SEED QUALITY AND YIELD OF SELECTED TRADITIONAL AND COMMERCIAL CROPS: VEGETABLE WATER USE AND NUTRITIONAL PRODUCTIVITY PERSPECTIVES

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PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa. The research was financially supported by the Water Research Commission (WRC) of South Africa through WRC Project No. K5/2493//4 'Water use and nutritional water productivity for improved health and nutrition in poor rural households' (WRC, 2016).

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Signed: Professor Albert T. Modi (Supervisor)

Date: November 2017

DECLARATION

I, Pretty Jabulisile Shelembe, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

Signed: Pretty J. Shelembe

Date: 30 November 2017

ABSTRACT

Sub-Saharan Africa (SSA) faces challenges of achieving nutrient and food security under water limitations due to climate change and variability. Under these conditions, it is important to adopt cropping systems that are likely to improve crop production. The aim of the study was to assess the feasibility of a legume - leafy vegetable intercrop system with a view to determine the yield and nutritional benefits. This was achieved through a series of studies which included conducting critical literature review, quantifying water use and nutritional water productivity efficiency of intercropping. Field trials were conducted at an Umbumbulu homestead and Fountain Hill Estate, in KwaZulu-Natal, during the 2016/2017 summer season, under rain-fed conditions. Intercrop combinations considered were sole cowpea, amaranth, garden pea and swiss chard, as well as intercrops of cowpea-amaranth, cowpea-garden pea and cowpea-swiss chard. Seed quality of selected crops were determined prior to planting to establish field planting value of seed lots. Data collection included plant growth (leaf number and plant height), and physiology (chlorophyll content index and stomatal conductance). Yield and yield components, water use (WU) and water use efficiency (WUE) were calculated at harvest. Nutritional analysis was determined after harvest. The results showed a significant ($P \leq 0.05$) difference between species with respect to seed vigour. There were significant differences ($P < 0.05$) with respect to growth and physiological parameters among crop species. Significant differences ($P < 0.05$) were also observed with respect to yield and yield components among crop species under cropping systems. Traditional species were significantly superior to exotic species with respect to seed germination and vigour. Field trials showed a general relationship between seed quality and crop performance. Although sole cropping showed better field crop performance than intercropping, there was evidence of significant water and nutrient productivity of the intercropping system.

Key words: African leafy vegetables, exotic seed, intercropping, mono-cropping, water use

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CHAPTER 1. GENERAL INTRODUCTION AND OBJECTIVES

1.1 Background and rationale

South Africa is a physically water scarce country (Dabrowski *et al.*, 2009). It is estimated that agriculture uses about 70% of freshwater resources. Despite this, water still remains a major limiting resource to crop production (Olayide *et al.*, 2016). Rain-fed agriculture is practised on approximately 80% of the agricultural land. In addition, 95% of the population depends on a rain-fed based rural economy (Malézieux *et al.*, 2009). Chauvin *et al.* (2012) indicated that rainfall can be unpredictable, unevenly distributed and highly erratic at the start and end of the rainy season, even in areas receiving enough rainfall for crop production. It is fundamental to focus on water productivity in both rain-fed and irrigated agriculture since the future food demands for production systems mostly depend on finite fresh water resources. Water demand in agriculture is predicted to increase by 90% in 2050, due to high competition for water (de Fraiture and Berndes, 2009).

These challenges threaten the world's food security, since there might be less available water for food production (Olayide *et al.*, 2016). In semi- arid and arid areas of sub-Saharan Africa, the population mostly depends on small-scale rain-fed agriculture. In such farming systems, farmers produce very low yields, especially during years of drought (Mavhura *et al.*, 2015; Hadebe *et al.*, 2017). In water limited regions, intercropping has been found to enhance crop productivity per unit area of land through increased land and water use efficiency (Rezig *et al.*, 2010; Yang *et al.*, 2011). African leafy vegetables (ALVs) are productive in semi-arid and arid areas of the region even without irrigation. In Africa, South America and Asia, local leafy vegetables play a significant role in food security systems of rural households. African leafy vegetables are indigenous plant species that have originated in Africa (Gockowski *et al.*, 2003) or plants that are traditionally (locally) used for food, and yet considered as weeds in both commercial and subsistence farming systems. They are mostly grown for their edible leaves, pods, seeds, tubers and roots (Wehmeyer and Rose, 1983).

In South Africa, Wehmeyer and Rose (1983) distinguished over 100 individual plant species utilized as leafy vegetables. Most African leafy vegetables (ALVs) are found to be adapted to different conditions, including dryland production. African leafy vegetables offer different opportunities to expand farming systems, ensure food security, reduce poverty, improving human health and increase income. These traditional crops are well adapted to the sometimes harsh African conditions as they grow voluntarily in many areas of the world (Mavengahama *et al.*, 2013). In Africa, it is estimated that starchy staples comprise 80% of diets. African leafy vegetables are an important source of vitamins and minerals. African leafy vegetables require less inputs than conventional crops, an attribute that is well suited for rural agriculture, where 70% of the malnourished population resides (Aliber and Hart, 2009; Chivenge *et al.*, 2015). African leafy vegetables were found to be mostly consumed by rural villagers, but that has changed since current consumption is more widespread.

African leafy vegetables have a potential to minimise effects of both micronutrient deficiency and water scarcity in regions where soils are characterised by drought and poor fertility. Despite this, ALVs grow wild with a few species being cultivated (Uusiku *et al.*, 2010). Currently, cereals occupy the highest land area in rural cropping systems. There is a need to incorporate them into cropping systems. Various studies have suggested that intercropping is a more productive and profitable system compared to sole cropping (Varghese, 2000; Baumann *et al.*, 2001). Intercropping saves water by improving ground cover, there is less soil evaporation and the water can be productively used by the crop. Since different plant species are grown together at the same time, assuming that different plants have different root systems, means that all plants will have sufficient water for crop production. Under water limited areas, intercropping has appeared to be a suitable approach to sustainable agriculture (Chimonyo *et al.*, 2016).

1.2 Hypothesis and aim

The null hypothesis was that intercropping African leafy vegetables and conventional legume vegetables under rain-fed conditions has no effect on crop growth, yield and nutritional value compared to monocropping. The aim of the study was to assess the feasibility of a legume - leafy vegetable intercrop system with a view to determine the yield and nutritional benefits.

1.3 Specific objectives

The study was based on four main objectives.

(a) To determine seed quality (seed vigour and seed viability) of selected leafy vegetables [amaranthus (*Amaranth hybridus*) and swiss chard (*Beta vulgaris subsp. vulgaris*)] and legumes [garden pea (*Pisum sativum*) and cowpea (*Vigna unguiculata*)];

(b) To determine yield of intercrop system (cowpea-amaranth; cowpea-swiss chard, cowpea-garden pea) compared with monocrops (cowpea, amaranth, swiss chard and garden pea, respectively);

(c) To determine water use of intercropping systems compared with the monocropping; and

(d) To determine the nutritional value of leafy vegetables [amaranthus (*Amaranth hybridus)* and swiss chard (*Beta vulgaris subsp*)] and legumes [garden pea (*Pisum sativum)* and cowpea (*Vigna unguiculata*)] grown under an intercropping and monocropping, respectively.

CHAPTER 2. LITERATURE REVIEW

2.1 Drought and water scarcity

Drought occurs when there is not enough water in the soil to support plant development and growth (Passioura, 2002) for potential yield even when all other crop requirements are met. Mabhaudhi (2009) reported that there are different types of drought. Meteorological drought is a measure of the variation from the normal rainfall over time. Agronomic drought results due to meteorological drought or other management factors that may limit soil water availability. Drought reduces food production in a region that is already plagued with food insecurity (Chimonyo *et al.*, 2016; Ortmann and King, 2010)

Sub-Saharan Africa (SSA) faces both physical and economic water scarcity (Hanjra and Qureshi, 2010). Water scarcity is when there no access to safe and affordable water for human needs (Rijsberman, 2006). Water scarcity is predominantly caused by limited amount of water resources combined with low and uneven seasonal and annual rainfall.Wenhold *et al.* (2007) indicated that water is important for crop production and food security. In water stressed countries, increasing agricultural water productivity and water use efficiency has become a priority (UN-Water, 2006). Cattivelli *et al.* (2002) stated that some crops have developed mechanisms for adaptation and survival during water stress periods (Cattivelli *et al.*, 2002). African indigenous crops have been reported to be highly adapted to harsh environments, including drought stress (Vorster *et al.*, 2002).

2.2 Malnutrition

In Sub-Saharan Africa (SSA) and South Africa (SA), nutritional deficiency is the major challenge. Micronutrients such as Iron (Fe) and Zinc (Zn) and vitamin A (Wenhold *et al.*, 2007; Chianu *et al.*, 2012) are generally lacking in diets. According to the FAO (2013), the majority of people in SSA depend on small-scale, rain-fed agriculture for their livelihoods. Agriculture remains the main channel for addressing nutrition and food security in a region where 70% of the population depends on agriculture. Increasing household agricultural productivity is important to improve food and nutrition security (Schmidhuber and Tubiello, 2007). Nutritional security is the foundation of human well-being (IFPRI, 2014). Neglected and underutilised crops could be promoted as part of efforts to ensure food and nutrition security (Modi and Mabhaudhi, 2013).

2.3 African leafy vegetables

Some rural South Africans use ALVs as a complement to their daily staple food (Bvenura and Afolayan, 2015). These are highly nutritious and have high iron and vitamin A content (Table 1). These vegetables are ranked higher in nutrition than many other crops. They supply 80% of the vitamin A (Kwenin *et al.*, 2011). African leafy vegetables have significantly contributed to dietary vitamin and mineral intake of local populations (Nordeide *et al.*, 1996) since they are great sources of minerals such as calcium, iron and vitamin C (Kwenin *et al.*, 2011). Leafy vegetables are cheap and available sources of essential proteins, vitamins and crucial amino acids (Van Rensburg *et al.*, 2004).

Regarding income generation and subsistence, ALVs have potential to play a major role (Schippers, 2000). Compared with other food items, ALVs are relatively affordable, which is a good thing for poor households. Production of legume-leafy vegetables could create more jobs in rural areas. It has been reported that a large number of leafy vegetables have health protecting properties and uses (Toivonen and Hodges, 2010). Recent studies have shown that AVLs contain non-nutrient bioactive phytochemicals that have been associated with cardiovascular and other degenerative disease protection (Nyathi et al. 2016; Toivonen and Hodges, 2011) (Table 2.1). Vegetables contain large amounts of water, and when eaten the body does not need to use a lot of its own water to digest them (Lussier, 2010).

Table 2.1: Micronutrient and macronutrient content of selected leafy vegetables per 100 g of edible fresh mass. Recommended daily nutrient intakes: Vitamin A = 400 µg RE (1-3 years) to 600 µg RE (19-65 years); Iron (Fe) = 5.8 mg (1-3 years) to 32.7 mg (10-14 years); Zinc (Zn) = 8.3 mg (1-3 years) to 17.1 mg (10 to 14 years) (Sourced from Nyathi et al., 2016 with some modifications).

	Micronutrients			
	Vitamin A	Iron	Zinc	Calcium
Scientific name	µg RE 100 g^{-1}	mg 100 g^{-1}	mg 100 g^{-1}	mg 100 g^{-1}
Amaranthus spp.	59-327	0.3-16.2	0.02-8.4	-
Bidens pilosa	-	2-6	0.9-2.6	1.971
Brassica rapa	-	1.44	0.3	-
Corchorus spp.	717	2-6	0.05-0.8	25.7
Citrullus lanatus	-	6.4	0.74	129.7-269.7
Cleome spp.	1200	2-29	0.6-1	213-434
Cucurbita pepo	194	4-16	0.6-0.9	-
Ipomoea batatas	103-980	0.6-1	0.03-3.1	28.44
Momordica	-	3.5	1.8	941
balsamina	-	-	-	11.49
Solanum nigrum	1070	7-13	0.6-3.5	73-400
Vigna unguiculata	99	0.3-4.7	0.2-0.5	-
Beta vulgaris	669	2.7	0.5	-
Brassica oleracea	75	0.3-0.5	0.2-0.5	-

Note: - means that data were not available at the time of publication of the current study.

2.4 Other uses and importance of African leafy vegetables

African leafy vegetables play an important role in income generation and support (Adebooye and Opabode, 2004). Musotsi *et al.* (2003) reported that ALV production could be done with little capital investment and that they offered a significant opportunity to poor people in western Kenya. For those that are outside the formal sectors, ALVs offer job opportunities as they are relatively easy to grow (Adebooye and Opabode, 2004). They do not require more agricultural input (irrigation and fertiliser), since genetically they are adapted to harsh environmental conditions (Van Jaarsveld *et al.*, 2014). African indigenous vegetables' chemical composition studies have shown that they contain significant amounts of crude protein, fat and oil, energy, vitamins and minerals (Adebooye and Bello, 1998). They are also known to make food more digestible and palatable. In southwest Nigeria, some of the plants are also sources of traditional medicine.

Modern science has shown that indigenous species have medicinal properties, which can be useful to humans (Adebooye and Opabode, 2004). Indigenous plants are well adapted to numerous tropical conditions, pests and diseases. These species can be used as a good reference of genes for genetic enhancement in developing new species that will be drought tolerant and resistant to diseases and pests (Adebooye and Opabode, 2004). Despite this, ALVs have been neglected for many years by farmers and researchers (Adebooye and Opabode, 2004). Therefore, there is a need to enhance their production and not only focus on sustaining their germplasm (Musotsi *et al.*, 2003). Worldwide as the utilisation of ALVs increases, availability of good seed of known quality is important to meet the demand for these vegetables (Abukutsa-Onyango, 2005). Seed systems for ALVs are informal and the quality of the seed is not known.

2.5 Seed quality

Seed quality is the sum of many individual components like genetic quality, physical purity, germination, vigour, uniform size and health (disease free seeds). De Geus *et al.* (2008) described seed quality as the physiological (seed germination ability and seed vigour) and genetic purity. According to Hampton (2002), seed quality is the standard of excellent features that regulate seed performance when seed is either sown or stored. Poor quality seeds generally exhibit low germination, reduced viability, poor emergence and seedling growth, and poor tolerance to sub-optimum conditions (Bedi and Basra, 1993). Odindo (2008) showed that germination capacity and physiological vigour were the two most essential indicators of seed quality, as they are inherent properties of the seed. Generally, good quality seeds are those that have the ability to germinate and produce normal seedlings under a wide range of environmental conditions (ISTA, 2012).

2.5.1 Seed germination

Seed germination is defined as emergence and development from the seed embryo of the key structures that signal the ability of the seed to produce a normal plant (ISTA, 2011). Cardwell (1984) defined germination as the sequence of processes transforming an inactive embryo into being metabolically active, after a seed takes up water (imbibition) and protrusion of embryo radicle through the seed coat. Laboratory germination tests are used to determine the ability of seeds to germinate, which then can be used to observe seed quality (ISTA, 2011).

2.5.2 Seed viability

Seed viability is the ability of a seed to germinate and produce a normal seedling under favourable conditions (McDonald and Copeland, 2012). Viable seeds are those seeds that are alive and when exposed to favourable germination conditions, have the potential to germinate (Basra, 1995; McDonald and Copeland, 1997). A seed may be viable but unable to germinate due to germination processes being hindered by physical and/or chemical inhibitors (Basra, 1995). This is referred to as dormancy. Seed viability measurement is an important necessity to evaluate seed quality before planting (Basra, 1995). Seed viability can be evaluated using tetrazolium chloride (TZ) test (Peter, 2000).

2.5.3 Seed vigour

Seed vigour comprises all the seed properties that determine the ability of the seed to have rapid germination, uniform emergence, and development of normal seedlings under a wide range of field conditions (McDonald and Copeland, 2012). Basra *et al.* (2005) stated that a vigorous seed lot is one that has the ability to perform well under unfavourable environmental conditions. Germination rate is taken as a tool for evaluation of seedling emergence and vigour (Maguire, 1962). Vigorous seeds are able to efficiently synthesize new materials and rapidly transfer these new products to the emerging embryotic axis resulting in enhanced dry weight (Burris *et al.*, 1976). Finch-Savage *et al.* (2010) indicated that evaluation of seed vigour in small seeded crops can be done using natural variation in field conditions. International Seed Testing Association (2011) stated that other methods that could be used to evaluate seed vigour were conductivity tests, controlled deterioration, accelerated aging and radicle emergence.

2.5.4 Seed dormancy

Dormant seeds are those seeds that do not have the ability to germinate even under favourable conditions (Bewley, 1997). There are several types of dormancy, primary dormancy which is caused by maternal tissues and secondary dormancy caused by metabolic blocks under an unfavourable germination environment (Basra, 2005). According to Baskin and Baskin (2004) seed dormancy is classified into five classes, namely, physiological dormancy (PD), morphological dormancy (MD), morpho-physiological (MPD), physical (PY) and combinational (PY + PD). Morphological dormancy (MD), is the kind of dormancy where the embryo is underdeveloped. In morphological dormancy, there is delay of germination due to requirement of a certain cold period exposure before seeds can germinate. In the seed or fruit coat, one or more water- impermeable layers of palisade cells can cause physical dormancy (PY). Combination dormancy (PY + PD) is found when seed coat is water impermeable and the embryo is physiologically dormant (Baskin and Baskin, 2004).

2.6 Agronomy of African leafy vegetables

African leafy vegetables are easy to grow since they take a short period to mature. They can grow in small areas and naturally in the field and in the wild without agricultural inputs (e.g., fertiliser and irrigation) (Neluheni *et al.*, 2007). African leafy vegetables grow voluntarily in the wild and fallow with crops such as maize, sorghum and cotton; some are cultivated landraces. Commercial farming systems regard ALVs as weeds, which will make them to likely go extinct (Neluheni *et al.*, 2007). Under small-scale farming, when they are seen in the field they are allowed to grow and are harvested (Metwally *et al.*, 2005), whereas in large-scale farming, when identified in the field, they are mechanically and/or chemically removed (Taleni *et al.*, 2012; Mavengahama *et al.*, 2013). A few examples of African leafy vegetables published by Araya (undated) include, but are not limited to the following:

- *Amaranthus* species (Amaranths, Pigweed)
- *Cleome gynandra* (Spider Plant)
- *Corchorus* spp (Gushe)
- *Brassica carinata* (Kale)
- *Solanum retroflexum* (Nightshade)
- *Cucurbita* spp (traditional pumpkin)
- *Citrullus lanatus* (Bitter melon)
- *Vigna unguiculata* (cowpea)
- *Colocasia esculenta* (Amadumbe)

Modern agriculture has managed to enhance the productivity of farming systems, however, chemical use, among others, may affect sustainability (Lichtfouse, 2010). Morden farming systems involve simpler environmental structures over large landscapes; thus substitute natural plant diversity with restricted plants over large spaces of monocultures. In developing countries, farm diversity common in traditional systems. Traditional farming systems are identified by genetic variety found in domesticated crop species and their wild related species (Altieri, 1999). These farming systems advance crop diversity for diet and income, stabilise and increase crop production with less resources, as well as minimise artificial crop protection needs (Anil *et al.*, 1998; Malézieux *et al.*, 2009).

2.7 Cropping systems

Cropping systems are defined as the mixture of crops grown in a given space within a season (Hamza and Anderson, 2005). Throughout the world, agricultural cropping systems are a result of variation in local climate, soil, economic, social systems and improvement of soil structure. Resources like water, solar radiation, soil and temperature are the major determinants of the physical and biological potential of crops to grow and cropping systems to exist (Palada and Harwood, 1975; Seran and Brintha, 2010). In the world, cropping systems differ from place to place. Cropping systems are designed to improve a given agro-ecosystem over the existing systems which were adapted by the farmers in terms of their production stability and biological productivity with least harm to the ecosystem. Generally, farmers select technologies to be used based on cost, risk and return (De Bruin *et al.*, 2009). There are many different cropping systems practiced in agriculture, including mono-cropping, intercropping, crop rotation, strip cropping, and fallow, among others.

2.7.1 Mono-cropping

Mono-cropping is an agricultural practice in which only one type of crop is grown year after year on a large area of land (Allaway, 1957). During the 1940s and 1950s, in industrialized countries mono-cropping was common as farming was more commodity-based and less subsistence-based. Mono-cropping is utilised to facilitate planting, application of pesticides and fertilisers, and harvest across a large piece of land (Zuo and Zhang, 2009). These techniques minimize labour needed for production, which is good because it eliminates labour cost. Mono-cropping allows farmers to specialize in a particular crop, meaning a farmer can invest in machinery designed specifically for that crop, along with high yield that will generate a great volume of the crop at harvest (Härdter *et al.*, 1991). However, mono-cropping has been implicated in environmental damage due to nutritional loss from the soil and decreases in crop yield over time, which is a threat to agriculture and food security (Ahmad *et al.*, 2013). Insects disperse more rapidly and easier in a monocrop, resulting in greater spreading of pests and diseases than in a mixed crop. Presence of other crops in the field lessens rapid spread of these, since insects will require more time to search for the host plant (Risch *et al.*, 1983).

2.7.2 Crop rotation

Crop rotation is the practice of changing what is grown in an area from year to year (West and Post, 2002). Crop rotation not only improves soil status but it is also important for economic sustainability (Reeves, 1997). Generally, crop rotation is assumed to increase yields, since it improves soil quality and nutrition. Crop rotation has a potential to improve productivity or to enhance crop yield and is generally associated with minimizing pests and diseases (Dick and Van Doren Jr., 1785; Dick et al., 1991).

2.7.3 Intercropping

Intercropping is an agricultural practice of growing two or more crops simultaneously in the same area at the same time (Andrews and Kassam, 1976). It is an agricultural practice found throughout the world and it results in economics, social structure, climate and soil variation (Zimmermann, 1996). The advantage of growing two or more crops together is that all the environmental resources are used to maximize crop production per unit area of land. It is also used to improve soil fertility through nitrogen fixation with the use of legumes. It also provides superior lodging resistance for crops susceptible to lodging and enhances soil conservation through greater ground cover. Intercrops often minimise pest incidence and enhance the quality of forage by increasing crude protein yield (Baumann *et al.*, 2002). Under unstable market prices for a given commodity, intercropping provides a buffer against crop failure, especially in areas which have extreme weather conditions such as frost, drought and floods. Thus, it provides system stability relative to sole cropping, which makes it more suitable for small farmers.

Guvenc and Yildirim (1999) reported that intercropping was a stable and safer cropping system for crop production than sole cropping for small farms. Studies have shown that intercropping with a variety of vegetables is more profitable and productive compared to sole cropping (Baumann *et al.*, 2001). Agricultural sustainability supports the use of intercropping systems for sustainable intensification (Brooker *et al.*, 2015). It is a productive soil conservation practice as it improves soil cover, and allows for different root depths for different species to pass through soil layers (Jeranyama *et al.*, 2000). Intercropping can significantly increase productivity of crops compared with sole system, through more effective use of water, nutrients and solar energy (Midmore, 1993).

2.8 Water use of intercrop systems

Evapotranspiration (ET) is defined as a combination evaporation and transpiration, which occur simultaneously. Evaporation refers to the physical process of water vaporisation into gaseous phase from the soil surface, whereas, transpiration is a biophysical process where water is transported from the plant root zone through its cells xylem and stomata into the atmosphere (Annandale *et al.*, 2002; Wegerich and Warner, 2010). In intercropping, enhanced root density and variation between rooting patterns ensures that a large volume of soil water is utilised and thus water use efficiency (WUE) is improved (Anil *et al.*, 1998; Walker and Ogindo, 2003).

2.8.1 Water use efficiency

Improving water use efficiency is essential to increasing food production under water scarcity. Given climate change projections, which show increasing temperature and decreasing rainfall in semi- and arid regions, enhancing crop WUE is necessary for ensuring food security. Water use efficiency, under water stress is an essential yield determinant (Molden *et al.*, 2010; Chimonyo *et al.*, 2016). Reduction in canopy size was reported as a trait that confers high WUE under water-limited conditions (Molden *et al.*, 2010; Chimonyo *et al.*, 2016). Water use efficiency is expressed as:

$$WUE_{Y/B} = \frac{Y/B}{ET} \text{ (kg ha}^{-1}\text{ mm}^{-1}\text{)} \qquad \textbf{Equation 2.1}$$

where: WUE= water use efficiency (kg mm^{-1}ha^{-1}), Y = economic yield (kg ha^{-1}), B= final biomass (kg ha^{-1}) and ET = evapotranspiration (mm).

2.9 Assessment of intercropping productivity

2.9.1 Land Equivalent Ratio (LER) method

Land equivalent ratio (LER) is the ratio of the area required under sole cropping to one of intercropping at the same management level to give an equal amount of yield. It is the sum of the fractions of the yields of the intercrops relative to their sole crop yields (Andrews and Kassam, 1976; Dariush *et al.*, 2006). Generally, yield benefits from intercropping compared to sole cropping relate to mutual compatible crops and complementary resource utilisation. According to Willey (1979), LER can be mathematically expressed as:

$$LER = L_a + L_b = \frac{Ya}{Sa} + \frac{Yb}{Sb} \qquad \textbf{Equation 2.2}$$

where: LER = Land equivalent ratio, L_a and L_b = LERs of component crop a (cowpea), and b (amaranth or swiss chard or garden pea), respectively; Y_a and Y_b represent intercrop yield component crop a (cowpea), and b (amaranth or swiss chard or garden pea), respectively; while S_a and S_b are their respective yield under sole cultivation. Land equivalent ratio values greater than 1.0 show a benefit to intercropping, while values less than 1.0 show a disadvantage to intercropping (Dariush *et al.*, 2006).

2.10 Crop response to water stress

Plant responses to water stress vary, depending on the plant species, growth stage and intensity and duration of stress (Lisar *et al.*, 2012). Blum (2011) indicated that such responses are regularly described as being complex. To plant breeders, understanding of crop responses to water stress is essential and basic for selection and breeding of drought tolerant plants (Mabhaudhi and Modi, 2010).

2.10.1 Physiology

2.10.1.2 Stomatal conductance

Stomatal conductance is the rate of passage of water vapour or carbon dioxide through the stomata. At the site of carboxylation, it allows the leaf to change the partial pressure of carbon dioxide during the transpiration rate. It has been stated that during water stress, most plants respond by stomata closure, which results in lower stomatal conductance (Cornic and Massacci, 1996) and reduced water loss through transpiration.

2.10.1.2 Chlorophyll content

Chlorophyll is a green pigment found in chloroplasts of green plant cells. Chlorophyll content is normally determined quantitatively and is strongly correlated to nitrogen content in leaves. Chlorophyll accumulation was shown to decrease in water-stressed seedlings (Dalal and

Tripathy, 2012). Chlorophyll content may be useful for evaluating plant responses to water stress. Mabhaudhi *et al.* (2013) used chlorophyll content to evaluate drought tolerance in bambara groundnut selections. They observed that it was lower at the early stages of plant growth in stressed plants relative to unstressed plants. They concluded that chlorophyll content was a good indicator of drought tolerance and required more study.

2.10.2 Plant growth and development

Plant growth and development is attained through mitosis, expansion and finally differentiation. Under water stress conditions, cell growth processes are some of the most sensitive to water stress due to decreased turgor pressure (Taiz and Zeiger, 2006). Cell growth is a turgor driven process, since plant growth results from cell division and cell expansion. Thus, under water stress, there is reduced plant growth, due to low turgor pressure, resulting in less cell division, expansion and differentiation. Germination, emergence and vegetative stages all fall under plant growth. Low germination and emergence is taken as one of the first effects of water stress (Harris et al., 2002). According to Kaya *et al.* (2006), drought stress seriously reduced germination and seedling establishment. Poor seedling stand results in low yield due to decreased plant stand and often smallholder farmers cannot recover from this initial setback (Mabhaudhi and Modi, 2010). Hussain *et al.* (2008) stated that plant height, leaf number and area were all reduced under water stress. Similar to plant height, water stress has been reported to affect leaf number and area in many crops, including soybean (Zhang *et al.*, 2004), and cowpea (Jaleel *et al.*, 2009).

2.10.3 Yield

Yield refers to the harvestable part of the crop. Blum (2005) reported that many breeding programmes' objective was to develop crops that will give high yields under all environmental conditions, including drought. Crop yields show significant differences under drought stress conditions (Jaleel *et al.*, 2009). Numerous yield-determining processes are affected by water stress (Farooq *et al.*, 2009). Many studies have demonstrated that yields are reduced under water stress (Frederick et al., 2001). Vurayai *et al.* (2011) reported reduced yield in response to water stress in bambara groundnut landraces.

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CHAPTER 3. SEED VIGOUR COMPARISON OF SELECTED TRADITIONAL AFRICAN AND EXOTIC VEGETABLEES

3.1 Introduction

Seed quality is an important indicator of crop performance under controlled environment and field conditions for establishment, growth and productivity (Basra 1995). Traditional vegetables are indigenous plant species grown for their edible leaves, pods and grain (van Rensburg *et al.*, 2007). African leafy vegetables (ALVs) are also known as those plants that have originally been domesticated and cultivated in Africa for centuries (Gockowski *et al.*, 2003). They are well adapted to conditions like drought and poor soil quality since they can grow well under harsh conditions (Dweba and Mearns 2011). Traditional vegetables grow voluntarily (wild) and others can be cultivated. There are traditional vegetables that do not originate in Africa, but have been recognised and domesticated. These vegetables have also adapted to African conditions (van Rensburg *et al.*, 2007). Early South African history showed that traditional vegetables played an important role (Laidler and Gelfand 1971), but information on their role in food security is not widely published (Mnzava 1997).

In South Africa, agricultural scientists and development communities have mostly neglected traditional vegetables used by indigenous Africans (Modi, 2003). Many South African subsistence farmers have known only organic farming until they were introduced to 'new seeds' and agricultural chemicals (Modi 2003). Although the 'green revolution' played an essential role in preventing possible famine that would have a great significance in history, it also had negative effects on micronutrient malnutrition and environmental pollution (Welch and Graham 1999; Modi 2003). These vegetables were found to be mostly consumed by rural villagers but that has changed since current consumption has become widespread (Bvenura and Afolayan 2015). African leafy vegetables offer different opportunities to diversify farming systems, improve food security and reduce poverty, thus improving human health and income (Flyman and Afolayan 2006). They are highly nutritious and have a high iron and vitamin A contents (Achigan-Dako et al. 2014). More production of ALVs is needed to prevent food insecurity (Kenan et al. 2011). For high and successful production, crops require good quality seed (Slouch et al. 2009), something that is yet to be demonstrated for many African traditional vegetables.

To seed scientists, good quality seed is the sum of many individual components like genetic quality, physical purity, germination and health (disease free seeds). To farmers, good quality seeds are those that have all the physical, pathological, physiological and genetic characteristics that give high quality and quantity of final yield (Basra 1995; Chibarabada et al. 2014). Seed viability, germination and vigour are three aspects used to test seed performance before seeds are even planted in the field (McDonald and Copeland 2012*a*). Seed viability is the ability of a seed to germinate and produce a normal seedling under favourable conditions (McDonald and Copeland 2012*b*). Seed germination is defined as the sequence processes transforming an inactive embryo into being metabolically active, after a seed takes up water (imbibition) and embryo radicle protrusion through the seed coat (Cardwell 1984). Laboratory germination test is used to determine the ability of seeds to germinate, which then can be used to observe seed quality (ISTA 2011).

Seed vigour comprises all the seed properties that determine the ability of the seed to have rapid germination, uniform emergence, and development of normal seedlings under a wide range of field conditions (McDonald and Copeland 2012). Seed viability and vigour are essential elements influencing seedling establishment, plant growth and productivity (TeKrony and Egli 1991). Rahim et al. (2007) indicated that shortage of quality seed and lack of high yielding varieties are the major restrictions to production of ALVs. Seed systems for ALVs are informal and comprise production of farmers from village markets or farmers who grow their own vegetables in their fields (Akubusta-Onyango 2007); the quality of their seed is not known. Worldwide as the utilisation of ALVs increases, availability of good seed of known quality is important to meet the demand for these vegetables (Akubusta-Onyango 2007). Lack of knowledge about ALVs and their seed quality has led to their poor utilisation (Modi et al. 2006). In this study, it is hypothesized that there is no difference in seed quality between wild and cultivated vegetable species. The objective of the study was to determine germinability, viability and vigour of selected underutilised cultivated and wild vegetable crops based on seed quality.

3.2 Materials and methods

3.2.1 Plant material

The study used seeds of traditional African traditional vegetables, red amaranthus (*Amaranthus hybridus*) and cowpea (*Vigna unguiculata*). These crops are traditionally and commercially used as sources both edible leaves and grain. Swiss chard (*Beta vulgaris*) and garden pea (*Pisum sativum*) were used to represent genetically improved commercial crops for comparison with traditional crops. Swiss chard seeds were obtained from McDonald Seed Co., Pietermaritzburg, South Africa. Garden pea seeds were obtained from Stark Ayres Seeds, Pietermaritzburg, South Africa. Amaranth seeds were obtained from multiplication trials at the Agricultural Research Council, South Africa. Cowpea seeds were sourced from Capstone Seeds, Mooi River, South Africa.

3.2.2 Standard germination test

The International Seed Testing Association (ISTA 2017) rules for testing seed were used to test germination of red amaranthus (*Amaranthus hybridus*), Swiss chard (*Beta vulgaris*), garden pea (*Pisum sativum*) and cowpea (*Vigna unguiculata*) under laboratory conditions. A completely randomised design was used, where four seedlots were germinated using paper towel method (ISTA 2017b). Twenty-five seeds from each seedlot were placed between moistened double-layered paper towels and placed in an incubator set to 25°C to germinate. The experiment was replicated three times. Seeds were considered to be germinated when radicle protrusion was longer than 2 mm. The germination count was recorded daily for nine days. Seedling biomass, root length and shoot length were measured on the last day of the germination test.

3.2.3 Seed vigour

In order to assess seed vigour, the germination velocity index (GVI; germination speed) was calculated based on Maguire's (1962) formula:

$$GVI = G1/N1 + G2/N2 + \ldots + Gn/Nn \qquad \textbf{Equation 3.1}$$

where G1, G2, …Gn = number of germinated seeds in first, second, … last count, and N1, N2, … Nn = number of germination days.

Mean germination time (MGT) was calculated according to Ellis and Roberts (1981):

$$MGT = \frac{\sum Dn}{\sum n} \qquad \textbf{Equation 3.2}$$

Where n = number of seeds that were germinated on day D, and D = number of days counted from the beginning of germination.

3.2.4 Data analysis
Data analysis (ANOVA) was performed using GenStat® version 18 (VSN International, Hemel Hempstead, UK, 2011) to determine significant differences at $P \leq 0.05$ and least significant difference (LSD) values ($P \leq 0.05$) were used to separate mean differences.

3.3 Results

3.3.1 Standard germination test
There were highly significant differences ($P < 0.001$) among crop species, with respect to germination (Fig 3.1). Amaranth showed 100% germination from the first day after incubation, whereas cowpea showed 13% germination on the first day and reached 100% germination by day six. Both garden pea and Swiss chard had 8% germination on day one and reached 100% germination by day nine after incubation. Amaranth had the fastest germination followed by cowpea and garden pea and Swiss chard showed slowest germination (Fig 3.1).

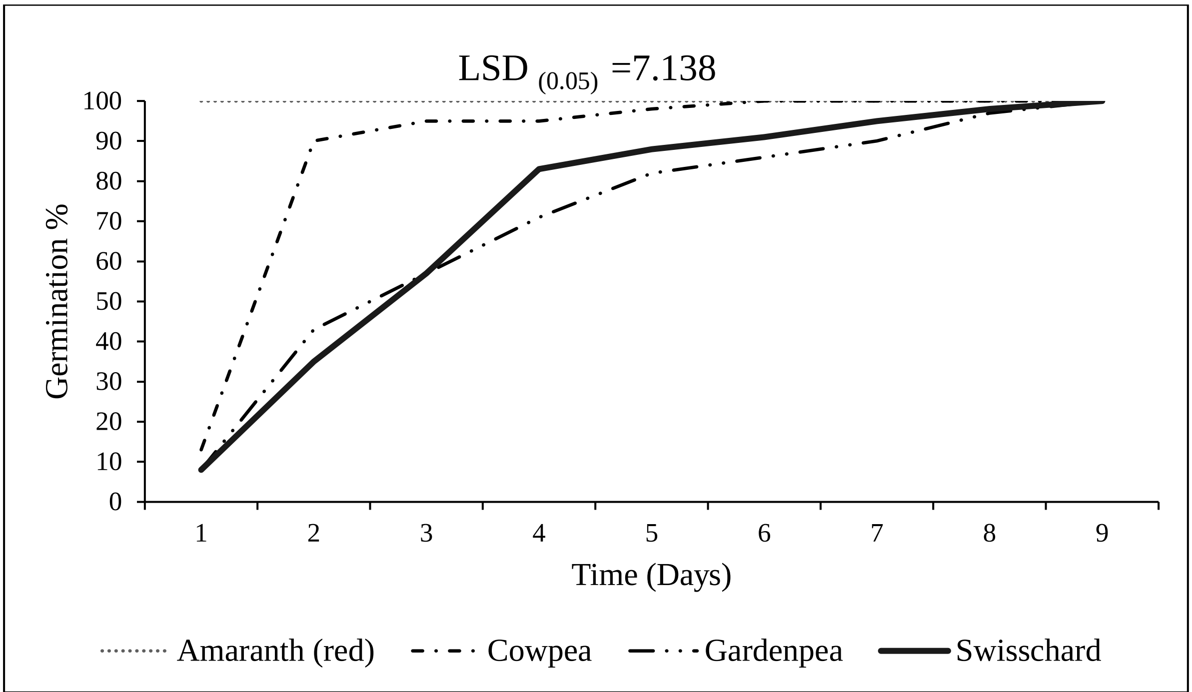

Figure 3.1: Daily germination percentage of traditional African vegetables (red-amaranth and cowpea) compared with exotic leafy vegetables (garden pea and swiss chard).

Results of germination velocity index (GVI) showed highly significant differences ($P<0.001$) among the crop species (Fig 3.2). Amaranth had highest GVI (70.72), followed by cowpea GVI

(46.9), while garden pea GVI (33.3) and Swiss chard GVI (33.74) had the lowest GVI which were not significantly different (Fig 3.2).

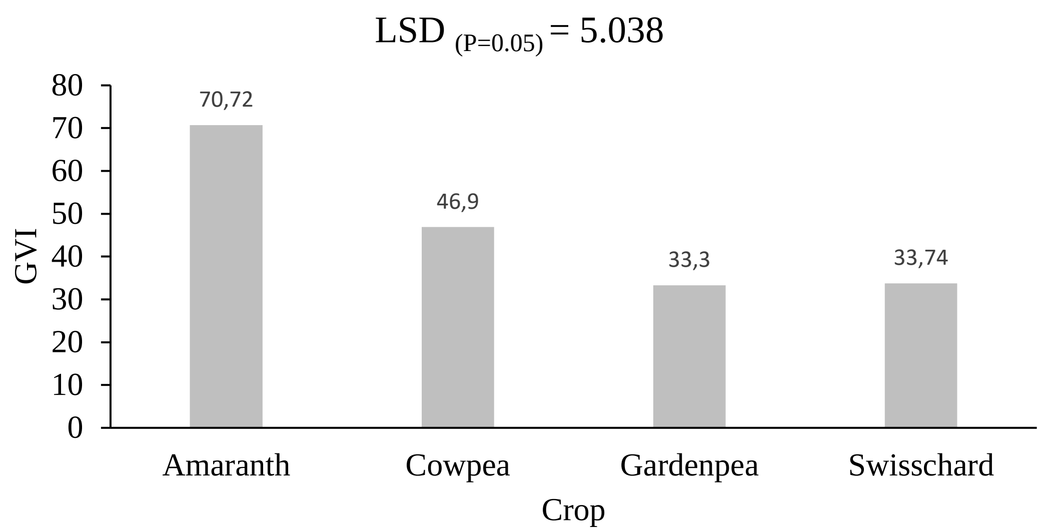

Figure 3.2: Germination velocity index (GVI) of traditional African vegetables (red-amaranth and cowpea) compared with exotic leafy vegetables (garden pea and Swiss chard).

There were highly significant differences ($P<0.001$) among crop species with respect to mean germination time (MGT) (Fig 3.3).

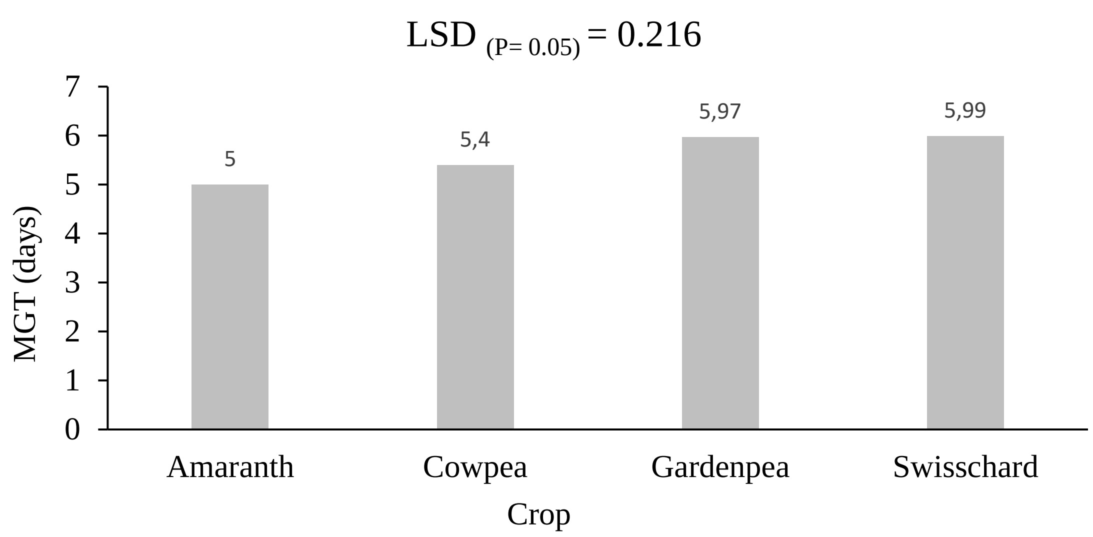

Figure 3.3: Mean germination time (MGT) of traditional African vegetables (red-amaranth and cowpea) compared with exotic leafy vegetables (garden pea and Swiss chard).

3.3.2 Germination vigour characteristics

There were highly significant differences ($P<0.001$) among crop species with respect to root length (Fig 3.4). Cowpea had the longest root length of 30.2 mm followed by amaranth (13.3 mm), garden pea (9.8 mm) and Swiss chard (4.4 mm) (Figure 3.4). Results of shoot length showed highly significant differences ($P<0.001$) among crop species (Fig 3.5). The longest shoot length (119.6 mm) was observed in cowpea and garden pea, while Swiss chard showed the shortest shoot length (14.6 mm) followed by amaranth (16.4 mm) (Fig 3.5). There were highly significant differences ($P<0.001$) among crop species, with respect to seedling size (Fig 3.6). Cowpea had the longest seedling length (151.6 mm) and Swiss chard had the smallest seedlings (18.9 mm) (Fig 3.6). There were no significant differences ($P= 0.062$) among crop species with respect to root: shoot ratio (Fig 3.7).

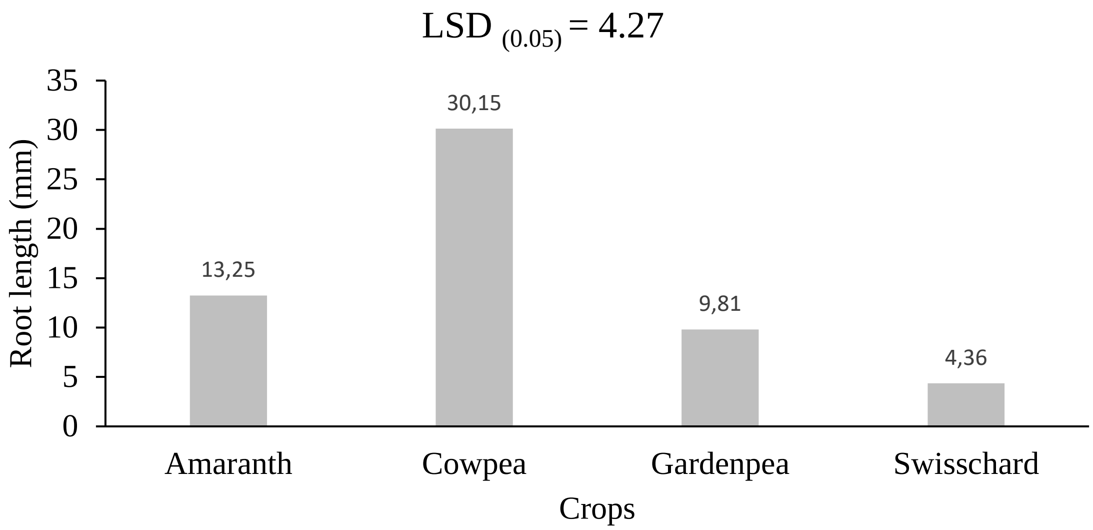

Figure 3.4: Root length of traditional African vegetables (amaranth and cowpea) compared with exotic leafy vegetables (Swiss chard and garden pea) after germination.

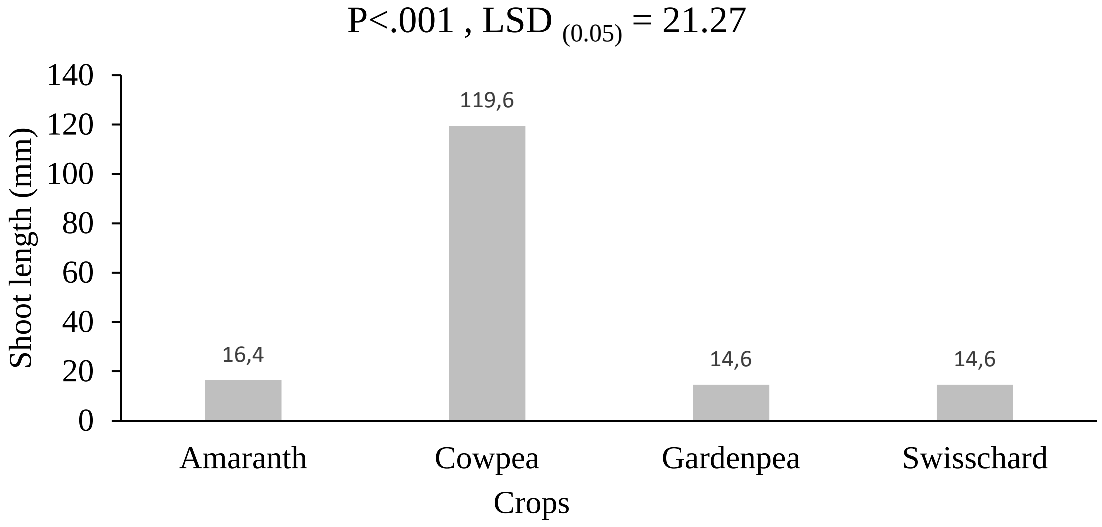

Figure 3.5: Shoot length of traditional African vegetables (amaranth and cowpea) compared with exotic leafy vegetables (Swiss chard and garden pea) after nine days.

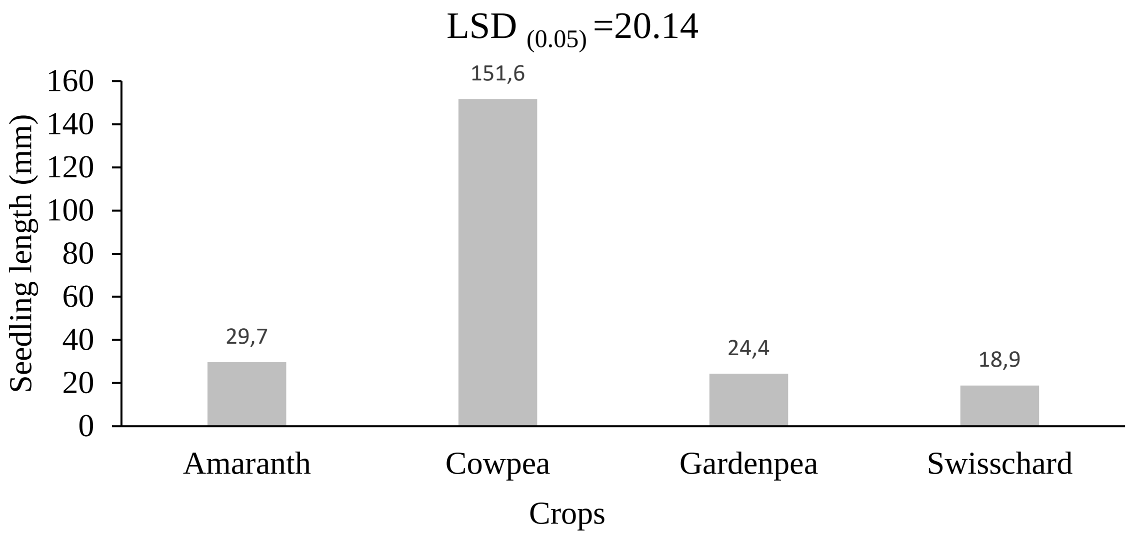

Figure 3.6: Seedling length of African leafy vegetables (amaranth and cowpea) compared with exotic leafy vegetables (Swiss chard and garden pea) after germination.

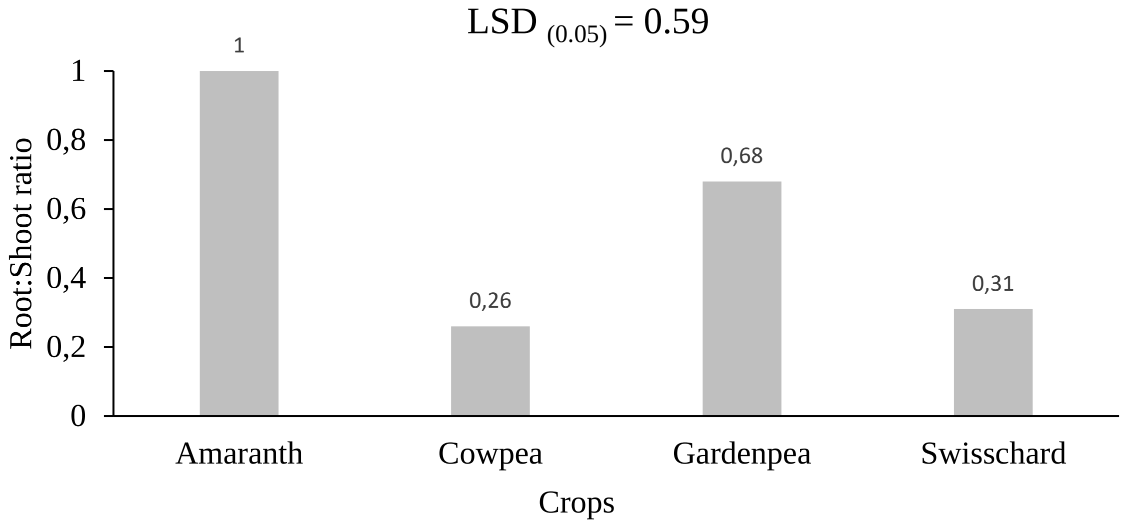

Figure 3.7: Root: Shoot ratio of African leafy vegetables (amaranth and cowpea) compared with exotic leafy vegetables (Swiss chard and garden pea) after germination.

It was informative to compare the average performance of crops (traditional vegetables vs. exotic vegetables; legumes vs leafy vegetables) with respect to seed quality parameters pertaining to seed vigour (Tables 3.1 and 3.2). Results clearly indicated superiority of traditional African vegetables, irrespective of use classification (legume or leafy vegetable) with respect to seed vigour (Tables 3.1 and 3.2).

Table 3.1. Comparing traditional and exotic vegetables for seed quality parameters (GVI = Germination Vigour Index), MGT (Mean Germination Time) and seedling shoot length at the end of germination test (9 days)

	Traditional vegetables	**Exotic vegetables**	**Difference (traditional-exotic) (%)**
GVI	58.81	33.52	42
MGT (days)	5.2	5.98	-15
Shoot length (cm)	68	14.6	78.5

Table 3.2. Traditional legume vs. exotic legume and traditional vs. leafy vegetables for seed quality parameters (GVI = Germination Vigour Index), MGT (Mean Germination Time) and seedling shoot length at the end of germination test (9 days)

	Traditional vegetables	Exotic vegetables	Differences (traditional-exotic) (%)
	GVI		
Legume	46.9	33.3	29
Leafy vegetable	70.72	33.74	52.3
	MGT (days)		
Legume	5.4	5.97	-10.6
Leafy vegetable	5	5.99	-19.8
	Shoot length (cm)		
Legume	119.6	14.6	87.8
Leafy vegetable	16.4	14.6	11

3.4 Discussion and conclusion

The objective of the study was to determine germinability, viability and vigour of selected African leafy vegetables and exotic vegetables based on seed quality. In any cropping system, good seed quality is found to be essential as it plays an important role in crop establishment, growth and yield (Goggi et al., 2008; Mazvimbakupa et al., 2015). Good seed quality allows better performance in the field in terms of germination, rapid emergence, and vigorous seedlings (Mabhaudhi and Modi, 2011; Mazvimbakupa et al., 2015). Seed germination is the most crucial stage in seedling establishment (Almansouri et al., 2001; Mabhaudhi and Modi, 2010). Seed viability is measured using standard germination test (ISTA 1985; Mabhaudhi and Modi, 2010). The results of this study showed that all the crop species had viable seeds since they could germinate and produce normal seedlings (Basu, 1995).

Traditional vegetables could germinate faster and more uniformly compared to exotic vegetables. According to Carvalho and Nakagawa (1980), germination velocity index (GVI) shows the relative physiological strength of a seedlot. The results showed strong link between final germination, GVI and MGT. Seeds that showed fast germination also had high GVI, which concurs with the results that were found by Sithole et al. (2016) that the higher the mean germination time the higher the final germination. Cowpea had the longest root length, shoot length and seedling length. This may be related to it having bigger seed size, not because other crop species were not performing well.

The significant differences in seedling size were likely associated with genetic differences among species. However, all species produced normal seedlings as indicated by root, shoot length and root: shoot ratio. Swiss chard and garden pea seeds had slow germination, which may suggest dormancy or poorer seed quality or vigour. Dormant seeds are those seeds that do not have ability to germinate even under favourable germination conditions. In morphological dormancy, there is delay of germination due to requirement of certain cold period of exposure before seeds are being germinated (Baskin and Baskin 2004). The results showed that traditional vegetables had lower MGT than exotic vegetables, which is a good indicator of seed vigour.

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CHAPTER 4. INTERCROPPING PERFORMANCE OF SELECTED AFRICAN TRADITIONAL CROPS COMPARED WITH COMMERCIAL CROPS

4.1 Introduction

Sub-Saharan Africa (SSA) is indicated as having both physical and economic water scarcity (Hanjra and Qureshi, 2010). Globally SSA is indicated as having major variability and vulnerable to climate change according to the Intergovernmental Panel on Climate Change (IPCC, 2014). The SSA region is already experiencing extreme weather: temperature, drought and floods. In this region, climate change variability poses a major threat to agricultural production. Agriculture remains a source of livelihood and food security for the SSA population. Most of agriculture (ca. 90%) is practised under rain-fed conditions (Van Duivenbooden *et al.*, 2000) and significant yield penalties have been attributed to water stress (Rockström, 2003). In rain-fed agriculture, drought stress is one of the most essential limiting factors and has a seriously influence on crop performance (Turner, 1996; Mabhaudhi and Modi, 2010). According to Mabhaudhi and Modi (2010), this is a major concern to agriculture impact, vulnerability of rural households and the urban poor, regarding nutrition and food security.

Water availability is a major priority to increase crop production, given the fundamental need to enhance food security (Chimonyo *et al.*, 2016). Passioura (2006) indicated that the effect of water scarcity can be minimized using crops that contain drought tolerant traits. In water scarce agricultural systems, growing crop species with a genetic makeup that allows effective soil water uptake for transpiration and efficient exchange of CO_2 could enhance yield production (Deng *et al.*, 2006; Zegada-Lizarazu *et al.*, 2012). African leafy vegetables promise to be the best crops to be grown under water scarce environments, since they are genetically adapted to grow under harsh conditions. They grow voluntarily in the wild and few are cultivated. African leafy vegetables are essential in improving food security. Globally, SSA has the highest percentage of malnourished people (FAO, 2001). In this region, starchy staples contribute about 80% of diets. Vitamins and minerals are most lacking in diets because vegetables are seasonal and in most cases unaffordable. This creates a great opportunity to utilize ALVs because they are inexpensive to produce. In addition, indigenous crops require less inputs than conventional crops, an attribute that is well suited for rural agriculture where 70% of the malnourished population resides.

Intercropping, rain-fed production systems of vegetables can be used to enhance water management in crop production (Jun et al., 2014). Intercropping is an agricultural practice of growing two or more crops simultaneously in the same land area during the same growing season period (Andrew and Kassam, 1976). Guvenc and Yildirim (1999) reported that intercropping is a stable cropping system for agriculture and safer system in terms of crop production than sole cropping for small farms. Intercropping can significantly increase productivity of crops compared with the sole system, through more efficient use of water, nutrients and solar energy (Midmore, 1993). In water-limited areas, intercropping has appeared to be a suitable approach for sustainable agriculture (Chimonyo *et al*, 2016) that can be used to improve production in subsistence small scale agricultural systems where land is limited and famers tend to intercop. It has been found that almost two of every three people in SSA live in rural areas and they depend on small-scale, rain-fed agriculture for their livelihood (FAO, 2014; Hadebe *et al*, 2017). Many studies have shown that under small-scale farming, intercropping main crops with short season vegetables can be more productive compared to sole cropping (Baumann et al., 2001). The aim of this study was to compare intercropping systems of traditional crops, amaranthus and cowpea, with those of commonly used commercial crops, Swiss chard and garden pea with respect to productivity, water use, and nutritional value under rain-fed conditions.

4.2 Materials and methods

4.2.1 Plant material

The study used seeds of traditional African leafy vegetables, red amaranthus (*Amaranthus hybridus*), and cowpea (*Vigna unguiculata*). In Africa, these indigenous crops are traditionally used as sources of both edible leaves and grain, but they are not improved for commercial agriculture and industry (FAO, 2014). Swiss chard (*Beta vulgaris*) and garden pea (*Pisum sativum*), on the other hand, were used as improved commercial crops for comparison with traditional crops. Swiss chard seeds were obtained from McDonald Seed Co., Pietermaritzburg, South Africa. Garden pea seeds were obtained from Stark Ayres Seeds, Pietermaritzburg, South Africa. Amaranth seeds were obtained from multiplication trials at the Agricultural Research Council (ARC), South Africa. Cowpea seeds were sourced from Capstone Seeds, Mooi River (South Africa).

4.2.2. Site description

Two sites in different locations of KwaZulu-Natal, South Africa, namely, Umbumbulu (29°59'S, 30°42'E) and Fountain Hill Estate (29.42° S, 30.57° E), were used for field trials.

Fountain Hill Estate (FHE) is a commercial farming estate located 20 km east of Pietermaritzburg in the private Hlambamasoka Game Reserve. It (FHE) is classified as having a subtropical highland climate with mean annual rainfall of 905 mm. It has a mean annual temperature of 20.4 °C, with February being the hottest month of the year and June the coldest month of the year. The soil is sandy-loam. Umbumbulu is a rural homestead subsistence agriculture area 60 km south-west of Pietermartzbutg with average rainfall of 1009 mm and mean annual temperature of 17.9 °C. The soil was classified as clayey loam. Field trials at both sites were planted in the same week in December 2016, the summer planting season in both areas.

4.2.3. Experimental design and layout

A completely randomized design with three replications was used under rain-fed conditions at both sites. The experiment comprised of two cropping systems, intercropping and mono-cropping. Cowpea and garden pea were the main crops. Amaranthus and Swiss chard were intercrops. With a spacing of 0.75 m (inter-row) and 0.3 m (intra-row) for the main crop, intercrops were planted in a constant pattern (Amujoyegbe and Elemo, 2013; Amujoyegbe and Elemo, 2013).

4.2.4. Data collection

4.2.4.1. Climate data

Daily meteorological data, including minimum and maximum temperature, rainfall, minimum and maximum relative humidity, wind speed and direction, solar radiation and reference evapotranspiration were collected at both locations. At Umbumbulu data were obtained from the (within 6 km radius) automatic weather station (AWS), courtesy of the South African Sugar Research Institute (SASRI) (http://sasri.sasa.org.za/irricane/tables/). For Fountain Hill Estate data were obtained from an AWS within a 5 km radius of the trial site.

4.2.4.2 Plant growth and development

Emergence data were taken from sowing untill seedling establishment. Crop growth and development data were collected bi-weekly. Seedling emergence was considered as full leaf protrusion above the soil surface. Fully expanded leaves were assumed photosynthetically active and counted as number of leaves after emergence. Plant height, distance from soil surface to the tip of the youngest leaf, was measured (Mabhaudhi and Modi, 2013). Chlorophyll content index (CCI) was measured using a SPAD-502 *Plus* chlorophyll meter (Konica Minolta, Osaka, Japan). Stomatal conductance (SC) was measured using a SC–1 leaf porometer (Decagon Devices®, Pullman, WA, USA). Leaf selection was done randomly and standardized through statistical analysis. All these measurements were taken at midday every two weeks on the adaxial surface of the first fully expanded, fully exposed leaf. For measurements of CCI and SC, six plants (a sample) were tagged per plot at crop establishment from which measurements were conducted throughout the growing season. Soil water content was determined from planting up to the end of grain filling stage using the gravimetric method (Mabhaudhi and Modi, 2013).

4.2.4.3. Yield determination

Harvesting of each component crop across the different treatments was done at harvest maturity. Since the cowpea variety is a semi-determinant crop, sequential harvesting of pods began at the first sign of pod drying. At harvest for all treatments, above ground plant matter of six representative plants of each treatment were taken for determination of yield parameters (harvest index) and overall yield. Pods were separated from the whole plant and air-dried in a glass house (ca. 20^{o}C day/night average temperature) until seeds shuttered from pods. Thereafter, the grain was shelled and mass and nutritional content were determined. Nutritional content for all treatments was analyzed in the laboratory. Harvest index was calculated as follows:

$$HI = \frac{Yg}{B} \qquad \textbf{Equation 4.1}$$

where: HI = harvest index (%); Yg = economic yield based on grain yield (kg); and B = aboveground biomass (kg).

4.2.4.4. Water use

Soil water content (SWC) was measured weekly using the normal gravimetric method. Soil samples were taken using an auger. Weekly SWC measurements were then used to calculate a soil water balance (Zhao et al., 2004) from sowing to physiological maturity as follows:

$$ET = I + P + C - D - R \pm \Delta SWC \qquad \textbf{Equation 4.2}$$

where: ET = evapotranspiration (mm); I = irrigation (mm); P = precipitation/rainfall (mm); C = capillary rise (mm); D = drainage (mm); R = runoff (mm); and ΔSWC = changes in soil water content.

Since the field trials were grown under rain-fed conditions, there was no irrigation (I) to be considered. Capillary rise (C) and drainage (D) were considered negligible (Ridolfi et al, 2008).

Runoff (R) was also considered negligible due to planting rows oriented across the slope limiting runoff. Therefore, the ET equation was simplified to:

$$ET = P - \Delta SWC \qquad \textbf{Equation 4.3}$$

Water productivity (WP) was calculated as follows (Renault and Wallander, 2000):

$$WP = [drymass] / [actual\ evapotranspiration] \qquad \textbf{Equation 4.4}$$

4.2.4.5. Water use efficiency

Water use efficiency refers to the ratio of water used by the plant in metabolism to water lost through transpiration and soil evaporation (evapotranspiration). Water use efficiency was calculated using the following formula (Kuslu et al., 2010):

$$WUE = B / ET \qquad \textbf{Equation 4.5}$$

Where: B = aboveground biomass (kg ha^{-1}) and ET = actual field evapotranspiration (mm).

Nutritional water productivity was determined according to a published formular (Renault and Wallender, 2000; Van Halsema and Vincent, 2012):

$$NWP = = \frac{Ya}{ETa} NP \qquad \textbf{Equation 4.6}$$

Where, NWP is the nutritional water productivity (nutrition unit/ m^3 of water); Ya = the actual harvested yield (kg/ha); ETa = actual evapotranspiration (m^3/ ha); and NP = is the nutrition content per kg of product (nutrition unit/ kg).

4.2.5. Agronomic practices

Prior to planting, soil samples were obtained from the field trial site and analyzed for soil fertility and textural analyses. Land preparation involved ploughing, disking and rotating to achieve fine tilt. Planting was done manually and no fertilizer was added since recommended levels for N, P and K were met or exceeded for all the crops. Upon full establishment (% emergence), seedlings were thinned to the required spacing. Routine weeding was done mechanically using hand hoes or hand-pulling.

4.2.6. Statistical analysis

Data were analysed (ANOVA) using GenStat® version 18 (VSN International, Hemel Hempstead, UK, 2011) to determine significant differences at P≤0.05 and least significant difference (LSD) values (P ≤ 0.05) were used to separate mean differences.

4.3. Results

4.3.1 Weather data

Comparing two sites (Umbumbulu and FHE), weather conditions varied. Seasonal maximum temperature at Umbumbulu (29.8°C) was 3.4°C higher than the observed temperature at FHE (26.4 °C) and minimum temperature at Umbumbulu (16.8°C) and FHE (13.2°C) also differed. Rainfall at Umbumbulu was 39.3% higher than at FHE and based on skewness it was more normally distributed (726 mm) than rainfall received at FHE (521 mm). However, there were more incidences of days where there was no rain at Umbumbulu compared to FHE (Fig 4.1). The observed results suggest that the possibility of intermittent water stress was higher at Umbumbulu than FHE. Cumulative reference evapotranspiration was 570.9 and 518.1 mm at Umbumbulu and FHE, respectively.

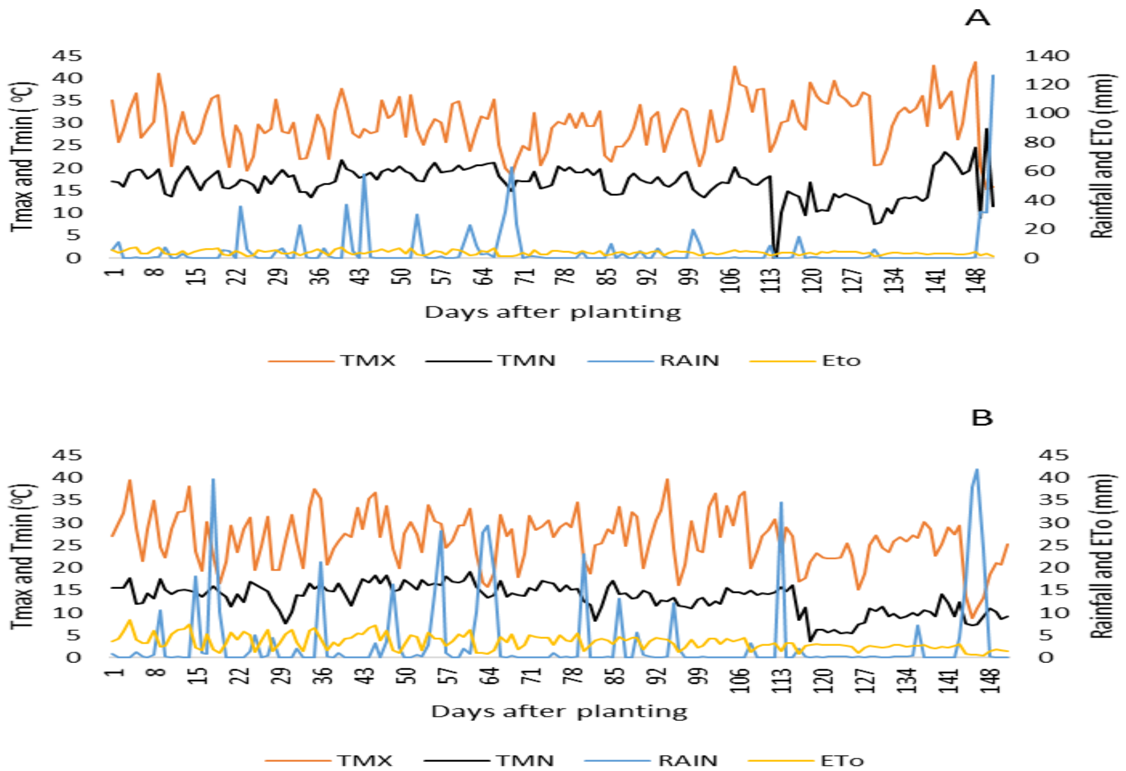

Figure 4.1: Daily temperature (maximum and minimum), reference evapotranspiration (ETo), and rainfall for both sites [(A) – Umbumbulu and (B) FHE), KwaZulu-Natal South Africa.

4.3.2 Emergence

There were highly significant differences (P < 0.001) among cropping systems and sites, with respect to emergence percentage (Fig 4.2). The FHE site showed high emergence percentage, whereas Umbumbulu had low emergence percentage. Cowpea at both sites showed great performance under both sole and intercropping systems. For FHE, under sole cropping system cowpea had highest emergence of 96.7% followed by amaranth (65%) and garden pea had least emergence (7.7%).

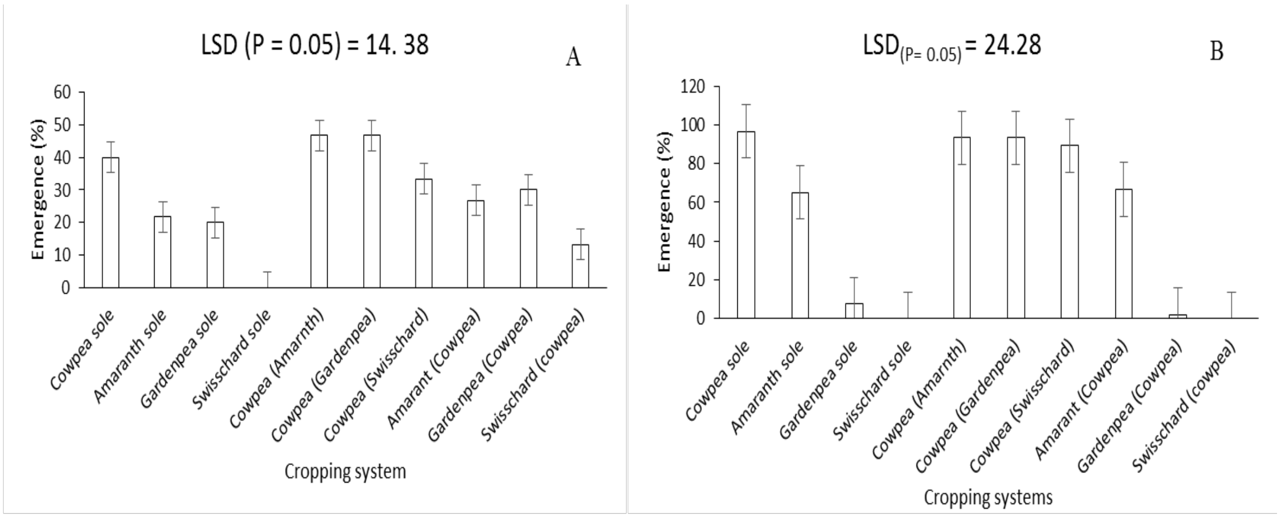

Figure 4.2: Comparison of leafy vegetables emergence (%) in response to site [(A) - Umbumbulu, (B) - FHE], and cropping system (Mono-cropping and intercropping).

4.3.3 Plant growth and development parameters

There were significant differences (P< 0.05) with respect to plant height of cowpea under sole and intercropping systems (Fig 4.3) at both sites. For both sites, cowpea when intercropped with Swiss chard had taller plants compared to other plants. There were significant differences (P < 0.05) with respect to plant height of garden pea under sole and intercropping (Fig 4.4) at both sites. However, the sole crop plants were, on average, taller (7.4 cm) than plants under intercropping (6.4 cm) at Umbumbulu, while at FHE it was the opposite. There were significant differences (P<0.05) with respect to plant height of amaranth under sole and intercropping (Fig 4.5). Plants grown under sole cropping were taller (129.6 cm) compared to those under intercropping (97.9 cm).

There were significant differences (P < 0.05) observed with respect to the number of leaves obtained for cowpea under both sole and intercropping systems (Fig 4.6). Plants under cowpea intercrop developed more leaves compared to sole cropping system for both sites. There were significant differences (P < 0.05) with respect to the number of leaves obtained for garden pea under sole and intercropping systems (Fig 4.7). The results showed that plants under sole cropping at Umbumbulu develop more leaves than under intercrop system, while at FHE more plant leaves were developed under intercrop than sole cropping system. There were significant differences (P < 0.05) with respect to the number of leaves obtained for amaranth under sole and intercropping systems (Fig 4.8). Plants grown under intercropping system developed more leaves compared to the ones grown under sole cropping system.

There were no significant differences (P < 0.05) with respect to chlorophyll content index (CCI) for cowpea at both sites under sole and intercropping systems (Figure 4.9). There were significant differences (P < 0.05) with respect to garden pea CCI at both sites under sole and intercropping systems. For Umbumbulu, garden pea under intercropping had higher CCI than sole cropping, while at FHE it was the opposite (Figure 4.10). There was significant a difference (P < 0.05) with respect to amaranth CCI (Figure 4.11). There was low germination for amaranth at Umbumbulu compared to FHE. As a result, the amaranth that was planted at Umbumbulu failed to grow. The crop stomatal conductivity showed a general pattern of decline from the start to the end of the season (Figs 12 and 13). However, there was an unusual peak in stomatal conductance later in the season.

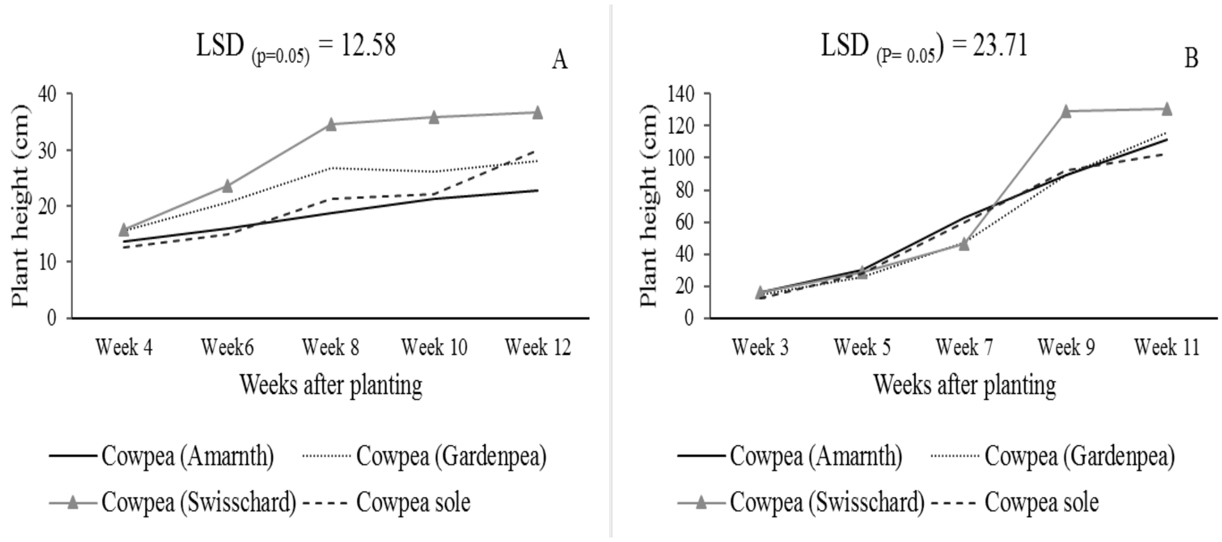

Figure 4.3: Comparison of cowpea plant height in response to site [(A) - Umbumbulu, (B) - FHE] and cropping system (Mono-cropping and intercropping).

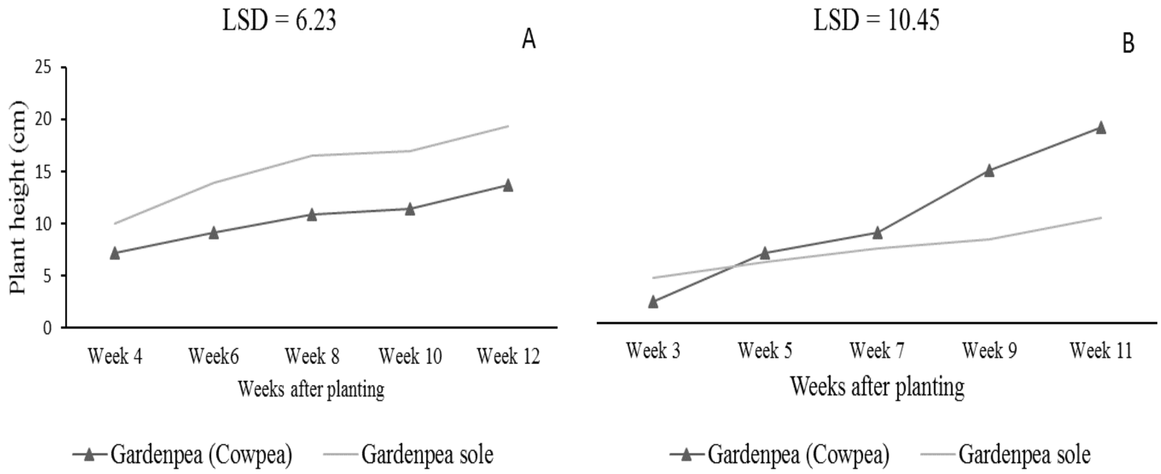

Figure 4.4: Comparison of garden pea plant height in response to site [(A) - Umbumbulu, (B) - FHE], and cropping system (monocropping and intercropping).

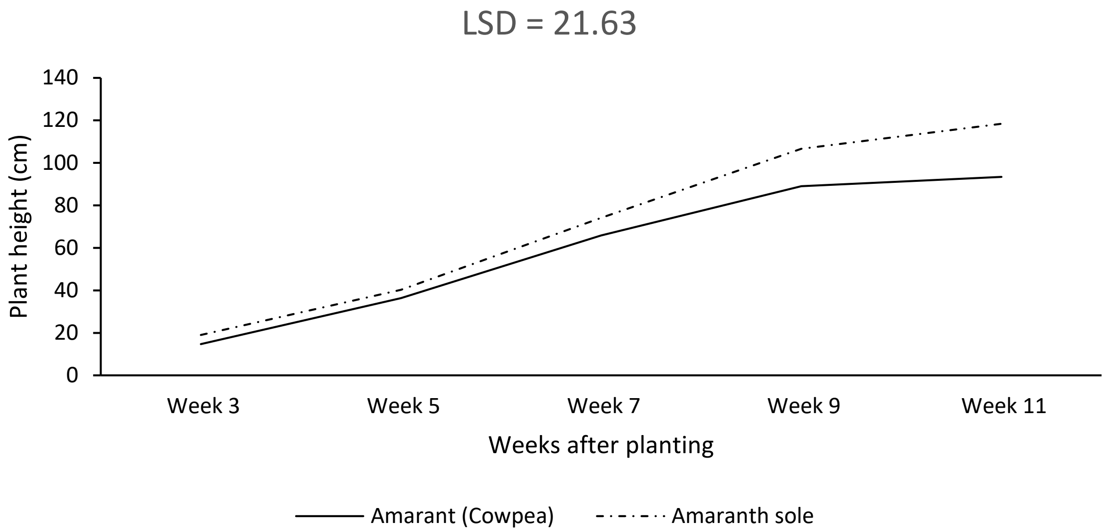

Figure 4.5: Comparison of amaranthus plant height in response to cropping system (monocropping and intercropping).

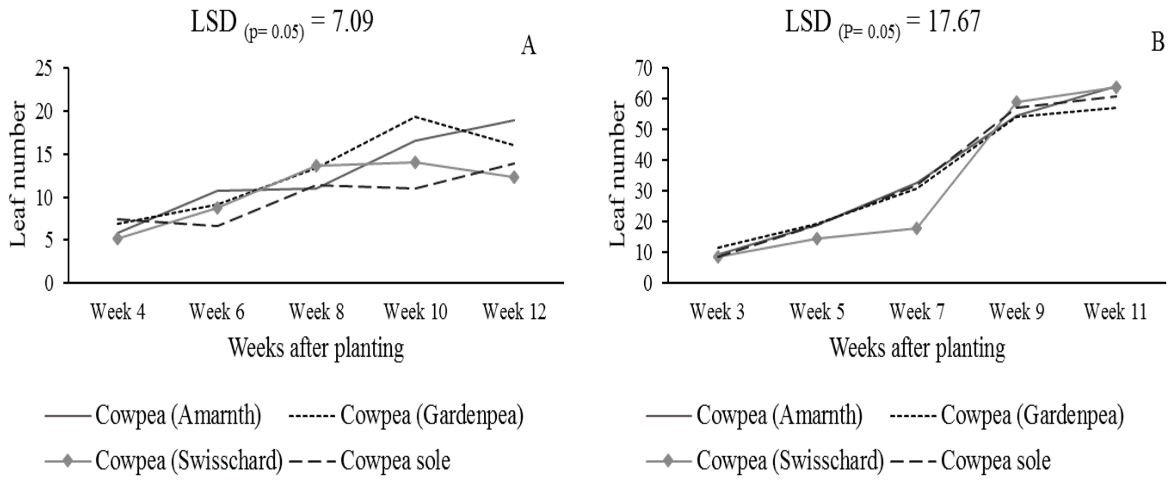

Figure 4.6: Comparison of cowpea leaf number in response to site [(A) - Umbumbulu, (B) - FHE], and cropping system (monocropping and intercropping).

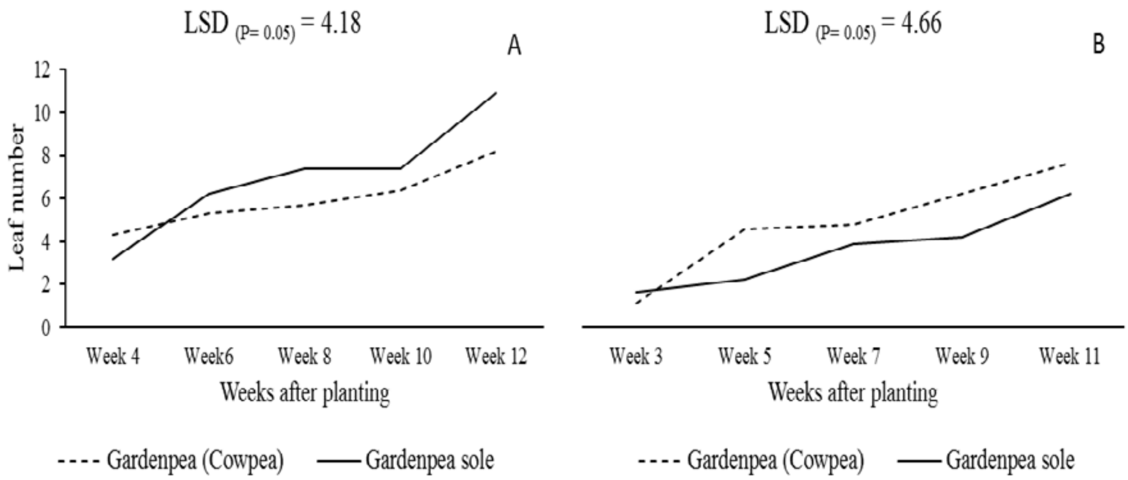

Figure 4.7: Comparison of garden pea leaf number in response to site [(A) - Umbumbulu, (B) - FHE], and cropping system (monocropping and intercropping).

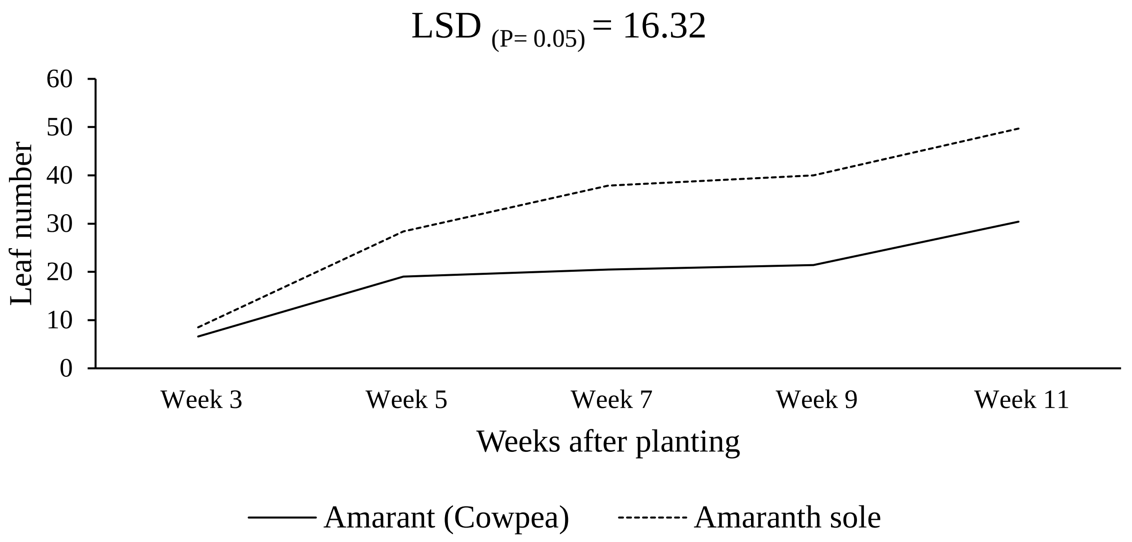

Figure 4.8: Comparison of amaranthus leaf number in response to cropping system (monocropping and intercropping).

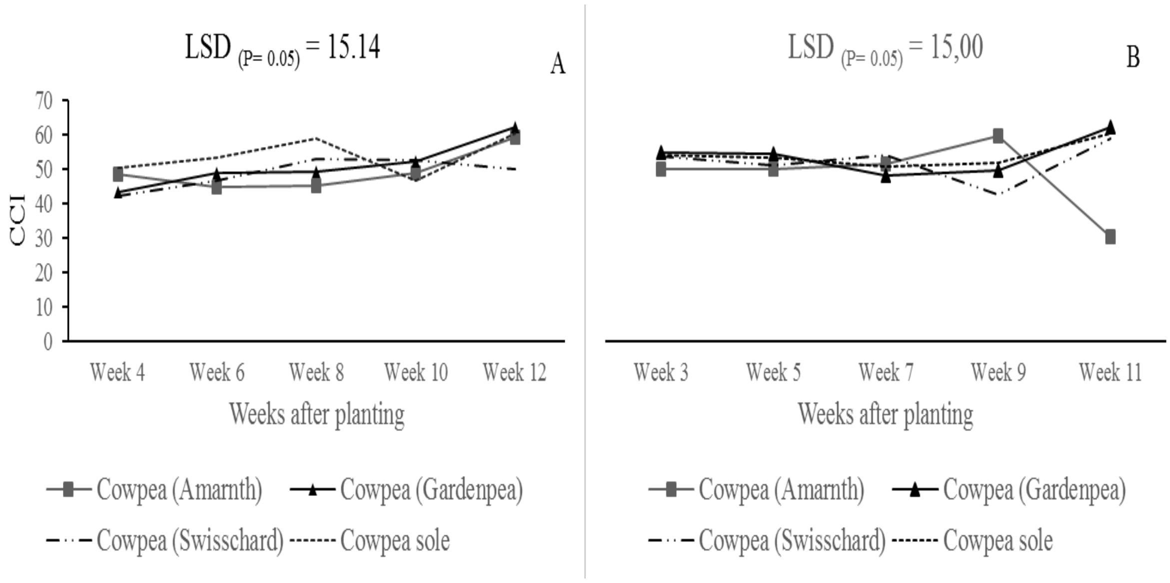

Figure 4.9: Comparison of cowpea CCI in response to site [(A) - Umbumbulu, (B) - FHE], and cropping system (monocropping and intercropping).

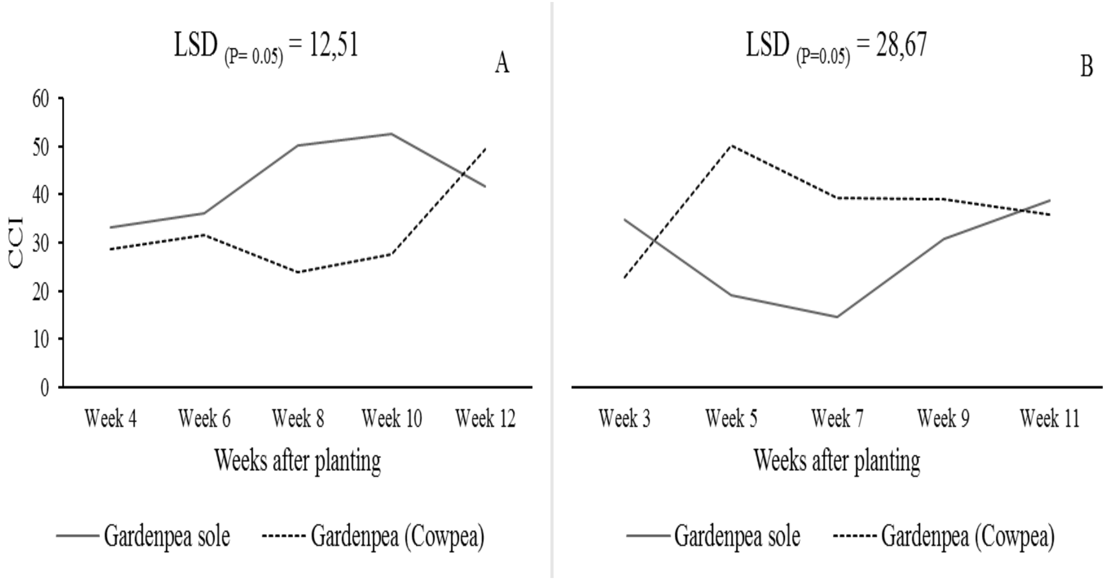

Figure 4.10: Comparison of garden pea CCI in response to site [(A) - Umbumbulu, (B) - FHE], and cropping system (onocropping and intercropping).

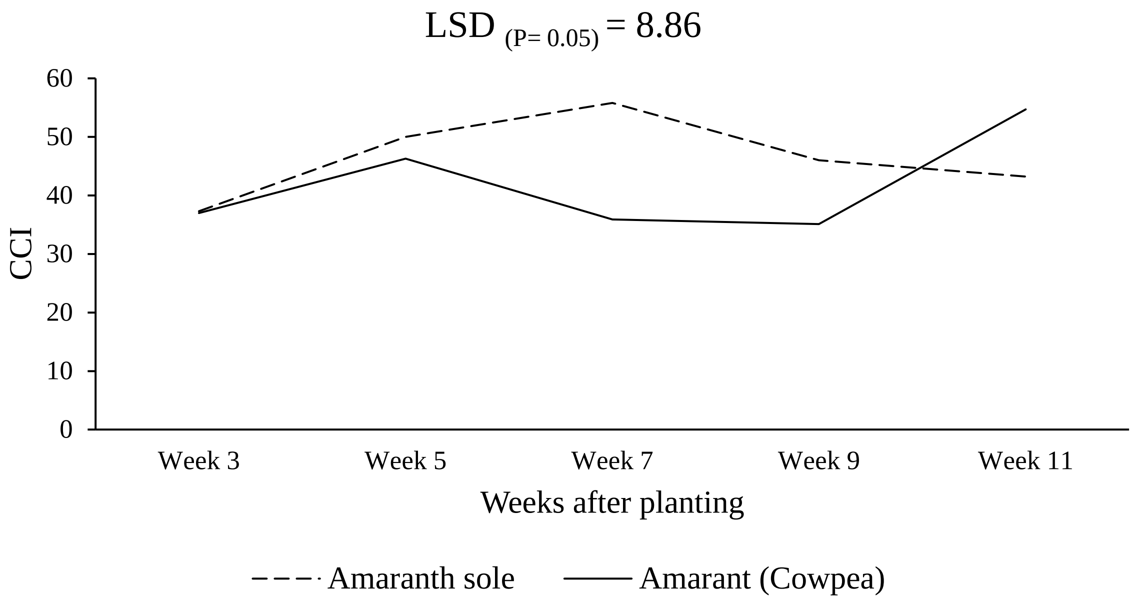

Figure 4.11: Comparison of garden pea CCI in response to cropping system (monocropping and intercropping).

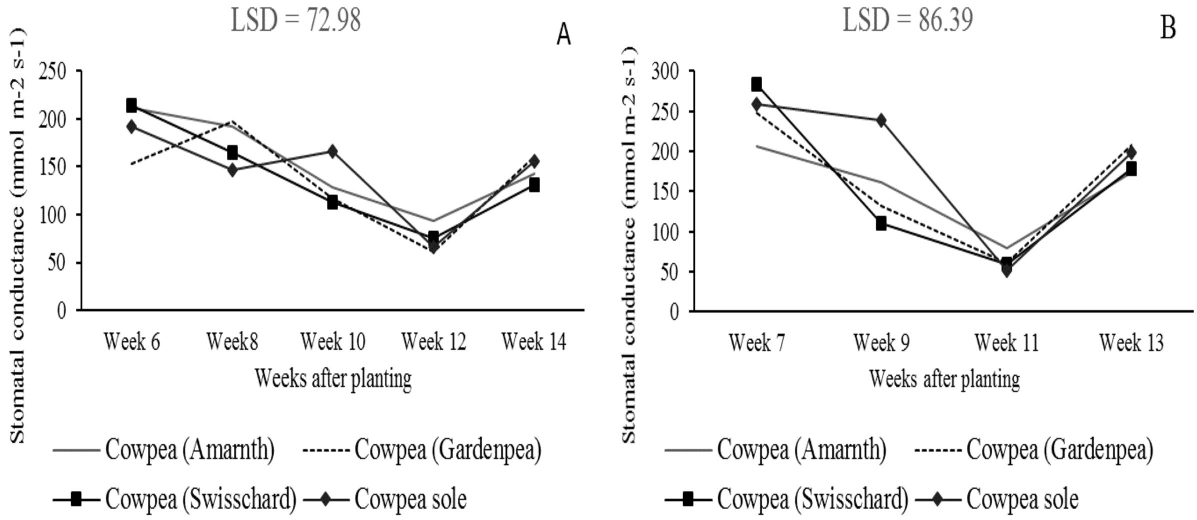

Figure 4.12: Comparison of cowpea stomatal conductance in response to site [(A) - Umbumbulu, (B) - FHE], and cropping system (monocropping and intercropping).

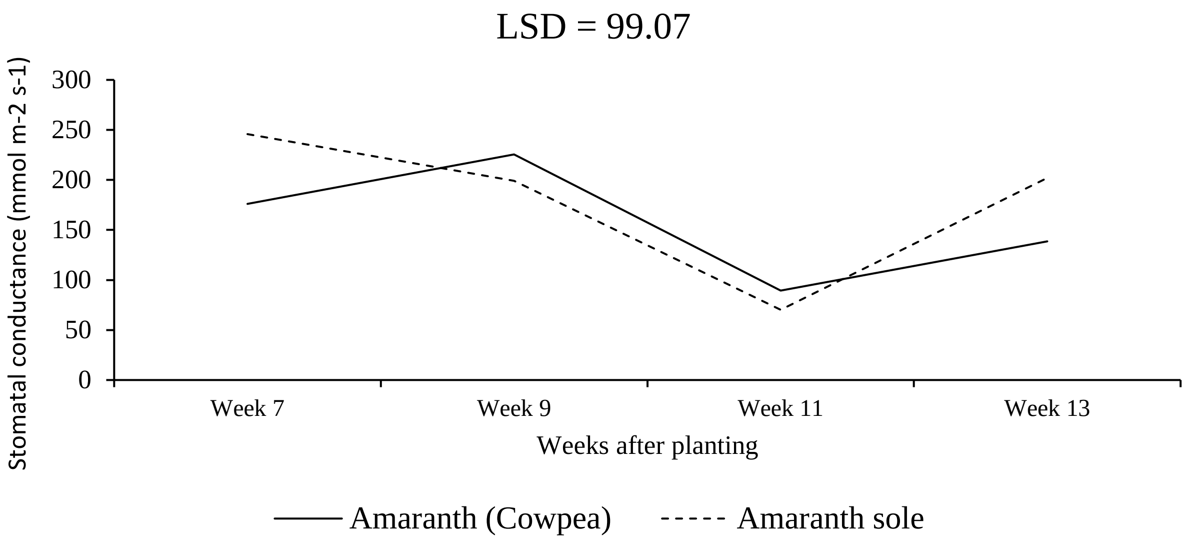

Figure 4.13: Comparison of amaranthus stomatal conductance in response to cropping system (monocropping and intercropping).

4.3.4 Yield and yield components

Final biomass yield for cowpea was significantly ($P < 0.05$) influenced by the interaction of cropping systems and sites (Table 4.1). Cowpea sole cropping showed higher biomass compared with intercropped cowpea at Fountain Hill, whereas at Umbumbulu, cowpea/Swiss chard had higher biomass. The reason for that might have been caused by less competition, since Swiss chard grew poorly for significant yield measurement. Yield for cowpea was about 93% higher ($P < 0.05$) at FHE compared to Umbumbulu. However, cowpea sole had higher yield at both sites. Final biomass of garden pea was significantly ($P < 0.05$) affected by the interaction of site and cropping system (Table 4.1). Final biomass at Umbumbulu was 68% higher than final biomass at Fountain Hill. Final biomass of amaranth was significantly ($P < 0.05$) influenced by cropping systems (Table 4.2). Final biomass for amaranth sole was 56% higher than intercropped amaranth. Amaranth only grew at FHE and at Umbumbulu it did not grow for significant measurement.

Although not statistically significant, differences in water use were observed across the cropping systems and sites. Results showed that Umbumbulu had higher water use under intercropping while at FHE higher water use was observed under sole cropping system (Table 4.3). Although not statistically significant, WUE calculated based on biomass varied across sites and cropping systems. The results showed that higher WUE of cowpea was observed under sole cropping compared to when intercropped at both sites. The same thing was observed for amaranth WUE at FHE (Table 4.3).

With respect to fat content, it was observed that intercropped amaranth had high fat content followed by garden pea sole at FHE, while at Umbumbulu, garden pea was found to have high fat content under both cropping systems (Table 4.4). Cowpea had high protein content under sole and intercropping systems at both sites compared to amaranth and garden pea. For the micronutrients, amaranth had high Ca and Mg contents under sole and intercropping systems at FHE, while at Umbumbulu cowpea sole had higher Ca content (Table 4.4). For Zn, Mn and Fe, amaranth had higher content of these micronutrients under both sole and intercropping at FHE, while at Umbumbulu garden pea had higher content of these micronutrients under both cropping systems compared to other crops. For Cu, amaranth had higher content at FHE and at Umbumbulu garden pea both sole and intercropping systems had higher content of Cu (Table 4.4).

NWP results for FHE for all nutrients (protein, fat, Ca, Mg, Zn, Cu, Mn and Fe) showed significant differences ($P < 0.05$), while Umbumbulu NWP results were not significantly different ($P < 0.05$) among crop species (Table 4.5). There was no significant difference for water use among crop species at both sites (Table 4.5). For FHE, amaranth and cowpea under sole cropping had highest NWP_{fat} compared to other crop species. Cowpea sole had highest

$NWP_{protein}$ followed by cowpea and intercropped amaranth had the lowest $NWP_{protein}$ among other crops. The results showed that cowpea and amaranth sole had higher $NWP_{Ca,\ Mg\ and\ Zn}$ compared when intercropped system at FHE. Intercropped amaranth had 78.1% higher NWP_{Cu} than amaranth sole, while cowpea had higher NWP_{Cu} under sole cropping than intercropping system. Amaranth sole had the highest $NWP_{Mn\ and\ Fe}$, followed by amaranth intercropped and garden pea had the lowest of these micronutrients.

Table 4.1: Final biomass, pod number, pod mass, seed number, seed mass and harvest index for leguminous vegetables.1

Site		Biomass (g)	Biomass (kg/ha)	Pod number	Pod mass (g)	Pod Mass (kg/ha)	Seed number	Seed mass (g)	Seed mass (kg/ha)	HI (%)
FHE	Cowpea Sole	361.67	16073.91	42.61	93.5	4155.51	406.6	54.4	2657.54	21.39
	Garden Pea Sole	5.82	258.79	2.54	3.62	160.84	19.8	1.41	62.81	22.93
	Cowpea- Amaranthus	176.94	7864.12	23.67	58.33	2592.57	168.4	26.76	1189.37	11.29
	Cowpea- Garden Pea	298.33	13259.13	42.61	84.44	3753.05	370.9	48.09	2137.09	14.32
	Cowpea- Swisschard	218.89	9728.3	38.72	40.28	1790.11	176.9	24.83	1103.35	19.63
	Mean									
UMbumbulu	Cowpea Sole	66.63	2961.35	7.7	3.81	125.04	65.1	6.5	185.26	12.19
	Garden Pea Sole	17.96	798.16	3.92	2.73	62.21	12.1	1.5	25.21	13.56
	Cowpea- Amaranthus	59.21	2631.58	4.49	4.98	191.5	27.5	3.61	160.59	6.06
	Cowpea- Garden Pea	37.49	1666.03	3.45	1.9	54.92	14.4	0.96	42.79	1.97
	Cowpea- Swisschard	75.74	3366.02	4.83	5.66	221.74	44.1	5.66	147.95	8.43
	Mean									
	LSD									
	Site	38.832	1725.83		12.626	757.177	35.07	5.41	224.773	
	Treatment	61.398	2728.776		19.964	1197.202	55.45	8.553	355.397	
	Site x Treat	86.83	3859.072		28.234	1693.099	78.41	12.096	502.607	

Table 4.2: Biomass, raw edible biomass (leaves), evapotranspiration (ETa) and WP for leafy vegetables.

Cropping system	**Biomass**		**Leaves**		**ETa**	**WP**
	FM	**DM**	**FM**	**DM**		
Sole	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	mm	kg m^{-3}
Amaranth	7320.9	60419.7	1227.7	777.77	353.6	0.47
Swiss chard	-	-	-	-	-	-
Intercrop						
Amaranth	3209.8	22345.67	400.0	224.7	354.5	0.20
Swiss chard	-	-	-	-	-	-

Table 4.3: Biomass, water use and WUE for selected leafy vegetables.

Location	**Cropping system**	**Treatment**	**Biomass**	**ETa**	**WUE**
			kg ha^{-1}	**mm**	**kg ha^{-1} mm^{-1}**
FHE	Sole	Cowpea	16073.91	351.05	45.79
FHE	Sole	Amaranth	7320.93	353.58	20.71
FHE	Sole	Gardenpea	258.79	356.04	0.73
FHE	Intercrop	Cowpea (amaranth)	7864.12	354.52	22.18
FHE	Intercrop	Amaranth (cowpea)	3209.83	354.52	9.05
FHE	Intercrop	Cowpea (gardenpea)	13259.13	353.97	37.46
FHE	Intercrop	Cowpea (swisschard)	9728.3	357.03	27.25
Umbumbulu	Sole	Cowpea	2961.35	325.14	9.11
Umbumbulu	Sole	Garden pea	798.16	342.75	2.33
Umbumbulu	Intercrop	Cowpea (amaranth)	2631.58	389.55	6.76
Umbumbulu	Intercrop	Cowpea (gardenpea)	1666.03	369.79	4.51
Umbumbulu	Intercrop	Cowpea (swisschard)	3366.02	423.24	7.95

Table 4.4: Macro (protein and fat) and micro (Ca, Mg, Zn, Cu, Mn and Fe) nutrients of leafy-legume crops (Cowpea, Amaranth, Garden pea and Swisschard) grown at two sites (Umbumbulu and Fountain Hill Estate) under two cropping systems (sole and intercropping).

Location	**Cropping system**	**Treatment**	**Nutrient content /kg of product**							
			Fat	**Protein**	**Ca**	**Mg**	**Zn**	**Cu**	**Mn**	**Fe**
FHE	Sole	Cowpea	11.2	299.3	1000	1900	38	4	15	58
FHE	Sole	Amaranth	24.9	203.4	36700	20200	231	17	865	195
FHE	Sole	Gardenpea	26.7	254.5	1000	1200	72	17	43	114
FHE	Intercrop	Cowpea (amaranth)	6.5	295.4	1200	2000	43	4	24	75
FHE	Intercrop	Amaranth (cowpea)	31.3	1.4	38800	18800	329	238	813	258
FHE	Intercrop	Cowpea (gardenpea)	6.5	295.4	1200	2000	43	4	24	75
FHE	Intercrop	Cowpea (swisschard)	6.5	295.4	1200	2000	43	4	24	75
Umbumbulu	Sole	Cowpea	12	319.2	1100	2100	43	4	21	54
Umbumbulu	Sole	Garden pea	16.4	287.8	1000	1400	71	9	53	70
Umbumbulu	Intercrop	Cowpea (amaranth)	10.4	323.6	1000	2100	41	4	18	53
Umbumbulu	Intercrop	Cowpea (gardenpea)	10.4	323.6	1000	2100	41	4	18	53
Umbumbulu	Intercrop	Garden pea (cowpea)	18.1	293.4	1000	1400	69	9	52	70
Umbumbulu	Intercrop	Cowpea (swisschard)	10.4	323.6	1000	2100	41	4	18	53

Table 4.5: Evapotranspiration (ETa, water productivity (WP) and nutrient water productivity (NWP for protein, fat, Ca, Mg, Zn, Cu, Mn and Fe) of selected leafy vegetables (cowpea, gardenpea, Swish chard and amaranth) grown under two cropping systems (sole and intercropping), at two sites (Umbumbulu and FHE).

Location	**Cropping system**	**Treatment**	**ETa**	**WP**	**NWP (nutritional unit m^{-3})**							
			m^3 ha^{-1}	**kg m^{-3}**	**Fat**	**Protein**	**Ca**	**Mg**	**Zn**	**Cu**	**Mn**	**Fe**
					g kg^{-1}		**mg kg^{-1}**					
FHE	Sole	Cowpea	3510.5	0.8	8.5	226.6	757.0	1438.3	28.8	3.0	11.4	43.9
FHE	Sole	Amaranth	3535.8	0.3	8.6	70.6	12743.0	7013.8	80.2	5.9	300.3	67.7
FHE	Sole	Gardenpea	3560.4	0.0	0.5	4.5	17.6	21.2	1.3	0.3	0.8	2.0
FHE	Intercrop	Cowpea (amaranth)	3545.2	0.3	2.2	99.1	402.6	671.0	14.4	1.3	8.1	25.2
FHE	Intercrop	Amaranth (cowpea)	3545.2	0.1	3.5	0.2	4377.8	2121.2	37.1	26.9	91.7	29.1
FHE	Intercrop	Cowpea (gardenpea)	3539.7	0.6	3.9	178.3	724.5	1207.5	26.0	2.4	14.5	45.3
FHE	Intercrop	Cowpea (swisschard)	3570.3	0.3	2.0	91.3	370.8	618.1	13.3	1.2	7.4	23.2
LSD **(P=0.05)**				0.3	2.7	79.9	1508.9	939.2	14.9	5.5	34.1	19.4
P value				12.0	0.0	0.0	<.001	<.001	<.001	<.001	<.001	<.001
Umbumbulu	Sole	Cowpea	3251.4	0.2	2.8	74.5	256.6	489.9	10.0	0.9	4.9	12.6
Umbumbulu	Sole	Garden pea	3427.5	0.0	0.6	10.6	36.7	51.3	2.6	0.3	1.9	2.6
Umbumbulu	Intercrop	Cowpea (amaranth)	3895.5	0.2	2.3	71.7	221.6	465.3	9.1	0.9	4.0	11.7
Umbumbulu	Intercrop	Cowpea (gardenpea)	3697.9	0.1	1.4	44.2	136.7	287.1	5.6	0.5	2.5	7.2
Umbumbulu	Intercrop	Garden pea (cowpea)	3697.9	0.0	0.6	9.9	33.6	47.1	2.3	0.3	1.7	2.4
Umbumbulu	Intercrop	Cowpea (swisschard)	4232.4	0.2	1.7	53.6	165.5	347.5	6.8	0.7	3.0	8.8
LSD **(P=0.05)**				0.2	2.0	66.4	211.4	454.0	7.3	0.6	2.6	10.1
P value				0.19	0.16	0.19	0.18	0.20	0.17	0.2	0.13	2.57

4.4 Discussion and conclusion

The objectives of the study were to determine yield and nutritional value of legume leafy vegetables grown under intercropping and mono-cropping systems in the context of water use. Crops differed in their response to monocropiing and intercropping. The differences were closely linked to crop combinations and production sites. These findings are consistent with those observed by Chimonyo et al (2016). Intercropping cowpea with amaranthus showed that both crops were not affected by the presence of the other crop. While in an intercropping of cowpea with garden pea, the two crops are not best competitors, since cowpea covers the whole area so garden pea failed to grow with it. This increases water uptake and loss through transpiration relative to what would have been lost through soil evaporation. This makes cowpea the best cover crop during crop production. Cowpea is also a leguminous crop species which fixes atmospheric nitrogen in to the soil and improves availability of soil nitrogen (Eskandari and Ghanbari, 2009).

Plant growth and development largely depends on the availability of resources such as water, nutrients and radiation. There were significant differences with respect to growth responses (plant height and leaf number) and physiological responses (chlorophyll content and stomatal conductance) among crop species. The observed results showed that cowpea was not affected by the presence of other crops in intercropping systems in terms of plant growth, this indicates that cowpea is a good competitor. More so, the ability of cowpea to grow as an indeterminate crop makes it difficult to compete with. However, amaranth was not affected by the presence of cowpea when intercropped compared to Swiss chard and garden pea. Additional benefits to cowpea and amaranth to survive water stress may be that these crops genetically are adapted to grow in water limited areas and poor soils (Mavengahama et al., 2013).

According to Lawlor and Cornic (2002) plant photosynthetic capacity is controlled by the potential to absorb and assimilate. The observed response of physiological parameters (CCI and stomatal conductance) is basically linked to photosynthetic capacity of leafy vegetables and its potential to adapt. The observed results showed that although the cowpea is drought tolerant, the photosynthetic capacity is affected under water limited conditions According to Chaves et al (2003) reduction of stomatal conductance is expected under limited water conditions. Stomatal conductance is often the first sign of water stress while responses of CCI usually occur after prolonged exposure.

Molden et al (2010) indicated that under water stress, water use efficiency is an essential yield determinant. Water use efficiency can be enhanced either by minimising water input with a fixed output or by enhancing output with a fixed water input. The observed results show that WUE and NWP were positively correlated. Cowpea sole had high WUE compared to other crops at both sites. This could be related to an increase in cowpea yield due to increased plant population. Increasing plant population increases canopy size per unit area, resulting in soil available water being used up by plants instead of being lost through soil evaporation. The results showed that crops differed in their nutritional content. Cowpea had the highest protein water productivity compared to other crops at both sites. This verifies arguments that legumes can be used as an alternative for meat to avoid protein energy malnutrition (Foyer et al. 2016). Amaranth had the highest NWP $_{Ca, Mg, Zn, Mn, Cu \text{ and } Fe}$, which makes it a nutritious crop.

In conclusion, the study showed that intercropping is a better system than mono-cropping. Intercropping optimises land use and crop quality while mono-cropping increases yield of one crop, which is minimised in an intercropping system.

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CHAPTER 5. GENERAL CONCLUSIONS AND FUTURE DIRECTIONS

Drought and water scarcity have been shown to be a major challenge to agricultural productivity. Enhanced crop productivity is important in regions that are facing malnutrition like SSA. Thus, there is a need to identify crops that can grow under drought conditions. The review of literature showed that African leafy vegetables have potential to contribute to food and nutrition security. These crops have high nutritional value and are often drought tolerant. However, ALVs are neglected and there is lack of good quality seed. More studies need to be done on these crops, since ALVs are a potential solution to food and nutrition security. Use of intercropping systems for such crops could be explored for their production. The study hypothesis that there is no difference in seed quality between wild and cultivated vegetable species is rejected. Traditional African species performed significantly better than exotic improved species with respect to seed quality indicators. This finding suggests that exotic seeds can germinate faster and produce more vigorous seedlings than improved crop seeds. However, this finding cannot be used to suggest that exotic seeds will produce better yield than improved seeds. The field trials of this study showed that there was an agreement between seed quality and crop establishment under both sole and intercropping systems. That plant growth and development under these systems showed good yield is significant. The study also showed that water use, water productivity and nutrient water productivity of traditional vegetables was significantly measurable and comparable to those of exotic commercial crops. These findings suggest that neglected traditional vegetables have value in the context of agronomy for management of water scarcity and food security.

The limitation of the current study was that selected crops belonged to different genera and species. Hence, their comparison is more general and useful for food production and less for botany. Future studies should compare genetics, morphology, physiology and nutritional value of crops within the same genera and species. Future studies should also include variables that are more relevant to climate change in relation to crop production.