# INTERACTION EFFECT OF SEAWEED EXTRACT AND INOCULATION ON GROWTH, NODULATION AND NUTRITIONAL QUALITY OF TWO COWPEA VARIETIES (*Vigna unguiculata* L. Walp)

by

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## DECLARATION

I declare that the mini-dissertation hereby submitted to the University of Limpopo for the degree of Master of science in Agriculture (Agronomy) has not previously been submitted by me for a degree at this or any other university; that it is my work is design and in execution, and that all material contained herein has been duly acknowledged.

**10 April 2015**

**Makoro M (Mr)** **Date**

## DEDICATION

I dedicate this mini-dissertation to my late grandfather, Mr Johannes Masipa Ramaboea. A man who comprehended the need for educated individuals in the modern society. A man who always told me that an educated man is a respectable man.

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**ABSTRACT**

Two studies (field and tunnel house experiments) were conducted during the 2012/2013 growing season to assess the effect of a commercial seaweed extract (Technikelp) and *Bradyrhizobia* inoculation on growth, nodulation, yield and nutritional quality of cowpea. The field experiment was laid out as a 3-way factorial arrangement, and fitted into a randomized complete block design (RCBD) with three factors: i) Two cowpea varieties (Brown landrace and Bechua na white), ii) Two Inoculation levels (with and without *Bradyrhizobium* inoculation) and iii) Three seaweed extract concentrations to water (1:100, 1:500 and no seaweed extract as the control). The treatments were combined and replicated four times. Cowpea seeds were sown at an intra-row spacing of 20 cm and inter- row spacing of 60 cm with a plot size of 3 m x 3.6 m (10.8 $m^2$) with each plot having six rows and a plant population of 96 plants per plot. Six litres (6000 ml) of each of the diluted seaweed extract levels was applied per plot as root drench at planting, 14 and 28 days after planting (DAP). The seaweed extract was applied immediately after irrigation. The tunnel house experiment was also laid out as a 3-way factorial experiment and fitted into a randomized complete block design (RCBD) with three factors: i) Two cowpea varieties (Brown cowpea landrace and commercial variety; Bechuana white), ii) Two Inoculation levels (with and without *Bradyrhizobium* inoculation) and iii) Three seaweed extract concentrations to water (1:100, 1:500 and no seaweed extract as the control). The factors were combined and replicated four times. Nine litre (9 L) nursery bags with a dimension of 175 x 150 x 350 mm were filled with 5 kg of sandy loam Hutton soil obtained from the University of Limpopo experimental farm.

Analysis of variance revealed that the variation in genetic composition dictated the growth and yield performance of the two cowpea varieties. The current study revealed that all three factors had a significant effect of growth, nodulation, yield as well as the uptake of several mineral nutrients. The results showed that the Brown landrace took longer to reach flowering (60.45 days) and physiological maturity (142.02 days) compared to Bechuana white variety which took 57.18 days to reach 50% flower and 121.11 days to reach physiological maturity. In both the field and tunnel house experiments, the application of 1:100 v/v seaweed extract resulted in a 81-88% increase in the number of effective nodules when compared to the control.

Variety, seaweed extract and inoculation had a significant ($p \leq 0.05$) effect on grain yield. The Bechuana white variety recorded grain yield of 1915 kg $ha^{-1}$ compared to the 1021 kg $ha^{-1}$ by the Brown landrace variety. The application of 1:500 v/v seaweed extract increased grain yield by 9.5% while the application of 1:100 v/v resulted in a 29.9% increase. The application of *Bradyrhizobia* inoculation increased grain yield by up to 40% when compared to the uninoculated treatment. In both the field and tunnel-house experiments, correlation analysis revealed a positive relationship between chlorophyll content and number of effective nodules per plant. In the tunnel house experiment, correlation analysis gave an $R^2$ value of 0.80 while an $R^2$ value of 0.70 was recorded in the field experiment, indicating a strong relationship between chlorophyll content and nodulation. Furthermore, a positive relationship was also observed between nodulation and pod formation with an $R^2$ value of 0.69. Correlation analysis also revealed a positive relationship between pod formation and grain yield with a $R^2$ value of 0.62.

Statistical analysis revealed a significant variety x inoculation effect on the number of days to 50% flowering, as well as the yield components and seed nutritional quality. The application of seaweed extract in the presence of inoculation improved nodulation and chlorophyll content, yield components, as well as leaf and grain nutritional quality. Response of variety to seaweed extract was observed on shelling percentage, as well as leaf K and Fe content, and seed B content. The combination of seaweed extract x inoculation x variety had a significant effect on the number of pods per plant, grain yield, shelling percentage as well as harvest index.

Economic analysis revealed that the application of both inoculation and seaweed extract are highly profitable. The application of inoculation resulted into greater profit of R32818/ha relative to uninoculated treatments while the application of 1:100 v/v seaweed extract concentration resulted into greater profitability of R32191/ha and ultimately resulted into higher returns to investment in the technology. Overall, the results from this study suggest that the adoption of application of inoculants and seaweed extract will not only improve yield and nutrition of cowpea, but has the potential to improve the livelihoods of small scale farmers due to their high marginal returns.

Keywords: Seaweed extract, *Bradyrhizobia* inoculation, Cowpea variety

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background information to the study

Cowpea is a multifunctional crop that provides food for both man and livestock; and also serves as a valuable and dependable revenue-generating commodity for farmers and grain traders (Singh *et al.,* 2002). Due to its ability to improve the nitrogen economy of cropping systems, cowpea is traditionally intercropped with millet, sorghum, maize, and cassava (Ehlers and Hall, 1997). As a food crop, cowpea is a primary source of cheap protein and mineral nutrients for many rural poor communities across the African continent (Bressani, 1985). African soils are generally nutrient deficient, a situation exacerbated by cultivation of crops without the application of chemical fertilizers. As a result, trace elements such as Fe, Se, Zn and Mn are low in African diets and their deficiency leads to many growth and health complications in humans (Caballero, 2002).

Seaweeds are aquatic plants that are usually found attached to the bottom of relatively shallow coastal water, or floating around in such environments. Liquid extract obtained from seaweeds popularly known as seaweed extracts or biostimulants are popular in agriculture as their application induces fast growth and increases yield in crop production (Bokil *et al.,* 1974). Such positive effects can be achieved irrespective of the application method adopted; either as foliar spray or root drench. A study by Cristobel (2008) found that liquid fertilizer extracted from the seaweed, *Sargassum wightii,* enhanced germination percentage, root, shoot and leaf growth, and increased chlorophyll content in green gram (*Phaseolus aureus*).

Most of these effects are attributed to the presence of macronutrients and organic compounds such as auxins and cytokinins in the extracts (Crouch and van Staden, 1993). Apart from the direct effect of these organic compounds, improvement in plant growth could be due to the stimulation of the rhizosphere microbial diversity by the seaweed extract (Alam *et al.,* 2013).

## 1.2 Problem statements

Low crop yields and malnutrition are major problems in Africa. The problem is exacerbated by poor soil fertility as crops grown on such soils tend to produce low yields that are low in nutrition value. Although the consumption of sea foods, dairy products and meat can supply the body's requirements for macro/micronutrients while the use of chemical fertilizers can increase crop yields, many resource-poor communities in rural Africa cannot afford these foods and chemical fertilizers. Besides their cost and unavailability, continuous use and over-application of fertilizers can lead to pollution of the environment. With the ever-increasing human population, there is an urgent need to explore several options, such as application of seaweed extract and inoculation of seed with bacteria, to improve soil productivity, and crop yield and quality. The growth, nodulation and yield response of cowpea to seaweed extract is not known.

## 1.3 Motivation of the study

Conventional agriculture has had an adverse impact on the health of not only the soil but also the beneficial soil microbial communities and the plants cultivated in these soils. Eventually, this has led to a high demand for the adoptation of eco- friendly agricultural practices and organic production systems by the present-day health conscious society. Attempts are being made by farmers all over the world to detoxify the land by switching to organic farming, dispensing with chemical fertilizers. In that context, $N_2$ fixing legume species, such as cowpea, and the use of seaweed extract and *Rhizobium* inoculants can be tapped to solve the problem of hunger and malnutrition in Africa.

## 1.4 Purpose of the study

### 1.4.1 Aim

The aim of this study was to evaluate the effect of a commercial seaweed extract (Technikelp) and *Bradyrhizobia* inoculation as well as their interaction on growth, nodulation, yield, and nutritional quality of two cowpea varieties, and ultimately provide recommendations on the use of seaweed extract and *Bradyrhizobia* inoculation in the production of cowpea.

### 1.4.2 Objectives

The objectives of the study were to determine:

i) The effect of seaweed extract on growth, nodulation, yield and nutritional quality of cowpea.

ii) The variation in growth, nodulation, yield and nutritional quality among the different cowpea varieties

iii) The effect of *Bradyrhizobia* inoculation on growth, nodulation, yield and nutritional quality of cowpea.

iv) Seaweed extract x cowpea variety interaction effects on growth, nodulation, yield and nutritional quality of cowpea.

v) Seaweed extract x inoculation interaction effects on growth, nodulation, yield and nutritional quality of cowpea.

vi) Cowpea variety x inoculation interaction effects on growth, nodulation, yield and nutritional quality of cowpea.

vii) Seaweed extract x cowpea variety x inoculation interaction effect on growth, nodulation, yield and nutritional quality of cowpea.

## 1.5 Hypotheses

i) Seaweed extract application has no effect on growth, nodulation, yield and nutritional quality of cowpea.

ii) There is no variability in growth, nodulation, yield and nutritional quality among the different cowpea varieties.

iii) *Bradyrhizobia* inoculation has no effect on growth, nodulation, yield and nutritional quality of cowpea.

iv) There is no seaweed extract x cowpea variety interaction effect on growth, nodulation, yield and nutritional quality of cowpea.

v) There is no seaweed x inoculation interaction effect on growth, nodulation, yield and nutritional quality of cowpea.

vi) There is no cowpea variety x inoculation effect on growth, nodulation, yield and nutritional quality of cowpea.

vii) There is no seaweed extract x cowpea variety x inoculation interaction effect growth, nodulation yield and nutritional quality of cowpea.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Botanical classification of cowpea

Cowpea (*Vigna unguiculata* L. Walp) is a legume crop that belongs to the family Fabaceae and member of the genus *Vigna*. The genus *Vigna* has several species but the most prominent specie are the cultivated species, which have been divided into five cultivar groups namely; Unguiculata, Melanophthalmus, Textilis, Biflora and Sesquipedialis. This grouping is based mainly on pod and seed characteristics (Pursglove, 1968). Cultivar group Unguiculata is the largest and includes most medium and large-seeded African grain and forage-type cowpeas.

## 2.2 Morphological characteristics and growth habit of cowpea

Following germination, emergence of the cowpea seedling from the soil is considered epigeal (Davis *et al.,* 1991). Cowpea has a very strong taproot and many spreading lateral roots in the surface soil making it adapted to semi-arid areas. The trifoliate leaves are smooth, dull to shiny and develop alternately with the terminal leaflet commonly longer and larger than the lateral leaflets (Davis *et al.,* 1991). Flowers are self-pollinating and may be white, dirty yellow, pink, pale blue or purple in colour. Two or three pods per peduncle are common and often four or more pods are carried on a single peduncle (Hadley *et al.,* 1983). Based on plant types, cowpea can be categorized as erect, semi-erect, prostrate (trailing), or climbing. There is variability in the growth habit within the species, which ranges from indeterminate to determinate with the non-vining types tending to be more determinate (Patel and Hall, 1990).

## 2.3 Origin, domestication and distribution of cowpea

Cowpea is indigenous to Africa and is used extensively in many cropping systems throughout Africa (Eaglesham *et al.,* 1981). However, the exact location of its origin is unknown but probable centres of domestication are thought to be mainly in West, Central and Southern Africa (Vavilov, 1951). Some studies strongly suggest that the highest genetic diversity of primitive wild forms of cowpea can be found in the region of the African continent currently encompassed by Namibia, Botswana, Zambia, Zimbabwe, Mozambique, Swaziland, and South Africa, with the most primitive species observed in the northern parts of South Africa and Swaziland (Padulosi *et al.,* 1991). Based on this observation, Padulosi and Ng (1997) argued that southern Africa could be the site of origin of cowpea with subsequent radiations of the primitive forms to other parts of southern and eastern Africa, and subsequently to West Africa and Asia.

## 2.4 Cowpea adaptation

Cowpea can yield satisfactorily under a greater diversity of climatic, soil, and cultural conditions than other leguminous crops (Patel and Hall, 1990). Cowpea requires temperatures above 10°C for germination, while optimal temperatures for growth and development ranged from 20°C to 30°C. A mean temperature of 27°C is described optimum for good pod formation and seed yield. Two weeks or more of consecutive or uninterrupted hot nights during the first four weeks after germination can cause complete suppression of the development of the first five floral buds on the main stem of sensitive genotypes (Ahmed *et al.,* 1992). This damage reduces pod set, number of seeds per pod, and thus seed yield. Cowpea grows on a wide range of soils but shows a preference for sandy loam soils that are well drained and less restrictive to root growth with a pH range of 5.6 to 6.5 (Davis *et al.,* 1991). Compared to other legumes, cowpea is known to have good adaptation and tolerance to drought stress (Hall, 2004) and performs better in regions with rainfall of 250-1000 mm per annum. Due to its strong taproot and large volume of lateral roots in the topsoil, cowpea can produce yields of up to one tonne seed and six tonnes of hay on as little as 300 mm rain spread over the growing season (Marfo and Hall, 1992).

## 2.5 Global statistics of cowpea production

About 70% of cowpea production occurs in the drier Savanna and Sahelian zones of West and Central Africa. Dry grain production is the only commodity of cowpea for which production estimates are generated on a worldwide basis. Production of cowpea accounts for 68% of the total world production of grain legumes and about 64% of the area under cowpea is grown in central and east Africa (Singh *et al.,* 1996). This figure is questionable given the prominence of other grain legumes such as, soybean, dry bean, groundnut and many others. Nigeria is the largest producer and consumer of cowpea grain with around five million hectare under cultivation with an annual yield estimate at around 2.0 million metric tons (mt). After Nigeria, Niger and Brazil are the next largest producers with annual yields estimated at 650,000 and 490,000 mt, respectively (Singh *et al.,* 2002).

## 2.6 Cowpea production in South Africa

Despite the importance of the crop in the national diet and economy, cowpea is still inefficiently produced by local farmers and seed yields are very low and inconsistent. According to Nell (1990), cowpea production in South Africa amounts to 5,000 tons per annum. Since cowpea thrives better in drier regions, small-scale farming of cowpea is mostly limited to Limpopo, Northwest and Kwa-Zulu Natal Provinces (Coetzee, 1990; Asiwe, 2009). According to Asiwe and Kutu (2009), cowpea research and production in South Africa has been neglected for decades resulting in many farmers being discouraged to enter into cowpea production due to lack of information on new techniques in cowpea production hence the low production. Diversification of cowpea dishes could also result in increased production of the crop.

## 2.7 Uses and nutritional value of cowpea

Cowpea is highly valued for both its grain for human consumption and forage for animal feed and therefore often has a dual utility (Henriet *et al.,* 1997). It is an important crop for the nutrition and the livelihoods of millions of people in less developed countries and serves as a cheap source of protein and minerals for many poor households (Fawole *et al.,* 2006). Young leaves, green pods and seeds are used as vegetables whereas dry seeds are used in a variety of food preparations (Nout, 1996). Cowpea grain and leaves have a high protein content of about 24.8%, fat content of 1.9%, fibre content of 6.3% and carbohydrate content of 6.3% (Dominic *et al*., 2005). Cowpea haulms serve as supplementary feed in dry seasons, making cowpea haulms a key food resource in certain crop-livestock systems. The haulm contains 13 to 17% protein with a high digestibility value and low fibre level (Tarawali *et al*., 1997).

## 2.8 Biological nitrogen fixation

Although nitrogen ($N_2$) is the most abundant gas in Earth's atmosphere, it is extremely unreactive. Before it can be incorporated into biological molecules, $N_2$ must be chemically reduced to the equivalent of ammonia. Biological nitrogen fixation (BNF) is an efficient and renewable source of nitrogen for agriculture. It is a process in which atmospheric nitrogen is reduced to ammonia by a specialized group of microorganisms, such as the symbiotic *Rhizobium* and *Sinorhizobium* bacteria (Wagner, 2011). Research into BNF has focused on the rhizobium-legume symbiosis because this association plays an important role in the N cycle (Mohammadi *et al.,* 2012).

## 2.9 Use of Cowpea as $N_2$ fixer

Symbiotic $N_2$ fixation (SNF) by legumes is an important source of nitrogen in agricultural and natural ecosystems. It has been shown that about 80% of the symbiotic fixed nitrogen comes from the atmosphere involving $N_2$-fixing leguminous plants and compatible *Rhizobium* species. The *Rhizobia* invades the host plant's roots and cause the formation of structures called nodules, which are the primary structure of BNF (Gage, 2002). Within these nodules, the *Rhizobia* uses enzymes to biologically convert $N_2$ gas from the atmosphere into a form of nitrogen that can be used by the host plant (Fischer, 1994).

Legume selections such as cowpea, soybean, groundnuts and pigionpea have been grown as companion intercrops with maize and have shown to improve soil and crop productivity that otherwise would have been declining over time (Jeranyama *et al.,* 2000; Tsubo *et al.,* 2003; Arim *et al.,* 2006; Mudita *et al.,* 2008). Cowpea provides a high proportion of its own nitrogen requirement through nitrogen fixation, leaving a fair nitrogen deposit in the soil. In the African continent, a number of studies, including those of Belane and Dakora (2009; 2010), have quantified symbiotic nitrogen contribution by cowpea with amounts of up to 210 kg $ha^{-1}$.

## 2.10 Rhizobia Inoculation

Nitrogen is a building block of proteins and is highly needed for all enzymatic reactions in a plant (Ayoola, 2010). It is a major part of the chlorophyll molecules and plays a necessary role in photosynthesis and also is a major component of several vitamins (Sara *et al.,* 2013). Nitrogen supply has significant effect on leaf growth because it increases the leaf area of plants and consequently it influences photosynthesis function (Bonjovic and Markovic, 2009). Furthermore, in legumes and other leafy vegetables, Nitrogen improves the quality and quantity of dry matter and protein (Uchida, 2000). However, green colour in the leaf is vanished due to Nitrogen deficiency and this may cause the decrease in leaf area and intensity of photosynthesis. This deficiency is also associated with symptoms of yellowing, dropping of leaves, poor growth, delayed flowering and fruiting (Wu *et al.,* 2005). Through this, it constitutes one of the major yield limiting factors for crop production.

Inoculation with appropriate strain(s) is considered to be an effective way of increasing growth and yield in legumes. It introduces specific types of Rhizobium bacteria into the soil so that biological nitrogen fixation takes place and assures adequate nitrogen for the legume. Although the cowpea plant is generally known to be infected by naturally occurring 'cowpea type' bacteria, inoculation with cowpea specific Rhizobia bacteria such as the *Bradyrhizobium* species has proven to be most efficient. *Rhizobium* inoculation has been found to improve the yield and all the other yield components such as number of pods per plant, number of seeds per plant, 100-seed weight, and seed yield of common bean and cowpea (Ndakidemi *et al*.,1998, Onduru *et al*., 2008, Bambara and Ndakidemi 2010).

## 2.11 Seaweed

Seaweeds are aquatic plants that are usually found attached to the bottom of relatively shallow coastal water, or float around in such environments and differ greatly from higher plants as they neither have true leaves, stems and roots nor vascular systems with specialized organs. These plants belong to the Thallophyta of the kingdom Plantae and classification of these plants is divided into three groups namely, green (Chlorophyceae), brown (Phaeophyceae), and red (Rhodophyceae). This classification is based on their pigments like chlorophylls, carotenoids and phycobilins (Sathya *et al.,* 2010).

## 2.12 Seaweed extracts composition

Seaweed extracts contain many plant growth promoters such as cytokinins (Durand *et al.,* 2003; Stirk *et al.,* 2003), auxins (Stirk *et al.,* 2004), gibberellins, betaines (Blunden, 1991; Wu *et al.,* 1997), macronutrients such as calcium, potassium, phosphorus, and micronutrients, like iron, copper, zinc, boron, manganese and molybdenum (Khan *et al.,* 2009), necessary for the development and growth of plants. Even though seaweed extracts contain macro and micro nutrients, researchers argue that the concentration of these nutrients is too low to improve plant growth. In fact, Booth (1969) reported that the value of seaweeds as fertilizer is not from mineral contents but from their trace elements and the metabolites similar to cytokinin, auxin, gibberellins and other related growth hormones. Blunden and Wildgoose (1977) also found close correlation between results obtained from the use of kinetin and commercial seaweed extract in potato field trials. Further evidence supporting this idea was the detection of cytokinin-like activity in a number of marine algae and later in commercial seaweed preparations (Tay *et al.,* 1985, Mooney and van Staden, 1986).

# CHAPTER 3

# RESEARCH METHODS

## 3.1 Description of trial sites

Two studies (field and tunnel-house) were conducted during 2012/2013 season. The field experiment was conducted at the University of Limpopo experimental farm, Syferkuil (latitude: 23° 51' 0''S, longitude: 29° 41' 60''E, altitude of 1324 meter above sea level. The farm has sandy loam soil, of the Hutton form, Glenrosa family, with pH range of between 6.0 and 6.2 (Moshia, 2005). The area receives annual rainfall of 500 mm and daily temperature ranges from 18°C to 35°C from October to March and 25ºC or lower from April to September (Shiringani, 2007; Mpangane *et al.,* 2004). The tunnel-house experiment was conducted at the University of Limpopo premises (latitude: 23°53'23''S, longitude: 29° 44'18''E)

## 3.2 Research design

### 3.2.1 Field experiment

The experiment was laid out in a 3-way factorial arrangement, and fitted into a randomized complete block design (RCBD) with three factors: i) Two cowpea varieties (Brown landrace and Bechuana white), ii) Two Inoculation levels (w ith and without *Bradyrhizobium* inoculation) and iii) Three seaweed extract concentrations to water (1:100 v/v, 1:500 v/v and no seaweed extract as the control). The treatment factors were combined and replicated four times. Cowpea seeds were sown at an intra-row spacing of 20 cm and inter row spacing of 60 cm with a plot size of 3 m x 3.6 m (10.8 $m^2$) with each plot having six rows and a plant population of 96 plants. Six litres (6000 ml) of each the diluted seaweed extract levels was applied per plot as root drench at planting, 14 and 28 days after planting (DAP). The seaweed extract was applied immediately after irrigation.

### 3.2.2 Tunnel-house experiment

The experiment was laid out as a 3-way factorial experiment and fitted into a randomized complete block design (RCBD) with three factors: i) Two cowpea varieties (Brown cowpea landrace and commercial variety; Bechuana white), ii) Two Inoculation levels (with and without *Bradyrhizobium* inoculation) and iii) Three seaweed extract concentrations to water (1:100 v/v, 1:500 v/v and no seaweed extract as the control). The factors were combined and replicated four times. Nine litre (9L) nursery bags with a dimension of 175 x 150 x 350 mm were filled with 5 kg of sandy loam Hutton soil obtained from the University of Limpopo experimental farm.

Five seeds were evenly planted per bag and later thinned to two plants per bag. The bags were irrigated to field capacity using a measuring cylinder before sowing and subsequently irrigated to 80% field capacity twice a week. Five hundred millilitres (500 ml) of each of the diluted seaweed extract levels was applied per bag as root drench at planting, 14 and 28 days after planting (DAP).

### 3.3 Technikelp

Technikelp is a locally available liquid bio-fertilizer, manufactured by the Kelp Products (Pty) Ltd., in Simons Town, South Africa and distributed by Technichem Oesbeskerming (Edms) Bpk. The liquid bio-fertilizer is extracted from strips of the brown algae called *Ecklonia maxima (Osbeck) pepenfuss*, using the cell bursting technique. This process involves the use of pressure on freshly harvested algae material to compress the cell walls and release of contents. Thus the seaweed is progressively reduced in particle size. The particles are then passed under extremely high pressure into a low-pressure chamber where they disintegrate, resulting in the liquid extract. This process excludes the use of heat, chemicals or dehydration that could affect some of the organic compounds of the liquid extract (Verkleij, 1992). Technikemp contains macronutrients, trace elements and organic compounds such as Magnesium, Zinc, Auxins and Cytokinins (Table 3.1).

Table 3.1: Total organic composition and elemental analysis of Technikelp®

| **Constituent** | **Content** |
|---|---|
| Magnesium (Mg) | 30 g $kg^{-1}$ |
| Molybdenum (Mo) | 200 mg $L^{-1}$ |
| Nitrogen (N) | 85 g $kg^{-1}$ |
| Potassium (K) | 11 g $kg^{-1}$ |
| Phosphorus (P) | 11 g $kg^{-1}$ |
| Sulphur (S) | 30 g $kg^{-1}$ |
| Iron (Fe) | 3000 mg $kg^{-1}$ |
| Copper (Cu) | 400 mg $kg^{-1}$ |
| Manganese (Mn) | 3000 g $kg^{-1}$ |
| Zinc (Zn) | 2500 mg $kg^{-1}$ |
| Boron (B) | 2000 mg $kg^{-1}$ |
| Cytokinin | 0.02 mg $L^{-1}$ |
| Auxin | 6 mg $L^{-1}$ |

## 3.4 Agronomic practices

In the field experiment, weeding was done regularly by hand hoeing. Survival irrigation of 15-20 mm was provided each time there was a lengthy dry period and evidence of severe moisture stress (leaf wilting and drooping by 10.00 HRS). In all, the field experiment received 340 mm of supplementary irrigation. In both trials, incidence of insect infestation were regularly controlled as required using Karate 2.5 EC at application rate of 75 ml $ha^{-1}$ based on manufacturer's recommendation. This was done bi-weekly.

## 3.5 Data collection

### 3.5.1 Days to 50% flowering and physiological maturity

The number of days to flowering was determined when 50% of the plants per net plot had flowered, while days to physiological maturity was similarly determined when 50% of the plants in the net plot had turned yellowish and started to lose their leaves.

### 3.5.2 Nodulation and chlorophyll content

In the field experiment, four plants were sampled per plot from two middle rows while in the tunnel house experiment; two plants were sampled and separated into shoots and roots. The nodules were detached from the roots and dissected to determine their effectiveness (those with pinkish pigment when dissected), and those found to be effective were counted and oven dried at 60 ºC for 48 hours. Nodule weight was measured using the Highland™ HCB 1002 weighing scale. Before sampling, the chlorophyll content was measured from the top trifoliate leaves of each of the sampled plants using the chlorophyll content meter (CCM-200). The chlorophyll content meter was calibrated after every reading.

### 3.5.3 Growth and yield performance

At physiological maturity, ten plants were sampled from the two middle rows of each plot. Pod length, pods per plant and seeds per pod were counted from each sampled plant. The plants were later separated into roots and shoot and later oven dried at 60 ºC for 48 hours and weighed. Grain yield, 100 seed weight and biomass were determined from each plot using a TSCALE T-28-15 model digital scale and converted to kg $ha^{-1}$.

Harvest index (HI) was calculated using the formula:

$$HI = \frac{\text{Grain yield}}{\text{Total above ground biomass}}$$

Shelling percentage was calculated using the formula:

$$\text{Shelling \%} \quad \frac{\text{Shelled grain weight}}{\text{Unshelled pod weight}} \times 100$$

### 3.5.4 Nutrient analyses

Fully emerged trifoliate leaves were picked from six randomly selected plants per plot at 42 days after planting (DAP). The fresh leaf samples were oven dried at 60°C overnight, ground to pass through a 40-mesh sieve and stored in airtight containers and sent for nutritional composition analysis. Cowpea seeds were sampled from harvest plot grain, processed and sent for nutritional composition analysis. All analyses were carried out on dry weight basis and expressed per 100 g of edible portion. Mineral content (Ca, Mg, K, P, Zn, Cu, Mn, Fe, B) was determined using standard laboratory procedures as described by the Association of Analytical Chemist, while the crude protein was estimated by the Kjeldahl method (AOAC, 1990).

## 3.6 Economic analysis

To compare the profit of treatments used, simple economic analyses were carried out in which the profit or marginal net return (MNR) was computed for each treatment as shown bellow.

$$MNR = Y \times P - TVC,$$

Where $Y$ is grain yield of cowpea crop (kg/ha), $P$ is selling price of crop at harvest (R/kg), and TVC is the total variable cost or cost of inputs related to the treatment (e.g. Seaweed extract, Inoculation, Labour, etc. in R/ha). The cost of input cost used in calculating MNR and MRR are shown in (Table 3.2). The selling price of the cowpea grain at harvest was R20/kg (Price obtained from the local informal market). The marginal rate of return (MRR) for each treatment was calculated using the formula:

$$MRR = MNR/TVC$$

Table 3.2: Variable cost or cost of inputs.

| **Input** | **Amount/ha** | **Unit price (Rands)** | **Total cost (Rands)** |
|---|---|---|---|
| Inoculants | 1 sachets | 130 | 130 |
| Extract | 2L | 34 | 68 |
| Agronomic practices | - | - | 930 |

### 3.7 Data analyses

Data obtained from the trial were subjected to Analysis of Variance using Statistix version 10. Differences amongst treatment means were separated using the least significant difference (LSD) test at 5% level of probability.

# CHAPTER 4

# RESULTS

The results of the analysis of variance in growth, nodulation, development, yield, yield components as well as leaf and seed nutritional quality suggested highly significant main effects of cowpea variety, seaweed extract concentration and inoculation and their interactions (Tables 4.1-4.7).

## 4.1 Days to 50% flowering and physiological maturity

The two cowpea varieties exhibited different growth traits. The Brown landrace variety took longer to reach 50% flowering with a mean days to 50% flowering (DTFF) of 60 and mean days to physiological maturity (DTPM) of 142 as compared to the Bechuana white variety with mean DTFF of 57 and mean DTPM of 121. Application of seaweed extract and inoculation had no significant effect on the number of days to 50% flowering as well as the number of days to physiological maturity (Table 4.1). However, there was a significant variety x inoculation interaction effect ($p \leq 0.05$) on the number of days to 50% flowering, where by the application of the *Bradyrhizobium* inoculation reduced the number of days to 50% flowering in both varieties when compared to the uninoculated treatments (Figure 4.1) but the reduction was more in Bechuana white.

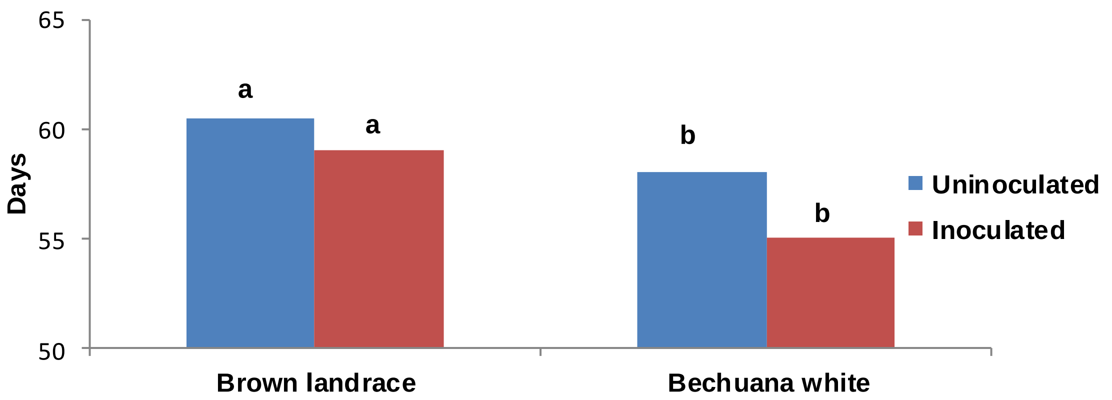


Figure 4.1: Variety x inoculation interaction effect on the number of days to 50% flowering

Table 4.1: Effect of variety, seaweed extract and inoculation on development of cowpea

| Treatment | Days to 50% flowering | Days to physiological maturity |
|---|---|---|
| **VARIETY (V)** | | |
| Brown landrace | 60.45a | 142.02a |
| Bechuana white | 57.18b | 121.11b |
| Significant | ** | ** |
| LSD $_{0.05}$ | 0.22 | 0.14 |
| **EXTRACT (E)** | | |
| Control | 59.27a | 131.51a |
| 1:500 | 59.05a | 131.65a |
| 1:100 | 59.44a | 131.54a |
| Significance | ns | ns |
| **INOCULATION (I)** | | |
| Uninoculated | 59.22a | 131.51a |
| Inoculated | 59.15a | 131.62a |
| Significance | ns | ns |
| **INTERACTION EFFECT** | | |
| E x V | ns | ns |
| V x I | * | ns |
| E x I | ns | ns |
| E x I x V | ns | ns |

LSD= Least Significant Difference, ns=non significant, ** significant at P≤0.01, * significant at P≤0.05. Means followed by the same letter in a column are not significantly different at P<0.05

## 4.2 Chlorophyll content

In both field and tunnel-house experiments, variety had no significant effect on leaf chlorophyll content while seaweed extract and inoculation increased leaf chlorophyll content significantly. In the field experiment, application of 1:500 v/v seaweed extract resulted in a 9.7% increase in the plant chlorophyll content, while the application of 1:100 v/v resulted in a 18.1% increase when compared to the control. A similar trend was observed in the tunnel house experiment, where the application of 1:500 v/v seaweed extract resulted in a 13.3% increase in the plant chlorophyll content while the application of 1:100 v/v resulted in a 20.6% increase when compared to the control (Table 4.2). In the field experiment, a 37.7% increase was observed when *Bradyrhizobia* inoculation was introduced while a 42.8% increase was observed in the tunnel house experiment (Table 4.2).

In both field and tunnel house experiments, the application of seaweed extract in the presence of inoculation significantly increased plant chlorophyll content index. In the field experiment, the application of 1:100 v/v seaweed extract in the presence of inoculation resulted in a 67.3% increase in plant chlorophyll content index reading followed by the application of 1:500 v/v seaweed extract concentration which recorded a 42.3% increase in plant chlorophyll content index relative to the control.

The same trend was observed in the tunnel house experiment where the application of 1:100 v/v seaweed extract in the presence of inoculation resulted in a 76.7% increase in plant chlorophyll content index reading followed by the application of 1:500 v/v seaweed extract concentration which recorded a 49.3% increase in plant chlorophyll content index relative to the control. In both the field and tunnel house studies, there were neither cultivar x seaweed extract nor cultivar x inoculation interaction effects on the chlorophyll content index.

4.3 Nodulation

Analysis of variance revealed that variety had no significant effect ($p \leq 0.05$) on the number of effective nodules per plant while application of seaweed extract and inoculation had a significant effect ($p \leq 0.05$) on the number of effective nodules per plant. The number of effective nodules increased as the concentration of seaweed extract increased. In the field experiment, the application of 1:500 v/v seaweed extract resulted in a 43.4% increase in the number of effective nodules while the application of 1:100 v/v seaweed extract resulted in a 81.3% increase in the number of effective nodules when compared to the control.

In the tunnel house experiment, the application of 1:500 v/v seaweed extract resulted in a 47.6% increase in the number of effective nodules while the application of 1:100

v/v seaweed extract resulted in a 88.4% increase in the number of effective nodules when compared to the control (Table 4.2). Application of inoculation increased the number of effective nodules significantly. In the field experiment, a 217.8% increase was observed when inoculation was introduced. The same trend was observed in the tunnel house experiment where the application of seaweed extract resulted in a 206.3% increase in the number of effective nodules per plant (Table 4.2).

The application of seaweed extract in the presence of inoculation increased the number of nodules significantly ($p \leq 0.05$). The application of 1:100 seaweed extract in the presence of inoculation resulted in the highest number of nodules per plant (88 nodules/plant) followed by the application of 1:500 v/v seaweed extract concentration. However, a slight decrease in the number of effective nodules was observed when 1:100 v/v seaweed extract was applied in the absence of inoculation (Figure 4.2; B and C)

Table 4.2: Effect of variety, seaweed extract and inoculation on cowpea nodulation and chlorophyll content

| Treatment | Tunnel house | | Field | |
|---|---|---|---|---|
| | Nodules/plant | Chlorophyll content (CCI/plant) | Nodules/plant | Chlorophyll content (CCI/plant) |
| **VARIETY (V)** | | | | |
| Brown landrace | 49.69a | 81.98a | 39.05a | 68.82a |
| Bechuana white | 55.71a | 85.34a | 45.16a | 71.77a |
| Significance | ns | ns | ns | ns |
| **EXTRACT (E)** | | | | |
| Control | 27.83c | 75.16b | 29.75c | 64.34c |
| 1:500 | 40.98b | 85.18a | 42.66b | 70.56b |
| 1:100 | 52.42a | 90.63a | 53.92a | 75.98a |
| Significance | ** | ** | ** | ** |
| $LSD_{0.05}$ | 6.63 | 6.95 | 9.62 | 4.64 |
| **INOCULATION (I)** | | | | |
| Uninoculated | 19.88b | 68.92b | 20.15b | 58.71b |
| Inoculated | 60.94a | 98.40a | 64.06a | 80.87a |
| Significance | ** | ** | ** | ** |
| $LSD_{0.05}$ | 6.63 | 4.69 | 6.50 | 3.13 |
| **INTERACTION EFFECT** | | | | |
| E x V | ns | ns | ns | ns |
| V x I | ns | ns | ns | ns |
| E x I | ** | ** | ** | ** |
| Ex I x V | ns | ns | ns | ns |

LSD= Least Significant Difference, ns=non significant, ** significant at P≤0.01, * significant at P≤0.05. Means followed by the same letter in a column are not significantly different at P≤0

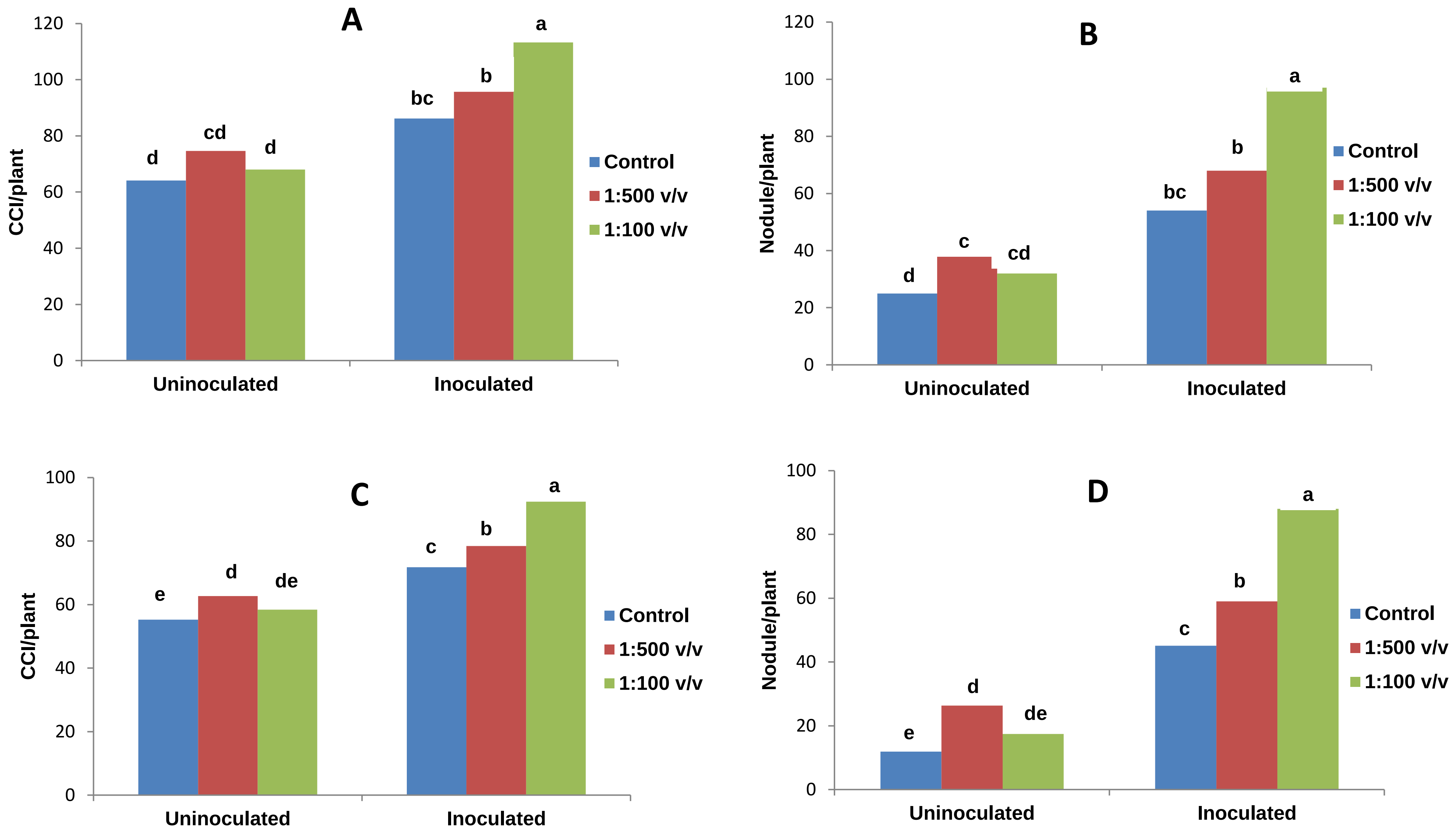


Figure 4.2: Interactive effects of Bradyrhizobium and seaweed extract on A) CCI under tunnel house conditions; B) Nodulation under tunnel house conditions; C) CCI under field conditions; D) Nodulation under field conditions. Different letters denote significant difference at 0.01%

## 4.4 Biomass accumulation at flowering

### 4.4.1 Nodule dry weight

In both field and tunnel house experiments, the Brown landrace variety accumulated higher root, shoot and total dry weight than the Bechuana white variety while inoculation and seaweed extract also had a significant ($p \leq 0.05$) effect on nodule, root, shoot and total dry weight. In the tunnel house experiment, the Brown landrace variety recorded a mean nodule dry weight of 0.61g $plant^{-1}$, while the Bechuana white variety recorded a mean nodule weight of 0.46 g/plant (Table 4.3). The application of 1:500 v/v seaweed extract resulted in a 21.4% increase in the nodule dry weight per plant, while the application of 1:100 v/v resulted in a 44% increase when compared to the control. The same trend was observed in the tunnel house experiment where, the application of 1:500 v/v seaweed extract resulted in a 51% increase in nodule dry weight per plant while the application of 1:100 v/v resulted in a 105.7% increase when compared to the control (Table 4.3).

The introduction of *Bradyrhizobia* inoculation improved nodule dry weight significantly as a 29.2% increase in nodule dry weight was observed in the field experiment while a 65% increase in nodule dry weight was observed in the tunnel house experiment. Analysis of variance revealed that there were no significant variety x seaweed extract, variety x inoculation and seaweed extract x inoculation interaction effect on nodule dry weight per plant in both field and tunnel house experiments.

### 4.4.2 Root dry weight

In both field and tunnel house experiments, analysis of variance showed that the Brown landrace accumulated 50% more root dry weight that the Bechuana white variety. Root dry weight per plant increased significantly as the concentration of seaweed extract was increased. In the field experiment, the application of 1:500 v/v seaweed extract resulted in a 26.2% increase in the root dry weight per plant, while the application of 1:100 v/v resulted in a 45.2% increase in root dry weight when compared to the control. The same trend was observed in the tunnel house experiment where, the application of 1:500 v/v seaweed extract resulted in a 61%

increase in root dry weight per plant while the application of 1:100 v/v resulted in a 78.2% increase when compared to the control. The application of inoculation increased root dry weight per plant significantly. The introduction of *Bradyrhizobia* inoculation resulted in a 26.8% increase in root dry weight, while a 127% increase was observed in the tunnel house experiment (Table 4.3).

4.4.3 Shoot dry weight

Variety had a significant effect (p≤ 0.05) on shoot dry weight while independent application of seaweed extract and inoculation had a significant effect on shoot dry weight (Table 4.3). In the field experiment, the Brown landrace variety accumulated more shoot dry weight (72.27 g/plant) than the Bechuana white variety (58.57 g/plant) while in the tunnel houses experiment, the Brown landrace variety accumulated more root dry weight (39.41 g/plant) than the Bechuana white variety (26.12 g/plant).

Application of seaweed extract had a significant effect on plant shoot weight. In the field experiment, application of 1:500 v/v seaweed extract resulted in 23.7% increase in the nodule dry weight per plant, while application of 1:100 v/v resulted in a 30.4% increase when compared to the control. The same trend was observed in the tunnel house experiment where, the application of 1:500 v/v seaweed extract resulted in a 61.6% increase in nodule dry weight per plant while the application of 1:100 v/v resulted in a 78.2% increase when compared to the control. The application of inoculation increased root dry weight per plant significantly. A 126% increase was observed when inoculation was introduced while a 128% increase was observed in the tunnel house experiment.

4.4.4 Total biomass

All factors, namely variety, seaweed extract and inoculation had a significant effect (p≤ 0.05) on the total biomass accumulation (Table 4.3). In the field experiment, the Brown landrace variety accumulated more total dry weight (80.4 g/plant) than the Bechuana white variety (64.2 g/plant) while in the tunnel houses experiment, the Brown landrace variety accumulated more root dry weight (46.1 g/plant) than the Bechuana white variety (30.7 g/plant). In the field experiment, the application of

1:500 v/v seaweed extract resulted in a 23.8% increase in total biomass accumulation while the application of 1:100 v/v seaweed extract resulted in a 31.7% increase when compared to the control. The same trend was observed in the tunnel house experiment where, the application of 1:500 v/v seaweed extract resulted in a 57.6% increase in total biomass accumulation while the application of 1:100 v/v seaweed extract resulted in a 75.5% increase when compared to the control. The application of inoculation increased the total biomass accumulation significantly. In the field experiment, a 34.8% increase was observed when inoculation was introduced while a 76% increase was observed in the tunnel house experiment. In both field, and tunnel house experiments, analysis of variance revealed a significant variety x inoculation interaction effect on root dry weight (Table 4.3).

Table 4.3: Effect of variety, seaweed extract and inoculation on biomass accumulation

| Treatments | Dry weight (g/plant) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Tunnel house | | | | Field | | | |
| | **Nodule** | **Root** | **Shoot** | **Total** | **Nodule** | **Root** | **Shoot** | **Total** |
| **VARIETY (V)** | | | | | | | | |
| Brown L | 0.61a | 6.03a | 39.41a | 46.05a | 1.10a | 6.98a | 72.27a | 80.35a |
| Bechuana W | 0.46b | 3.68b | 26.12b | 30.27b | 0.95a | 4.63b | 58.57b | 64.16b |
| Significance | * | ** | ** | ** | ns | ** | ** | ** |
| LSD $_{0.05}$ | 0.14 | 0.98 | 9.47 | 10.15 | - | 0.71 | 6.16 | 6.36 |
| **EXTRACT (E)** | | | | | | | | |
| Control | 0.35b | 3.74b | 22.35b | 26.45b | 0.84b | 4.69b | 55.43b | 60.97b |
| 1:500 | 0.53ab | 4.97ab | 36.12a | 41.62a | 1.02ab | 5.92ab | 68.57a | 75.51a |
| 1:100 | 0.72a | 5.86a | 39.83a | 46.41a | 1.21a | 6.81a | 72.28a | 80.30a |
| Significance | ** | ** | ** | ** | ** | * | ** | ** |
| LSD$_{0.05}$ | 0.21 | 1.353 | 11.45 | 12.36 | 0.21 | 1.05 | 9.12 | 9.41 |
| **INOCULATION (I)** | | | | | | | | |
| Uninoculated | 0.40b | 4.17b | 23.08b | 27.66b | 0.89b | 5.12b | 55.53b | 61.55b |
| Inoculated | 0.66a | 5.54a | 52.45a | 48.66a | 1.15a | 6.49a | 75.32a | 82.96a |
| Significance | ** | ** | ** | ** | ** | * | ** | ** |
| LSD $_{0.05}$ | 0.14 | 1.13 | 8.50 | 9.28 | 0.14 | 0.71 | 6.16 | 6.36 |
| **INTERACTION EFFECT** | | | | | | | | |
| E x V | ns | ns | ns | ns | ns | ns | ns | ns |
| V x I | ns | ** | ns | ns | ns | ** | ns | ns |
| E x I | ns | ns | ns | ns | ns | ns | ns | ns |
| E x I x V | ns | ns | ns | ns | ns | ns | ns | ns |

LSD= Least Significant Difference, ns=non significant, ** significant at P≤0.01, * significant at P≤0.05. Means followed by the same letter in a column are not significantly different at P<0.05

In the field experiment, inoculating the Brown landrace with *Bradyrhizobia* resulted in the highest root dry weight (7.2 g/plant) compared to the 3.9 g/plant obtained from the Bechuana white variety (Figure 4.3). The same trend was observed in the tunnel house experiment where the inoculated Brown landrace eight accumulated more root dry matter compared to Bechuana white (Figure 4.4).

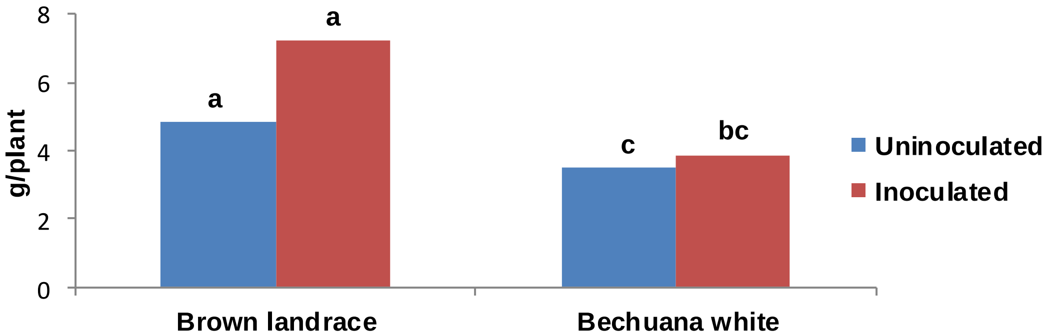


Figure 4.3: Variety x inoculation interaction effect on root dry weight under tunnel house conditions. Different letters denote significance at 0.1% level

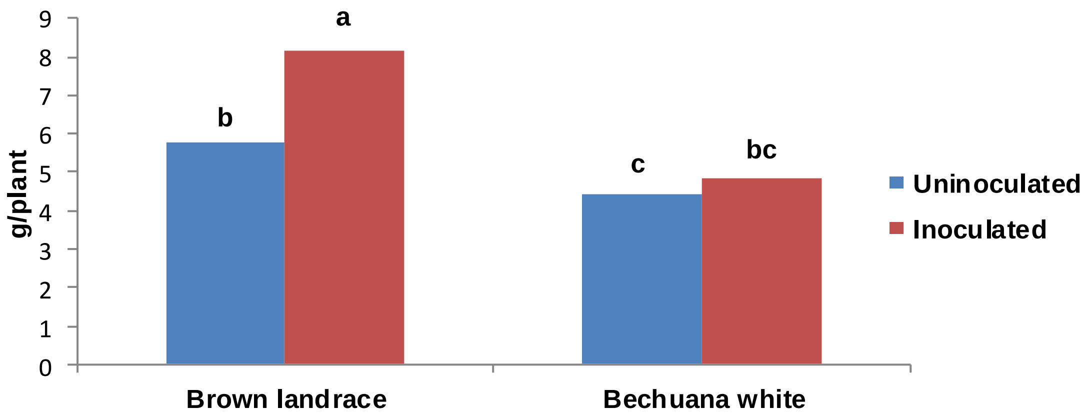


Figure 4.4: Variety x inoculation interaction effect on root dry weight under field conditions. Different letters denote significance at 0.1% level

## 4.5 Yield and yield components

### 4.5.1 Pods per plant

Differences in the number of pods per plant were significant. The Bechuana white variety recorded the highest number of pods per plant (25.6 pod/plant) compared to the 16.5 pods per plant by the Brown landrace variety. Application of seaweed extract and inoculation also had significant effects on the number of pod per plant.

The application of 1:500 v/v seaweed extract resulted in a 6.88% increase in the number of pods per plant while the application of 1:100 v/v seaweed extract concentration resulted in a 17.5% increase when compared to the control (0:0 v/v). The same trend was observed with the application of inoculation where the application of inoculation resulted in a 23.6% increase in the number of pods per plant (Table 4.4).

There were significant ($p \leq 0.05$) variety x inoculation and seaweed extract x inoculation interaction effects on the number of pods per plant. Bechuana white responded better to the application of inoculation resulting in a mean pods per plant of 28.4 as compared to the 18.16 pods per plant by the Brown landrace variety (Figure 4.5). The application of seaweed extract in the presence of inoculation improved the number of pods per plant. Application of inoculation and 1:100 v/v resulted in a 49.2% increase in the number of pods per plant (Figure 4.6). A significant variety x seaweed extract x inoculation interaction effect was also observed, with the combination of Bechuana white, inoculation and 1:100 v/v seaweed extract resulting in the greatest mean number of pods per plant (31.52 pods per plant) (Figure 4.7).

### 4.5.2 Pod length

The difference in pod length between the two varieties was significant. The Brown landrace recorded a mean pod length of 21.89 cm while Bechuana white variety recorded a mean pod length of 17.58 cm (Table 4.4). However, the differences in pod length did not differ significantly following the application of seaweed extract and inoculation ($p \leq 0.05$). Analysis of variance showed no significant seaweed x variety, variety x inoculation, inoculation x seaweed extract and variety x seaweed extract x inoculation interaction effect on the number of seeds per pod (Table 4.4).

### 4.5.3 Seed per pod

Analysis of variance revealed a significant variety effect on the number of seeds per pod. Brown landrace had the highest mean seeds per pods (16 seeds/pod) while Bechuana white recorded a mean number of 13 seeds per pod. Independent application of seaweed extract and inoculation had no significant effect on seeds per pod. Analysis of variance also showed no significant seaweed x variety, variety x inoculation, inoculation x seaweed extract and variety x seaweed extract x inoculation interaction effect on the number of seeds per pod (Table 4.4).

4.5.4 Hundred seed weight

Analysis of variance showed that variety, seaweed extract and inoculation had no significant ($p\leq 0.05$) effect on 100 seed weight (Table 4.4).

4.5.5 Grain yield

Variety, seaweed extract and inoculation all had a significant ($p\leq 0.05$) effect on grain yield. The Bechuana white variety recorded grain yield of 1915 kg $ha^{-1}$ compared to the 1021 kg $ha^{-1}$ by the Brown landrace variety. The application of 1:500 v/v seaweed extract increased grain yield by 9.5% while the application of 1:100 v/v resulted in a 30 % increase. The application of *Bradyrhizobia* inoculation increased grain yield by up to 40% when compared to the uninoculated treatment (Table 4.4). Analysis of variance revealed a significant ($p\leq 0.05$) inoculation x variety interaction effect on grain yield. Inoculation of Bechuana white variety with *Bradyrhizobia* yielded 2246 kg $ha^{-1}$ compared to 1181 kg $ha^{-1}$ by Brown landrace (Figure 4.8).

The application of seaweed extract in the presence of *Bradyrhizobia* inoculation improved grain yield significantly. High yield was obtained when 1:100 v/v seaweed extract was applied in the presence of *Bradyrhizobia* inoculation. However, the application of seaweed extract in the absence of *Bradyrhizobia* inoculation proved to have no or little effect on grain yield (Figure 4.9). Analysis of variance also revealed a significant variety x seaweed extract x inoculation on grain yield. The application of 1:100 v/v seaweed extract concentration on the Inoculated Bechuana white variety resulted in grain yields of 2784 kg $ha^{-1}$ (Figure 4.10).

Table 4.4: Effect of variety, seaweed extract and inoculation on yield and yield components of cowpea in the field experiment

| Treatment | Pods/Plant | Pod length (cm/pod) | Seed/Pod | 100 seed weight (g) | Grain yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| **VARIETY (V)** | | | | | |
| Brown L | 16.52b | 21.89a | 15.91a | 14.95a | 1021.10b |
| Bechuana W | 25.57a | 17.58b | 13.02b | 15.03a | 1915.60a |
| Significance | ** | ** | ** | Ns | ** |
| LSD $_{0.05}$ | 0.69 | 0.68 | 0.65 | - | 85.00 |
| **EXTRACT (E)** | | | | | |
| Control | 19.46c | 19.61a | 14.58a | 14.90a | 1298.10b |
| 1:500 | 20.80b | 20.084a | 14.52a | 15.09a | 1421.20b |
| 1:100 | 22.86a | 19.52a | 14.28a | 14.98a | 1685.80a |
| Significance | ** | ns | ns | ns | ** |
| $LSD_{0.05}$ | 1.03 | - | - | - | 125.77 |
| **INOCULATION (I)** | | | | | |
| Uninoculated | 18.82b | 19.74a | 14.41a | 15.07a | 1222.90b |
| Inoculated | 23.27a | 19.73a | 14.51a | 14.92a | 1713.80a |
| Significance | ** | ns | ns | ns | ** |
| LSD $_{0.05}$ | 0.69 | - | - | - | 85.00 |
| **INTERACTION EFFECT** | | | | | |
| E x V | ns | ns | ns | ns | ns |
| V x I | ** | ns | ns | ns | ** |
| E x I | ** | ns | ns | ns | ** |
| Ex I x V | ** | ns | ns | ns | ** |

LSD= Least Significant Difference, ns=non significant, ** significant at P≤0.01, * significant at P≤0.05. Means followed by the same letter along a column are not significantly different at P≤0.05.

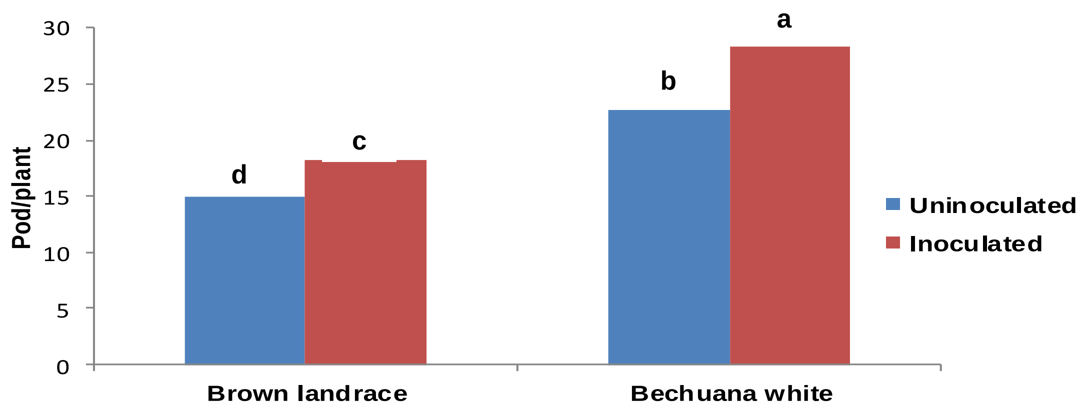


Figure 4.5: Variety x inoculation interaction effect on the number of pods per plant under field conditions. Different letters denote significance at 0.1% level

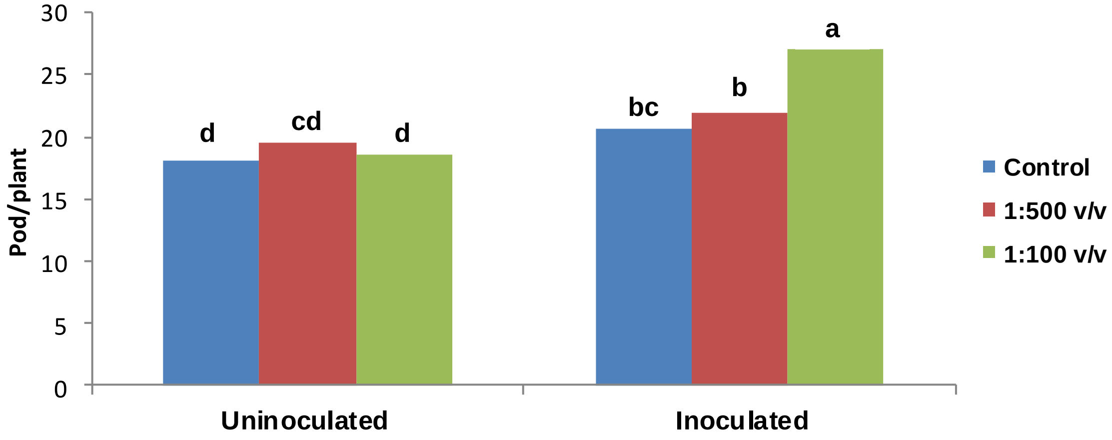


Figure 4.6: Seaweed extract x inoculation interaction effect on the number of pods per plant under field conditions. Different letters denote significance at 0.1% level

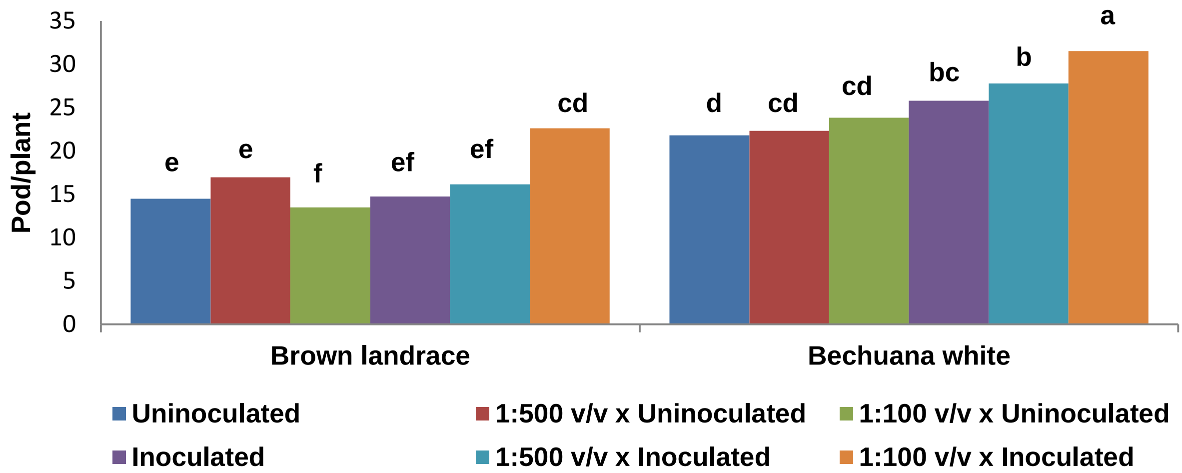


Figure 4.7: Variety x seaweed extract x inoculation interaction effect on the number of pods per plant under field conditions. Different letters denote significance at 0.1% level

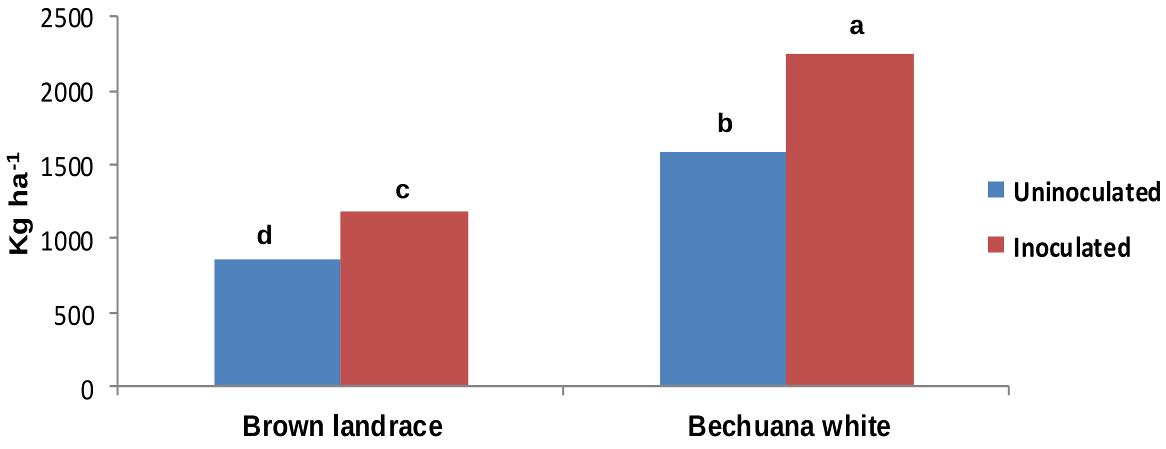


Figure 4.8: Variety x inoculation interaction effect on grain yield. Different letters denote significance at 0.1% level

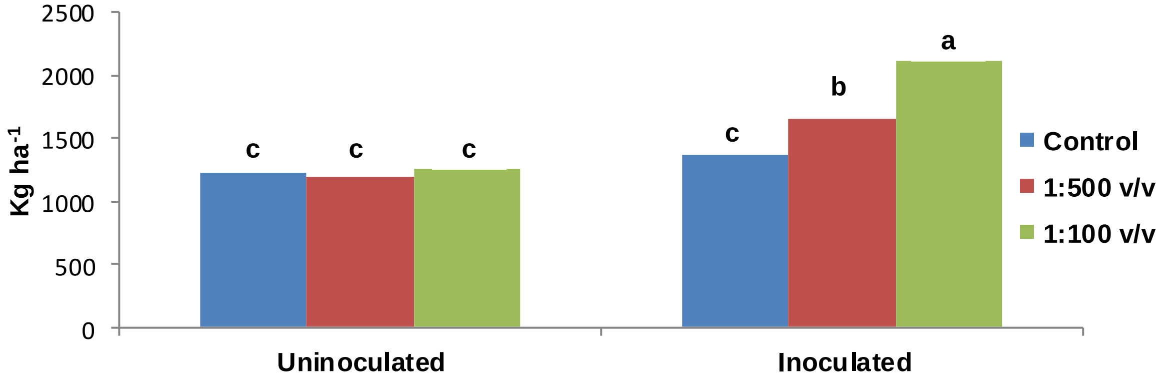


Fig 4.9: Inoculation x seaweed extract interaction effect on grain yield. Different letters denote significance at 0.1% level

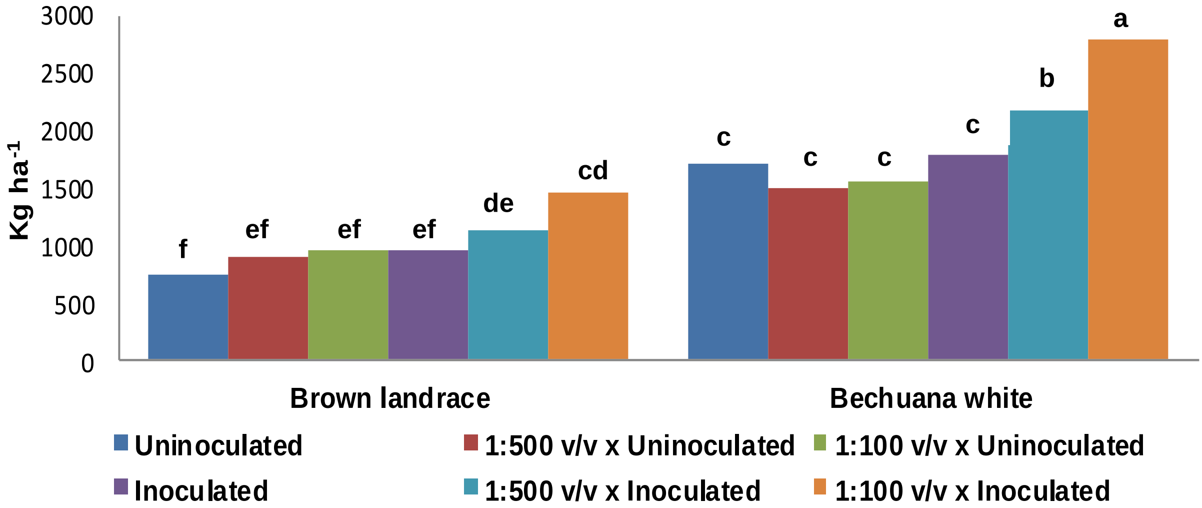


Figure 4.10: Variety x seaweed extract x inoculation interaction effect on grain yield. Different letters denote significance at 0.1% level

4.6 Correlation analysis

In both field and tunnel house experiments, correlation analysis revealed a positive relationship between chlorophyll content and number of effective nodules per plant, suggesting that the increase in leaf chlorophyll content resulted in an increase in the number of effective nodules. In the tunnel house experiment, correlation analysis gave an $R^2$ value of 0.86 (Figure 4.11) while an $R^2$ value of 0.71 (Figure 4.12) was recorded in the field experiment indicating a strong relationship between chlorophyll content and nodulation. Furthermore, a positive relationship was also observed between nodulation and pod formation with an $R^2$ value of 0.69 (Figure 4.13). Correlation analysis also revealed a positive relationship between pod formation and grain yield with a $R^2$ value of 0.62 (Figure 4.14).

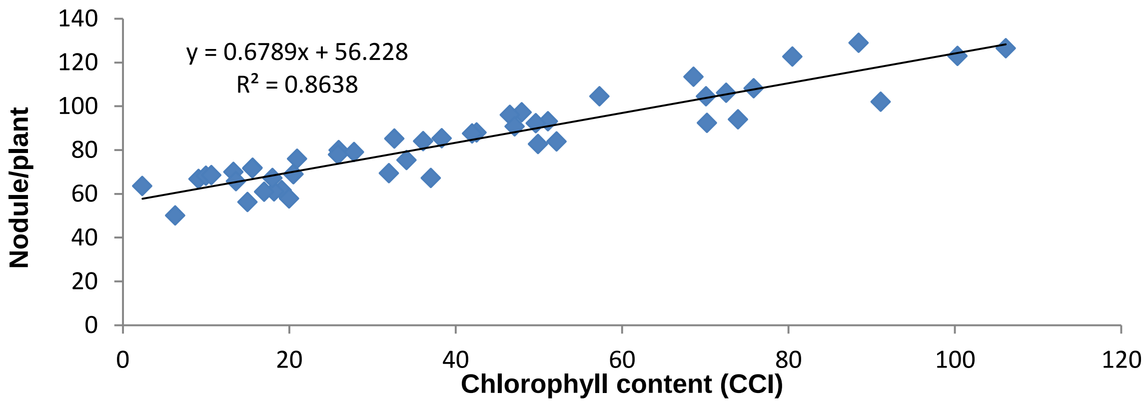


Figure 4.11: Linear correlation between chlorophyll content and nodulation under tunnel house conditions

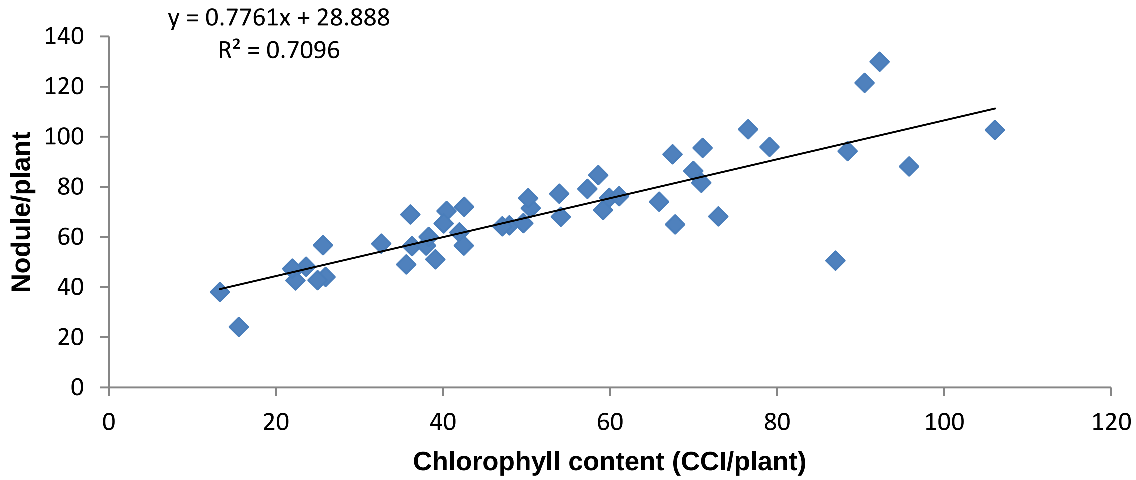


Figure 4.12: Linear correlation between chlorophyll content and nodulation under field conditions.

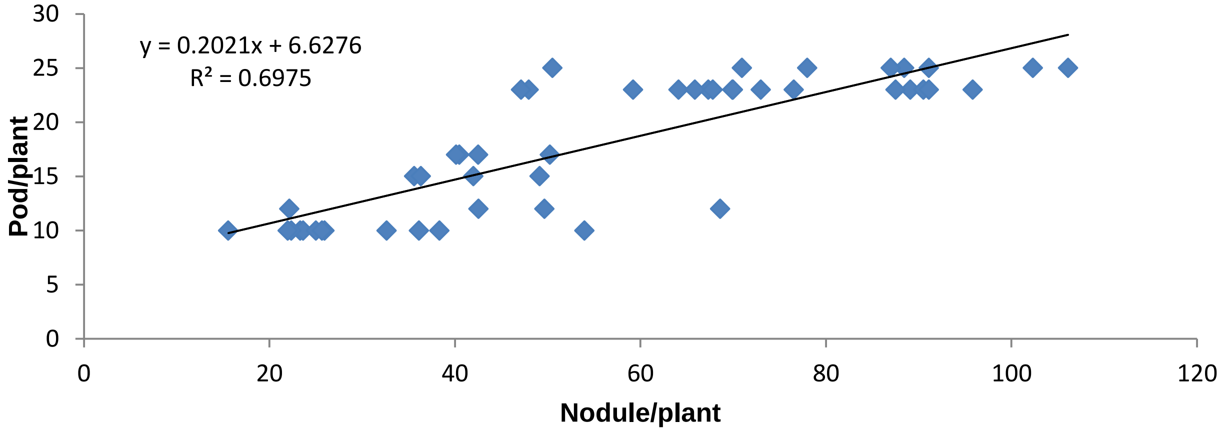


Figure 4.13: Linear correlation between nodulation and pods per plant under field conditions

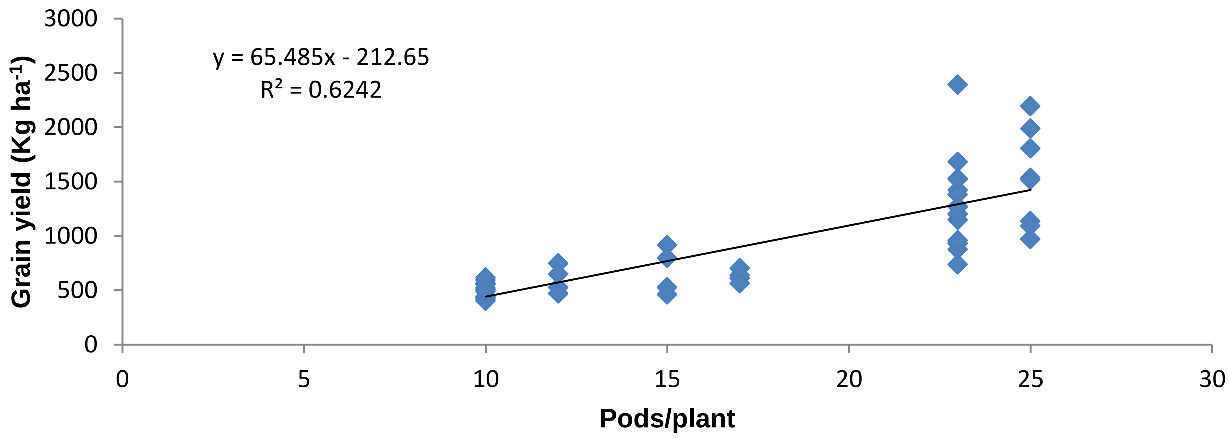


Figure 4.14: Linear correlation between pod number and grain yield under field conditions

4.7 Total above ground biomass

Variety, seaweed extract and inoculation had a significant ($p \leq 0.05$) effect on biomass accumulation. The Brown landrace accumulated the greatest biomass (2399 kg $ha^{-1}$) as compared to the Bechuana white variety (1399 kg $ha^{-1}$). Application of 1:500 v/v seaweed extract resulted in a 3.4% increase while the application of 1:100 v/v seaweed extract resulted in a 3% increase when compared to the control. However, the two seaweed extract concentrations were not significantly different from one another. The application of *Bradyrhizobia* inoculation increased biomass accumulation by up to 5% when compared to the control (Table 4.5).

## 4.8 Shelling percentage

Differences in shelling percentage were significant amongst the varieties. The Bechuana white variety recorded the higher shelling percentage when compared to the Brown landrace variety. Application of seaweed extract also had a significant effect on shelling percentage. The application of 1:500 v/v increased the shelling percentage by 1.92% increase while the application of 1:100 v/v resulted in a 4% increase compared to the control. Application of *Bradyrhizobia* inoculation resulted in a 4.8% increase in shelling percentage when compared to the uninoculated treatment. Analysis of variance revealed a significant ($p \leq 0.05$) interaction effect between all three factors on shelling percentage and harvest index (Table 4.5). Results showed that the application of seaweed extract on Bechuana white variety, in the presence of *Bradyrhizobia* inoculation improved the shelling percentage significantly (Figure 4.15-4.17)

## 4.9 Harvest index

Variety, seaweed extract and inoculation had a significant effect on the harvest index. The Bechuana white variety resulted in a high harvest index of 0.53, compared to the 0.27 by the Brown landrace (Table 4.5). The application of seaweed extract had a significant effect on the harvest index. Harvest index increased with an increase in seaweed extract concentration. The application of 1:500 v/v seaweed extract concentration resulted in a 8.1% increase in harvest index compared to the control, while the application of 1:100 v/v seaweed extract resulted in a 16% increase in the harvest index compared to the control. The application of *Bradyrhizobia* inoculation resulted in a 13% increase in harvest index when compared to the uninoculated treatment (Table 4.5).

There was a significant ($p \leq 0.05$) seaweed extract x inoculation interaction effect on harvest index (Figure 4.17). Overall, the application of seaweed extract in the presence of *Bradyrhizobia* inoculation improved the harvest index significantly when compared to the application of seaweed extract in the absence of *Bradyrhizobia* inoculation, while the combination of the Bechuana white variety x inoculation x 1:100 v/v seaweed extract resulted in the highest harvest index (Figure 4.18).

Table 4.5: Effect of variety, seaweed extract and inoculation on biomass yield, shelling percentage and harvest index

| Treatment | Total biomass (kg ha$^{-1}$) | Shelling % | Harvest index |
|---|---|---|---|
| **VARIETY (V)** | | | |
| Brown landrace | 2399.44a | 80.24b | 0.27b |
| Bechuana white | 1399.44b | 88.31a | 0.53a |
| Significance | ** | ** | ** |
| LSD $_{0.05}$ | 41.66 | 0.58 | 0.01 |
| **EXTRACT (E)** | | | |
| Control | 1859.48b | 82.64c | 0.37c |
| 1:500 | 1923.13a | 84.23b | 0.40b |
| 1:100 | 1915.70ab | 85.95a | 0.43a |
| Significance | * | ns | ns |
| LSD$_{0.05}$ | 61.63 | - | - |
| **INOCULATION (I)** | | | |
| Uninoculated | 1852.31b | 82.26b | 0.38b |
| inoculated | 1946.57a | 86.29a | 0.43a |
| Significance | ** | ** | ns |
| LSD $_{0.05}$ | 41.72 | 0.58 | - |
| **INTERACT EFFECT** | | | |
| E x V | ns | ** | ns |
| V x I | ns | * | ns |
| E x I | ns | ** | ** |
| Ex I x V | ns | ** | ** |

LSD= Least Significant Difference, ns = non-significant, ** significant at P≤0.01, * significant at P≤0.05. Means followed by the same letter in a column are not significantly different at P<0.05

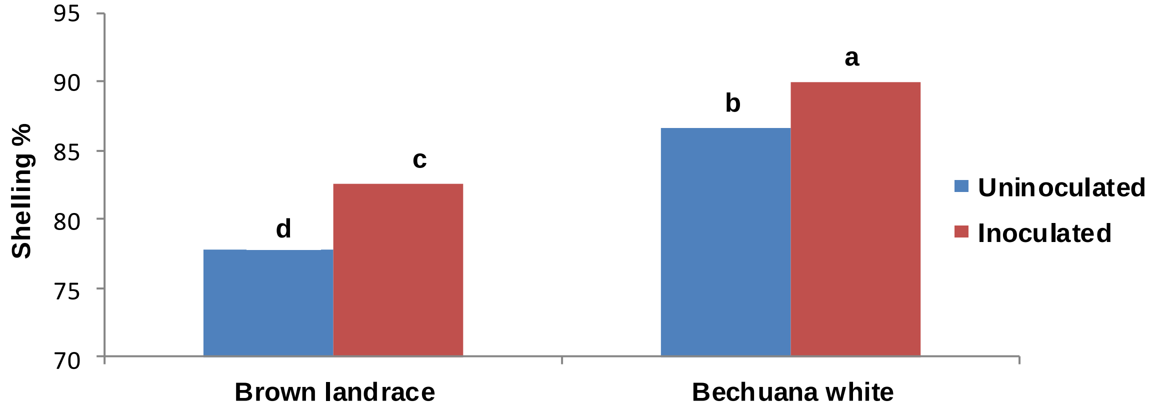


Figure 4.15: Variety x inoculation interaction effect on shelling percentage. Different letters denote significance at 0.1% level.

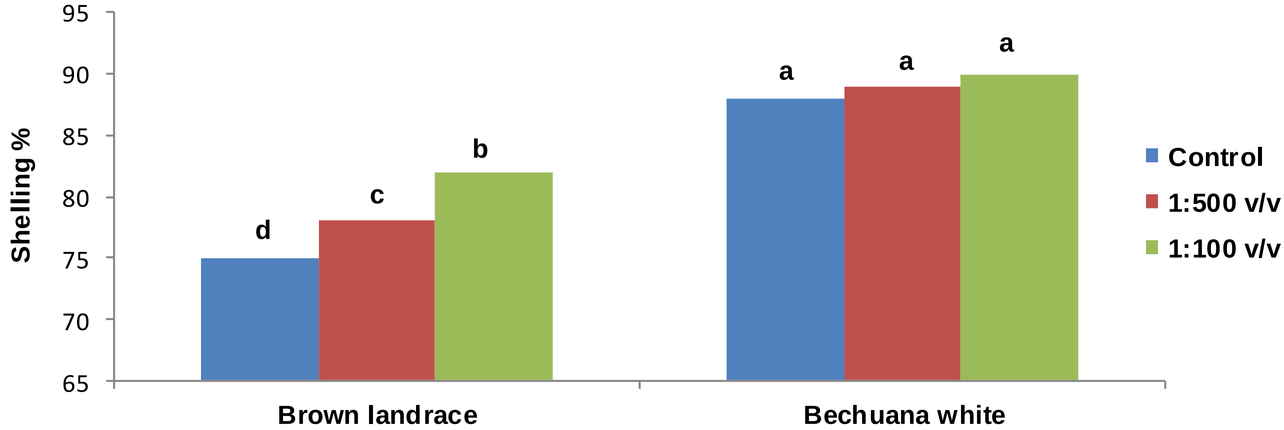


Figure 4.16: Variety x seaweed extract interaction effect on shelling percentage. Different letters denote significance at 0.1% level

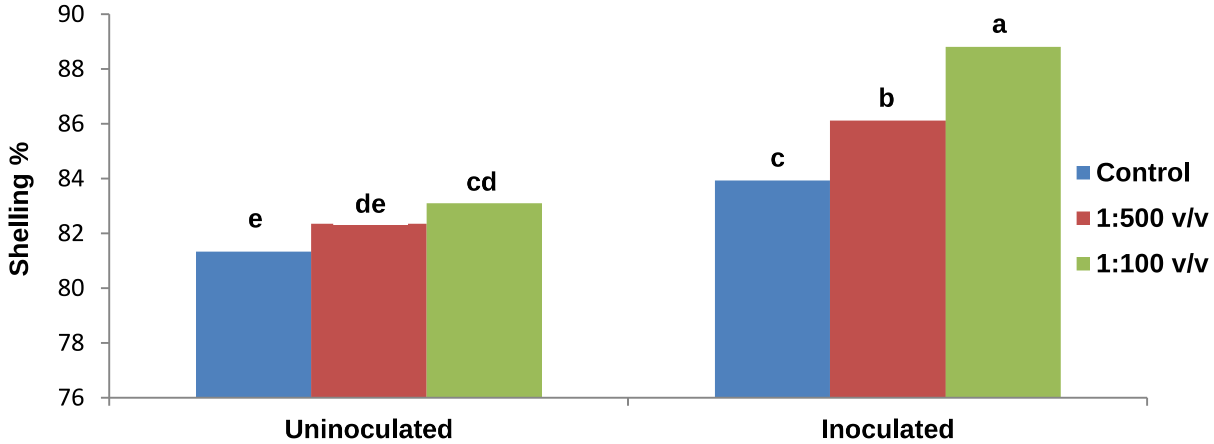


Figure 4.17: Seaweed extract x inoculation interaction effect on shelling percentage. Different letters denote significance at 0.1% level

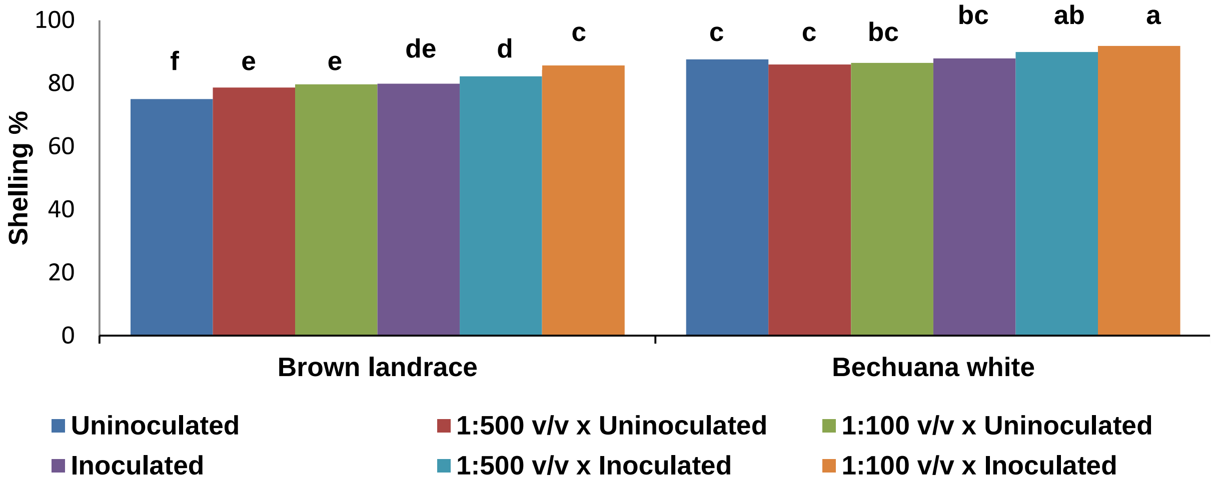


Figure 4.18: Variety x seaweed extract x inoculation interaction effect on shelling percentage. Different letters denote significance at 0.1% level

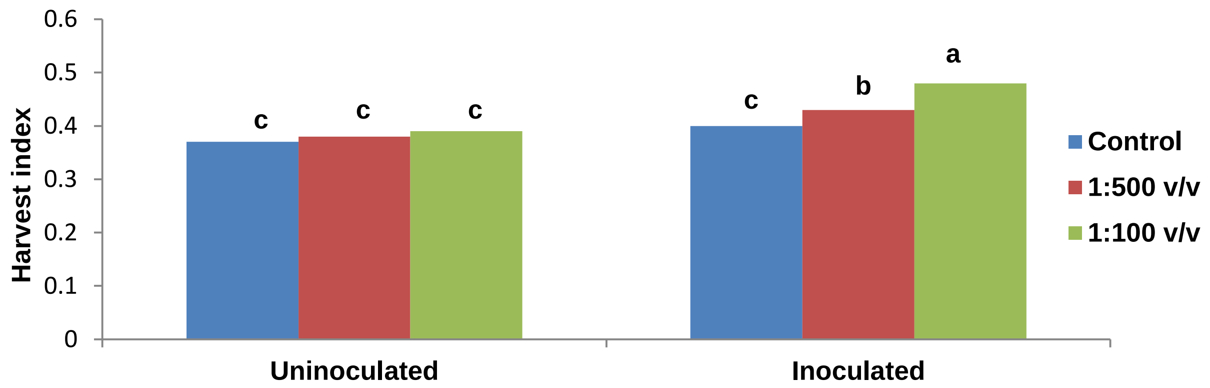


Figure 4.19: Seaweed extract x inoculation interaction effect on harvest index. Different letters denote significance at 0.1% level

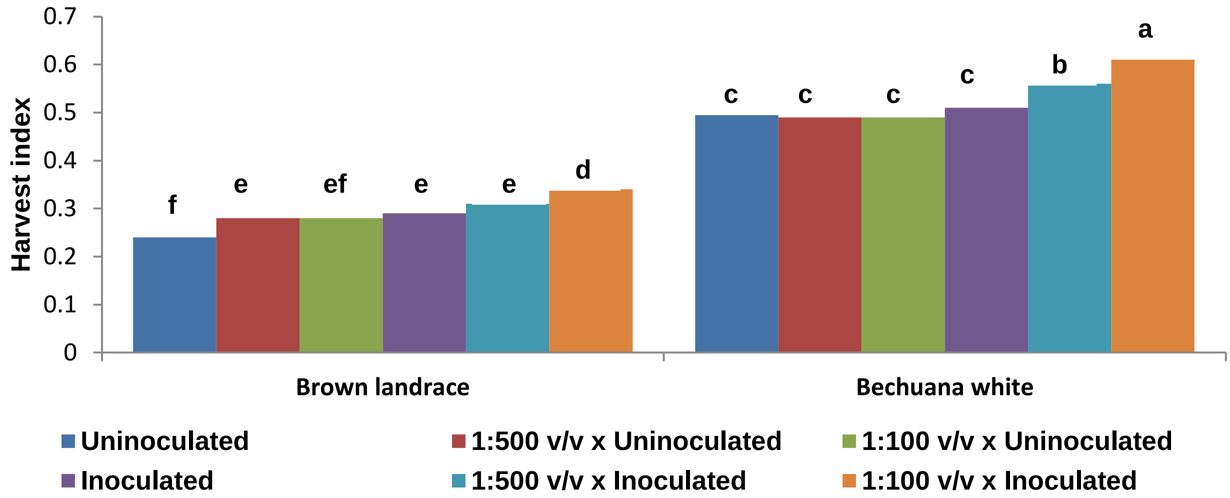


Figure 4.20: Variety x seaweed extract x inoculation interaction effect on harvest index. Different letters denote significance at 0.1% level

## 4.10 Nutritional quality of leaf and seed sample

### 4.10.1 Macro nutrient content of leaf samples

In the field experiment, analysis of variance revealed that all three factors: variety, seaweed extract and inoculation had no significant effect on leaf calcium concentration. However, in the tunnel house experiment, analysis of variance revealed that variety had a significant effect on leaf calcium content. The Bechuana white cultivar recorded leaf calcium content of 0.91 mg $kg^{-1}$ compared to 0.12 mg $kg^{-1}$ by the Brown landrace variety.

In the field experiment, variety had a significant effect on leaf magnesium concentration with the Bechuana white variety recording leaf mg content that is 18.2% greater than that of the Brown landrace. In the tunnel house experiment, analysis of variance revealed that all three factors: variety, seaweed extract and inoculation had no significant effect on leaf magnesium content.

In the field experiment, analysis of variance revealed that both variety and seaweed extract had a significant effect on leaf K content. The Brown landrace leaf K content was 12.2% greater than that of the Bechuana white. The application of 1:500 v/v and 1:100 v/v seaweed concentrate increase leaf K content by 14-16%. In the tunnel house experiment, the Brown landrace variety recorded leaf K of 1.33 mg $kg^{-1}$ which was 25.4% higher than that of the Bechuana white variety. In the field experiment, analysis of variance revealed that all three factors: variety, seaweed extract and inoculation had no significant effect on leaf P content. In the tunnel house experiment, the Brown landrace variety recorded leaf P of 0.18 mg $kg^{-1}$ which was 25% higher than that of the Bechuana white variety.

Further analysis of variance revealed no significant ($p \leq 0.05$) interaction effect between all three factors on leaf Ca content. However, in the tunnel house condition, analysis of variance revealed a significant variety x inoculation interaction effect on leaf Mg content. In the field experiment, analysis of variance also revealed a significant ($p \leq 0.05$) interaction effect between all three factors variety on leaf K content. However, in the tunnel house condition, analysis of variance revealed a significant variety x inoculation interaction effect on leaf K content. In both field and tunnel house experiments, analysis of variance revealed that all three factors had no significant interaction effect on leaf K content (Table 4.6).

The results show that the application of *Bradyrhizobia* inoculation increased leaf K content in both cowpea varieties by 20% (Figure 4.21). The results also showed that the application of seaweed extract on the Bechuana white variety improved leaf K content significantly (Figure 4.22). All levels of seaweed extract and inoculation improved leaf K content of the Brown landrace (Figure 4.23 and 4.24). The application of *Bradyrhizobia* inoculation resulted in a 19-22% increase in leaf Ca content (Figure 4.25), 15.8-16.5% increase in Mg content (Figure 4.26). Application of *Bradyrhizobia* inoculation resulted in a 23.8% increase in leaf K content on the Brown landrace variety (Figure 4.27).

Table 4.6: Effect of variety, seaweed extract and inoculation on leaf macronutrient content

| **Treatment** | **Field** | | | | **Tunnel house** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Ca** | **Mg** | **K** | **P** | **Ca** | **Mg** | **K** | **P** |
| **VARIETY (V)** | | | | **mg kg$^{-1}$ DM** | | | | |
| Brown landrace | 1.74a | 0.49b | 1.13a | 0.17a | 0.12b | 0.37a | 1.33a | 0.18a |
| Bechuana white | 1.05a | 0.59a | 1.00b | 0.16a | 0.91a | 0.38a | 1.03b | 0.14b |
| Significance | ns | ** | ** | ns | ** | ns | ** | ** |
| LSD $_{0.05}$ | - | 0.05 | 0.078 | - | 0.08 | - | 0.12 | 0.03 |
| **EXTRACT (E)** | | | | | | | | |
| Control | 1.19a | 0.53a | 0.96b | 0.16a | 1.03a | 0.37a | 1.18a | 0.15a |
| 1:500 | 1.20a | 0.53a | 1.13a | 0.17a | 1.03a | 0.39a | 1.12a | 0.17a |
| 1:100 | 1.79a | 0.51a | 1.11a | 0.16a | 0.99a | 0.37a | 1.24a | 0.17a |
| Significance | ns | ns | ** | ns | ns | ns | ns | ns |
| LSD$_{0.05}$ | - | - | 0.114 | - | - | - | - | - |
| **INOCULATION (I)** | | | | | | | | |
| Uninoculated | 1.153a | 0.51a | 1.06a | 0.17a | 1.10a | 0.37a | 1.12a | 0.17a |
| Inoculated | 1.648a | 0.53a | 1.07a | 0.16a | 1.07a | 0.39a | 1.24a | 0.15a |
| Significance | ns | ns | ns | ns | ns | ns | ns | ns |
| **INTERACTION EFFECT** | | | | | | | | |
| E x V | ns | ns | ** | ns | ns | ns | ns | ns |
| V x I | ns | ns | ** | ns | ** | ** | ** | ns |
| E x I | ns | ns | ** | ns | ns | ns | ns | ns |
| Ex I x V | ns | ns | ** | ns | ns | ns | ns | ns |

LSD= Least Significant Difference, ns= non-significant, ** significant at $P \leq 0.01$, * significant at $P \leq 0.05$. Means followed by the same letter in a column are not significantly different at $P<0.05$

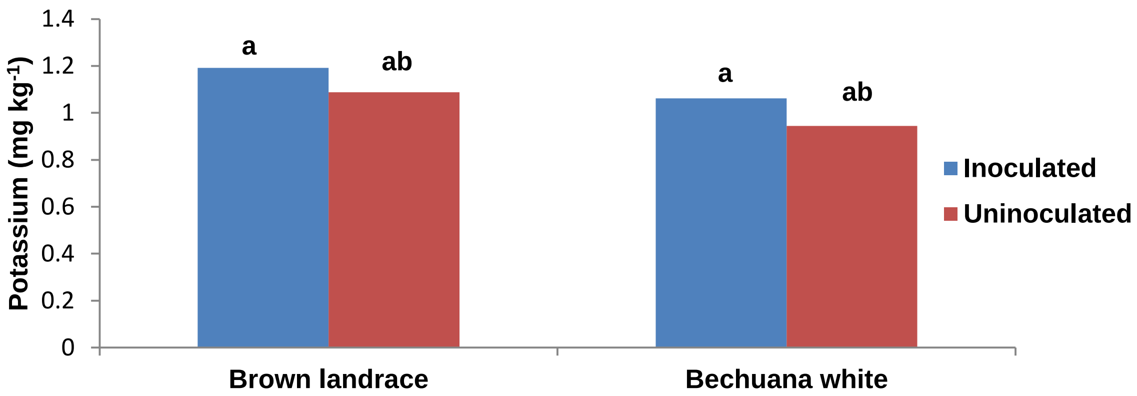


Figure 4.21: Variety x inoculation interaction effect on leaf K content under field condition. Different letters denote significance at 0.1% level

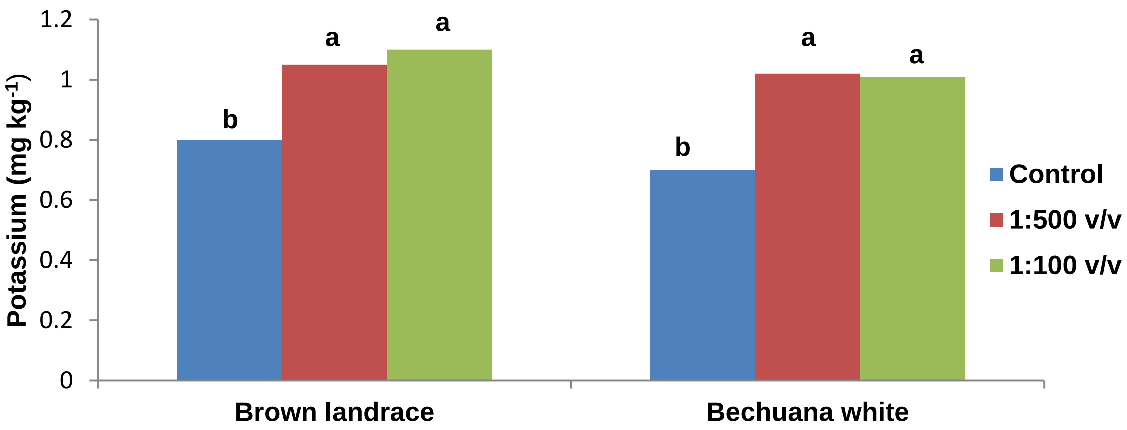


Figure 4.22: Variety x seaweed extract interaction effect on leaf K content under field condition. Different letters denote significance at 0.1% level

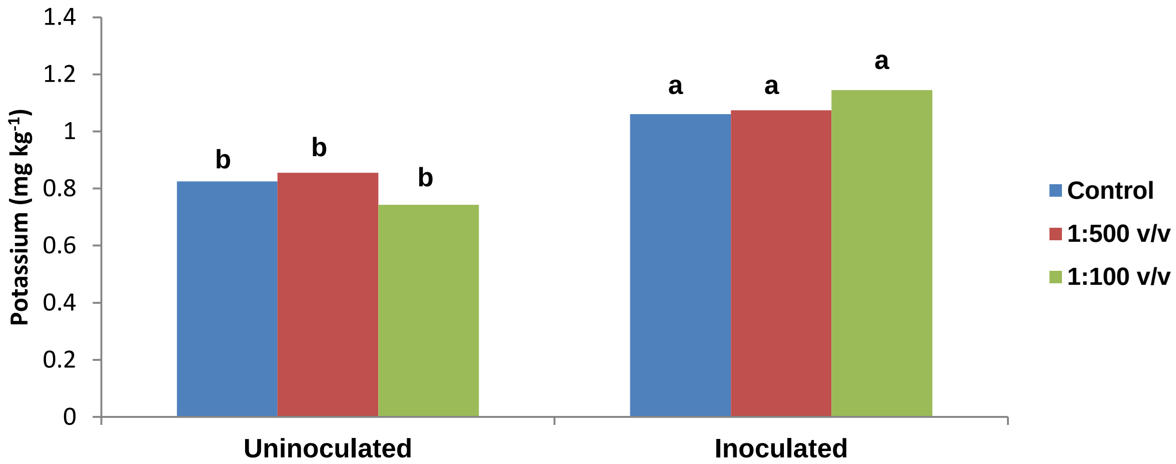


Figure 4.23: Inoculation x seaweed extract interaction effect on leaf K content under field conditions. Different letters denote significance at 0.1% level

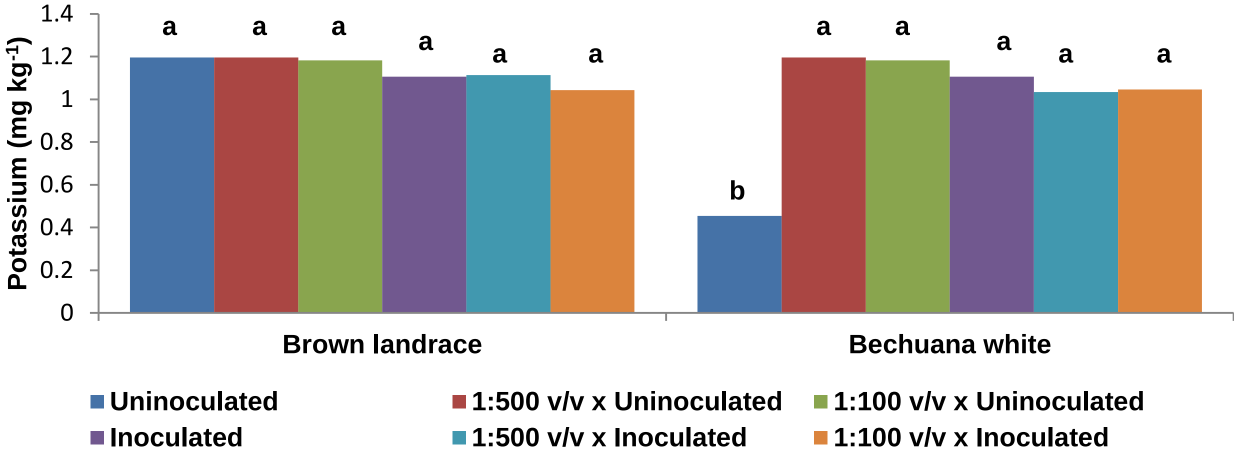


Figure 4.24: Variety x inoculation x seaweed extract interaction effect on leaf K content under field conditions. Different letters denote significance at 0.1% level

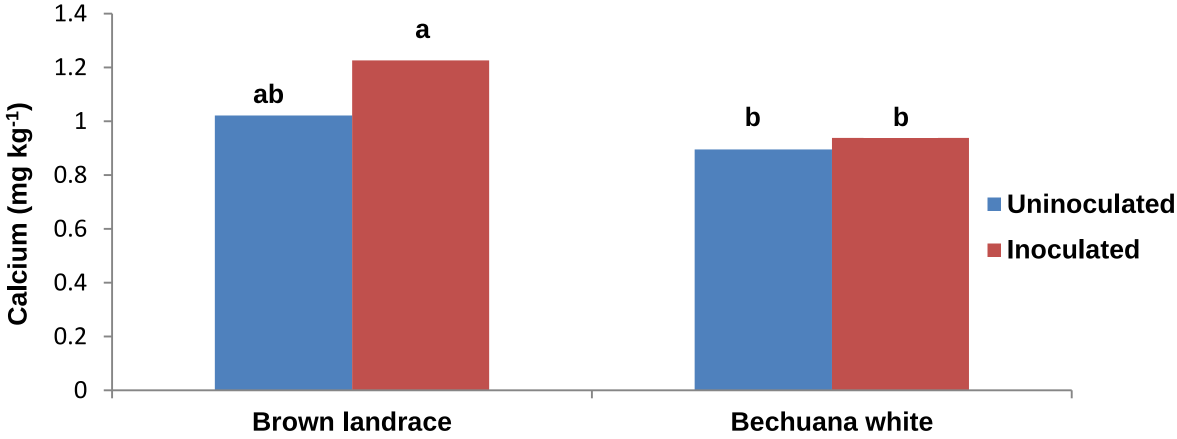


Figure 4.25: Variety x inoculation interaction effect on leaf Ca content under tunnel house conditions. Different letters denote significance at 0.1% level

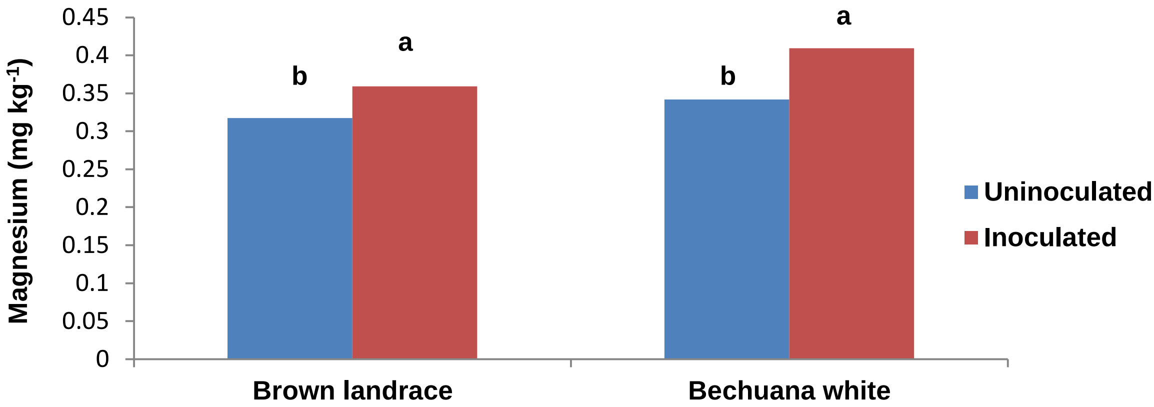


Figure 4.26: Variety x inoculation interaction effect on leaf Mg content under tunnel house conditions. Different letters denote significance at 0.1% level

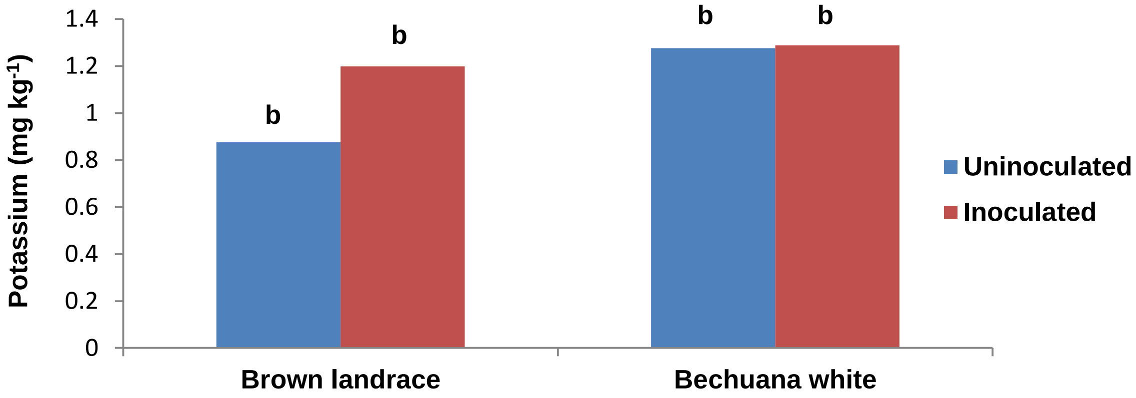

Figure 4.27: Variety x inoculation interaction effect on leaf K content under tunnel house conditions. Different letters denote significance at 0.1% level

4.10.2 Leaf micro nutrient content

In both field and tunnel house experiments, analysis of variance revealed that independent application of seaweed extract and inoculation as well as variety had no significant effect on leaf Zn and Cu as well as Fe leaf content (Table 4.7). In the field experiment, analyses of variance revealed that all three factors had no significant effect on leaf Mn content. However, in the tunnel house experiment, analysis of variance revealed that variety had a significant effect on leaf Mn content where the Brown landrace recorded leaf Mn content of 56.6 mg $kg^{-1}$ compared to the 45.5 mg $kg^{-1}$ by the Bechuana white variety (Table 4.7).

In the field experiment, analysis of variance revealed significant variety x seaweed extract and variety x inoculation effects on Fe (Table 4.7). In the tunnel house experiment, analysis of variance revealed a significant variety x inoculation effect on leaf Mn and Fe content (Table 4.7). The results also show that both 1:100 v/v and 1:500 v/v seaweed extract concentrations increased leaf Fe content of Bechuana white variety by 48% (Figure 4.28) while the application of *Bradyrhizobia* inoculation on the Bechuana white variety improved leaf Fe content by 70-76% (Figure 4.29, 4.30). The application of *Bradyrhizobia* inoculation on the Brown landrace resulted in a 21.14% increase in Mn when compared to uninoculated treatment (Figure 4.31).

Table 4.7: Effect of variety, seaweed extract and inoculation leaf micronutrient quality

| Treatment | Field | | | | Tunnel-house | | | |
|---|---|---|---|---|---|---|---|---|
| | Zn | Cu | Mn | Fe | Zn | Cu | Mn | Fe |
| **VARIETY (V)** | | | | **mg kg$^{-1}$ DM** | | | | |
| Brown L | 19.21a | 6.04a | 66.3a | 146.1a | 19.6a | 4.1a | 56.6a | 93.1a |
| Bechuana W | 16.91a | 5.08a | 70.6a | 158.9a | 20.1a | 3.6a | 45.5b | 89.6a |
| Significance | ns | ns | ns | ns | ns | ns | ** | ns |
| LSD $_{0.05}$ | - | - | - | - | - | - | 6.66 | - |
| **EXTRACT (E)** | | | | | | | | |
| Control | 17.3a | 4.9a | 68.4a | 135.3a | 19.2a | 3.5a | 52.9a | 90.8a |
| 1:500 | 17.3a | 4.7a | 71.2a | 161.8a | 20.2a | 4.1a | 51.0a | 93.8a |
| 1:100 | 19.2a | 7.0a | 65.4a | 160.5a | 20.3a | 4.1a | 49.4a | 89.3a |
| Significance | ns | ns | ns | ns | ns | ns | ns | ns |
| **INOCULATION (I)** | | | | | | | | |
| Uninoculated | 06.0a | 4.8a | 69.2a | 155.9a | 20.5a | 3.7a | 53.8a | 91.9a |
| Inoculated | 19.0a | 6.2a | 67.7a | 149.2a | 19.3a | 3.9a | 48.3a | 90.8a |
| Significance | ns | ns | ns | ns | ns | ns | ns | ns |
| **INTERACTION EFFECT** | | | | | | | | |
| E x V | ns | ns | ns | * | ns | ns | ns | ns |
| V x I | ns | ns | ns | ** | ns | ns | ** | * |
| E x I | ns | ns | ns | ns | ns | ns | ns | ns |
| E x I x V | ns | ns | ns | ns | ns | ns | ns | ns |

LSD= Least Significant Difference, ns = non-significant, ** significant at $P \leq 0.01$, * significant at $P \leq 0.05$. Means followed by the same letter in a column are not significantly different at $P < 0.05$

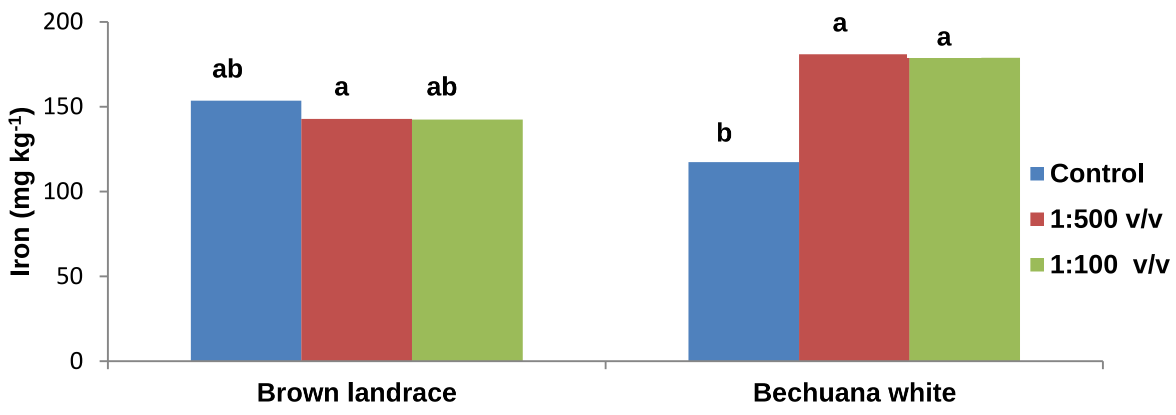


Figure 4.28: Variety x Seaweed extract interaction effect on leaf Fe content under field conditions. Different letters denote significance at 0.1% level

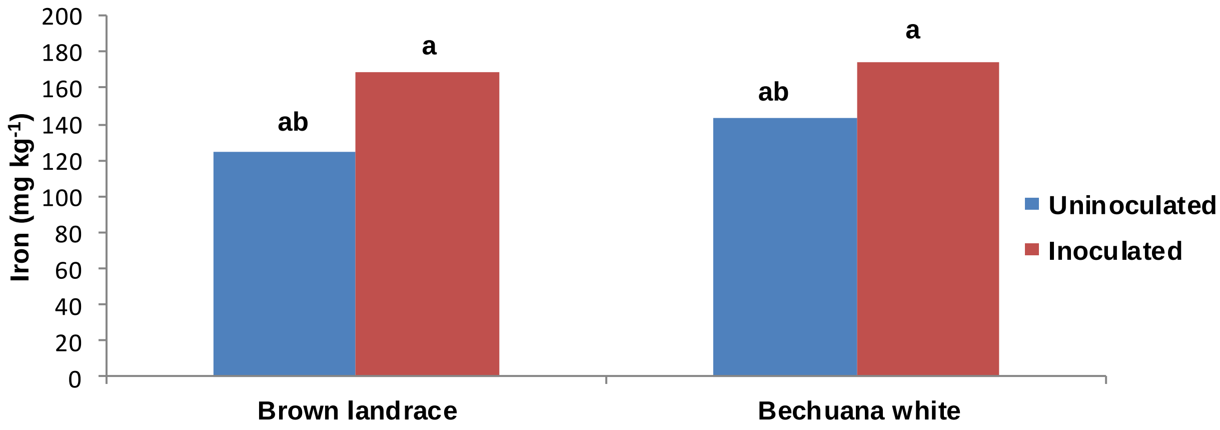


Figure 4.29: Variety x inoculation interaction effect on leaf Fe content under field condition. Different letters denote significance at 0.1% level

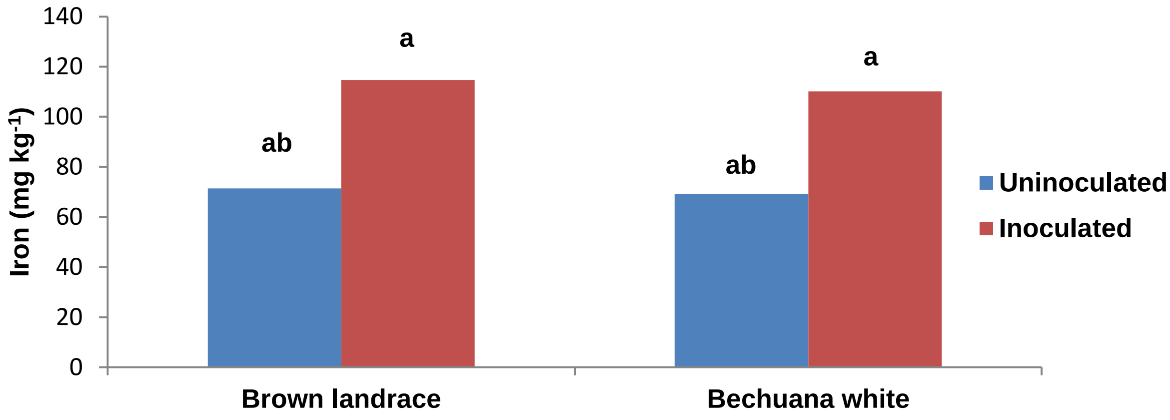


Figure 4.30: Variety x inoculation interaction effect on leaf Fe content under tunnel house condition. Different letters denote significance at 0.1% level

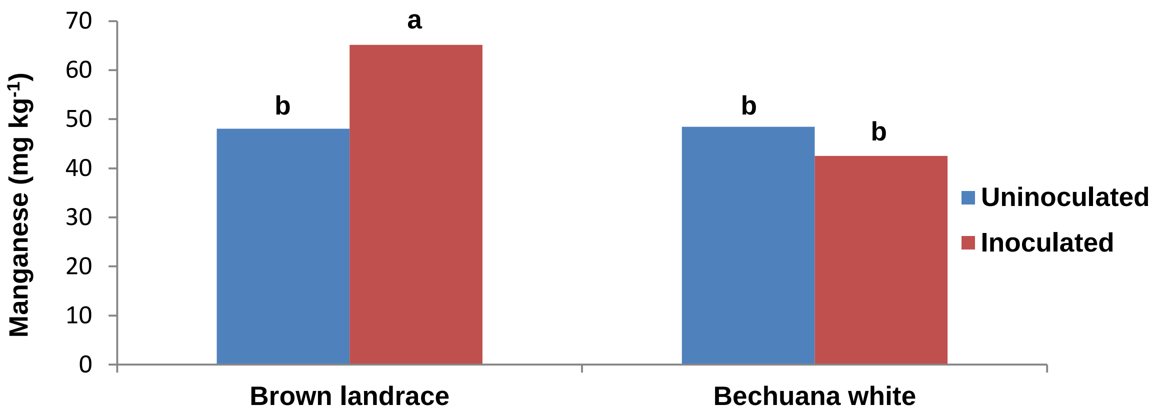


Figure 4.31: Variety x inoculation interaction effect on leaf Mn content under tunnel house condition. Different letters denote significance at 0.1% level

4.10.3 Seed nutritional quality

Analysis of variance revealed that all three factors; variety, seaweed extract and inoculation had no significant effect on seed calcium content. Analysis of variance also revealed that variety had a significant effect on seed Mg content with the Bechuana white cultivar recording 0.19 mg kg$^{-1}$ compared to the Brown landrace's 0.20 mg kg$^{-1}$. The application of *Bradyrhizobia* inoculation resulted in a 10.52% increase in seed Mg content compared to the uninoculated treatment.

Seaweed extract had no significant effect on seed K content. However, the application of *Bradyrhizobia* inoculation resulted in a 5.8% increase in seed K content compared to the uninoculated treatment. Analysis of variance revealed that seaweed extract and inoculation had no significant effect on the seed P content. However, variety had a significant effect on seed P content. The Bechuana white recorded a higher seed P content of 0.45 mg kg$^{-1}$ compared to 0.47 mg kg$^{-1}$ by the Brown landrace variety.

Analysis of variance revealed that all three factors; variety, seaweed extract and inoculation had no significant effect on seed Zn content. Analysis of variance revealed that all three factors; variety, seaweed extract as well as inoculation had no significant effect on seed Cu content. Seaweed extract and inoculation had no significant effect on seed Mn content. However, variety had a significant effect on seed P content. The Brown landrace recorded a higher seed Mn content of 16.63 mg kg$^{-1}$ compared to 13.80 mg kg$^{-1}$ by the Bechuana white variety.

Analysis of variance revealed that all three factors; variety, seaweed extract and inoculation had no significant effect on seed Fe concentration. All three factors; variety, seaweed extract and inoculation had a significant effect on seed B content. The Bechuana white recorded a higher seed B content of 16.42 mg $kg^{-1}$ compared to 15.78 mg $kg^{-1}$ by the Brown landrace variety. The application of seaweed extract improved seed B levels. The application of 1:100 v/v increased seed B levels by 4.74 % while the application of 1:500 v/v was not significantly different from the control. The application of *Bradyrhizobia* inoculation resulted in a 5.5% increase in seed B content compared to the uninoculated treatment.

Further analysis of variance revealed a significant cultivar x seaweed extract, variety inoculation, seaweed extract x inoculation interaction effect on seed B content (Table 4.8). The results showed that the application of *Bradyrhizobia* inoculation on the Brown landrace improved seed B by 14.8% when compared to the uninoculated treatment (Figure 4.32). The results also show that the application of 1:100 v/v seaweed extract in the presence of inoculation improved seed B content significantly (Figure 4.33) compared to when applied in the absence of inoculation. Brown landrace variety. The results also show that the application of 1:100 v/v seaweed extract concentrate increased seed B content significantly when applied on the Brown landrace cultivar (Figure 4.34).

Table 4.8: Effect of variety, seaweed extract and inoculation on seed nutritional quality

| Treatment | Ca | Mg | K | P | Zn | Cu | Mn | Fe | B |
|---|---|---|---|---|---|---|---|---|---|
| **VARIETY (V)** | | | | | **mg kg$^{-1}$ DM** | | | | |
| Brown L | 0.08a | 0.20a | 1.40a | 0.45a | 23.28a | 9.28a | 16.62a | 62.92a | 15.78b |
| Bechuana W | 0.07a | 0.19b | 1.38a | 0.47b | 26.38a | 8.69a | 13.80b | 63.96a | 16.42a |
| Significance | ns | ** | ns | ** | ns | ns | ** | ns | ** |
| LSD $_{0.05}$ | - | 3.05 | - | 0.01 | - | - | 0.62 | - | 0.31 |
| **EXTRACT (E)** | | | | | | | | | |
| Control | 0.07a | 0.19a | 1.39a | 0.46a | 24.68a | 8.80a | 14.90a | 65.10a | 15.82b |
| 1:500 | 0.07a | 0.19a | 1.39a | 0.46a | 25.25a | 9.63a | 15.31a | 61.53a | 15.91b |
| 1:100 | 0.07a | 0.19a | 1.39a | 0.46a | 24.54a | 8.53a | 15.42a | 63.70a | 16.57a |
| Significance | ns | ns | ns | ns | ns | ns | ns | ns | ** |
| LSD$_{0.05}$ | - | - | - | - | - | - | - | - | 0.45 |
| **INOCULATION (I)** | | | | | | | | | |
| Uninoculated | 0.07a | 0.19b | 1.38b | 0.46a | 26.19a | 10.5a | 14.92a | 62.92a | 15.67b |
| Inoculated | 0.07a | 0.21a | 1.40a | 0.46a | 23.47a | 7.46a | 15.50a | 63.96 | 16.53a |
| Significance | ns | ** | ** | ns | ns | ns | ns | ns | ** |
| LSD$_{0.05}$ | - | 3.04 | 0.01 | - | - | - | - | - | 0.31 |
| **INTERACTION EFFECT** | | | | | | | | | |
| E x V | ns | ns | ns | ns | ns | ns | ns | ns | ** |
| V x I | ns | ns | ns | ns | ns | ns | ns | ns | ** |
| E x I | ns | ns | ns | ns | ns | ns | ns | ns | ** |
| E x I x V | ns | ns | ns | ns | ns | ns | ns | ns | ns |

LSD = Least Significant Difference, ns = non significant, ** significant at $P\leq0.01$, * significant at $P\leq0.05$. Means followed by the same letter along a column are not significantly different at $P<0.05$

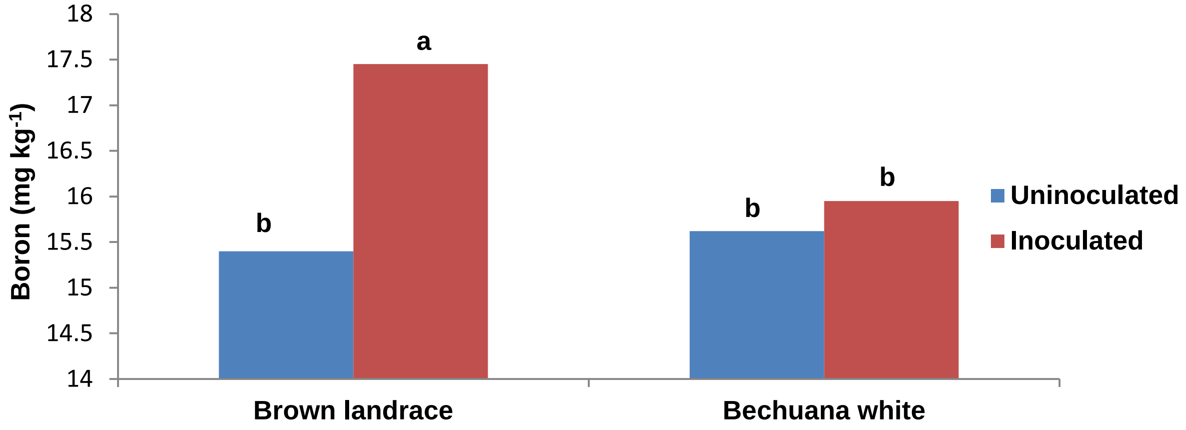


Figure 4.32: Variety x inoculation interaction effect on seed B content. Different letters denote significance at 0.1% level

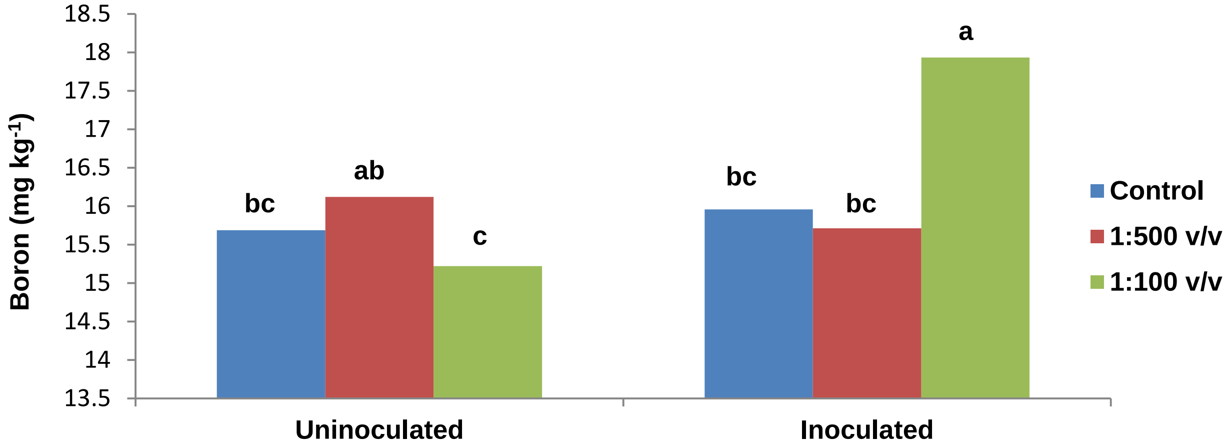


Figure 4.33: Seaweed extract x inoculation interaction effect on seed B content. Different letters denote significance at 0.1% level

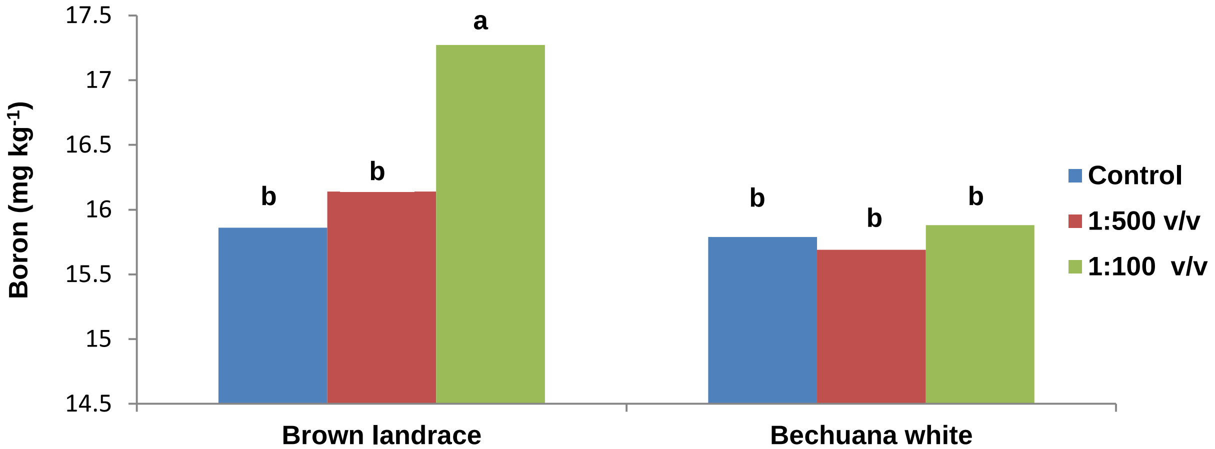


Figure 4.34: Variety x seaweed extract interaction effect on seed B content. Different letters denote significance at 0.1% level

### 4.10.4 Leaf and seed crude protein

Analysis of variance revealed that variety and inoculation had a significant effect on leaf and seed protein content. In both field and tunnel house experiments, the results showed that the Brown landrace leaves were richer in protein than the Bechuana white (Table 4.9). However, the Bechuana white variety recorded high seed crude protein than the Brown landrace variety (Table 4.9). Furthermore, analysis of variance revealed a significant variety x inoculation as well as inoculation x seaweed extract interaction effect on both leaf and seed protein content (Table 4.9).

Table 4.9**:** Leaf and seed crude protein content as affected by variety, seaweed extract and inoculation

| **Treatments** | **Crude protein (mg kg$^{-1}$ DM)** | | |
|---|---|---|---|
| | **Leaf** | | **Seed** |
| | **Field** | **Tunnel house** | **Field** |
| **VARIETY (V)** | | | |
| Brown landrace | 27.13a | 26.22a | 22.75b |
| Bechuana white | 24.28b | 23.67b | 23.47a |
| Significant | ** | ** | ** |
| LSD $_{0.05}$ | 2.54 | 1.56 | 0.40 |
| **EXTRACT (E)** | | | |
| Control | 26.29a | 24.30a | 23.02a |
| 1:500 | 26.51a | 24.75a | 23.07a |
| 1:100 | 24.39a | 25.78a | 23.24a |
| Significant | ns | ns | ns |
| LSD$_{0.05}$ | 3.77 | 2.31 | 0.59 |
| **INOCULATION (I)** | | | |
| Uninoculated | 24.89a | 23.97a | 22.92a |
| Inoculated | 26.52a | 25.92a | 23.30a |
| Significance | ns | ** | ns |
| LSD$_{0.05}$ | 2.54 | 1.56 | 0.40 |
| **INTERACT EFFECT** | | | |
| E x V | ns | ns | ns |
| V x I | ns | * | ** |
| E x I | * | ns | ns |
| E x I x V | ns | ns | ns |

LSD= Least Significant Difference, ns=non significant, ** significant at P≤0.01, * significant at P≤0.05. Means followed by the same letter along a column are not significantly different at P<0.05

Further analysis of variance revealed that the application of 1:100 v/v and 1:100 v/v seaweed extract in the presence of inoculation were not significantly different from one another nor the control (0:0 v/v). However, the application of both 1:100 v/v and 1:500 v/v seaweed extract concentration in the absence of inoculation improved leaf protein content by 31% when compared to 0:0 v/v (Figure 4.35). Furthermore, the results showed that *Bradyrhizobia* inoculation improved leaf crude protein in Brown landrace variety. The application of *Bradyrhizobia* inoculation resulted in a 25% increase in leaf protein content when compared to the uninoculated treatment (Figure 4.36) and a 10% increase in seed protein content of the Bechuana white variety (Figure 4.37).

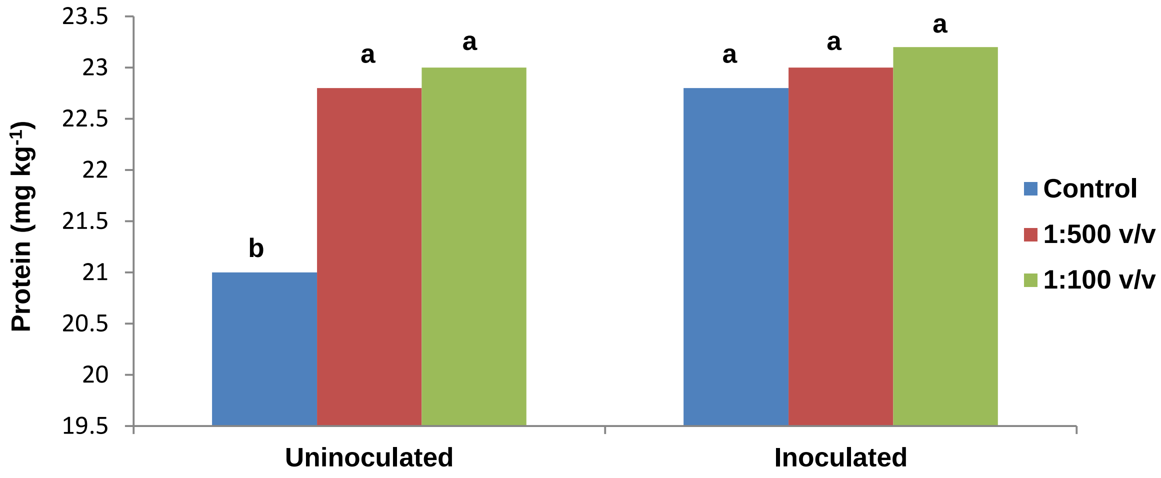


Figure 4.35: Seaweed extract x inoculation interaction effect on leaf protein content under field conditions. Different letters denote significance at 0.1% level

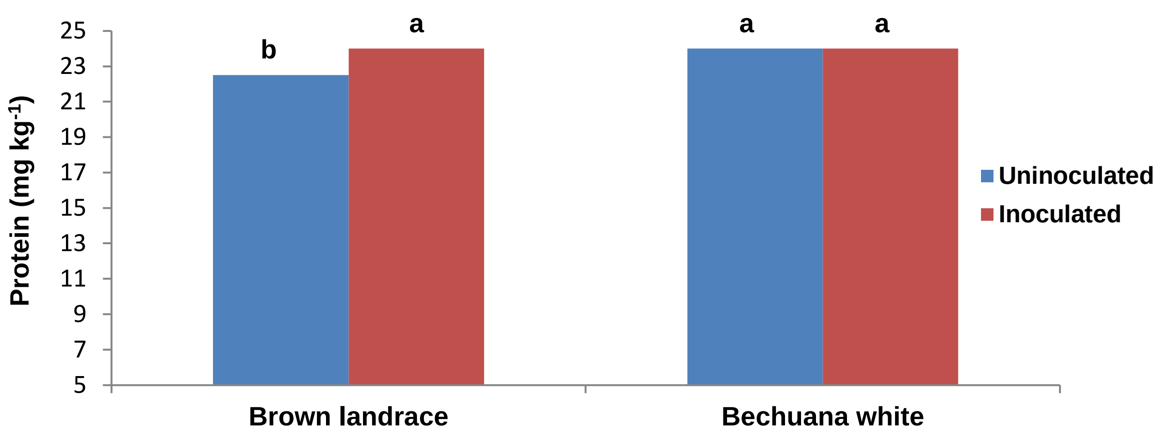


Figure 4.36: Variety x inoculation interaction effect on leaf protein under tunnel house conditions. Different letters denote significance at 0.1% level

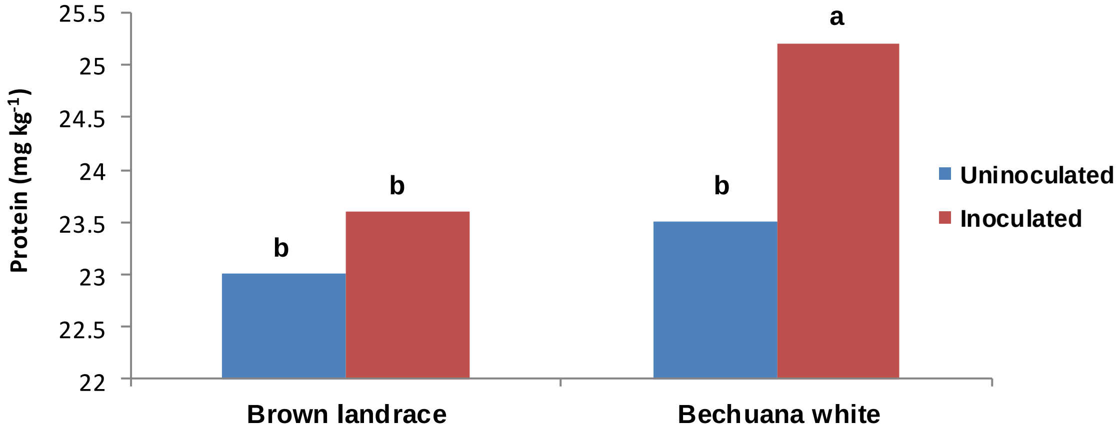


Figure 4.37: Variety x inoculation interaction effect on seed protein content. Different letters denote significance at 0.1% level

4.11 Economic benefits

Analysis of variance revealed that the application of seaweed extract as well as inoculation had significant economic benefits for the farmers ($p \leq 0.05$). The results showed that the application of *Bradyrhizobia* inoculation as well as 1:100 v/v seaweed extract concentration can be highly profitable (Table 4.10). Similar results were observed in percentage increase over control. For example, *Bradyrhizobium* inoculation on cowpea have resulted into greater profit of R32818/ha relative to uninoculated treatments which gave R22128/ha and ultimately resulted into higher rand value change over control and marginal rate of return. The application of 1:100 v/v seaweed extract concentration also resulted into greater profitability of R32191/ha and ultimately resulted into high rand value change over control and marginal rate of return while the application of 1:500 v/v seaweed resulted in a 26911/ha profit and a R2263/ha value change over the control

Table 4.10: Economic profit (MNR), total variable costs (TVC) and marginal rate of return (MRR) of cowpea under different treatments

| Treatment | Yield change over control (kg/ha) | TVC of production (R/ha) | MNR (R/ha) | Rand value change over control | MRR (R/ha) |
|---|---|---|---|---|---|
| **INOCULATION** | | | | | |
| Uninoculated | - | 1312 | 22128b | - | 16.86b |
| Inoculated | 490a | 1442 | 32818a | 10690c | 22.75a |
| **EXTRACT** | | | | | |
| Control | - | 1312 | 24648b | - | 18.78ab |
| 1:100 | 387ab | 1509 | 32191a | 7543a | 21.33a |
| 1:500 | 123b | 1509 | 26911b | 2263b | 17.83ab |
| Significance | ** | - | ** | ** | ** |
| LSD | 21.85 | - | 221.8 | 258.11 | 3.84 |

# CHAPTER 5

# DISCUSSION

## 5.1 Growth and development

Results from this study showed that the Brown landrace variety took longer to reach flowering when compared to the Bechuana white variety. The results conform to that of Egbe *et al.* (2010) who observed significant differences in the number of days to 50% flowering and days to maturity between different cowpea varieties. Independent application of inoculation reduced the number of days to flowering in both varieties while seaweed extract had no significant effect on the number of days to 50% flowering and physiological maturity by the cowpea. The results from this study are contrary to that of Tairo and Ndakidemi (2013) who reported that *Bradyrhizobia* inoculation significantly delayed flowering by 6% and 3% in both glasshouse and field experiments, respectively, relative to the control treatment.

## 5.2 Chlorophyll content and nodulation

The application of *Bradyrhizobia* Inoculation improved the leaf chlorophyll content when compared to the uninoculated control. From early flowering stages onward, clear differences in leaf colour were visible which was due to differences in the availability of nitrogen and subsequent chlorophyll synthesis. The results agree with those of Vollmann *et al.* (2011) who reported that nodulating soybean types had significantly higher chlorophyll content at full flowering stage as compared to non-nodulating types. The results also conforms with those of Bejandi *et al.* (2012) who reported an increase in chlorophyll content in inoculated chickpea as compared to the uninoculated chickpea. Bambara and Ndakidemi (2009) also reported an increase in chlorophyll content in common bean following the introduction of *Bradyrhizobium* inoculation. Tairo and Ndakidemi (2013) also reported an increase in leaf chlorophyll content in soybean following the application of inoculation.

The application of seaweed extract also improved leaf chlorophyll content in both cowpea varieties. Results from this study agree with those of Thirumaran *et al.* (2009) and Pise and Sabale (2010) who reported that the application of seaweed extract enhanced leaf chlorophyll level in plants of cluster bean as well as funugreek. Whapham *et al.* (1993) and Genard *et al.* (1991) believe that the increase in chlorophyll content is due to the presence of glycine betaines, which delay the loss of photosynthetic activity by reducing the degradation of chlorophyll pigments during storage conditions in isolated chloroplasts.

Both cowpea varieties exhibited a greater response to inoculation. The results conform with those of Okereke *et al.* (2001), Chude *et al.* (2006), Uzoma *et al.* (2006), Yakubu *et al.* (2010), Teymur *et al.* (2012) and Gicharu *et al.* (2013) who reported that *Bradyrhizobium* inoculation improved nodulation in soybean, chickpea, climbing bean as well as cowpea, respectively. In the current study, nodulation was also observed in the control treatments, which signify that there were native *Rhizobia* in the soil which nodulated the cowpea. This also signifies that the cowpea were promiscuous variety which can be nodulated by any indigenous *Rhizobia* in the soil and that the Syferkuil soil had indigenous *Rhizobia.* These results conform to those of Nyoki and Ndakidemi (2013) who recorded a significant number of nodules in uninoculated cowpea.

Independent application of seaweed extract promoted nodulation in cowpea. These findings are in line with that of Khan *et al.* (2008) who reported that root irrigation with seaweed based extract improved the total number of functional nodules in alfalfa. A study by Gurusaravanan *et al.* (2010) also revealed an increase in the number of nodules in *Vigna radiata* following the application of seaweed extract. Another study by Gurusaravanana *et al.* (2011) also reported an increase in the number of nodules per plant in *Cicer arietinum* following the application of seaweed extract. Results from the present study also showed that the co-application of seaweed extract and inoculation increased the number of effective nodules significantly. The results are in-line with that of Sangeetha and Thevanathan (2010) who reported an increase in nodulation following the application of seaweed based Panchagavya (panchagavya: soil; 1:100) in the presence of *Rhizobium* R4 strain and postulated that this sea weed-based Panchagavya promoted both the survival ability and nodulating efficiency of the inoculated *Rhizobium*.

Independent application of seaweed extract and inoculation improved nodule dry weight significantly. The results from this study agree with those by Habtemichial *et* *al.* (2007) and Bejandi *et al.* (2012) who reported an increase in garden pea and chickpea, respectively, nodule biomass following the introduction of *Rhizobia* compared to uninoculated plants. The application of seaweed extract also improved the nodule dry weight. As discussed earlier that the application of seaweed increases leaf chlorophyll content, which in-turn increases photo-assimilation. It is also expected that bacteria in the nodule (bacteroids) need large amounts of energy to support their nitrogen-fixing activity and the plant provides energy in the form of sucrose, produced through photosynthesis. Hence, the increase in chlorophyll content triggered by the application of seaweed extract facilitated the maintenance of functional nodules by increasing the photo assimilates to the nodule, which results in increased nodule weight. In both field and tunnel house experiment, correlation analysis revealed a positive relationship between chlorophyll content and nodulation where $R^2$ was 0.7 and 0.86 respectively. This results suggests

5.3 Biomass accumulation

Independent application of inoculation and seaweed extract also improved root, shoot and total dry weight at flowering as well as biomass yield at physiological maturity. The results from this study are in conformity with the observation made by Hafeez *et al.* (1988) who reported that un-inoculated plants produced lower dry matter than inoculated ones. Similar findings have also been reported by Hoque and Hashem (1991) in soybean and groundnut and Namvar *et al.* (2011) who revealed that the application of inoculation improved total dry matter accumulation in chickpea.

Temple and Bomke (1989) reported that foliar and soil application of seaweed extracts stimulated shoot growth and branching in bean crop while Featonby-Smith and van Staden (1989) also reported an increase in shoot and root growth in tomato following the applying of seaweed extract. The application of seaweed extract also improved the total above ground biomass. Results from the current study agree with those of earlier studies carried out on *Cajanus cajan* (L.) Millsp (Mohan *et al.,* 1994) and *Vigna sinensis* L. (Sivasankari *et al.,* 2006) where the application of seaweed extract increased the plant vegetative growth. According to Khan *et al.* (2009) and Craigie (2010), the mechanisms by which seaweed extracts affects plant metabolism are probably due to the hormone-like plant growth regulators which affect cellular metabolism resulting in increased plant growth. Increase in biomass can be an advantage to farmers who feed the cowpea fodder to livestock or to those who plough in the residues or use them to enrich compost heaps.

5.4 Yield and yield components

Cowpea variety as a single factor showed a tremendous variation in seed yield and yield components, such as number of pods per plant, pod length and number of seeds per pod. Generally, genotypic makeup influences yield and yield components of many crops. Razaq (1995) and Ahmad *et al.* (2001) observed variation in yield components in mung bean and wheat varieties. The introduction of Inoculation improved grain yield significantly. A number of studies have report a significant improvement in the yield and all the other yield components such as number of pods per plant, number of seeds per plant, 100-seed weight, and grain yield following the introduction of *Rhizobium* (Bhuiyan *et al.,* 2009; Bambara and Ndakidemi, 2010). In this study, the application of inoculation improved the number of pods per plant and ultimately, grain yield.

However, pod length, number of seeds per pod and 100 seed weight were not affected by the application of inoculation. Lack of response to inoculation has been observed in common bean as well as in soybean. Amos *et al.* (2001) reported that the application of inoculation in common bean did not affect the number of seed per pod as well as seed weight in a study repeated over two growing seasons. Akpalu *et al.* (2014) also reported that the application of inoculation in soybean did not affect the number of seeds per pod as well as hundred seed weight.

Both seaweed extract concentrations improved the number of pods per plant and ultimately, yield. The findings of this study concur with those of Rathore *et al.* (2009) who reported that the application of seaweed extract significantly enhanced the number of pods per pod and grain yield in soybean. They also reported that the measured parameters gradually increased with increasing concentration of seaweed extract. Abdel-Mawgoud *et al.* (2010) reported that the application of seaweed extract at concentrations of 1, 2 and 3 g/L increased the response of all growth parameters and yield of watermelon while Zodape *et al.* (2010), on mung bean, also reported that the application of seaweed extract significantly increased grain yield.

A correlation analysis revealed a positive relationship between the number of pods per plant and grain yield where $R^2$ was 0.62. Kuruvadi and Escobar (1987) also observed a positive association between yield and number of pods per plant in common bean. Pandey and Gritton (1975) and Kumar and Hirochika (2001) also concluded that the number of pods per plant is the most important component in determining yield in most legume crops as opposed to the postulations by Krarup and Davis (1970) who postulated that that number of seeds per pod is related to yield in a positive manner as in this case, the Brown landrace produced longer pods resulting in higher number of seeds per pod, but produced the least number of pods per plant. The Bechuana white variety on the other hand, produced the shorter pods when compared to that of the Brown landrace, but the least number of seeds per pod were compensated for by the higher number of pods per plant.

## 5.5 Shelling percentage and harvest index

Saxena (1984) reported that harvest index (HI) has been shown to be low in legume crops with longer growth duration, mainly because of the extended period of vegetative growth. In this study, the Brown landrace variety took longer to reach 50 % flowering and days to physiological maturity and recorded a harvest index value of 0.27 relative to Bechuana white's harvest index value of 0.53. Angus *et al.* (1983) reported that mung bean recorded HI of 0.52 at maturity (65 DAS) compared to HI of 0.34 in soybean at flowering while Moot and McNeil (1995) reported HI variation of between 0.53 and 0.62 between pea genotypes.

In this study, the application of inoculation and seaweed increased both harvest index and shelling percentage in both cowpea varieties. Roy *et al.* (1995) reported a significant increase in harvest index of gram following the application of inoculation while Partani (2013) reported an increase in harvest index of corn treated with different levels of seaweed extract. These results therefore suggest that the growth vigour stimulated by application of seaweed extract improves photo-assimilate partitioning to the seed in the two cowpea varieties tested. This should be an advantage to farmers who grow the cowpea mainly for grain.

## 5.6 Nutritional quality

*Rhizobium* inoculation of legumes has positive effects on nutrient availability and hence improving the nutritional quality of different plant components (Rodelas *et al.,* 1999). In the current study, the application of inoculation improved seed Mg, K and B. The results agree with those of Ndakidemi *et al.* (2011) who reported that *Rhizobia* inoculation increased the uptake of P, K, Ca, and Mg in common bean plant parts. Howell (1987) also reported an increase in the uptake of minerals in groundnut by superior *Rhizobia* strains.

Seaweed extract facilitated the uptake of K and B in leaves and seed respectively. Crouch *et al.* (1990) reported an increase in the uptake of Mg, K and Ca in lettuce with seaweed concentrate application. Mancuso *et al.* (2006) and Rathore *et al.,* (2009) reported an increase in the uptake of N, P and K with application of seaweed extract in potted common grape vine plants and soybean. Arthur *et al.* (2003) on pepper, and Zodape *et al.* (2008, 2010), on okra and mungbean, indicated that application of seaweed extract improved nutritional values of seed protein and carbohydrates. The results from the present study strongly suggest that the application of seaweed extract and inoculation can significantly improve the nutritional quality of cowpea leaf and grain. This could impact positively on the health of most rural families in Southern Africa who depend on vegetable protein, primarily from cowpea, as they cannot afford animal protein.

## 5.7 Economic benefits

The economic analysis showed that *Bradyrhizobia* inoculation or the application of seaweed extract on cowpea are very profitable and the technologies are feasible to farmers who may adopt them from a cost and simplicity perspective. Also there was a significantly higher marginal net return and as a result the percentage increase over control was also improved. The findings of this study agree with Ndakidemi *et al*. (2006), Nyoki and Ndakidemi (2013) who reported that inoculation resulted in high dollar profit for common bean, soybean and cowpea farmers in northern Tanzania.

# CHAPTER 6

## CONCLUSION AND RECOMMENDATIONS

The study demonstrated that differences in the performance of cowpea varieties are function of genes expression in response to the growing environment. Since both varieties in this study were grown under the same environmental conditions, growth, nodulation, development, yield and responses to inoculation and seaweed extract depended solely on the genetic composition of each variety. To a large extent, all three factors; variety, seaweed extract and *Bradyrhizobia* inoculation had an influence on growth, nodulation, yield as well as the nutritional quality of cowpea.

Overall, the Bechuana white variety out-performed the Brown landrace in most of the parameters measured. The Bechuana white variety proved to be a high grain yielder. More of its resources were concentrated towards reproduction as opposed to the Brown landrace, which had a high biomass yield at the expense of grain yield. Both varieties responded positively to *Bradyrhizobia* inoculation. The introduction of *Bradyrhizobia* proved to be very effective in improving growth, nodulation as well as seed nutritional quality in both varieties, which in the long run contributed toward obtaining higher yields in comparison with the uninoculated treatments.

The introduction of seaweed extract also improved growth, nodulation, yield, and to some extent, leaf and seed nutritional quality. The presence of the phytohormones in the extract probably facilitated certain biochemical and metabolic processes that promote growth and development. Results from this study also revealed a significant interaction relationship between seaweed extract and *Bradyrhizobia.* However, the mechanism responsible for the improvement of nodulation in the presence of the seaweed extract depends on one's interpretation of the results and how one builds up his case. Hence, more research work still needs to be conducted in order to authenticate and generate a concrete conclusion on the effect of seaweed extract on legume nodulation

The increase in seed yield, crude protein, macro and micronutrients uptake following application of inoculation and seaweed extract may be advantageous to small-scale farmers across Africa who may practice this technology to improve their production.

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**APPENDICES**

Appendix 1: Analysis of variance for nodule number, chlorophyll content as well as nodule, shoot and total dry weight as influenced by variety, seaweed extract and *Bradyrhizobia* inoculation using four replications under field conditions.

| Source of variance | Nodule number | Chlorophyll content | Dry weight (g/plant) | | | |
|---|---|---|---|---|---|---|
| | | | Nodule | Root | Shoot | Total |
| VARIETY (V) | 0.0850 | 0.0650 | 0.0472 | 0.0000 | 0.0001 | 0.0000 |
| EXTRACT (E) | 0.0000 | 0.0000 | 0.0009 | 0.0001 | 0.0002 | 0.0000 |
| INOCULATION (I) | 0.0000 | 0.0000 | 0.0009 | 0.0004 | 0.0000 | 0.0000 |
| VXE | 0.1832 | 0.2832 | 0.0652 | 0.8039 | 0.5129 | 0.5869 |
| VXI | 0.5063 | 0.7063 | 0.8293 | 0.0078 | 0.9930 | 0.7510 |
| EXI | 0.0000 | 0.0000 | 0.6199 | 0.3286 | 0.5270 | 0.4482 |
| VXEXI | 0.0886 | 0.0886 | 0.2319 | 0.9963 | 0.2654 | 0.2819 |
| CV | 26.35 | 7.61 | 23.93 | 20.89 | 16.06 | 15.02 |
| Grand mean | 42.110 | 70.297 | 1.0269 | 5.8079 | 65.428 | 72.263 |

Appendix 2: Analysis of variance for nodule number, chlorophyll content as well as nodule, shoot and total dry weight as influenced by variety, seaweed extract and *Bradyrhizobia* inoculation using four replications under tunnel house conditions.

| **Source of variance** | **Nodule number** | **Chlorophyll Content** | **Weight (g/plant)** | | | |
|---|---|---|---|---|---|---|
| | | | **Nodule** | **Root** | **Shoot** | **Total** |
| VARIETY (V) | 0.0787 | 0.1565 | 0.0466 | 0.0000 | 0.0001 | 0.0000 |
| EXTRACT (E) | 0.0000 | 0.0000 | 0.0009 | 0.0001 | 0.0001 | 0.0000 |
| INOCULATION (I) | 0.0000 | 0.0000 | 0.0009 | 0.0004 | 0.0000 | 0.0000 |
| VXE | 0.4090 | 0.3195 | 0.0663 | 0.8039 | 0.4163 | 0.4861 |
| VXI | 0.6692 | 0.5167 | 0.8248 | 0.0078 | 0.8999 | 0.8544 |
| EXI | 0.0001 | 0.0001 | 0.6150 | 0.3286 | 0.4319 | 0.3636 |
| VXEXI | 0.0621 | 0.3075 | 0.2289 | 0.9963 | 0.2178 | 0.2333 |
| CV | 40.414 | 9.57 | 45.79 | 24.98 | 32.51 | 28.75 |
| Grand mean | 27.99 | 83.665 | 0.5367 | 4.8579 | 32.770 | 38.164 |

Appendix 3: Analysis of variance for days to 50% flowering, days to physiological maturity, pods per plant, pod length, seed per pod, 100 seed weight, grain yield, shilling percentage, harvest index as well as total biomass as influenced by variety, seaweed extract and *Bradyrhizobia* inoculation using four replications.

| **Source of variance** | **DTFF** | **DTPM** | **Pods/plant** | **Pod length** | **Seed per pod** | **100 seed weight** | **Grain yield** | **Shelling %** | **Biomass** | **Harvest index** |
|---|---|---|---|---|---|---|---|---|---|---|
| VARIETY (V) | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.5414 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| EXTRACT (E) | 0.0502 | 0.7493 | 0.0000 | 0.3563 | 0.7256 | 0.4125 | 0.0000 | 0.0000 | 0.0317 | 0.0000 |
| INOCULATION (I) | 0.6537 | 0.2215 | 0.0000 | 0.9852 | 0.7574 | 0.2081 | 0.0000 | 0.0000 | 0.0001 | 0.0000 |
| VXE | 0.0502 | 0.51390 | 0.3773 | 0.4555 | 0.7170 | 0.0468 | 0.3680 | 0.0000 | 1.0000 | 0.1597 |
| VXI | 0.0303 | 0.2215 | 0.0008 | 0.1899 | 0.1486 | 0.9607 | 0.0003 | 0.0121 | 1.0000 | 0.2753 |
| EXI | 0.4493 | 0.29650 | 0.0000 | 0.21320 | 0.7304 | 0.9801 | 0.000 | 0.0004 | 0.0918 | 0.000 |
| VXEXI | 0.4493 | 0.9078 | 0.0003 | 0.7472 | 0.1858 | 0.2685 | 0.0004 | 0.0038 | 1.0000 | 0.0053 |
| CV | 0.54 | 0.35 | 5.65 | 5.87 | 7.69 | 14.995 | 1468.4 | 84.28 | 1899.4 | 4.86 |
| Grand mean | 59.354 | 131.38 | 21.046 | 19.743 | 14.467 | 2.71 | 9.87 | 1.19 | 3.74 | 0.4038 |

Appendix 4: Analysis of variance for leaf Ca, Mg, K, P and crude protein content as influenced by variety, seaweed extract and *Bradyrhizobia* inoculation using four replications.

| **Source of variance** | **Field** | | | | | **Tunnel-house** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Ca** | **Mg** | **K** | **P** | **Protein** | **Ca** | **Mg** | **K** | **P** | **Protein** |
| VARIETY (V) | 0.2556 | 0.0217 | 0.0013 | 0.1065 | 0.0295 | 0.0000 | 0.5788 | 0.0000 | 0.0144 | 0.0022 |
| EXTRACT (E) | 0.6412 | 0.8231 | 0.0018 | 0.9262 | 0.3044 | 0.7349 | 0.7301 | 0.3203 | 0.6166 | 0.2884 |
| INOCULATION (I) | 0.4061 | 0.5132 | 0.8533 | 0.0811 | 0.2031 | 0.0668 | 0.8415 | 0.0653 | 0.4312 | 0.0165 |
| VXE | 0.4295 | 0.8907 | 0.0005 | 0.9894 | 0.3282 | 0.7018 | 0.4890 | 0.689 | 0.8334 | 0.4797 |
| VXI | 0.2791 | 0.2213 | 0.0070 | 0.4954 | 0.1452 | 0.0071 | 0.0090 | 0.0019 | 0.2750 | 0.0101 |
| EXI | 0.5776 | 0.4108 | 0.0001 | 0.3286 | 0.0485 | 0.4541 | 0.8387 | 0.6452 | 0.8764 | 0.8463 |
| VXEXI | 0.4046 | 0.1198 | 0.0002 | 0.3260 | 0.0879 | 0.6515 | 0.7230 | 0.6896 | 0.7665 | 0.8688 |
| CV | 144.56 | 90.25 | 12.20 | 14.28 | 16.76 | 14.61 | 20.63 | 17.86 | 32.36 | 10.68 |
| Grand mean | 1.4009 | 0.1043 | 1.0715 | 0.1694 | 25.708 | 1.0204 | 0.3819 | 1.1847 | 0.1659 | 24.94 |

Appendix 5: Analysis of variance for leaf Zn, Cu, Mn and Fe content as influenced by variety, seaweed extract and *Bradyrhizobia* inoculation using four replications.

| Source of variance | Field | | | | Tunnel-house | | | |
|---|---|---|---|---|---|---|---|---|
| | **Zn** | **Cu** | **Mn** | **Fe** | **Zn** | **Cu** | **Mn** | **Fe** |
| VARIETY (V) | 0.3700 | 0.2432 | 0.2143 | 0.2788 | 0.8074 | 0.6481 | 0.0020 | 0.8268 |
| EXTRACT (E) | 0.7517 | 0.0638 | 0.3868 | 0.1235 | 0.8831 | 0.8187 | 0.6877 | 0.9704 |
| INOCULATION (I) | 0.1003 | 0.1016 | 0.6702 | 0.5687 | 0.5345 | 0.8279 | 0.1025 | 0.9429 |
| VXE | 0.9723 | 0.5988 | 0.8132 | 0.0186 | 0.4292 | 0.5654 | 0.2879 | 0.6422 |
| VXI | 0.6883 | 0.3532 | 0.3525 | 0.0032 | 0.1469 | 0.4805 | 0.0012 | 0.0100 |
| EXI | 0.6295 | 0.9046 | 0.7213 | 0.8233 | 0.7111 | 0.8713 | 0.1894 | 0.3236 |
| VXEXI | 0.6974 | 0.466 | 0.5707 | 0.9974 | 0.9652 | 0.3908 | 0.7648 | 0.9688 |
| CV | 44.23 | 50.05 | 16.80 | 26.13 | 32.47 | 68.67 | 22.05 | 57.91 |
| Grand mean | 17.966 | 5.5642 | 68.490 | 152.58 | 19.911 | 3.8337 | 51.086 | 91.362 |

Appendix 6: Analysis of variance for seed Ca, Mg, K, P, Zn, Cu, Mn, Fe, B and crude protein content as influenced by variety, seaweed extract and *Bradyrhizobia* inoculation using four replications.

| **Source of variance** | **Ca** | **Mg** | **K** | **P** | **Zn** | **Cu** | **Mn** | **Fe** | **B** | **Protein** |
|---|---|---|---|---|---|---|---|---|---|---|
| VARIETY (V) | 0.1476 | 0.0059 | 0.0002 | 0.0001 | 0.1622 | 0.8081 | 0.0004 | 0.4865 | 0.0002 | 0.0010 |
| EXTRACT (E) | 0.7569 | 0.6087 | 0.6728 | 0.9218 | 0.9610 | 0.9269 | 0.3530 | 0.6668 | 0.0006 | 0.6602 |
| INOCULATION (I) | 0.0669 | 0.0110 | 0.0024 | 0.4064 | 0.2173 | 0.2111 | 0.0716 | 0.7516 | 0.0001 | 0.0605 |
| VXE | 0.8033 | 0.4704 | 0.7251 | 0.9469 | 0.8766 | 0.8988 | 0.7282 | 0.4161 | 0.0044 | 0.7961 |
| VXI | 0.0258 | 0.1508 | 0.2312 | 0.1535 | 0.1581 | 0.4547 | 0.1873 | 0.0634 | 0.0001 | 0.0097 |
| EXI | 0.9648 | 0.8505 | 0.7363 | 0.8023 | 0.8977 | 0.8017 | 0.8028 | 0.3633 | 0.0006 | 0.3394 |
| VXEXI | 0.9923 | 0.8771 | 0.9788 | 0.4158 | 0.4852 | 0.8089 | 0.3506 | 0.5498 | 0.3523 | 0.6691 |
| CV | 13.72 | 2.64 | 1.57 | 4.21 | 29.92 | 91.99 | 6.97 | 17.70 | 3.28 | 2.95 |
| Grand mean | 00733 | 0.1956 | 1.3962 | 0.4665 | 24.834 | 8.9922 | 15.215 | 63.447 | 16.106 | 23.115 |

Appendix 7. Economic profit (MNR), total variable costs (TVC) and marginal rate of return (MRR) of cowpea under different treatments

| Treatment | Yield change over control | MNR (R/ha) | Rand value change over control | MRR (R/ha) |
|---|---|---|---|---|
| Uninoculated | - | 0.0543 | - | 0.533 |
| Inoculated | 0.0543 | 0.0454 | 0.0522 | 0.454 |
| **Extract** | | | | |
| Control | - | 0.05435 | - | 0.0534 |
| 1:100 | 0.04345 | 0.0556 | 0.0523 | 0.0434 |
| 1:500 | 0.0556 | 0.0432 | 0.0534 | 0.0543 |
| CV | 13.45 | 33.71 | 22.42 | 14.43 |
| Grand mean | 9.32 | 23.32 | 34.3 | 23.8 |

Appendix 8: Peer reviewed abstract of paper presented as oral at the 14th combined congress, Rhodes University, Grahamstown- South Africa 20-23 January 2014.

## INTERACTIVE EFFECT OF SEAWEED EXTRACT AND INOCULATION ON YIELD AND YIELD COMPONENTS OF TWO COWPEA VARIETIES

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### INTRODUCTION

Cowpea is a popular crop amongst many rural communities and serves as a primary source of protein and mineral nutrients for many poor households across the Africa continent. Low crop yields is a major problems in Africa, a problem exacerbated by poor soil fertility management and inflated fertilizer prices. The use of seaweed extracts products has become popular in the agricultural industry due to their affordability and ability to improve plant growth and yield (Cristobel, 2008).The aim of this study was to assess the interactive effect of a commercial seaweed extract (Technikelp) and Bradyrhizobia inoculation on yield and yield components of cowpea

### MATERIALS AND RESULTS

A 2X2X3 factorial experiment was carried out at the University of Limpopo's experimental farm, Syferkuil during the 2012/13 planting season. Three treatment factors namely; cowpea variety (Brown landrace, Bechuana white), Inoculation (+I,-I) and seaweed extract concentrations (0:0 v/v. 1:100 v/v. 1:500 v/v) were combined and arranged in a randomized complete block design. All the treatments were replicated four times. The seaweed extract was applied as root drench at planting, 14 and 28 days after planting. Data were subjected to analysis of variance using STATISTIX program V10.

## RESULTS AND DISCUSSION

Independent application of seaweed extract had a significant effect on the number of pods per plant and grain yield, but had no significant effect on genetically dependent traits such as pod length and number of seed per pod. There was no cultivar x seaweed extract interaction effect on any parameter measured. Cultivar x inoculation x seaweed extract had a significant effect on the number of pods per plant and grain yield. The combination of Bechuana white x inoculation (+I) x seaweed extract (1:100 v/v) resulted in the greatest number of pods per plant (31.5) and grain yield (2784 kg/ha).

## CONCLUSIONS

Preliminary results suggest that the application of seaweed extract and Bradyrhizobia inoculation may be an inexpensive solution to low cowpea yields.

## REFFERENCE

Cristobel, G.J. 2008. Effect of seaweed (*Sargassum wightii* L.) on the germination and growth of green gram (*Phaseolus aureus*). *Journal of Basic and Applied Biology* 2:105-108.

## ACKNOWLEDGEMENT

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*Keywords*: Inoculation, Seaweed extract, Yield components, Technikelp

Appendix 9: Peer reviewed abstract of paper presented as poster at the 14th combined congress, Rhodes University, Grahamstown- South Africa 20-23 January 2014.

## INTERACTION EFFECT OF SEAWEED EXTRACT AND BRADYRHIZOBIA INOCULATION ON GROWTH AND NODULATION OF COWPEA UNDER FIELD AND TUNNEL-HOUSE CONDITIONS

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### INTRODUCTION

Cowpea has the ability to improve soil nitrogen economy through biological nitrogen fixation by forming a symbiotic relationship with beneficial soil micro-organisms, such as the *Rhizobia* species. Seaweed extracts are cheap, easy to apply and have been found to improve plant growth and soil microbial activity (Alam *et al.,* 2010). The aim of this study was to investigate the interactive effect of seaweed extract and *Rhizobia* inoculation on growth and nodulation of cowpea.

### METERIALS AND METHODS

Two experiments (field and pot experiments) were carried out during the 2012/13 planting season with three treatment factors namely; i) Cowpea varieties (Brown landrace, Bechuana-white), ii) Inoculation and iii) Seaweed extract concentrations (0:0 v/v, 1:500 v/v, 1:100 v/v) were combined (2X2X3 factorial) and arranged in a randomized complete block design, with four replicates. The seaweed extract was applied as root drench at planting, 14 and 28 days after planting. Data were subjected to analysis of variance to determine treatment effect using STATISTIX program V10.

## RESULTS AND DISCUSSION

Independent applications of seaweed extract and *Rhizobia* inoculation had a significant effect on the number of active nodules, CCI as well as root and shoot biomass accumulation. Application of 1:100 v/v seaweed extract concentration in the presence of Bradyrhizobia inoculation under tunnel-house conditions resulted in a 56.67% increase in the number of active nodules/plant and 27.12 % increase in CCI/plant. Similar trends were observed under field conditions with a 64.43% increase in the number of active nodules per plant and 25.18% increase in CCI/plant. These effects are due to components such as plant hormones and amino acids which play a role in modulating specific metabolic pathways in both the legume and the bacterium, resulting in enhanced growth and *rhizobium*-legume symbiosis.

## CONCLUSIONS

Results from this study suggest that application of seaweed extract in the presents of Bradyrhizobia inoculation would result in improved growth and nodulation of cowpea.

## REFFERENCES

Alam, M.Z., Braun, P.G., Norrie, J and D.M Hodges. 2013. Effect of Ascophyllum extract application on plant growth, fruit yield and soil microbial communities of strawberry. *Canadian Journal of Plant Science* 93: 23-36.

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*Keywords*: Cowpea, Inoculation, Seaweed extract, Nodulation, Technikelp