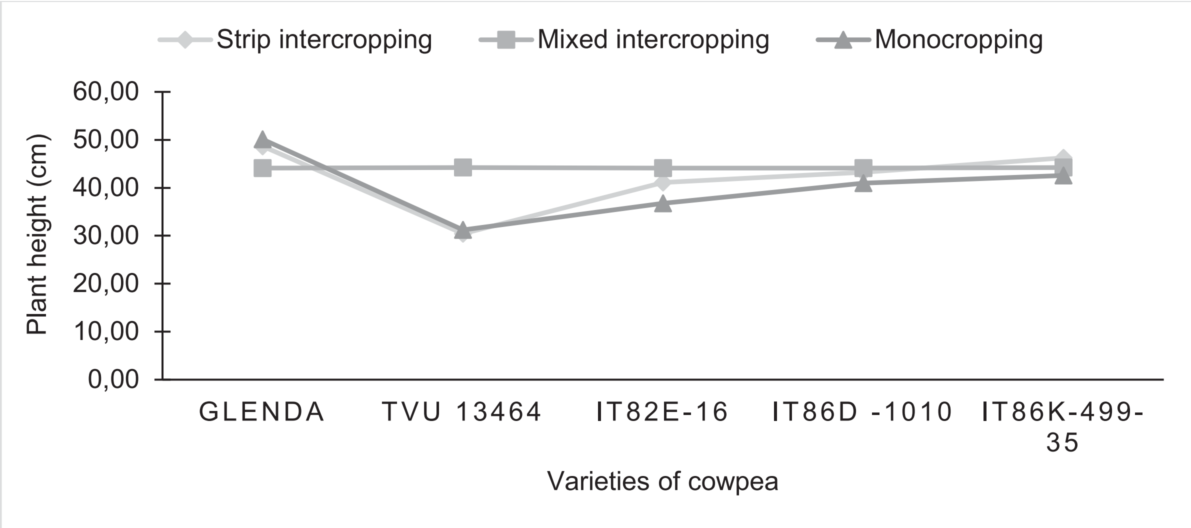

Figure 2.9: Interaction plot between cowpea variety and cropping system on plant height at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

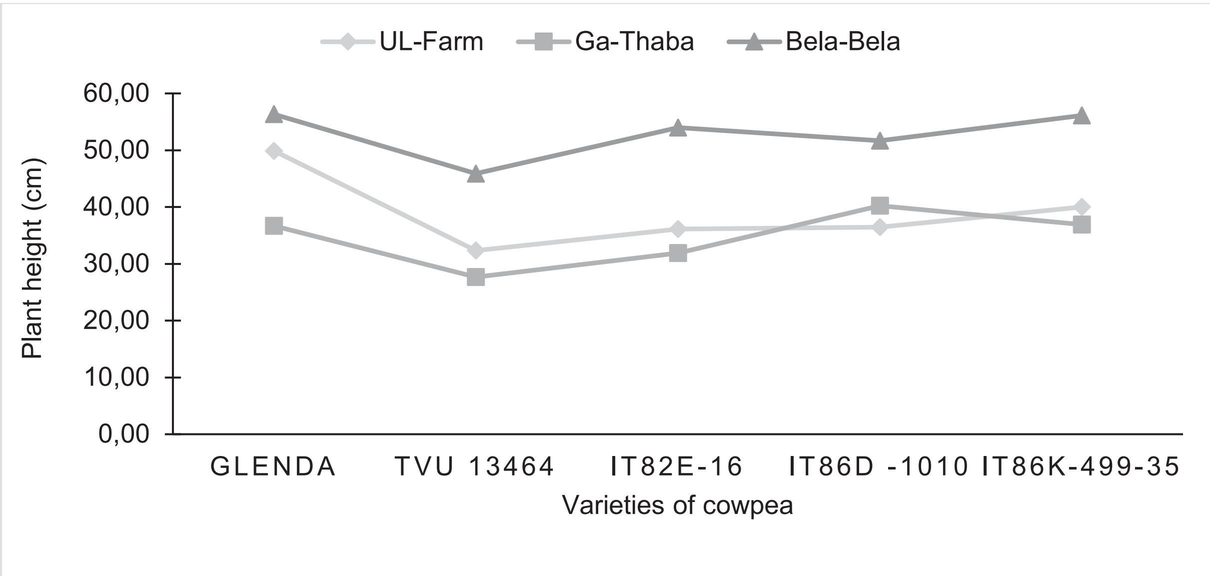

Figure 2.10: Interaction plot between cowpea varieties and location on plant height at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

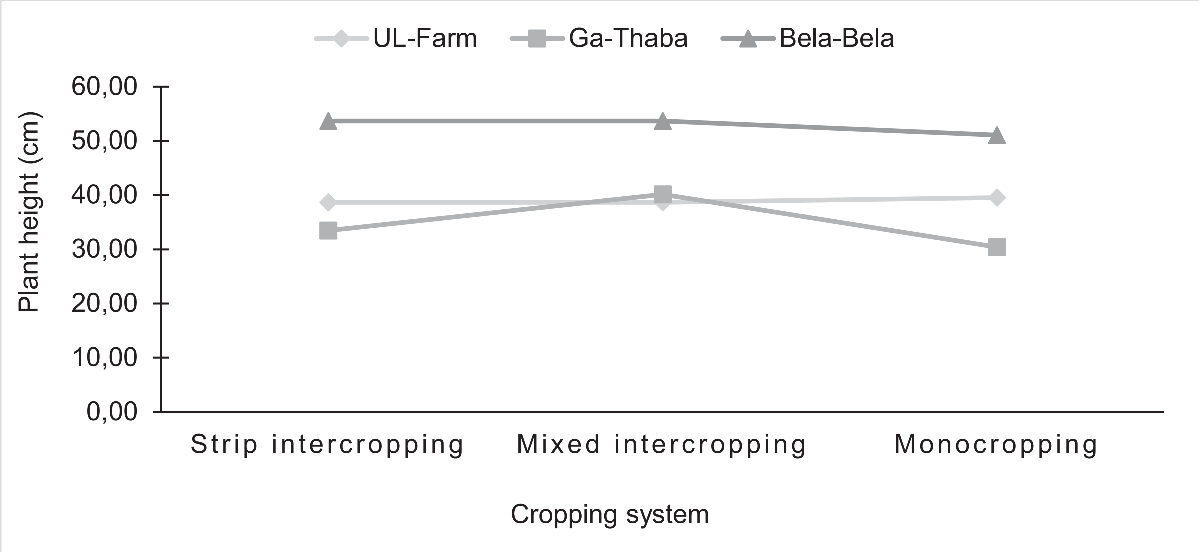

Figure 2.11: Interaction plot between cropping systems and location on plant height at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Results show that significant differences were obtained among the varieties in peduncle length, as well as in cropping systems and between locations, and among interactions for V*CS and V*L, except for CS*L and V*CS*L (Table 2.3, Figure 2.12). Peduncles were longer at Ga-Thaba than at Bela-Bela and UL-Farm, which did not vary significantly from each other. No significant difference was obtained among the cropping systems. However, results show that, although peduncle length varied between TVu 13464 and IT82E-16, no significant difference was found among Glenda, IT86D-1010 and IT87K-499-35 (Table 2.4). Significant variation was obtained for V*CS and V*L (Table 2.3, Figure 2.15).

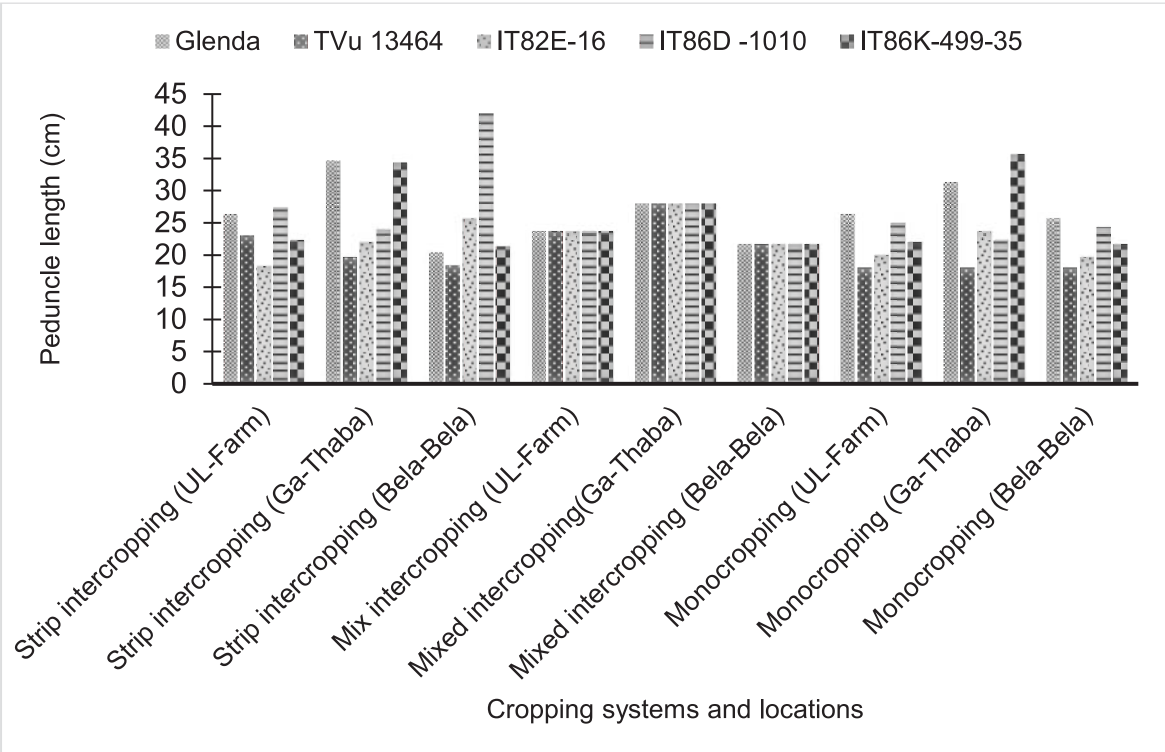

Figure 2.12: Interaction plot between cowpea variety, cropping system and location for peduncle length of cowpea at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Significant differences (P < 0.05) were obtained in the plant canopy among the varieties and location (Table 2.3, Figure 2.13 and Figure 2.14). Results of the means show that the canopy of the varieties was widest at Bela-Bela, which was significantly different from the plant canopy at Ga-Thaba and UL-Farm, which did not differ from each other (Figure 2.13). Among the varieties, the canopy was widest with IT86D-1010, followed by IT87K-499-35 and IT82E-16. TVu 13464 exhibited the smallest canopy width (Table 2.4). No significant difference was observed in the canopy for cropping system. Only V*L and V*CS showed significant differences (P < 0.05) for canopy width (Table 2.4, Figure 2.14). Canopy width was widest at Bela-Bela.

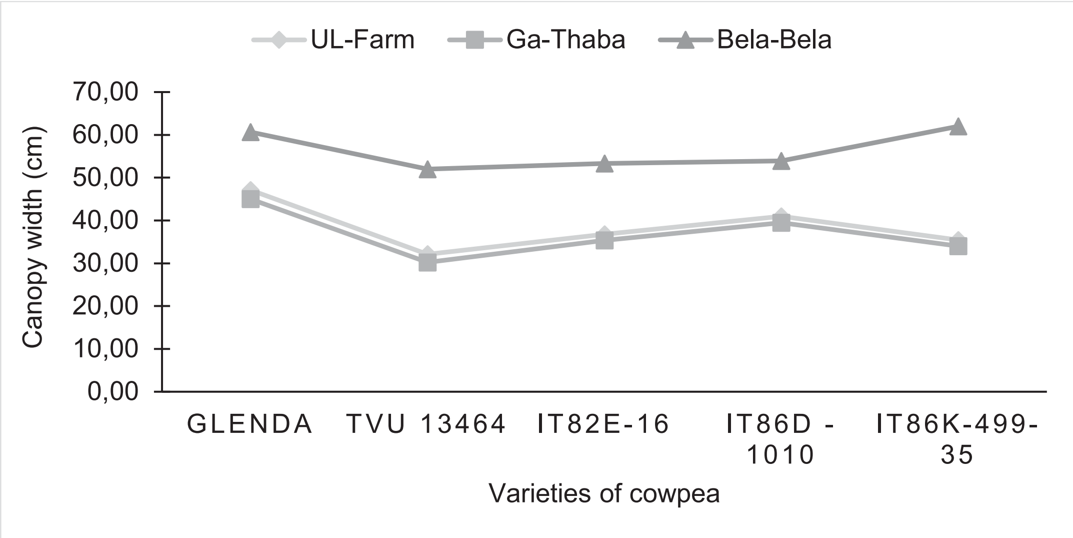

Figure 2.13: Interaction between cowpea varieties and location in terms of canopy width at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

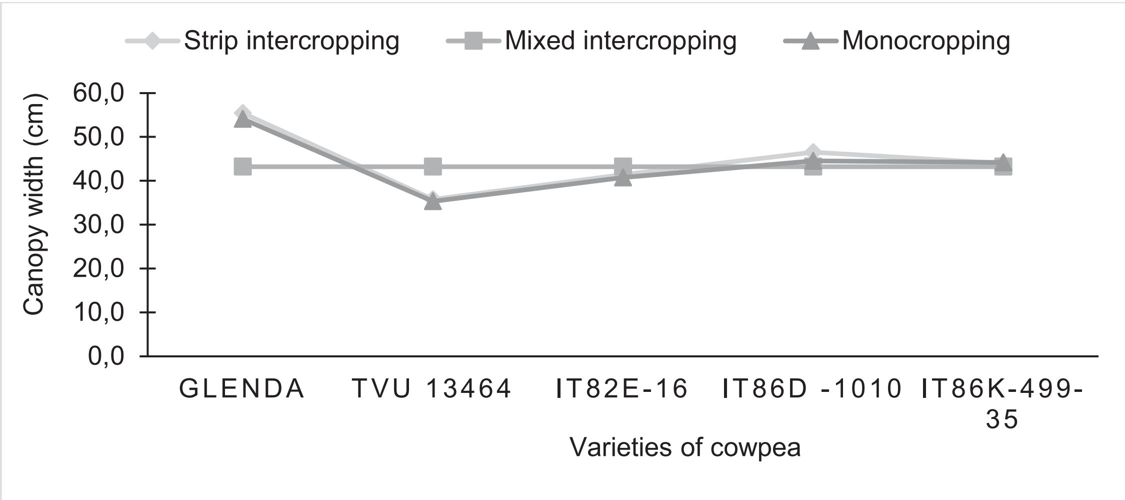

Figure 2.14: Interaction plot between cowpea variety and cropping systems for canopy width at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Significant differences (P < 0.05) were obtained in leaf length only between location (Table 2.3, Figure 2.15). Results of the means show that the leaves of the varieties were longest at UL-Farm (11.47 cm), followed by Bela-Bela (11.07 cm) and Ga-Thaba (9.07 cm), which exhibited the shortest leaf length (Table 2.4). Leaf length among the cropping systems was longest (12.49 cm) in mixed intercropping, followed by monocropping and strip intercropping, which was the shortest with 9.53 cm. Significant variation was only obtained for CS*L (Table 2.3, Figure 2.15).

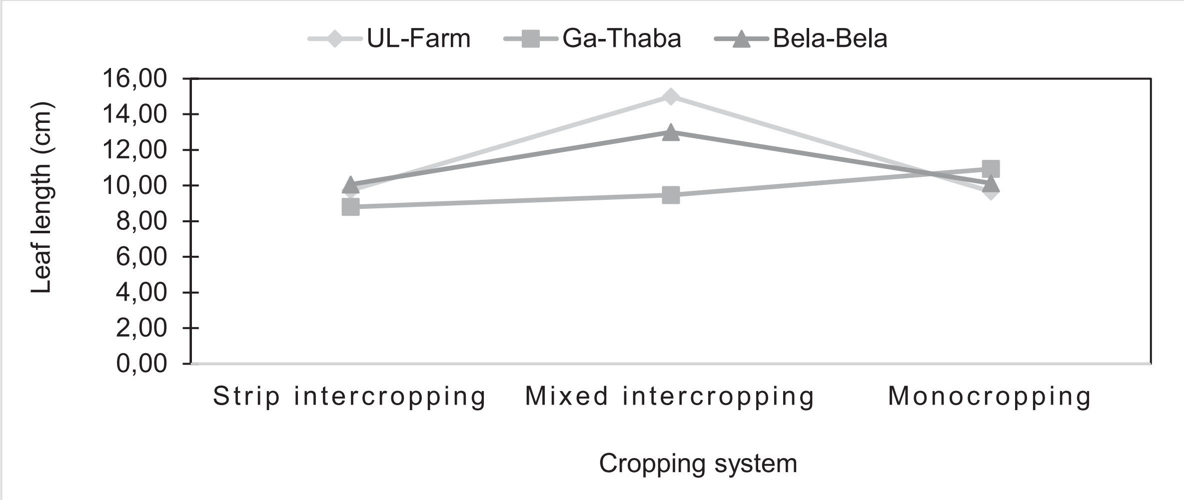

Figure 2.15: Interaction plot between cropping system and location in leaf length at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Results show that significant differences (P < 0.05) were obtained in pod length among the varieties, cropping systems and between locations, as well as in the interaction of V*CS (Table 2.3, Figure 2.16). Pods were longer at Ga-Thaba than at Bela-Bela and UL-Farm, which did not vary significantly from each other. No significant difference was obtained among the cropping systems. However, results show that, although pod length varied between TVu 13464 and IT82E-16, there was no significant difference among Glenda, IT86D-1010 and IT87K-499-35. Significant variation was obtained for V*CS and V*L (Table 2.3, Figure 2.16).

Pod length was significantly different (P < 0.05) among the varieties, cropping systems and between locations (Table 2.3). Pod length was significantly longer (P < 0.05) at Bela-Bela (15.91 cm) than at UL-Farm (14.69 cm) and Ga-Thaba (14.42 cm). Pods of IT86D-1010 and IT82E-16 were longest, which were not significantly different from each other, but different from the rest. This was followed by IT87K-499-35, Glenda and TVu13464, which had the shortest pod length (Table 2.4). Among cropping systems, pod length was significantly different (P < 0.05) in mixed cropping, but not in strip and monocropping. Significant differences existed in the interaction of V*CS (Table 2.4, Figure 2.16).

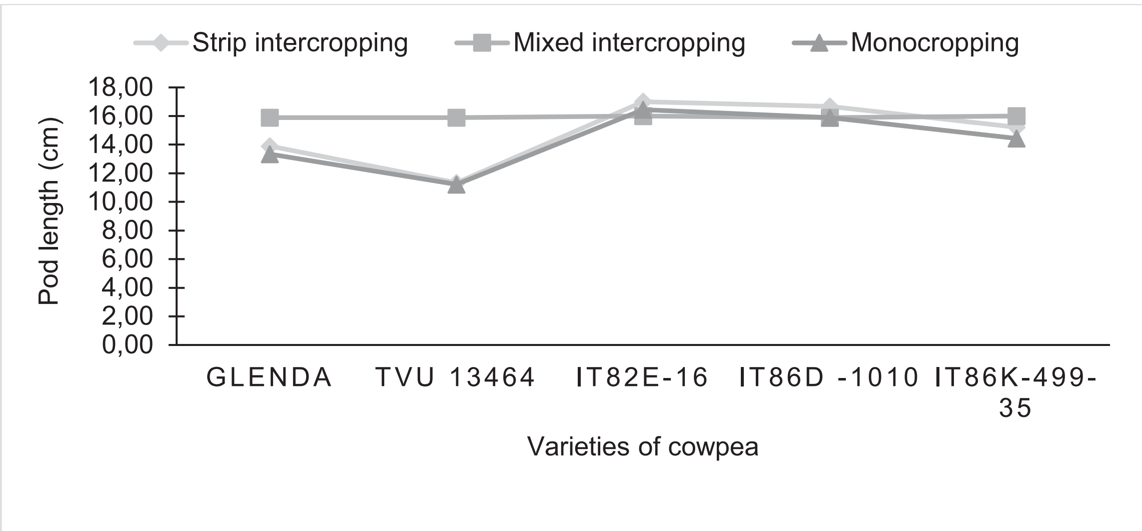

Figure 2.16: Interaction plot between cowpea variety and cropping system in terms of pod length at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

The number of pods per plant showed significant differences (P < 0.05) in cropping system and location, and its interaction of CS*L (Table 2.3, Figure 2.17). Results show that the number of pods per plant was most at Ga-Thaba, followed by Bela-Bela and UL-Farm. Among the cropping system, mixed intercropping produced the most pods per plant, followed by strip intercropping and monocropping (Table 2.4).

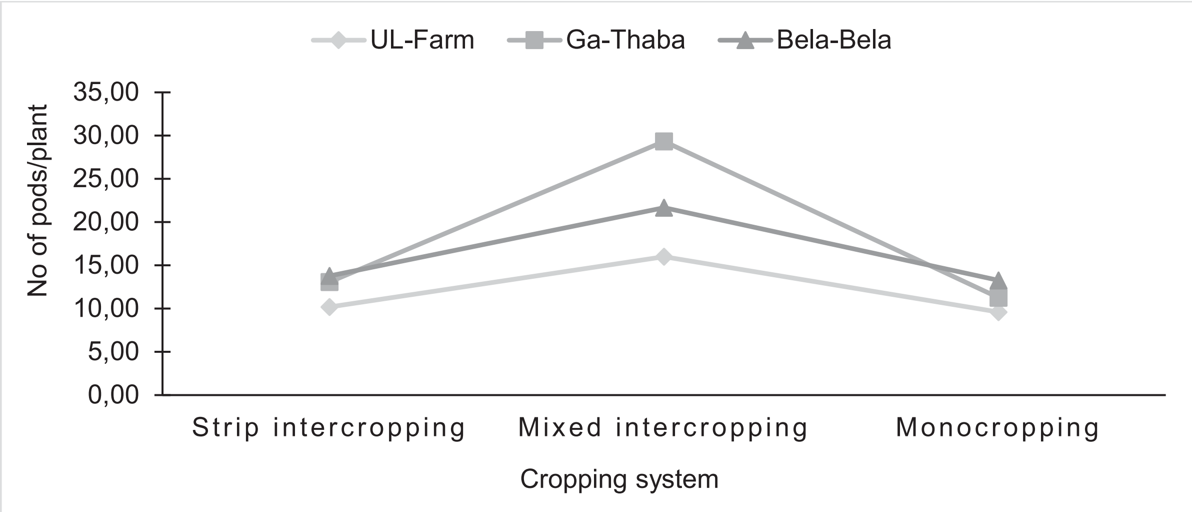

Figure 2.17: Interaction plot between cropping system and location in terms of number of pods per plant at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Seed size varied significantly among varieties (P < 0.05), as well as the interactions of V*CS and CS*L (Table 2.3, Figure 2.18). No significant differences were observed for cropping system and location. Among the varieties, IT86D-1010 exhibited the largest seed size (18.25 g) across cropping systems, followed by IT87K-499-35 at 17.68 g per 100 seeds and IT82E-16 (16.27 g), which was significantly different to the seed sizes of Glenda (15.12 g) and TVu 13464 (14.53 g) (Table 2.4). Seed size was significantly higher (P < 0.05) at Ga-Thaba in mixed intercropping, followed by Bela-Bela and UL-Farm (Figure 2.19).

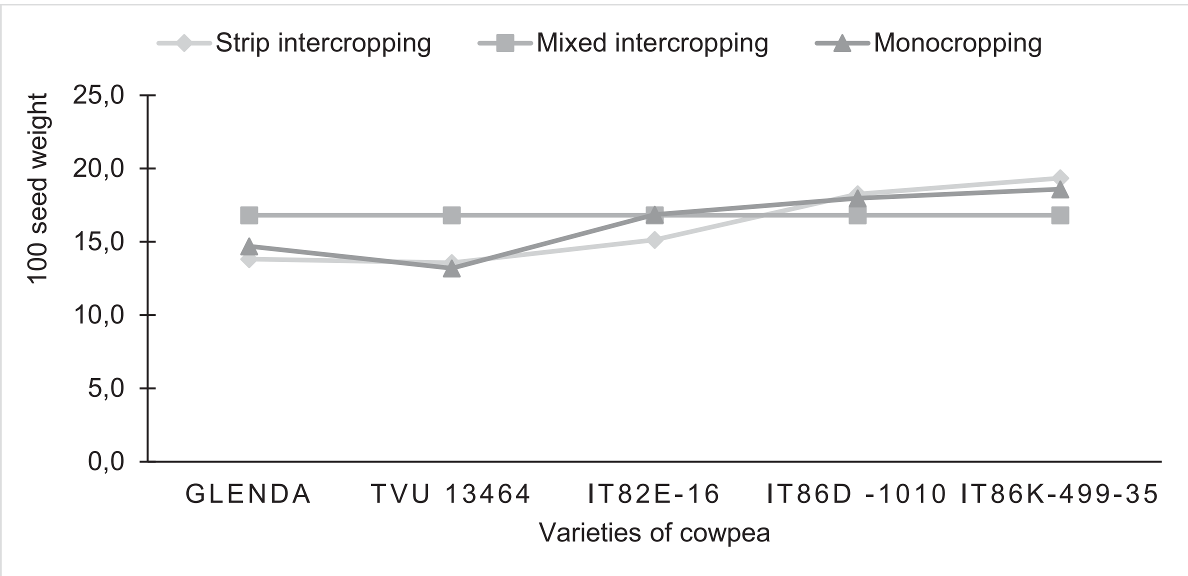

Figure 2.18: Interaction plot between cowpea variety and cropping system in terms of 100 seed weight at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

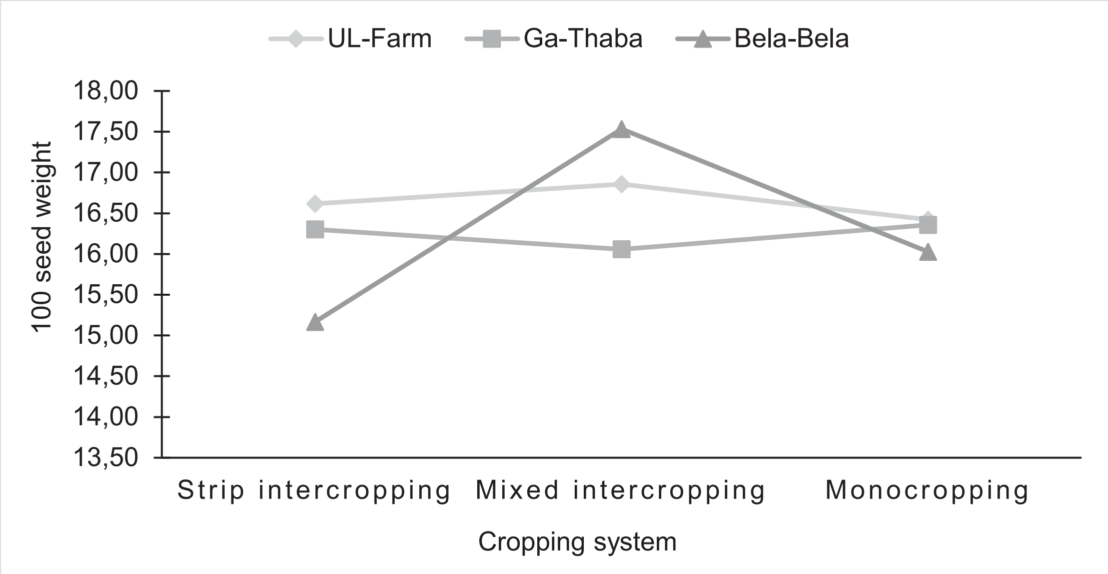

Figure 2.19: Interaction between cropping systems and location in terms of 100 seed weight at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Results on grain yield show significant differences (P < 0.05) among five cowpea varieties, cropping systems and location (Table 2.3). Among the five varieties, only TVu 13464 did not perform consistently well across the three locations. The grain yield of the cowpea varieties varied from 511.93 to 800.89 kg/ha, with the highest mean yield from IT97K-499-35 (800.89 kg/ha), while Glenda exhibited the lowest yield (511.93 kg/ha) (Table 2.4). The performance of the locations are in the following order: Ga-Thaba, UL-Farm and Bela-Bela with 709.44, 691.00 and 641.620 kg/ha, respectively. The monocropping (918 kg/ha) performed significantly better (P < 0.05) in the three locations than the strip intercropping (724.30 kg/ha), and the best performance was exhibited by mixed intercropping with a mean yield of 398.89 kg/ha. The interactions of V*L and CS*L were significant (P < 0.05) (Table 2.4, Figure 2.20 and Figure 2.21).

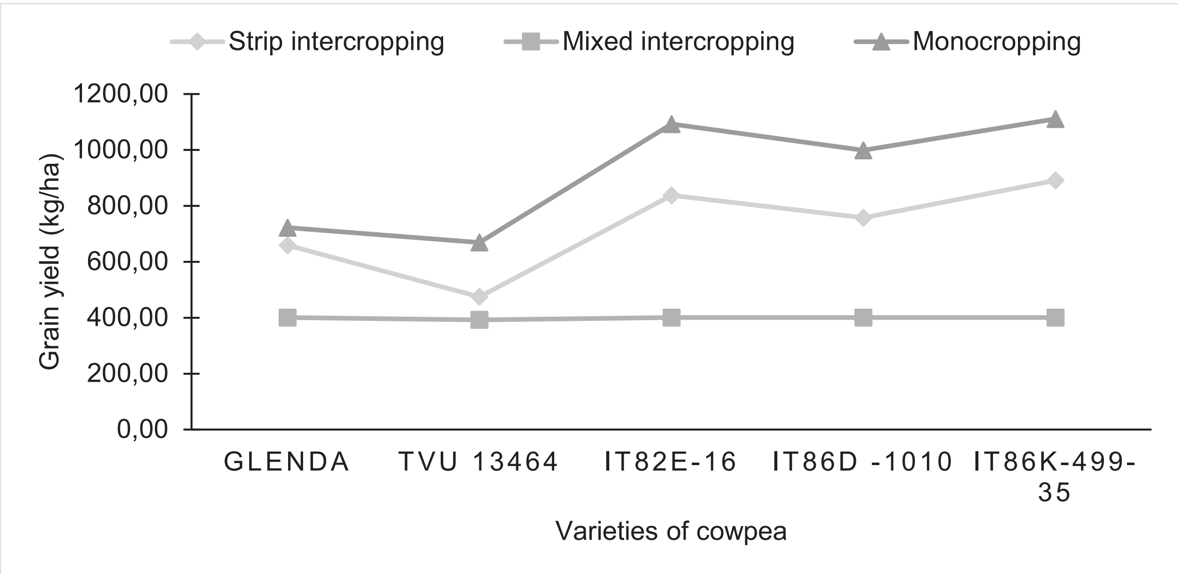

Figure 2.20: Interaction between cowpea varieties and cropping systems in terms of grain yield at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

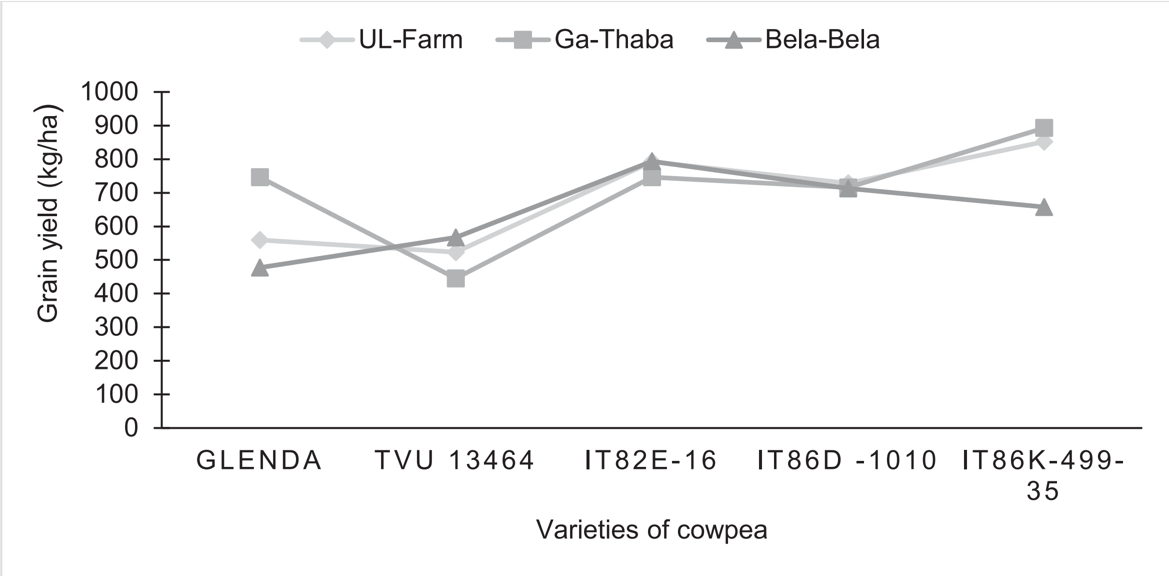

Figure 2.21: Interaction between cowpea varieties and location in terms of grain yield at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

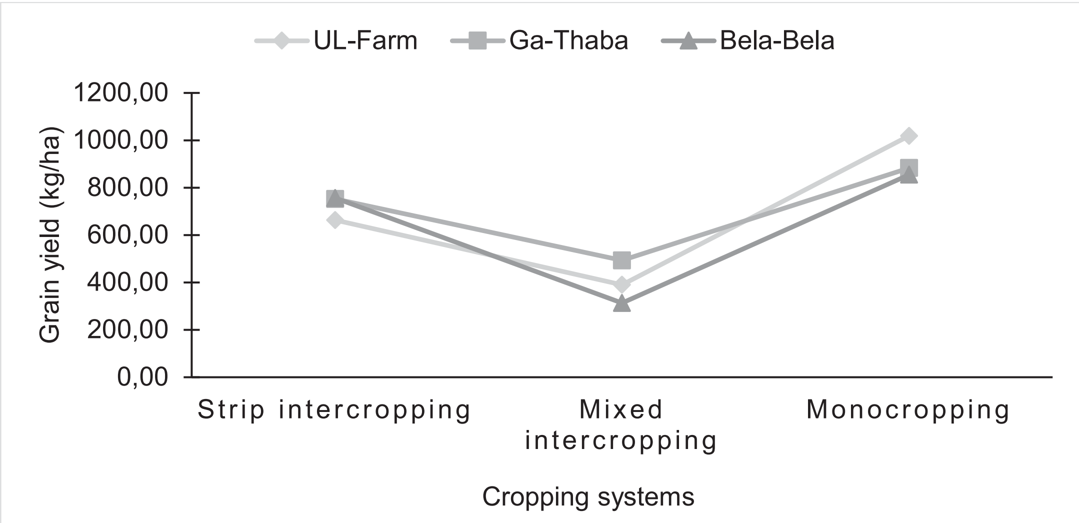

Figure 2.22: Interaction between cropping systems and location in terms of grain yield at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Among the maize variables, 50% tasselling, plant height, cob length and number of cobs per plant exhibited significant ($P < 0.05$) difference except number of days to 50% silking (Table 2.5). Number of days to tasselling was lowest with mixed intercropping (71 days), while strip intercropping tasselled at 73 days after planting (Table 2.6). Plants were taller at UL-Farm and Ga-Thaba (143 cm) than at Bela-Bela (108 cm). Maize cobs were longer at UL-Farm and Ga-Thaba at 16 and 15 cm, respectively, compared to Bela-Bela with a cob length of 14 cm. The number of cobs per plant was highest at Ga-Thaba (1.73), followed by UL-Farm (1.69). Bela-Bela had the least cobs per plant (1.4). Interactions between CS*L for 50% silking and number of cobs per plant were significant ($P < 0.05$) (Table 2.5). The interaction plots showed that number of days to 50% silking was lower with mixed intercropping (80 days) at UL-Farm than with strip intercropping and monocropping (where it was 82 days at Ga-Thaba and Bela-Bela) (Table 2.6, Figure 2.22). The number of cobs per plant was higher with mixed intercropping at UL-Farm (1.69) (Figure 2.26).

The LER results show that UL-Farm performed better than Ga-Thaba. The LER at UL-Farm varied from 1.76 to 2.14 under strip intercropping, and 0.83 to 1.04 under mixed intercropping (Table 2.7). At Ga-Thaba, the LER varied from 1.76 to 1.94 for strip intercropping and from 0.76 to 1.67 for mixed intercropping (Table 2.8). The LER for Bela-Bela was not determined because of the exclusion of maize in the calculation due to severe damage by army worms, which resulted in total maize failure. The grand mean LER values for strip intercropping were twice those of mixed intercropping at both locations. This implies that strip intercropping can give double the crop yields compared to mixed crops under the same land area.

Table 2.5: Analysis of variance of maize growth and yield parameters taken from all locations (Ga-Thaba, Bela-Bela and UL-Farm)

	Cropping system	**Location**			**CS*L**	
Parameters	F-value	P-value	F-value	P-value	F-value	P-value
50% tasselling	7.33	0.0459	48.58	0.0000	1.35	0.2569
50% silking	3.07	0.1554	1.45	0.2385	2.73	0.0322
Plant height	3.16	0.1500	56.05	0.0000	1.97	0.1028
Cob length	0.92	0.4701	40.10	0.0000	0.34	0.8514
Number of cobs per plant	0.35	0.7243	8.82	0.0003	2.67	0.0355

Table 2.6: Means of maize growth and yield parameters taken from cropping systems and locations (Ga-Thaba, Bela-Bela and UL-Farm) during the 2016/17 growing season

Parameters	**50% tasseling**	**50% silking**	**Plant height (cm)**	**Cob length (cm)**	**Cobs per plant**
Cropping system					
Monocropping	72.51a	82.16a	135.60a	14.67a	1.56a
Strip intercropping	72.56a	82.18a	133.98a	14.96a	1.58a
Mixed intercropping	71.22b	80.42a	125.78a	15.00a	1.67a
Location					
UL-Farm	71.09b	81.04a	143.33a	15.84a	1.69a
Ga-Thaba	69.91c	81.49a	143.69a	15.20b	1.73a
Bela-Bela	75.29a	82.22a	108.33b	13.58c	1.38b
Grand mean	**72.10**	**81.59**	**131.79**	**14.87**	**1.60**

Table 2.7: Partial and total LER for strip and mixed intercropping at UL-Farm during the 2016/17 season

Crop mixture	**Strip intercropping**			**Mixed intercropping**		
	LER maize	**LER cowpea**	**Total LER**	**LER maize**	**LER cowpea**	**Total LER**
Glenda + PAN 6479	1.43a	0.46b	1.89	0,73a	0.31ab	1.04
Tvu 13464 + PAN 6479	1.24a	0.52b	1.76	0,61a	0.39a	1.00
IT82E-16 + PAN 6479	1.42a	0 .54ab	1.96	0,69a	0.14c	0.83
IT86D -1010 + PAN 6479	1.30a	0.59ab	1.89	0,70a	0.21bc	0.91
IT86K-499-35 + PAN 6479	1.45a	0.69a	2.14	0,73a	0.31ab	1.04
Mean	1.37	0.56	0.97	0,69	0.27	0.48
P-level	0,9459 ns	0.0581 ns		0,5723 ns	0.0378**	

Table 2.8: Partial and total LER in respect of strip and mixed intercropping at Ga-Thaba during the 2016/17 season

Crop mixture	Strip intercropping			Mixed intercropping		
	LER maize	LER cowpea	Total LER	LER maize	LER cowpea	Total LER
Glenda + PAN 6479	1.48a	0.46b	1.94	0,64b	0.31ab	0.95
TVu 13464 + PAN 6479	1.44a	0.49b	1.93	1,29a	0.38a	1.67
IT82E-16 + PAN 6479	1.32a	0.52b	1.84	0,67b	0.15c	0.82
IT86D -1010 + PAN 6479	1.19a	0.57ab	1.76	0,64b	0.22bc	0.86
IT86K-499-35 + PAN 6479	1.23a	0.69a	1.92	0,45b	0.31ab	0.76
Mean	1.33	0.55	0.94	0,74	0.23	0.49
P-level	0.6104 ns	0.0521*		0,0056**	0.0021***	

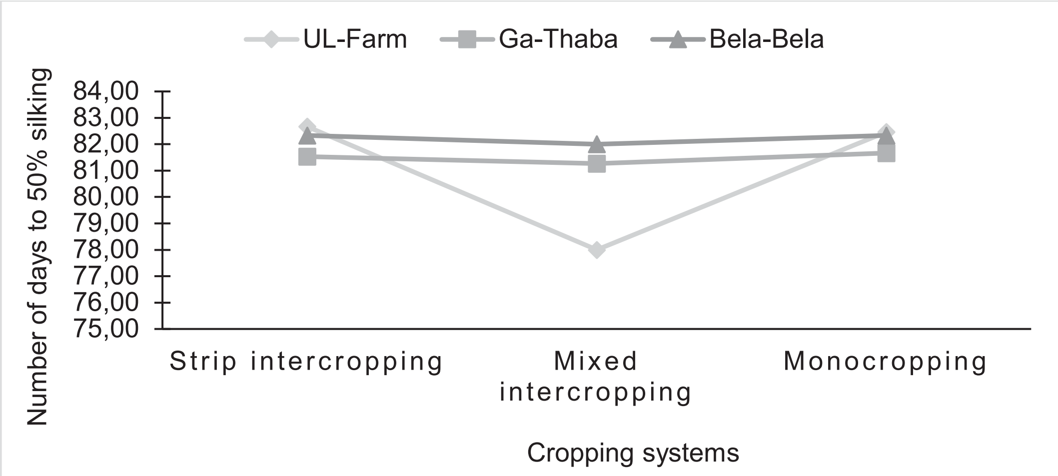

Figure 2.23: Interaction between cropping systems and location in terms of number of days to 50% silking at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

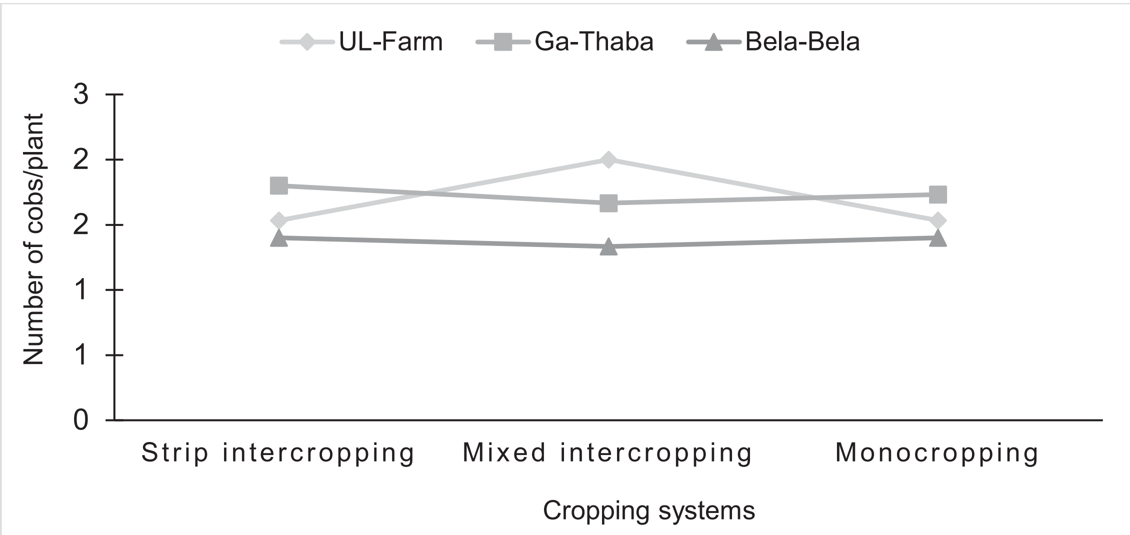

Figure 2.24: Interaction between cropping systems and location in terms of number of cobs per plant at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

Water use efficiency results show that significant differences (P < 0-05) were obtained among the varieties, locations and cropping systems (Table 2.9). Among the varieties, IT97K-499-35 was the most water use efficient (2.53 kg ha mm^{-1}), followed by IT82E-16 (2.35 kg ha mm^{-1}) and IT86D-1010 (2.21 kg ha mm^{-1}) (Table 2.9). The least water use efficient was TVu 13464 (1.52 kg ha mm^{-1}) after Glenda with 1.85 kg ha mm^{-1}. Among the locations, Ga-Thaba was more water use efficient, followed by UL-Farm and Bela-Bela with 2.68, 2.15 and 1.45 kg ha mm^{-1}, respectively. Monocropping had a greater water use efficiency than strip intercropping and mixed intercropping, with WUE values of 2.84, 2.19 and 1.28 kg ha mm^{-1}, respectively.

Table 2.9: Mean cowpea water use efficiency taken from varieties, cropping systems and locations (Ga-Thaba, Bela-Bela and UL-Farm) during the 2016/17 season

Variety	Water use efficiency gg/mm
Glenda	1.85^{ab}
TVu 13464	1.52^{a}
IT82E-16	2.35^{bc}
IT86D -1010	2.21b^{c}
IT87K-499-35	2.53^{c}
P-level	0.009
Grand mean	2.09
Cropping systems	
Monocropping	2.84^{a}
Strip intercropping	2.19^{b}
Mixed intercropping	1.28^{c}
P-level	<.001
Locations	
UL-Farm	2.15^{b}
Ga-Thaba	2.68^{c}
Bela-Bela	1.45^{a}
P-level	<.001

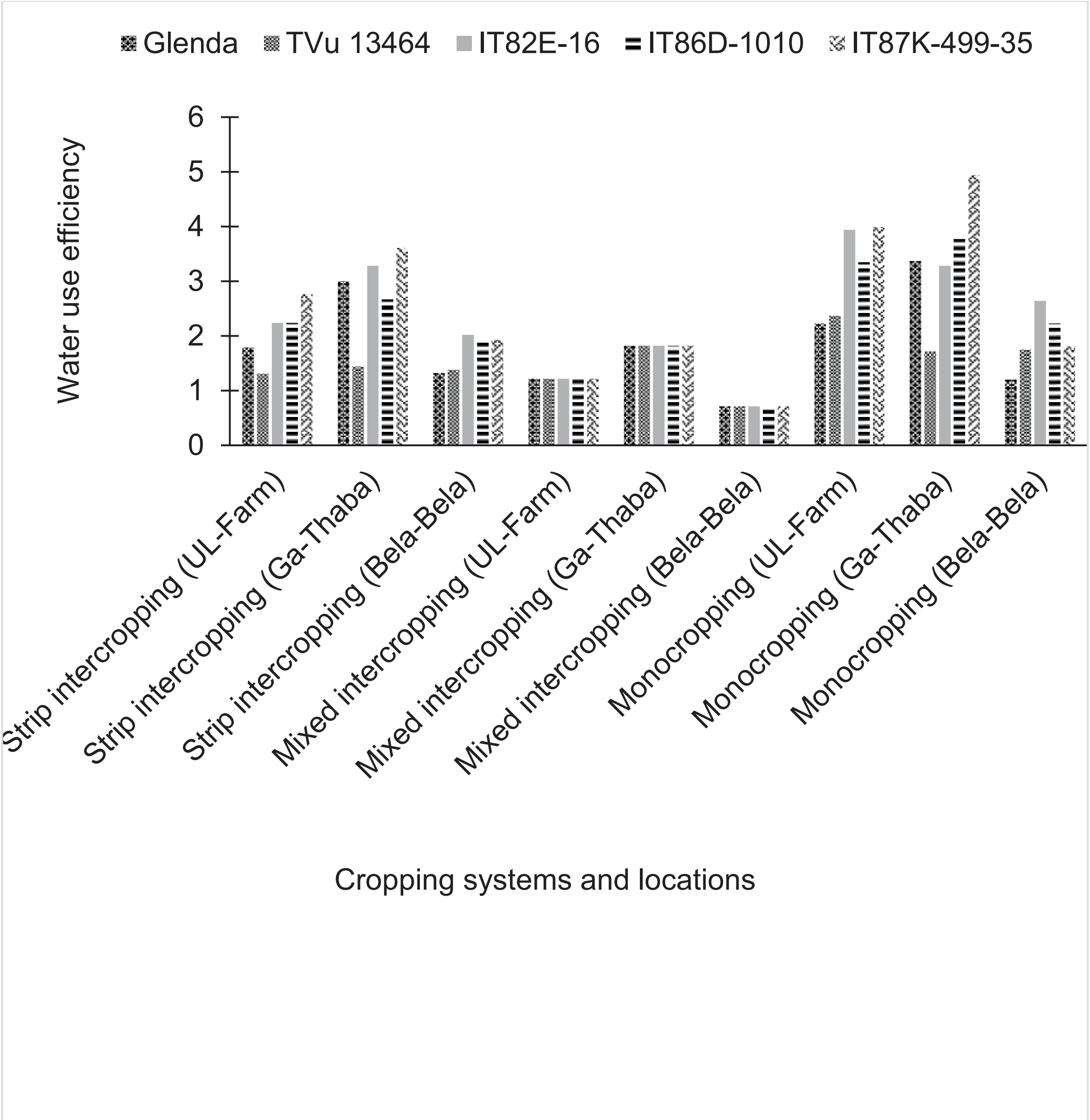

Figure 2.25: Interaction plot between cowpea variety, cropping system and location in water use efficiency at UL-Farm, Ga-Thaba and Bela-Bela during the 2016/17 season

2.3.4 Discussion

The findings of this study showed that cowpea varieties flowered and matured differently. Glenda exhibited later flowering and maturity than other varieties. The difference in their flowering and maturity habits was due to the genetic make-up of the varieties, which implied that farmers can make a selection among the varieties that will meet their needs in adapting to erratic rainfall condition in their communities. Since drought is a limitation to production, the cultivation of early-maturing varieties as obtained in this study would improve the productivity of the farmers in the drought-prone areas of Limpopo.

The report of Kamai et al*.* (2014) showed that cowpea genotypes may vary in terms of flowering and maturity duration because of their genetic constitution. The study also showed that, although strip intercropping flowered earlier than monocropping and mixed intercropping, the varieties in monocropping matured earlier than in strip and mixed intercropping, which is an indication that the varieties were bred for monocropping.

The IITA (2017) reported that cowpea breeding lines destined for intercropping systems should be selected and advanced under an intercropping system for better performance. The variation in flowering and maturity among the locations was due to variations associated with weather variables such as rainfall and temperature. Maturity was earlier at Ga-Thaba and Bela-Bela than at UL-Farm because the temperature at the two locations during the reproductive period of the crop was higher than at UL-Farm. The presence of the three-way interaction (variety x cropping system x location) indicated that varieties responded differently to cropping system and climatic factors as influenced by location, especially temperature, which was reported by Summerfield (1980) to be the dominant factor that affects duration to flowering in cowpea.

Previous findings (Ehlers and Hall, 1996; Craufurd et al*.,* 1996; Jadhav et al*.,* 1991) reported that higher day and night temperatures, along with moderate humidity, favoured early flowering in cowpea. In their study, Jadhav et al. (1991) reported that night temperature and humidity plays a bigger role in flowering than day length, and indicated that flowering was delayed as the night temperatures became cooler and relative humidity fell below 68%. However, Summerfield (1980) mentioned that warmer temperature hastens the initiation of flowering in day length-sensitive breeding lines.

Our study showed that variation among varieties in plant height, peduncle length and canopy width were due to varietal characteristics and genetic variation. For example, peduncle length, canopy width and plant height were lowest with TVu 13464 and highest with IT86D-1010. Our study found that such varietal attributes are important and offer variations from which farmers can make their selection. For example, varieties with long peduncles are known to be either erect or semi-erect cowpea types that farmers will select for easy harvesting by hand or with a combine harvester, while varieties with wide canopy widths such as IT86D-1010 and IT87K-499-35 will be preferred by farmers for dual-purpose or fodder cowpea for animal feed. In addition, cowpea varieties with a wide canopy are known to cover the ground quickly and suppress weed growth. Ndiso et al. (2016) reported wide canopy cover to suppress weed growth, thus reducing competition that might be exerted by weeds on growth and crop yields. However, the variation among locations in plant height, canopy and peduncle length was due to the effect of weather variables, especially rainfall, during the crop's reproductive phase. The overall implication is that plant height, peduncle length and canopy width can be promoted by rain or can be negatively affected by lack of enough rain. This finding agrees with the results of Ichi et al. (2013) who report that environmental and genotypic effects played a significant role in cowpea plant height. All breeding lines had longer peduncles compared to Glenda and TVu 13464. Ezeaku et al. (2015) also report that improved cultivars have longer peduncles compared to local varieties.

Our study indicated that leaf length was greatly influenced by location. This implies that the use of cowpea leaves for vegetables can be affected by location. Pod length results indicated that pod length varied among the varieties. This implies that varieties with longer pods such as IT82E-16 and IT86D-1010 could be eaten by farmers as green pods or to garnish their meals. In addition, varieties with long pods are known to contain more seeds. This characteristic will contribute to total grain yield. The presence of the two-way interaction (variety x cropping system x location) indicated that varieties responded differently to cropping system and climatic factors as influenced by location. Pod length was longest at Bela-Bela, which implied that the weather conditions (rainfall and temperature) in that location were adequate during the crop's reproductive phase to enhance full pod development, better than at UL-Farm and Ga-Thaba. Results indicated pod length to be longest with mixed intercropping. This was due to the fact that plant population in mixed intercropping was not optimal.

The results of the study indicated that the number of pods per plant did not vary among varieties, thus indicating that their genetic potential for podding was similar. Results indicated that the number of pods per plant was highest with mixed intercropping. This was due to the fact that plant population in mixed intercropping was not optimal.

Our study also revealed that location influenced the number of pods per plant, based on whether rainfall and/or temperature was adequate during the crop's reproductive phase. Ga-Thaba provided such adequacy during the crop's reproductive phase. Hence, more pods were recorded in cowpea varieties planted at Ga-Thaba. Previous reports (Addo-Quaye et al., 2011; Suliman, 2007) showed that the number of pods per plant reduced with increasing moisture stress.

The results showed that seed size varied among varieties, thus indicating genetic variation among them. IT86D-1010 and IT87K-499-35 produced the largest seed size across the cropping systems. The results of the current study are in accordance with previous findings by Kamai et al. (2014), who reported that significant genetic variation exists among cowpea varieties in 100 seed weight. Drabo et al. (1984) also reported that seed size in cowpea is highly heritable, but they also indicated that the environment could modify seed size. This report is in conformity with the findings of our study that 100 seed weight varied across the three locations. In this study, we found that seed size was affected by location and cropping system. The interaction revealed that seed size was higher at Ga-Thaba and in mixed intercropping.

Similar to the results of the number of pods per plant, seed size was largest in mixed intercropping. This was probably due to the fact that plant population in mixed intercropping was not optimal. Our study therefore found that farmers have the opportunity to make a choice according to their preferences for seed size. Large cowpea seeds are usually preferred to small-sized seeds because they cook faster.

The results on grain yield showed that variation of the varieties in grain yield was due to genetic variation, thus giving farmers the opportunity to make a selection. In our findings, varieties IT97K-449-35, IT86D-1010 and IT82E-16 performed better than Glenda, indicating their adaptation in the three locations. Cowpea yield is the result of many interacting components, such as number of pods per plant, pod length, number of seeds per pod and mean seed weight. Among the locations, Ga-Thaba produced the highest yield, indicating that the weather there better supported plant growth and development than at UL-Farm and Bela-Bela. Monocropping produced more grain yield, thus indicating that the varieties were bred for monocropping. The IITA (1993) reported that cowpea breeding lines destined for intercropping systems should be selected and advanced under intercropping systems for better performance. Similar reports were obtained from Dahmardeh et al. (2010), who reported higher grain yields under sole cowpea planting as opposed to intercropping. Competition for water, nutrients and shade are probably the three factors that could reduce cowpea yield under the high density of maize plants in intercropping.

The results of our findings indicated that maize yield attributes (number of days to tasselling, plant height, number of cobs and cob length) were affected by cropping system and location, which, in turn, influenced the eventual grain yield. Our study indicated that the LER was higher at UL-Farm than at Ga-Thaba. The LER obtained in the strip intercropping plots was higher than that obtained from mixed intercropping. This indicated that strip cropping outperformed mixed intercropping on an area per area basis. This implies that productivity from strip intercropping was double that of mixed intercropping (the traditional cropping system).

The water use efficiency results indicated that IT97K-449-35, IT86D-1010 and IT82E-16 were more water use efficient than TVu 13464 and Glenda, indicating that, given a certain amount of rainfall consumed by the varieties, these varieties were able to produce a greater grain yield. This attribute makes the varieties more adaptable to environments with low rainfall. We also found that, based on the amount of rainfall received, the varieties were more water use efficient at Ga-Thaba than at UL-Farm. The WUE values obtained in this study fell within the expected range as reported by Wenhold et al. (2012), who reported that the WUE values of cowpea could vary from 1.0 to 6.0 kg ha mm^{-1}.

2.3.5 Conclusions

In drought-prone environments, such as those found in the study areas, the identification and selection of varieties that are resource-use efficient are critical for sustaining food security and nutrition in rural communities. This study has provided agronomic data for farmers to make an informed decision to select varieties that performed well under rainfed condition in rural communities. The findings of this study have shown that IT86D-1010, IT87K-499-35, IT82E-16 and TVu 13464 performed better than Glenda in terms of early maturity, grain yield and water use efficiency. Farmers were able to select these varieties as the preferred varieties in addition to their seed quality, size and colour. Therefore, they were recommended for cultivation in the study areas. The study also provided significant information and agronomic data, including the LER that suggests that strip intercropping was superior and performed better than traditional mixed intercropping. For the sustainability of cowpea production and cropping systems, the four varieties were recommended to farmers for adoption and cultivation in their demonstration plots.

2.3.6 References

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CHAPTER 3: INTRODUCTION AND PROMOTION OF PRODUCTION OF NEW HIGH-YIELDING, PEST-RESISTANT, WATER USE AND RESOURCE-EFFICIENT GRAIN LEGUMES: PIGEONPEA VARIETY VALIDATION TRIAL AND STRIP INTERCROPPING OF PIGEONPEA WITH MAIZE TRIAL PIGEONPEA VARIETY VALIDATION TRIAL

JAN Asiwe and KS Madimabe

3.1 INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is one of the most important grain legumes grown in over 82 countries across the globe. It ranks as the world's fifth-most important pulse crop. The crop is cultivated on an estimated 2.9 million hectares across the world, with an average of 684 kg/ha. The major pigeonpea-producing areas in the world are India, Eastern Africa, Central and South America, the Caribbean and the West Indies. Pigeonpea most probably originated in India from its progenitor, *C. cajanifolius,* and later spread to Africa and Australia. It has several economic uses in the form of feed, fuel, forage and green manure. It has the potential to produce a very high biomass and fix atmospheric nitrogen up to 40 kg/ha in a cropping season. It is a multi-purpose crop because it can extract phosphorus. It is used as a hedge and as a wind break.

The productivity of pigeonpea has not increased over the years, despite its importance in diverse cropping systems, low-input requirements, drought tolerance and availability of a large spectrum of variability. The availability of early-maturing cultivars has a profound effect on cropping systems in changing the existing production systems. Pigeonpea is increasingly being grown in marginal areas, where several abiotic and biotic stresses affect yield and production stability. Most pigeonpea cultivars grown in Limpopo are late-maturity types, which are not sustained with adequate rainfall. The majority of the cultivars grown do not even flower before the onset of frost or winter. These make the yield potential of those varieties unattainable. The introduction and subsequent evaluation of diverse germplasm, including early- and medium-maturity types, are critically important to sustainable food security in Limpopo.

This activity focused on the evaluation of genetic variation among pigeonpea lines introduced from ICRISAT in Kenya for the purpose of selecting candidates to participate in strip intercropping trials and also to validate their agronomic traits. Five early-maturing and high-yielding varieties were selected for this purpose.

Pigeonpea (*Cajanus cajan* (L.) Millsp.), also known as red gram, Congo pea, gungo pea and no-eye pea, occurs in several varieties (Saxena et al., 2002). It is a drought-tolerant crop and one of the most important legumes grown in the tropics and subtropics (Gwata and Siambi, 2009). As a rich source of protein for humans (Saxena et al., 2002), pigeonpea is mostly used in diets to supplement cereals that are protein deficient (Saxena et al., 2002). A hundred grams of dry seed contains 343 calories, and 21.70 g or 39% of the recommended daily value of protein (Saxena et al., 2002).

Pigeonpea seeds are made up of 85% cotyledons, 14% seed coat and about 1% embryo, and contain a variety of dietary nutrients (Ezeaku et al., 2016). Pigeonpea seeds have good amounts of dietary fibre, providing 15 g or 39% of fibre per 100 grams. Pigeonpea is highly nutritious and may contain 18-25% protein, 51-58% carbohydrates, and important minerals and vitamins (Odeny et al., 2007). Furthermore, its high nutritional value has made pigeonpea a reliable source of fodder (Saxena et al., 2002).

The plant is a short-lived perennial shrub. It grows to two to four metres in height, and its flowers are yellow or yellow and red (Valenzuela and Smith, 2002). Pigeonpea leaves consist of three leaflets and are dark green on the top and silvery underneath (Saxena et al., 2010). The pods are usually 5 to 9 cm long and 12 to 13 mm wide, containing four to five seeds (Valenzuela and Smith, 2002). The seeds can be a range of colours; some are light brown, but they can be cream, grey, purple or black, depending on the variety (Saxena et al., 2010). Pigeonpea is a drought-tolerant crop with large variation for days to maturity, ranging from extra short duration (90 days) to long duration (300 days) (Saxena et al*.,* 2010). Being a drought-tolerant crop makes it well adapted in areas where rainfall is low or erratic and where other crops do not perform well (Gwata and Siambi, 2009).

3.1.1 Importance of pigeonpea

Globally, pigeonpea is the fifth-most important pulse crop, which is mainly grown in developing countries (Saxena et al*.,* 2010). It is considered to be one of the most nutritious legumes with high levels of amino acids. It is mainly used to supplement food that contains high levels of carbohydrates such as maize, cassava and rice (Saxena et al., 2010). Because of the high protein levels (18-25% protein, 51-58% carbohydrate, and important minerals and vitamins) in the grain (Odeny et al., 2007), the legumes are a valuable source of affordable protein, particularly in rural smallholder communities that largely depend on cereal-based diets and face high risks of malnutrition (Gwata, 2010). Pigeonpea seeds are made up of 85% cotyledons, 14% seed coat and about 1% embryo, and contain a variety of dietary nutrients (Ezeaku et al., 2016). The cotyledons are rich in carbohydrates (66.7%), while a major proportion (about 50%) of the seed protein is in the embryo (Sarode et al., 2009). Dry pigeonpea leaves are used as fodder for livestock feeding (Mathews and Saxena, 2000). It can also be used as a shadow crop, windbreak, cover crop and green manure for vegetables, and even as a traditional medicine (Kooner and Cheema, 2010). The dry branches and stems serve as firewood and roofing (Mula and Saxena, 2010).

Like most members of the Fabaceae family (cowpea, soybean and groundnut), pigeonpea has root nodules and helps improve soil quality through biological nitrogen fixation (Rao and Mathuva, 2000; Abunyewa and Karbo, 2005). Therefore, pigeonpea is mainly cultivated in intercropping systems with maize, leading to the reduced need for commercial nitrogen fertilizers (Adu-Gyamfi et al*.,* 2007). Makelo (2011) stated that pigeonpea is also capable of bringing minerals from deeper soil horizons to the soil surface, and improving soil aeration. Pigeonpea has been found to be very useful in intercropping with cereal crops such as maize, as it can replenish nitrogen in the soil, being rich in nutrients, which helps to enrich the soil for increased productivity. This is particularly important for smallholder farmers who are subjected to erratic rainfall and poor soil fertility (Nndwambi, 2015). Pigeonpea can fix up to 235 kg of nitrogen per hectare (Peoples et al., 1995; Egbe, 2007; Njira et al*.,* 2012) and produces more nitrogen per unit area from plant biomass than many other legumes (Njira et al*.,* 2012). Cereal-legume intercropping is beneficial as legumes supply most of the nitrogen in the soil. Thus, atmospheric nitrogen fixation is achieved through a symbiotic relationship between the legume and specific rhizobium, thereby increasing the soil nitrogen available for the companion crop (Bambalele, 2016). Legume species commonly used for the provision of grain and green manure have the potential to fix between 100 and 300 kg of nitrogen per hectare from the atmosphere (Jerenyama et al*.,* 2000).

3.1.2 Types of pigeonpea

There are many varieties of pigeonpea around the world, from a tall tree-like species to smaller bushes and dwarf varieties (Saxena et al*.,* 2010). The different varieties also mature at different times (Saxena et al*.,* 2010). The duration of maturity is a very important factor that determines the adaptation of varieties to different agro-climatic areas and cropping systems (Mathews and Saxena, 2000).

Most smallholder farmers in South Africa grow local land races of pigeonpea (Kooner and Cheema, 2010). The land races are characterised by late maturity, inherently low grain yield and dark seeds (Gwata and Shimelis, 2013). Land races of pigeonpea have been associated with low yields in countries where they are grown (Khaki, 2014). The average yields of pigeonpea landraces are as low as 250 to 450 kg/ha, and some take time to mature (Khaki, 2014). The improved cultivars are introduced through breeding and fall into either short-duration, medium-duration or long-duration types (Gwata and Shimelis, 2013). This classification is based on duration to maturity (Mligo and Craufurd, 2005). The short-duration types require about 120 days to mature (Mligo and Craufurd, 2005). Therefore, they mature before the onset of drought conditions. These varieties are suitable for places that experience erratic or low rainfall, such as Limpopo. The adaptation of pigeonpea to semi-arid and arid regions and poor soils makes it a suitable crop to provide income and ensure food security in regions that are less suitable for many other crops (Khoury et al., 2015). Short-duration pigeonpea varieties usually escape drought and are less sensitive to photoperiod than traditional varieties with longer growth cycles (Silim et al., 2007). Medium-duration types require about 180 days to attain maturity, while long-duration types can require up to 240 days to mature fully and are sensitive to photoperiod (Gwata and Shimelis, 2013). Maturity duration is a very important factor that determines the adaptation of varieties to different agro-climatic areas and cropping systems (Matthews et al., 2001). Field duration of pigeonpea is controlled by temperature and sensitivity to photoperiod (Orr et al., 2013).

3.1.3 World pigeonpea production statistics

Pulses are of the greatest importance in the human diet (Sarika et al., 2013). Pigeonpea is one of the most protein-rich legumes of the semi-arid tropics. It is grown throughout the tropical and subtropical regions of the world (Sarika et al., 2013). After chickpea, pigeonpea is the second-most important pulse crop of India. It is well balanced nutritionally (Khaki, 2014). India is one of the major pigeonpea-producing countries with 63.74% of total global production, followed by Myanmar (18.98%), Malawi (6.07%), Tanzania (4.42%) and Uganda (1.98%) (Hardev, 2016). In India, pigeonpea occupies an area of 3.81 million hectares, with production and productivity of 3.07 million tons and 806 kg/ha, respectively (Hardev, 2016).

According to Odeny, cited by Nndwambi (2015), production in African countries contributes 9.3% of world production, which is very little compared to the 74% contribution from India alone. In South Africa, pigeonpea is not widely grown as a field crop. It is mainly planted in home gardens, particularly in Limpopo, Mpumalanga and KwaZulu-Natal (Nndwambi, 2015; Hluyako, 2015). However, pigeonpea can also serve as an important grain legume crop for human consumption that can be used in rural areas and can supplement the range of food crops available (Gwata and Siambi, 2009). Production areas in Limpopo are the Bohlabela and Mopani districts, while, in Mpumalanga, pigeonpea is grown in the the Gert Sibande, Enkangala and Ehlanzeni districts (Department of Agriculture, 2010).

3.2 MATERIALS AND METHODS

3.2.1 Description of the study area

The trial was conducted at U-Farm (23°53'9.6" S, 29°43'4.8" E) during the 2015/16 season. The soil at Syferkuil is sandy loam. The mean average summer day temperature at Syferkuil varies from 28 to 30 °C, and the area receives a mean annual rainfall that ranges from 400 to 600 mm.

3.2.2 Field layout and design

The experimental unit was ploughed and harrowed to ensure a good seed bed. Twenty-two pigeonpea germplasm lines, introduced from ICRISAT, Kenya, were planted for agronomic performance. The varieties consisted of 22 lines. (Photograph 3.1). The trials were laid in a randomised complete block design with three replications.

3.2.3 Agronomic practices

Pre- and post-emergence herbicides (Dual and Roundup) were applied two days after planting, and subsequent weed control was effected using Fusilade and Bentazone, which are selective herbicides for both grass and broad-leaf weed situations. All the herbicides were applied at 3 ℓ of the formulation per hectare except Dual, which was applied at 0.5 ℓ ha^{-1}. Insect pests, particularly blister beetle

(Photograph 3.2), defoliators and pod-sucking bugs, were controlled using Karate at the recommended application of 1 ℓ ha^{-1}. Overhead irrigation was provided for optimum growth conditions in order to have enough seed produced for multi-location trials.

3.2.4 Data collection

To characterise and identify promising lines for strip intercropping during crop growth, the following agronomic variables were collected: plant stand, plant height, number of days to 50% flowering, number of branches per plant, number of days to 75% maturity and number of pods per plant, as indicated by Singh and Oswalt (1992).

- Number of days to 50% flowering: This was determined by counting the number of days from planting to the date that 50% of the crop stands had flowered.
- Number of days to 90% maturity: This was determined by counting the number of days taken from planting to when 90% of the crop stand had reached physiological maturity. It was rated by field visual observations when 90% of the pods had changed colour from green to brown.
- Plant height (cm): Five plants at maturity were tagged randomly from middle rows for sampling. The height was measured using a measuring tape and recorded from five tagged plants.
- Number of primary branches: Five plants were tagged randomly from middle rows for sampling. The number of primary branches of the five tagged plants was counted and the mean number of primary branches was calculated.
- Number of pods per plant: Fully developed pods from five tagged plants were counted and the average was calculated.
- Grain yield: The grain yield was determined by harvesting two middle rows and threshing the grain manually to record grain yields per plot using electronic weighing balance. The net yield was converted to kg ha^{-1}. Several or repeated harvesting was done to recover as much seed as possible.


Photograph 3.1: A varietal evaluation trial of pigeonpea at flowering stage
Photograph 3.2: An infestation of blister beetles on the flowers

3.2.5 Data analysis

Data collected was analysed using the SAS procedure. Means that show signicant differences at a significant level of 0.05 were separated using the Duncan Multiple Range Test. The means were summarised and presented in tables and graphs.

3.3 RESULTS AND DISCUSSION

Table 3.1 shows the means of all the variables taken. Results show that significant differences ($P < 0.05$) were observed among the varieties for all the variables measured.

3.3.1 Number of days to first and 50% flowering

Significant variation existed among the varieties in the number of days to first flower and 50% flowering (Table 3.1, Figure 3.1 and Figure 3.2). Early flowering is an indication of the varieties that mature early and also that they are not photo sensitive. Varieties that flower very late are often affected by early frost incidence and are recommended for cultivation in frost-free localities in South Africa. Among the 22 varieties, nine varieties (ICEAP 00604, ICEAP 00612, ICEAP 00652-2, ICEAP 01101-1, ICEAP 01101-2, ICEAP 01106-1, ICEAP 01107-5, ICEAP 01107-6 and ICEAP 01107) flowered early with a range of between 89 and 95 days to attain 50% flowering.

Table 3.1: Means of variables taken from 22 selected early-maturity pigeonpea varieties

Variety	DFF	50% flowering	Plant height (cm)	Number of branches	Number of pods	Maturity	Grain yield kg/ha
ICEAP 00604	80.67	91.33	79.36	7.94	104.11	186[c]	2665
ICEAP 00612	80.67	95.67	76.13	5.67	167.28	195[abc]	1124
ICEAP 00652-2	78.67	89.00	81.87	6.39	87.75	198[ab]	1521
ICEAP 00654	89.67	113.67	65.43	7.06	148.67	-	4202
ICEAP 00659	99.70	117.67	56.58	10.39	249.39	-	5371
ICEAP 00660-3	92.00	120.33	71.08	6.89	180.92	192[abc]	1858
ICEAP 00661	88.00	110.33	59.97	8.00	224.17	186[c]	2196
ICEAP 01101-1	82.00	89.33	82.75	7.94	113.39	199[ab]	951
ICEAP 01101-2	80.00	93.33	76.56	6.72	151.94	193[abc]	2036
ICEAP 01106-1	83.00	92.00	84.80	6.28	109.28	202[ab]	1096
ICEAP 01107-5	82.67	91.67	76.30	7.22	175.44	193[abc]	1935
ICEAP 01107-6	81.00	93.00	81.58	5.67	100.00	187[c]	1880
ICEAP 01107-8	83.00	94.00	69.72	9.11	100.28	212[a]	1533
ICEAP 01117-9	84.33	115.00	62.02	6.45	129.78	-	3693
ICEAP 01125	100.30	119.33	61.28	9.06	215.05	192[abc]	2529
ICEAP 01126	103.00	126.67	61.78	8.39	145.09	-	5294
ICEAP 01129	93.70	119.67	70.42	7.56	143.00	-	3366
ICEAP 01130-3	95.70	115.67	63.00	8.95	147.50	-	3763
ICEAP 01133-1	87.00	114.67	61.64	9.61	232.28	-	4303
ICEAP 01284	82.33	96.00	77.89	6.89	76.72	180[c]	2467
ICPL 86012	83.00	91.00	78.13	5.17	127.17	188[abc]	1314
ICPL 87091	80.50	106.50	74.63	6.58	157.17	191[c]	3024
P-level	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.01**	**0.001**	**0.01**

Variation in number of days to 50% flowering was due to varietal characteristics. Khaki (2014) observed a similar outcome when reporting significant differences in pigeonpea due to varietal characteristics under different seasons. Deshmuk and Mate (2013) made a similar observation when reporting significant differences among pigeonpea due to genetic variability. Varieties that combine early maturity with high yield will be selected for the intercropping trial.

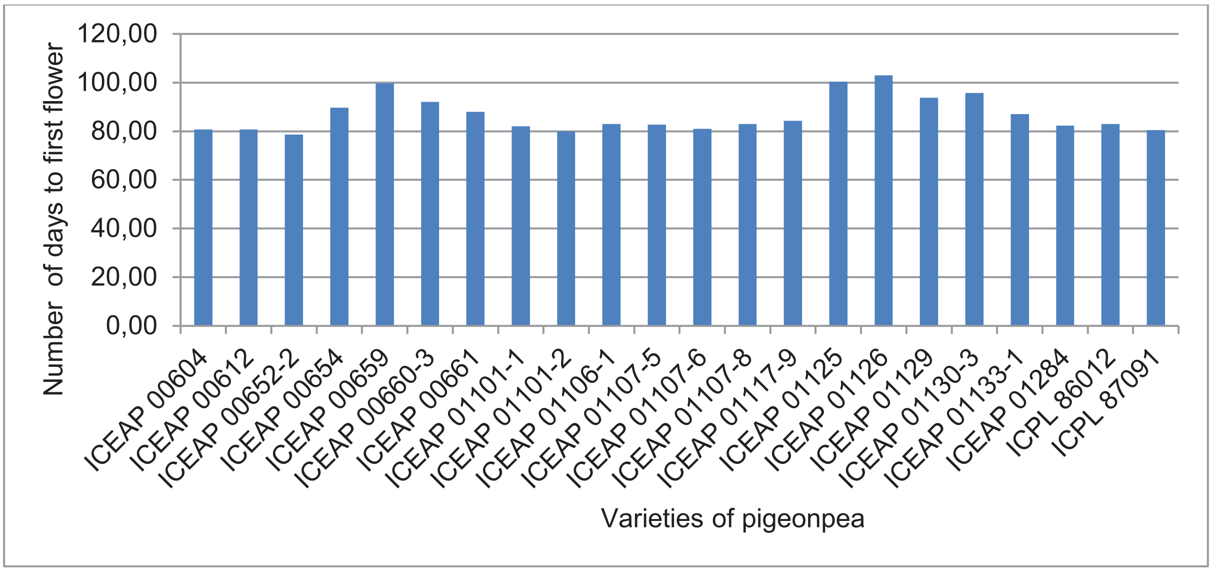

Figure 3.1: Number of days to first flower of 22 selected early-maturity pigeonpea varieties

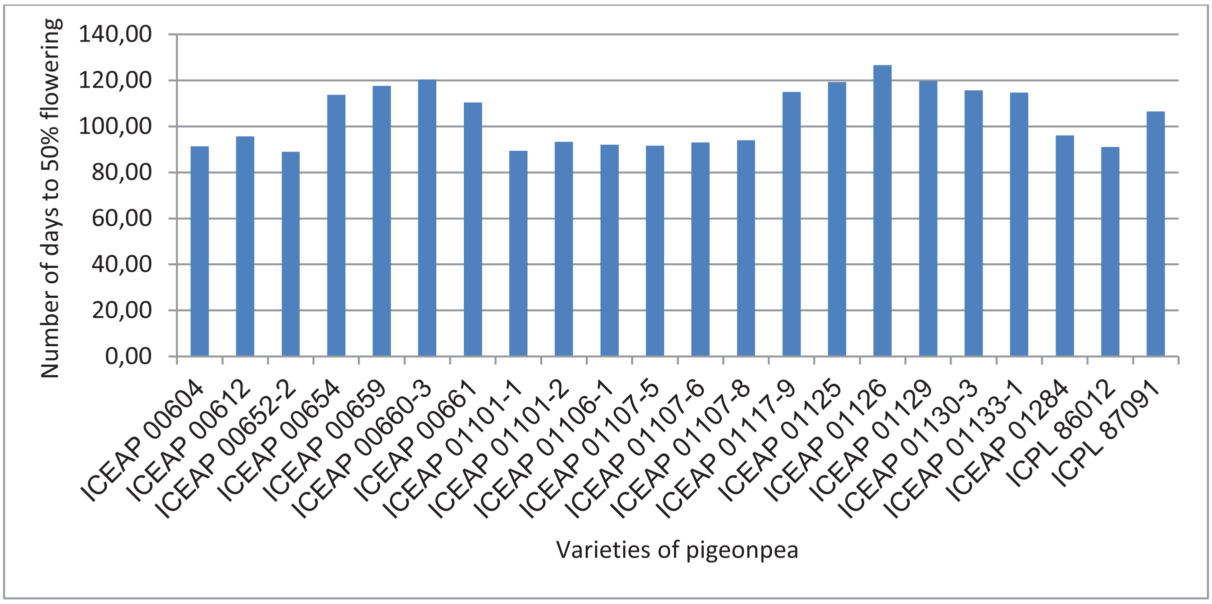

Figure 3.2: Number of days to 50% flowering of 22 selected early-maturity pigeonpea varieties

3.3.2 Plant height

Significant differences ($P < 0.05$) in plant height were observed among the varieties. Plant height ranged between 60 and 84.80 cm for ICEAP 00661 and ICEAP 01106-1, respectively (Table 3.1). The variation in height was due to the genetic make-up of the varieties. This observation is in line with the report of Reddy (1990), who observed that 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 explains that an increase in plant height is associated with longer days to flowering due to a prolonged vegetative phase, which is a response of the plant to photo sensitivity. Two pigeonpea plant types exist: determinate and indeterminate. Short-statured, determinate types cease to grow once they reach flowering, whereas vigorous, indeterminate types continue to grow even after flowering. Farmers in high-rainfall areas prefer the long-duration pigeonpea. However, their continuous flowering, followed by non-synchronous harvesting, poses a limitation on their use in mechanised commercial production. On the other hand, evasion of drought and ease in mechanical harvesting in short-duration determinate types are important agronomic traits that farmers in low-rainfall areas prefer over the long-duration determinate pigeonpea. Therefore, the short-duration pigeonpea varieties offer a promising trait to be exploited by farmers in Limpopo where rainfall is low and erratic.

3.3.3 Number of branches

Significant differences ($P < 0.05$) in number of branches per plant were observed among the varieties (Table 3.1). The number of branches varied from five to ten, obtained from ICPL 86012 and ICEAP 00659, respectively. The variation was due to the genetic make-up of the varieties. Varieties that exhibited less primary branches probably had a shorter vegetative period and were determinate pigeonpea types. An increase in the number of branches offers opportunities for peduncles, racemes or flowers and pods to be borne. This trait has a direct relationship with grain yield. According to Mwanamwenge et al. (1999), an increase in the number of primary branches, secondary branches, number of pods per plant and plant height would result in increased seed yield per plant. Rani and Reddy (1990) also reported that an increase in yield was attributed to more branches, the number of pods per plant and the Harvest Index. Santosh and Madrap (2007) reported that primary branches and 100 gram weight had a direct positive effect on seed yield. Hence, simultaneous selection based on these characteristics could lead to improved yield.

3.3.4 Number of days to 90% maturity

The analysis showed significant differences ($P \leq 0.05$) between pigeonpea varieties with respect to days to 90% physiological maturity (Table 3.1). Varieties (ICEAP 01284, ICEAP 00604, ICPL87091 and ICEAP 00661) exhibited the shortest number of days, 180, 186, 191 and 192, respectively, to 90% physiological maturity. These varieties, according to the classification of Gwata and Shimelis (2013), can be regarded as medium-duration pigeonpea types, while those that matured above 200 days can be regarded as late-maturity types in addition to those with missing values, which were damaged by frost. However, it is important to note that pigeonpea is a perennial crop by nature, and its maturity in any season can be influenced by the distribution of rainfall. In a season that is characterised by short rainfall duration, their maturity is shortened, while their maturity is lengthened during a season of prolonged rainfall, which causes continuous flowering and podding among the indeterminate types. In a season of good rainfall distribution, it offers the opportunity for multiple harvesting. Differences in 90% physiological maturity among varieties were due to varietal characteristics. This corroborates the finding of Deshmuk and Mate (2013), Ojwang (2015) and Silim et al. (2007), who reported that variation in the number of days to 90% physiological maturity among pigeonpea varieties was due to genetic make-up. Based on the maturity of pigeonpea varieties in this study, ICEAP 01284, ICEAP 00604, ICPL87091, ICEAP 00661 and ICEAP 00101-2 are promising varieties to be selected for the intercrop trial based on their number of days to maturity. These varieties will fit into the short-duration period of rainfed agriculture in Limpopo.

3.3.5 Number of pods per plant and grain yield

The number of pods, branches per plant, plant height and grain yield varied significantly ($P < 0.05$) among the varieties (Table 3.1). This indicates genotypic diversity among the population. Grain yield is a function of many plant attributes, including plant height and number of branches, as well as the number of pods produced per plant (Table 3.1, Figure 3.3).

The grain yield varies from 951 to 5,371 kg/ha, with ICEAP 00659 exhibiting the highest yield, while ICEAP 01101-1 had the poorest yield (951 kg/ha). Varieties that combine early maturity with high yield will be selected for the intercrop trial. Some of the high-yielding varieties (ICEAP 01126, ICEAP 01129, ICEAP 01130-3 and ICEAP 01133-1) exhibited indeterminate characteristics that caused them to mature very late. Such varieties are not suitable for cultivation in low rainfall regions and are vulnerable to damage by the early frost that usually occurs between May and June. According to Snapp et al. (2003), such varieties are suitable for cultivation in locations with medium altitudes (600 to 1,500 m above sea level) and rainfall of 400-1,500 mm over two seasons (Snapp et al., 2003). In this study, five promising varieties that combine early maturity with high yield include ICEAP 01284, ICEAP 00604, ICPL87091, ICEAP 00661 and ICEAP 00101-2.

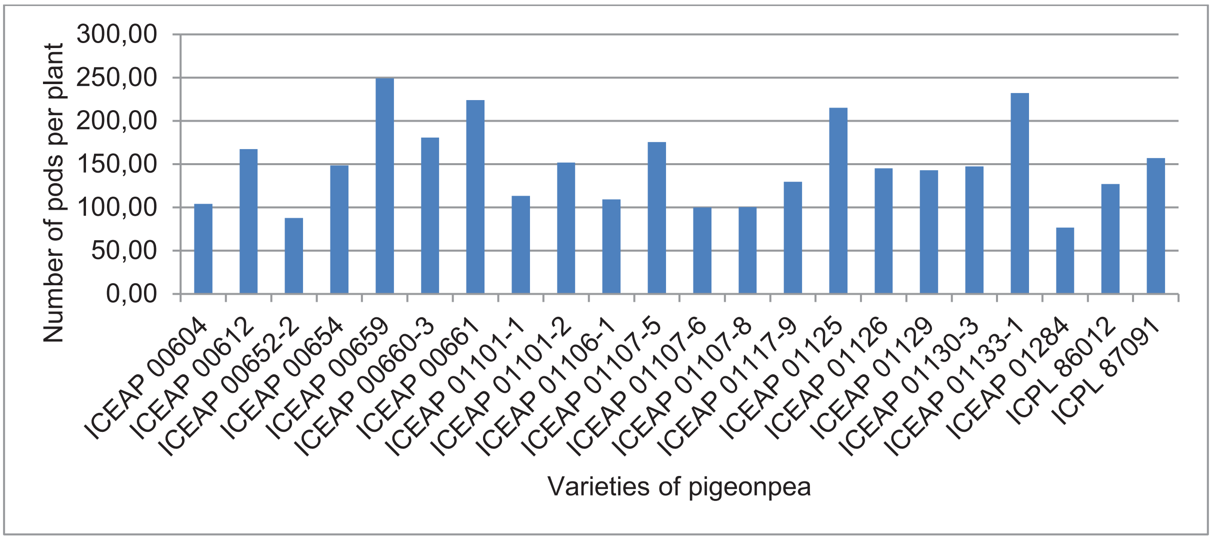

Figure 3.3: Number of pods per plant of 22 selected early-maturity pigeonpea varieties

3.3.6 Conclusion

In conclusion, the purpose of the trial was to generate baseline data to make an informed decision about the selection of varieties that will participate in the intercrop experiment scheduled for the next growing season. Varieties that combine early maturity and grain yield were selected. These varieties included ICEAP 01284, ICEAP 00604, ICPL87091, ICEAP 00661 and ICEAP 00101-2.

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3.4 STRIP INTERCROPPING OF PIGEONPEA WITH MAIZE

3.4.1 Introduction

Pigeonpea is one of the most important grain leguminous crops grown in the tropics and subtropics. It is believed to have originated from India (Saxena et al*.,* 2002). It is a multipurpose, drought-tolerant crop that produces seeds for human consumption as a source of protein and quality fodder for animal feed (Gwata and Siambi, 2009). Pigeonpea is cultivated as an important companion crop, because it fixes nitrogen and uses its deep root system to bring minerals up from horizons that are inaccessible by other crops (Kumar et al., 2011). Therefore, pigeonpea is commonly cultivated in intercropping systems with maize, leading to the reduced need for commercial nitrogen fertilizers (Adu-Gyamfi et al*.,* 2007). Pigeonpea seeds are made up of 85% cotyledons, 14% seed coat and about 1% embryo, and contain a variety of dietary nutrients (Ezeaku et al*.,* 2016). The cotyledons are rich in carbohydrates (66.7%), and about 50% of seed protein is located in the embryo (Sarode et al*.,* 2009). It is highly nutritious and may contain 18-25% protein, 51-58% carbohydrates, and important minerals and vitamins (Odeny et al., 2007). Besides its nutritional value, pigeonpea is also important to improve soil fertility through biological nitrogen fixation. Pigeonpea has the ability to fix up to 235 kg of nitrogen ha^{-1} (Egbe, 2007; Kumar et al., 2011; Njira et al*.,* 2012) and produces more nitrogen per unit area from plant biomass than many other legumes (Njira et al., 2012). Legume intercrops are a source of plant nitrogen through atmospheric fixation that can offer a practical complement to inorganic fertilizers (Jerenyama et al*.,* 2000; Adu-Gyamfi et al., 2007) and can reduce competition for nitrogen from cereals (Allen and Obura, 1983).

Maize (*Zea mays (L.*)) is the third-most important cereal crop in the world after wheat and rice. Maize grain is used for many purposes; for example, as a staple food for human beings, feed for livestock and as a raw material for many industrial products (Dahmardeh et al*.,* 2013). However, maize yields in Limpopo are in a decline due to continuous maize intercropping with legume crops, and risks from erratic and low rainfall (Makgoga, 2013). Therefore, the inclusion of pigeonpea in a cropping system will provide assurance against crop failure. The crop also has the potential to improve the livelihoods of farm households through increased protein in their diets.

The intercropping of legumes with cereals is an ancient practice and is important for the development of a sustainable food production system, particularly among smallholder farmers in South Africa (Thobatsi, 2009). Cereal-legume intercropping is commonly practised in South Africa, including in Limpopo, because of the yield advantage, greater stability and lower risks of crop failures that are often associated with monoculture (Sullivan, 2003). According to Nndwambi (2015), cereal-legume intercropping trials in South Africa have been reported by different authors. These include maize and pigeonpea (Mathews et al*.,* 2001), and maize and dry bean intercropping (Kutu et al., 2010). In Limpopo, mixed interplanting is a common intercropping practice, whereby legumes are planted together with cereals without any definite row arrangement. This practice does not optimise plant density, nor does it allow the efficient management of crops using modernised equipment. It hinders the application of farm inputs and is characterised by low yields (Belane et al., 2011). Strip intercropping is a novel practice and involves growing two or more crops together in strips wide enough to permit the separate management of the crops, but close enough for the crops to interact (Singh and Ajeigbe, 2007). This practice has great potential for reducing inter-species competition, allowing the individual management of intercrops and optimising plant density, thereby increasing yield per unit area. However, the performance of improved early to medium pigeonpea varieties from ICRISAT has not been studied in detail under a strip intercropping system with maize in Limpopo. This offers great potential for elite pigeonpea varieties introduced from ICRISAT to be tested under this cropping system. South Africa, particularly Limpopo, is a semi-arid region, characterised by marginal soil and low erratic rainfall distribution. This results in reduced crop yields (Mpandeli et al., 2015). Therefore, introducing improved early-maturing varieties of pigeonpea, which are drought tolerant, to smallholder farmers in an intercropping system will increase their productivity.

3.4.1.1 Types of pigeonpea

There are many varieties of pigeonpea around the world, from a tall tree-like species to smaller bushes and dwarf varieties (Saxena et al*.,* 2010). The different varieties also mature at different times (Saxena et al*.,* 2010). Maturity duration is a very important factor that determines the adaptation of varieties to different agro-climatic areas and cropping systems (Mathews and Saxena, 2000).

Most smallholder farmers in South Africa grow local land races of pigeonpea (Kooner and Cheema, 2010). The land races are characterised by late maturity, inherently low grain yield and dark seeds (Gwata and Shimelis, 2013). Land races of pigeonpea have been associated with low yields in countries where they are grown (Khaki, 2014). The average yields of pigeonpea land races are as low as 250 to 450 kg/ha, and some take too long to mature (Khaki, 2014). The improved cultivars are introduced through breeding and fall into either short-duration, medium-duration or long-duration types (Mligo and Crauford, 2005; Gwata and Shimelis, 2013). The short-duration types require about 120 days to mature (Mligo and Craufurd, 2005). Therefore, they mature before the onset of winter conditions. These pigeonpea types are suitable for regions that experience erratic or low rainfall, such as Limpopo. The adaptation of pigeonpea to semi-arid and arid regions, and poor soils makes it a suitable crop to provide an income and ensure food security in these regions, which are less suitable for many other crops (Khoury et al*.,* 2015). Silim et al. (2007) reported that short-duration pigeonpea varieties usually escape drought and are less sensitive to photoperiod than traditional varieties with longer growth cycles. Medium-duration types require about 180 days to attain maturity, while long-duration types can require up to 240 days to mature fully due to sensitivity to photoperiodism (Gwata and Shimelis, 2013).

3.4.1.2 World pigeonpea production statistics

Pulses are of the greatest importance in the human diet (Sarika et al., 2013). Pigeonpea is one of the most protein-rich legumes of the semi-arid tropics, and is grown throughout the tropical and subtropical regions of the world (Sarika et al., 2013). After chickpea, pigeonpea is the second-most important pulse crop of India, and it is well balanced nutritionally (Khaki*,* 2014).

India is one of the major pigeonpea-producing countries in the world with 63.74% of total global production, followed by Myanmar (18.98%), Malawi (6.07%), Tanzania (4.42%) and Uganda (1.98%)

(Hardev, 2016). In India, pigeonpea occupies an area of 3.81 million hectares, with production and productivity of 3.07 million tons and 806 kg/ha, respectively (Hardev, 2016).

According to Odeny, cited by Nndwambi (2015), production in African countries contributes 9.3% of the world pigeonpea production, which is very little compared to the 74% contribution from India alone. In South Africa, pigeonpea is not widely grown as a field crop, but is mainly planted in home gardens, particularly in Limpopo, Mpumalanga and KwaZulu-Natal (Nndwambi, 2015; Hluyako, 2015). However, pigeonpea can also serve as an important grain legume crop for human consumption, which can be used in rural areas to supplement the range of food crops available (Gwata and Siambi, 2009). Production areas in Limpopo are the Bohlabela and Mopani districts, while, in Mpumalanga, pigeonpea is grown in the Gert Sibande, Enkangala and Ehlanzeni districts (Department of Agriculture, 2010).

3.4.1.3 Background of maize

Maize (*Zea mays* (L.)), also called corn, belongs to the family Gramineae (grass family) and originated from Mexico. Its production quickly spread around the world (Kgonyane et al., 2013). It is the third-most important cereal crop after wheat *(Triticum aestivum L.*) and rice *(Oryza sativa*) in the world and is used as a staple food for human beings, and feed for livestock and poultry (Thobatsi, 2009). Maize is the most important grain crop in South Africa, being both the major feed grain and the staple food of the majority of the South African population (Medupe, 2010). Maize contains about 72% starch and 10% protein (Kgonyane et al*.,* 2013).

3.4.1.4 Maize production in South Africa

Maize is a dominant crop in smallholder farming systems in South Africa and is produced throughout the country under diverse environments (Kgonyane et al., 2013). Generally, it is cultivated as a monocrop or intercrop with grain legumes such as cowpea, groundnut, Bambara groundnut and pigeonpea (Thobatsi, 2009). Despite the drought and erratic rainfall in South Africa, maize is still grown during the summer months, although there is significant yield variation (Medupe, 2010). Area under maize varies from year to year, depending on the weather and market conditions, but an average of approximately 10 to 12 million tons of maize on 2.5 to 2.75 million hectares of land is under production in South Africa annually (Syngentia, 2012). About 59% of maize produced in South Africa is white and the remaining 41% is yellow maize (DAFF, 2017). White maize is primarily used for human consumption, while yellow maize is mostly used for animal feed production (Department of Agriculture, 2010). According to DAFF (2017), the two main provinces in South Africa where white maize is grown are the Free State and North West, which produce about 78% of the country's white maize, and the Free State and Mpumalanga, which produce about 67% of the country's yellow maize. The Free State (44%), North West (19%), Mpumalanga (20%), Gauteng (5%) KwaZulu-Natal (4%), Northern Cape (4%), Limpopo (3%), Eastern Cape (1%) and Western Cape (0%) recorded production of maize in South Africa during the 2016/17 production season, contributing to the national total (DAFF, 2017).

3.4.1.5 Cropping systems

Cropping systems are defined as the pattern of crops taken up for a given piece of land or sequence in which the crops are cultivated on a piece of land over a fixed period, and their interaction with farm resources and other farm enterprises (Medupe, 2010).

The forms of cropping systems that are practised throughout the world are the result of variations in local climate, as well as the availability of moisture and nutrients in the soil (Medupe, 2010; Makgoga, 2013). Monocropping, intercropping and the mixed intercropping of legumes and cereals are dominant cropping systems that are practised by smallholder farmers in South Africa to increase crop diversity and intensification (Medupe, 2010).

Legumes are generally cheap sources of proteins, micronutrients, vitamins and minerals, and are good complements to starchy diets (Khan, 1987). Graecub et al. (2015); McDemott et al. (2015) and Shetty (2015) reported that one of the ways to enhance food and nutrition security is through crop diversity and productivity. Modi and Mabhaudhi (2017) are of the opinion that such an initiative should consider limitations posed by water scarcity, recognising the water-food-nutrition-health nexus. This includes the promotion of crops that are adapted to dry areas and are nutrient-rich, such as legumes (Chivenge et al., 2015).

3.4.1.6 Monocropping

Monocropping or single-cropping refers to growing only one crop on a piece of land year after year or the practice of growing only one crop on a piece of land annually (Medupe, 2010). Due to limited land availability in Limpopo (Ayisi and Mpangane, 2004), smallholder farmers are forced to practise intercropping. Examples of annual crops that are currently cultivated by smallholder farmers in Limpopo annually are maize and grain legumes. Grain legumes are grown on small portions of land on smallholder farms. Cultivating a single crop annually can lead to total crop failure, especially in an area associated with erratic seasonal rainfall distribution such as Limpopo (Makgoga, 2013). Makgoga (2013) reports that the practice of monoculture in dry areas could result in reduced yield due to the build-up of insect pests and diseases, particularly when a field is cropped annually. This offers the opportunity to include legumes in the cropping system through strip intercropping, which can reduce the risk of crop failure.

Reduced soil fertility has been reported as one of the major factors causing a decline in food production (Thobatsi, 2009). This has been caused by the continuous cultivation of cereals through monocropping. Medupe (2010) also reports that, in areas where monocropping is mainly practised by smallholder farmers, soil fertility and crop yields decline rapidly if nutrients are not supplemented. Therefore, the cultivation of a leguminous crop like pigeonpea using strip intercropping does not only improve the nutrient status of the soil, but also improves and sustains agricultural productivity.

Monocropping is characterised by high competition for growth factors such as water and nutrients (Thobatsi, 2009). Makgoga (2013) reports that deep-rooted legumes, such as pigeonpea, also take up nutrients from the deeper soil layers and reduce the competition for nutrient uptake with cereals, thus enhancing the absorption of nutrients by cereals in the top layers. Medupe (2010) further reports that cereal-legume intercropping uses water more efficiently than monoculture does through reduced soil surface evaporation, which results in less water competition, which is important under unfavourable water conditions. The advantages of practising monocropping include low labour requirements compared to intercropping, as with sole cropping, it is easier to plant and harvest single crops (Makgoga, 2013).

3.4.1.7 Mixed intercropping

Mixed intercropping is the cultivation of two or more crops simultaneously on the same field without a row arrangement (Singh and Ajeigbe, 2007). Due to limited land availability in Limpopo (Ayisi and Mpangane, 2004), smallholder farmers practise mixed intercropping. Examples of mixed annual crops that are grown in mixed intercropping by smallholder farmers in Limpopo are maize, cowpea, watermelon, groundnuts and squash.

Farmers broadcast seeds of these crops without row arrangement as it is an easy way of accomplishing planting with minimum labour and time. However, this practice does not optimise plant density, and limits the application of farm inputs, operations and the use of machinery. The practice is characterised by a reduction in the yield of the component crops, which may occur due to intense competition for growth factors such as light, water and nutrients (Bambalele, 2016).

Sullivan (2003) reported that labour requirements in the mixed intercropping system are higher than in sole cropping, as multiple crops are planted at the same time or shortly after one another, and are harvested at various times.

Therefore, the introduction of a new technique such as strip intercropping to smallholder farmers is an advantageous alternative compared to other intercropping arrangements, since it allows the efficient management of crops and use of modernised equipment (Sullivan, 2003).

3.4.1.8 Strip intercropping

This type of intercropping entails growing two or more crops together in strips wide enough to permit the separate management of crops, including the use of machinery, but close enough for the crops to interact agronomically (Sullivan, 2003).

3.4.1.9 Intercropping

Intercropping is the practice of growing two or more crops simultaneously in the same field at the same time (Sullivan, 2003). Cereal-legume intercropping is the most common intercropping system, which has been practised by smallholder farmers for decades (Dania et al*.,* 2014). In Mozambique, smallholder farmers usually intercrop maize with cowpea or pigeonpea (Rusinamhodzi et al*.,* 2012). Similarly, smallholder farmers generally intercrop maize with pigeonpea, cowpea, Bambara groundnut and dry beans in countries such as Kenya, Nigeria and South Africa (Dania et al*.,* 2014; Egbe and Adeyemo, 2006; Dahmardeh, 2013; Kutu et al., 2010).

The intercropping system is being practised in many areas of South Africa, but mainly in Limpopo (Thobatsi, 2009). Intercropping in Limpopo is practised on small farms in areas where land is limited, forcing smallholder farmers to produce different crops on the same piece of land (Nndwambi, 2015). Areas subjected to a lower or uneven distribution of rainfall force smallholder farmers to practise intercropping, since they try to maximise the use of water (Thobatsi, 2009).

Intercropping is superior compared to monoculture and mixed intercropping (Medupe, 2010). The advantages of intercropping over sole cropping and mixed intercropping are that competition for resources between species is less than within the same species (Egbe and Idoko, 2012; Thobatsi, 2009). The principal reason for smallholder farmers to practise intercropping is to increase profitability, create insurance against crop failure and minimise risk, enable plants of different heights, rooting depths and nutrient requirements to make better use of resources, soil conservation, as well as low fixed costs of land as a result of a second crop in the same field (Thobatsi, 2009; Egbe and Idoko, 2012; Dahmardeh, 2013; Nndwambi, 2015). Addo-Quaye et al*.* (2011) and Pathak and Singh (2006) also reported that one of the most important reasons for smallholder farmers to intercrop is to minimise the risk of total crop failure (if one crop of a mixture fails, the other component crop may still be harvested), and to harvest different products for a family's food and income. Furthermore, Makgoga (2013) reports that the advantages of intercropping include higher yields than sole crop yields. This is probably due to less intra-species competition, greater yield stability and more efficient use of environmental resources. Nndwambi (2015) also reports that intercropping maize and pigeonpea is a good option, since pigeonpea is drought tolerant, can fix nitrogen and uses its deep root system to bring up nutrients from horizons that are inaccessible by the component crop. Makgoga (2013) stated that cereal-legume intercropping systems reduced the number of nutrients taken from the soil compared to sole crops. Kariaga (2004) also reported that the intercropping of cereal with legumes is an excellent practice for reducing soil erosion and sustaining crop production.

The availability of moisture in the soil is one of the most crucial factors that determine the productivity of crops in the cropping system (Egbe and Idoko, 2012). Makgoga (2013) reports that an intercrop of two crop species such as legume and cereal uses water more efficiently than monoculture, especially if the component crops have different rooting patterns. Therefore, smallholder farmers who farm in regions with rainfall challenges, especially those in Limpopo, are encouraged to practise intercropping to maximise the use of water.

3.4.1.10 Benefit of pigeonpea in an intercropping system

Pigeonpea is one of the most widely adapted, stress tolerant, indigenous and nutritious grain legumes in the warm to hot regions of Africa (Gwata and Siambi, 2009). The benefit derived from legumes as part of intercropping has been attributed to nutrient contribution to the component crops, especially nitrogen. Zerihun (2016) reports that continuous maize monoculture is one of the major factors causing a decline in crop productivity. Therefore, inclusion of pigeonpea in an intercropping system plays a vital role in rehabilitating degraded and depleted soil due to its capacity to fix nitrogen, delivering a high biomass production, and high litterfall. Other advantages of pigeonpea include the opportunity to grow crops simultaneously without causing land degradation or higher water infiltration because of its rooting pattern (Zerihun et al., 2016). Intercropping systems involving pigeonpea and annual crops such as maize significantly improve yields and contribute to poverty alleviation among smallholder farmers (Adjei-Nsiah, 2012).

Makgoba (2013) reports that intercrops with different rooting systems and nutrient uptake patterns result in a more efficient use of nutrients, mainly nitrogen uptake. For this reason, pigeonpea in an intercropping system takes up nutrients from the deeper soil layer to be utilised by the component crop due to its deeper rooting system. Pigeonpea in intercropping minimises the risk of crop failure due to its ability to produce grain under harsh environments imposed by drought and erratic or uneven rainfall distribution (Gwata and Siambi, 2009). According to Bambalele (2016), pigeonpea has an extensive root system, which enables it to be more compatible when intercropped with cereals or any other crops.

3.4.1.11 Pigeonpea-maize intercropping system

The cultivation of a leguminous crop in intercropping with a cereal crop has been recognised as one of the most effective ways farmers can enhance crop productivity, as well as minimise the risk of crop failure (Egbe and Idoko, 2012). Pigeonpea is becoming increasingly important in smallholder farming systems in Eastern and Southern Africa due to its ability to produce high grain yields despite uneven rainfall, high temperatures or infertile soil (Gwata and Siambi, 2009). The study of Egbe and Idoko (2012) reveals that the yield of pigeonpea genotypes varied with the cropping systems adopted. Their results further indicate that pigeonpea genotypes show significant differences under intercropping compared to sole cropping in the pigeonpea-maize system (Egbe and Idoko, 2012). A study conducted in Tanzania and Malawi showed mean grain yields of pigeonpea ranging from 172 to 740 kg ha^{-1} across several environments (Høgh-Jensen et al., 2007). Dwivedi et al. (2015) report that intercropping gave higher pigeonpea equivalent yields than the sole crop, whereby the highest pigeonpea equivalent yield (2 t/ha) and LER (1.89) was recorded.

The study by Mashingaidze et al. (2006) revealed that monocropping maize had significantly higher yields than intercropping maize. The result further indicated that the calculated total LER for the two crops gave positive values and values higher than 1, which suggested a favourable grain yield advantage for the maize-pigeonpea intercrop. Similar LER values greater than 1 in maize-pigeonpea intercropping were reported (Egbe and Adeyemo, 2006; Smith et al., 2001), which showed that strip intercropping has advantages over monocropping. Marer et al. (2007) also stated that large yield advantages in the intercropping system were due to component crops that differed in their use of natural resources. According to them, the utilisation of natural resources by an intercropping system is more efficient, resulting in higher yields per unit area than those produced by their sole crops.

3.4.1.12 Land Equivalent Ratio

One of the most important reasons for growing two or more crops simultaneously is to ensure that an increased and diverse productivity per unit area is obtained compared to sole cropping (Thobatsi, 2009). An assessment of return on land is made from the yield of pure stands and from each separate crop within the mixture.

The calculated figure is called the Land Equivalent Ratio. Intercrop yields are divided by the pure stand yields for each crop in the intercropping system and the two figures are summed (Sullivan, 2003). The LER is defined as the total land area required under monocropping to give the yields that are obtained under the intercropping mixture. It is normally used to analyse the possible advantages of intercropping (Mead and Willey, 1980). The LER is the most common index adopted in intercropping to measure land productivity, and is often used as an indicator to determine the efficacy of intercropping (Sullivan, 2003). Yield advantage in intercropping is attained through an improved LER, and is one of the key components in evaluating the effectiveness of the intercropping system (Hirpa, 2014).

The LER is determined according to the following formula (Mead and Willey, 1980):

LER (strip intercropping) = (intercrop yield of pigeonpea / monocrop yield of pigeonpea) + (intercrop yield of maize / monocrop yield of maize)

LER (mixed Intercropping) = (mixed intercrop yield of pigeonpea / monocrop yield of pigeonpea) + (mixed intercrop yield of maize / monocrop yield of maize)

An LER of less than 1 indicates lower productivity of intercropping relative to sole crops; an LER of 1 shows no yield difference between intercropping and sole crops; and an LER greater than 1 shows a yield advantage of intercropping compared to sole crops. Dahmardeh (2013) explains that the greater LER can be attributed to the morphological differences of the two crops. The optimal utilisation of resources supports this. According to Ullah et al. (2007), the total LER for yield ranged between 1.06 and 1.58, which showed both the yield and growth advantage of intercropping. Similar LER values greater than 1 in maize-pigeonpea intercropping were also reported (Egbe and Adeyemo, 2006; Smith et al*.,* 2001). According to Quiroz and Marin (2003), a maize-based intercropping system has a higher LER compared to sole cropping. Addo-Quaye et al. (2011) find that LER is greater than unity, implying that it will be more productive to intercrop maize-soybean than to grow the respective crops in monoculture. Better use of growth resources is believed to be a major source of yield advantage from intercropping because of the complementary effect between component crops (Willey, 2006). Addo-Quaye et al. (2011) find that the productivity of the intercropping system indicates a yield advantage of 2-63%, as depicted by the LER of 1.02 to 1.63, showing the efficient utilisation of land resources by growing the crops together.

3.5 MATERIALS AND METHODS

3.5.1 Site description

The experiments were conducted in three locations: UL-Farm (23°53’9.6” S, 29°43’4.8” E), which is researcher-managed, and Ga-Thaba (24°01’59” S, 29°47’56” E) and Bela-Bela (Towoomba research station 24°25’ S, 28°21’ E), which are farmer-managed, during the 2016/17 seasons. These sites were under different rainfall and temperature regimes.

3.5.2 Field layout and design

The experimental field was prepared using a tractor to plough and harrow it in order to ensure a good seed soil tilt. Five early- to medium-maturing varieties of pigeonpea, ICEAP 001284, ICEAP 00604, ICEAP 87091, ICEAP 00661 and ICEAP 01101-2, and a maize variety (PAN 6479) were planted in the field. The pigeonpea varieties were selected as promising early-maturing varieties from previous pigeonpea evaluation trials (Asiwe, 2016).

The planting was done at each of the three sites on 12, 13 and 15 December 2016, respectively. The trial was laid out in a split plot design. The main plot was planted according to cropping systems (intercropping and monocropping). The mono and mixed cropping systems were included as standard control practices.

The subplot was the variety that consisted of five pigeonpea varieties (ICEAP 001284, ICEAP 00604, ICEAP 87091, ICEAP 00661 and ICEAP 01101-2) in three replications. The maize cultivar was planted at an inter-row spacing of 0.9 m, an intra-row spacing of 0.3 m and a row length of 4 m. The intercrop consisted of four rows of pigeonpea sandwiched between three rows of maize. The monocrop consisted of seven rows of pigeonpea planted at an inter-row spacing of 0.75 m and an intra-row spacing of 0.5 m. The same plant arrangement and spacing were used in the three locations. The field plan is shown in Figure 3.4.

3.5.3 Agronomic practices

The land was prepared using a disc and harrow plough. A mixture of two herbicides, Roundup (with an active ingredient of Glyphosate, N-(phosphonomethyl) glycine, in the form of isopropylamine salt at the recommended rate (240 mℓ per 15 ℓ water = 3 ℓ per hectare) and Dual Gold (with an active ingredient of S-metolachlor (chloro-acetanilide) at a rate of 30 mℓ per 15 ℓ water = 0.5 ℓ per hectare), were applied using Knapsack to control weeds before planting. Weeds in the plots were subsequently controlled manually as and when necessary. Karate (lambda-cyhalothrin) was applied at a rate of 1 ℓ per hectare to control post-flowering insect pests.

R_1	R_2	R_3	R_4	R_5	R_6	R_7
O	O	O	O	O	O	O
O	O	O	O	O	O	O
O	O	O	O	O	O	O
O	O	O	O	O	O	O

R_1	R_2	R_3	R_4	R_5	R_6
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X

a. Monocropping showing six rows (6 x 0.9 cm) of maize (right) and seven rows (7 x 0.75 cm) of pigeonpea (left)

R_1	R_2	R_3	R_1	R_2	R_3	R_4	R_1	R2	R3
O	O	O	X	X	X	X	O	O	O
O	O	O	X	X	X	X	O	O	O
O	O	O	X	X	X	X	O	O	O
O	O	O	X	X	X	X	O	O	

b. Strip intercropping showing four rows (4 x 0.75 cm) of pigeonpea sandwiched between three rows of maize (1.8 m - 3 m - 1.8 m)

O	O	X	X	O	O	O	X
X	O	X	O	X	O	X	O
O	X	O	X	O	X	O	X
X	O	X	O	X	O	X	X
X	X	O	O	X	O	X	O

c. Mixed intercropping showing a mixture of maize and pigeonpea

Figure 3.4: Trial plan (monocropping, strip and mixed intercropping), where X = pigeonpea; O = maize; R = row

Photograph 3.3: Showing pigeonpea rows sandwiched by maize rows

3.5.4 Data collection

Sharma et al*.* (2010), Kumar et al*.* (2011) and Nndwambi (2015) list relevant variables measured when assessing the agronomic performance of pigeonpea under intercropping. The following parameters were measured in the same way in the two locations and seasons:

- **Number of days to 50% flowering:** This was determined by counting the number of days from planting to the date on which 50% of the plant population in each plot had flowered. It was rated by field visual observations when 50% of the plant population had flowered.
- **Number of days to 90% maturity:** This was determined by counting the number of days taken from planting to when 90% of the plant population in each plot had reached physiological maturity. It was rated by field visual observations when 90% of the pods had changed colour from green to brown or tan.
- **Plant height:** Five plants at maturity were tagged randomly from middle rows for sampling and their heights were measured using a measuring tape.
- **Number of primary branches:** The number of primary branches of the five tagged plants was counted and the mean number of primary branches was calculated.
- **Pod length and number of pods per plant:** Pod length was measured from five pods collected from each of five tagged plants. The average was then calculated. Fully developed pods from five tagged plants were counted and the average was calculated.
- **Number of seeds per pod:** Seeds from pods of five tagged plants were counted. This figure was then divided by the number of pods from those five plants.
- **Grain yield:** The grain yield was determined by harvesting pods from the two middle rows and threshing them manually to record grain yields per plot using an electronic weighing balance. The net yield was converted to kg ha^{-1} based on the proportion of area harvested per size of the plot.
- **Hundred seed weight:** Two samples of good 100 seeds were randomly counted and weighed in grams using a digital scale. Their average was computed to obtain the weight of 100 seeds.
- **Number of days to 50% tasselling:** This was determined from each plot by counting the number of days taken from the date of planting to the date on which 50% of the plant population had attained 50% tasselling.

- **Number of days to 50% silking:** This was determined from each plot by counting the number of days taken from the date of planting to the date on which 50% of the plant population had attained 50% silking.
- **Plant height and number of cobs per plant:** Five plants at maturity in the net plot were selected randomly and measured with a measuring tape and their height recorded. The average was then calculated. Five plants were tagged randomly from the middle rows of maize for sampling. Five cobs were taken from the sampled plants at maturity, and measured using a metre rule and the average was calculated.
- **Grain yield:** The grain yield was determined by harvesting two middle rows. The pods were threshed and weighed to record grain yield per plot based on the proportion of area harvested to the total area of the plot. This was then used to extrapolate the yield on a hectare basis.
- **Stover yield:** This was determined by harvesting stover from the two middle rows and weighing it to determine the yield per plot based on the proportion of area harvested to the total area of the plot. This was then used to extrapolate the yield on a hectare basis.

3.5.4.1 Land Equivalent Ratio

To assess intercrop productivity, the LER was calculated from the relative yield of pigeonpea and maize with their sole treatments by using the following formulae:

LER (strip intercropping) = (intercrop yield of pigeonpea / monocrop yield of pigeonpea) + (intercrop yield of maize / monocrop yield of maize)

LER (mixed intercropping) = (mixed intercrop yield of pigeonpea / monocrop yield of pigeonpea) + (mixed intercrop yield of maize / monocrop yield of maize)

An LER less than 1 indicates lower productivity of intercropping relative to sole crops. An LER of 1 shows no yield difference between intercropping and sole crops, and an LER greater than 1 shows the yield advantage of intercropping compared to sole crops.

3.5.4.2 Water use of pigeonpea

The water use efficiency was measured using the gravimetric method described by IAEA (2008). The water use efficiency of pigeonpea may vary from 0.6 to 2.0 kg ha mm^{-1} (FAO, 2011). The WUE values obtained among pigeonpea varieties in this study varied from 1.65 to 2.37 kg ha mm^{-1}, which compared favourably with results cited by Wenhold et al, (2012) that the water use efficiency of pigeonpea varied from 0.6 to 2.0 kg ha mm^{-1}. The soil samples were obtained using metal cylinders. Soil samples from soil depths of 15, 30, 45 and 60 cm were taken using a core sampler and collected in aluminium soil moisture boxes. These samples were weighed immediately and dried in an oven at 105 °C for 48 hours until a constant weight was obtained. The moisture content is expressed as a percentage. The moisture content in the soil was determined using the relationship below.

Mass basis water content (θ m, g g^{-1}) is θ m = (mass of water) / (mass of soil solids) = Mw/Md

Where, Md is the mass of the soil after drying, and Mw = Ms – Md, and where Ms is the mass of the soil immediately after it has been sampled.

3.5.4.3 Data analysis

Data for the agronomic characteristics obtained from the three locations was subjected to analysis of variance using Statistix 10.0 software to determine the performance of pigeonpea and maize under strip intercropping across the locations, and the interaction effects among the various factors (variety, cropping system and location). Means that showed significant differences were separated using LSD at the probability level of 5%. Interactions were presented in figures.

3.6 RESULTS

3.6.1 Number of days to 50% flowering

The number days to 50% flowering varied significantly ($P < 0.05$) among the varieties, locations and cropping systems (Table 3.2). The variety ICEAP 001284 flowered earliest (104 days), followed by ICEAP 00604, ICEAP 00661 and ICEAP 87091, which attained 50% flowering between 110 and 112 days and did not significantly differ from each other. Variety ICEAP 01101-2 was last to attain 50% flowering in 117 days (Table 3.3). Flowering was significantly earlier ($P < 0.05$) at Bela-Bela (103 days) than at Ga-Thaba and UL-Farm (114 days), which did not differ significantly from each other. The cropping system results show that strip intercropping flowered earlier than mixed intercropping, but this was not significantly different from the monocropping system (Table 3.2). Significant interactions were obtained between variety x cropping system (V*CS), variety x location (V*L), cropping system x location (CS*L) and variety x cropping system x location (V*CS*L) (Table 3.2, Figure 3.5 and Figure 3.6).

Table 3.2: Analysis of variance of pigeonpea growth and yield attributes at Ga-Thaba, Bela-Bela and UL-Farm

Parameters	**Variety**		**Cropping system**		**Location**		**V*CS**		**V*L**		**CS*L**		**V*CS*L**	
	F value	P value	F value	P value	F value	P value	F value	P value	F value	P value	F value	P value	F value	P value
50% flowering	47.00	0.0000	100.32	0.0000	490.80	0.0000	4.95	0.0017	6.68	0.0000	5.59	0.0007	2.62	0.0037
90% maturity	55.42	0.0000	273.98	0.0000	211.16	0.0000	21.44	0.0000	2.51	0.0203	18.75	0.0000	1.32	0.2150
Plant height	20.94	0.0003	14.96	0.0001	1.47	0.2391	1.59	0.1893	0.09	0.9995	2.34	0.0650	1.87	0.0417
Number of branches	3.00	0.0868	4.82	0.0196	20.33	0.0000	1.17	0.3648	0.66	0.7231	1.15	0.3406	0.87	0.6088
Pods per plant	7.25	0.0090	44.91	0.0000	57.86	0.0000	2.18	0.0756	0.90	0.5261	1.63	0.1789	0.41	0.9748
Pod length	1.01	0.4551	0.42	0.6600	708.76	0.0000	0.41	0.9043	0.67	0.7185	0.19	0.9425	1.02	0.4459
Seeds per pod	0.49	0.7450	2.95	0.0753	0.74	0.6602	1.09	0.3413	0.25	0.9790	0.77	0.5488	0.43	0.9673
Hundred seed weight	1.88	0.2072	3.10	0.0670	23.15	0.0000	0.66	0.7171	0.33	0.9499	0.21	0.9299	0.20	0.9996
Grain yield (kg/ha)	0.76	0.5817	66.02	0.0000	21.83	0.0000	0.71	0.6834	0.55	0.8115	1.37	0.2563	0.52	0.9258

Table 3.3: Means of pigeonpea growth and yield attributes taken from varieties, cropping systems and locations (Ga-Thaba, Bela-Bela and UL-Farm) during the 2016/17 growing season

Variety	50% flowering	90% maturity	Plant height (cm)	Number of branches	Number of pods per plant	Pod length (cm)	Number of seeds per pod	Hundred seed weight (g)	Grain yield (kg/ha)
ICEAP 00661	110.89b	197.48b	141.33b	7.33ab	109.48bc	6.00a	5.41a	13.43a	554.1b
ICEAP 87091	111.70b	194.00c	141.67b	7.60a	102.56c	5.70a	5.32a	13.45a	423.98c
ICEAP 01101-2	117.22a	202.52a	159.26a	7.78a	152.63a	5.89a	5.33a	13.67a	562.96b
ICEAP 00604	110.41b	190.70 d	140.78b	7.22ab	112.44 bc	5.92a	5.41a	13.12a	668.89a
ICEAP 001284	103.78c	183.07e	127.11c	6.67b	129.30ab	5.74a	5.60a	13.04a	591.64b
Grand mean	110.80	193.56	142.03	7.34	121.28	5.86	5.42	13.27	560.31
Cropping system									
Monocropping	107.96b	189.18b	138.11b	7.47a	122.18b	5.87a	5.31b	13.38ab	600.53b
Strip intercropping	106.76b	186.16c	150.31a	7.67a	149.33a	5.91a	5.67a	13.47a	797.63a
Mixed intercropping	117.56a	205.33a	137.67b	6.82b	92.33c	5.78a	5.29b	12.95b	422.78c
Location									
UL-Farm	114.76a	188.23b	140.06b	6.80b	98.71b	6.77a	5.46a	13.64a	713.19a
Ga-Thaba	114.54a	188.73b	140.96b	6.87b	120.71b	6.76a	5.36a	13.64a	571.96b
Bela-Bela	102.89b	203.20a	148.18a	8.22 a	166.42a	4.04a	5.56a	12.51b	335.79c

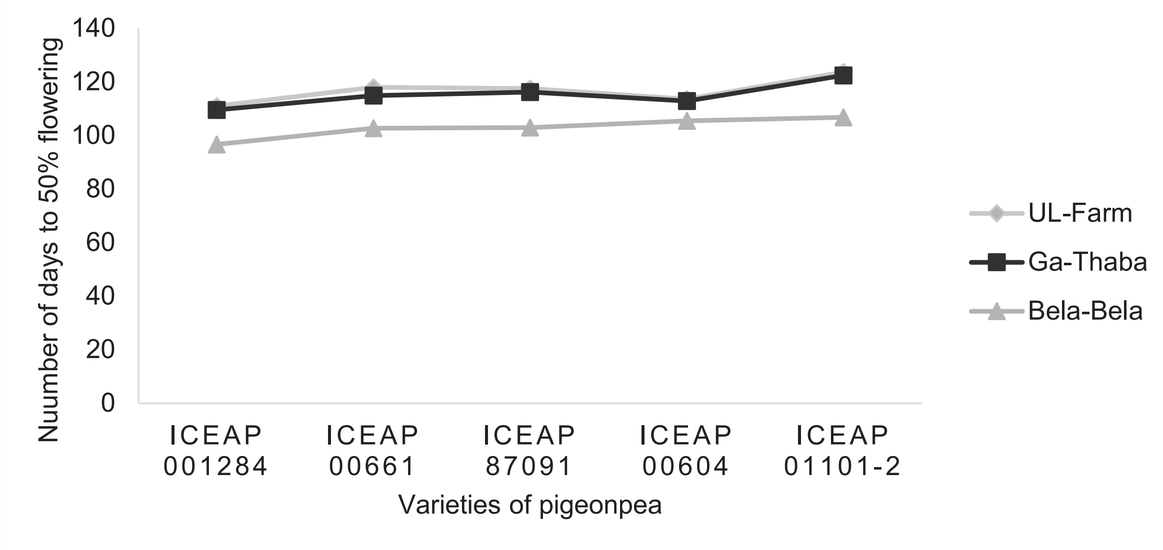

Figure 3.5: Interaction plot between variety and location in number of days to 50% during the 2016/2017 season

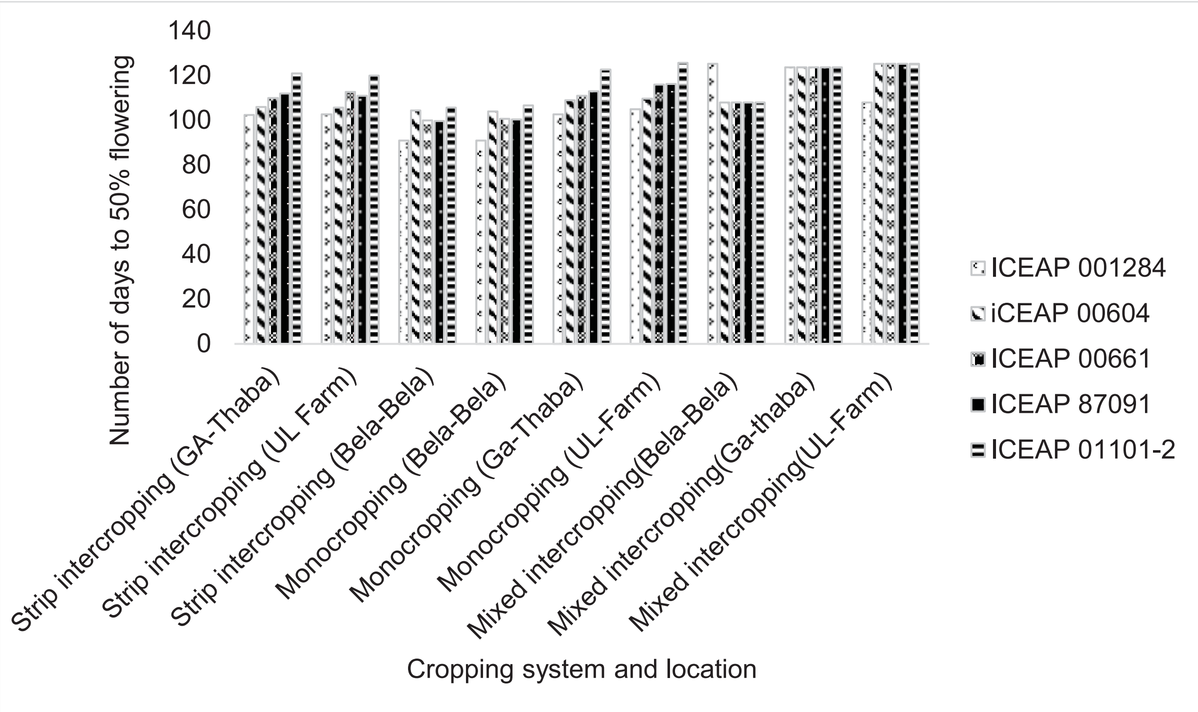

*Figure 3.6: Interaction plot between variety, cropping system and location (V*CS*L) in number of days to 50% flowering during the 2016/2017 season*

3.6.2 Number of days to 90% maturity

The number days to 90% maturity varied significantly ($P < 0.05$) among the varieties, locations and cropping systems (Table 3.2). Variety ICEAP 001284 matured earliest (183 days), followed by ICEAP 00604, ICEAP 87091, ICEAP 00661 and ICEAP 01101-2, which matured latest at 202 days (Table 3.3). Maturity was significantly earlier ($P < 0.05$) at Ga-Thaba and UL-Farm with an average of 189 days for varieties to attain maturity, while it was late (202 days) at Bela-Bela.

Cropping system results show that strip intercropping matured earlier (186 days) than monocropping (189 days) and mixed intercropping, which matured in 205 days (Table 3.3). Significant interactions (P ≤ 0.05) were obtained between V*CS, V*L and CS*L (Table 3.2, Figure 3.7 and Figure 3.8). The interaction results reveal that maturity was earlier among the varieties and cropping systems at UL-Farm than at Ga-Thaba and Bela-Bela (Figure 3.7 and Figure 3.8).

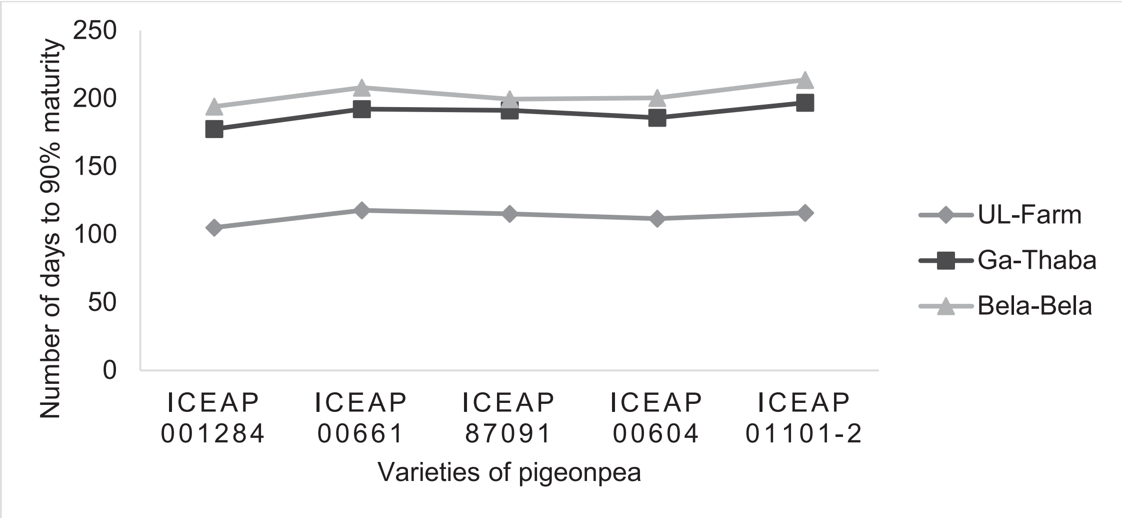

Figure 3.7: Interaction plot between variety and location in number of days to 90% maturity during the 2016/2017 season

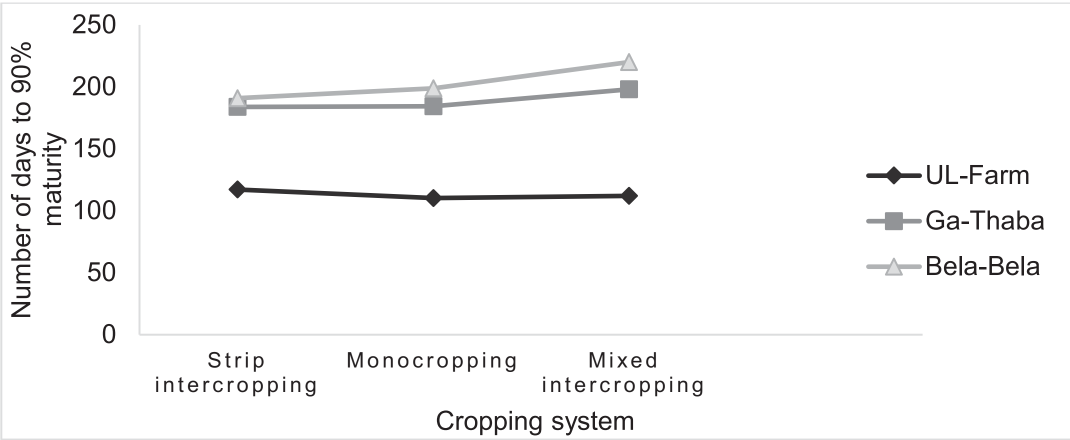

Figure 3.8: Interaction plot between cropping system and location in number of days to 90% maturity during the 2016/2017 season

3.6.3 Plant height

Plant height varied significantly (P < 0.05) among the varieties and cropping systems (Table 3.2). Variety ICEAP 001284 significantly exhibited the shortest height (127 cm), followed by ICEAP 00604, ICEAP 87091 and ICEAP 00661, with heights that varied between 141 and 142 cm, and ICEAP 01101-2, which produced the tallest plants (159 cm) (Table 3.3). Plant height was significantly higher (P < 0.05) at Bela-Bela (148 cm) than at Ga-Thaba and UL-Farm, with an average of 140 cm. The cropping system results show that plants were taller (150 cm) in strip intercropping than in monocropping and mixed intercropping, with plant heights of 138 cm (Table 3.3). Significant interaction (P ≤ 0.05) was only obtained between V*CS*L (Figure 3.9). The interaction results reveal that varieties were tallest in all the cropping systems at UL-Farm compared to those at Ga-Thaba and Bela-Bela (Figure 3.9).

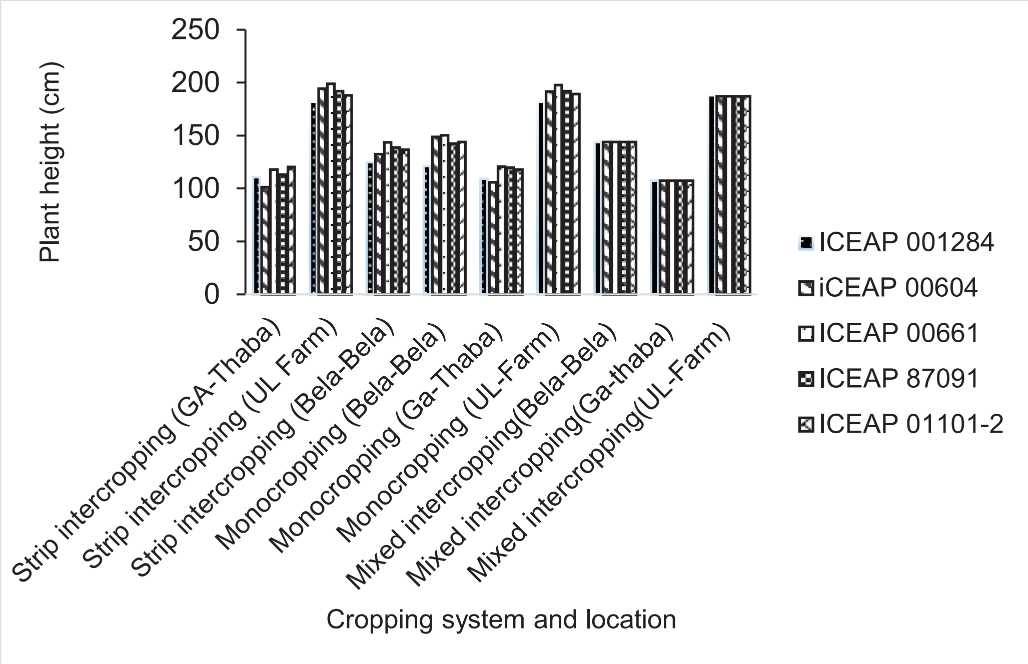

Figure 3.9: Interaction plot between variety, cropping system and location in plant height of five pigeonpea varieties during the 2016/2017 season

3.6.4 Number of primary branches

Results on the number of primary branches showed that significant differences ($P < 0.05$) were observed among variety, cropping system and location (Table 3.2). No significant interaction was obtained. Varieties ICEAP 87091 and ICEAP 01101-2 had more primary branches (eight branches), followed by ICEAP 00604 and ICEAP 00661, which did not differ significantly ($P < 0.05$) from each other. Variety ICEAP 001284 significantly exhibited the least primary branches with an average of 6.7. Bela-Bela generally had more primary branches (eight) than Ga-Thaba and UL-Farm, which had an average of seven branches. Mixed intercropping significantly ($P < 0.05$) exhibited the least primary branches (6.8) compared to strip intercropping and monocropping (Table 3.3).

3.6.5 Number of pods per plant

The number of pods per plant varied significantly ($P < 0.05$) among varieties, locations and cropping systems (Table 3.2). Variety ICEAP 01101-2 produced the most pods (153), followed by ICEAP 001284 with 129 pods, Variety ICEAP 87091 produced the least pods (102 pods). Bela-Bela significantly ($P < 0.05$) produced more pods (166) per plant than Ga-Thaba and UL-Farm, with pods varying from 99 to 121 (Table 3.3), which did not differ significantly from each other. Cropping system results show that strip intercropping produced more pods (149) than mixed intercropping (92), but did not differ significantly from monocropping with 122 pods (Table 3.3).

3.6.6 Pod length

Results reveal that no significant difference was obtained among varieties, cropping systems and locations, as well as among interactions (Table 3.2).

3.6.7 Number seeds per pod

Results reveal that no significant difference was obtained among varieties, cropping systems and locations, as well as among interactions (Table 3.2).

3.6.8 Hundred seed weight

The 100 seed weight only varied significantly among location. No significant difference was obtained among varieties, cropping systems and interactions (Table 3.2).

3.6.9 Grain yield

Results on grain yield show significant differences (P < 0.05) among five pigeonea varieties, cropping systems and location (Table 3.2). Among the five varieties, ICEAP 00604 produced the highest grain yield (669 kg ha^{-1}), followed by ICEAP 001284, ICEAP 01101-2, ICEAP 00661 and ICEAP 87091, which produced the lowest grain yield (424 kg ha^{-1}) (Table 3.2). The performance of the locations is in the following order: UL-Farm with 713.00 kg ha^{-1}, and Ga-Thaba and Bela-Bela with 571.00 kg ha^{-1} and 336.00 kg ha^{-1}, respectively. Strip intercropping (798 kg ha^{-1}) performed significantly better (P < 0.05) in the three locations than monocropping (601 kg ha^{-1}), while the lowest performance was exhibited by mixed intercropping with a mean yield of 423 kg ha^{-1}. No significant interaction (P < 0.05) was observed among the variables in grain yield (Table 3.2).

The maize variables, number of days to 50% tassling and silking exhibited significant differences (P < 0.05), except in terms of plant height, cob length, number of cobs per plant and grain yield (Table 3.4). Number of days to 50% tasselling was longer in mixed intercropping (73 days), while varieties grown according to monocropping and strip intercropping tasselled at 71 days after planting (Table 3.5). Number of days to 50% silking was longer in mixed intercropping (87 days), while varieties grown according to monocropping and strip intercropping tasselled an average of 83 days after planting. Number of days to 50% tassling and silking, plant height, cob length and number of cobs per plant, and grain yield showed significant differences (P < 0.05) in all locations. Number of days to 50% tasselling and silking was longest at Ga-Thaba (76 and 86 days, respectively) compared to UL-Farm and Bela-Bela (Table 3.5). Similarly, plant height, cob length and number of cobs per plant were higher at Ga-Thaba than at UL-Farm and Ga-Thaba. Interactions between CS x L for 50% silking, number of cobs per plant, plant height and cob length were significant (P < 0.05) (Table 3.4).

The LER results show that UL-Farm performed better than Ga-Thaba (Table 3.6 and Table 3.7). Under strip intercropping, the LER at UL-Farm varied from 1.98 to 2.40, with an average of 2.16, and was higher than the LER obtained for mixed intercropping, which varied from 0.12 to 0.54 with an average of 0.29 (Table 3.6). At Ga-Thaba, the LER for strip intercropping varied from 1.51 to 2.05 and from 0.22 to 0.76 for mixed intercropping (Table 3.7). The LER for Bela-Bela was not determined because of the exclusion of maize in the calculation due to severe damage by army worm, which resulted in total maize failure. The grand mean LER values for strip intercropping was twice that of mixed intercropping at both locations. This implies that strip intercropping can give double the crop yield compared to mixed intercropping under the same land area.

Table 3.4: Analysis of variance of maize growth and yield parameters taken from all locations (Ga-Thaba, Bela-Bela and UL-Farm)

Parameters	Cropping system		Location		CS*L	
	F-value	P-value	F-value	P-value	F-value	P-value
50% tasseling	4.72	0.0885	143.21	0.0000	1.44	0.2256
50% silking	28.31	0.0044	37.94	0.0000	8.13	0.0000
Plant height	0.91	0.4726	18.58	0.0000	19.90	0.0000
Cobs per plant	0.08	0.9221	12.37	0.0000	4.13	0.0036
Cob length	2.78	35.56	0.1753	0.0000	7.55	0.0000
Grain yield kg/ha						

Table 3.5: Means of maize growth and yield parameters taken from cropping systems and locations (Ga-Thaba, Bela-Bela and UL-Farm) during the 2016/17 growing season

Parameters	**50% tasseling**	**50% silking**	**Plant height (cm)**	**Cob length (cm)**	**Cobs per plant**	**Grain yield**
			Cropping system			
Monocropping	70.69a	83.84b	128.22a	12.91a	1.47a	
Strip intercropping	70.47ab	83.04b	131.02a	13.11a	1.53a	
Mixed intercropping	72.67b	86.89a	125.44 a	12.00 a	1.56a	
Grand mean	71.27	84.60	128.23	12.67	1.52	
			Location			
UL-Farm	71.64b	83.16b	125.02a	13.33a	1.31b	
Ga-Thaba	76.20a	86.09a	138.07b	13.87a	1.82a	
Bela-Bela	65.98 c	84.53c	121.60b	10.82b	1.42b	

Table 3.6: Partial and total LER for strip and mixed intercropping at UL-Farm during the 2016/17 seasons

	Strip intercropping			**Mixed intercropping**		
Crop mixture	LER $_{maize}$	LER $_{pigeonpea}$	LER$_{Total}$	LER $_{maize}$	LER $_{pigeonpea}$	LER$_{Total}$
ICEAP 001284 + maize	1.12	1.19	2.31	0.12	0.10	0.22
ICEAP 00604 + maize	1.30	1.10	2.40	0.19	0.15	0.34
ICEAP 00661 + maize	1.03	1.00	2.03	0.25	0.29	0.54
ICEAP 01101-2 + maize	0.86	1.12	1.98	0.08	0.04	0.12
ICEAP 87091 + maize	0.97	1.07	2.04	0.11	0.10	0.21
Mean	1.06^{a}	1.10^{a}	2.16^{a}	0.15^{a}	0.14^{a}	0.29^{a}
	0.2310	0.0451	0.0142	0.3452	0.1065	0.2867

Table 3.7: Partial and total LER for strip and mixed intercropping at Ga-Thaba during the 2016/17 seasons

			2016/17 season			
	Strip intercropping			**Mixed intercropping**		
Crop mixture	LER $_{maize}$	LER $_{pigeonpea}$	LER $_{Total}$	LER $_{maize}$	LER$_{pigeonpea}$	LER $_{Total}$
ICEAP 001284 + maize	0.73	1.02	1.75	0.23	0.20	0.43
ICEAP 00604 + maize	0.88	0.97	1.85	0.28	0.39	0.67
ICEAP 00661 + maize	0.86	0.78	1.64	0.13	0.09	0.22
ICEAP 01101-2 + maize	0.89	1.16	2.05	0.36	0.40	0.76
ICEAP 87091 + maize	0.79	0.72	1.51	0.14	0.18	0.32
Mean	0.83^{a}	0.93^{a}	1.76^{a}	0.23^{a}	0.25^{a}	0.48^{a}
	0.5674	0.8750	0.0462	0.0564	0.7801	0.6755

Table 3.8: Mean water use efficiency of pigeonpea varieties, cropping systems and locations (Ga-Thaba, Bela-Bela and UL-Farm) during the 2016/17 season

Variety	Water use efficiency
ICEAP 001284	2.16[b]
ICEAP 00604	1.84[c]
ICEAP 87091	1.65[d]
ICEAP 00661	1.85[c]
ICEAP 01101-2	2.37.[a]
P-level	<.0001
Grand mean	1.97
Cropping systems	
Monocropping	2.40b
Strip intercropping	2.93[a]
Mixed intercropping	0.60[c]
P-level	<.0001
Locations	
UL-Farm	4.64[a]
Ga-Thaba	1.43[a]
Bela-Bela	0.91[b]
P level	<.0001

3.6.10 Water-use efficiency of pigeonpea varieties

The water use efficiency results show that significant differences (P < 0-05) were obtained among varieties, locations and cropping systems (Table 3.8). Among varieties, ICEAP 01101-2 was the most water use efficient (2.37 kg ha mm^{-1}), followed by ICEAP 001284 (2.16 kg ha mm^{-1}) and ICEAP 00661 (1.85 kg ha mm^{-1}). The least water use efficient variety was ICEAP 87091 (1.65 kg/mm) after ICEAP 00604 with 1.84 kg/mm. Among the locations, UL-Farm was the most water use efficient, followed by Ga-Thaba and Bela-Bela with 4.64, 1.43 and 0.92 kg ha mm^{-1}, respectively. The strip intercropping system was more water use efficient than monocropping and mixed intercropping, with WUE values of 2.93, 2.40 and 0.60 kg ha mm^{-1}, respectively.

3.7 DISCUSSION

The findings of this study showed that pigeonpea varieties flowered and matured differently. Variety ICEAP 001284 matured early, while ICEAP 01101-2 matured late. The difference in their flowering and maturity habits was due to the genetic make-up of the varieties, which implied that farmers can make a selection among the varieties that will meet their needs in adapting to erratic rainfall conditions in their communities. The study also found that the five varieties could flower spontaneously with the problem of day-length sensitivity. Since day-length sensitivity is a limitation to pigeonpea production, the cultivation of varieties that can flower within the day-length of the location of the rural communities as obtained in this study would improve the productivity of farmers in Limpopo. Variety ICEAP 001284 matured early due to its short vegetative growth, while a taller variety like ICEAP 01101-2 matured late because of its indeterminate character. The findings of this study are in line with the report of Ojwang (2015), who reports that differences in the flowering and physiological maturity of pigeonpea genotypes were due to their genetic make-up.

The study also showed that varieties planted according to strip intercropping flowered earlier than those planted according to monocropping and mixed intercropping. The interactions observed in the study among the factors indicated that the flowering and maturity duration of the varieties was influenced differently by the factors cropping system and location. The variation in flowering and maturity among locations was due to variation associated with weather variables such as rainfall and temperature. Maturity was earlier at UL-Farm than at Ga-Thaba and Bela-Bela. Poor rainfall distribution during germination and seedling establishment at Ga-Thaba and Bela-Bela could have led to a ripple effect in the maturity of the varieties in those locations, despite the temperature being slightly higher.

Results of the study showed that plant height varied among the varieties, with ICEAP 001284 exhibiting the shortest height and ICEAP 01101-2 being the tallest. This indicated that genetic variation offers an opportunity for farmers to make their selection. Tall pigeonpea genotypes are indeterminate and usually mature late. They are good sources of firewood, stakes and fencing or hedging row material for farmers. Egbe and Vange (2008) and Hluyako (2015) report that plant height is known to be affected by maturity duration, genetic factors and the environment. The five pigeonpea varieties expressed different heights, which were due to their genetic make-up. The findings also showed that plant height was higher in strip intercropping than in mixed intercropping and monocropping, and was due to the better use of soil moisture, nutrients and other resources. Our study also showed that plants at UL-Farm were the highest, followed by Bela-Bela. The variation could be attributed to variation in rainfall distribution among the three locations.

Our study showed that the production of primary branches varied among varieties, and was due to variation in the varieties' genetic constitution. Since primary branches form the articulation points for bearing pod peduncles, the more branches there are, the greater the potential to bear pods. The findings of this report conform to that of previous reports (Mwanamwenge et al., 1999; Rani and Reddy, 2010) that reported that an increase in yield was attributed to a greater number of branches, number of pods and Harvest Index.

Results revealed that strip intercropping outperformed monocropping and mixed intercropping in the production of primary branches, thus indicating that strip intercropping was better in the efficient utilisation of soil moisture, nutrient and light to produce more branches. The results also showed that location affected the varieties to create variation in the production of primary branches. The variation could be attributed to the variation in rainfall distribution among the three locations.

The findings of the study showed that the number of pods per plant was higher in ICEAP 01101-2 and ICEAP 001284, which was the manifestation of their genetic potential and offers farmers the opportunity to make their choice in varietal selection. Farmers usually prefer varieties that can translate a copious flowering habit into the production of pods and grain yield. These findings agree with those of Cheboi et al. (2016), who record differences in the number of pods per plant due to genetic make-up. Podding in legumes is negatively affected by water stress. A reduced number of pods per plant under rain-stressed conditions (limited rainfall) was attributed to a sequence of events such as flower abortion during the main flowering period and pod abortion during a period of rapid development after flowering (Kamel and Abbas, 2012; Patel and Mehta, 2001). Similarly, low moisture content in the soil during drought affects the anthesis stage due to a lack of adequate water in plants, causing a drastic reduction in yield and yield components (Saleem et al., 2005). Our study also showed that the number of pods per plant was higher at Bela-Bela than at UL-Farm and Ga-Thaba. The variation observed among the locations could be attributed to variation in rainfall distribution among the three locations.

The grain yield results indicated that the varieties displayed genetic variation, which offered an opportunity for farmers to make their selections. Similar findings of previous studies (Sujatha and Babalad, 2018; Manivel et al., 2012) reveal that significant differences obtained from the grain yield of pigeonpea genotypes are due to their genetic make-up.

The data of the study indicated that ICEAP 00604, ICEAP 001284, ICEAP 01101-2 and ICEAP 00661 were the best yielders. It is important to state that varieties with the highest number of pods did not translate into being the highest yielders as it was observed that some pods were empty due to the high temperature during the fruit set stage. This must have reduced the observed yield of the varieties. Yield also varied among locations, with UL-Farm producing a higher yield than Ga-Thaba and Bela-Bela. Better management of trials could be responsible for the higher yield, since it was found on the researcher-managed station. Better rainfall distribution during the reproductive phase of the crop could also have contributed to better yield than at other locations.

The findings of this study showed that cropping systems significantly affected number of days to 50% tasselling and silking. Tasselling occurred earlier in strip intercropping than in mixed intercropping and monocropping. Tasselling occurred later at Ga-Thaba than the other two locations, probably due to poor distribution of rainfall during planting, which could have resulted in germination that was not uniform. Maize results from the study also indicated that the LER was higher with strip intercropping than with mixed intercropping at both Ga-Thaba and UL-Farm, thus indicating that farmers will get a greater yield and higher monetary values from the same piece of land under strip intercropping than under monocropping. The LER at UL-Farm was higher than at Ga-Thaba due to better management as it was researcher-managed. The LER at Bela-Bela was not computed because of the maize failure due to army worm damage.

The water use efficiency results indicated that ICEAP 01101-2, ICEAP 001284 and ICEAP 00661 were more water use efficient than ICEAP 00604 and ICEAP 87091, indicating that, given a certain amount of rainfall consumed by the varieties, they were able to utilise the available moisture to produce a greater grain yield. This attribute makes the varieties more adaptable to environments with a low rainfall. We also found that, based on the amount of rainfall received, the varieties were more water use efficient at UL-Farm, followed by Ga-Thaba and Bela-Bela. The water use efficiency at UL-Farm was higher than at Ga-Thaba and Bela-Bela, which were farmer-managed stations.

This was due to better management, which must have had a positive impact on grain yield at UL-Farm. The results also indicated that yields of plants under strip intercropping were four-fold higher than those under mixed intercropping. This also indicated that strip intercropping is superior to traditional mixed intercropping and is a better cropping practice. This information will give farmers the opportunity to make informed decisions in adopting a cropping system. The WUE values obtained in this study were comparable to those reported by Wenhold et al. (2012) and FAO (2011), which reported that the WUE values of pigeonpea could vary from 0.6 to 2.0 kg ha mm^{-1}.

3.8 CONCLUSIONS

The project was adapted to water-stress situations in selected rural communities by introducing a resource-use efficient crop such as pigeonpea and the strip intercropping practice. Such climate-smart varieties and practices are critical to sustaining food security and nutrition in rural communities. This study has provided significant agronomic data for farmers making an informed decision to select varieties that are promising under rainfed or water-stress conditions in their rural communities. The findings of this study have shown that ICEAP 01101-2, ICEAP 001284 and ICEAP 00661 performed very well in terms of early maturity, grain yield and water use efficiency. Farmers were able to identify these as preferred varieties, which could be recommended for cultivation in the study areas. The study also provided useful information and agronomic data, including the LER and WUE values that suggest that strip intercropping was superior and performed better than traditional mixed intercropping. For the sustainability of pigeonpea production and the cropping system, the three varieties were recommended for farmers to adopt and cultivate in their communities.

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CHAPTER 4: IMPROVEMENT OF NUTRITIONAL DIETARY INTAKE OF COMMUNITIES THROUGH THE INTRODUCTION OF COWPEA-BASED FOOD PRODUCTS (AKARA AND MOIN-MOIN) AND FORTIFICATION OF THEIR MAIZE SOLE DIETS WITH COWPEA PRODUCTS

JAN Asiwe and IB Oluwatayo

4.1 POST-PROJECT SURVEY

4.1.1 Introduction

The promotion of cereal production occasioned by the Green Revolution has brought stagnation in the production and utilisation of grain legumes (Pingali, 2012). However, Modi and Mabhaudhi (2017) report that the promotion and reinstatement of grain legumes is critical for the attainment of food crop diversity and nutrition in rural communities. According to them, this diversity will translate into food and nutrition security and improve the dietary intake of rural communities. Alleyne et al. (1977) reported that protein-energy malnutrition is a major concern in rural communities. Legumes are generally cheap sources of protein, micronutrients, vitamins and minerals, and are good complements to starchy diets (Khan, 1987). Graecub et al. (2015), McDemott et al. (2015) and Shetty (2015) report that one of the ways to enhance food and nutrition security is through crop diversity and productivity. Modi and Mabhaudhi (2017) maintain that such initiatives should consider the limitations posed by water scarcity, recognising the water-food-nutrition-health nexus. According to them, this includes the promotion of crops that are adapted to dry areas and are nutrient-rich, such as legumes (Chivenge et al*.,* 2015).

Given the above background, it is important to review the status of crop diversity available for the provision of good nutrition and dietary intakes of communities. In light of this, a post-project commencement scoping survey was conducted to determine the status of the cropping systems, crops grown, constraints to production and dietary intakes in communities at the initiation of this project. This was to ascertain whether there were potential gaps or needs that the current project would fill in the communities, and whether there was value in the project being conducted. In addition, the survey would determine whether there are changes stemming from the cultural practices of farmers compared to what Asiwe et al. (2009b) had reported before.

Table 4.1: Farmers' responses taken from a survey conducted at the end of the project

Respondents	Number of farmers	Implications
Biography		
All 50 (100%) farmers were above 35 years old.	50	Some of them were retirees, widows, parents and workers.
Cropping practices		
46 (92%) of the respondents practise strip intercropping.	50	Knowledgeable and have acquired skills about strip intercropping.
47 (94%) grow cowpea in rows and stands.	50	Independent and knowledgeable about growing cowpea and pigeonpea in rows. They have mastered the practice of planting in rows.
45 (90%) of the farmers plant manually without a tractor, but can plant using row strip intercropping even on small plots.	50	They are capable of marking their plots and plant in rows without the aid of a tractor.
Constraints		

Respondents	**Number of farmers**	**Implications**
All farmers (100%) indicated that drought poses a serious problem to production.	50	This implied that the crops they have adopted, which are water use efficient legumes, early-maturing and high-yielding, are appropriate to adapt to drought conditions in their communities.
45 (90%) of the farmers claimed that insect pest (aphids and weevils) constitutes one of the major constraints to production.	50	This implied that the crops they have adopted, which are water use efficient legumes, early-maturing, high-yielding and insect-resistant, are appropriate to meet their needs.
All 50 (100%) farmers claimed that grass and broadleaf weeds constitute great threats to production.	50	This implied that the adoption of efficient weed control practices and using selective herbicides will increase their productivity and make profits.
30 (60%) of the farmers indicated that the lack of storage facilities limited their production.	50	Farmers need siloes for storage.
All 50 (100%) of the respondents concurred that maize is a staple and is the most widely grown crop.	50	This implied that the crops (cowpea and pigeonpea) they have adopted are appropriate to meet their nutrient and crop diversification needs.
Utilisation and consumption of cowpea		
50 (100%) of the farmers stated that they produce legumes solely for consumption. 20 (40%) of the farmers indicated that they produce legumes for sale to generate a family income.	50	This implied that their production is still small scale and there is a high potential for scaling up through improved production practices and introducing high-yielding varieties. In addition, cowpea has a great potential of generating a family income.
All the farmers indicated high preferences for seed size (100%), seed colour (100%) and early maturity (100%).	50	This implied that the introduction and adoption of legume varieties with different morphological and seed attributes are important to meet their needs.
45 (90%) of the farmers indicated that they sell their produce at the local markets.	50	Improvement in yield recorded from the varieties introduced and adopted by the farmers have greater potential to be sold and increase marketability. This will, in turn, translate into better income for the farmers and their families.
All (100%) of the farmers affirmed that they consume cowpea in different preparations: soup, porridge, cowpea cake or Akara, Moin-moin or pudding and fortified or in combination with other cereals.	50	This implied that rural households can now eat a balanced, nutritious meal, fortified with cereals. This will enhance utilisation and production, and intensify demand and supply pull.
In responding to what constitutes their daily diets, all (100%) the farmers indicated that they now take cowpea meals fortified with carbohydrate as breakfast, lunch and dinner.	50	This implied that most of the farmers can now eat cowpea or pigeonpea meals, fortified with cereals to meet their daily nutritional requirements with enhanced diversity.

4.1.2 Materials and methods

To assess the impact of the project in terms of the transformation of farmers' cultural practices, the diversity of crops grown and their daily diet, and the daily diets of the farmers in the study areas (Ga-Thaba and Bela-Bela), structured interviews were conducted. This enabled the project team to evaluate the contributions and value addition to the livelihoods of the farmers in the study areas.

Fifty farmers were interviewed in both communities. Fifteen of these farmers came from Ga-Thaba and 35 came from Bela-Bela. The same structured questionnaire (Appendix 2) that was used for the pre-project commencement survey was administered to the farmers. Responses from the farmers were recorded and the implications of their responses were discussed and summarised in Table 4.1.

4.1.3 Results and discussion

Farmers' responses to cropping practices indicate that 69% of the respondents practise intercropping, while 9% practice sole cropping (Question 2). This indicates that farmers in Limpopo are familiar with intercropping, which might stir up the interest of the farmers to evaluate the potential gain of the new technique (strip intercropping) being introduced through this project. The survey on the cropping systems still indicates that the majority of local farmers, especially in the Ga-Malepo area, practise mixed intercropping, which is subject to farm size and the non-availability of a tractor. Few farmers who have tractors cultivate large hectrages of more than one hectare and can plant in row arrangements with a tractor or animal-driven implements, while farmers without tractors plant on small farms, and dominantly practise mixed intercropping with no definite row arrangement. Results also reveal that 67% of the participants grow crop mixtures, which may consist of cowpea in mixed stands with other legumes, vegetables and cereals (mostly maize) (Question 3). Maize is a staple food crop and is the most widely grown crop. This confirms that maize is a dominant crop in the communities and supplies carbohydrate-rich nutrients (Steyn et al*.,* 2015). Less than 5% of surveyed farmers own tractors or can hire tractors. This implies that the majority (88%) of the farmers plant without the use of a tractor and practise mixed intercropping (Question 6). This also indicates that the new techniques being introduced have great potential to improve the productivity of farmers who do not own or have access to tractors and who also possess small farms.

The survey on the constraints to production shows that insect pests (aphids and weevils) constitute one of the major constraints and limitations to production (Question 12). This implies that the introduction of aphid- and bruchid-resistant cowpea varieties have great potential to improve the yield and quality of seeds with concurrent reduction in pest control cost. Question 15 shows that 83% of participants indicated that drought is a serious production constraint to crop production in the selected communities. This implies that the introduction of early-maturing and resource-efficient cowpea and pigeonpea varieties have great potential in enhancing the productivity of the farmers in the drought-prone communities of Limpopo. Question 22, in addition to the focus group interviews, affirms that the majority of the participants (83-90%) rely on sole carbohydrates as their daily diet, with occasionally some vegetables added (depending on availability). This implies that the introduction of various protein-rich cowpea and pigeonpea crops and relevant recipes will improve their daily dietary intake. The summary of the survey information and its implications are shown in Table 4.1.

4.1.4 Conclusion

The implications drawn from the variables that the farmers responded to in the survey provided significant information to indicate that the project was appropriate to meet the needs of the farmers, filling the gaps identified at the commencement of the project. This implied that the project was successfully able to attain the stated objectives and added value to the livelihoods of the farmers in terms of crop diversification, food security and the dietary diversity of people in the study areas. The achieved outcomes or impacts are listed under the Innovation in Chapter 6.6.

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CHAPTER 5: IDENTIFICATION OF STAKEHOLDERS IN THE COWPEA VALUE CHAIN AND ENHANCEMENT OF HUMAN CAPITAL DEVELOPMENT THROUGH TRAINING AND A FARMERS' SCHOOL

IB Oluwatayo, SV Chauke and CM Masegela

5.1 ECONOMIC EFFICIENCY OF COWPEA PRODUCTION IN LIMPOPO

South Africa is characterised by a dual economy with a thriving commercial farming sector, as well as a smaller-scale communal farming sector located in the former homeland areas (Brand, 1969; Gerald, Ortmann and Robert, 2006). According to Statistics South Africa (StatsSA) (2017), the agricultural sector (including forestry and fisheries) grew by more than 22% and contributed a relative share to the total gross domestic product (GDP) of about 0.4% in the third quarter of 2017. South Africa is also classified as a semi-arid country with an annual average rainfall of 464 mm. Like all African countries, it is not immune to climate change and its effects.

The South African National Development Plan (NDP) acknowledges the agricultural sector as a sector to expand, with intensive, export-orientated industries particularly identified as key in creating jobs within the rural economy (BFAP, 2016). In 2015, South Africa experienced severe drought that resulted in a decrease in agricultural production levels where provinces such as KwaZulu-Natal, Eastern Cape and Limpopo experienced decreased maize production and a major loss of livestock. The recent severe drought also had long-term financial and debt implications for farm businesses.

The Bureau for Food and Agricultural Policy (BFAP)'s policy brief (BFAP, 2016) further revealed that poor rural households in South Africa continue to depend on household agricultural production and more than 1.2 million individuals were affected by the recent drought, which had a significant impact on maize yields, leading to food insecurity. Figure 5.1 indicates the effects of the 2015/16 drought through changes in the volumes of agricultural production in South Africa.

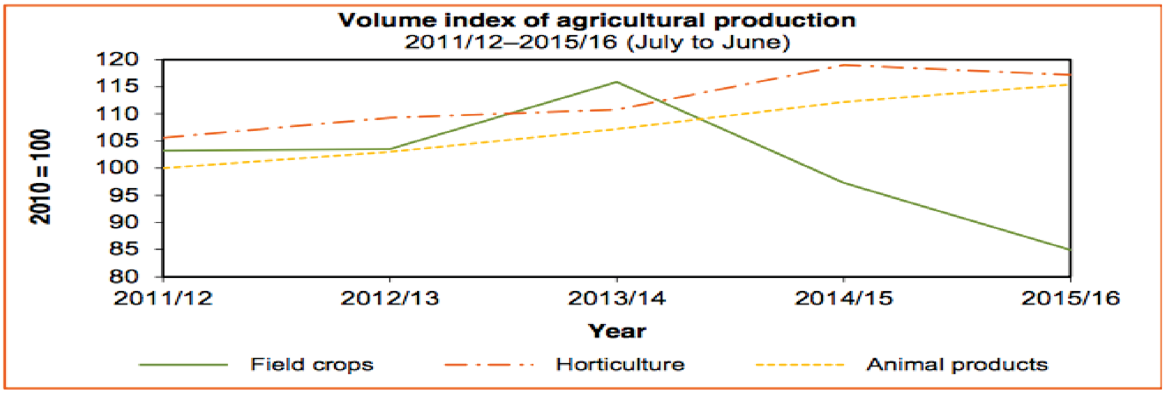

Figure 5.1: Volume index of agricultural production in South Africa

Source: DAFF (2016)

Figure 5.1 illustrates changes in the agricultural sector from the 2011/12 to 2015/16 production seasons in South Africa. Due to the effect of drought, field crop production yields decreased by 12.7% mainly due to a decrease in maize and sorghum yields. Maize production decreased by 2.9 million tons (27.6%) and sorghum by 36,800 tons (26.6%) from the previous season.

The drought experienced in South Africa in the 2015/16 production season resulted in a decrease in the yield of various crops and livestock. South Africa has previously been reported to be the net exporter of maize into most southern African countries, such as Botswana, Lesotho, Mozambique, Namibia and Swaziland. According to BFAP (2016), South Africa is an importer of maize (both white and yellow), and the country is expected to import 856,000 tons of white maize and 1.9 million tons of yellow maize that is estimated to cost R11.5 billion.

Maize imports (while and yellow) are estimated to increase to 1.2 and 2.2 million tons, respectively, and this increment will be at a cost of R14.5 billion by 2019. This calls for the promotion of the consumption of crops that are nutritious and can withstand drought, particularly legumes such as cowpeas and dry beans. Furthermore, the promotion of these crops will assist in terms of improving the farmers' income and reduce food insecurity, malnutrition and poverty.

The inefficient production in the agricultural sector comes as a result of climate change and other factors, such as the inability of farmers to fully utilise the available technologies, attributing to inefficiency of production. According to Harwood (1987), the efficient use of various inputs in any sector contributes to the sustainability of that sector. The ability to produce efficiently can decrease production costs and enhance cowpea yield, as well as improve the farmers' livelihoods through higher income earned from selling cowpea.

Cowpea in Limpopo is currently grown for home consumption with a small quantity being sold in the market. This is attributable to poor agronomic practices, lack of improved cowpea varieties and inadequate good-quality seeds (DAFF, 2011). The low importance placed on cowpea as an income-generating crop also has a negative impact on the production of cowpea in Limpopo. According to DAFF (2011), in South Africa, cowpea is produced in KwaZulu-Natal, Mpumalanga and Limpopo. The Capricorn and Waterberg districts of Limpopo are the main producers of cowpea in Limpopo.

Cowpea has been produced as an indigenous legume for several years in Africa, mainly for home consumption with a few farmers producing it for income generation. Smallholder cowpea farmers in Limpopo are faced with numerous challenges, such as the inability to produce cowpea in large enough quantities to sell to local or broader markets in South Africa. Additional challenges faced by farmers include plant diseases and pests, a lack of access to credit and information about financial assistance, a lack of or poor access to markets, as well as a lack of improved seed varieties.

In South Africa, the emphasis has been on field crops such as maize, dry beans, soybeans, wheat, sunflower and sorghum. There is not much documentation about the production of cowpeas or its introduction to households as a crop that can withstand drought and be used as a source of protein in Limpopo. Most of the studies done on arable crops focused on these crops, with very few studies on cowpeas. This has resulted in production inefficiency among smallholder cowpea farmers, especially with the rising cost of production. This study therefore examined the factors that influence and limit the production of this legume in the study area. From the foregoing, this study attempted to provide answers to the following research questions:

1. What are the socioeconomic characteristics of the smallholder cowpea farmers of the Capricorn and Waterberg districts?
2. What are the determinants of economic efficiency among smallholder cowpea farmers in the study area?

5.2 RATIONALE FOR THE STUDY

Legumes are crops that needs to be prioritised in African countries such as South Africa where there are more than 30 million people living in poverty (StatsSA, 2017). Legumes are crops that are rich in protein and can be acquired at lower costs. There is a need to create an awareness of the importance of these legumes as this will assist in ensuring that households reduce their dependence on animal protein to nourish their bodies. The consumption of cowpea also has the ability to reduce malnutrition and food insecurity in South Africa by providing protein, minerals and energy. It can also be a source of income for smallholder farmers.

Photograph 5.1: Matured cowpea pods

Source: Photograph taken by the author during the survey

Despite cowpea's contribution to the diet of rural families, its use as livestock feed and as a soil fertility enhancer, it is one of the neglected crops in South Africa (Asiwe, 2009). Producers of cowpea are faced with numerous challenges that result in low productivity. Based on the low production of cowpea in South Africa, and Limpopo in particular, there is a need to conduct studies that will provide information and alternative ways of producing this legume in larger quantities to address the persistent food insecurity in the study area.

The motivation for the study arises from the need to determine the current efficiency levels of cowpea producers in the study area and raise awareness of the ability of the crop to generate an income for smallholder farmers and its potential to reduce malnutrition and food insecurity. This study examined the factors that affect the efficiency of cowpea production. Based on the continuous effect of climate change on the agriculture sector, there is a need to alert smallholder farmers to the importance of prioritising cowpeas since maize, wheat and sorghum will not be able to sustain households in the near future.

There is an urgent need to provide information about planting techniques that can yield more cowpeas for famers to consume at household level and be able to sell at market level. These techniques include efficiently allocating resources to produce cowpea. Again, South African households need to be provided with alternative ways of cooking cowpea rather than boiling it, since poor cooking methods and meal preparations are also reasons that cowpea is not largely planted by South African farmers. This study will also serve as a tool for the government to address nutrition challenges in the country.

The study further revealed some of the main constraints to the economic efficiency of cowpea production. An increase in the efficiency of cowpea production could lead to an improvement in the welfare of farmers, their dietary intake and, consequently, a reduction in their poverty level and food insecurity. The profitability of cowpea enterprises could be a motivating factor for farmers to produce cowpea. Farmers are assumed to be rational and thus tend to make production decisions in favour of crops that will yield the most benefits, whether market or non-market.

5.3 AIM OF THE STUDY

The aim of this study was to examine the economic efficiency of cowpea production among smallholder farmers in the Capricorn and Waterberg districts of Limpopo.

5.3.1 Objectives of the study

- Identify and describe the socioeconomic characteristics of smallholder cowpea farmers in the Capricorn and Waterberg districts of Limpopo.
- Determine the efficiency levels of smallholder cowpea farmers in the study area.
- Examine determinants of economic efficiency among smallholder cowpea farmers in the Capricorn and Waterberg districts of Limpopo.

5.4 WHY COWPEA?

Cowpea, *Vigna unguiculata* (L.) Walp, is one of the most time-honoured crops known to man (Martin et al., 1967). The centre of its genesis is in West Africa (Ng and Padulosi, 1988). It is an essential legume and a useful component of the traditional cropping systems in the semi-arid tropics, including Asia, Africa, Central and South America (Mortimore et al., 1997; Singh et al., 2003). In Africa, the largest producer and consumer of the cowpea legume is Nigeria with around 5 million ha and over 2 million metric tons produced yearly, followed by Niger (with 650,000 metric tons), then Brazil (with 490,000 metric tons) (Singh et al., 2003).

The Consultative Group on International Agricultural Research (CGIAR) (CRP GL, 2012) revealed that the land that is under cowpea cultivation annually is around 14.5 million hectares worldwide, and in 2010, the production of cowpea globally stood at 5.5 million metric tons. A study conduted by Coulibaly and Lowenberg-DeBoer (2002) noted that the demand for cowpeas in West Africa has risen due to high population growth, poverty and demand for food that costs less.

5.4.1 Importance of cowpea

Developing countries are characterised by rapidly growing populations. This is followed by major crises such as food insecurity, malnutrition and poverty. These issues are in one way or another reduced by increasing food production, either from crops, legumes or livestock. Cowpea is one of the legumes that can reduce these challenges with the assistance of other crops, livestock and other agricultural produce. Cowpea is of great importance to the nourishment and livelihood of millions of people in the less-developed countries of the tropics (Singh et al., 2003). According to Odindo (2007), cowpea can play a significant role in food security initiatives aimed at addressing problems of food production in these regions.

Vigna unguiculata is a leafy crop that is drought tolerant due to its ability to withstand warm weather conditions. According to Manjula (2011), this legume is well adapted to areas that are drier and where other food legumes struggle to thrive. It develops well, even in poor soils, with more than 85% sand with less than 0.2% organic matter, and low amounts of phosphorus (Manjula, 2011). This legume has numerous benefits. It can be used as a livestock feed supplement during dry seasons, its young shoots and leaves can be consumed as leafy vegetables, it can be used as manure or as a cover crop and its dried seeds can even be used as a coffee substitute (Odindo, 2007).

5.5 MATERIALS AND METHODS

5.5.1 Description of the study area

The study was carried out in Limpopo, one of South Africa's nine provinces, located in the northern-most part of the country. This province was formerly known as the Northern Province and its capital city was named Pietersburg until 2003. The province's name has since been changed to Limpopo (Figure 5.2) and its capital city is now known as Polokwane. According to STATSA (2011), the land area of Limpopo amounts to 125,745 km^2, about 10.4% of the total land area of South Africa. It is the fifth-largest province in South Africa and had a population of 4,995 462 in 2011 (STATSA, 2011).

Limpopo comprises five districts: Capricorn, Mopani, Sekhukhune, Vhembe and Waterberg. This study only focused on two districts: Capricorn and Waterberg. These were selected based on the location of the WRC's bigger project. The climate of Limpopo is suitable for cowpea cultivation. According to DAFF (2011), the Waterberg and Capricorn districts are some of the main cowpea-producing areas of Limpopo. The study focused on Bela-Bela Municipality of the Waterberg District and Lepelle-Nkumpi Municipality of the Capricorn District.

Figure 5.2: Map showing Limpopo and its district municipalities

Source: Municipalities of South Africa (2015)

5.5.2 Capricorn District Municipality

The Capricorn district (Figure 5.3) consists of five municipalities: Aganang, Blouberg, Lepelle-Nkumpi, Molemole and Polokwane. The district covers up to 21,705 km^2 of Limpopo. The study focused on the Lepelle-Nkumpi Municipality. Agriculture is one of the most important driving forces of the district in terms of employment and food supply to households. The main economic sectors are manufacturing, community services, electricity, finance, trade, transport, construction and agriculture.

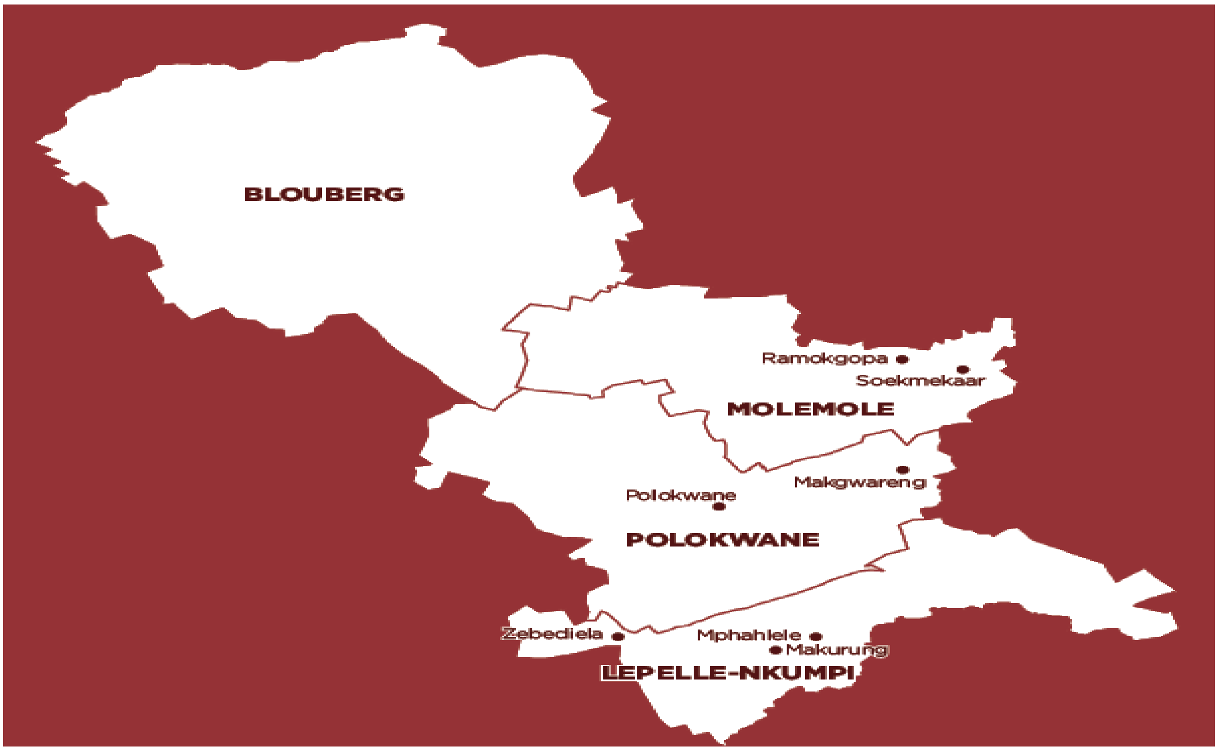

Figure 5.3: Map showing the Capricorn district municipalities

Source: Municipalities of South Africa (2015)

5.5.3 Waterberg District Municipality

The Waterberg District Municipality (Figure 5.4) comprises five local municipalities: Bela-Bela, Lephalale, Mogalakwena, Mookgophong and Thabazimbi. The total area covered by the district municipality is about 44,913 km^2. Bela-Bela is the local municipality that was surveyed. The main economic sectors in the district municipality are agriculture, tourism and mining.

Figure 5.4: Map showing the Waterberg District Municipality

Source: Municipalities of South Africa (2015)

5.5.4 Data collection and sampling procedure

Purposive sampling was used to select the study area. Cowpea farmers in both districts were selected as outlined in WRC Project R096. Primary data was collected through the administration of a structured questionnaire to representative farmers selected from the two districts based on probability proportionate to size. Data was collected on variables such as socioeconomic characteristics, production inputs and other production constraints. Sixty smallholder cowpea farmers were interviewed during the 2016/17 production season.

5.5.5 Analytical techniques

Purposive sampling was used to select the study area. Cowpea farmers in both districts were selected as outlined in WRC Project R096. Primary data was collected through the administration of a structured questionnaire to representative farmers selected from the two districts based on probability proportionate to size. Data was collected on variables such as socioeconomic characteristics, production inputs and other production constraints. Sixty smallholder cowpea farmers were interviewed during the 2016/17 production season.

5.5.5.1 Descriptive statistics

Descriptive statistics was employed in analysing and describing the socioeconomic characteristics of smallholder cowpea farmers. The results were expressed in the form of tables, frequencies, percentages, sums, averages and charts.

5.5.5.2 Data envelopment analysis

Background of the approach

Data envelopment analysis is known as a non-parametric, linear programming approach that is used to measure relative efficiency among a set of decision-making units. In this study, the decision-making units are cowpea farmers of the Capricorn and Waterberg districts of Limpopo.

The DEA approach was originally developed by Farrell (1957) and was advanced by Charnes et al. (1978) and modified by Banker et al. (1984). Farrell initiated the idea of comparative efficiency in which the efficiency of certain decision-making units may be compared with other decision-making units within a given group. The DEA approach is a mathematical method that measures the relative impacts of decision-making units, which are assumed to be uniform, by using the multiple inputs-outputs approach. The assumption of DEA consisted of constant returns to scale and variable returns to scale at optimal scale (Javed et al., 2010). Firms cannot operate at optimal scale when there are factors such as financing constraints, unequal competition or lack of access to equipment, education or other business constraints.

Classification of efficiencies

Farrell (1957) classified and identified the three different types of efficiencies: technical, allocative (price) and economic (overall) efficiency. He suggested that the efficiency of any given firm comprises its technical and allocative components. Charnes et al. (1978) defined DEA as the cornerstone for all successive developments in the non-parametric approach. According to Lubis et al. (2014), numerous methods that have been developed to estimate efficiency are classified as parametric and non-parametric approaches. The DEA approach is characterised as having various advantages, such as not requiring prior specification of functional form for the production frontier, its ability to handle multiple outputs and inputs, not entailing distributional assumptions of the inefficiency term, and having the ability to identify the best practice for every firm.

The ability of a firm to produce on the iso-quant frontier is associated with technical efficiency. Technical efficiency measures the ability of a firm to produce the highest possible output from a given bundle of inputs. Allocative efficiency refers to the ability of a firm to produce at a given level of output using the cost-minimising input ratios. Allocative efficiency is computed by the proportion of least production costs required by the decision-making unit to produce a given level of outputs and the actual costs of the decision-making unit adjusted for technical efficiency. Economic efficiency, also known as cost efficiency, is the product of both technical efficiency and allocative efficiency (Farrell, 1957), and is the combination of technical and allocative efficiency, which is described as the capability of a firm to produce a predetermined quantity of output at a minimum cost for a given level of technology. Economic efficiency is calculated by the ratio of least feasible costs and actual perceived costs for a decision-making unit.

5.5.5.3 Stochastic frontier approach, production and data envelopment analysis

Relative efficiency indices are estimated by the use of two approaches, including the parametric or stochastic frontier approach (SFA) and the non-parametric or DEA approach (Coelli,1995). The SFA assumes that there is a functional relationship between inputs and outputs. It uses statistical techniques to estimate parameters for the function, and allows hypothesis testing.

According to Chavas and Aliber (1993), the technical efficiency value, obtained through DEA, ranges between 0 and 1. When technical efficiency equals 1, the decision-making unit is said to be technically efficient. The input-oriented DEA was used in this case because the comparability of inputs in this study is higher than that of the output

5.5.5.4 Justification of approach selected

The two approaches differ because of the disadvantage of SFA of imposing specific assumptions on both the frontier-functional form and the disturbance term. On the contrary, the DEA uses linear programming methods to construct a hybrid frontier of data. The DEA approach is less sensitive to misspecification compared to SFA. Both methods seem to achieve relatively the same results, as most studies do not seem to lead to any conclusion on which method is superior to the other. This study opted to use DEA because it did not require or impose a priori parametric constraints on fundamental technologies.

5.5.5.5 The DEA model specification

This study only estimated the technical efficiency, allocative efficiency and economic efficiency scores for cowpea production in the Capricorn and Waterberg districts of Limpopo. The DEA-specified models for these efficiencies were as follows:

- *Technical efficiency*

$$(1) \qquad TE_n = \frac{min\ \theta_n}{\lambda_i\ \theta_n}$$

subject to:

$$\sum_{i=1}^{I} \lambda_i\, x_{ij} - \theta_n x_{nj} \leq 0$$

$$\sum_{i=1}^{I} \lambda_i\, y_{ik} - \theta_n x_{nk} \geq 0$$

$$\sum_{i=1}^{I} \lambda_i = 1$$

$$\lambda_i \geq 0$$

$Where\ i = One\ to\ I\ cowpea\ farmer$;

$J = one\ to\ J\ inputs$;

$k = one\ to\ K\ outputs$;

$\lambda = the\ negative\ weights\ for\ I\ cowpea\ farmer$;

$x_{ij} = the\ amount\ of\ input\ j\ used\ by\ cowpea\ farmer\ \ i$;

$x_{nj} = the\ amount\ of\ input\ j\ used\ by\ cowpea\ farmer\ n$;

$y_{ik} = the\ amount\ of\ output\ k\ produced\ by\ cowpea\ farmer\ \ i$;

$y_{nk} = the\ amount\ of\ output\ k\ produced\ by\ cowpea\ farmer\ n$; and

$\theta_n = a\ scalar\ \leq one\ that\ defines\ the\ TE\ of\ cowpea\ farmer\ n,$

$with\ a\ value\ of\ indicating\ a\ technically\ inefficient\ fcowpea\ farmer$

$with\ the\ level\ of\ technical\ inefficiency\ equal\ to\ 1 -\ TE_n.(Coelli, 1995)$

The constraint $\sum_{i=1}^{I} \lambda_i = 1$ in Equation (1) ensured that TE_n was computed under the variable returns to scale assumption (Coelli,1995).

- *Economic efficiency*

The economic efficiency score for a given cowpea farmer was given by first solving this cost-minimising linear programming model as follows:

(2) $$MC_n = min\ \lambda_i\, x^*{}_{ij} \sum_{J=1}^{J} P_{nj}\, x^*{}_{nj}$$

subject to:

$$\sum_{i=1}^{j} \lambda_i x_{ij} - x^*{}_{nj} \leq 0$$

$$\sum_{i=1}^{I} \lambda_i y_{ik} - y_{nk} \geq 0$$

$$\sum_{i=1}^{I} \lambda_i = 1$$

$$\lambda_i \geq 0$$

$Where\ MC_n = the\ minimum\ total\ cost\ incured\ by\ cowpea\ farmer\ \ n$;

$P_{nj} = price\ of\ inputs\ j\ purchased\ by\ cowpea\ farmer\ n$;

$x^*{}_{nj} = cost - minimising\ level\ of\ input\ j\ incured$

$by\ cowpea\ farmer\ n\ given\ its\ input\ price\ and\ output\ levels$

The constraint $\sum_{i=1}^{I} \lambda_i = 1$ in Equation (2) ensured that the minimum total costs incurred by cowpea farmers were computed under the variable returns to scale assumption (Fletscher and Zepeda, 2002). The economic efficiency was given by the following equation:

(3) $$EE_n = \frac{\sum_{J=1}^{J} P_{nj}\, x^*{}_{nj}}{\sum_{J=1}^{J} P_{nj}\, x_{nj}}$$

where, $\sum_{J=1}^{J} P_{nj}\, x^*{}_{nj} = the\ minimum\ total\ cost\ attained\ by\ cowpea\ farmer\ \ using\ eq\ (2)$

and $\sum_{J=1}^{J} P_{nj}\, x_{nj} = the\ actual\ total\ cost\ observed\ by\ cowpea\ farmer\ \ n.$

The EE_n that takes on a value of $\leq$ 1, with an $EE_n = 1$ indicated that the cowpea farmer was economically efficient.

$EE_n < 1$ indicated that the cowpea farmer was economically inefficient with the level of economic efficiency = $1 - EE_n$

According to Farrell (1957), the economic efficiency for a decision-making unit can also be expressed as the product of both technical efficiency and allocative efficiency ($EE_n = TE_n \times AE_n$).

- *Allocative efficiency*

(4) $$AE_n = \frac{EE_n}{TE_n}$$

where $AE_n\ is\ the\ allocative\ efficiency\ given\ by\ diving\ EE_n\ by\ TE_n$. *The* value for AE_n will be ≤ 1 with an AE_n = *1,* indicating that the cowpea farmer was allocatively efficient and an AE_n *<1* indicating that the cowpea farmer was allocatively inefficient with the level of allocative inefficient = $1 - AE_n$. The efficiency score computed using DEA is expressed as follows:

$y_i = 1\ \ if\ y_i^* \geq 1$

$y_i = y_i^*\ \ if\ 0\ \leq y_i^* \leq 1$

$y_i = 0\ \ if\ y_i^* \leq 0$

5.5.5.6 Tobit regression model

The Tobit regression or censored model was used to address the third objective of the study, which was to examine the factors influencing technical, allocative and economic efficiency among smallholder cowpea farmers in the study area. Tobit regression was first initiated by Tobin (1958). It involved a censored regression model of the economy and was first analysed in the econometric literature. As the efficiency index derived from DEA is bound between a value of 0 and 1, it is suitable for use as a simulation analysis to identify the determinants of technical efficiency among farmers. A two-limit Tobit model was used in this analysis because the scores were bound between 0 and 1 (Maddala, 1983).

Briefly, Tobit's regression can be written as follows:

$$y_i^* = \beta_0 + \sum_{m}^{M} \beta_m x_{im} + \varepsilon_i, \varepsilon_i \sim IN(0, \sigma^2)$$

where, y_i^* a latent variable symbolizing the efficiency score for the cowpea farmer i;

β_0 and β_m = unknown parametres to estimate;

x_{im} = 1 to M explanatory field specific variables (Tables 19 and 20) related with the cowpea farmer ;

ε_i = error term that is autonomously and normally distributed

with zero mean and constant varience σ^2.

Table 5.1: Description of variables

Explanatory variables	Description	Measurement
Gender (X_1)	Gender of the farmer	1 = Female 0 = Non-female
Age (X_2)	Age of the farmer	Number of years
Household size (X_3)	Family members living with the farmer	Number of people
Marital status(X_4)	Farmer's marital status	1 = Married 0 = Not married
Educational level (X_5)	The grade accomplished by the farmer	1 = Primary school 0 = No primary school
Years of schooling (X_6)	The years a farmer spent schooling	Number of years
Primary dconomic activity (X_7)	The main economic activity	1 = Full-time farmer 0 = Not full-time farmer
Primary income source (X_8)	The main source of income	1 = Farm 0 = Non-farm
Status of land ownership (X_9)	Land ownership	1 = Own land 0 = Not own land
Farm size (X_{10})	The size of land owned by the farmer	Hectares
Income earned from cowpea (X_{11})	The income earned from selling cowpeas	Rands
Method of intercropping (X_{12})	The method that the farmer uses to plant cowpea	1 = Strip intercropping 0 = No strip intercropping
Source of field labour (X_{14})	The labour used for production	1 = Family members 0 = Non-family members
Working hours per day (X_{15})	The hours spent in the field in a day	Number of hours
Farm workers' income (X_{16})	The amount the farm workers earn in a month	Amount in rands
Aggregated agri-chemical costs (X_{17})	Aggregated amount of money spent on pesticides used during production	Cost in rands
IT82E-16 seed cost (X_{18})	The amount of money spent on purchasing the modified cowpea seed	Amount in rands
Experience in farming (X_{19})	The years that the farmer has been involved in farming	Number of years

Table 5.2: Description of hypothesised independent variables used in the economic efficiency of cowpea production

Explanatory variables	**Description and measurement**	**Expected sign**
Gender (X_1)	Gender of the farmer (male or female)	+/-
Age (X_2)	Age of the farmer (number of years)	-
Household size (X_3)	Family members living with the farmer (number of people)	-
Marital status(X_4)	Farmer's marital status (married, not married, separated or divorced)	+
Educational level (X_5)	The grade accomplished by the farmer (not attended school, primary school, secondary school or tertiary level)	-
Years of schooling (X_6)	The years a farmer spent in schooling (number of years)	+
Primary economic activity (X_7)	The main economic activity (full-time farmer, part-time farmer, government employee, private sector employee, self-employed or unemployed)	+
Primary income source (X_8)	The main source of income (farming, pension, salary, wage or social grants)	+
Status of land ownership (X_9)	Land ownership (inherited, communal, leased, bought or granted by the chief)	-
Farm size (X_{10})	The size of the land owned by the farmer (hectares)	+
Income earned from cowpea (X_{11})	The income earned from selling cowpea (rands)	+/-
Method of intercropping (X_{12})	The method the farmer uses to plant (broadcasting, strip-intercropping, mono-cropping or mixed cropping)	-
Purpose of growing cowpea (X_{13})	Reasons for planting cowpea in the field (household consumption, income generation, livestock feed, manure or soil covering)	+
Source of field labour (X_{14})	The labour used for production (family members, full-time members or part-time workers)	+
Working hours per day (X_{15})	The hours spent in the field in a day (number of hours)	+
Farm workers' income (X_{16})	The amount the farm workers earn in a month (rands)	-
Aggregated agri-chemical costs (X_{17})	Aggregated amount of money spent on pesticides used during production	-
IT82E-16 seed cost (X_{18})	The amount of money spent on purchasing the modified cowpea seed (rands)	-
Experience in farming (X_{19})	The years that the farmer has been involved in farming	+

5.6 RESULTS AND DISCUSSION

Socioeconomic characteristics of cowpea farmers

Table 5.3 shows the socioeconomic characteristics of the smallholder cowpea farmers interviewed in the study. The characteristics were age, gender, years of schooling, primary source of income and primary activity of the farmer. The study revealed that the age of the farmers ranged between 33 and 78 years. The average age of the farmers was 61 years. The household size of the farmers in the study area was found to range between two and 14, with an average of seven family members per household. The study further indicated that the interviewed farmers had no to 13 years of schooling, with an average of five years of schooling. On average, in this study, cowpea smallholder farmers were found to have been involved in farming for more than 38 years, ranging between three and 58 years. The average income received from agricultural production is R1,735.83 per month.

Table 5.3: Socioeconomic characteristics of cowpea smallholder farmers in the Waterberg and Capricorn districts

Variable	Minimum	Maximum	Mean	Standard deviation
Age of the farmer	33	78	61.20	11.327
Household size	2	14	6.87	2.548
Years of schooling	0	13	5.44	3.905
Years involved in farming	3	58	37.53	12.580
Agricultural income per month	R650.00	R3,500.00	R1,735.833	R694.8413

Source: *Computed by the authors from survey data*

5.6.1 Age of cowpea farmers

The age of the smallholder cowpea farmers was considered as one of the key socioeconomic factors influencing efficiency in cowpea production. Figure 5.5 depicts the age distribution of cowpea farmers in the study area. As indicated on the figure, of the 60 farmers interviewed, 2% are under 35 years of age, 10% are between 35 and 45 years of age, and 23% are between 46 and 56 years of age. On average, the age of smallholder cowpea farmers in the study area is 62 years, while the two largest age groups of farmers are between the ages of 57 and 67 years (32%) and above 67 years (33%).

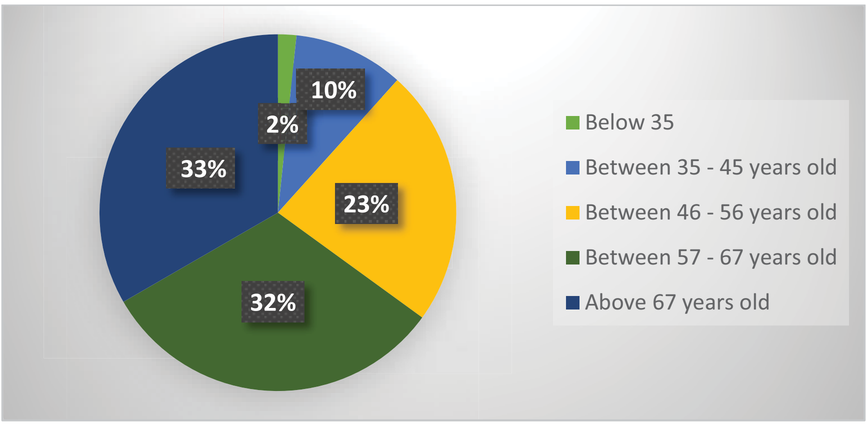

Figure 5.5: The age of cowpea farmers

Source: Authors' computation from survey data

5.6.2 Gender of cowpea farmers

In order to address gender inequality in agriculture, there is a need to account for the different roles of both men and women, as this will assist in resource distribution and the establishment of programmes (Gender in Agriculture Sourcebook, 2009). The Gender in Agriculture Sourcebook (2009) states that gender inequality is a constraint to agricultural productivity and efficiency. According to the Food and Agricultral Organisation (FAO)'s Division of Agricultural Development Economics (FAO, 2011), women in sub-Saharan African countries provide 60 to 80% of the agricultural labour to produce food for household consumption and income. In both districts, the study found that female smallholder farmers are dominant, with 72% of the farmers in the study area being female and 28% being male (Figure 5.6).

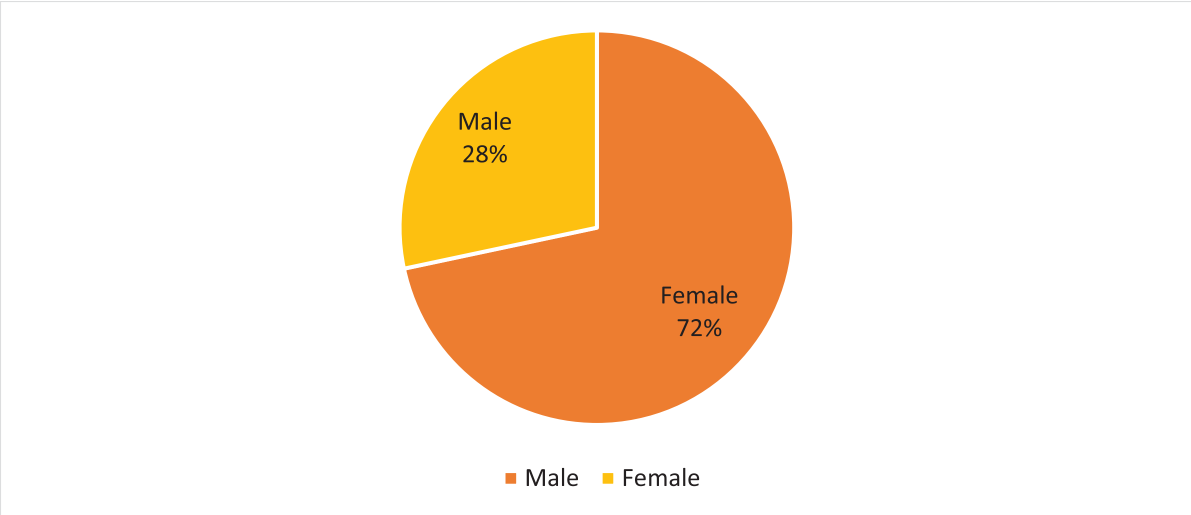

Figure 5.6: The gender of cowpea farmers

Source: Authors' computation from survey data

5.6.3 Economic activity of cowpea farmers

The primary economic activity was defined as the most important activity in which the smallholder farmer is involved on a daily basis. The primary economic activity variable was divided into three categories: full-time farmers who are operating on the farm full-time and are not involved in any other activities; part-time farmers who work part-time on the farm and have other additional activities in which they are involved; and government employees who are owners of the land, but leave their family members to work on the farms while they work in government institutions. Figure 5.7 shows that 81% of the farmers interviewed are full-time farmers, 17% are part-time farmers, and 2% are fully employed as government employees who own farms and have their family members working on their farms.

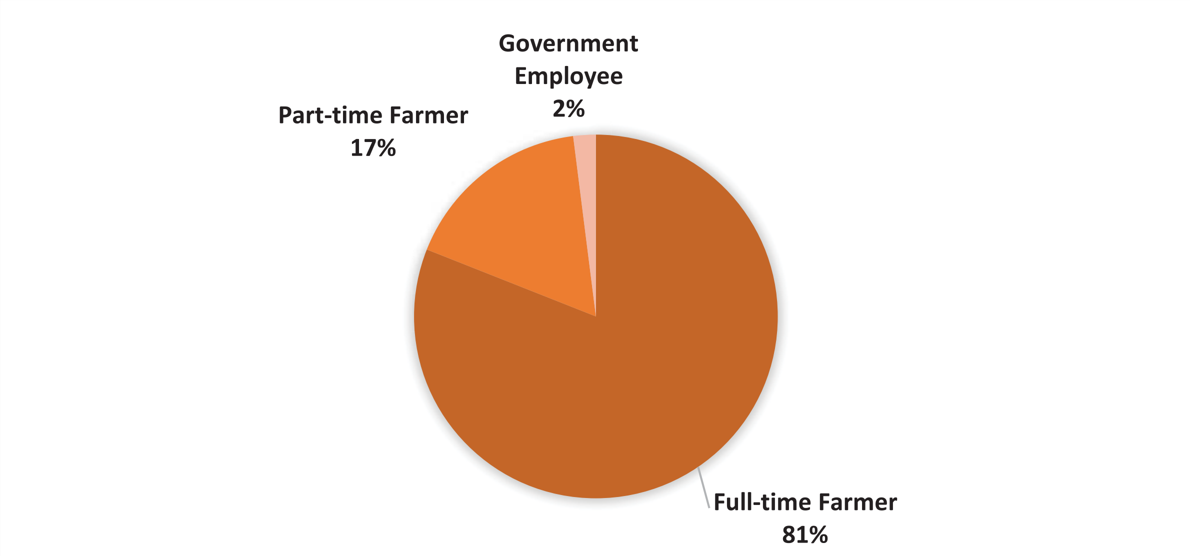

Figure 5.7: The primary economic activity of the farmers

Source: Authors' computation from survey data

5.6.4 Primary source of income among cowpea farmers

Primary source of income (Figure 5.8) was an important variable in the study as it indicated the main source of income for the smallholder cowpea farmers in the study area. It was defined as the main source of income for the farmers in the study area. There were five categories: farming, pension grant, salaries, wages and child social grant. Pension grant is revealed to be the main source of income for these mostly elderly farmers (48%), followed by income through farming (35%), wages (12%), receiving a child social grant (3%) or receiving a salary (2%).The recipients of pension grants are farmers who receive grants from the government to sustain themselves.

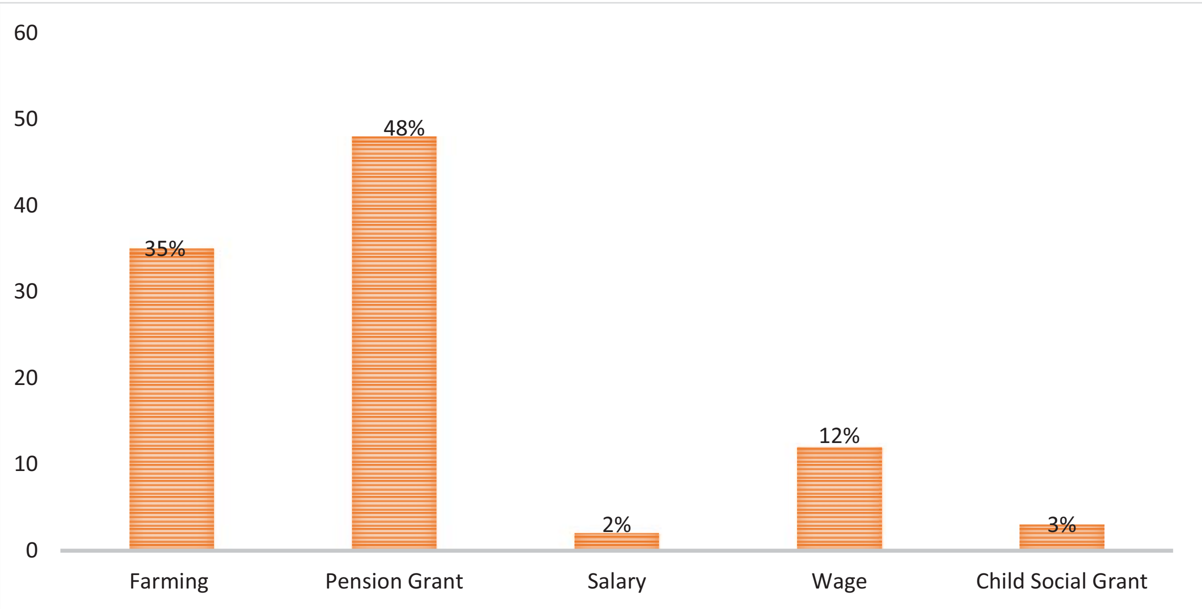

Figure 5.8: The primary source of income among cowpea farmers

Source: Authors' computation from survey data

5.6.5 Educational status of cowpea farmers

The educational level variable was divided into four categories: never attended school, attended primary school, secondary school and tertiary school, while years of schooling was defined as the number of years a farmer had attended school. Figure 5.9 shows that 23% of the farmers attended school, 42% attended primary school, 33% attended secondary school and 2% had received a tertiary education. This indicates that, of the farmers interviewed, 77% had gone to school and were able to read and write (basic literacy). These results show that the majority of the cowpea farmers in the Waterberg and Capricorn districts (65%) have at least a basic education.

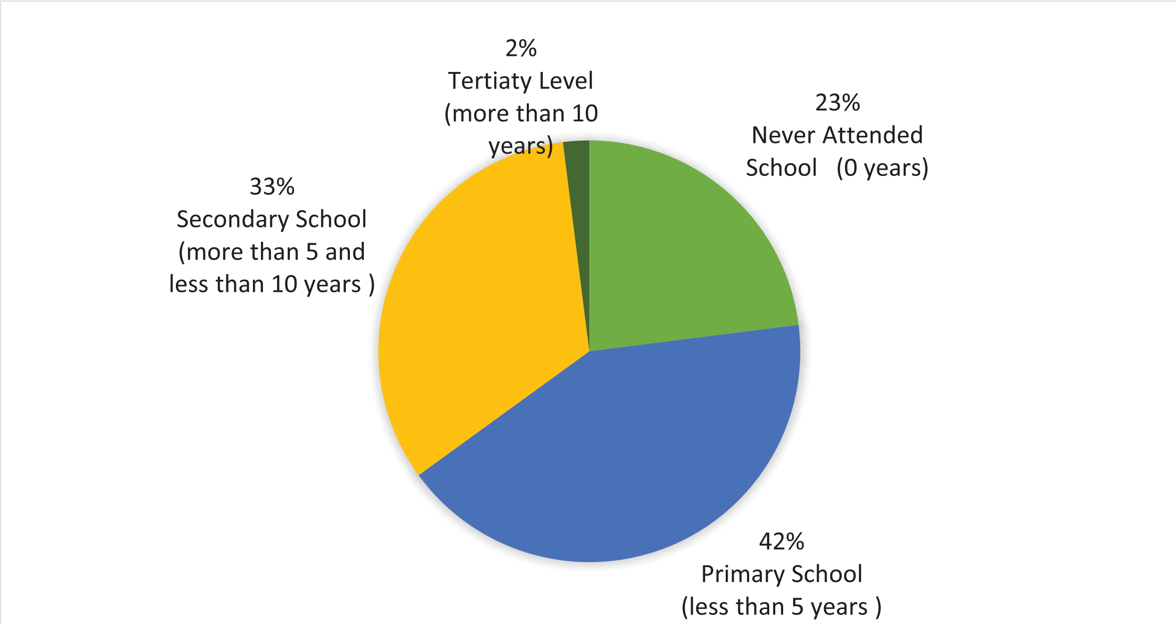

Figure 5.9: The educational status of cowpea farmers

Source: Authors' computation from survey data

5.6.6 Determinants of technical efficiency – application of DEA

The study used the DEA to determine the technical, allocative and economic efficiency scores of the smallholder cowpea farmers. Table 5.4 provides an overall summary of the outputs obtained from the utilisation of the inputs (cowpea seed, Dual herbicide, Roundup herbicide, Cypermetrin pesticide, labour hours and farm size) and the cost of each output.

Table 5.4: Output, input and prices summary statistics used in DEA

Variable	Mean	Standard deviation	Minimum	Maximum
Output (yield)				
Cowpea bags (tons)	3.852	2.065	1.874	8.509
Inputs				
Cowpea seed bags (kg)	2.24	2.483	1	15
Dual herbicide (mℓ)	1,243.33	569.379	600	2,800
Roundup herbicide (mℓ)	5,714.83	2,604.234	2,700	12,830
Cypermetrin pesticide (mℓ)	1,865.00	854.068	900	4,200
Aphox pesticide (mℓ)	982.50	444.822	450	2100
Labour hours (day)	5.45	.910	3	7
Farm size (hectares)	16,458.3333	7,595.32175	7,500.00	35,000.00
Input prices				
Cowpea seed cost (500 g)	41.77	6.863	30	50
Dual herbicide cost (ℓ)	183.6167	5.09600	168.00	198.00
Roundup herbicide cost (ℓ)	198.0000	.00000	198.00	198.00
Cypermetrin pesticide cost (mℓ)	138.0000	.00000	138.00	138.00
Cost of labour (month)	219.67	82.256	130	400
Aphox pesticide cost (mℓ)	137.600	4.9273	120.0	145.0

Source: Authors' computation from survey data

5.6.7 Inputs in quantities

Table 5.4 shows that, on average, 2.24 kg of PAN311 seeds were used in the production of cowpea. This implies that the smallholder cowpea farmers in the Capricorn and Waterberg districts of Limpopo were utilising over 2.24 kg of seed on a hectare of land. The 2.24 kg can produce approximately 4 tons of cowpeas. The PAN311 cowpea seed showed that it has a high yield. The minimum cowpea bags harvested is 2 tons per production season. For weed control, famers apply Dual and Roundup herbicides. On average, they use 1,243.33 mℓ and 5,714.83 mℓ, respectively, per season.

Farmers in this study area do not apply fertilizers in their fields. Cowpeas are prone to aphids. Therefore, the farmers applied Cypermetrin and Aphox to control the aphids. For aphid control, a farmer would, on average, apply 1,865.00 mℓ Cypermetrin and 982.50 mℓ Aphox per hectare per season. Labour is one of the crucial inputs in cowpea production. For high and good-quality cowpea yield, labourers need to spend at least five hours a day in the field.

5.6.8 Costs of inputs

The average cost of the IT82E-16 cowpea variety is R41.77 per 500g. For a farmer to produce on a hectare of land, a minimum of a 500 g packet of cowpea seed is needed. On average, the cost of Dual and Roundup herbicides amounts to R183.62 and R198.00 per litre, respectively. The farmers pay the labourers an average of R219 per month, irrespective of the days that the labourer works in the field. The field workers are paid monthly during the production season. Each litre of Cypermetrin and Aphox for the control of aphids costs the farmer R137.60. On average, expenses per hectare are about R918.65.

Table 5.5: Efficiency score summary for cowpea farmers in Waterberg and Capricorn districts

Variable	Mean	Standard deviation	Minimum	Maximum
Technical efficiency	.9588333	.0698566	.75	1
Allocative efficiency	.65195	.188587	.407	1
Economic efficiency	.6218167	.1750136	.382	1

Source: Authors' computation from survey data

The results of the study show that the technical efficiency scores of cowpea farmers (Table 5.5) have a mean of 0.9588 with a minimum of 0.7500 and a maximum of 1.000. This means that 95% of the farmers are technically efficient and that the farmers are able to produce over 75% of the maximum feasible output. The allocative efficiency score ranges from a minimum of 0.4070 to a maximum of 1 with a mean of 0.6519. The allocative efficiency scores imply that farmers are not utilising their inputs efficiently, given the input price and average costs. Given the current prices of inputs, average costs may be reduced by almost 35% to obtain the same level of output. These results concur with the results obtained by Watkins et al. (2014) that indicated a technical score that ranges from 0.440 to 1 and an allocative score that ranges from 0.332 to 1.

The economic efficiency scores range from a minimum of 0.3820 to a maximum of 1 with a mean score of 0.6218. The implications are that smallholder cowpea farmers are economically inefficient on average and that the cost of cowpea production for each farm could be decreased on average by approximately 38% to obtain the same level of output. These results concur with the results obtained by Watkins et al. (2014), which indicate an economic score that ranges from 0.29 to 1.

5.6.9 Determinants of technical efficiency (result of the Tobit regression analysis)

The explanatory variables used in the Tobit regression model (Table 5.5) are gender, age, household size, marital status, educational level, years of schooling, primary economic activity, primary income source, experience in farming, status of land ownership, farm size, income earned from cowpea, method of intercropping, source of field labour, working hours per day, farm workers' income, aggregated agri-chemical costs, IT82-16 seed costs and experience in farming. Table 5.6 presents the results of technical efficiency determinants among cowpea farmers. Of the 18 explanatory variables, five are found to be statistically significant at different levels. The variables that are found to be significant are age, educational level, primary income source, farm size, method of intercropping and source of field labour.

Table 5.6: Technical efficiency determinants (the Tobit analysis results)

Technical efficiency	Coefficient	Standard error	Tons	P > |t|
Gender	-.0001354	.0006643	2.11	0.041**
Age	-.0107634	.0061515	-1.75	0.088*
Educational level Never attended school	-.1705851	.0743186	-2.30	0.027**
Primary source of income Pension grant Wage	 .4370177 -.2808479	 .142945 .1232637	 3.06 -2.28	 0.004** 0.028**
Experience in farming	.3786064	.1074765	3.52	0.001***

****1%, ** 5% and *10% significance levels*

Source: Authors' computation from survey data

5.6.10 Determinants of technical efficiency in cowpea production

5.6.10.1 Gender of farmers

Table 5.6 indicates that the gender of the farmer negatively affects the technical efficiency of the cowpea farmers in the study area. The gender of the farmer is found to be statistically significant at 5% with a negative coefficient of .0001. This study disagrees with the results of the study conducted by Baloyi (2011), which indicates that gender is non-responsive to the technical efficiency of farmers.

5.6.10.2 Age of farmers

The age of the cowpea smallholder farmers is considered as one of the explanatory variables influencing technical efficiency in cowpea production in the study area. The age of the farmer is found to be significant at 10%, with a negative coefficient of -0.0107. This explains that the age of the farmer negatively affects technical efficiency. This could mean that aged farmers are less active in undertaking farm activities. Furthermore, age is indirectly proportional to productivity in cowpea production.

5.6.10.3 Educational level and status

The farmers' level of education, particularly the category of those who never went to school, is found to have a negative relationship with technical efficiency with a coefficient of -0.175 and a significance level of 5%. This explains that farmers who never attended school are found to be technically inefficient. This implies that, as farmers become more educated, they tend to have a better understanding of efficiency in production. This study concurs with the results of the study conducted by Nchare (2007), which indicated that educational level was the main variable influencing technical efficiency level and was a significant variable.

5.6.10.4 Primary source of income

Based on the descriptive analysis of this study, most of the farmers are found to be recipients of the pension grant from the South African Department of Social Development. The pension grant is one of the categories of source of income that is found to have a positive relationship with technical efficiency with a coefficient of 0.4370. This justifies the fact that most of the farmers who are grant recipients use the money they receive to sustain their cowpea production expenses. The farmers who receive wages from undertaking different jobs are found to have a negative relationship with technical efficiency with a coefficient of -.2808, significant at the 5% level. These results concur with the study conducted by Ndjodhi (2016), who indicated that off-farm income has a positive relationship with technical efficiency and is significant at a level of 5%. This implies a positive relationship between off-farm income (grants, wages and salaries) and the technical efficiency level of the farmers.

5.6.10.5 Experience in farming

The results in Table 5.4 indicate that experience is significant at 1% with a positive coefficient of 0.3786. It is assumed that the more experience the farmer gains in farming, the more the efficiency level is likely to increase. The results concur with the study of Mokgalabone (2015), who found a positive relationship between experience in farming and efficiency in production. This is not in line with previous findings and might be because of the age of farmers, considering that they were relatively old at an average of 61 years.

5.6.10.6 Allocative efficiency and its determinants

Table 5.7 represents the technical efficiency results of the study. Of the 19 explanatory variables, five were found to be statistically significant at different levels. The variables that are found to be significant are farm size, source of field labour, income earned from cowpea and method of intercropping.

Table 5.7: Allocative efficiency determinants

Allocative efficiency	Coefficient	Standard error	Tons	P > |t|
Farm size	*.0001436*	*.0001213*	*2.05*	*0.047***
Source of field labour Part-time workers	.0002487	.0000798	-0.24	0.010**
Income earned from cowpea	.00883408	.2514498	2.38	0.023**
Methods of intercropping planting in rows	.0005865	.0005133	2.09	0.030**

****1%, ** 5% and *10% significance levels*

Source: Author’s computation from survey data

5.6.11 Determinants of allocative efficiency in cowpea production

Farm size

There is a positive relationship between farm size and level of production. Therefore, farm size is found to be one of the explanatory variables that influence technical efficiency in cowpea production. It is found to be significant at the 5% level, with a positive coefficient of 0.001. This implies that the size of the farm has an impact on the production levels of cowpea farmers. A study conducted by Dipeolu and Akinbode (2008) indicated that farm size was found to have a significant contribution on the allocative efficiency of farmers.

Source of field labour

The source of field labour is one of the variables that is expected to improve the production of cowpea. Source of labour is categorised into three groups: full-time workers, part-time workers and family labour. The farm’s part-time workers are found to be significant at 5% with a negative coefficient of 0.002. The results of this study show that the employment of part-time workers negatively affects the allocative efficiency of cowpea farmers.

Income earned from cowpea

The results in Table 5.6 reveal that income earned from selling cowpea positively relates to allocative efficiency at the 5% level with a positive coefficient of 0.008. This implies that, when the income earned from selling cowpea increases, the level of allocative efficiency is also likely to increase. These results concur with the study conducted by Ndjodhi (2016), who states that income shows a positive relationship with efficiency and is significant at the 5% level.

Method of intercropping

Planting for optimum cowpea yield comes as a result of planting methods. Cowpea has the ability to fix nitrogen in the soil, making the field fertile for the crops either planted after cowpea or intercropped with cowpea. One can plant cowpea in three ways: broadcasting, mixed cropping or planting in rows. Farmers who plant in rows have a greater cowpea yield than those who use mixed cropping or who broadcast the seed during planting. Planting in rows is found to be significant at 5% with a positive coefficient of 0.005. These findings concur with a study conducted by Mustapha and Salihu (2015), who reveal that the mean technical efficiency of the farmers is 0.84, indicating that female farmers are relatively efficient in maize-cowpea intercropping.

5.6.12 Economic efficiency and its determinants

Table 5.8 depicts the economic efficiency results of the study. Of the 19 explanatory variables, four were found to be statistically significant at different levels. The variables that are found to be significant are age, educational level, primary income source and status of land ownership.

Table 5.8: Determinants of economic efficiency among cowpea farmers

Economic efficiency	Coefficient	Standard error	Tons	P > t
Age	-.021559	.005873	3.67	0.001***
Educational level Primary school	 .6266844	 .2664316	 2.35	 0.025**
Primary source of income Pension grant Child grant	 .2414884 .5983408	 .1037099 .2514498	 -2.33 2.38	 0.026** 0.023**
Status of land ownership Granted by the Chief	 .1335735	 .0785524	 1.70	 0.008*

****1%, ** 5% and *10% significance levels*

Source: Authors' computation from survey data

5.6.13 Determinants of economic efficiency in cowpea production

Age of the farmers

The age of the cowpea smallholder farmers is found to be one of the variables influencing the economic efficiency of cowpea production in the study area. The results in Table 5.8 show that age is significant at 1% with a negative coefficient of -0.021559. This explains that the age of the farmer negatively affects the economic efficiency of the cowpea farmers' production. As the farmers grow older, their effectiveness in the field gradually decreases.

Educational level

Education is believed to have an impact on decision-making and the allocation of resources to maximise cowpea output. Educational level is defined according to three levels: never went to school, primary education level, and secondary and tertiary level. Primary education level is found to positively influence economic efficiency in cowpea production in the study area. The results in Table 5.8 show primary education to be significantly related to the economic efficiency of cowpea farmers at 5% with a positive coefficient of 0.6266. This concurs with a study conducted by Mokgalabone (2015), who concludes that educational level has a positive influence on the efficiency of the farmer.

Primary source of income

Pension and child grants are some of the categories of sources of income that are found to be have a positive relationship with economic efficiency with a coefficient of 0.2424 and 0.5983, respectively. This means that farmers who are grant beneficiaries use their grants to sustain their production expenses. Pension and child grant recipients are economically efficient, significant at 5%. These results concur with a study conducted by Ndjodhi (2016), who states that off-farm income has a positive relationship and is significant at 5%.

Status of land ownership

The status of land ownership is found to have a positive relationship with the economic efficiency level of the cowpea farmers. Land ownership is found to be significant at the 11% level with a positive coefficient of 0.1335. Farmers who own land are more courageous to produce or practise farming, since they do not have any expenses related to the renting of land. Most of the farmers are granted land by the Chief, who permits them to own the land. They do not share this land as is done with communal land. A study conducted by Mohamed and Authayla (2012) concludes that a positive coefficient of the land ownership variable means that the owners of land achieve more outputs than the renters of land.

5.7 CONCLUSIONS

The main aim of the study was to examine the economic efficiency of cowpea production among smallholder farmers in the Capricorn and Waterberg districts of Limpopo. The study used three techniques to analyse data: descriptive statistics, DEA and the Tobit regression model. While descriptive statistics was used to analyse and describe smallholder cowpea farmers' socioeconomic characteristics, DEA was employed to determine the efficiency levels of the farmers and the Tobit regression model was used to explain the determinants of the technical, allocative and economic efficiency of smallholder cowpea farmers in the study area.

The study used all the necessary official documents, statistics and data programs, as well as relevant literature to capture information on smallholder cowpea farmers in the two districts of Limpopo. A descriptive analysis of the data collected reveals that 72% of the cowpea smallholder farmers are female, with 28% of the farmers in the study area being male. The study finds that the age of the farmers ranges between 33 and 78, with the average age of the farmers being 61 years. The household size of the farmers in the study area was found to range between two and 14, with an average of seven family members per household. The study further indicates that years of schooling of the interviewed farmers ranges from 0 to 13 years, with an average of five years of attending school. On average, in this study, cowpea smallholder farmers have been involved in farming for more than 38 years, with a range of between three and 58 years. The average income they received from agricultural production was R1,735.83 per month.

The DEA results of the study show that the technical efficiency scores of cowpea farmers have a mean of 0.9588 with a minimum of 0.7500 and maximum of 1. This means that 95% of the farmers are technically efficient and that the farmers are able to produce over 75% of the maximum feasible output. The allocative efficiency scores range from a minimum of 0.4070 to a maximum of 1 with a mean of 0.6519. The allocative efficiency scores, however, imply that farmers are not utilising inputs efficiently. Given the current prices of inputs, average costs may be reduced by about 35% to obtain the same level of output. The economic efficiency scores range from a minimum of 0.3820 to a maximum of 1 with a mean score of 0.6218. The implications are that smallholder cowpea farmers are economically inefficient on average and that the cost of cowpea production for each farm could be reduced on average by approximately 38% to obtain the same level of output.

The study also finds that socioeconomic factors influencing economic efficiency include age, educational level, primary source of income and status of land ownership. The age of the farmers is significant at 1% with a negative coefficient of -0.021559. Primary education is found to positively influence economic efficiency at 5% with a positive coefficient of 0.6266. Pensions and child grants are some of the categories of source of income that are found to have a positive relationship with economic efficiency with a coefficient of 0.2424 and 0.5983, respectively.

Based on the empirical results of the analysis, the study concludes that smallholder cowpea farmers in the Capricorn and Waterberg districts of Limpopo, despite being technically efficient, are economically inefficient and the cost of cowpea production for each farm could be decreased, on average, by approximately 38% to obtain the same level of output.

5.8 VALUE CHAIN ANALYSIS AND MARKETING EFFICIENCY AMONG SMALLHOLDER COWPEA FARMERS IN LIMPOPO

5.8.1 Introduction

Cowpea is one of the most ancient crops known to humankind, with its centre of origin being in Africa. The crop has the ability to provide the earliest food for millions of Africans during the hungry season before cereals can mature for food consumption (Black, 2015). Most farmers grow cowpea intercropped with other crops such as maize and sorghum because of its ability to fix nitrogen, which is essential for maize production, in particular. The nutrients not only come from the pods, but cowpea leaves can also be consumed to supplement staple food like maize meal.

The crop has various common names, such as crowder pea, black eye pea and southern pea, but all these names account for one scientific name for the crop: *Vigna unguiculata* (Mbene, 2005). Cowpea is a food and animal feed crop that originated and was domesticated in Southern Africa. It is a warm season crop that is relatively easy to grow in various types of soil, ranging from acid to alkaline, and it is tolerant to low soil fertility. These agronomical attributes make it possible for the crop to be produced across a wide range of agro-ecological zones.

However, Singh et al. (2003) argued that cultivating and storing the crop (cowpea) comes with its challenges as insect pests are the biggest constraints and a problem when it comes to cowpea production. Different obstacles such as drought and heat limit high productivity. For some time now, research and the production of cowpea in South Africa have been neglected due to a lack of improved varieties, knowledge of good agronomic practices, the availability of good seeds and the discouragingly poor and marginal returns to farmers (Asiwe, 2009).

According to Faith et al. (2014), cowpea is regarded as a key protein source for the urban and rural poor, and also plays an important role as a cash crop. Leafy vegetable crops such as cowpea are considered to be food legumes, since they are consumed in most African countries because of their drought tolerance, being inexpensive to plant and to harvest. Most people, especially the rural poor, rely on this indigenous leafy vegetable as a source of protein. A study done by Chagomoka et al. (2014) has shown that traditional leafy vegetables have high market potential, and contribute substantially to household incomes and nutrition. Despite several nutritional benefits and the welfare-enhancing potential of cowpea, farmers still do not have sufficient information or knowledge about the value that can be added to their cowpea, and also the potential and competitiveness of this traditional leafy vegetable (Labadarios et al., 2011a; Faber et al., 2011). Therefore, there is a need to understand the interaction of the various actors along the value chain of cowpea in order to understand the role of these actors in an effort to improve the profitability and marketing efficiency of cowpea.

Chagomoka et al. (2014) state that few studies have been done on traditional leafy vegetables' value chains and related subjects in Southern Africa. Scientific research previously gave less attention to research on traditional vegetables' value chains. Therefore, value chain mapping is important in identifying the different role-players along the chain, and addressing the constraints faced by these role-players at different nodes of the chain. With the new improved cowpea variety, which is high-yielding, drought-resistant and pest-resistant, cowpea farmers will be able to produce more. Most smallholder farmers usually sell their produce at a price just to have an income, but they do not take into consideration all the costs incurred from production until the product gets to the final consumer. This results in low bargaining power on the part of these farmers because of their lack of information with regard to marketing their produce.

5.8.2 Aim of the study

The aim of the study is to map the value chain and determine the marketing efficiency of smallholder cowpea farmers in the Capricorn and Waterberg districts of Limpopo.

5.8.3 Objectives of the study

The specific objectives of the study are to do the following:

- Identify and describe the socioeconomic characteristics of smallholder cowpea farmers
- Identify and define role-players along the cowpea value chain
- Determine the marketing efficiency of smallholder cowpea farmers
- Examine the determinants of marketing efficiency among smallholder cowpea farmers
- Identify marketing constraints among smallholder cowpea farmers

5.8.4 Research hypotheses

Ho_1: Smallholder cowpea farmers are inefficient in marketing cowpea.

Ho_2: The socioeconomic characteristics of smallholder cowpea farmers have no effect on their marketing efficiency

5.9 MATERIALS AND METHODS

Limpopo (Figure 5.10) is the fifth-largest province in South Africa in terms of population size, with 5.8 million people living in it (StatsSA, 2016). There are nine provinces in South Africa: Eastern Cape, Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga, Northern Cape, North West and Western Cape (StatSA, 2016). Limpopo is situated in the northern part of the country and shares borders with Botswana, Mozambique and Zimbabwe. The province was formerly known as Northern Transvaal and Northern Province. The name was changed to Limpopo in 2003. It was called Limpopo after the Limpopo River, which forms the border between South Africa and Zimbabwe. The capital city of Limpopo is Polokwane, formerly known as Pietersburg. This name was changed at the same time as the name of the province changed.

Limpopo covers an area of 125,755 km^2, which is about 10.3% of the country's total area (Polokwane City, 2017a). The most-spoken languages in the province are Sepedi, Xitsonga and Tshivenda, with 52.9, 17 and 16.7% of the country's speakers, respectively. Limpopo comprises five districts: Capricorn, Mopani, Sekhukhune, Vhembe and Waterberg. There are several local municipalities within these districts (Polokwane City, 2017a).

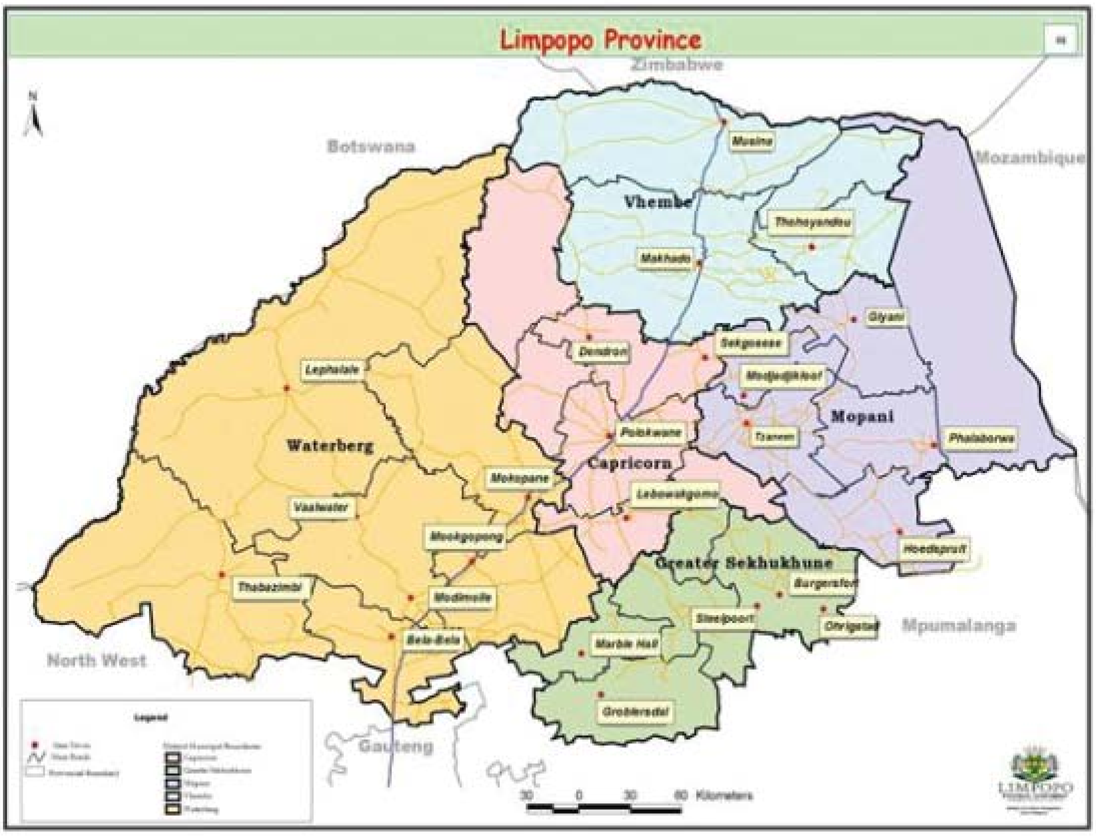

Figure 5.10: Map of Limpopo

Source: Limpopo Department of Transport, 2015

Capricorn District (Figure 5.11) is divided into five local municipalities: Aganang, Blouberg, Lepelle-Nkumpi, Molemole and Polokwane. Polokwane Local Municipality covers only 3% of the total of Limpopo. However, over 10% of the population of Limpopo resides within its boundaries (Polokwane City, 2017b). The Polokwane Local Municipality serves as the economic hub of the province. The highest population density is in Capricorn District. Polokwane, in Northern Sotho, means “place of safety”.

Ga-Molepo village is a rural community, which falls under the Polokwane Local Municipality. Ga-Molepo is situated southwest of Polokwane City, about 50 km from the city (Kganyago, 2008). Ga-Molepo, translated into English, means “place of relaxation”. Ga-Molepo is among the poorest areas in the Polokwane Local Municipality, where the majority of the population is involved in subsistence agriculture (Chaminuka et al*.,* 2006).

Figure 5.11: Map of Capricorn District (Polokwane Local Municipality)

Source: Limpopo Municipalities, 2017.

Waterberg District (Figure 5.12) is one of the districts in Limpopo. It is situated in the western part of Limpopo and is considered to be the largest district in the province (Phala, 2015), with more local municipalities than any other district in the province. However, Waterberg District ranks the lowest when it comes to the share of households in the province compared to the other districts (StatsSA, 2016). Waterberg District comprises six local municipalities: Bela-Bela, Lephalale, Modimolle, Mogalakwena, Mookgopong and Thabazimbi. Bela-Bela is one of the local municipalities in the Waterberg District, formerly known as Warmbaths. The name change took place at the same time as the name of Northern Province was changed to Limpopo in 2003. Bela-Bela Local Municipality covers an area of 4,000 km^2 of the entire Waterberg District of 49,504 km^2 (StatsSA, 2016). The population in the local municipality is estimated at 76,296 (StatsSA, 2016), which is reasonable considering that the municipality is the smallest in the district. The local municipality is in the southwestern part of the Waterberg District and shares borders with Gauteng, Mpumalanga and North West. The main economic sectors, which contribute substantially to the district's GDP, are agriculture and tourism (Bela-Bela Local-Municipality, 2017), especially given the fact that the district is predominantly rural. Bela-Bela is generally hot and has a semi-arid climate, with an average rainfall of 600-650 mm. The highest measurements occur from January to December (Bela-Bela Local Municipality, 2016). The climate in the area is suitable for agricultural production such as maize, sorghum and cowpea, which are produced between November and January when much of the rainfall is expected.

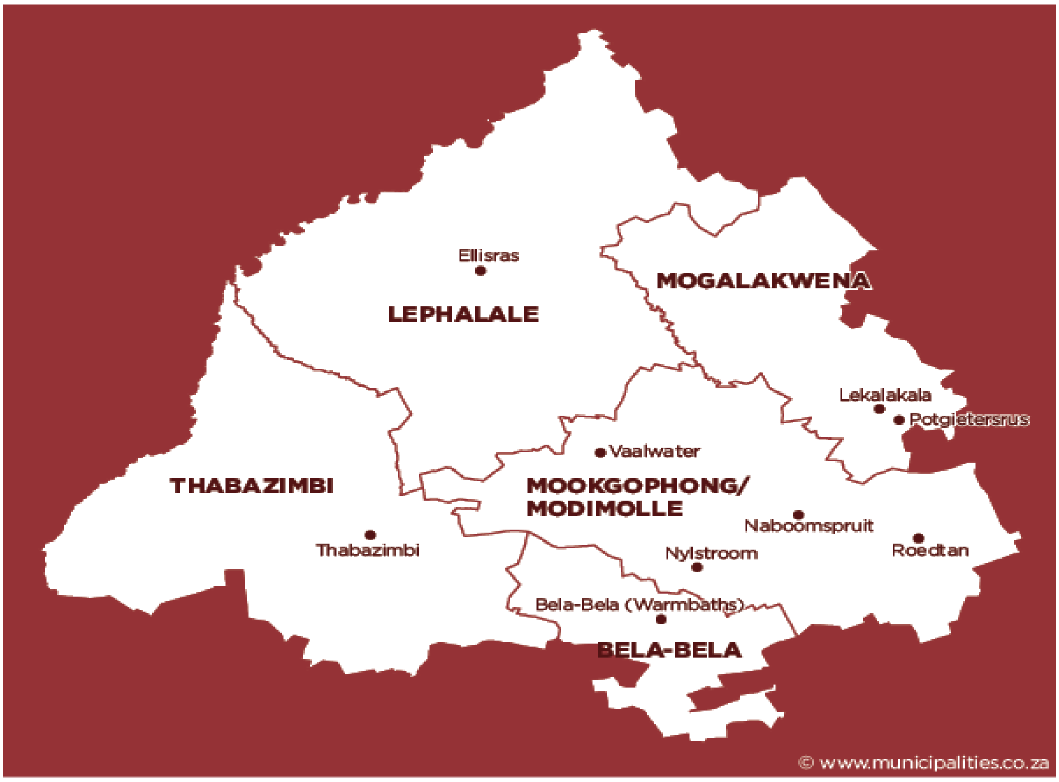

Figure 5.12: Map of Waterberg District (Bela-Bela Local Municipality)

Source: Limpopo Municipalities, 2017

5.9.1 Types, sources and data collection method

Primary data was collected from farmers producing cowpea. The information was collected by means of face-to-face interviews, using a structured questionnaire. The questionnaire focused on individual farmers, and the questions were based on the objective of trying to establish the socioeconomic factors, cowpea production, other crop production, quantities of cowpea sold and the cowpea value chain, among other variables. A sample size of 80 cowpea farmers was used in this study. A purposive sampling technique was used to identify farmers in this study. Purposive sampling is a non-probability sampling technique, which is the deliberate choice of an informant due to the qualities an informant possesses (Tongco, 2002). Bernard (2002) and Lewis and Sherpard (2006), as cited by Tongco (2002), further explain that, with purposive sampling, the researcher decides what needs to be known, and sets out to find people who can and are willing to provide the information by virtue of their knowledge or experience. Therefore, the study areas were chosen on the basis that the farmers in the area were representative of what the study was aimed at determining, particularly given the fact that all the farmers were producing cowpea.

5.9.2 Methods of data analysis

Data was captured and analysed using SPSS 24.0. Binary logistic regression analysis was used to define the determinants of marketing efficiency of cowpea farmers. In determining whether the cowpea farmers were market efficient or not, a marketing efficiency measure was used for the calculations. For descriptive statistics, the mean, averages and frequencies were calculated. Pie charts and bar charts were also used to describe the socioeconomic characteristics of smallholder cowpea farmers in the Ga-Thaba and Bela-Bela areas.

The study applied three methods in the analysis of data in accordance with the main objectives. In describing the socioeconomic characteristics of cowpea farmers, descriptive statistics, in the form of charts, frequencies and means or averages, was used. In identifying and defining the role-players along the cowpea value chain, a value chain for cowpea was constructed. A marketing efficiency measure was used to determine the marketing efficiency of smallholder cowpea farmers. Lastly, a binary logistic regression model was used to examine the determinants of marketing efficiency.

Descriptive statistics

Descriptive statistics, in the form of means, frequencies, pie charts and bar charts, was used to describe the socioeconomic characteristics of cowpea farmers in the Capricorn and Waterberg districts.

Value chain mapping

A value chain map, in the form of a flow chart, was constructed to identify and define role-players along the cowpea value chain. A flow chart is an easier tool to use in the sense that it can demonstrate a number of stages in the value chain that a product goes through before it reaches the final consumer.

Marketing efficiency measure

According to Rit (2014), marketing efficiency is the ratio of market output (satisfaction) to marketing input (cost of resources). An increase in this ratio represents increased efficiency, and a decrease denotes low efficiency. Therefore, in analysing whether the farmers are efficient in marketing their cowpeas, the costs of resources employed have to be less than the output produced from the limited resources.

Therefore, marketing efficiency can be measured by using the marketing efficiency measure. This method for measuring marketing efficiency was given by Acharya and Agarwal (2001). The method is known for its simplicity in calculating marketing efficiency and ease of interpretation.

The method is given by:

$$\mathrm{ME} = \frac{\mathrm{NFP}}{\mathrm{TMC+TMM}}$$

where ME = marketing efficiency; NFP = net price received by farmers; TMC = total marketing cost; TMM = total marketing margin.

For a farmer to be efficient in marketing, ME ≥ 1 indicates efficiency and < 1 shows inefficiency (Longwe et al., n.d.).

Binary logistic regression model

To examine the determinants of marketing efficiency, a binary logistic regression model was used. Logistic regression is a statistical method that is used to predict a categorical (usually dichotomous) variable from a set of predictor variables (Wuensch, 2015). With this model, there can be one or more independent variables that determine the outcome, where there are only two possibilities for the outcome.

The assumption is that P (Y = 1) is the probability of the event occurring. Therefore, it is important that the dependent variable is coded accordingly. The factor level 1 of the dependent variable should represent the desired outcome. Another fundamental assumption is that the binary logistic regression model assumes linearity of the independent variables and the log odds.

The general binary logistic regression model is expressed as follows:

$$\mathrm{Log}\ (P) = \ln\left(\frac{Pi}{1-Pi}\right) = \alpha + \beta_i X_i + \ldots + \beta_k X_k + U_i$$

where $(\frac{Pi}{1-Pi})$ is the natural log of the odds, P_i is the probability that the farmer is market efficient, 1-P_i is the probability that the farmer is not market efficient, β_i is the estimated parameter, X_i is the explanatory variable and U_i is the disturbance term.

The model is specified as follows:

$$ME = \beta_0 + \beta_1 AGE + \beta_2 GNDR + \beta_3 HSLDSZ + \beta_4 EDLVL + \beta_5 OCCPT + \beta_6 LNDOWN + \beta_7 FRMEXP + \beta_8 QNTYSLD + \beta_9 INCMGNRTD + \beta_{10} MRKTACC + Ui$$

Table 5.9: Description of variables

Variables	Description	Unit of measurement	Expected sign
	Dependent variable		
Marketing efficiency	1 if farmer is efficient in marketing, otherwise 0	Dummy	
	Independent variables		
X_1 = AGE	Age of the farmer	Years	+
X_2 = GNDR	1 if farmer is male, otherwise 0	Dummy	+
X_3 = HSLDSZ	Number of people in the household	Number	+
X_4 = EDLVL	Years of formal education	Years	+
X_5 = OCCPT	Occupation of the farmer	Category	+/-
X_6 = LNDOWN	1 if farmers owns land, otherwise 0	Dummy	+/-
X_7 = FRMEXP	Years a farmer has been farming cowpea	Years	+
X_8 = QNTYSLD	Quantities of cowpea sold	Kg	-
X_9 = INCMGNRTD	Income generated from selling cowpea	Rand	+/-
X_{10} = MRKTACC	1 if farmer has formal market access, otherwise 0	Dummy	+

5.10 RESULTS AND DISCUSSION

5.10.1 Socioeconomic characteristics of smallholder cowpea farmers

Below is a description of the socioeconomic characteristics of smallholder farmers in the Waterberg and Capricorn districts of Limpopo.

Table 5.10: Summary statistics of socioeconomic characteristics of cowpea farmers

Variables	N	Minimum	Maximum	Mean/average	Standard deviation
Age of the farmer	80	26	83	63.93	10.459
Household size	80	1	12	5.36	2.414
Years in schooling	80	0	15	7.36	3.671
Years in growing cowpea	80	1	45	9.38	12.099
Income generated from selling cowpea	80	200	2,000	680.63	542.293

Source: Authors' computation from survey data

5.10.2 Age of cowpea farmers

The mean age of smallholder cowpea farmers is 63.93 years. The minimum age of cowpea farmers in Ga-Thaba and Bela-Bela is 26 and the maximum age is 83.

5.10.3 Household size (number of people in the household)

The average household size is 5.36, the minimum number of people found living in a household is one, while the maximum is 12. With the average and maximum numbers being as stated, this is likely to imply that family labour is more often used than hired labour.

5.10.4 Years of schooling

Most farmers are considered to be illiterate and lack formal schooling experience. The results from descriptive statistics shows that the minimum number of years a farmer has been to school is 0, while the maximum is 15 and the average years of schooling is 7.36 years.

5.10.5 Years of farming

The minimum number of years a farmer has been farming cowpea is one year, which includes those farmers that have just started farming cowpea and have less than one year's experience. The maximum number of years' experience in cowpea farming is 45 years and the mean or average is 9.38 years.

5.10.6 Income generated from selling cowpea

The results acquired from descriptive statistics show that the minimum amount of money cowpea farmers receive from selling their cowpea harvest is R200. From the farmers who were interviewed, some do not have a reliable market because they have just started planting cowpea. The maximum amount of money cowpea farmers receive from their cowpea harvest sales is R2,000, while the average amount is R680.83.

5.10.7 Gender of cowpea farmers

Figure 5.13 shows the gender of the cowpea farmers, indicating which gender is more involved in cowpea farming. The results show that more women are involved in cowpea farming (57%), compared to their male counterparts (43%). Cowpea farming has traditionally been considered a woman's job in these areas, which is probably the reason why there are more women participating in cowpea farming than men.

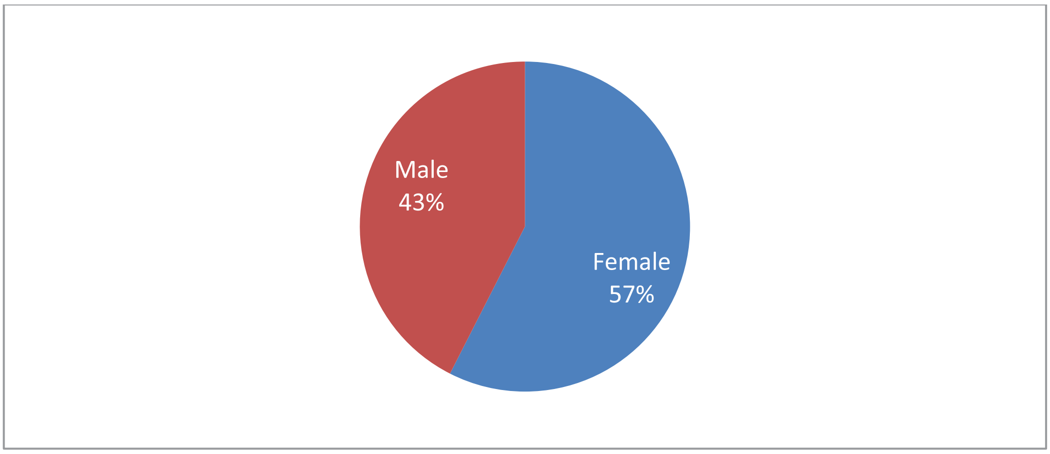

Figure 5.13: The gender of cowpea farmers

Source: Authors' computation from survey data

5.10.8 Occupation of cowpea farmers

Different activities in which farmers are involved (excluding farming) are among the major factors that affect the farmers' level of production. Highlighting and discussing these activities can pinpoint the reasons why cowpea farmers are succeeding in or failing at producing cowpea. Activities such as another occupation of the farmer is relevant in showing whether this leads to a farmer succeeding or failing in cowpea farming. Figure 5.14 presents the results of the occupation of the farmer. The results show that 37 of the 80 study participants are full-time cowpea farmers, followed by those who are full-time farmers and on pension (20). Few farmers farming cowpea are self-employed, pensioners, employed or unemployed.

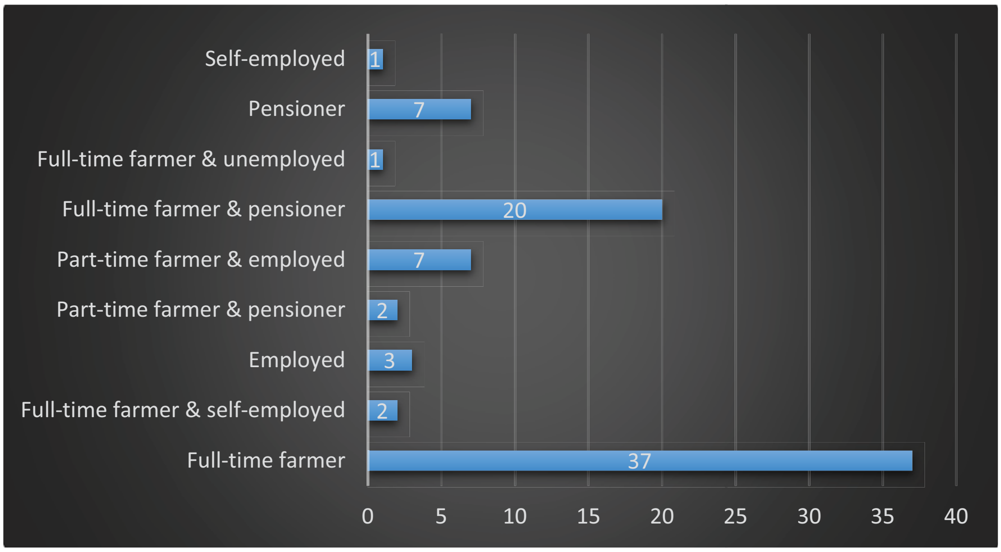

Figure 5.14: The occupation of cowpea farmers

Source: Authors' computation from survey data.

5.10.9 Land ownership of cowpea farmers

Land is one of the most important factors in agricultural practices. A farmer who owns land is more likely to be productive than a farmer with rented or leased land. Land ownership gives security in cases where a farmer needs capital to start or continue with their farming practices. Figure 5.15 shows that 81% of the farmers farming cowpea own the land they farm, whereas 19% do not have land ownership. However, with respect to this study, having no land ownership does not mean the farmers have no access to land.

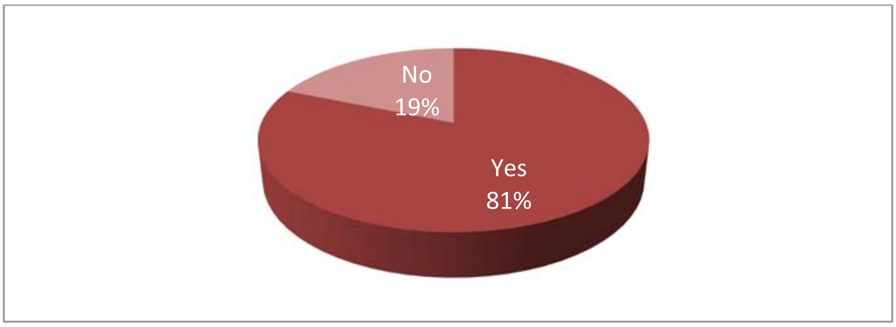

Figure 5.15: Land ownership by cowpea farmers

Source: Authors' computation from survey data

5.10.10 Quantities of cowpea sold

One of the determinants of farmers being profitable when selling their produce is the quantities of cowpea sold. Studies have shown that farmers are more likely to make a profit if they sell their products in (smaller quantity) kilograms, giving consumers the choice of coming back to buy more if they like the product. With regard to the quantities and weights at which the cowpea farmers sold their produce, Figure 5.16 shows that of the 80 interviewed farmers, only a few sell their cowpeas at 1, 5 or 10 kg; 1, 2 or 5 kg; 500 g, 1 kg or 2 kg; 500 g, 1 kg, 2 kg or 5 kg; and 5, 10 or 20 kg. Others sell their produce in larger quantities, such as 10 and 20 kg bags, but these are very few.

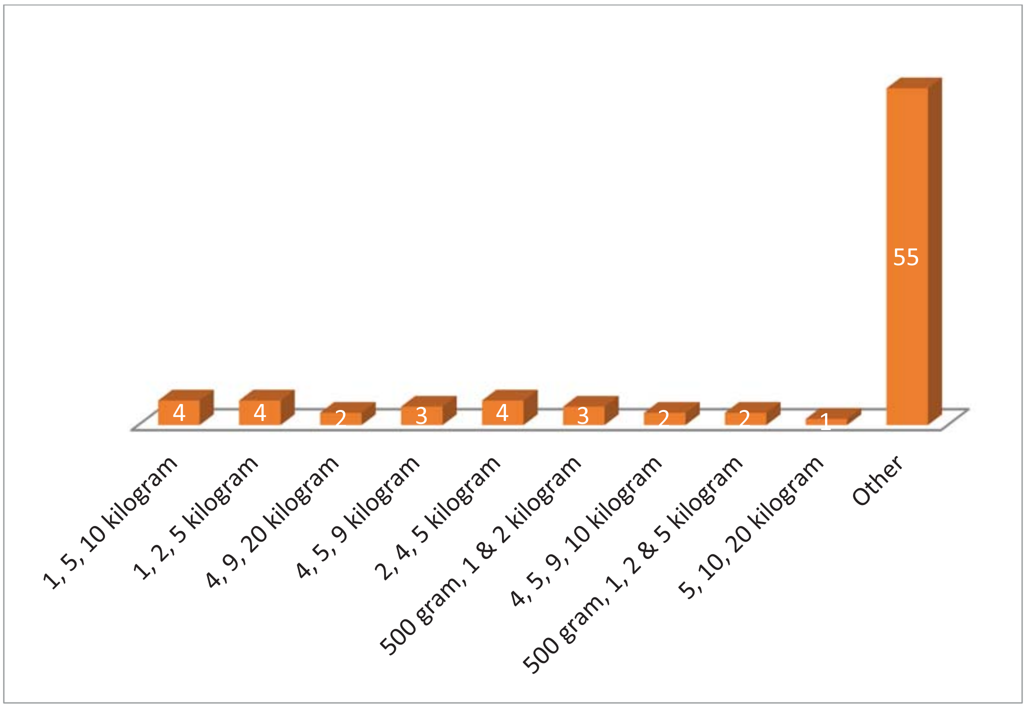

Figure 5.16: Quantities of cowpea sold

Source: Authors' computation from survey data

5.10.11 Formal market access of cowpea farmers

Access to markets is a vital requirement for poorly resourced farmers in rural areas if they are to enjoy the benefits of agricultural growth. In this regard, it is important that farmers have access to large enough formal markets on a regular basis to be able to realise higher returns from selling their produce. Figure 5.17 depicts that only 22% of cowpea farmers have access to a formal market, whereas the majority (78%) has no access to formal markets. This implies that 78% of these cowpea farmers only have access to informal markets. This could be due to the fact that some of the cowpea farmers have just started selling cowpea. It can also be due to the fact that these farmers do not have the relevant transport, the finances needed to transport their produce to formal markets or no access to traders.

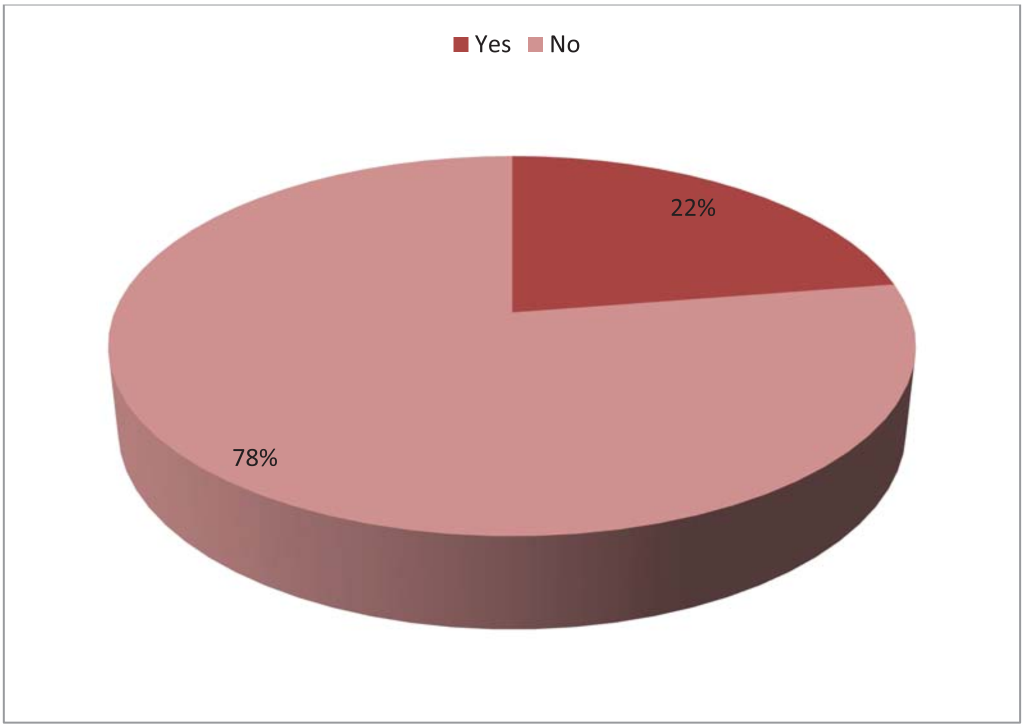

Figure 5.17: The formal market access of cowpea farmers

Source: Authors' computation from survey data

5.11 VALUE CHAIN MAPPING AMONG SMALLHOLDER COWPEA FARMERS

The main aim of this section is to map the value chain of cowpea and analyse whether smallholder cowpea farmers, in particular, are profitable along the value chain. Kaplinsky and Morris (2001) defined the value chain as a description of the range of activities that are required, from conception, to bring a product or a service through the different phases of production. It involves a combination of the physical transformation of the inputs of various producer services to the final consumers. A value chain enables all the participants involved to understand the activities that take place at each stage to add value to the product. From an agricultural perspective, Miller and Jones (2010), as cited by Adeoye et al. (2013), define a value chain as the full range of activities and participants involved in moving agricultural products, from input suppliers to farmers' fields, and ultimately to the consumer.

Value chain mapping, on the other hand, involves creating a visual representation of the connection between actors in the value chain analysis, as well as other stakeholders, as explained by McComick and Schmitz (2001). In mapping the value chain for cowpea in Ga-Thaba and Bela-Bela, smallholder cowpea farmers were asked questions regarding what takes place from the point of cowpea production to getting their products to their consumers. The value chain mapping shows different stakeholders participating in the cowpea value chain. The relationships and linkages are as shown in Figure 5.18.

5.11.1 Participants in the cowpea value chain and their roles at Ga-Thaba

Input suppliers

The input suppliers in the study area include the Farmers' Cooperative (NTK), general dealers, Progress Milling and the Department of Agriculture. These participants are responsible for supplying inputs to the farmers, such as fertilizers and pesticides. The farmers are able to ask these participants for more information regarding cowpea production and other agriculture-related matters.

Smallholder cowpea farmers

The role smallholder cowpea farmers play in the value chain is that they serve as a link between the input suppliers and consumers. These farmers play the main role in the chain by adding value through the production of cowpea and making it available to consumers. On the other hand, these cowpea farmers serve as a market for input suppliers like NTK, general dealers and Progress Milling. After production, farmers package cowpea in different sizes.

Local wholesalers

Wholesalers are able to buy cowpeas in surplus at a low price from the farmers and later sell the produce to consumers at a higher price than that for which they initially bought the produce. The reason for this is that they add value to the product in the form of packaging, making it attractive for the consumers to buy. They also provide storage.

Local processors

Smallholder cowpea farmers take their seeds to the processing company, where local processing adds value to the cowpea by cleaning, grading and storing the product. Since farmers do not have the facilities to store and grade their produce, they take their post-harvests to local processors.

Local traders and hawkers

The role of local traders and hawkers along the value chain is that they help farmers to generate more sales from their harvests. They sell various fruits and vegetables as a way of earning a living. Cowpea is known in local communities for its importance as a relish to supplement maize. Informal traders serve as a link between suppliers and consumers. They also provide a reliable market for the farmers. The informal traders buy cowpea seeds in larger quantities from farmers. Cowpea would be packaged in different sizes ready to be sold. However, the way in which the product is packaged does not involve too much value addition as generic packaging is employed to make the product more presentable.

Final consumers

Final consumers as participants in the cowpea value chain include people in surrounding villages and towns. The role these consumers play in the cowpea value chain is that they make farmers aware of what kind of seeds need to be produced through their preference of what they buy. Final consumers serve as the main market for cowpea farmers, informal traders, local wholesalers and some of the input suppliers in Ga-Molepo in the sense that they have a choice to buy from different participants in the cowpea value chain.

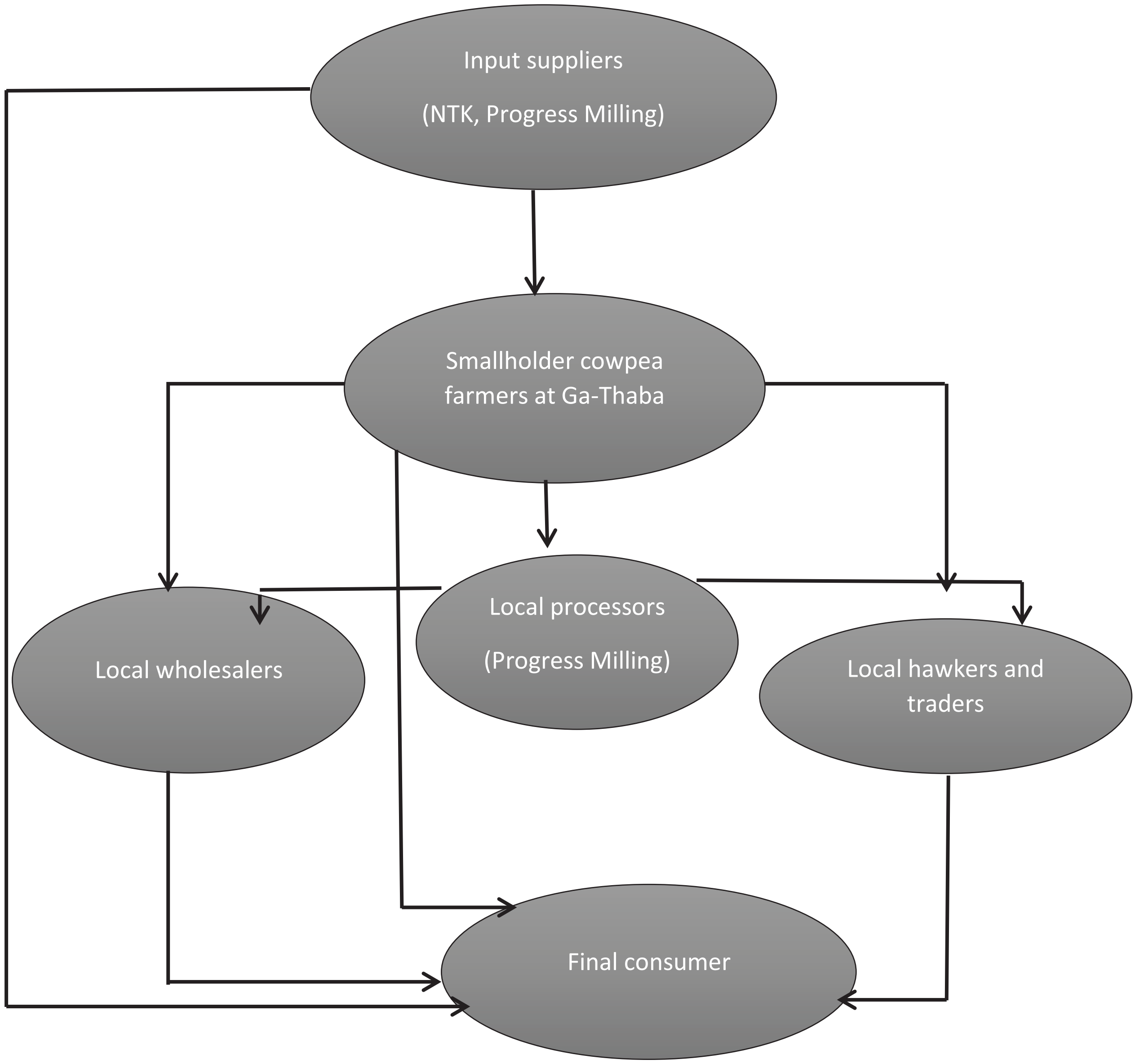

Figure 5.18: Value chain mapping of cowpea at Ga-Thaba

Source: Authors' sketch from survey data

Several farmers at Ga-Thaba engage in crop farming, particularly cowpea, among other crops. Figure 5.18 shows that the farmers purchase inputs from the suppliers. These include seeds, fertilizers and pesticides. Although growing cowpea does not need the application of fertilizers as it fixes nitrogen in the soil, the fertilizers are bought so as to strengthen the soil further for planting maize. These farmers intercrop cowpea with maize. For this reason, comparatively little fertilizer is applied. During the interviews, some of the farmers growing cowpea indicated that they usually take their cowpea to local processors and these processors sell the cowpea directly to the final consumers, as well as to other participants in the value chain.

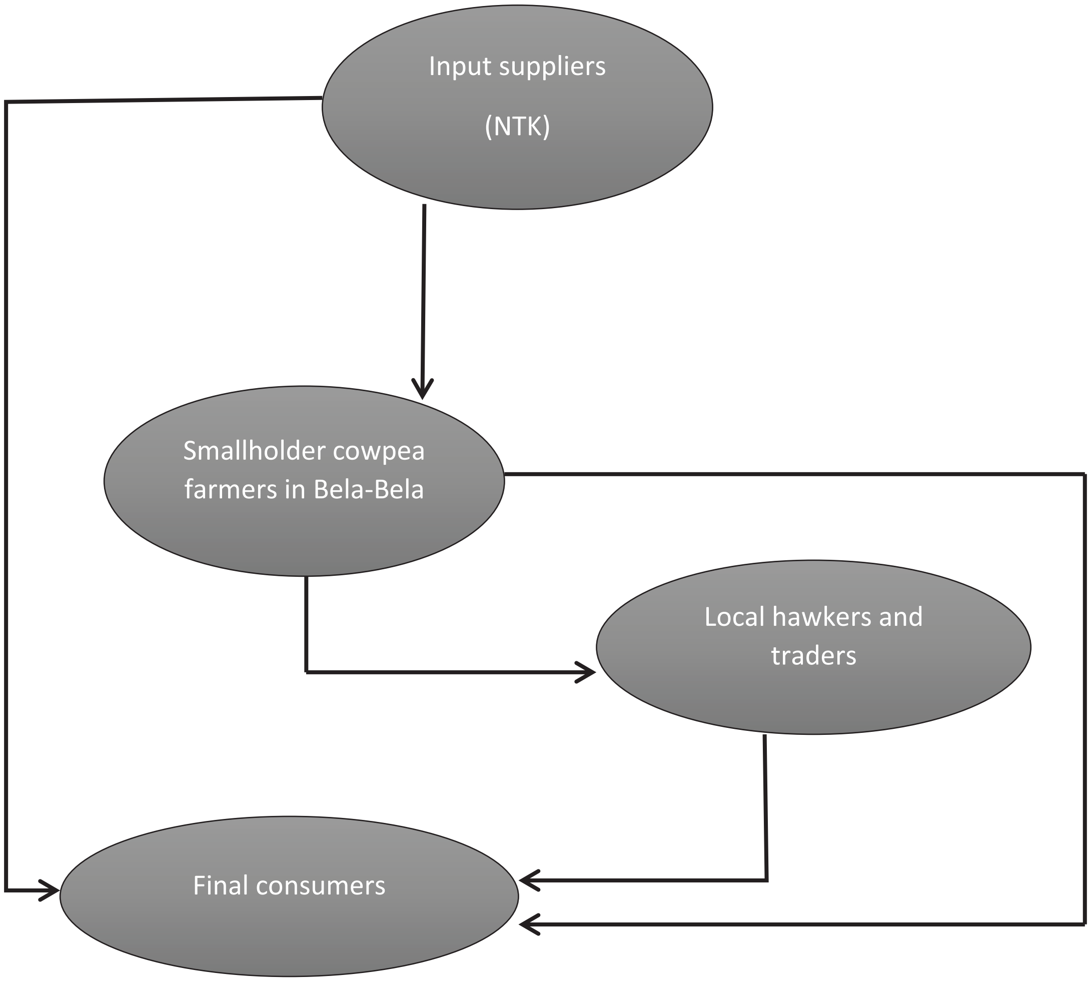

Figure 5.19: Value chain mapping of cowpea at Bela-Bela in the Waterberg district

Source: Authors' sketch from survey data

Bela-Bela is a small area in the Waterberg district, which is a few kilometres from Gauteng. The farmers in this area are predominantly small-scale farmers, producing mostly for their own consumption and for some income generation. They mostly grow sunflower, maize, sorghum, sugar beans, butternuts, sugarcane and cowpea. The smallholder farming in this area includes livestock, which mostly involves cattle farming. Some of these farmers also produce fruit and vegetables on a larger scale compared to cowpea because they are able to take their produce to the Johannesburg Fresh Produce Market. Cowpea production in Bela-Bela is still at a low level, where smallholder farmers grow the crop mainly for their own consumption. A few of the farmers interviewed are able to produce the crop for both own consumption and to generate an income. In mapping the value chain, farmers indicated that they buy the seeds from suppliers in town, plant them and sell the harvest to people living in the surrounding villages.

5.11.2 Participants and their roles in the cowpea value chain at Bela-Bela

Input suppliers

Input suppliers in Bela-Bela comprise NTK as the main supplier of agricultural production inputs (Figure 5.19). They are responsible for supplying inputs to the farmers, such as seeds, fertilizers and pesticides. The farmers are able to ask them for more information regarding what they are producing, and the suppliers are able to help them.

Smallholder cowpea farmers

The role smallholder cowpea farmers play in the value chain is the actual cowpea production, producing the crop in the most suitable manner, and achieving quality yields, which are made available to consumers. The smallholder cowpea farmers in Bela-Bela also serve as a link between the input suppliers and the final consumers. The final consumers serve as the main market for these cowpea farmers as the major part of their harvest is bought and consumed by people from neighbouring villages.

Informal traders and hawkers

The role of traders and hawkers along the value chain is that they help farmers generate more sales from their harvest, but they also make a profit for themselves in the process. The local hawkers buy cowpea seeds from the farmers, and direct the sales to the final consumer.

Final consumers

Consumers are the most important factor in the value chain because they serve as the main market for input suppliers, smallholder cowpea farmers and informal traders. They add value to cowpea farmers by buying the final product, alerting them indirectly about their preferences and what kind of seeds they want to buy; thus, what needs to be produced, as these consumers are always looking to get the best value for money.

5.12 MARKETING EFFICIENCY AMONG SMALLHOLDER COWPEA FARMERS

Table 5.11: Frequency and percentage of farmers' marketing efficiency and inefficiency

	Frequency	Percentage (%)
Marketing efficiency	53	66
Marketing inefficiency	27	34
Total	**80**	**100**

Source: Authors' computation from survey data

Table 5.11 shows the frequencies and percentages of smallholder cowpea farmers in being efficient and inefficient in marketing cowpea. Results from descriptive statistics reveal that 53 (66%) of the 80 interviewed farmers are efficient in marketing cowpea, while the remaining 27 (34%) are inefficient.

5.13 DETERMINANTS OF MARKETING EFFICIENCY (BINARY LOGISTIC REGRESSION MODEL RESULT

Table 5.12 shows the results from the binary logistic regression model, which indicates that seven of the ten variables that were regressed (age, household size, years in schooling, occupation of the farmer, years in farming cowpea, quantities at which cowpea is sold and income generated from selling cowpea) are significant in influencing the marketing efficiency of cowpea farmers in Ga-Molepo and Bela-Bela. The model was tested for goodness of fit using Hosmer and Lemeshow's goodness-of-fit for logistic regression models. The Hosmer and Lemeshow test shows a Chi-square value of 62.6 and is statistically significant at 1, implying that the model fit the data well.

With regard to coefficient of determination (R^2), for regression models with categorical dependent variables such as the binary logistic regression, it is not possible to compute the R^2. Therefore, approximations such as the Nagelkerke R^2 are calculated instead. Nagelkerke R^2 was used in this study as a proxy estimate to R^2, which measures the variation in the response that is explained by the model. The Nagelkerke R^2 is found to be 91.1%, which indicates that 91.1% of the variation in the marketing efficiency of cowpea farmers is explained by the explanatory variables. The log likelihood value is 16.565 and the Cox and Snell R^2 is 65.8%.

5.13.1 Age of the cowpea farmers

The results show that age has a positive coefficient of 0.435 and is statistically significant at the 5% level. The positive coefficient suggests that there is a positive relationship between age and the marketing efficiency of smallholder cowpea farmers. A study done by Oteh and Njoku (2014) finds that age is negatively significant to the marketing efficiency of farmers. The authors highlight that it can be expected that an increase in the age of the farmer will bring about a decrease in marketing efficiency, since as a farmer gets older, the less likely they are to adopt new technologies to improve their marketing efficiency. However, this is not consistent with findings of Farayola et al. (2013), who find that an increase in the age of the farmer leads to an increase in their marketing efficiency. This is also corroborated by the results from the descriptive statistics of this study that show that the maximum age of farmers producing cowpea is 83, with the average being 63 and the minimum being 26. Most of the time, farmers are regarded as being illiterate, and therefore unable to adopt new methods introduced. Experience is an important factor in this regard. Cowpea can be tiring to plant and therefore needs farmers who have patience and a passion for the crop. Ovwigho and Ifie (2009), as cited by Adesina and Eforuoku (2016), mention that young people are not interested in hard labour, more specifically agriculture, as they perceive it as to be hard and dirty.

5.13.2 Household size of cowpea farmers

Household size is found to be statistically significant at the 5% level, p-value of 0.026 with a positive coefficient of 1.710 and odds ratio of 5.530. This shows that the number of people in the household has a positive influence on the marketing efficiency of cowpea farmers. As a household size increases, the odds are that it is 5.530 times more likely that the farmer will use family labour to increase their marketing efficiency if all other independent variables are held constant. This is supported by Oteh and Njoku (2014), indicating that household size is positively significant at the 5% level. It is further stated that large household sizes are seen as an advantage in terms of contributing to labour and, as such, is perceived as being a source of cost reduction. In support of this statement, Etwire et al. (2013) also find that there is a positive relationship between household size and participation in agricultural practices. Farmers with a large household can delegate important activities to other household members, while they participate in agricultural projects.

5.13.3 Years of schooling

Number of years of schooling of a household head was found to be significant at 10% with a p-value of 0.058. The number of years a farmer has been at school has an impact on how a farmer responds to adopting information, or even new technologies, which will help them improve their marketing efficiency. Nnadi and Akwikwu (2008) also mentioned that years in schooling affects the use of information efficiently, emphasising that the more years a farmer has been at school, the less likely they are to have difficulty adopting modern agricultural technologies. However, Farayola et al. (2013) find that a farmer's years in schooling is highly significant, but negatively related to marketing efficiency. The results are in contrast with former expectations as it was expected that education should enhance the level of market information, hence marketing efficiency.

5.13.4 Occupation of cowpea farmers

The occupation of cowpea farmers has a negative influence on their marketing efficiency. The variable is significant at the 5% level, with a p-value of 0.029, a coefficient of 1.137 and a log odds ratio of 0.321. The descriptive statistics on the occupation of the farmer indicates that a farmer does not solely have farming as an occupation, but has other work commitments besides farming. Only 37 of the 80 farmers interviewed were full-time farmers. The negative relationship means that the more jobs a farmer has, while holding all other variables constant, the smaller the likelihood of a farmer being market efficient. However, Adesina and Eforuoku (2016) and Nnadi and Akwikwu (2008) indicated that parents' engagement in farming as an occupation is significant as a determinant of youth participating in agriculture. This corroborates the fact that the occupation of a farmer influences how successful a farmer will be in their agricultural production.

5.13.5 Years of growing cowpea

Years of having grown cowpea is found to have a negative influence on the marketing efficiency of farmers. Years of farming cowpea is significant at 5% and is negatively related with a coefficient of -0.259. Years of farming cowpea is expected to be positively related with marketing efficiency, as together with experience comes knowledge on how to be market efficient. A study done by Adenuga et al. (2013) on marketing efficiency and the determinants of marketable surplus in vegetable production found that there is a significance and positive relationship between years of farming (experience) and the marketing efficiency of farmers. Farming experience may be due to the fact that experienced farmers are more enlightened. They are thus familiar with the efficient marketing tools of their marketable surplus and are able to reduce market loss. However, Farayola et al. (2013) state that there is no significance or relationship between marketing experience and the marketing efficiency of cocoa farmers.

5.13.6 Quantities of cowpea sold

Quantities of cowpea sold is found to be statistically significant at 10%, with a p-value of 0.054 and a coefficient of -0.541, which indicates that the variable is negatively related to marketing efficiency. This means that, with an increase in quantity sold, there is a decrease in the marketing efficiency of cowpea farmers. Since the descriptive statistics shows that more farmers have access to informal markets (78%), this implies that consumers have the freedom to buy cowpea wherever the quantities sold are being sold at a reasonable price. Consumers are likely to get the best value for their money. Farayola et al. (2013) find that quantities of cocoa sold are not significantly related to the marketing efficiency of farmers, but that the selling price is significant at the 5% level and positively related to marketing efficiency. A positive relationship between selling price and marketing efficiency could exist because consumers are motivated by a favourable selling price.

5.13.7 Income generated from selling cowpea

The variable income generated from selling cowpea is found to be statistically significant at 5% with a p-value of 0.015, coefficient of -0.016 and odds ratio of 0.984. Income generated by farmers from selling their cowpea is negatively related to marketing efficiency. This means that the amount of money the farmers receive from selling their produce has no effect on how efficient they are in marketing. The results from the descriptive statistics show that only about 22% of the interviewed farmers have access to formal markets, while 78% have access to informal markets. The lack of access to formal markets could have an effect on the income generated, and hence a decrease in marketing efficiency. Farmers do not have a stable and reliable market for their source of income. However, these results are in contrast with findings of Oteh and Njoku (2014), who state that income generated by farmers from selling their products is highly significant and related to marketing efficiency, stating that an increase in income contributes to an increase in marketing efficiency.

Table 5.12: Results from the binary logistic regression model for examining the determinants of marketing efficiency of cowpea farmers in Ga-Thaba and Bela-Bela

Predictor variables	Coefficient (B)	SE	Wald	Significance	Exp (B)
Constant	-21.002	14.729	2.033	.154	.000
Age of the farmer	.435	.195	4.977	.026*	1.545
Gender of cowpea farmers	-2.831	1.852	2.336	.126	.059
Household size	1.710	.780	4.804	.028*	5.530
Years of schooling of cowpea farmers	1.014	.536	3.583	.058**	2.756
Occupation of cowpea farmers	-1.137	.520	4.787	.029*	.321
Land ownership of cowpea farmers	-2.614	6.097	.184	.668	.073
Years of growing cowpea	-.259	.129	4.015	.045*	.772
Quantities of cowpea sold	-.581	.301	3.724	.054**	.559
Income generated from selling cowpea	-.016	.007	5.932	.015*	.984
Access to formal market	-.332	1.592	.044	.835	.717
Model summary					
Chi-square (df = 8)					.626
-2 Log likelihood					16.565
Cox and Snell R^2					.658
Nagelkerke R^2					.911
Note at * ,**, indicate significant at 0.05 and 0.10 respectively					

Source: Authors' computation from survey data.

5.14 CONSTRAINTS TO AND PROSPECTS OF COWPEA PRODUCTION AND MARKETING AS AN INCOME-GENERATING VENTURE (WELFARE BOOSTER) AMONG SMALLHOLDER FARMERS IN LIMPOPO

Table 5.13 highlights a number of constraints that hinder farmers in marketing their cowpeas. A descriptive analysis of the constraints indicated that, among all the challenges and constraints farmers were facing, pests were the most problematic. This is due to the fact that cowpeas are subject to weevils, aphids and other types of bugs, which suck on pods and leave the outer part of the cowpea. This leads to farmers having nothing or less to sell, which is a big concern since they are losing out on making a profit. These farmers are operating on a small-scale basis and therefore do not have adequate storage facilities. However, some farmers manage to send their cowpeas to processing or milling facilities to process and store their produce. Farayola et al. (2013) highlight that, among the problems facing cocoa marketers, inadequate storage facilities, pests, diseases, price instability and the high cost of transportation were the most problematic, with pests and diseases ranking number one.

Table 5.13: Constraints encountered in producing, marketing and selling cowpea

Challenges	Frequency	Percentage (%)
Pests and access to markets	13	16.3
Lack of access to markets	2	2.5
Pests and lack of access to credit	4	5.0
Lack of access to credit	6	7.5
Lack of information on how to process cowpea	9	11.3
Weeds and pest problems	6	7.5
Pests	23	28.8
Pests and water shortages	8	10.0
Others	9	11.3
Total	80	100

Source: Authors' computation from survey data

5.15 CONCLUSIONS

The main aim of the study was to map the value chain and determine the marketing efficiency of smallholder cowpea farmers in the Capricorn and Waterberg districts of Limpopo. The first objective of the study was to identify and describe the socioeconomic characteristics of smallholder cowpea farmers. The second objective was to identify and define the participants along the cowpea value chain. The third objective was to determine the marketing efficiency of smallholder cowpea farmers. The fourth objective was to examine the determinants of marketing efficiency. The last objective was to identify marketing constraints among smallholder cowpea farmers.

Data was collected from 80 smallholder cowpea farmers, using a structured questionnaire and purposive sampling technique at Ga-Thaba in the Capricorn District and Bela-Bela in the Waterberg District. Data collected was analysed using descriptive statistics and the binary logistic regression model. Information regarding the value chain was mapped to indicate the different stages cowpea goes through before it reaches the final consumer. In determining the marketing efficiency of smallholder cowpea farmers, a marketing efficiency measure was used.

Descriptive statistics was used to address the first objective. The second objective was addressed by compiling a value chain map showing all the stakeholders involved before the product reaches the final consumer. The third objective was addressed by using a marketing efficiency measure to find out if farmers were efficient in marketing their product. The fourth objective was addressed using a binary logistic regression model. Descriptive statistics was also used to address the last objective.

5.16 DECISION ON THE NULL HYPOTHESES

Both of the two null hypotheses in this study were rejected.

The first hypothesis, which stated that smallholder cowpea farmers in the Capricorn and Waterberg districts are inefficient in marketing cowpea, was rejected based on the marketing efficiency measure that was used to determine each farmer's marketing efficiency. The results of the descriptive statistics indicated that 53 of the 80 farmers (66% of the farmers) were efficient in marketing cowpea. This was supported by the results from the binary logistic regression model, which revealed that seven of the 10 variables that were considered were significant in determining the marketing efficiency of cowpea farmers.

The second hypothesis, which stated that the socioeconomic characteristics of smallholder cowpea farmers have no effect on their marketing efficiency, was rejected as the results from the binary logistic regression model revealed that the variables age of the farmer, household size, years of schooling, income generated from selling cowpea and occupation of the farmer had a positive influence on marketing efficiency. Variables such as occupation of the farmer, years of farming cowpea, quantities of cowpea sold and income generated from selling cowpea were found to have a negative influence on the marketing efficiency of cowpea farmers in both Ga-Thaba and Bela-Bela.

Value chain mapping in Ga-Thaba indicated that the main participants in the cowpea value chain in the Capricorn District were input suppliers, smallholder cowpea farmers, local wholesalers, local hawkers and traders, local processing companies, contractors and the final consumer. It was indicated that each participant in the value chain added value to the product to ensure profitability, while the final consumers got value for their money.

In Bela-Bela, the value chain map for the Waterberg District showed that the main participants in the value chain of cowpea were input suppliers, smallholder cowpea farmers, local hawkers and traders, processors and final consumers. Most farmers in Bela-Bela are engaged in farming, particularly farming sunflower, maize and other types of beans. Cowpea is produced at a small scale and hence there are not many participants in the value chain. Farmers in this area have great interest in farming cowpea on a larger scale. Lack of information on how to farm cowpea to be profitable, and lack of access to high-yielding, pest-resistant and heat-resistant seeds inhibit farmers from succeeding.

Using the marketing efficiency measure to determine if smallholder cowpea farmers were efficient or not, it was found that 66% of the farmers were efficient and 34% of the farmers were inefficient. A binary logistic regression model was used to examine the determinants of marketing efficiency. Age of the household head, household size and years of schooling were found to be positively significant, while years of farming cowpea, income generated from selling cowpea, quantities at which cowpea is sold and occupation of the household head were found to be negatively significant. The implication of these negatively significant variables is that the likelihood of smallholder cowpea farmers being market efficient decreases with years of farming, income generated from selling cowpea, quantities of cowpea sold and occupation of the farmer. Other variables that were considered were gender of the household head, access to the formal market and land ownership, which were all found to be negatively significant. This implies that these variables had no impact on the marketing efficiency of smallholder cowpea farmers.

Constraints were identified that smallholder cowpea farmers encountered with regard to the production, marketing and selling of cowpea. The constraints encountered included a lack of access to formal markets, a lack of information on how to process cowpea, weed infestation and water shortages, among other challenges. Pest problems were the main challenge farmers faced regarding cowpea production.

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CHAPTER 6: STIMULATION OF SUSTAINABLE DEVELOPMENT THROUGH THE IMPROVEMENT OF TRADITIONAL AGRONOMIC PRODUCTION PRACTICES, PREPARATION OF COWPEA DIETS AND CULTIVATION OF RESOURCE-USE EFFICIENT LEGUMES: TRANSFORMATION

JAN Asiwe and DN Asiwe

6.1 INTRODUCTION

To stimulate the sustainable development of improved cultural practices, on which farmers have received training and adopted, it is important that demonstration plots are continually planted and that farmers upscale the practices (strip intercropping) and production of their chosen crop varieties. This enables the production of seed for home consumption and sale to generate a family income, as well as to enhance dietary intake and nutrition.

6.2 MATERIALS AND METHODS

Two demonstration plots were planted by farmers at Ga-Thaba and Bela-Bela during the 2017/18 growing season. In addition, farmers were given a 2-3 kg seed package of cowpea and pigeonpea varieties to plant on their private or personal farms and in their home gardens. The demonstration plots were solely managed by the farmers. Pre- and post-emergence herbicides (Dual and Roundup) were applied two to three days after planting, and subsequent weed control was effected using Fusilade and Bentazone, which are selective herbicides for both grass and broadleaf weed situations. All the herbicides were applied at 3 ℓ of the formulation per hectare, except Dual, which was applied at 0.5 ℓ ha-$^{1.}$ Insect pests, particularly blister beetles, defoliators and pod-sucking bugs, were controlled using Karate at the recommended rate of 1 ℓ ha-^{1}. Grain yield collected by farmers was analysed and presented in Table 6.1 and Table 6.2. To back up seed production and reduce the risk of crop failure, multiplication plots were esterblished at Taung, Venterdorp and Koster.

6.3 RESULTS AND DISCUSSION

Results show that significant differences ($P < 0.05$) were obtained among varieties, cropping system and location (Table 6.1). Demonstration plots at Ga-Thaba and UL-Farm were considered. The demonstration plots at Bela-Bela failed due to poor establishment, even in two plantings, due to a prolonged dry spell during the planting time. Results show that ICEAP 001284 outperformed ICEAP 01101-2 due to its early flowering and it maturing earlier than ICEAP 01101-2, which is an indeterminate variety. Among cropping systems, strip intercropping performed better than monocropping and mixed intercropping. Between the two locations, Ga-Thaba performed better than UL-Farm as a result of better rainfall distribution during crop growth. The results also indicate that interactions between variety and location, as well as between cropping system and location, were significant ($P < 0.05$), indicating the impact played by location as affected by weather variables, especially rainfall and temperature.

For the grain yield of cowpea, results indicate that significant differences ($P < 0.05$) were obtained among varieties, cropping system and location (Table 6.2). Demonstration plots at Ga-Thaba and UL-Farm were considered. The trial at Bela-Bela failed due to poor establishment because of a prolonged dry spell during the planting time. Results show that IT86D-1010 performed better than IT82E-16. Among cropping systems, strip intercropping performed better than monocropping and mixed intercropping. Strip intercropping was three-fold better than mixed cropping. Between the two locations, UL-Farm performed better than Ga-Thaba as a result of adequate moisture at UL-Farm to better support crop growth than at Ga-Thaba (Table 6.3). No significant interaction was obtained among the factors.

Table 6.1: Mean yield of pigeonpea in two locations (UL-Farm and Ga-Thaba)

Varieties	**Grain yield (kg/ha)**
ICEAP 001284	491.94a
ICEAP 01101-2	345.28b
Grand mean	418.61
P-level	0.0432
Cropping system	
Strip intercropping	562.92a
Monocropping	461.67a
Mixed intercropping	231.25b
P-level	0.0006
Location	
UL-Farm	225.56b
Ga-Thaba	611.67a
P-level	0.0000
Interaction	
V*C	0.2044
V*L	0.0298
C*L	0.0227
V*C*L	0.2160

Table 6.2: Mean yield of cowpea varieties in two locations (UL-Farm and Ga-Thaba)

Varieties	**Grain yield (kg/ha)**
IT86D-1010	623.19a
IT82E-16	527.78b
Grand mean	575.49
P-level	0.03
Cropping system	
Strip intercropping	806.25a
Monocropping	676.87a
Mixed intercropping	243.33b
P-level	0.02
Location	
UL-Farm	649.44
Ga-Thaba	501.53
P-level	0.22
Interaction	
V*C	0.7958
V*L	0.9103
C*L	0.5291
V*C*L	0.9334

Photograph 6.1: IT86D-1010 at maturity in the field

Photograph 6.2: IT82E-16 in the field

6.4 CAPACITY BUILDING AND STUDENT PARTICIPATION

The capacity building report is given in Appendix 1. Four students participated in the project. They were Ms KA Maimela and Ms KS Madimabe, who worked on strip intercropping with cowpea and pigeonpea, respectively, while Ms SV Chauke and Ms CM Masegela were involved in the socioeconomic aspects of the project. Ms KA Maimela, Ms KS Madimabe and Ms CM Masegela graduated in April 2019, while Ms SV Chauke graduated in September 2018. Apart from the fact that these students obtained their degrees through this project, they also benefitted from the training conducted for the farmers on both the agronomic and entrepreneurial aspects of cowpea production as a profitable venture to stem the tide of rising unemployment in the study area. The students acquired demonstrable skills in cowpea production and utilisation. Three of them are gainfully employed. The abstracts of their mini-dissertations are presented in appendices 4 to 6.

Project No 2494

Project title: Enhancing food security and nutrition of selected rural communities in Limpopo Province using high-yielding and water use efficient grain legume varieties

Project leader: Prof JAN Asiwe

Organisation: University of Limpopo

Table 6.3: Capacity building report for 2018/19

Student name	Gender	Race	Degree	University	Country of origin	Student email address	Year of graduation
KA Maimela	F	B	MSc	UL	SA	katlegoalocia@gmail.com	2019
SV Chauke	F	B	MSc	UL	SA	chaukeshiluva@gmail.com	2019
KS Madimabe	F	B	MSc	UL	SA	kokestomadimabe@gmail.com	2019
CM Masegela	F	B	MSc	UL	SA	Kgaogelo.masegela@gmail.com	2019

F = Female; B = Black; UL = University of Limpopo; SA = South Africa

6.5 IMPROVEMENT OF DIET

Part of the objectives of this project was to train and capacitate farmers in the preparation of cowpea and pigeonpea menus. This was not only to improve their dietary intake and nutrition, but also to stimulate the utilisation and production of these crops in the rural communities. A total of 125 farmers received training on cowpea meal preparation in three selected communities (Ga-Thaba, Ga-Chuene and Bela-Bela). Table 6.4 shows details of the training received by farmers to improve their diets. The menus and recipes are shown in detail in Volume 2 of this project report.

Table 6.4: Training on cowpea menus received by farmers at Ga-Thaba, Ga-Chuene and Bela-Bela

Training received	Number of farmers (Ga-Thaba and Ga-Chuene) N = 45	Number of farmers (Bela-Bela) N = 80
Cowpea/pigeonpea cake (Akara)	45	80
Bean pudding (Moin-moin)	45	80
Cowpea or pigeonpea soup	45	80
Cowpea or pigeonpea porridge + bread	45	80
Bean + rice	45	80
Cowpea + potato	45	80
Cowpea + butternut	45	80
Cowpea or pigeonpea + pap	45	80
Cowpea or pigeonpea + custard	45	80
Processing of cowpea or pigeonpea seed for menu preparation	45	80

6.6 INNOVATION

Part of the outcomes of this project was to bring innovative practices to the farmers that will increase their productivity, skills, dietary intakes and utilisation, as well as to generate an income. The indicators listed below are key indicators of innovative end-products achieved by the project.

- Three high-yielding, pest-resistant and water use efficient cowpea varieties (IT82E-16, IT86D-1010 and IT97K-499-35) were introduced and adopted by farmers. These varieties were selected by farmers because they performed better than the local control (Glenda).
- Two high-yielding, pest-resistant and water use efficient pigeonpea varieties (ICEAP 001284 and ICEAP 01101-2) were selected by farmers because they performed well in terms of water use efficiency, early maturity and grain yield.

- A new intercropping system (strip intercropping) was introduced and adopted by farmers because it performed better than traditional mixed intercropping.
- In terms of human capital development, four MSc students, six technicians (extension officers) and 125 farmers were trained on improved cowpea and pigeonpea production practices.
- A total of 125 farmers, four MSc students and six technicians were trained on different cowpea and pigeonpea menus and recipes to enhance utilisation, dietary intake and diversity.
- The famers were trained on record-keeping and other farm management techniques for profit-making and the tracking of resources used in production.

6.7 CONCLUSIONS

Water stress will continue to limit crop production, especially in Limpopo, where agricultural production is predominantly rainfed. This problem is aggravated by a lack of improved varieties of grain legumes. The development of climate-smart varieties through breeding and the application of improved cultural practices are panacea for adapting to or mitigating the effects of climate change on crop production. The findings of the study have demonstrated and proved that improved cowpea and pigeonpea varieties are superior over the local varieties and can improve the productivity of farmers in rural areas. Farmers should continue to cultivate the adopted varieties to enhance their crop diversity and nutrition security. The study also showed that strip intercropping has performed better than traditional mixed intercropping and it is recommended that farmers should continue to practise strip intercropping on their farms and in their home gardens.

The training offered to farmers was to empower them with agronomic skills in profitable cowpea and pigeonpea production and to utilise the crop through agro-processing training in order to improve their dietary intake to prevent malnutrition and avoid over-dependence on sole maize meal diets. The production guide will assist farmers with any technical or agronomic operation problems. The introduction of different cowpea menus to farmers was an eye-opener to realise the potential of indigenous legumes to improve their nutrition and dietary diversity. Farmers should continue to use the legumes in their homes and train other members of their communities. The recipes will assist end-users to prepare cowpea and pigeonpea, and improve their daily diets.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Drought and the lack of good agronomic practices and cropping systems continue to pose constraints on crop production in drought-prone ares of South Africa, especially in Limpopo. This problem is worsened by the lack of improved varieties of grain legumes. The development of climate-smart varieties through breeding and the application of improved cultural practices are panacea for adapting to or mitigating the effects of climate change on crop production. This project addressed ways to enhance sustainable food production, food security and nutrition in drought-prone communities in Limpopo through the introduction and cultivation of high-yielding, and water use efficient cowpea and pigeonpea, as well as strip intercropping. The key outcomes of this study are summarised below.

In the validation trials, baseline data was generated to make informed decisions to select varieties that were used in the intercropping experiments. In light of this, cowpea and pigeonpea varieties that combine early maturity and high grain yield were selected. Cowpea varieties selected included IT82E-16, 82D-889, IT86D 1010, TVu 13464 and IT001263. Pigeonpea varieties selected included ICEAP 01284, ICEAP 00604, ICPL87091, ICEAP 00661 and ICEAP 00101-2.

In drought–prone environments such as those found in the study areas, the identification and selection of varieties that are resource-use efficient are critical to sustaining food security and nutrition in rural communities. This study has provided agronomic data for farmers to make an informed decision to select varieties that have performed well under rainfed condition in their communities. The findings of the study have demonstrated and proved that improved cowpea and pigeonpea varieties are superior over local varieties and can improve the productivity of farmers in rural areas. The study showed that IT86D-1010, IT87K-499-35, IT82E-16 and TVu 13464 performed better than Glenda in terms of early maturity, grain yield and water use efficiency. Farmers could select these varieties as preferred varieties in addition to their seed qualities, size and colour. Therefore, they were recommended for cultivation in the study areas. The study also provided significant information and agronomic data, including an LER that suggests that strip intercropping is superior to and performed better than traditional mixed intercropping. For the sustainability of the cowpea production and cropping system, the four varieties were recommended to farmers for adoption and cultivation in their demonstration plots.

The findings of this study also showed that pigeonpea varieties ICEAP 01101-2, ICEAP 001284 and ICEAP 00661 performed very well in terms of early maturity, grain yield and water use efficiency. Farmers were able to identify these varieties, which were recommended for cultivation in the study areas. The study also provided useful agronomic data, including an LER and a WUE valuen that suggest that the strip intercropping of pigeonpea with maize was superior and performed better than traditional mixed intercropping.

The implications drawn from the variables to which the farmers responded in the survey provided significant information, which indicated that the project was appropriate to meet the needs of the farmers, filling the gaps identified at the commencement of the project, as well as showing the impact and innovations attained by the project in the improvement of the dietary, intake and diversities of crops grown and nutrition in the selected communities. The post-project commencement survey revealed that the poject was successfully able to add value to the livelihoods of the farmers in terms of crop diversification, food security and the dietary diversity of people in the study areas.

Part of the objectives of this project was to train and capacitate farmers in the preparation of cowpea and pigeonpea menus. This was not only to improve their dietary intake and nutrition, but also to stimulate the utilisation and production of these crops in rural communities.

A total of 125 farmers received training on cowpea meal preparation in three selected communities (Ga-Thaba, Ga-Chuene and Bela-Bela). The training offered to the farmers was to empower them with agronomic skills in profitable cowpea and pigeonpea production and to utilise the crop through agro-processing training in order to improve their dietary intake to prevent malnutrition and avoid over-dependence on sole maize meal diets. The introduction of different cowpea menus to farmers was an eye-opener to realise the potential of indigenous legumes in improving their nutrition and dietary diversity. Farmers should continue to use the legumes in their homes and train other members of their communities. The recipes will assist end-users to prepare cowpea and pigeonpea and improve their daily diets.

Four students participated in the project. They were Ms KA Maimela and Ms KS Madimabe, who worked on strip intercropping with cowpea and pigeonpea, respectively, while Ms SV Chauke and Ms CM Masegela were involved in the socioeconomic aspects of the project. Ms KA Maimela, Ms KS Madimabe and Ms CM Masegela graduated in April 2019, while Ms SV Chauke graduated in September 2018. Apart from the fact that these students obtained their degrees through this project, they also benefitted from the training conducted for the farmers on both the agronomic and entrepreneurial aspects of cowpea production as a profitable venture to stem the tide of rising unemployment in the study area. The students acquired demonstrable skills in cowpea production and utilisation. Three of them are already gainfully employed.

For sustainable development, the study showed that farmers planted demonstration plots consisting of selected pigeonpea (ICEAP 001284 and ICEAP 01101-2) and cowpea (IT86D-1010 and IT82E-16) varieties in strip intercropping with maize. Although farmers were able to produce more than 500 kg of cowpea grain from their demonstration plots, they had none left over for the following season's planting because they shared and consumed all they produced. "They often say that cowpea is very delicious." This implied that greater seed increase and commercialisation are needed to meet the seed demand. Farmers reported that, among cropping systems, strip intercropping performed better than monocropping and mixed intercropping. Among the three locations used in the study (UL-Farm, Bela-Bela and Ga-Thaba), Bela-Bela was the most unpredictable location in terms of weather condictions. In favourable weather conditions, it could support the best yield, but in bad weather conditions, it could lead to 100% crop failure.

The study on the economic efficiency of cowpea production among smallholder farmers in the Capricorn and Waterberg districts was examined. The study used three techniques to analyse data: descriptive statistics, DEA and the Tobit regression model. While descriptive statistics was used to analyse and describe smallholder cowpea farmers' socioeconomic characteristics, DEA was employed to determine the farmers' efficiency levels, and the Tobit regression model was used to explain the determinants of the technical, allocative and economic efficiency of smallholder cowpea farmers in the study area.

The study used all the necessary official documents, statistics, data programs, as well as relevant literature, to capture information on smallholder cowpea farmers in the two districts of Limpopo. A descriptive analysis of the data collected revealed that 72% of the cowpea smallholder farmers are female, with 28% of the farmers in the study area being male. The study found that the age of the farmers ranged between 33 and 78, with the average age of the farmers being 61 years. The household size of the farmers in the study area was found to range between two and 14, with an average of seven family members per household. The study further indicated that the years of schooling of the interviewed farmers ranged from 0 to 13 years, with an average of five years of attending school. On average, in this study, cowpea smallholder farmers have been involved in farming for more than 38 years, with a range of between three and 58 years. The average income they receive from agricultural production was R1,735.83 per month.

The DEA results of the study show that the technical efficiency scores of cowpea farmers have a mean of 0.9588 with a minimum of 0.75 and a maximum of 1. This means that 95% of the farmers are technically efficient and that farmers are able to produce over 75% of the maximum feasible output. The allocative efficiency scores range from a minimum of 0.4070 and a maximum of 1 with a mean of 0.6519. The allocative efficiency scores, however, imply that farmers are not utilising inputs efficiently. Given the current price of inputs, average costs may be reduced by about 35% to obtain the same level of output. The economic efficiency scores ranged from a minimum of 0.3820 to a maximum of 1 with a mean score of 0.6218. The implications are that smallholder cowpea farmers are economically inefficient on average and that the cost of cowpea production for each farm could be reduced on average by approximately 38% to obtain the same level of output.

The study also found that socioeconomic factors that influence economic efficiency include age, educational level, primary source of income and status of land ownership. The age of the farmers is significant at 1% with a negative coefficient of -0.021559. Primary education is found to positively influence economic efficiency at 5% with a positive coefficient of 0.6266. Pension and child grants are some of the categories of source of income that are found to have a positive relationship with economic efficiency, with a coefficient of 0.2424 and 0.5983, respectively.

Based on the empirical results of the analysis, the study concludes that smallholder cowpea farmers in the Capricorn and Waterberg districts, despite being technically efficient, are economically inefficient and that the cost of cowpea production for each farm could be decreased, on average, by approximately 38% to obtain the same level of output.

The aim of the study on the value chain was to determine the marketing efficiency of smallholder cowpea farmers in the Capricorn and Waterberg districts of Limpopo. The first objective of the study was to identify and describe the socioeconomic characteristics of smallholder cowpea farmers. The second objective was to identify and define the participants along the cowpea value chain. This was addressed by a value chain map showing all the stakeholders involved before the product reaches the final consumer. The third objective was to determine the marketing efficiency of smallholder cowpea farmers. To address this objective, a marketing efficiency measure was used to find out if farmers were efficient or inefficient in marketing their product. The fourth objective was to examine the determinants of marketing efficiency. This objective was addressed using a binary logistic regression model. The last objective was to identify marketing constraints among smallholder cowpea farmers. This objective was addressed using descriptive statistics.

7.2 DECISION ON THE NULL HYPOTHESES

With regard to the two null hypotheses of this study, both hypotheses were rejected. The first hypothesis stated that smallholder cowpea farmers in the Capricorn and Waterberg districts are inefficient in marketing cowpea. It was rejected based on the marketing efficiency measure that was used to determine each farmer's marketing efficiency. Descriptive statistics results indicated that 53 out of 80 farmers (66% of the farmers) were efficient in marketing cowpea. This was supported by the results from the binary logistic regression model that revealed that seven of the 10 variables that were considered were significant in determining the marketing efficiency of cowpea farmers.

The second hypothesis stated that the socioeconomic characteristics of smallholder cowpea farmers have no effect on their marketing efficiency. It was rejected as the results from the binary logistic regression model revealed that the variables of age of the farmer, household size, years of schooling, income generated from selling cowpea and occupation of the farmer had a positive influence on marketing efficiency. Variables such as occupation of the farmer, years of farming cowpea, quantities of cowpea sold and income generated from selling cowpea were found to have a negative influence on the marketing efficiency of cowpea farmers in both Ga-Thaba and Bela-Bela.

The value chain mapping conducted at Ga-Thaba in the Capricorn District indicated that the main participants in the cowpea value chain were input suppliers, smallholder cowpea farmers, local wholesalers, local hawkers and traders, local processing companies, contractors and the final consumer. It was indicated that each participant in the value chain added value to the product to ensure profitability, while the final consumers got value for their money.

In Bela-Bela in the Waterberg District, the value chain map showed that the main participants in the cowpea value chain were input suppliers, smallholder cowpea farmers, local hawkers and traders, processors and final consumers. Most farmers in Bela-Bela are engaged in farming, particularly the farming of sunflower, maize and other types of beans. Cowpea is produced on a small scale; hence, there are not many participants in the value chain. Farmers in this area have a great interest in farming cowpea on a larger scale. Lack of information on how to farm cowpea profitably, and lack of access to high-yielding, pest-resistant and heat-resistant seeds inhibit the farmers from succeeding.

Using the marketing efficiency measure to determine if smallholder cowpea farmers were efficient, it was found that 66% of the farmers were efficient and that 34% of the farmers were inefficient. A binary logistic regression model was used to examine the determinants of marketing efficiency. Age of the household head, household size and years of schooling were found to be positively significant, while years of farming cowpea, income generated from selling cowpea, quantities at which cowpea is sold and occupation of the household head were found to be negatively significant. The implication of these negatively significant variables is that the likelihood of smallholder cowpea farmers being market efficient decreases with years of farming, income generated from selling cowpea, quantities of cowpea sold and occupation of the farmer. Other variables that were considered were the gender of the household head, access to the formal market and land ownership, which were all found to be negatively significant. This implies that these variables have no impact on the marketing efficiency of smallholder cowpea farmers. Constraints that smallholder cowpea farmers encountered with regard to production, marketing and selling cowpea were identified. The constraints encountered included lack of access to formal markets and lack of information on how to process cowpea, weed infestation and water shortages, among other challenges. Pest problems were the main challenge farmers faced regarding cowpea production.

7.3 RECOMMENDATIONS

Two important challehges that were encountered during the project execution included seed increase and weed control. Although, farmers generated a lot of seeds from their demonstration plots, they could not retain or save more than 5 kg of seed for the next season's planting because they could not resist the temptation of consuming almost all the seeds they produced during the season. "They often say that cowpea is very delicious." This implies that an extrogenous seed supply source is critically needed to support and produce seed for the sustainability of the project until the farmers are self-sufficient to produce above their home consumption.

The commercialisation of the recommended varieties is the way to address this challenge. The varieties need to be commercialised to upscale the project. The commercialisation of the varieties, on the other hand, should be matched with the extensive promotion of menus and recipes so that the demand pull of utilisation will create supply and incentives for farmers to produce. It is therefore recommended that the varieties be commercialised to produce enough seed for sale in local and urban markets. The seed production of promising varieties of the two legumes studied in this project is critically important for the sustainability of the system in rural communities until cowpea seed is available for consumption and sale in South Africa. Further funding is recommended, and the WRC should take advantage of the work done in this project to provide funding in the critical areas mentioned. The innovative products of this project should be promoted and extended to other local and urban communities, schools, colleges, hotels and correctional services for wider coverage and adoption.

Weeds continue to pose serious interference to crop production, and further research is needed to screen herbicides for registration in cowpea production in South Africa. Local farmers rely on the manual weeding of their farms. This method of weed control is not sustainable if farmers are to upscale their farm size above half a hectare. Smart weed control methods are recommended. Further funding is recommended and the WRC should take advantage of the work done in this project to provide funding to screen herbicide products that are compatible for use under legume's sole and intercrop situations.

The results of the study indicated that several factors must be considered to improve efficiency levels among cowpea farmers. The farmers are technically efficient, but allocatively and economically inefficient in cowpea production. There is a need to invest in resources that will ensure that there is an increase in production and sustainability. The farmers have the potential and ability to upscale their production levels and earn a higher income from their production. Prior to the study, these farmers were using the indigenous knowledge (broadcasting method) of planting cowpeas, leading to low production.

The study recommends the following measures to improve efficiency in cowpea production in the study area:

- There is a need to encourage young people and graduates to be more involved in farming, and to ensure that agricultural production improves because most of the farmers are old and unable to learn new ways of improving their production. The age of farmers negatively affects the economic efficiency of cowpea farmers. As the farmers grow older, their effectiveness in the field gradually decreases.
- Primary education was found to positively influence economic efficiency in cowpea production in the study area. There is a need to provide primary education to farmers for them to be able to

measure and calculate the inputs they use and outputs they attain to improve their efficiency levels.

- The study further recommends that farms should continuously engage with private and academic institutions on how they can improve their farming methods to be more efficient and effective in the agricultural sector, such as methods of planting cowpea, and especially the measurement of the field when preparing to plant in rows to enhance yield.
- Method of planting has an impact on cowpea yield, since farmers who planted in rows had a greater yield than those who used mixed cropping or broadcast the seed when they planted. Therefore, there is a need to educate farmers on planting in rows to increase yield and improve efficiency.
- Ownership of land and the size of the land that farmers cultivate is significant for allocative and economic efficiency. This means that both of these factors have an impact on the crops that farmers choose to cultivate in their fields. There is a need to ensure that farmers own the land on which they practise agriculture.

Most smallholder farmers focus mostly on producing maize and other subsistence crops, as they do not have enough information on producing other staple food such as cowpea. However, literature has provided only limited information regarding cowpea production and marketing. Smallholder farmers do not have the resources and capacity, or the relevant knowledge on how to use their land optimally. Access to storage facilities was found to be one of the challenges facing smallholder cowpea farmers. In ensuring that their cowpea post-harvest production was not lost due to insect infestation, they had to make sure that they sold their harvest as soon as possible. This resulted in sales often not being at a competitive price.

This study revealed that, with proper funding from government and other agricultural financial institutions, smallholder farmers have the potential to succeed in making food value chains beneficial. It is often not only extra funding that is needed, but the provision of easier access to markets, particularly where transport and transport costs are a problem. Farmers at Bela-Bela do not have enough information on cowpea production and how to turn it into a profitable business. Therefore, only a few farmers are producing cowpea.

The following recommendations are made:

- Government (value chain analysts, policy makers and extension workers), together with other stakeholders, should assist in ensuring that food value chain relationships are established so that market opportunities can be created for smallholder cowpea farmers.
- Age was found to be significant and most smallholder cowpea farmers were old people dominated by female household heads. Aged people are the ones who are committed to farming more than young people, thus it is recommended that farm schools be introduced in rural areas. At these schools, farmers can be taught the basic knowledge relating to agricultural production. Farmers should also be trained on new technologies that will make production more efficient and easier. Knowledge forms a crucial part in the success of smallholder agricultural production, as years of schooling was a significant factor that contributes to the marketing efficiency of smallholder cowpea farmers. The farmers could also be taught about bookkeeping systems, whereby they are able to see the costs of production and marketing; and if they are making profit in managing their operations.
- Household size was also found to be a significant factor in determining smallholder cowpea farmers' marketing efficiency. Therefore, if farmers can form cooperatives, where they produce in groups, government is more likely to help such farming cooperatives in terms of funding and providing the resources to work with. When farmers come together as a collective, they display a sense of unity and determination towards accomplishing their goals. That makes it easier for funding organisations to approach such farmers. Cooperatives also help ensure that the farmers within those cooperatives are able to get bigger lands to enable them to produce different crops.

APPENDICES

APPENDIX 1: PROJECT NO: 2494

Project title: Enhancing food security and nutrition of selected rural communities in Limpopo Province using high yielding and water use efficient grain legume varieties

Project leader: Prof JAN Asiwe

Organisation: University of Limpopo

Capacity building report for 2018/19

Student name	Gender	Race	Degree	University	Country of origin	Student email address
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APPENDIX 2: QUESTIONNAIRE AND DATA OBTAINED FOR THE SURVEY

1. Respondent

Code		
1	Head of household	26 (61.9%)
2	Wife	11 (38.1%)
3	Children	0

Cropping systems

2. Which cropping systems do you practice?

Code		
1	Sole cropping	9 (21%)
2	Intercropping	29 (69%)
3	Mixed farming	0
4	Crop/livestock farming	4 (9%)
5	Others (specify)	

3. What are the important crop mixtures? Rank in order of preference

Code		
1	Cowpea/sorghum	
2	Cowpea/vegetables/maize	28 (67%)
3	Cowpea/Bambara nut	10 (24%)
4	Cowpea/groundnut	1 (2.3%)
5	Cowpea/millet	
6	Cowpea/drybeans	3 (7.1%)
7	Cowpea/soya bean	
8	Cowpea/lucine	
9	Others (specify)	

4. What crops are grown?

Code	Do not know	
1	Cowpea	6 (14.2%)
2	Bambara nut	7 (16.7)
3	Sorghum	
4	Millet	
5	Groundnut	9 (21.4%)
6	Maize	38 (90.4%)
7	Dry bean	10 (23.8%)
8	Soya bean	
9	Sunflower	
10	Lucine	
11	Others (specify)	

5. What are your reasons for cultivating the existing varieties?

Code		
1	Source of food for the family	36 (85.7%)
2	Source of income	6 (14.3%)
3	Testing the varieties	
4	Leisure	
5	Other means (specify)	

6. What are the existing cropping patterns?

Code		
1	Row cropping	3 (7.1%)
2	Mixed planting	37 (88.1%)
3	Strip planting	0
4	Others (specify)	

7. What is the average area under cowpea cultivation?

Code		
1	Cowpea/sorghum	< 0.5 ha
2	Cowpea/maize	< 0.5 ha
3	Cowpea/Bambara nut	
4	Cowpea/groundnut	
5	Cowpea/millet	
6	Cowpea/drybeans	
7	Cowpea/soya bean	
8	Cowpea/lucine	
9	Others (specify)	3 > 1.0 ha (7.1%)

8. Where do you source your seeds?

Code		
1	Own seeds	28 (66.7%)
2	Purchased	
3	Neighbour	
4	Research stations	10 (23.8%)
5	Others (specify)	4 (9.5%)

9. How is the land prepared?

Code		
1	Own tractor	5 (11.9%)
2	Contractor	2 (4.8%)
3	Animal traction	
4	Other means (name)	35 (83.3%)

10. What are the inputs you employ for crop production? List all of them.

Code		
1	Fertilizer	
2	Irrigation	
3	Seeds supply	37 (88.0%)
4	Insecticides	
5	Herbicides	
6	Tractors	4 (9.5%)
7	Oxen	
8	Family labour	26 (61.9%)
9	Manure	
10	Others (specify)	

11. What are the obtainable yield levels? List all of them.

Code		
1	Cowpea sole	<50 kg bag
2	Bambara sole	
3	Cowpea/sorghum	
4	Cowpea/maize	<50 kg bag

Code		
5	Cowpea/Bambara nut	
6	Cowpea/groundnut	
7	Cowpea/millet	
8	Cowpea/drybeans	< 50 kg bag
9	Cowpea/soya bean	
10	Cowpea/lucine	
11	Others (specify)	

Production constraints

12. What are major insect pests you encountered in the field?

Code		
1	Aphids	38 (90.0%)
2	Thrips	
3	Maruca	
4	Pod-sucking bugs	
5	Weevils	40 (95.2%)
6	Rodents (meercat)	10 (23.8%)
7	Others (specify)	

13. What are major diseases you encountered in the field?

Code		
1	Viruses (golden yellow)	
2	Bacterial diseases (bacterial blight) – brown spots	
3	Fungal (root/stem rot)	
4	Others (specify)	Do not know

14. What weed species affect your field? List all of them.

Code		
1	Alectra	
2	Striga	
3	Grasses	41 (97.0%)
4	Broadleaves	40 (95.2%)
5	Others (specify)	

15. What are other production constraints? List all of them.

Code		
1	Labour	
2	Drought	35 (83.3%)
3	Poor seed supply	
4	Weeds	
5	Rodents	10 (23.8%)
6	No market for the produce	
7	Poor pricing	
8	Low capital	
9	Lack of storage facilities	30 (71.4%)
10	Pilfering	
11	Others (specify)	

Post-harvest:

16. How do you store your seed?

Code		
1	Cribs (rooms) made from plant materials	N/A
2	Clay/earthenware pots	
3	Calabashes	
4	Tins	
5	Silos/granary	
6	Others (specify)	

17. What problems do you encounter with the seed during and after storage?

Code		
1	Insects	40 (95.2%)
2	Moldiness	
3	Rodents	
4	Others (specify)	

Utilisation:

18. For what purpose do you use your cowpea?

Code		
1	Sell to generate income	
2	Own consumption	40 (95.2%)
3	Animal feed	
4	Medicinal purposes	
5	Others (specify)	

19. Farmers' preferences in cowpea varieties.

Code		
1	Seed colour	38 (90.4%)
2	Seed size	40 (95.2%)
3	Growth habit (spreading)	30 (71.4%)
4	Leaf types – dual types	30 (71.4%)
5	Maturity periods (early/late)	30 (71.4%)
6	Others (specify)	

20. Who are your potential markets for your produce? List all of them.

Code		
1	Neighbour	
2	Local market	40 (95.2%)
3	Shopping malls	
4	Others (specify)	2 (4.8%)

21. How do you consume cowpea?

Code		
1	Whole cooked seeds	25 (59%)
2	Ingredient in dishes	0
3	Leaves as a vegetable	38 (90.4%)
4	Fresh pods	10 (23.8%)
5	Baking product	
6	Others (specify)	

22. What constitutes your daily diet?

Code			
1	Breakfast	Mostly carbohydrates	35 (83.33%)
2	Lunch	Mostly carbohydrates + vegetables	40 (95.2%)
3	Dinner	Mostly carbohydrates	38 (90.4%)
4		Vegetables	10 (23.8%)
5			
6		Others (specify)	

APPENDIX 3: PRODUCTIVITY OF FIVE PIGEONPEA (*CAJANUS CAJAN*) VARIETIES IN A PIGEONPEA-MAIZE STRIP INTERCROPPING IN LIMPOPO PROVINCE

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Abstract

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is an important grain legume crop in tropical and subtropical countries where it provides a cheap source of protein. Smallholder farmers in Limpopo cultivate land races, which are characterised by late maturity and low grain yield, and are sensitive to photoperiod. Farmers plant these land races using mixed intercropping without definite row arrangement. This practice does not optimise plant density. It hinders farm input applications and is also characterised by low yields. However, strip intercropping, which allows crops to be planted in rows and strips, promotes a higher yield and allows mechanisation and ease of the application of farm inputs. Therefore, the inclusion of early-maturing and high-yielding pigeonpea varieties in strip intercropping will enable farmers to select varieties suited for strip intercropping and enhance productivity. The objectives of this study were therefore to assess the agronomic performance of five pigeonpea varieties in pigeonpea-maize strip intercropping and to determine the effect of strip intercropping on maize yield.

Experiments were conducted at the University of Limpopo Experimental Farm (UL-Farm) and Ga-Thaba village during the 2015/16 and 2016/17 seasons. Five improved early- to medium-maturing pigeonpea varieties (ICEAP 001284, ICEAP 00604, ICEAP 87091, ICEAP 00661 and ICEAP 01101-2) from the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) were evaluated under strip intercropping with a maize cultivar (PAN 6479). The varieties were selected as early- to medium-maturing varieties from previous pigeonpea trials. The trials were laid in a split plot design. The main plot used cropping systems (intercropping and monocropping), while the subplot contained the variety with three replications. Data collected on pigeonpea were number of days to 50% flowering and 90% maturity, number of primary branches, plant height (cm), number of pods per plant, pod length (cm), number of seeds per pod, 100 seed weight (g) and grain yields (kg/ha), whereas for maize, data was collected on number of days to 50% tasseling and silking, plant height (cm), cob length (cm), cobs per plant, grain yield (kg/ha) and stover (kg/ha). The Land Equivalent Ratio (LER) was calculated to determine intercropping productivity. Data analysis was done using Statistic 10.0. The results revealed significant differences in nearly all variables taken on pigeonpea (pod length, number of seeds per pod and 100 seed weight). Variables that showed significant differences in maize were plant height, cob length, grain yields and stover.

Number of days to 50% flowering and 90% physiological maturity differed significantly ($P \leq 0.05$) among the varieties at UL-Farm and Ga-Thaba. The varieties ICEAP 001284 and ICEAP 00604 exhibited the shortest number of days to 50% flowering and 90% maturity in both locations during both seasons. The interaction between variety and season (V*S) showed significant differences ($P \leq 0.05$) in pigeonpea grain yield. The top yielders at UL-Farm during 2015/16 were ICEAP 01101-2 (1,555.00 kg/ha) and ICEAP 001284 (1,280.20 kg/ha), while during the 2016/17 season, the top yielders were ICEAP 001284 (937.10 kg/ha) and ICEAP 01101-2 (912.60 kg/ha). High yielders at Ga-Thaba during the 2016/17 season were ICEAP 001284 and ICEAP 01101-2 with a grain yield of 671.31 and 627.15 kg/ha, respectively. Furthermore, varieties that produced a high yield during the 2015/16 season were ICEAP 001284 (504.07 kg/ha) and ICEAP 00604 (541.04 kg/ha). Most of the varieties during both seasons at UL-Farm and Ga-Thaba yielded more than 500 kg/ha under strip intercropping compared to mixed intercropping, which obtained yield averages below 400 kg/ha. The highest maize grain yield of 1,450.50 kg/ha was recorded during 2015/16 compared to 958.50 kg/ha during 2016/17 at UL-Farm. The calculated total LER for the two crops in both locations was greater than 1, which suggests a favourable grain yield advantage for maize-pigeonpea strip intercropping over mixed intercropping.

Key words: *Cajanus cajan*, maize, strip intercropping, maturity, grain yields, Land Equivalent Ratio

APPENDIX 4: PERFORMANCE OF FIVE COWPEA (*VIGNA UNGUICULATA* (L.)) VARIETIES IN A COWPEA-MAIZE STRIP INTERCROPPING IN LIMPOPO

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Abstract

The traditional practice of farmers in Limpopo is to mix and broadcast crops at planting without a definite row arrangement. This practice hinders farm input applications and results in a low crop yield. Strip intercropping, where crops are planted with a definite row arrangement, has the advantage of reducing inter-species competition, optimising plant population and increasing crop yield. This study was aimed at improving cowpea-maize cropping systems using strip intercropping. The experiment was conducted at UL-Farm and Ga-Thaba village. Five cowpea varieties (Glenda (the control), IT86K-499-35, IT82E-16, IT86D -1010 and TVu-13464) and maize (PAN 6479) were evaluated during 2015/16 and 2016/17 using randomised complete block design with three replications. Data collected included flowering, maturity, plant height, canopy width, peduncle length, pod length, number of pods per plant, 100 seed weight, grain yield and fodder weight, and the LER was determined. Data was analysed using Statistix 9.0. The results revealed that, in both locations, TVu 13464 flowered early (50 days). At UL-Farm, TVu 13464, IT82E-16 and IT86D-1010 matured early (at 89, 88 and 91 days, respectively). At UL-Farm, IT82E-16 had the highest cowpea grain yield (2,230 kg/ha) under monocropping and also produced a grain yield of 1,373 kg/ha during the 2016/17 season. At Ga-Thaba, IT86D-1010 produced the highest cowpea grain yield of 1,085 kg/ha under monocropping and 660 kg/ha during 2015/16, while IT86K-499-35 also produced a grain yield of 915 kg/ha during 2016/17.

At UL-Farm, strip intercropping exhibited a high maize grain yield of 3,960.8 kg/ha during 2016/17. At Ga-Thaba, strip intercropping produced a grain yield of 747.2 and 1,024.2 kg/ha during 2015/16 and 2016/17, respectively. Monocropping produced a lower grain yield during 2015/16 with a mean of 425 kg/ha, compared to a mean of 498.5 kg/ha during 2016/17 for mixed intercropping. At UL-Farm, strip intercropping gave an LER greater than 1 in all crop mixtures, which ranged from 1.25 to 2.3, compared to mixed intercropping, which ranged from 0 to 0.6 in both seasons. At Ga-Thaba, strip intercropping showed no significant difference in both seasons with an LER range of 1.96 to 2.98, but mixed intercropping had LER values greater than 1, ranging from 1.18 to 2.36 among varieties, except where IT86K-499-35 was mixed intercropped with PAN 6479, where it provided a mean of 0.83. TVu 13464, IT82E-16 and IT86D-1010 were promising varieties suitable for strip intercropping in low rainfall areas because of their early maturity and high grain yield.

Key words: Cowpea, maize, intercropping, grain yield, Land Equivalent Ratio

APPENDIX 5: DETERMINANTS OF ECONOMIC EFFICIENCY AMONG SMALLHOLDER COWPEA FARMERS: A CASE STUDY OF CAPRICORN AND WATERBERG DISTRICTS, LIMPOPO PROVINCE, SOUTH AFRICA

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Abstract

The paper examined the economic efficiency of cowpea production among smallholder cowpea farmers in the Capricorn and Waterberg districts of Limpopo. Data envelopment analysis (DEA) and the Tobit regression model were used to analyse the data. The DEA approach was used to explain the technical, allocative and economic efficiency of cowpea farmers and also the socioeconomic factors that result in inefficiency. The study served as a guideline for conducting efficiency studies in the agricultural sector. The study also used descriptive statistics to describe the socioeconomic characteristics of cowpea farmers and constraints pertaining to cowpea production. The Tobit regression model found that the explanatory variables that were significant are age, educational level, primary income source, farm size, method of intercropping, purpose of growing cowpea and source of field labour. The DEA results showed that the technical efficiency scores of cowpea farmers had a mean of 0.9588 with a minimum of 0.75 and a maximum of 1. This means that 95% of the farmers were technically efficient. The allocative efficiency score ranged from a minimum of 0.4070 to a maximum of 1 with a mean of 0.6519. The allocative efficiency scores implied that farmers were not utilising inputs. The economic efficiency scores ranged from a minimum of 0.3820 to a maximum of 1 with a mean score of 0.6218. This implies that cowpea smallholder farmers were economically inefficient on average and that the cost of cowpea production for each farm could be decreased on average by approximately 38% to obtain the same level of output. The result of the descriptive statistics indicated that the interviewed farmers' years of schooling ranged from 0 to 13 years, with an average of five years of attending school. Farmers' ages ranged from 33 to 78, with an average age of 61 years. The average income received on a monthly basis from the overall agricultural produce was R1,735.83 per farmer. The study recommends that there is a need to provide primary education to the farmers for them to be able to measure and calculate the inputs they use and outputs they attain in order to improve their efficiency levels.

Key words: Economic efficiency, cowpea production, Limpopo Province, smallholder farmers, Data Envelopment Analysis (DEA)

APPENDIX 6: VALUE CHAIN MAPPING AND MARKETING EFFICIENCY OF SMALLHOLDER COWPEA FARMERS IN CAPRICORN AND WATERBERG DISTRICTS OF LIMPOPO PROVINCE

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Abstract

Marketing plays a major role in agricultural production. This is because agriculture has the potential to provide the majority of smallholder farmers with employment and an income. However, for smallholder farmers to enjoy the benefits provided by agriculture, they need to have a reliable market for their produce. This paper therefore examined cowpea value chain mapping and marketing efficiency among cowpea farmers in Ga-Molepo in the Capricorn District, and Bela-Bela in the Waterberg District of Limpopo. Primary data was collected through face-to-face interviews with 80 smallholder cowpea farmers using a structured questionnaire. A value chain map, descriptive statistics and the binary logistic regression model were used to analyse the data. The study findings showed that 66% of the smallholder cowpea farmers were market efficient, and 34% were market inefficient. It was also revealed that women were more involved in cowpea production than men. The results of the binary logistic regression model employed indicated that age, household size, years of schooling, years of farming cowpea, income generated from selling cowpea, quantity of cowpea sold and occupation of the farmers had a significant positive influence on marketing efficiency in the study area. The paper therefore recommends increased investment in education and training opportunities for smallholder farmers for better profit making and that stakeholders in the agriculture value chain in the study area should come together for proper coordination of their activities to further enhance efficiency.

Keywords: Cowpea production, Limpopo Province, marketing efficiency, value chain mapping, smallholder farmers

APPENDIX 7: PRESENTATIONS AT CONFERENCES

MC Masegela attended the 56th Annual Conference of the Agricultural Economics Association of South Africa, 25-27 September 2018, Lord Charles Hotel, Somerset-West, Cape Town. The following presentation was delivered:

- Masegela CM and Oluwatayo IB (2018). Value chain mapping and marketing efficiency of smallholder cowpea farmers in Capricorn and Waterberg districts of Limpopo province. Abstract. Paper presented at the 56th Annual Conference of the Agricultural Economics Association of South Africa, 25–27 September 2018, Lord Charles Hotel, Somerset-West, Cape Town, South Africa.

Other conference presentations included the following:

- Madimabe KS and Asiwe JAN (2018). Productivity of five Pigeonpea (*Cajanus cajan*) varieties in a pigeonpea-maize strip intercropping in Limpopo Province. Abstract. Paper presented at the 12th Southern African Plant Breeders Association Symposium, 11–15 March 2018, Gateway Hotel, Umhlanga, Durban, South Africa.
- Maimela KA and Asiwe JAN (2018). Performance of five cowpeas *(Vigna unguiculata L.*) varieties in a cowpea maize strip intercropping in Limpopo Province. Abstract. Paper presented at the 12th Southern African Plant Breeders Association Symposium, 11–15 March 2018, Gateway Hotel, Umhlanga, Durban, South Africa.
- Asiwe JAN (2016). Phenotypic performance of exotic pigeonpea varieties in South Africa. Book of Abstract. Paper presented at the Southern Africa Plant Breeding Symposium, 8–10 March 2016, Protea Hotel, Stellenbosch, South Africa.