THE EVALUATION, CROP MANAGEMENT AND ECONOMIC POTENTIAL OF DIVERSE OF GUAR ACCESSIONS FOR LIMPOPO PROVINCE, SOUTH AFRICA

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A DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF AGRICULTURAL MANAGEMENT (CROP SCIENCE) IN THE DEPARTMENT OF PLANT PRODUCTION, SOIL SCIENCE AND AGRICULTURAL ENGINEERING, IN THE FACULTY OF SCIENCE AND AGRICULTURE, UNIVERSITY OF LIMPOPO, SOUTH AFRICA

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DEDICATION

I dedicate this dissertation to God almighty, through his strength I got through this study and to my family thank you for the support.

DECLARATION

I hereby declare that the work herein submitted as a dissertation for the Masters of Agricultural Management degree is the result of my own studies and that it has not been presented as a dissertation for the degree in this University or elsewhere. Work by other authors that served as sources of information have been duly acknowledged by reference to the authors.

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ABSTRACT

Guar bean (*Cyamopsis tetragonoloba L. Taub*) is a drought tolerant leguminous crop usually grown for its seed which has a special gum (galactomannan) used in the food and the mining industries. The study aimed at evaluation of yield potential and agronomic management of 14 determinate and indeterminate guar accession lines sourced from the Australian Tropical Crops and Forages collection grown under dry-land conditions of Limpopo province and assessing their response to phosphorus and inoculation. Two different experiments, one on variety evaluation and the other on response to P fertilizer and inoculation were conducted during 2006/7 and 2007/8 growing seasons at Syferkuil and Tompi Seleka in the Limpopo Province, South Africa.

There were significant differences amongst the 14 guar accession lines at Syferkuil during 2006/7 and 2007/8 and Tompi Seleka during 2007/8 growing seasons. Tompi Seleka showed higher potential for guar bean production over Syferkuil on the basis of grain yield. Seed yield from the two locations during the two seasons ranged from 326 kg ha^{-1} by variety Stonewall to 2340 kg ha^{-1} by variety Durgapurasaffed. At Syferkuil in 2006/7 Brooks variety recorded the highest seed yield of 1103 kg ha^{-1} while Hall achieved lowest seed yield of 353 kg ha^{-1}. During 2007/8 at Syferkuil, TRCF 95203 recorded the highest seed yield of 701 kg ha^{-1} and Stonewall recorded lowest of 326 kg ha^{-1}. At Tompi Seleka in the same season, the highest yield was recorded with Durgpurasaffed variety that recorded 2340 kg ha^{-1} and lowest Stonewall with 720 kg ha^{-1}. The varieties which consistently performed well and were within the top five performing lines at the two locations were Durgapurasaffed, TRCF CSIRO and Brooks. The accession lines at Tompi Seleka experiment gave higher dry matter and seed yields than at Syferkuil, suggesting their preference for hot environments. In the second experiment, the response of two guar bean varieties to phosphorus level and inoculation was evaluated. Variety did not influence seed yield. Application of phosphorus (P) at 60 kg ha^{-1} plus inoculation significantly increased seed yield. At Tompi Seleka 2007/8 season, 60 kg ha^{-1} of P application achieved seed yield 37% higher than the control treatment. In the same season at Syferkuil the highest seed yield was also recorded at 60 kg ha^{-1} P application and was 57%

more than lowest seed yield from the control treatment. Grain yield significantly increased during 2006/7 as influenced by P application rate of 30 kg ha^{-1} compared to zero P fertilizer while there was no significant different between P rates during 2007/8 season at this site. The results from the study showed good response P application in the range of 30 to 60 kg ha^{-1}. Inoculation significantly increased seed and dry matter yield at all sites. Variety X P levels and variety X inoculation interactions significantly influenced seed yield and dry matter at all sites. Both varieties achieved the highest seed yield at 60 kg ha^{-1} and the lowest was with the control at Syferkuil for both varieties. At Tompi Seleka, the control and application 30 kg ha^{-1} of fertilizer gave similar seed yield for both varieties. At Syferkuil in 2006/7 and Tompi Seleka in 2007/8 both Stonewall and Cedric were higher with inoculation but in 2007/8 Cedric had lower seed yield with inoculation at Syferkuil. The Phosphorus X inoculation interaction was significant with combination of 60 kg P ha^{-1} and inoculation giving significantly higher seed yield than the 0 kg P ha^{-1} and no inoculation. Future experiments should consider inclusion test in these guar accession under dryland conditions, levels of P higher than 60 kg P ha^{-1}, include nodulation data, quality evaluation of guar seed and conducting basic growth margin analysis on P and inoculation of guar.

PREFACE

This dissertation comprises of six chapters. Chapter one is a general introduction. Chapter two is a detailed review of the literature. Chapter three presents materials and methods common to the two experiments conducted. Chapter four reports on on variety evaluation. Chapter five reports on evaluating the effect of variety, rhizobium inoculation and phosphorus levels on guar yield performance. Chapter six comprises of the summary of the study, conclusions and recommendations. A survey that attempted to establish the demand for guar in the mining and food industries failed due to poor response from the companies using guar flour or its derivatives as ingredients. There was wide spread of unwillingness to divulge sources and quantities used.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Guar or cluster bean (*Cyamopsis tetragonoloba L. Taub*.) is a coarse, upright, bushy, drought tolerant summer annual legume that belongs to the family Fabaceae. It is a plant native to India and Pakistan where it is grown principally for its green fodder and for the pods that are used for food and feed (Jackson and Doughton, 1982). It is grown in tropical Asia, Africa and America. The major world suppliers of guar are India, Pakistan and the United States, with smaller hectarages in Australia and Africa. Guar is a new crop in Sudan, and is grown commercially on limited scale near Singa, Blue Nile, for seed processing into flour. This crop grows well on a variety of soils and thrives on alluvial and sandy loams with well-drained subsoil (Jackson *et al*., 1985).

India and Pakistan are the leading guar cultivating countries due to their highly suitable weather conditions and long history with the crop. India produces close to 80% of world guar seed production (Pahuja *et al*., 2009). In 1903, guar was introduced to the United States from India. Commercial production of guar in the United States began in the early 1950’s (Undersander *et al.,* 2006). In the early 1980s, Texas growers were planting about 40 000 ha annually. They harvested about half of the planted hectarage and ploughed the rest under as green manure.

Guar bean is commercially grown for its seed, which contains the guar gum, galactomannan (Nyakunda *et al.*, 2006). Unlike the seeds of other legumes, the guar bean has a large endosperm containing significant amounts of galactomannan gum (19 to 43% of the whole seed), which forms a viscous gel in cold water. Fine finished guar gum powder is available in different viscosities and different granulometries (i.e. granulometry is the measurement of the size distribution in a collection of grains) depending on the desired viscosity development and application (Beech, 1981). Guar gum is a natural high molecular weight hydrocolloid polysaccharide composed of gallatin and mannan units combined through glycoside linkages, which may be described chemically as galactomannan.

In Asia, guar beans are used as a vegetable for human consumption, and the crop is also grown for cattle feed and as a green manure crop. In the United States, highly refined guar gum is used as a stiffener in soft ice cream, a stabilizer for cheeses, instant puddings and whipped cream substitutes and as a meat binder (Beech, 1990). Most of the crop gum is used in cloth and paper manufacture, postage, textile, food industry, oil well drilling muds, explosives, ore flotation, and a host of other industrial applications like in the mining industry, as well as in the pharmaceutical industry.

India has been a dominant player in the context of guar and guar gum in the world market. It has been the major producer of guar seed in the world. Rajasthan wholly retains the credit for India's position producing 70% of the production itself. However, it has been observed that there is a lack of stability in India's performance due to the fluctuations in the rainfall level in the country (Stutzel *et al*., 1989). The country exports over 117 000 tons of guar and its derivatives, comprised of 33 000 tons of refined split guar gum, and 84 000 tons of treated and pulverized guar gum (Undersander *et al.,* 2006). The factors influencing the market for guar supply are:

i) Changes in production due to rainfall fluctuation,

ii) Demand and supply mismatch,

iii) Hoarding and black marketing, and

iv) Government policies

Guar production in the region of Africa was piloted in the Zambezi Valley of Zimbabwe where it has been promoted through a collaborative initiative between Intermediate Technology Development Group (ITDG) Southern Africa and Bindura Nickel Corporation (BNC). Initiated in April 2000, the guar bean production project sought to facilitate thriving local guar bean production and processing by small-scale farmers in areas along the northern part of the country (Nyamapfene and Mugova, 2002). The Intermediate Technology Development Group (ITDG) Southern Africa project did not have much impact as it experienced a number of challenges: such as poor pricing, late deliveries of seed resulting in low seed yield, and poor quality of the seed. As a result, the farmers received lower price on the market, which acted as a decentive for continued production. In South Africa, however products made from guar bean are widely used particularly in the mining and food industry. To date, the entire product is imported so there is interest from mining companies and private investors to source guar from local sources.

1.2 Problem statement

As a province, Limpopo is faced with extreme levels of poverty, particularly in the rural areas. In the Limpopo Province drought and poor suitability of soils for arable production are the most limiting factors for crop production. The climate variability and change are a major threat to food security, which is closely dependent on natural rainfall. However, the province has abundant agricultural land comprised of communal land, private farms and land reform projects, all of which require assistance through injection of appropriate technologies. In addition, the challenge is to develop vibrant technologies that move agriculture from subsistence to commercial production. The Limpopo Department of Agriculture administers some of the state land which has several irrigation schemes which are currently being revitalized (Machethe *et al*., 2004). Bringing the guar crop into some of these projects could be of economic value through the efficient use of irrigation schemes and land reform projects. Guar bean, as an industrial crop, has the potential to contribute to the employment and economic value of the province since Limpopo province is booming with platinum mines which are mushrooming throughout the province. The potential of different guar accessions under local climate condition has not been evaluated.

1.3 Rationale of the study

Limpopo province’s climate is generally suitable for agricultural production. The province is a summer rainfall area receiving its rain between October and March. It is considered as semi-arid with a greater portion of the region receiving less than 600 mm of annual rainfall and experiencing high summer temperatures. Crops grown include a wide array of field and vegetables crops as well as fruit and pasture crops. Vegetables and fruit crops are typically produced under irrigation but this facility is limited. Dryland farming is the predominant farming system among smallholder (SH) farmers in the province (Molatudi and Mariga, 2012). Under dryland farming, maize is the dominant crop in areas receiving about 550 mm and above. Growing dryland crops, SH farmers usually encounter challenges such as:

i. Low soil water during growing seasons,
ii. Low soil N and P status,
iii. Acidic soil condition,
iv. Poor stand establishment,
iv. Low use of organic and inorganic fertilizers, and
v. Insect pest and disease problems.

In most instances, low crop productivity is attributed to inadequate amounts of soil moisture during the growing season, but even in areas with adequate amounts and proper distribution of rainfall, good crop growth and yield cannot be maintained.

Most of the SH cropping systems are dominated by sandy soil; with low organic matter level, low soil fertility particularly N and P (Mpangane, 2001) and this results in low yields. Because the SH farmers are financially constrained, fertiliser use is often too low to meet crop demand and sustain food production. Planting guar bean can reduce the problem of poor soil fertility in Limpopo Province due to its unique ability to fix atmospheric N through its nodules, effective symbiosis with mycorrhizae (Kwapata and Hall, 1985) and its ability to withstand both acid and alkaline soil conditions.

There is a growing demand for guar gum by mining and food manufacturing industries in Limpopo province and South Africa in general. Successful guar production could generate income that can uplift the livelihoods of rural communities in the province (Nyamapfene and Mugova, 2002). However, data on current usage and quantities used are not available. Evaluation of guar demand for industrial use and household food security is necessary. Successful introduction of guar could provide SH farmers with an additional commercial crop.

1.4 Aims and objectives

The main aim of this study was to evaluate determinate and indeterminate guar bean lines sourced from the Australian Tropical Crops and Forages Collection grown under dryland conditions of Limpopo province and assess the economic potential of the crop for industrial use and soil fertility amelioration.

Specific objective 1

To evaluate the growth and yield of a range of guar bean accessions and commercially used varieties under the conditions of Limpopo province.

Specific objective 2

To determine the response of two guar varieties to inoculation and fertilizer P application.

1.5 Hypothesis

1. The Australian guar lines have low potential under the environmental condition of Limpopo province.
2. On soils low in P status, there is a positive interaction between P and inoculation with Rhizobium in the productivity of guar.

CHAPTER 2
LITERATURE REVIEW

Figure 1: Guar bean (*Cyamopsis tetragonoloba*) plant and seeds (Guar, 2014)

2.1 Botanical characteristics of the guar plant

Guar (*Cyamopsis tetragonoloba*) is an upright, summer growing annual legume known for its drought resistance (Figure 1). Guar, also known as cluster bean, is an annual legume crop that is a natural source of hydrocolloid substance that forms thick solution at low concentrations with water (Anon, 1911). Guar plant is a rough to touch, bushy plant.

Figure 2: Guar bean stand in the field (Guar, 2014)

The crop is consumed as a bean, livestock feed and also utilized in the form of green manure in the fields. Its deep tap root reaches moisture deep below the soil surface (Jackson, 1991). Most of the improved varieties of guar have smooth, not hairy leaves, stem and pods (Figure 2). Plants have single stems with fine branching or basal branching (depending on the variety) and grow to be 45 – 100 cm tall. Racemes are distributed on the main stem and lateral branches (Undersander *et al*., 2014.)

Figure 3: Guar bean seeds and pods (Star foods, 2014)

Pods are generally 4 – 10 cm long and contain 5 to 12 seeds each (Figure 3). Seeds vary from dull-white to pink to light grey or black and range from 32 to 56 seeds per gram. The seeds of the guar plant have three parts i.e. the germ, the endosperm and the husk. The popular guar gum, which is used in mining, petroleum drilling and textile manufacturing sectors, is obtained from the endosperm of the seed of the plant. The gum is refined to make a yellowish white powder and it is consumed worldwide in this powder form only (Undersander *et al*., 2014).

2.2 Adaptability

Guar production is greatly affected by climatic factors (rainfall and temperature), soil factors and cultural practices e.g. sowing date, seed rate, plant spacing, sowing method, weeding and harvesting method (Beech, 1990). Although guar is grown under wide range of annual precipitation, the amount and distribution of rainfall is often the limiting factor for guar production in semi-arid regions (Jackson, 1991). Guar was introduced and tested in Sudan under rainfed and irrigated conditions (Mohamed and El Hag, 2006). Its yield potential was highly affected by cultural practices, mainly plant spacing and population. The highest seed yield of rain-grown guar was found at the closest spacing of 10 x 60 cm in Samsam (Taha, 1993). Spacing of 75 x 15 cm and 2 plants per hole gave the highest yield under rainfed condition at Abu Naama. The highest yield was obtained at 60 x 20 cm spacing under rainfed conditions (Osman, 2001).

Environmental factors such as light and water can produce variation in plant growth and this variation is greater than genetic differences (Dennis, 1977). Information from previous studies has shown that shade effects on growth and yield of legume crops result in a decrease in dry matter yield and an increase in plant height as radiation reduction increases (Stafford and Seiler, 1986).

2.3 Soil and pH

Guar can be grown on a range of soil types but the crop has a preference for fertile deep sand and sandy loam soils. It performs best on medium to light textured soil or on well drained heavy soil (Poats, 1960; Allen, 1964; Dennis, 1977). Although varietal differences occur, good drainage is vital for guar as the crop is susceptible to water-logging (Singh *et al*., 1962, Allen, 1964). Crusting of the soil surface is likely to reduce emergence of guar seed. Moderately alkaline soil (pH 7.5 – 8) is considered to be optimum for guar. The crop tolerates both alkalinity and salinity (Undersander *et al*., 2014)

2.4 Rainfall and water management

Guar is a drought tolerant legume requiring 400-500 mm of annual rainfall (Yousif, 1984). When moisture is limited, the plant stops growing but does not die (Undersander *et al*., 2014). The crop showed best growth performance in the United States with the annual rainfall of 900mm (Francois *et al*., 1990). Guar performed well in areas with 400 - 900 mm of annual rainfall (Anon and Esser, 1975) and can also be cultivated in regions with 300 - 500 mm annual rainfall (Mukhtar, 1981). Seeds can germinate with a minimum amount of water in the soil, but young seedlings are susceptible to moisture stress. For optimum yields, the soil must be kept in a thoroughly moist condition until the plants are well established. Guar is grown without irrigation where mean annual rainfall ranges from 250 to 1500 mm (Alexander *et al*., 1988; Beech *et al*., 1988). Main production occurs where rainfall is less than 800 mm in India and around 630 mm in Texas and South Western Oklahoma. Best quality seed is produced where the rainfall ranges from 500 to 700 mm per annum during the growing season. In wetter areas vegetative growth is greater but seed quality is inferior and the crop then is more suitable as a fodder or green manure crop. Rainfall pattern is also important as prolonged wet weather during seed maturation results in discoloration of the seeds (Jackson and Doughton, 1982).

Growing season ranges from 60-90 days (determinate varieties) to 120-150 days (indeterminate varieties). Guar responds to irrigation during dry periods. Excessive rain or humidity after maturity causes the beans to turn black and shrivel, reducing their quality and marketability. Guar can be successfully grown as a green manure crop under these conditions.

2.5 Temperature

Guar tolerates high temperatures and dry conditions and is adapted to arid and semi-arid climates. Optimum soil temperature for root development is 25-35°C. Growth is severely retarded in cold weather, and the crop is highly susceptible to frost. The optimum soil temperature for good germination is 30°C although rapid germination has occurred at soil temperature as low as 21°C (Dennis, 1977). Seed should not be planted before the soil temperature reaches 21°C or more (Undersander *et al*., 1991).

2.6 Agronomic management

Planting date

Delay planting of guar bean gave better quality grain less affected by seed blackening. In India, guar is normally planted in July at the start of the summer rainy season and harvested in October to November (Jackson and Doughton, 1982). In the Northern states of Punjab and Haryana, it is possible to obtain two harvests per annum. A spring summer crop, usually grown under irrigation, is sown in March and harvested by mid June while the second crop is grown during the rainy season.

Sowing rate and seeding methods

Guar is normally direct seeded following land preparation similar to that required by grain sorghum. Row spacing experiments in Queensland, USA and Zimbabwe have mostly shown that highest yields were obtained with row spacing of 50 cm or less (Allen, 1964; Sanderson, 1974; Hymowitz and Matlock, 1964), but no significant yield difference between 25, 50 and 100 cm row spacing were found in Oklahoma.

Experiments on plant competition in guar by Hymowitz and Matlock (1963) found that 20 - 30 seeds per meter with 50 cm between rows were the most successful planting arrangement. In Australian experiment seeding rates varied from 28 to 50 kg ha^{-1} (Allen, 1964), and did not affect grain yield. Recommended sowing rates suggested for grain production in Texas are 5, 7 and 13 kg ha^{-1} for single row, double row and broadcasting plantings, respectively.

Guar diseases

Soil related diseases have been a serious problem reported by Davey *et al*., (1984) with guar on the Darling Downs in Australia. Two diseases have been widely reported in literature. Alternaria leaf or target spot (*Alternaria alternata*) may become severe during periods of heavy dew and high humidity. The symptoms of Alternaria leaf spot are brown zonate or target like lesions on the leaf. Bacterial blight (*Xanthomonas cyamopsidis*): this seed-borne disease can cause loss of plants from the seedling stage until maturity. Symptoms include large angular necrotic lesions at the tips of leaves, which cause defoliation and black streaking of the stems. This is potentially the greatest disease hazard to guar (Undersander *et.al*., 1991).

Guar pests and other predators:

The guar midge (*Contarinia texana*) is the primary guar insect pest in South- West Oklahoma. Heavy midge infestations have caused up to 30% loss in seed production. Guar midge infestations are generally heavier in fields with sandy or sandy loam soils (Undersander *et al*., 2014). Damage to guar is caused by the larvae, which develop in the guar buds. Infested buds eventually dry up and fall from the plant. The adult female midge deposits her eggs in developing buds. After larvae complete their development, they drop from the buds to the ground to pupate. There are several generations each year. The gall midge, *Asphondylia spp.,* is found in both India and the USA but has not been considered an economic pest (Patel and Chari, 1970).

Weeding

Young guar plants grow slowly and are particularly susceptible to weed problems. Weeds can reduce yields and create harvesting problems**.** Mechanical control on guar should not be done in fields heavily infested with Johnson grass (*Sorghum halepense*) and other perennial weeds. Early preparation of land and mechanical cultivations during the growing season will help minimize weed problems (Akasha, 1967). Covering the lower branches during cultivation may promote development of diseases and increase harvest difficulties. Chemical control, for example with Treflan (trifluralin), a registered chemical for use on guar, applied as a pre-plant incorporated treatment to control most annual grass and several annual broadleaf weeds can be done (Undersander *et al*., 2014).

Harvest and processing

Most guar varieties reach maturity in 125 - 160 days especially indeterminate type. Harvesting machinery can be used but drum rotation speeds should be reduced to avoid damage to the seed. For storage, drying to at least 14% moisture is important. The gum is extracted by either a wet or dry processing method (Rodge *et al*., 2012). The old method is more efficient and involves cleaning, boiling in $NaHCO_3$ and urea, washing, dehusking, drying, separation and drying, suspension in methanol, refluxing and drying. This result in guar splits will be like the Figure 4.

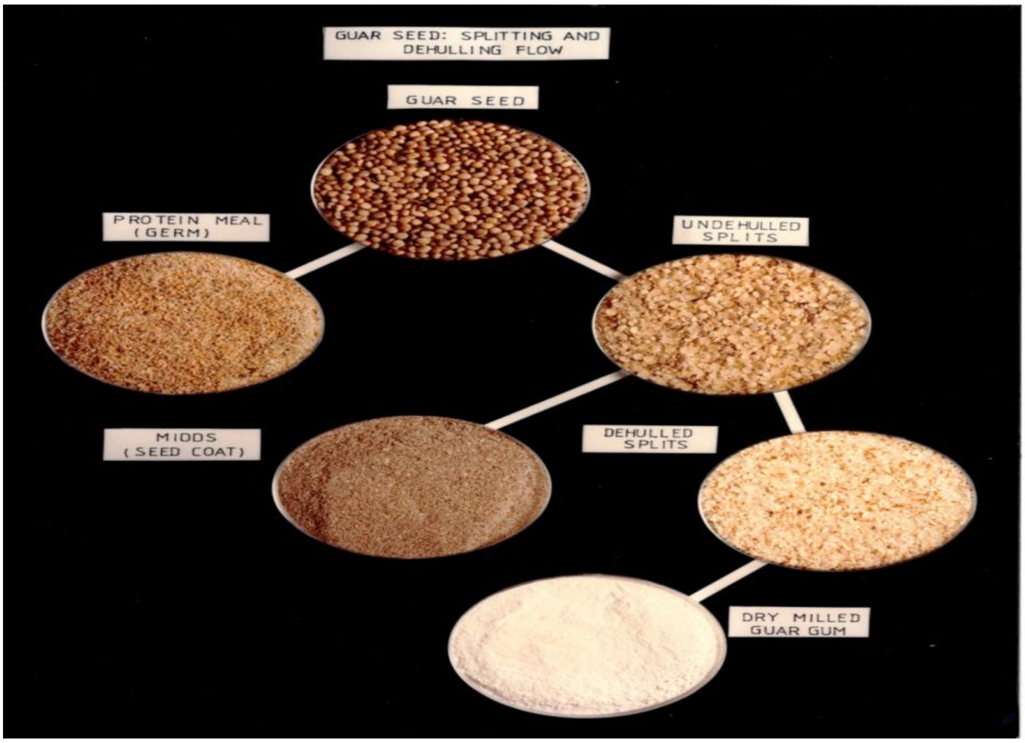

Figure 4: Processed guar splits (Dr.-Ing. N.K. Gupta Technical Consultants, 2014).

Guar bean uses

Guar gum is a cold water soluble polysaccharide, and it has broad uses in food and mining industries. One of its most useful properties is its ability to hydrate rapidly in cold water to give highly viscous solutions that are stable over a wide pH range (Anon, 1968; Glicksman, 1969).

i) Oil, gas and well drilling

With the increasing cost of discovering new oil, gas and water wells, there have been numerous applications developed to increase oil recovery in existing wells using well stimulation. Guar gum is used in the fracturing treatment of oil, gas and water wells to enhance recovery and to stimulate production (Undersander *et al*., 2014).

ii) Food

The largest market for guar gum is in the food industry. Guar gum is used as a thickener and a binder of free water in sauces, salad dressings, ice creams and many other applications (Undersander *et al*., 2014). Young guar pods can be cooked and eaten and are a popular vegetable in India and Pakistan (Kachroo and Arif, 1970).

iii) Feed uses

Guar is also a useful fodder crop. It is widely grown in northern India to feed working animals (Jackson and Doughton, 1982).

iv) Cosmetics and pharmaceuticals

Guar gum is used to thicken various cosmetics and pharmaceuticals. It is also used to bind and to disintegrate compressed tablets and pellets. It is also used as a mild laxative (Undersander *et al*., 2014).

v) Paper industry

Guar gum, along with other gums, is used in the paper industry for improved sheet formation, increased bursting strength, increased fold strength, and increased finishing (Undersander *et.al.,* 2006).

vi) Explosives

Guar gum is used in the explosives industry as a waterproofing agent. Its ability to hydrate in saturated solutions of ammonium nitrate causes it to be widely used in this industry. For this purpose DFS-33 is the most commonly used guar gum product (Undersander *et al*. 2006).

2.7 Varieties of guar bean

Approximately 400 guar accessions exist in the Australian Tropical Forages Genetic. Resource Centre (ATFGRC) in Biloela, Australia and more than 100 of these have been included in field trials. The strongly – branching varieties Brooks and ECR 67, and CP177 have been commonly used for research in Queensland. Undersander *et al*., (1991) indicated that Brooks is high yielding and resistant to major guar diseases. Branching varieties are considered more suited to seed production and the single stem varieties better suited to vegetable pod production.

The development of diseases resistant varieties since the early 1960’s has increased guar yields and stabilized production more than any other single factor. During seasons of normal rainfall these improved varieties allow increased production due to better disease resistance and better harvest efficiency (Tripp *et al*., 1982)

Brooks: Brooks is high-yielding and resistant to the major guar diseases, alternaria leaf spot and bacterial blight. It is medium to late in maturity. Plants have a fine-branching growth habit and small racemes of medium-sized pods. Leaves and stems are glabrous. The seed is of medium size (Jackson and Doughton, 1982).

The following early maturing varieties are being recommended for production in Wisconsin and Minnesota:

Lewis: Lewis is a medium-to-late maturing variety that is highly resistant to Alternaria leaf spot and bacterial leaf blight. Leaves, stems and pods are glabrous. Plants have a basal branching growth habit. Plants are of average height, and racemes and pods are of medium length. Pods generally contain 5 to 9 seeds of average size. In 10 yield tests at five Texas locations during 1980-1983, Lewis produced mean seed yields approximately 25% higher than Kinman and 21% higher than Esser (Undersander *et al*., 2014). The guar variety Lewis had the highest numerical yield in both dry- land and irrigated variety trials (Table 1).

Table 1: Dryland guar yield at Chillicothe and irrigated guar yield at Munday, kg ha^{-1}, in 2000.

Variety	Dry land	Irrigated
Lewis	743	1699
Santa Cruz	657	1342
Kinmen	638	1334
Esser	610	1663
$LSD_{0.05}$	188	380
CV%	17.7	15.5
Test mean	662	1535

Source: Olson, Sij and Baughman, 2000.

Hall is a slightly later-maturing variety than Brooks. It is resistant to bacterial blight and Alternaria leaf spot. Plants are relatively tall, coarse, finely branched, and produce small racemes of medium-sized pods. Leaves and stems are glabrous. This variety is best adapted to heavier soil types and higher elevations (Undersander *et al*., 1991).

Mills is an early-maturing variety which is also resistant to bacterial blight and Alternaria leaf spot. Plants are short and finely branched and produce small racemes with relatively large pods. Leaves and stems are pubescent. Seeds are larger than those of Brooks and Hall. In dry seasons, Mills does not grow tall enough for efficient harvesting. Yields are generally lower than those of Brooks and Hall (Undersander *et al*., 1991).

Kinman The variety is derived from Brooks and Mills. Kinman is about 7 days earlier in maturity than Hall and of the same maturity as Brooks. It is highly resistant to bacterial leaf blight and Alternaria leaf spot. Kinman is slightly taller and coarser-stemmed than Brooks, but less so than Hall. It is fine branched and produces small-to-medium sized racemes. Seed pods are medium in length and generally contain from 7 to 9 seeds each (Undersander *et.al*., 1991).

Esser has better disease tolerance than Brooks. It is medium to late in maturity. It has high resistance to Alternaria leaf spot and bacterial leaf blight. Esser has shown superior disease tolerance as compared to Brooks and Kinman under severe bacterial blight conditions. Esser plants have Brooks' fine branching growth habit, but Esser has stronger main stems and fewer lateral branches. Esser produces small racemes with medium-sized pods (Undersander., *et.al*., 1991).

According to Ismail and Abuelgasim, (2006) a set of guar varieties were tested for three seasons (1998-99, 1999-2000, 2000-01) at El Fasher research station in semi-arid Darfur region, Sudan under rainfed conditions. The objective of the study was to evaluate the adaptability of the crop to the region. Average seed yield of all the guar varieties in three seasons were 1036, 1088, and 490 kg ha^{-1} respectively while the overall average across the three seasons was 871 kg ha^{-1}. The effect of inter-row spacing (40,60,and 90 cm), intra- row spacing (20, 30 and 40 cm) and plant population (1, 2, 3 plants per hole) on yield and some agronomic traits of guar were studied in separate experiments at the same location during each season. Significant difference in seeds and hay yield among the three seasons were observed. This was mainly attributed to the variation in rainfall during the growing season. Seeds and hay yields increased with decreased inter row and intra row spacing (Ismail and Abuelgasim, 2006).

Bhardwai and Eitenmiller (1991) reported that 10 varieties of guar bean grown at Fort valley, Georgia gave significant variation among genotypes where the objective of the experiment was to determine the yield potential and different harvesting days. The bean yield varied from 9549 (Kinman) to 1629 kg ha^{-1} (HG-75) at 85 DAP. The highest yield at 100 DAP was recorded for Lewis.

2.8 Fertilizers influencing guar growth

While legumes can improve soil fertility, prevailing low soil fertility limits N fixation by legumes and the overall growth and yield of legumes grown by SH farmers. Phosphorus deficiency is one often important factor (Whitbread and Ayisi, 2004). Phosphorus is needed in large amounts by legumes for growth and N fixation and their effectiveness in soil improvement is hindered by deficiencies (Giller and Cadisch, 1995).

In sandy soils of semiarid regions, drought stress and lack of nutrients (mainly N and P) are considered as the main production constraints. Therefore guar is expected to fit very well as an important drought tolerant cash crop and soil-building crop, with respect to available N through N fixation (Rao and Willey, 1985). Perhaps the most critical factors when trying to grow guar or any other legume is to understand the importance of the role of P on plant growth. Phosphorus uptake is essential in the function of plant growth and development.

The P deficiency accounts for the major limiting factor for the growth of legumes (Sharma *et al*., 2001). There is little published data about the use of phosphate fertilizer on guar. In India P applied at rates up to 60 kg ha^{-1} was reported to increase grain yield in guar and the application of 40 kg ha^{-1} in trial work is common (Jackson, 1991). Rewari *et al*., (1965) has shown positive relationship between soil P uptake and N fixation.

The application of P fertilizer can overcome the deficiency in soil that does not strongly adsorb P (Giller, 2001). In Malawi low yield of legumes grown by SH farmers may be strongly linked to minimal use of P fertilizer (Mwalwanda *et al*., 2003) among other factors, and this was also identified during simulation modeling of response of maize to legumes and N fertilizer in central Malawi (Robertson *et al* ., 2005). The days taken to 50% flowering and maturity were markedly influenced by P application.

Application of 60 kg P ha^{-1} produced taller plants (86.19 cm) and more leaves than other levels in fodder (Singh and Thrived, 1981). Increasing levels of application of P increased the leaf area index (LAI) and branching in legumes. Similar trend was reported by Singh and Singh, (1991) in cowpea.

Khan *et al*., (2002) also made a study on the yield response of inoculated and un-inoculated mung bean to P application. The response was that the number of pods at 100 kg P_2O_5 ha^{-1} with inoculation resulted in maximum number of pods plant which was at par with all treatments. They further observed that application of P with inoculation gave higher yields than uninoculated conditions, while the control gave the lowest grain yield. The grain yield with inoculation and 75 kg P_2O_5 ha^{-1} was almost similar to that obtained by 100 kg P_2O_5 ha^{-1} without inoculation. They concluded that inoculation with *Rhizobium* can increase N fixation and yield. The combination of P and inoculation has maximum positive effects on P uptake and concentration of plants.

2.9 Inoculation of guar seeds

Seeds should be inoculated before planting with special guar inoculants or cowpea (Group E) inoculants. Sunlight, heat and excessive drying will impair or destroy effectiveness of the bacteria but properly inoculated guar will fix atmospheric N in amounts similar to cowpea or other legumes. For this reason crops following guar in rotation generally benefit from the residual N (Tripp *et al*., 1982).

2.9.1 Factors that influence inoculation and nodulation

Problems that affect nodulation and N-fixation in tropical cropping systems are:

1. A short supply of high quality inoculants (Olsen *et al.,* 1995).
2. Infertile-acid soils (Von Uexkull and Mutert, 1995).
3. Stress associated with salinity.

2.9.2 The effect of bacteria during inoculation

Hellriegel (1886), and Hellriegel and Wilfarth’s (1888) discovered that bacteria that form the N-fixing nodules on plants. The inoculation process is done by coating the seed with innoculant, just prior to sowing, or with soil from locations where the legume had grown previously. The distribution of *Rhizobium* bacteria in the soil is of crucial practical importance because it determines the natural inoculation of leguminous plants (Mishustin and Shilnikova, 1971).

Following many years of work on techniques of isolation and inoculation, several researchers (Allen and Baldwin 1931; Konishi, 1931) developed techniques that made it possible to isolate *Rhizobium b*acteria from the soil and to determine which species of plant they associate with. It was practically impossible to make a quantitative estimation of particular species of *Rhizobium* bacteria in the soil.

2.9.3 Effect of inoculation on yield

When new crops of leguminous plants are sown, inoculation always increases production both in terms yield and quality (Goss and Shiptown, 1965). Richardson *et al.,* (1957) reported that leguminous plants inoculated with effective races of *Rhizobium* bacteria have a considerably higher content of N (in particular protein). *Rhizobium* bacteria stimulate the accumulation of vitamins in the host plant. Krasilnikov (1958) established that most *Rhizobium* bacteria synthesize vitamin B_1, while Burton and Lochead (1952) noted their ability to accumulate vitamin B_{12} and reported that inoculated plants contained considerably more vitamins of the Vitamin B complex than uninoculated plants.

In the case of legume plants, increment in dry matter or grain yield have been observed when rhizo-bacteria are co-inoculated with the *rhizobia* strain on seeds (Grimes and Mount, 1984). Nevertheless there are cases where no response or even negative effects have been observed. Greater pod length was recorded in the plants from inoculated seed compared to un-inoculated seeds. Similar results were given by Patel and Patel (1991) who also showed significant increase in pod length due to inoculation in green gram [*Vigna radiata (L*.).

The number of seeds per pod is perceived as a significant constituent that directly imparts in exploiting potential yield recovery in leguminous crops. Highest number of seeds per pod was recorded in plants from inoculated seed as compared to plants from un-inoculated seed (Hernandez and Cuevas, 2003). Similar results were also reported by Patel and Patel (1991) where the highest number of seeds per pod were produced when 100 kg P_2O_5 ha^{-1} was applied and lowest number was recorded where no P was applied.

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CHAPTER 3

GENERAL MATERIALS AND METHODS

3.1 Background of the study

The study was conducted in Limpopo province of South Africa in 2006/7 and 2007/8 growing seasons. Limpopo province has five districts: Sekhukhune, Capricorn, Waterberg, Mopani and Vhembe. The experiments were conducted in Capricorn and Sekhukhune districts (Figure 5). Within the Capricorn district, the experiments were sited in the Polokwane municipality area at the University of Limpopo- Turfloop Campus Syferkuil experimental farm (23°51'S, 29°42'E). The second location was at Sekhukhune district in the Ephraim Mogale local municipality area at the Limpopo Department of Agriculture Tompi Seleka training centre farm (24°58'70''S and 29°17'2.54''E).

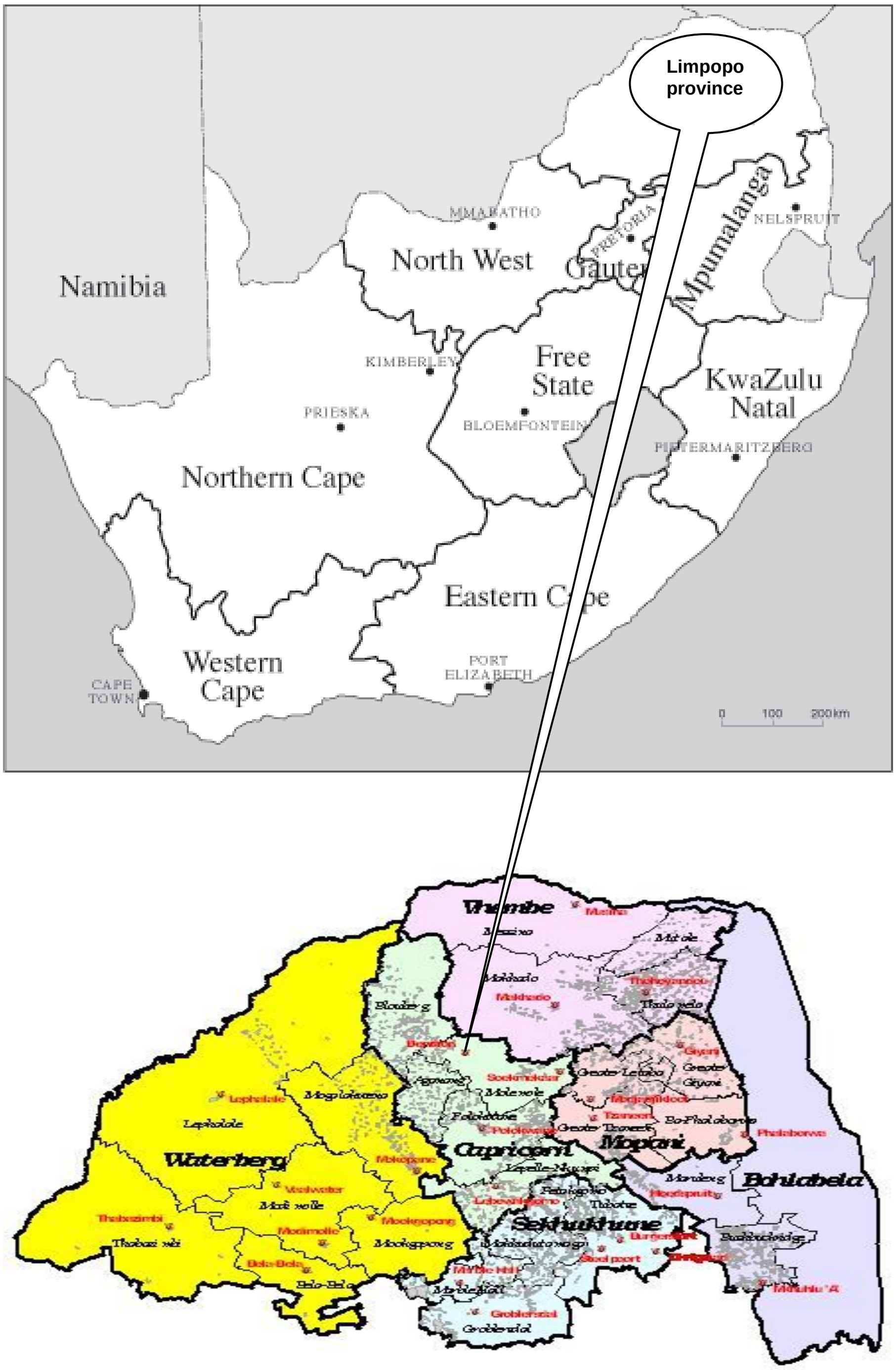

Figure 5: Map of South Africa and the districts in the Limpopo Province (Rainbow nation, 2014)

The study comprised of two experiments. The first experiment was the evaluation of the performance of the 14 guar accession lines under the conditions of Limpopo province. The second experiment investigated the response of guar bean to P fertilizer levels and inoculation. In 2006/7 growing season the experiments were only conducted at Syferkuil because of limited availability of guar seeds. In the following season, 2007/8, the trials were established at both Syferkuil and Tompi Seleka.

3.2 Soil and site description

The soils at the experimental sites; Syferkuil and Tompi Seleka composed of the characteristics shown in the Table 2:

Table 2: Physical and chemical properties of the soil at the experimental sites: Syferkuil and Tompi Seleka

Site	Texture	p^H (H_2O)	P (mg kg^{-1}) (Bray1 extractable P)
Syferkuil	Clay loamy	6.9	35
Tompi Seleka	Sandy loam	6.5	5.6

Figure 6 and Table 3 indicate the average rainfall and temperature for the two sites where the experiments were conducted.

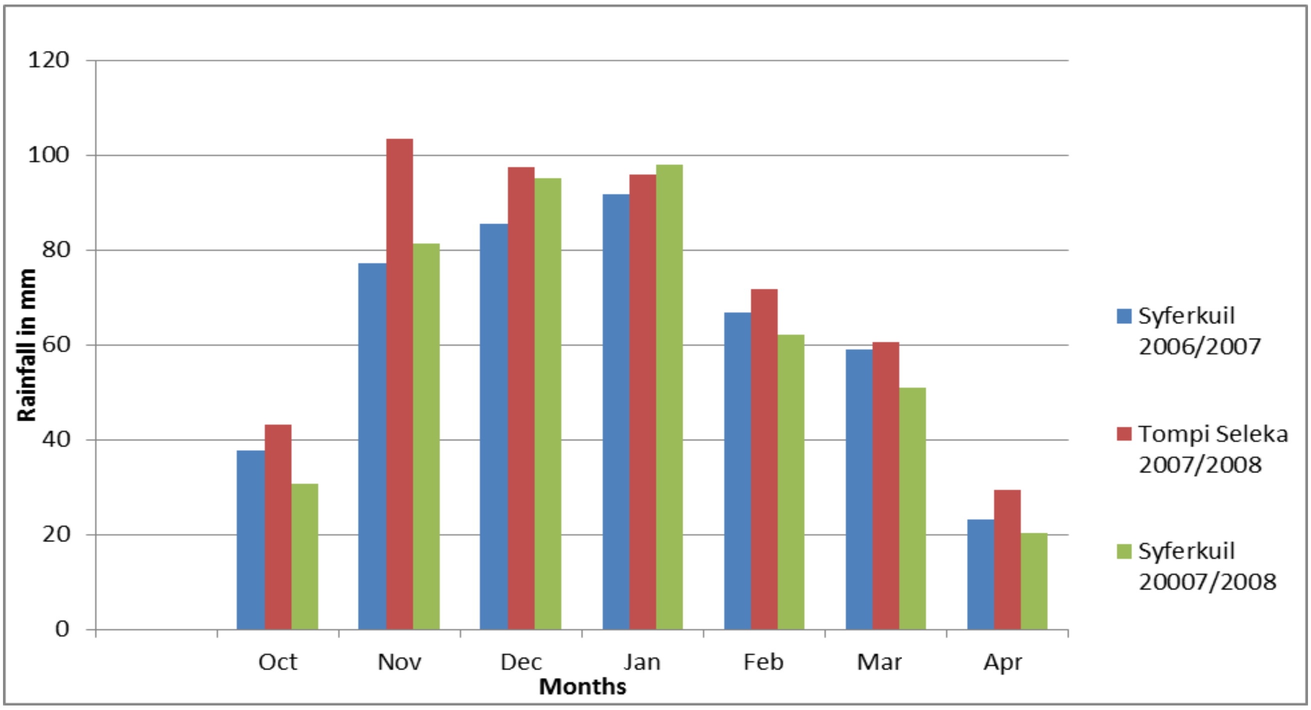

Figure 6: Monthly rainfall data at Tompi Seleka (Sekhukhune district) and Syferkuil (Capricorn district) during the 2006/7 and 2007/8 growing seasons.

Table 3: Average monthly temperatures °C for Tompi Seleka and Syferkuil

Month	Tompi Seleka		Syferkuil			
	2007/8		2006/7		2007/8	
	Min	Max	Min	Max	Min	Max
October	15	30	12	25	16	26
November	17	30	13	27	15	27
December	18	31	16	27	16	26
January	19	31	18	29	16	27
February	18	31	18	28	16	29
March	10	30	16	26	14	26
April	12	27	10	25	12	26

3.3 Experimental Design and Treatments

Experiment one was a variety evaluation of 14 guar accession lines and was laid out in a Randomized Complete Block Design (RCBD) with three replications. The second experiment was testing the response of two guar accession lines to inoculation and P levels and was laid out as split- split plot design with four replications.

3.4 Data collection

Rainfall and temperature were measured from October, the beginning of growing season, to April, the end of growing season. Above ground portions of the plant were sampled at 30, 60, 90 and 120 days after planting. They were sun dried for dry matter determination at the different growth stages. Vegetative dry matter was taken between 30 and 35 days after planting and flowering was determined visually when 50% of the plants from the experimental unit had exposed flowers. Physiological maturity was measured when the plants started losing moisture as indicated by browning of the pods and yellowing of plant leaves. Plant height was measured at physiological maturity. Seed yield was determined from 9 m^2 in the middle two rows of each experimental unit. Yield components were determined on four plants selected randomly from the harvested plants and later returned to the bulk harvest to determine the total grain yield. The yield components measured were number of pods per plant, seeds per pod, branching per plant and the seed yield.

3.5 Data analysis

Data were subjected to analysis of variance using the general linear model procedure of Statistical Analysis System (SAS Institute, 2000). Differences between treatment means were separated and compared using Tukey $HSD_{0.05}$ all pair-wise comparison test. Partial analysis of variance for experiment 1 is given in Table 4 and for experiment 2 in Table 5.

Table 4: Partial analysis of variance for Experiment 1

Source of variation	Degree of freedom
Replication	(r- 1) = 2
Varieties	(V – 1) = 13
Error	(r-1) (V – 1) = 26
Total	**41**

Table 5: Partial analysis of variance for Experiment 2

Sources of variation	**Degree of freedom**
Replication	3
Variety	1
Error Rep* Variety	3
Phosphorus	2
Variety*Phosphorus	2
Error Rep* Var*Phosphorus	12
Inoculation	1
Variety*Inoculation	1
Phosphorus*Inoculation	2
Variety*Phosphorus*Inoculation	2
Error Rep* Var*Phos*Inoc	18
Total	**47**

CHAPTER 4

GUAR BEAN VARIETY EVALUATION

4.1 Introduction

Guar bean or cluster bean is a coarse, upright; bushy, drought-tolerant summer annual legume belonging to the family Fabaceae (Jackson and Doughton, 1982). Guar is a plant native to India and Pakistan where it is grown principally for its green fodder and for the pods that are used for food and feed. It is grown in tropical Asia, Africa and America. The major world suppliers are India, Pakistan and the United States, with smaller acreages in Australia and Africa (Undersander *et al.,* 2006). Plants have single stems with fine branching or basal branching (depending on the variety) and grow to be 45 – 100 cm tall. Racemes are distributed on the main stem and lateral branches. Pods are 4 to 10 cm long and contain 5 to 12 seeds each. Seeds vary from dull-white to pink to light grey or black and range from 32 to 56 seeds /g (Undersander *et al*., 2014).

Guar tolerates high temperatures and dry conditions and is adapted to arid and semi-arid climates. When moisture is limited, the plant stops growing but does not die. While intermittent growth helps the plant to survive, drought also delays maturity. Growing season ranges from 60-90 days for determinate varieties and 120-150 days for indeterminate varieties. Guar responds to irrigation during dry periods. It is grown without irrigation in areas with 225 to 900 mm of annual rainfall (Anon and Esser, 1975). Excessive rain or humidity after maturity causes the beans to turn black and shrivel, reducing their quality and marketability. While profitable seed production in southern USA areas of high rainfall and humidity is likely to be limited, guar can be successfully grown as a green manure crop under these conditions. Guar varieties that require a particular day length to flower or day-neutral have been described.

Guar bean grows well under a wide range of soil conditions. It performs best on fertile, medium-textured and sandy loam soil with good structure and well-drained sub-soils (Singh *et al*., 1962; Allen, 1964). The crop is susceptible to water logging. Guar is considered to be tolerant to both soil salinity and alkalinity. The seedbed should be firm and weed-free. Soil in the row should be ridged slightly to facilitate harvest of low-set beans. Guar should be planted when soil temperature is above

21°C, the optimum soil temperature for germination is 30°C. A warm seedbed, adequate soil moisture and warm growing weather are essential for establishment of a good stand (Undersander *et al*., 2014).

Guar production is greatly affected by climatic factors such as rainfall, temperature, soil factors and cultural practices (sowing date, seed rate, planting space, sowing methods, weeding and harvesting methods). Although guar is grown under a wide range of annual precipitation, the amount and distribution of rainfall is the limiting factor for guar production (Osman, 2001).

Undersander *et al*., (2006) reported that there have been notable improvements in guar varieties developed in the last 30 years. The newer cultivars are much more disease resistant with higher yield. Pod set in improved varieties is higher, and pods are well distributed on the main stem and branches, increasing harvest efficiency. The multiple branching of these newer cultivars also produces more pods. Guar production potential under Limpopo dryland conditions has not been explored. This trial was therefore conducted to evaluated the growth and yield performance of exotic lines from Australia under local conditions.

4.2 Materials and methods

Site description (see chapter 3)

Land preparation and planting dates

Land preparation during both seasons involved ploughing with mouldboard followed by disking with a tine harrow. In season 1, the trial was planted on the 4th of December 2006 at Syferkuil while in season 2; plantings took place on 20th of January 2008 at Syferkuil and 12th December 2007 at Tompi Seleka. The first season trials were harvested in May 2007 and the second season trials were harvested in May 2008.

Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design with three replications in both seasons. Seeds were sown manually at a spacing of 30 cm in rows spaced at 60 cm. Weeds were controlled regularly by hoeing and no fertilizer was applied to the trial. The 14 accession lines used in the trial are listed in Table 6.

Table 6: Description of Guar accession lines used in the trial sourced from ATFGRC.

Accession	Name	Origin	Type
AusTRCF113478	RGC 471	-	-
AusTRCF77998	Brooks	USA	Strongly branching
AusTRCF77999	Esser	USA	Strongly branching
AusTRCF78000	Hall	USA	Strongly branching Later maturing than Brooks
AusTRCF95327	Q20023	-	-
AusTRCF61052	ECRS67	India	Strongly branching
AusTRCF95351	Durgpurasaffed	India	Grain/forage type
AusTRCF95034	Texsel (early)	India	-
AusTRCF300522	PHD	-.	-
AusTRCF61102	HF223	India	-
AusTRCF	CP177 (Cedric)	Australia	This line was provided by Cedric Proud of Surat, Queensland
AusTRCF	CP177 (Stonewall)	Australia	This line from Ian Parkin of Australian Gum Products
AusTRCF 300557	CSIRO Seln 13	Australia	-
AusTRCF 95203	T64001 -30-1-3-2	-	-

-= not known

Management of the crop, irrigation and pest control

Irrigation was done only to supplement rainfall in cases where rainfall was not received for a week. The crop was irrigated twice a week with a sprinkler irrigation system to supplement rainfall. The control of pest, which was mainly aphids, was achieved by applying Metasystox R 250 EC organophosphate) which was applied once at flowering.

Data collection and analysis

Data were collected and analyzed as indicated in Chapter 3 (the general materials and methods). In addition, Pearson's Correlation coefficients of yield and its components were also determined.

Analysis of data

4.3 Results

Stand establishment - The 2006/7 variety evaluation trial at Syferkuil farm achieved 40% germination percentage by the 6th day and this increased to 90% after 10 days. In the 2007/8 growing season, the experiment at Tompi Seleka farm showed good germination percentage by reaching 60% germination within 6 days and 95% by the 10^{th} day. In the same season, the experiment at Syferkuil achieved 40% germination by the 6^{th} day and realized 90% germination by the 12^{th} day. The Tompi Seleka trial showed better crop stand and had taller seedlings than the two experiments at Syferkuil.

Dry matter- Dry matter of 14 accession lines at vegetative, flowering and physiological maturity stage at Syferkuil and Tompi Seleka were statistically different, except at Syferkuil in 2007/8 (Table 7). TRCF95203 variety recorded the highest dry matter and Esser variety recorded the lowest dry matter for the growth stages at Syferkuil in the 2006/7 growing season. Plant dry matter at maturity was higher by 40% compared to the lowest performing variety Esser. The top three performing varieties in dry matter at Syferkuil in the 2006/7 growing season were TRCF 95203 variety followed by Brooks and then Stonewall. These three varieties, in the same ranking order, gave the highest dry matter at vegetative, flowering and maturity stages.

In the 2007/8 growing season, TRCF CSIRO gave the highest dry matter at Syferkuil whilst the lowest was by Q20023. The highest cultivar maturity had 48.9% higher dry matter than the lowest performing variety Q20023. The top five performing varieties in terms of plant dry matter were TRCF CSIRO, followed by Texsel, TRCF95203, Brooks and Esser. Even at flowering and maturity the ranking of top five varieties was in the same order. The highest plant dry matter content was achieved by

Durgapurasaffed and the lowest dry matter was recorded with TRCF 61052. Durgapurasaffed had 73% higher plant dry matter than TRCF 61052. The three varieties with the highest plant dry matter were Durgapurasaffed followed by Stonewall then TRCF CSIRO. The dry matter at maturity for all lines was much lower at Syferkuil than at Tompi Seleka (Table 7). For example the top three lines in terms of dry matter at maturity at Syferkuil in 20006/7 were TRCF 95203, Brooks and Stonewall with 1534, 1521 and 1498 kg ha^{-1} , respectively, while the top three at Tompi Seleka in 2007/8 were Durgapurasaffed, Stonewall and TRCF CSIRO with 13667, 10508 and 10392 kg ha^{-1}, respectively.

Table 7: Dry matter (DM) kg ha^{-1} accumulation of guar bean accession at Syferkuil and Tompi Seleka at different growth stages during the 2006/7 and 2007/8 growing seasons

Variety	DM at vegetative	DM at flowering	DM at maturity	DM at vegetative	DM at flowering	DM at maturity	DM at vegetative	DM at flowering	DM at maturity
	Syferkuil 2006/7			Tompi Seleka 2007/8			Syferkuil 2007/8		
TRCF 61052	1211 ab	1384 ab	1497 a	3200 d	4440 d	5084 c	833 a	994 a	1171 a
Hall	760 b	986 ab	1080 ab	7613 abcd	8053 bcd	8771 abc	633 a	760 a	986 a
TRCF CSIRO	1020 ab	1265 ab	1370 ab	8601 ab	9465 abc	10392 ab	1093 a	1333 a	1613 a
Brooks	1227 ab	1367ab	1521 a	5747 bcd	6548 bcd	7168 bc	943 a	1128 a	1300 a
TRC 61102	910 ab	1133 ab	1245 ab	5813 bcd	6200 bcd	6633 bc	746 a	906 a	1133 a
TRCF 95203	1280 a	1458 a	1534 a	8080 abc	8427 bcd	8659 bc	1003 a	1140 a	1288 a
RGC 471	920 ab	1160 ab	1228 ab	8613 ab	8973 abcd	9369 abc	726 a	920 a	1160 a
Esser	733 b	877 b	1002 b	3600 cd	4867 cd	5195 c	913 a	992 a	1138 a
Texsel	1106 ab	1373 ab	1459 ab	6933 bcd	7400 bcd	7751 bc	1020 a	1160 a	1373 a
Durgapurasaffed	917 ab	1043 ab	1209 ab	12184 a	13225 a	13667 a	896 a	1012 a	1213 a
S-47-2	816 ab	1067 ab	1226 ab	4673 bcd	5520 bcd	6135bc	533 a	693 a	946 a
Q 20023	946 ab	1186 ab	1337 ab	4701 bcd	4299 bcd	5311 c	720 a	823 a	920 a
Cedric 177	926 ab	1213 ab	1370 ab	6155 bcd	6773 bcd	7312 bc	620 a	760 a	1013 a
Stonewall	1154 ab	1320 ab	1498 a	8893 ab	9952 ab	10508a b	826 a	986 a	1213 a
Significance	***	***	***	***	***	***	ns	ns	ns
Tukey HSD	511	513	474	4744	4915	4915	-	-	-
CV%	17	14	11	41	25	28.37	31.44	29.06	26.63

*, **, ***=Significantly different at the p≤ 0.05, p≤ 0.01 p≤ 0.001, respectively, ns=Non Significant , CV%=Coefficient of Variation, Means followed by same letter in a column do not differ significantly at P=0.05

Days to Physiological Maturity: Statistically there were no significant differences in duration to maturity between all the 14 guar accession lines at Syferkuil in 2006/7-2007/8 and Tompi Seleka in 2007/8 (Table 8).

At Syferkuil in 2006/7 the days to maturity ranged from 75 to 86 days. Brooks variety had the longest growth duration whilst Q20023 had the shortest duration. In the 2007/8 season, at Syferkuil, TRC 61052 took the longest time to reach physiological maturity and the shortest was with Durgapurasaffed and S-47-2 at 84 days to reach maturity. In the same season (2007/8) at Tompi Seleka, growth duration ranged from 70 to 77 days. TRCF CSIRO had the longest growth duration while the earliest to mature was RGC 471 variety. The crop at Tompi Seleka matured earlier with an average of 75 days to physiological maturity in all the varieties (Table 8) in the 2007/8 season.

Plant height: The 14 guar lines showed no difference in terms of their height ($P \leq 0.05$) at maturity over the two seasons and at the two locations (Table 8). In 2006/7 growing season at Syferkuil, variety TRCF 95203 recorded the tallest plants while Texsel had the shortest plants. TRCF 95203 plants were 10.5% taller than those of the Texsel variety. In 2007/8 growing season in the Syferkuil experiment the tallest varieties were Cedric 177 and TRCF CSIRO while the shortest was Stonewall. The height of varieties in that location ranged from 52 cm to 58 cm. The tallest varieties at Tompi Seleka in the 2007/8 season were Texsel and Durgapurasaffed and the shortest were Hall and esser. The tallest was 12.9% higher than the shortest. The plants at Tompi Seleka were taller than those at Syferkuil in both seasons.

Table 8: Growth duration and plant height at maturity of the 14 guar accession lines at Syferkuil and Tompi Seleka in 2006/7 and 2007/8 growing seasons

	Days to physiological maturity			Plant height (cm)		
Varieties	**Syferkuil 2006/7**	**Syferkuil 2007/8**	**Tompi 2007/8**	**Syferkuil 2006/7**	**Syferkuil 2007/8**	**Tompi Seleka 2007/8**
TRCF 61052	82	91	72	63	55	66
Hall	85	86	76	64	56	62
TRCF CSIRO	82	88	77	61	58	63
Brooks	86	90	76	66	54	69
TRC 61102	82	88	75	63	55	70
TRCF 95203	81	85	75	67	53	70
RGC 471	81	87	70	64	54	66
Esser	83	85	75	61	55	62
Texsel	83	85	72	60	55	71
Durgapurasaffed	83	84	76	64	55	71
S-47-2	81	84	76	65	53	67
Q 20023	75	86	76	61	55	66
Cedric 177	81	87	74	63	58	70
Stonewall	83	86	75	65	52	68
Significance	ns	ns	ns	ns	ns	ns
Tukey HSD	38	9	32	-	-	-
CV%	15	3	14	9	7	18

*, **, ***=Significant at the $p \leq 0.05$, $p \leq 0.01$ $p \leq 0.001$, respectively. ns=Non Significant, CV=Coefficient of Variation

Yield Components

Number of pods plant^{-1}*:* Highly significant differences (P<0.05) in number of pods per plant were observed among the 14 accession lines in the two seasons for the two locations.

At Syferkuil in the 2006/7 growing season, Brooks had the highest number of pods per plant (44) and S-47-2 had the lowest (11) (Figure 7). The top five varieties were Brooks, TRCF 95203, Durgapurasaffed, Cedric17 and Q20023, respectively in their ranking order.

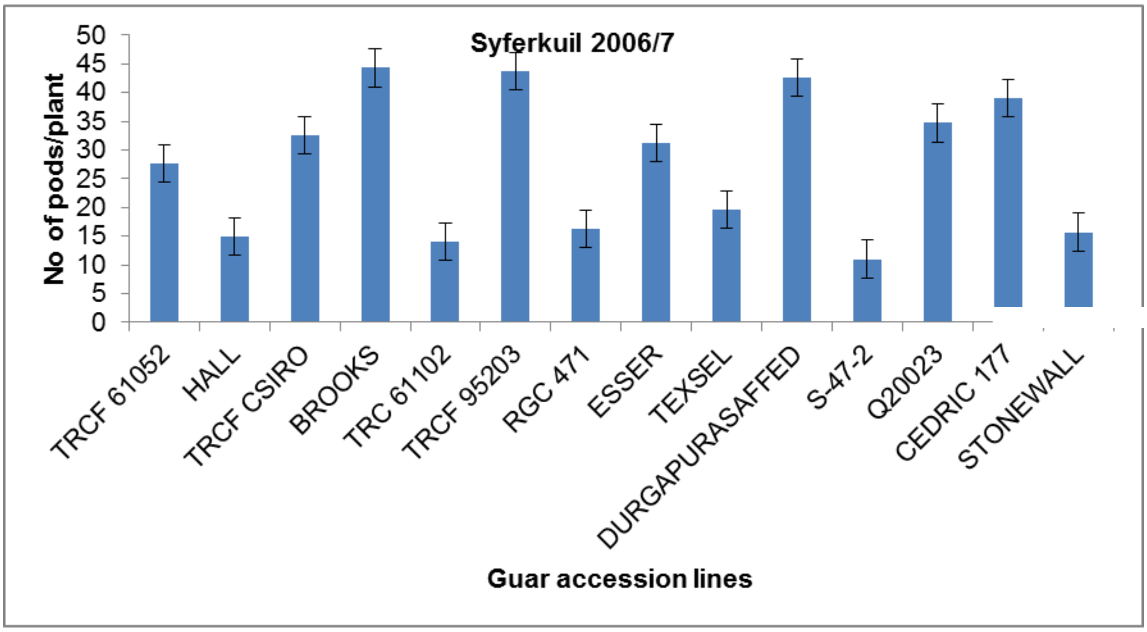

Figure 7: Number of pods per plant for 14 accessions lines at Syferkuil during the 2006/7 growing season

In the Tompi Seleka trial in the 2007/8 growing season, the highest number of pods were recorded for Durgapurasaffed and the lowest were from TRCF 61052 (Figure 8). The highest accession line had 78% higher number of pods per plant than the lowest performing variety. The five varieties with the highest number of pods per plant, in their ranking order at Tompi Seleka, were Durgapurasaffed followed by Esser, TRCF CSIRO, TRCF 95203 and brooks.

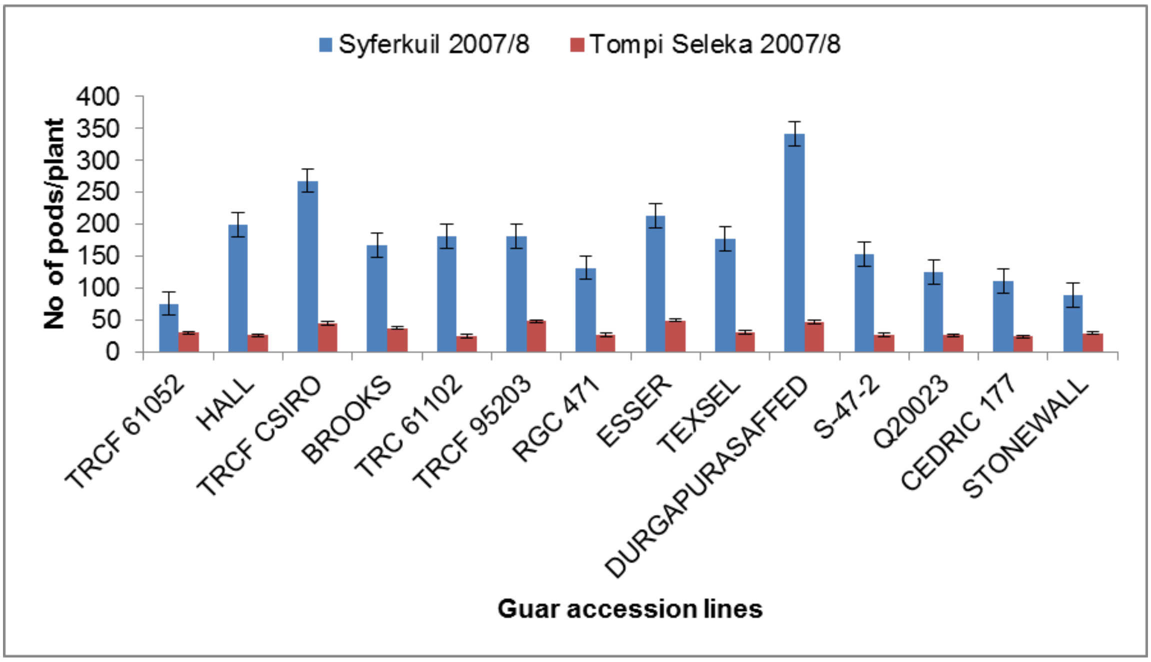

Figure 8: Number of pods per plant for 14 accession lines at Syferkuil and Tompi Seleka sites during the 2007/8growing season

Number of seeds per pod: The number of seeds per pod did not show any statistically significant difference between guar varieties tested in both seasons. The 14 guar accession lines had similar number of seeds per pod at Syferkuil during 2006/7 (Figure 9).

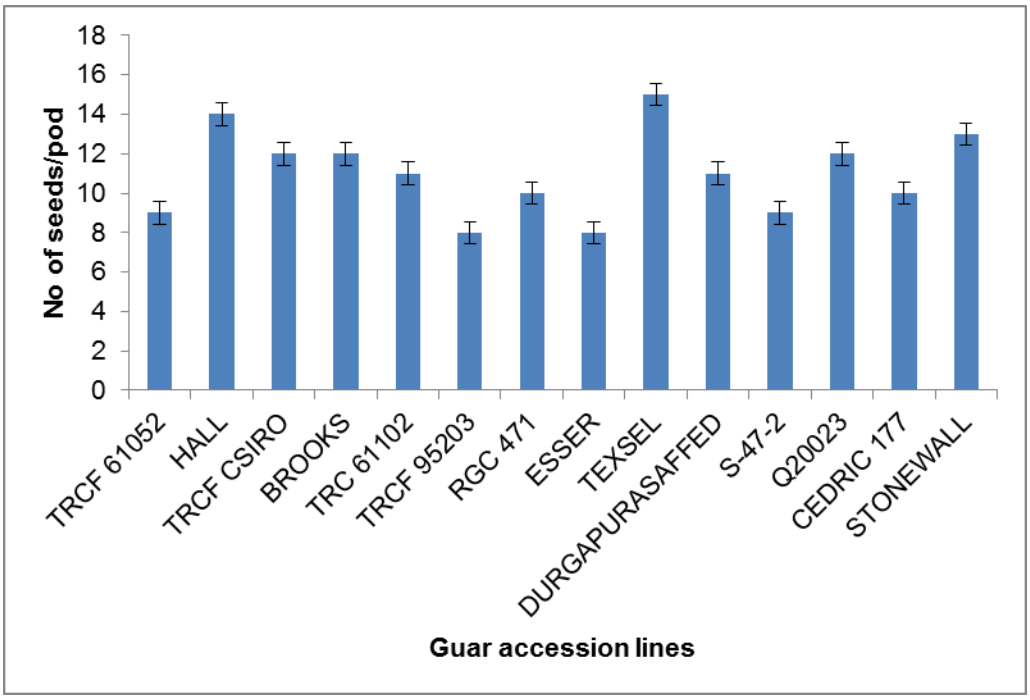

Figure 9: Number of seeds per pod for 14 guar accession lines at Syferkuil during the 2006/7 growing season

In the 2007/8 growing season, at Tompi Seleka, the highest number of seeds per pod was attained by TRCF CSIRO followed by S-47-2 (Figure 10). The number of seeds per pod ranged from five to twelve seeds per pod. The lowest number of seeds was produced by Stonewall, TRCF 61052, Texsel and Brooks which had similar number of seeds per pod. At Syferkuil in that same season, the variety with the highest number of seeds per pod was Hall and the lowest number of seeds per pod produced was six. The number of seeds per pod ranged from five to twelve. The Syferkuil trial produced higher number of seeds per pod than the Tompi Seleka experiment.

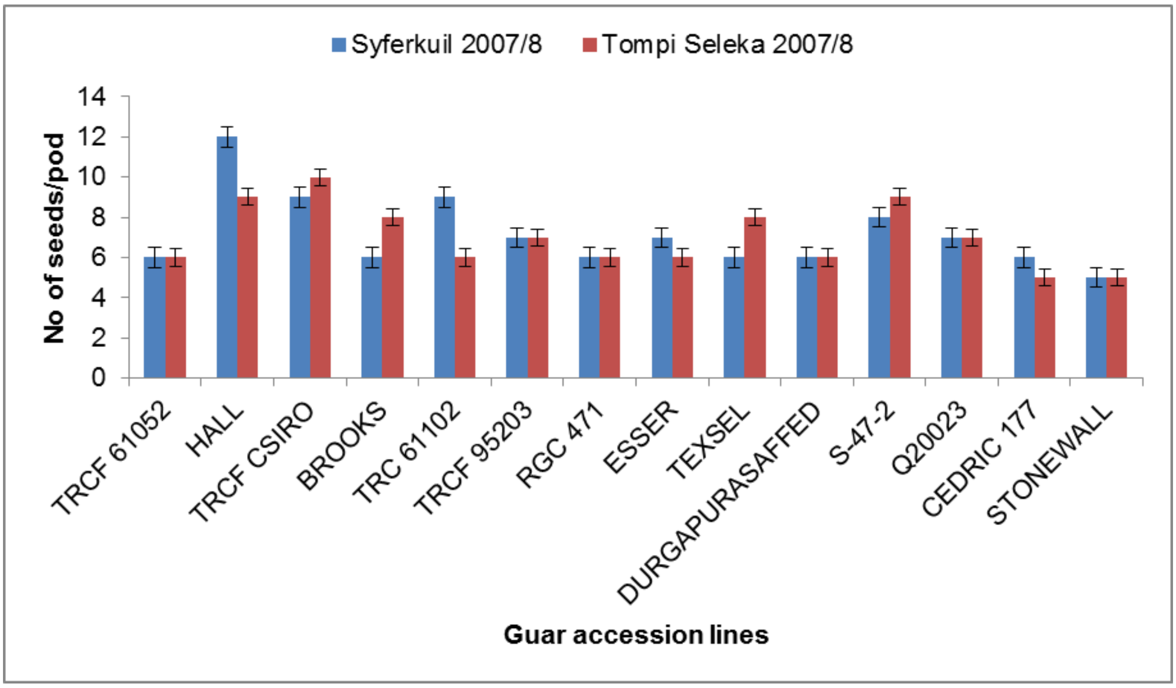

Figure 10: Number of seeds per pod for 14 guar accession lines at Syferkuil and Tompi Seleka sites during the 2007/8 growing season

Number of branches plant^{-1}: The 14 guar accession lines showed statistically different number of primary branches per plant at the two locations (Figure 11). Only in the first season the varieties did not differ in the number of primary branches. In the 2006/7 growing season the 14 guar accession averaged six branches per plant. The highest number of branches was six and the lowest was five branches.

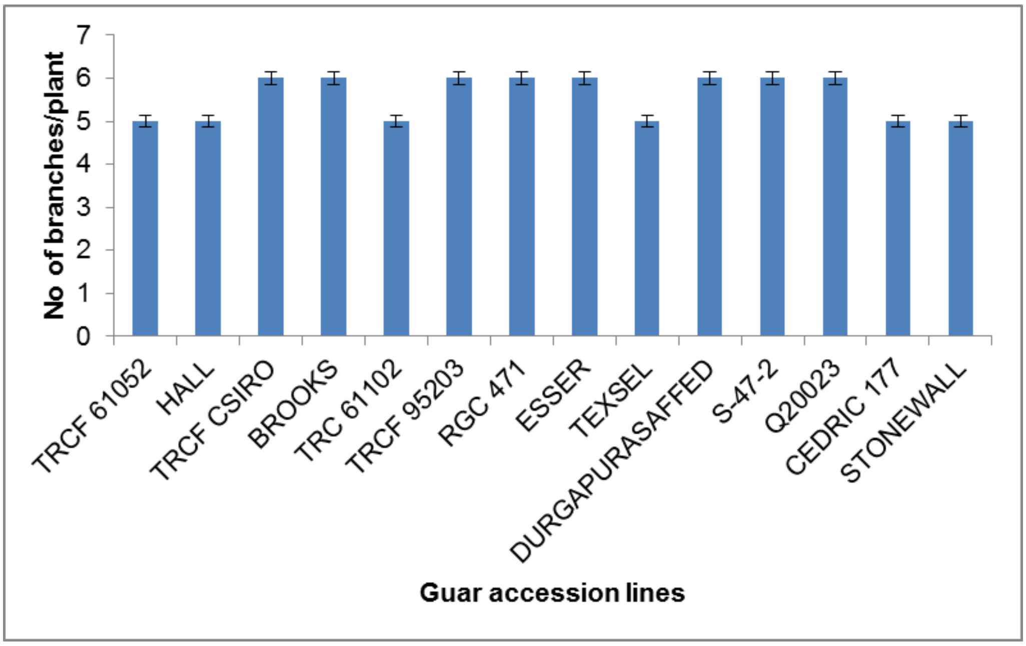

Figure11: Number of branches per plant for 14 guar accession lines at Syferkuil experiment during the 2006/7 growing season

At the Tompi Seleka trial in the 2007/8 growing season, the highest branching variety was Hall followed by Q 20023. The least branching variety was Cedric 177 with only 5 branches per plant. Branching ranged from six to thirteen branches per plant. At Syferkuil in the 2007/8 growing season, Q20023 was the highest branched variety, followed by Hall. The lowest branching variety was Cedric177. The branching of varieties ranged from five to twelve branches per plant (Figure 12).

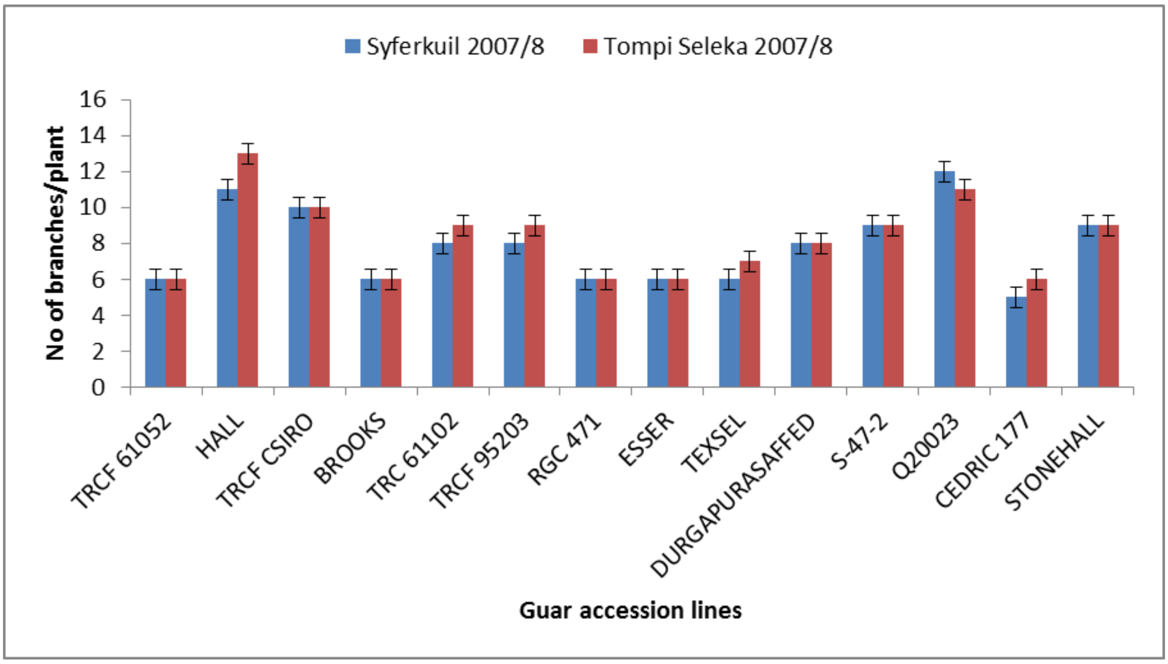

Figure 12: Number of branches per plant for 14 guar accession lines for Syferkuil and Tompi Seleka experiment during the 2007/8 growing season

Seed Yield

Seed yield was Significant ($P<0.05$) differences among the 14 guar accession lines at Syferkuil for the 2006/7 and at Tompi Seleka in 2007/8 growing seasons (Table 9). At Syferkuil in 2006/7 variety Brooks produced the highest seed yield and the lowest was recorded from Hall. The lowest yielding variety only yielded 32% of the highest yielding accession line. Only Brooks attained a seed yield above 1000 kg ha^{-1}. At the same location and season, the highest five performing varieties in terms of seed yield were Brooks, TRCF 95203 Durgapurasaffed, TRCF CSIRO and TRCF 61052 respectively, in order of ranking (Table 9). Their seed yield ranged from 556 kg ha^{-1} to 1103 kg ha^{-1}. All the guar lines performed far better at Tompi Seleka relative to Syferkuil in the 2007/8 growing season (Table 9)

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In the 2007/8 growing season at Tompi Seleka, variety Durgapurasaffed gave the highest seed yield of 2340 kg ha^{-1} and variety Stonewall was the lowest performing variety at 720 kg ha^{-1}. The top five varieties as indicated in Table 9 in their ranking order were Durgapurasaffed, Hall, Texsel, Brooks and TRCF CSIRO. At Tompi Seleka, seven lines achieved seed yield of 1500 kg ha^{-1} or higher. Lastly at Syferkuil in the 2007/8 season, the highest performing variety was TRCF 95203 with 701kg ha^{-1} and the lowest being Stonewall with 326 kg ha^{-1}. The top five performing varieties in ranking order were TRCF 95203, Esser, Brooks, Durgapurasaffed and TRCF CSIRO. The only guar lines that were stable in their seed yield were TRCF 61052 and Durgapurasaffed that attained ranking positions of four or above across the two seasons and locations (Table 9).

Table 9: Seed yield and ranking order for yield of 14 guar bean varieties at Syferkuil for 2006/7-2007/8 and Tompi Seleka for 2007/8 growing seasons

Variety	Syferkuil 2006/7		Syferkuil 2007/8		Tompi Seleka 2007/8	
	Seed Yield Kg ha^{-1}	Ranking	Seed Yield Kg ha^{-1}	Ranking	Seed Yield Kg ha^{-1}	Ranking
TRCF 61052	556 bc	5	507	6	933 cd	12
Hall	353 c	14	353	13	1940ab	2
TRCF CSIRO	610 bc	4	543	5	1620 abc	5
Brooks	1103 a	1	566	3	1640. abc	4
TRC 61102	456 c	12	480	9	1500 abcd	7
TRCF 95203	970 ab	2	701	1	1333 bcd	9
RGC 471	473 c	10	473	10	733 d	13
Esser	490 c	9	622	2	1549 abcd	6
Texsel	500 c	8	500	8	1760 abc	3
Durgapurasaffed	706 abc	3	562	4	2340 a	1
S-47-2	466 c	11	436	11	1353 bcd	8
Q 20023	513c	6	386	12	937 cd	11
Cedric 177	506 c	7	506	7	1000 cd	10
Stonewall l	396 c	13	326	14	720 d	14
Significance	**		ns		***	
Tukey HSD	421		-		874	
CV%	24		25		21	

*, **, ***=Significantly different at the p≤ 0.05, p≤ 0.01 p≤ 0.001, respectively, ns=Non Significant, CV%=Coefficient of Variation, Means followed by same letter in a column do not differ significantly at P=0.05

Seed Yield versus Number of pods per plant: Seed yield showed a positive relationship to the number of pods per plant (R^2=0.84). When the number of pods per plant increased it related in an increase in seed yield (Figures 13). For example at Syferkuil in 2006/7 growing season (Figure 14) variety TRCF 95203 recorded the highest number of pods related to the highest seed yield from the same variety (table9). Then with low seed yield from Stonewall variety the number of pods was also low (figure 7).

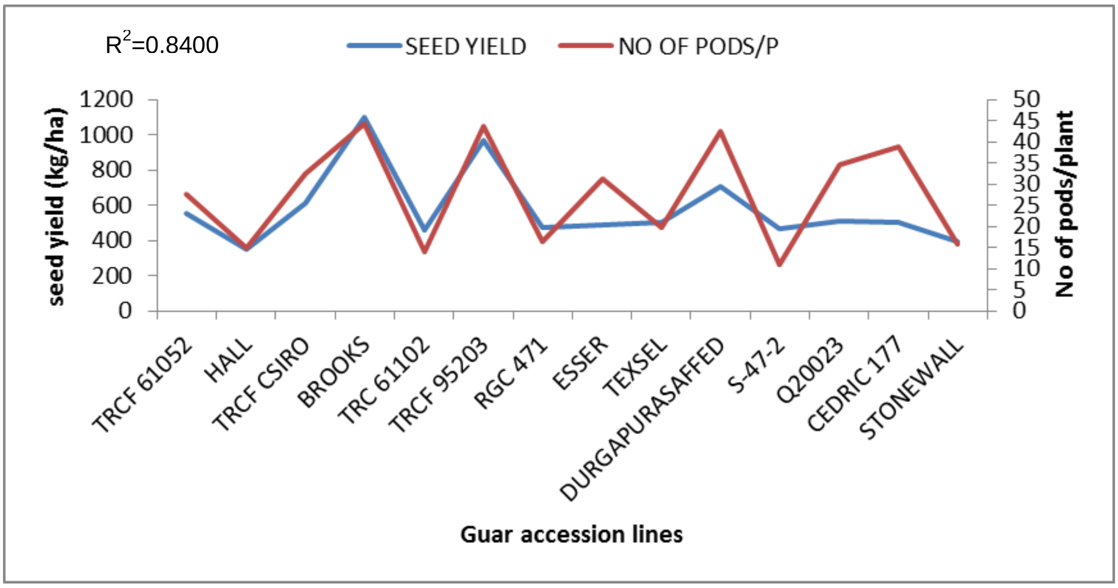

Figure 13: Seed yield versus number of pods per plant at Syferkuil during the 2006/7 growing season

In the 2007/8 growing season at the Tompi Seleka experiment, the same trend held true as demonstrated by Durgapurasaffed and Stonewall (Figure 13).

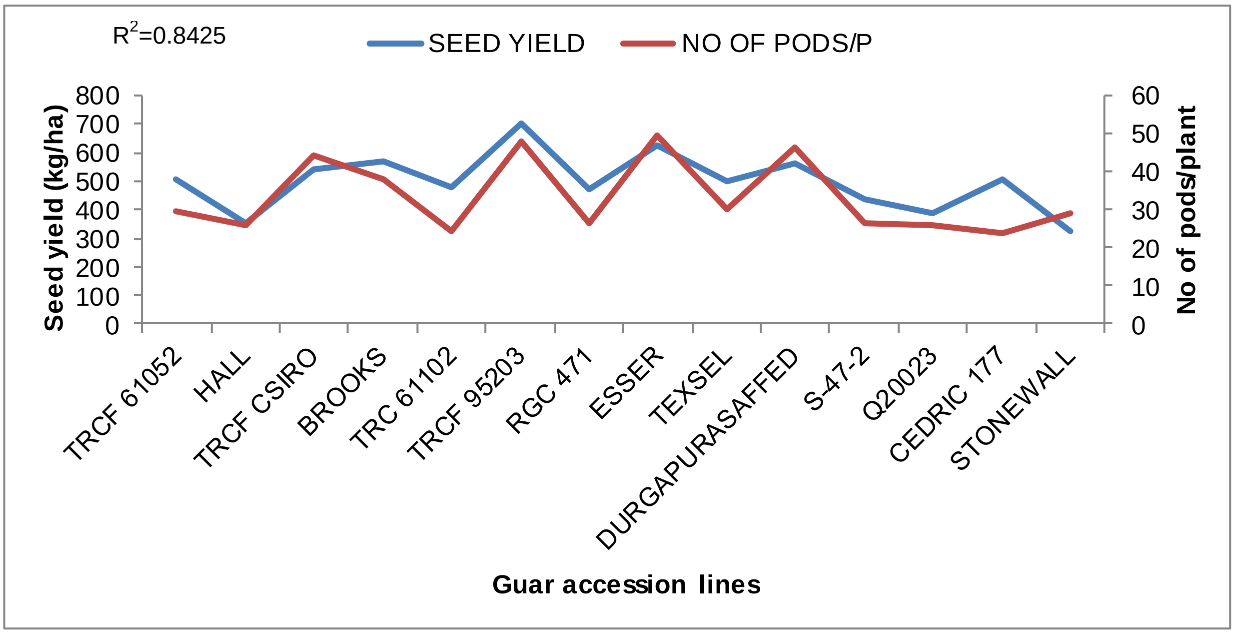

Figure 14: Seed yield versus number of pods per plant at Tompi Seleka during the 2007/8 growing season

At Syferkuil in the same season 2007/8, there was also high correlation between seed yield and number of pods per plant (R^2=0.71) (Figure 15).

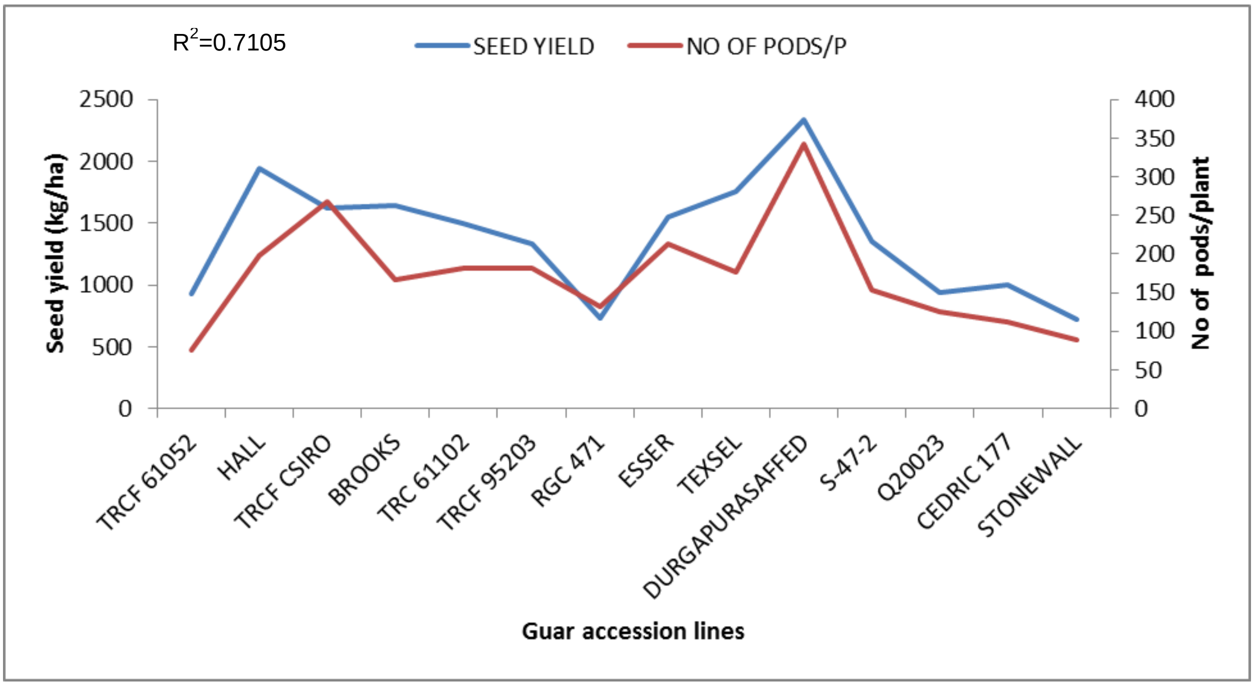

Figure 15: Seed yield versus number of pods per plant at Syferkuil during the 2007/8 growing season

Seed Yield versus number of seeds per pod: Seed yield versus number of seeds per pod showed poor correlation at all the three sites (R^2=0.77, 0.78 and 0.64, for Figures 16-18, respectively).

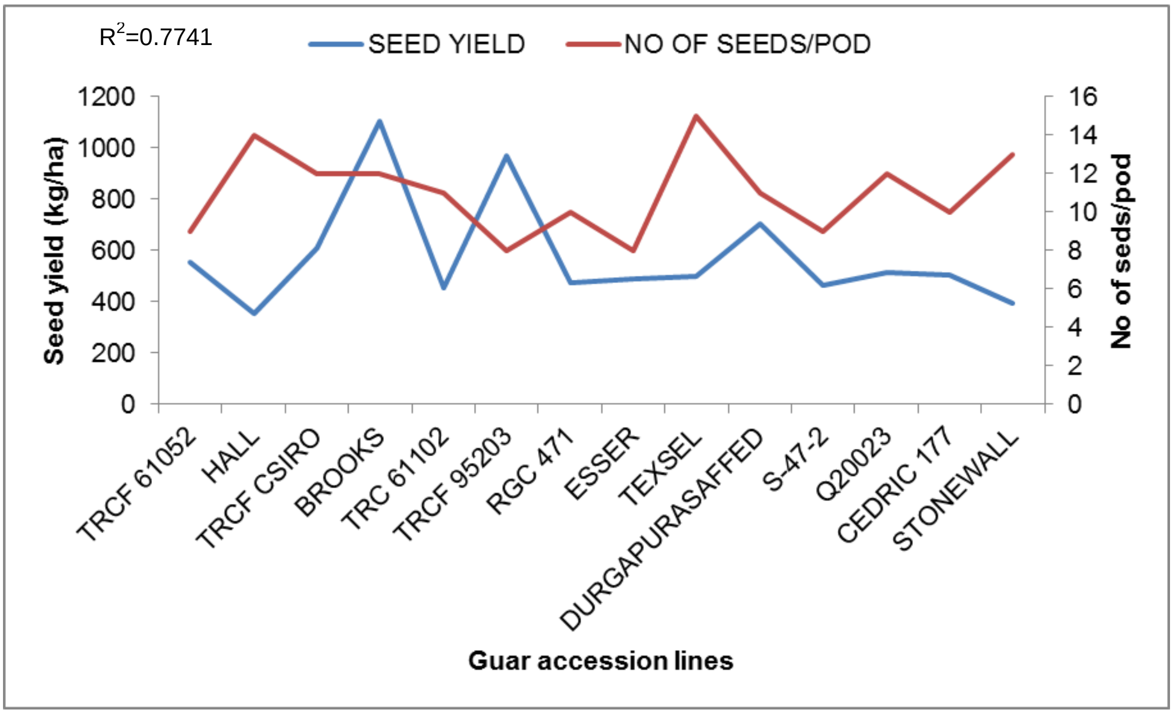

Figure 16: Seed yield versus number of seeds per pod at Syferkuil during 2006/7 growing season

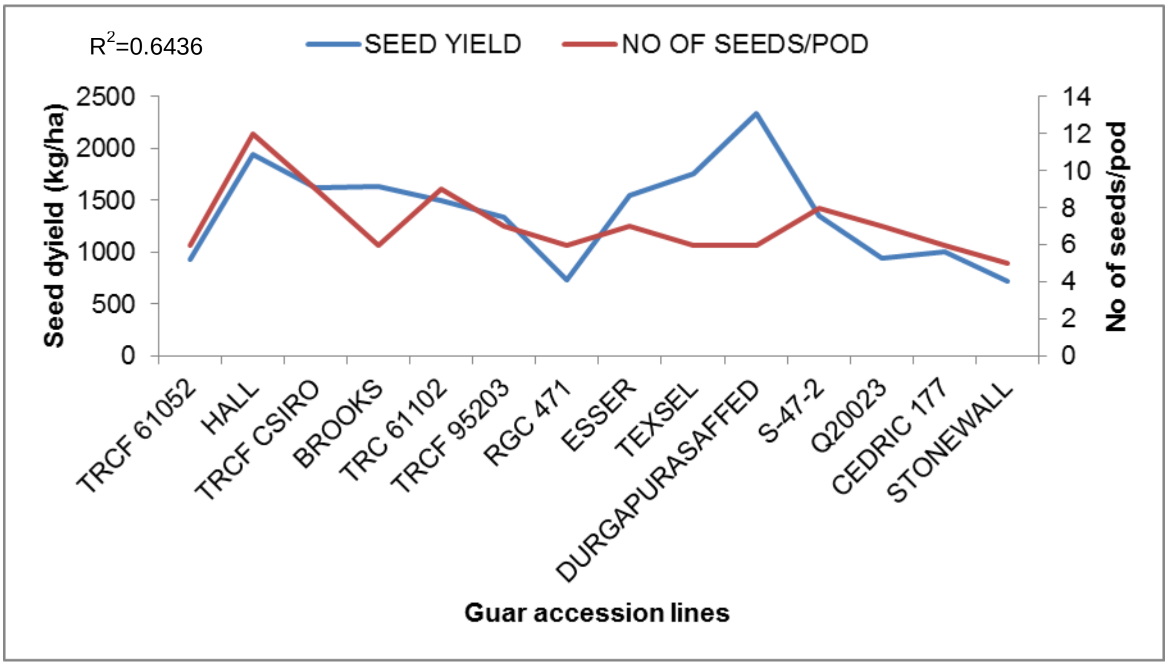

Figure 17: Seed yield versus number of seeds per pod at Tompi Seleka during the 2007/8 growing season

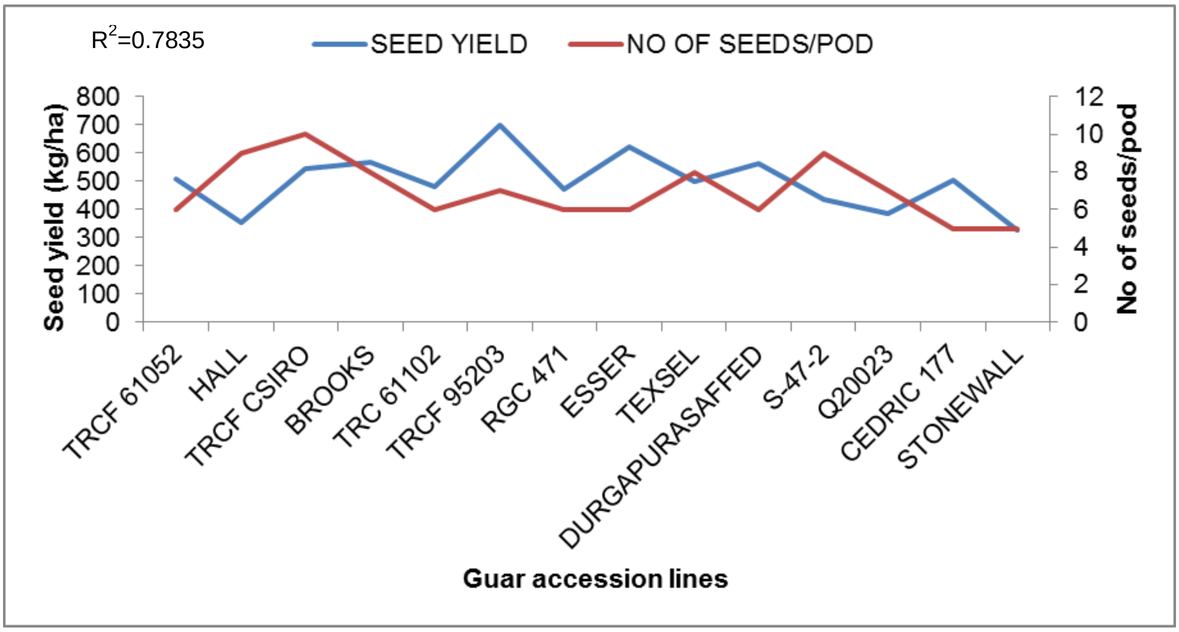

Figure 18: Seed yield versus number of seeds per pod at Syferkuil location during the 2007/8 growing season

Seed yield versus number of branches per plant: Number of branches per plant did not show any effect on seed yield. As shown in Figure 19, at Syferkuil 2006/7 experiment, the branching of varieties ranged from five to 15. Seed yield did not relate to the number of branches.

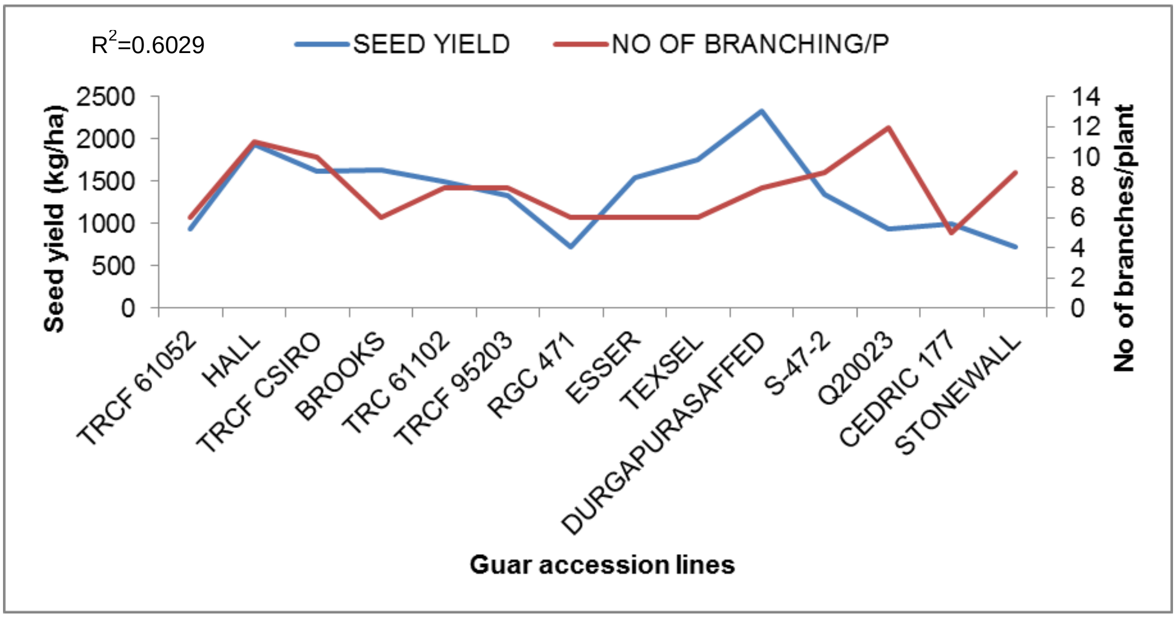

Figure 19: Seed yield versus number of branches per plant at Syferkuil during the 2006/7 growing season

In 2007/8 growing season, as shown in Figure 18 with Tompi Seleka experiment Hall variety with 1940.0 kg ha^{-1} of seed yield recorded 11.6 branches and Stonewall variety with 720 kg ha^{-1} of seed yield recorded nine branches per plant. In the same season 2007/8 at Syferkuil (Figures 20 and 21), TRCF 95203 variety with seed yield of 701.6 kg ha^{-1} recorded branching of nine and Stonewall with seed yield of 326.7 kg ha^{-1} also recorded 9 branches per plant. Thus on average, branching did not show effect on seed yield in the two locations over the two seasons.

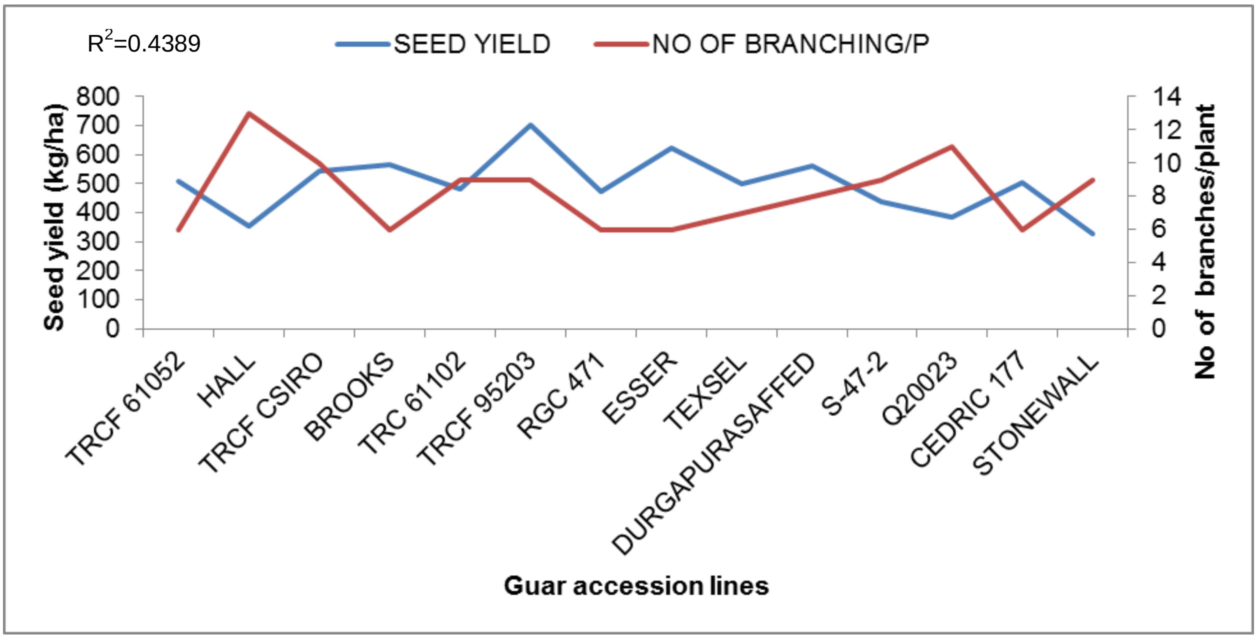

Figure 20: Seed yield versus number of branches per plant at Tompi Seleka during the 2007/8 growing season

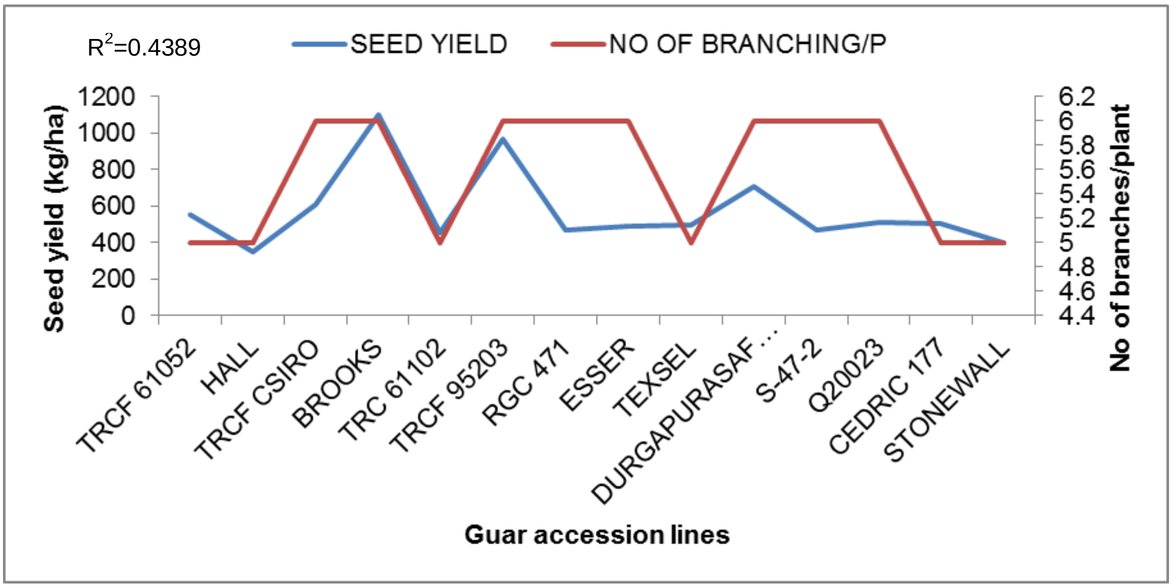

Figure 21: Seed yield versus number of branches per plant at Syferkuil during the 2007/8 growing season

Pearson's correlation coefficients: Correlation co-efficient analysis is shown in Table 10. Correlation on yield and growth parameters were done at different growth stage in both locations. Seed yield showed a strong positive correlation with yield components and dry matter components at Syferkuil and Tompi Seleka in the two seasons. However, there was a weak relationship of yield to number of branching per plant at Syferkuil in 2007/8 growing season. But at Tompi Seleka the relationship of yield and the yield components was very strong. Seed yield showed strong correlation with number of pods per plant giving R^2 values of 0.706, 0.505 and 0.710 at Syferkuil 2006/7, Tompi Seleka 2007/8 and Syferkuil 2007/8, respectively.

Table 10: Pearson's correlation co-efficient (r) for yield components of the 14 Guar accession lines

Syferkuil experimental farm 2006/7						
	DF	**DV**	**DM**	**NB**	**NP**	**NS**
DV	0.9903					
DM	0.9339	0.9234				
NB	0.5807	0.5900	0.5929			
NP	0.7783	0.7837	0.7468	0.6389		
NS	0.7628	0.7606	0.7468	0.5093	0.6714	
Y	0.7794	0.7914	0.8097	0.6029	0.8400	0.7741
Syferkuil experimental farm : 2007/8						
	DF	**DM**	**DV**	**NB**	**NP**	**NS**
DV	0.8879					
DM	0.9437	0.8577				
NB	0.1057	0.1245	0.0453			
NP	0.7347	0.7569	0.7676	0.0643		
NS	0.5812	0.6113	0.6406	0.0265	0.5870	
Y	0.7417	0.6977	0.7727	0.0607	0.7105	0.7835
Tompi Seleka experimental farm : 2007/8						
	DF	**DM**	**DV**	**NB**	**NP**	**NS**
DM	0.9616					
DV	0.9694	0.9268				
NB	0.6166	0.6163	0.6195			
NP	0.8199	0.7944	0.8422	0.5984		
NS	0.6601	0.6345	0.6661	0.4890	0.7231	
Y	0.7563	0.7082	0.7650	0.4389	0.8425	0.6436

(DM- Dry matter at maturity, DF- Dry matter at flowering, DV- Dry matter at vegetative, NB- number of branches/plant, NP- number of pods/plant, NS- Number of seeds/pod, Y- Seed yield)

4.4 Discussion

Seed yield

The results of this study showed good potential for economic guar bean production under Limpopo province conditions. Several lines performed well at both Syferkuil and Tompi Seleka. Adaptability of the crop plays a vital role in the response of the crop to the location. In terms of the crop production, adaptability refers to good crop performance over a range of geographic regions under conditions of variable climatic and environmental regimes (Stoskopf, 1981). Several factors greatly affect performance of a crop and are inclusive of climatic factors (rainfall and temperature), soil factors (ph, fertilizer) and cultural practices (sowing date, seed rate, weeding and harvesting methods) (Osman, 2001). In the current study, most of the guar lines performed well at Tompi Seleka, suggesting that climatic, and perhaps soil conditions there were better suited to guar growth and development. The major climatic difference between Syferkuil and Tompi Seleka was temperature. The maximum temperatures during guar growth at Tompi Seleka ranged from 30-31°C whereas at Syferkuil ranged from 26 – 29°C (Table 3). Thus Tompi Seleka was considerably warmer than Syferkuil. These results thus suggest that the lowveld of Limpopo has higher potential for guar production, provided moisture supply is adequate. Chapman and Pratt (1961) and Tyagi *et al*., (1982) also confirm that guar grows best under temperatures of up to 30°C.

The 14 guar accession lines showed significant differences in terms of their yield and response to the locations and seasons. Rankings of the guar lines showed wide variability in yield performance across seasons and locations. The only guar lines that were stable in their seed yield were TRCF 61052 and Durgapurasaffed that attained ranking positions of four or above across the two seasons and locations (Table 9). TRCF CSIRO was also stable attaining position four and five for the three plantings (Table 9). The yield potential varied widely and this tended to be greatly influenced by location effect. Seed yield of guar reported in literature are highly variable, ranging from less than 1000 kg ha^{-1} without irrigation (Tucker and Foraker, 1975) to 5000 kg ha^{-1} in irrigated plots (Beech., *et al*, 1989). The lines largely performed poorly at Syferkuil where only one line, Brooks attained a seed yield above 1000 kg ha^{-1} in 2006/7 and all lines had seed yield below 1000 kg ha^{-1} in 2007/8, where Brooks only managed to produce 701 kg ha^{-1}. However, the performance of several of the guar lines was much better with the highest yield being 2340 kg ha^{-1} and with seven lines achieving seed yield of 1500 kg ha^{-1} and above at Tompi Seleka. In fact 10 lines in all attained seed yields of 1000 kg ha^{-1} and above at this site. Only TRCF 61052, RGC 471, Stonewall and Q20023 had seed yield of less than 1000 kg ha^{-1} of 933, 733, 720 and 937 kg ha^{-1}, respectively. These four however performed much better at Tompi Seleka than their dismal seed yields at Syferkuil. On the basis of these limited data (Table 8), it may be concluded that most of the guar lines evaluated in this study have potential under lowveld conditions and further yield evaluation at several sites is needed before discarding any. However for other guar research purposes, the results from this study single out Brooks and Durgapurasaffed as the two lines with the highest potential under local conditions. However, acceptability of any guar variety should consider seed yield together with biomass and seed quality. Further evaluation should also indicate dryland production since the majority of SH farmers do not access irrigation facilities.

Dry matter

Another important aspect of evaluation of grain legumes is that of biomass as that can be very important when it comes to soil fertility amelioration. The plant material is worked into the soil to improve both nutrient level and soil structure. At Syferkuil 2006/7 growing season the three best performing varieties at maturity in terms of dry matter in ranking order was TRCF 95203 variety followed by Brooks and Stonewall in the third place. Undersander, *et al* (2006) also reported that Brooks is a high yielding variety and also resistant to some major diseases hence it is among the top performing varieties. In the 2007/8 growing season at Syferkuil TRCF CSIRO gave the highest dry matter at maturity and the lowest was Q20023.

At Tompi Seleka the highest performing variety with regards to dry matter yield at maturity was Durgapurasaffed and the lowest was variety TRCF 61052. In India Durgapurasaffed has been a successful variety for both grain and forage production (Bhan and Prasad, 1967). However, amongst the two locations during 2007/8 growing seasons, yield was highest at Tompi Seleka with Durgapurasaffed recording 13667 kg ha^{-1} at maturity. The better plant growth at Tompi Seleka shows that the guar crop has potential to ameliorate soil fertility problems on the smallholder irrigation schemes located in the lowveld of the Limpopo province. Soil fertility management has always been cited as a challenge for smallholder farmers (Ayisi, 2000). It is interesting to note that guar lines that exhibited low seed yield potential, such as Stonewall, showed much higher dry matter production at Tompi Seleka thus suggesting good value for use to ameliorate soil fertility. This suggests that evaluation of the guar lines should distinguish between seed yield and plant biomass.

Yield components

In the current study yield components were used to analyze the yield potential of the 14 accession lines. According to Evans (1993), the balance among the yield components is an important adaptive characteristic and is likely to differ across environments because yield components are determined sequentially, they often behave in a compensatory manner. Thus lower values for the components to be determined can result in almost perfect yield compensation (Evans, 1993). The association between yield and its components is often subtle and counter intuitive, and by no means always negative. It is the association between yield and the yield components in relation to environment and agronomy that is important (Ayaz *et al*., 2001). The number of pods per plant and the number of seeds per pod are not independent from each other. These factors are recognized as associated components of yield, for an increase in one component leads to a decrease in the other (Burger, 1984).

In this study, number of pods per plant was found to significantly influence seed yield, implying that it is an important parameter when selecting guar lines for seed yield potential in any given location. Previous studies of seed yield versus number of pods per plant have shown that the number of pods per plant is the yield component most closely associated with seed yield (Sinha, 1982; Withers, 1982; Ayaz *et al*., 2001). Stafford and Seiler (1986) also confirmed that the seed yield of guar can be closely related to the number of pods per plant.

The number of branches per plant among the 14 guar accession lines was statistically different only in the first season 2006/7 (Figure 9) at Syferkuil. At Tompi Seleka a higher number of branches per plant were recorded than at Syferkuil (Figure 10). But the average number of branches per plant was 7 for all 14 guar varieties. The number of branches per plant seemed to be associated with the vigour of plant growth. This study established very weak association between number of branches per plant with seed yield. This suggests that this parameter is not critical in the selection of high yielding guar varieties.

4.5 Conclusion

The results of the current study suggest that guar accession lines are adaptable to the hotter region of the Limpopo province under supplement irrigation. The hotter weather of Tompi Seleka favoured seed yield and plant biomass in the guar accessions evaluated. Most of the lines that performed poorly in terms of seed yield performed well in terms of plant biomass thus showing good potential for soil fertility amelioration. Selection of adaptable guar lines may therefore require consideration of both seed yield and biomass, particularly for the smallholder sector where soil fertility management is always a challenge. In line with findings of previous studies, the present study established the strong influence of number of pods per plant on guar seed yield. This parameter can therefore be considered important in evaluation and selection for high yielding guar varieties. There is need for further evaluation of the guar lines tested in this study, preferably in the lowveld of Limpopo province. It will also be necessary to evaluate these guar lines under dryland conditions. The current study did not evaluate seed quality. All future studies need to include this crucial aspect to ensure that only lines with acceptable quality are grown or used in further research. The results from the current study show good promise of the potential of guar as an additional commercial crop to smallholder farming in the Limpopo province.

CHAPTER 5

RESPONSE OF GUAR BEAN TO PHOSPHORUS LEVELS AND INOCULATION

5.1 Introduction

Legumes are P loving plants as they require P for growth and seed development, and most especially in N fixation which is energy driven. Furthermore, the use of fertilizer P is limited by its high cost, while organic inputs generally do not provide sufficient P for optimum crop growth due to their low P concentration (Aulakh *et al*., 2003). It is an important nutrient for providing cellular energy for biochemical synthesis in plants (Uyovbisere *et al*., 2000). Phosphorus has important effects on photosynthesis, N fixation, root development, flowering, seed formation, fruiting and development of crop quality (Brady et al., 1993). Legumes can fix between 11 – 120 kg N ha^{-1} (Sanginga, et al., 2000) but this is not achievable if there is low soil fertility and poor farming practices. With declines in soil fertility and widespread declines in soil pH in generally fragile soils, P limitation is becoming a serious constraint to plant production usually due to its fixation by the oxides of Fe and Al and their hydroxides (Moyin-Jesu, 2008). Legumes require relatively high amounts of P so as to provide good yield and to enhance seed quality

The fundamental practice of liming acids soils to the pH range of 6.5 to 7.0 is significant to the relationship between P and the symbiotic N fixation process. It improves the availability of soil P for plant absorption and creates a soil environment more favorable for beneficial bacteria such as different strains of *Rhizobium* (Sanginga, *et al*., 2000). Application of P as a fertilizer to soils where deficiency exists is essential as it is an ingredient for *Rhizobium* bacteria to convert atmospheric N (N_2) into an ammonium (NH_4) form usable by plants. *Rhizobium* is able to synthesize the enzyme nitrogenase, which catalyzes the conversion of N_2 to two molecules of ammonia (NH_3). Inadequate P restricts root growth, the process of photosynthesis, translocation of sugars and other functions which directly or indirectly influence N fixation by legume plants. Phosphorus influences nodule development through its basic functions in plants as an energy source.

Inoculating the guar crop with the appropriate strain of *Rhizobium* bacteria assists the legume to be able to fix a large portion of its N requirement from air in the soil. Inoculation of guar with *Rhizobium* enhance seed yield (Sighn and Sighn, 1991). Brokwell and Bottmely, 1995 in their study reported that inoculation of guar with *Rhizobium* on sandy loam soil elevated seed yield, seed gum, and protein content. Uninoculated plants grow poorly and may have numerous ineffective nodules, indicating nodulation by unsuitable native strains of bacteria. Inoculated plants are effectively nodulated and grow well, demonstrating that the inoculum strain was both competitive with the native strain for nodule sites and effective in N_2 fixation with the test host (Tittabutr, 2005). Therefore, inoculation of legumes is a practical means of ensuring effective N fixation (Date, 2000).

It is important and beneficial to know the extent and effectiveness of N fixation in legumes. The contribution made by fixed N to growth and yield of legumes depends on factors such as the amount of alternative sources of N (soil nitrate) available to plants, existence of effective or ineffective native japonicum population, soil moisture and other nutritional and environmental factors. Assessment of N fixation is an evaluation of the effects of specific interactions between the legume host, the Rhizobium strain and the environment.

Plant growth characteristics are some of the criteria used most frequently to evaluate inoculation in legumes. These include nodulation, dry matter production, seed yield and amount of N accumulated. The nodule number and nodule mass may be used as criteria for assessing nodulation response to inoculation. The reliability of this method is indicated by the fact that a high correlation is often found between nodule mass and indices of growth such as dry matter and N content. As an indicator of the effectiveness of N fixation, nodulation must be used with caution as it can be misleading. Singleton *et al*., (1985) found that strain USDA 110 produced substantially fewer nodules than the strain USDA 123 and SM-5, yet strain USDA 110 fixed significantly more N.

Yield could also be used to measure N fixed. During vegetative and early reproductive phase, dry matter production is the most reliable indicator of total N uptake (Brockwell *et al*., 1982). The relationship between dry matter and total N uptake is indicated by the significantly greater dry matter accumulation of effectively nodulated or N supplied plants compared to dry matter accumulation by ineffectively nodulated or non nodulated legumes. Dry matter yield is a reliable index of N fixation in a soil depleted of mineral N (Brockwell *et al*., 1982). Failure of the legume to respond to inoculation does not always indicate ineffective nodulation because fully symbiotic, partly symbiotic and non-symbiotic crops may have identical growth when soil nitrate levels are high (Herridge and Betts 1988). Hence the objective of experiment 2 was to determine the response of two guar varieties to inoculation and P fertilizer application.

5.2 Material and methods

Site and soil description

The experiment was carried out over two seasons, 2006/7 and 2007/8, at two locations: Syferkuil (23°51'S, 29°42'E) and one season (2007/8) at Tompi Seleka (24°58'70''S, 29°17'2.54''E). The structure and composition of the soil for Syferkuil and Tompi Seleka is shown Table 11 and 12. At Syferkuil the experiment was planted on the 7th of December 2006 and at Tompi Seleka 2007/8 it was planted on 14 December 2008. Syferkuil farm is the University of Limpopo research farm whilst Tompi Seleka, located in Sekhukhune district is a Limpopo Department of Agriculture Training Centre. The structure and composition of the soil for Syferkuil and Tompi Seleka is shown in Tables 11 and 12.

Table 11: **Soil chemical analyses before planting of the experiment at Syferkuil**

	Depths (cm)	
	0-15	15-30
pH (H_2O)	6.5	6.9
	Mg kg^{-1}	
TN	469	455
P(Bray 1)	35	39
K	120	135
Ca	540	550
Na	55	60
Mg	351	327

TN= total nitrogen, P=phosphorus, K=potassium, Ca=calcium, Na=sodium, Mg=magnesium

Table12: Soil chemical analyses before planting of the experiment at Tompi Seleka

	Depths (cm)	
	0-15	15-30
pH (H_2O)	6.5	6.9
	Mg kg^{-1}	
P(Bray 1)	5.6	7.9
K	30	33
Ca	135	170
Na	1	1.3
Mg	25	27

P=phosphorus, K=potassium, Ca=calcium, Na=sodium, Mg=magnesium

Experiment design and treatments

The trial was laid out as a split- split plot in a standardized randomized complete block design with four replications in two seasons. The experiment comprised of three treatment factors: two varieties, with inoculation and without inoculation, and three levels of P fertilizer. Variety was the main factor, inoculation (with and without) as the sub factor and the sub- sub factor was three levels of P fertilizer.

Main plot factor:	Variety	V_1 – Cedric
		V_2 – Stone wall
Sub-plot factor:	Phosphorus rate	P_1 – 0 kg ha^{-1} (Control)
		P_2 – 30 kg ha^{-1}
		P_3 – 60 kg ha^{-1}
Sub-sub plot factor:	Inoculation	I_1 – Inoculation (With)
		I_2 – Control (Without)

The seeds were inoculated with Bradyrhizobium CB756 (XS21) prior to seeding P fertilizer was applied as single super-phosphate (10.5% P) one week after planting. Each plot measured 3 m X 6 m. Seeds were sown manually at a spacing of 60cm X 30cm to give 5 rows of 6m length per plot. The crop was irrigated twice depending if it did not rain and the plots were kept weed free throughout the growing season.

Data collection

Above ground portions of six sampled plants were taken at 30, 60, 90 and 120 days after planting. They were sun dried for dry matter determination at different growth stages. Vegetative dry matter was taken at 30 to 35 days after planting and flowering was determined visually when 50% of the plants from the experimental unit had exposed flowers and physiological maturity was measured when the plants started losing moisture indicating browning for each experimental unit. Plant height was measured at physiological maturity on six plants. Seed yield was determined from 9 m^2 in the middle two rows of each experimental unit. Yield components were determined on four plants selected randomly from the harvested plants which were later returned to the bulk harvest to determine the grain yield. The components measured were number of pods per plant, seeds per pod, primary branches per plant and the seed yield.

Analysis of data

Data were subjected to analysis of variance (ANOVA) using the General Linear Model procedure of Statistical Analysis System (SAS, 2000). Differences between treatment means were separated using the Least Significant Difference ($LSD_{0.05}$) procedure (Gomez and Gomez, 1984). For interactions, LSD values were obtained by using Agrobase program (2000). Pearson's Correlation coefficients of yield and its components were also determined.

5.3 Results

Although there were no significant interactions found between the three factors variety, P and inoculation, P levels and inoculation as independent treatment factors showed statistically significant difference on guar performance. Variety did not influence response to P and inoculation.

Effect of P levels on guar bean

Phosphorus level of application showed significant effect on dry matter, seed yield, number of seeds per pod, number of branches per plant and number of pods per plant for the two locations: Syferkuil and Tompi Seleka as shown in Table 13.

Dry matter: Significant difference ($P \leq 0.05$) was shown between P application levels on dry matter at vegetative, flowering and maturity stages. Application of 60 kg P ha^{-1} out yielded 0 and 30 kg P ha^{-1} in terms of dry matter but o and 30 kg P ha-1 achieved similar dry matter. At Syferkuil in the 2006/7 season, application of 60 kg P ha^{-1} resulted in 96% and 69% higher dry matter than the control treatment at vegetative and maturity stages, respectively (Table 13). In the 2007/8 season at Syferkuil, 60 kg P ha^{-1} recorded 39% higher dry matter than the control at physiological maturity. At Tompi Seleka in the 2007/8 season, the highest dry matter during all growth stages was also recorded with application of 60 kg P ha^{-1} while the lowest dry matter was achieved by the control treatment. Again there was significantly ($P \leq 0.05$) higher than 30 kg P ha^{-1} and the control treatment.

Table13: Effect of phosphorus levels on dry matter at vegetative, flowering and maturity stage of two guar accession lines at Syferkuil for 2006/7- 2007/8 and Tompi Seleka for 2007/8 growing seasons

Treatments	**Dry matter – Syferkuil (kg ha^{-1}) 2006/7**			**Dry matter– Syferkuil (kg ha^{-1}) 2007/8**			**Dry matter – Tompi Seleka (kg ha^{-1}) 2007/8**		
	DM at vegetative	DM at Flowering	DM at Maturity	DM at vegetative	DM at Flowering	DM at Maturity	DM at vegetative	DM at Flowering	DM at Maturity
0	3411 b	3543b	4191 b	546 c	690 b	796 b	5318 b	5786 b	6160 c
30	3744 b	3828 b	4631b	604 b	765 b	828 b	5436 b	5916 b	6750 b
60	6694 a	6834 a	7097 a	993 a	1147 a	1303 a	8528 a	9173 a	10008 a
Significance	**	**	**	***	***	***	***	***	***
$LSD_{0.05}$	612	565	612	125	133	153	573	672	570.4
CV%	17	15	14	22	19	20	11	12	9.6
Varieties									
Cedric	4382 a	4694 a	5297a	714 a	847 a	966a	6568a	7163 a	7707 a
Stonewall	4851 a	4777 a	5315 a	715 a	887 a	985 a	6287 a	6754 a	7571 a
Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns
$LSD_{0.05}$	-	-	-	-	-	-	-	-	-
CV%	10	10	19	26	29	21	21	16	13

*, **, ***=Significantly different at the P≤ 0.05, P≤ 0.01 P≤ 0.001, respectively, ns=Non Significant, CV%=Coefficient of Variation, Means followed by same letter in a column do not differ significantly at P=0.05

Yield components

Number of seeds per pod: The number of seeds per pod was significant different ($P \leq 0.05$) as influenced by P application at both locations (Table 14). At Syferkuil in 2006/7, the highest number of seeds per pod of 8 was achieved with 60 kg P ha^{-1} compared to five seeds per pod at 30 kg P ha^{-1} and zero P application. Response similar to the 2006/7 season was observed at Syferkuil in 2007/8 season. At Tompi Seleka, the highest number of seeds per pods was recorded with 60 kg P ha^{-1} with nine seeds per pod.

Number of branches per plant: The number of branches per plant was significantly influenced ($P \leq 0.05$) by P application at Tompi Seleka (2007/8) and Syferkuil farm (2006/7). In both cases, 60 kg P ha^{-1} resulted in significantly more branches per plant than 30 kg P ha^{-1} and the control (Table 14). Phosphorus application rate did not influence branching at Syferkuil in the 2007/8 growing season (Table 14).

Number of pods per plant: Phosphorus application rate significantly ($P \leq 0.05$) influenced the number of pods per plant (Table 14). At Syferkuil in 2006/7and 2007/8 growing seasons, the highest number of pods was recorded at 60 kg P ha^{-1} being 55% and 46% higher than the control in the respective seasons. At Tompi Seleka, the highest number of pods per plant of 222 was recorded at 60 kg P ha^{-1} followed by 154 and 140 pods per plant at 30 kg P ha^{-1} and the control, respectively (Table 14). This was significantly larger than the control and 30 kg P ha^{-1}. Application of 30 kg P ha^{-1} and the control did not differ in number of pods per plant in the 2007/8 season at both sites.

Table 14: Effect of phosphorus levels on number of pods per plant of guar accession lines at Syferkuil for 2006/7- 2007/8 and Tompi Seleka for 2007/8 growing season

Treatment	**No of Pods per plant**			**No of Seeds per pod**			**No of branches per plant**		
Phosphorus	Syferkuil 2006/7	Syferkuil 2007/8	Tompi 2007/8	Syferkuil 2006/7	Syferkuil 2007/8	Tompi 2007/8	Syferkuil 2006/7	Syferkuil 2007/8	Tompi 2007/8
0	78 c	31 b	140 b	5b	6b	6 b	6 b	7	6 b
30	117 b	31 b	154 b	5 b	6 b	7 b	6 b	7	6 b
60	175 a	58 a	222 a	8 a	8 a	9 a	8 a	7	8 a
Significance	***	**	***	**	**	**	**	ns	**
$LSD_{0.05}$	16	2	14	1	1	1	1	2	1
CV%	17	9	10	11	14	20	13	33	13
Varieties									
Cedric	130 a	40	173	7	7	8	7	7	7
Stonewall	116 b	41	171	6	6	7	6	6	6
Significance	*	ns	ns	ns	ns	ns	ns	ns	ns
$LSD_{0.05}$	-	-	-	-	-	-	-	-	-
CV%	6	12	3	10	9	14	19	15	19

*, **, ***=Significantly different at the P≤ 0.05, P≤ 0.01 P≤ 0.001, respectively, ns=Non Significant, CV%=Coefficient of Variation, Means followed by same letter in a column do not differ significantly at P=0.05

Seed Yield

Seed yield: Highly significant ($P \leq 0.01$) differences were found in seed yield with phosphorus fertilizer application at both locations (Table 15). At Syferkuil in 2006/7 and 2007/8 and at Tompi Seleka in 2007/8, the highest seed yield was obtained at 60 kg P ha^{-1} and these were significantly higher than 30 kg P ha^{-1} and the control in all the three plantings. In the 2007/8 season, 60 kg P ha^{-1} achieved seed yield of 133 and 38% higher than the control at Syferkuil and Tompi Seleka, respectively. The control and 30 kg P ha-1 achieved similar seed yields in this season. In 2006/7 there were significant ($P \leq 0.05$) different in seed yield between all three P level. Seed yield did not differ significantly as influenced by both varieties

Table 15: Effect of phosphorus levels on seed yield of guar accession lines at Syferkuil for 2006/7- 2007/8 and Tompi Seleka for 2007/8 growing season

Treatment	**Seed yield kg ha^{-1}**		
Phosphorus	Syferkuil 2006/7	Syferkuil 2007/8	Tompi Seleka 2007/8
0	295 c	244 b	948 b
30	393 b	280 b	995 b
60	701 a	569 a	1523 a
Significance	***	**	***
$LSD_{0.05}$	48	72	152
CV%	13	25	17
Varieties			
Cedric	460	352	1165
Stonewall	466	377	1145
Significance	ns	ns	ns
$LSD_{0.05}$	-	-	-
CV%	10	25	116

*, **, ***=Significantly different at the $P \leq 0.05$, $P \leq 0.01$ $P \leq 0.001$, respectively, ns=Non Significant, CV%=Coefficient of Variation, Means followed by same letter in a column do not differ significantly at P=0.05

Effect of Inoculation

Inoculation treatment showed significantly higher ($P \leq 0.05$) dry matter, number of pods per plant and seed yield at both Syferkuil and Tompi Seleka in the two seasons.

Dry matter: inoculated plants gave significantly superior ($P \leq 0.05$) dry matter at all growth stages in the 2007/8 growing season at the two locations. In 2006/7 season at Syferkuil, inoculation only showed increased dry matter at physiological maturity (Table 16) where the inoculated treatment had 5592 kg ha^{-1} compared to 5020 kg ha^{-1} for the control, an increase of 11.4%.

In addition, at Syferkuil in the 2007/8 season, inoculation resulted in 23% and 19% higher dry matter than the control at the vegetative and maturity stages, respectively (Table 16). At Tompi Seleka inoculation resulted in 28% higher dry matter than the control. Much higher dry matter were at Tompi Seleka in 2007/8 season than at Syferkuil (Table16).

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Table 16: Effect of inoculation on dry matter at vegetative, flowering and maturity stages of guar accession lines at Syferkuil for 2006/7- 2007/8 and Tompi Seleka for the 2007/8 growing seasons

Treatments	Dry matter – kg ha^{-1} – Syferkuil 2006/7			Dry matter – kg ha^{-1} – Syferkuil 2007/8			Dry matter – kg ha^{-1} – Tompi Seleka 2007/8		
	DM at vegetative	DM at Flowering	DM at Maturity	DM at vegetative	DM at Flowering	DM at Maturity	DM at vegetative	DM at Flowering	DM at Maturity
With	4851 a	4956 a	5592 a	809 a	947 a	1084 a	7491 a	7969 a	8664 a
Without	4382 a	4515 a	5020 b	620 b	787 b	868 b	5363 b	5948 b	6614 b
Significance	ns	ns	*	***	***	***	***	***	***
$LSD_{0.05}$	-	-	395	80	91	129	524	507	642
CV%	17	18	12	18	17	21	13	12.	14

*, **, ***=Significantly different at the P≤ 0.05, P≤ 0.01 P≤ 0.001, respectively, ns=Non Significant, CV%=Coefficient of Variation, Means followed by same letter in a column do not differ significantly at P=0.05

Number of pods per plant: Inoculated plants had significantly (P≤0.05) more pods per plant than uninoculated ones in both seasons at Syferkuil (Table 17). Inoculated plants had 16% and 44% higher number of pods per plant than the control in the first and second seasons, respectively. At Tompi Seleka, the uninoculated plants recorded 30.6% higher number of pods than the inoculated plants (Table 17).

Number of seeds per pod: The number of seeds per pod showed significant differences due to inoculation at Tompi Seleka only (Table 17). At Tompi Seleka, eight seeds per pod were recorded with inoculation while uninoculated plants averaged seven seeds per pod. In both seasons at Syferkuil, inoculated and control had average number of six seeds per pod.

Number of branches per plant: Inoculation did not influence the number of branches per plant at all the locations for the two seasons (Table 17). At Syferkuil both treated and untreated plants gave seven and six branches per plant in both seasons, respectively. The trial at Tompi Seleka also recorded five and eight branches per plant for both inoculated and control plants, respectively.

Table 17: Effect of inoculation on number of pods per plant, number of seeds per plant and number of branches per plant of guar accession lines at Syferkuil for 2006/7-2007/8 and Tompi Seleka for 2007/8 growing season

Treatment	**No of pods per plant**			**No of seeds per pod**			**No of branches per plant**		
Inoculation	Syferkuil 2006/7	Syferkuil 2007/8	Tompi Seleka 2007/8	Syferkuil 2006/7	Syferkuil 2007/8	Tompi Seleka 2007/8	Syferkuil 2006/7	Syferkuil 2007/8	Tompi Seleka 2007/8
With	134 a	52 a	154 b	6 a	6 a	5 b	7 a	7 a	5 b
Without	112 b	29 b	222 a	6 a	6 a	7 a	6 a	6 a	8 a
Significance	*	**	***	ns	ns	***	ns	ns	**
$LSD_{0.05}$	12	2.8	14.4	-	-	2.1	-	-	0.6
CV%	16	11.3	10.8	10.2	11.6	10.1	25.9	33.2	13.1

*, **, ***=Significantly different at the P≤ 0.05, P≤ 0.01 P≤ 0.001, respectively, ns=Non Significant , CV%=Coefficient of Variation, Means followed by same letter in a column do not differ significantly at P=0.05

Seed Yield: Seed yield showed significant increase ($P \leq 0.05$) with inoculation. In the 2006/7 season at Syferkuil, inoculated plants recorded seed yield of 506.0 kg ha^{-1} and the plants without inoculation recorded seed yield of 421.0 kg ha^{-1}. Thus the inoculated seeds recorded 16% higher seed yield than the uninoculated seeds (Table 18).

In the 2007/8 growing season at Syferkuil inoculated plants recorded 15 % higher seed yield than the uninoculated plants and at Tompi Seleka the highest seed yield was recorded with inoculated plants recording 21% more yield than uninoculated plants. The seed yields at Tompi Seleka were higher than those at Syferkuil.

Table18: Effect of inoculation on seed yield of guar accession lines at Syferkuil for 2006/7 and 2007/8 and Tompi Seleka for 2007/8 growing season

Treatment	**Seed yield kg ha^{-1}**		
Inoculation	Syferkuil 2006/7	Syferkuil 2007/8	Tompi Seleka 2007/8
With	506 a	396 a	1293 a
Without	421 b	333 b	1017 b
Significance	*	*	***
$LSD_{0.05}$	46	40	154
CV%	16	18	22

*, **, ***=Significant at the $P \leq 0.05$,$P \leq 0.01$ $P \leq 0.001$, respectively., ns=Non Significant, CV=Coefficient of Variation

Effect of interaction of guar varieties with phosphorus and guar varieties with inoculation

Interaction of guar varieties and phosphorus and variety with inoculation were statistically different ($P \leq 0.05$). Interaction between P levels and guar varieties observed during 2006/7 and 2007/8 at Syferkuil indicated that increase in P levels resulted in increase in seed yield in both Stonewall and Cedric (Table 19). Variety Cedric with 60 kg P ha^{-1} produced the highest seed yield during 2006/7 season while in 2007/8, Stonewall with 60 kg P ha^{-1} yielded highest seed yields. Interaction between P levels and guar varieties also exhibited significant effect on the number of seeds per pod, number of branches per plant and number of pods per plant during both seasons at Syferkuil. Guar varieties and P levels interaction also showed significant differences in seed yield, number of seeds per pod, number of branches per plant and number of pods per plant during 2007/8 season at Tompi Seleka.

Inoculation and guar varieties interaction indicated significant differences in seed yield and also number of pods per plant in both seasons at Syferkuil (Table 19). At Tompi Seleka, seed yield, number of seeds per pod and number of pods per plant were significantly influenced by inoculation and guar varieties interaction during 2007/8 season.

Guar varieties X P levels interaction effect on the dry mater at vegetative, flowering and maturity stage was significant during 2006/7 and 2007/8 growing seasons at Syferkuil (Table 20). Furthermore, interaction between guar varieties and P levels on the dry mater at vegetative, flowering and maturity stage was also significant different at Tompi Seleka during 2007/8 season.

Dry mater at vegetative and maturity stage was significantly influenced by inoculation X guar variety interaction during 2006/7 season at Syferkuil. During 2007/8 growing season, there was inoculation X guar variety effect on dry mater at vegetative, flowering and maturity stage at Syferkuil (Table 20). At Tompi Seleka, dry mater at vegetative, flowering and maturity stage were also significantly influenced by inoculation X guar variety interaction during the 2007/8 season.

Table 19: Interaction of variety and phosphorus, variety and inoculation on seed yield, number of pods per plant, number of seeds per pod and number of branches per plant of guar accession lines varieties at Syferkuil for 2006/7- 2007/8 and Tompi Seleka for 2007/8 growing season

Treatments		Syferkuil 2006/7				Syferkuil 200708				Tompi Seleka 2007/8			
		Seeds Yield kg ha^{-1}	No of Seeds/ pod	No of Branches/plant	No of Pods/plant	Seeds Yield kg ha^{-1}	No of Seeds/ pod	No of Branches/plant	No of Pods/plant	Seeds Yield kg ha^{-1}	No of Seeds/ pod	No of Branches /plant	No of Pods/plant
Kg P ha^{-1}	**Varieties**												
0	S/wall	311 c	5 b	5 c	67 d	232 b	5 b	6 ab	31.7 b	853 b	6 bc	5.6 cd	139 c
0	Cedric	278 c	5 b	5 c	88 c	257 b	6 b	7 a	32.1 b	1044 b	7 ab	5.3 d	141 bc
30	S/wall	402b	5 b	6 bc	108 bc	283 b	5 b	5 b	32.7 b	971 b	7 ab	5.0 d	148 bc
30	Cedric	385 b	5 b	5 c	125 b	277 b	5 b	7 a	30.5 b	1018 b	5 c	6.9 bc	161 b
60	Cedric	717 a	8 a	7 ab	176 a	522 a	8 a	6 ab	59.1 a	1434 a	8 a	7.6 ab	218 a
60	S/wall	685 a	7 a	8 a	173 a	616 a	8 a	7 a	58.7 a	1612 a	8 a	8.6 a	226 a
S/ficance		*	*	*	*	*	*	*	*	*	*	*	*
$LSD_{0.05}$		67	0.8	0.9	22	101	1.0	2	4.0	215.8	1	1	20
CV%		13	11	13	17	25	20	13	10	17	20	13	10
Inoculation	**Varieties**												
With	S/hall	510 a	6 a	6a	126 b	405 a	6 a	6 a	53 a	1309 a	7 ab	6 a	201 a
With	Cedric	501 a	6 a	7 a	142 a	288 c	6 a	6 a	52a	1278 a	8 a	7a	200a
Without	S/hall	422 b	6.0 a	6 a	105 c	350 b	6 a	6 a	29.1 b	981 b	6 c	6 a	141 b
Without	Cedric	419 b	6.5 a	6 a	118bc	316 bc	6 a	7 a	28 b	1053b	6 bc	6 a	147 b
S/ficance		*	ns	ns	*	*	ns	ns	*	*	*	ns	*
$LSD_{0.05}$		-	-	-	17	57	-	-	-	-	0.9	-	-
CV%		16.6	10.2	25.9	16.4	18.4	14.3	25.9	9.5	22.1	14.3	25.9	9.5

*, **, ***=Significantly different at the p≤ 0.05, P≤ 0.01 P≤ 0.001, respectively, ns=Non Significant , CV%=Coefficient of Variation, Means followed by same letter in a column do not differ significantly at P=0.05 S/hall= Stone hall, S/ficance=significance

Table 20: Interaction of guar varieties to phosphorus and inoculation on dry matter at vegetative, flowering and maturity stages of guar accession lines at Syferkuil for 2006/7- 2007/8 and Tompi Seleka for 2007/8 growing seasons

		Dry matter Kg ha^{-1} -Syferkuil 2006/7			Dry matter Kg ha^{-1} Syferkuil 2007/8			Dry matter Kg ha^{-1} Tompi Seleka 2007/8		
		DM at Vegetative	DM at Flowering	DM at Maturity	DM at Vegetative	DM at Flowering	DM at Maturity	DM at Vegetative	DM at Flowering	DM at Maturity
Kg P ha^{-1}	**Varieties**									
0	S/wall	3627 bc	3660 b	4268 b	557 b	73 b	823 b	5438 b	5806 b	6290 b
0	Cedric	3196 c	3427 b	4115 b	535 b	666 b	769 b	5197 b	5765 b	6030 b
30	S/wall	3978 b	4037 b	4727 b	578 b	755 b	776 b	5801 b	5600 b	6700 b
30	Cedric	3510 bc	3620 b	4535 b	631 b	775. b	881 b	5072 b	6233 b	6799 b
60	Cedric	6858 a	7035 a	7241 a	975 a	1101 a	1250 a	8705 a	9492 a	10 293a
60	S/wall	6530 a	6634 a	6952 a	1011 a	1192 a	1356 a	8350 a	8855 a	9723 a
S/ficance		***	*	*	*	*	*	*	*	*
LSD $_{0.05}$		-	-	-	-	-	-	-	-	-
CV%		17.2	15.5	14.9	11.5	12.5	9.6	11.5	12.5	9.6
Inoculation	**Varieties**									
With	S/wall	4995 a	5043 a	5690 a	768 ab	916 ab	1077 a	7265 a	7751 a	8386 a
With	Cedric	4707 a	4868 a	5495 ab	849 a	978 a	1090 a	7717 a	8186 a	8948 a
Without	S/wall	4428 ab	4510 a	4941 c	662 bc	857 ab	893 ab	5309 b	5756 b	6756 b
Without	Cedric	4335 b	4520 a	5099 bc	578 c	717 b	843 b	5418 b	6140 b	6473 b
S/ficance		*	ns	*	*	*	*	*	*	*
LSD $_{0.05}$		-	-	-	114		-	-	-	-
CV%		17	18	12	13	12	13	13	12	13

*, **, ***=Significantly different at the P≤ 0.05, P≤ 0.01 P≤ 0.001, respectively, ns=Non Significant , CV%=Coefficient of Variation, Means followed by same letter in a column do not differ significantly at P=0.05 S/hall= Stone hall, S/ficance=significance

5.4 Discussion

Effect on Guar Varieties

Both varieties responded to P levels and inoculation indicating the need for both P application and inoculation of guar under Limpopo condition.

Effect of phosphorus

Seed yield

In the current study the crop showed good responses to P application levels of 60 kg ha^{-1} as it increased seed yield. Phosphorus application probably significantly increased N fixation of the guar bean varieties even though legumes have been reported to respond differently to the P application in their ability to fix atmospheric N (Singleton *et al*., 1985). The presence of P was found to stimulate early development of nodule tissue which contributed not only to earlier onset of N fixation but also to longer functioning of the nodules. Kumar and Kushwaha (2006) also reported that increase in P application, increased the yield significantly. Sanginga *et al*., 2000, also made similar observations. From intial soil nutrient status of the two sites, response to P application was expected to be more pronounced only at Tompi Seleka where P was as high as 5.6 mg ha^{-1}. The Syferkuil site had 3.5 mg kg^{-1} of P

Yield components

Yield components such as number of pods $plant^{-1}$ and number of branches per plant were highly significantly greater at 60 kg ha^{-1} of P than zero application of P and these components are positively correlated to yield. Increase in these parameters by the application of P clearly indicated the influence of P on guar growth and yield. These findings conform to the findings of Rao and Reddy (1997) on pigeon pea and Sign *et al*., (1981) on field pea. Sharma *et al.,* (2001) indicated that the mung bean crop's photosynthetic efficiency was influenced by P application. The highest value of all yield parameters was recorded with the application of 60 kg P_2O_5 ha^{-1}. As the plant has a well-developed root system due to P fertilization there is higher possibility of fixation of atmospheric N and ultimately it may influence photosynthetic efficiency at various stages and increase yield. Moreover, Tompi Seleka crops outperformed crops from Syferkuil thus indicating the effect of variability in terms of climate and nutrient status of the soil. Muhammad *et al.*, (2009) indicated that guar production is greatly affected by climatic (rainfall and temperature), soil and cultural practices e.g.

sowing date, seed rate, plant spacing, sowing methods, weeding and harvesting methods.

The highest number of pods per plant were recorded with 60 kg P ha^{-1} at Syferkuil and Tompi Seleka. Generally a legume dominant stand shows better response to P application because they obtain their N requirements via symbiotic pathways (Miller and Reetz, 1995). Application of P increased number of pods per plant and seeds per pod significantly. Ahmed *et al*. (1986) observed that phosphorus application up to 60 kg ha^{-1} progressively and significantly enhanced the growth and yield parameters of mung bean. The responses to P application in this study and those of other legumes cited from literature clearly show the need o P application and the general optimum application rate of 60 kg P ha^{-1} is widely reported.

Dry Matter

Guar bean dry matter increased with increased level of P level. In most instances there were no differences in dry matter yield between the control and 30 kg P ha^{-1} but there were significantly lower than at 60 kg ha^{-1}. This suggests the successful, and perhaps sustainable, guar production requires application of around 60 kg P ha^{-1}, but depend on initial soil P status.

Effect of Inoculation

Seed Yield

Legumes with their capability of fixing nitrogen have the ability to give higher yields but inoculating the legume seeds gives the crop an added advantage of good performance. Even through visual observation on the experiments in both locations the plots that were inoculated were greener than the uninoculated plants.

Inoculation of seeds had a highly significant effect on yield and yield parameters as compared to the control treatment. Inoculated seeds performed beter at both locations. Sighn and Sighn (1981) indicated that inoculation of guar with *Rhizobium* enhances seed yield. The positive effect of inoculation was indicated by the fact that all inoculated treatments accumulated greater dry matter and higher seed yield than the uninoculated control. However the differences between inoculated and uninoculated treatments were not significant in some cases like number of seeds per pod and number of branches per plant at both locations.

Yield components

Seed yield of guar varieties varied significantly due to different P application. Seed yield of both guar varieties increased with increased P application levels to 60 kg P ha^{-1} at both locations. Other yield parameters such as number of pods per plant also responded to P application. The response among the yield parameters may be due to nitrogen fixation by guar varieties as influenced by P application.

Inoculated treatments in the current study produced higher seed yield compared inoculated treatments. For example, Stonewall increase seed yield from uninoculated to inoculated treatment by 20.9% at Syferkuil while Cedric increased by 19.5%. Furthermore, at Tompi Seleka, there were 33.4 and 21.4% increase from uninoculated to inoculated treatment in Stone hall and Cedric variety, respectively. According to Malik *et al* (2006) inoculating legume seeds increases yield by 19.6 % compared to the control treatment. Number of pods per plant were also higher within inoculated treatment compared to uninoculated treatment.

Dry matter

There was positive response of both varieties to inoculation. The highest dry matter was obtained from the inoculated seeds whereas the lowest values were obtained from the un-inoculated treatment. Increment on dry matter at all growth stages obtained from current study might be due to nitrogen fixation by rhizobium. Patel and Patel, (1991), indicated that the positive effect of inoculation was indicated by the fact that all inoculated treatments of green gram accumulated greater dry matter, total N total P and had higher seed yield than the uninoculated control.

Literature indicates that when leguminous plants are sown, inoculation always increases production in terms of both yield and quality (Goss and Shipton, 1965). The positive relationship of yield with inoculation could be related to the N fixation ability of nodules which consequently results in increased growth and yield. Similar results were found by Maiti *et al*., (1988), Bengtson (1989) and David (1991) compared well with the results of this study.

The effect of the interaction of guar cultivars to phosphorus levels and inoculation was not significant as indicated by the ANOVA results but greatly affected by P fertility and inoculation. Interaction between phosphorus fertilizer and guar bean showed that the crop responded to P application. The effect of inoculation on dry matter was greatly affected by P fertility. There was no significant effect of P fertilization at the lowest rate. However plants inoculated had significantly more dry matter especially when fertilized with 60 kg ha^{-1}. Application of P and inoculation gave the highest seed yield, yield components and dry matter. However inoculating seeds with 30 kg P ha^{-1} increased yield and at 60 kg P ha^{-1} yield was the highest. Malik *et al*., (2006) also reported highest yield on soya bean as a result of P and inoculation. Mandal and Sikder (1999) also reported that the growth and yield increased significantly with the application of P and inoculation. The combination of P fertilizer and inoculation showed to give the highest seed yield at Syferkuil.

Interaction

Interaction between P fertilizer and guar bean showed that the crop responded to P application. The effect of inoculation on dry matter was greatly affected by P fertility and there was significant effect of P fertilization at lowest rate. However plants inoculated respectively had significant dry matter especially when fertilized by 60 kg P ha^{-1} (Appendix C). Application of P and inoculation gave the highest seed yield, yield components and dry matter. 30 kg P ha^{-1} and the control treatment had the same effect (Appendix C). However, 30 kg P ha^{-1} with inoculation increased yield and highest yield was obtained at 60 kg P ha^{-1}. In the Syferkuil experiment, the combination of 60 kg P ha^{-1} and inoculation resulted highest yield.

5.5 Conclusion

Study indicates that P fertilizer and inoculation are very important factors for increased guar yield. The application of P is essential for production of more dry matter. The yield and biomass was maximized when 60 kg P ha^{-1} was applied. In areas with low P content, 60 kg P ha^{-1} should be recommended. Furthermore, application of 60 kg P ha^{-1} and *Rhizobium* strain inoculants resulted in a high yield than the control treatment. For successful guar production, there is need for application of both inoculant and P. inoculation is fairly cheap technology which is unlikely to financially strain even smallholder farmers.

CHAPTER 6

SUMMARY, CONCLUSION AND RECCOMENDATION

The experiments were conducted at two locations in Limpopo Province namely: Syferkuil and Tompi Seleka in two seasons 2006/7 and 2007/8. This study comprised of two experiments i) to evaluate the growth and yield of 14 exotic guar bean varieties and ii) to determine the response of guar varieties to P level and inoculation. The attempted survey which was supposed to be part of the study was unsuccessful due to unreliable responses and lack of responses in some cases from institutions which are presumably protecting their commercial interest. A comprehensive survey on guar flour usage remains an important gap as that information is necessary to guide researchers in future research on guar (Appendix B).

In the varietal evaluation experiment it was shown that guar bean is a potential industrial crop that is highly adapted to conditions in the Limpopo province. The 14 guar accession lines differed significantly in yield at both locations. At Tompi Seleka considerably higher yield were recorded at Syferkuil. At Syferkuil in 2006/7 Brooks variety recorded the highest seed yield of 1103 kg ha^{-1} while Hall achieved lowest seed yield of 353 kg ha^{-1}. During 2007/8 TRCF 95203 recorded highest seed yield of 701 kg ha^{-1} and Stonewall recording the lowest seed yield of 326 kg ha^{-1}. In Tompi Seleka in the same season the highest was Durgpurasaffed variety (2340 kg ha^{-1}) and lowest with Stonewall (720 kg ha^{-1}). The three varieties which were consistent in performance and are amongst the highest five performing varieties in order of their ranking were Brooks, Durgapurasaffed and TRCF CSIRO. These are the varieties that may be considered for future guar agronomic trials. However, all 14 accessions still need to be tested at more sites in warmer parts of the Limpopo Province.

The application of 60 kg ha^{-1} of superphosphate significantly increased yield and biomass in guar production compared to zero application of P. In areas with low P content, application of P at 60 kg ha^{-1} should be recommended. Also, the application of Rhizobium strain provided increased number of nodules but the application of P and *Rhizobium* strain provided the highest yield than plots with no P. Rhizobium inoculation is important for atmospheric N fixation. Future experiments should consider inclusion of:

i) Test in these guar accession under dryland conditions
ii) Levels of P higher than 60 kg P ha^{-1},
iii) Include nodulation data,
iv) Quality evaluation of guar seed and
v) Conducting basic growth margin analysis on P and inoculation of guar

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APPENDIX- A

ANOVA TABLES

VARIETY EVALUATION EXPERIMENT - SYFERKUIL 2006/7 GROWING SEASON

Randomized Complete Block AOV Table for SW

Source	DF	SS	MS	F	P
REP	2	49942	24971		
VARIET	13	1775525	136579	6.94	0.0000
Error	26	511552	19675		
Total	41	2337019			

Grand Mean 578.79 CV 24.23

Randomized Complete Block AOV Table for PH

Source	DF	SS	MS	F	P
REP	2	46.33	23.1667		
VARIET	13	151.14	11.6264	0.30	0.9865
Error	26	1005.00	38.6538		
Total	41	1202.48			

Grand Mean 63.810 CV 9.74

Randomized Complete Block AOV Table for NS

Source	DF	SS	MS	F	P
REP	2	0.1429	0.07143		
VARIET	13	10.6667	0.82051	0.47	0.9212
Error	26	45.1905	1.73810		
Total	41	56.0000			

Grand Mean 6.0000   CV 21.97

Randomized Complete Block AOV Table for NP

Source	DF	SS	MS	F	P
REP	2	141.05	70.526		
VARIET	13	5817.92	447.533	5.38	0.0001
Error	26	2160.87	83.111		
Total	41	8119.85			

Grand Mean 27.698   CV 32.91

Randomized Complete Block AOV Table for NB

Source	DF	SS	MS	F	P
REP	2	1.71	0.8531		
VARIET	13	173.44	13.3418	0.34	0.9782
Error	26	1029.43	39.5936		
Total	41	1204.58			

Grand Mean 11.355   CV 55.42

Randomized Complete Block AOV Table for DMV

Source	DF	SS	MS	F	P
REP	2	112351	56175.5		
VARIET	13	1205417	92724.4	3.21	0.0055
Error	26	751583	28907.0		
Total	41	2069351			

Grand Mean 994.98   CV 17.09

Randomized Complete Block AOV Table for DMM

Source	DF	SS	MS	F	P
REP	2	27066	13533.2		
VARIET	13	1101152	84704.0	3.41	0.0038

Error	26	646005	24846.3
Total	41	1774224	

Grand Mean 1327.2   CV 11.88

Randomized Complete Block AOV Table for DMF

Source	DF	SS	MS	F	P
REP	2	69498	34749.0		
VARIET	13	1128304	86792.6	2.97	0.0087
Error	26	758563	29175.5		
Total	41	1956364			

Grand Mean 1202.8   CV 14.20

Randomized Complete Block AOV Table for DM

Source	DF	SS	MS	F	P
REP	2	388.00	194.000		
VARIET	13	1848.00	142.154	0.88	0.5842
Error	26	4212.00	162.000		
Total	41	6448.00			

Grand Mean 81.000   CV 15.71

VARIETY EVALUTION EXPERIMENT – SYFERKUIL 2007/8 GROWING SEASON

Randomized Complete Block AOV Table for DM

Source	DF	SS	MS	F	P
REP	2	52.048	26.0238		
VARIET	13	160.405	12.3388	1.40	0.2269
Error	26	229.952	8.8443		
Total	41	442.405			

Grand Mean 86.881   CV 3.42

Randomized Complete Block AOV Table for DMF

Source	DF	SS	MS	F	P
REP	2	191849	95924.7		
VARIET	13	1254075	96467.3	1.21	0.3277
Error	26	2075704	79834.8		
Total	41	3521628			

Grand Mean 972.19 CV 29.06

Randomized Complete Block AOV Table for DMM

Source	DF	SS	MS	F	P
REP	2	91181	45591		
VARIET	13	1334868	102682	1.05	0.4418
Error	26	2552169	98160		
Total	41	3978218			

Grand Mean 1176.5 CV 26.63

Randomized Complete Block AOV Table for DMV

Source	DF	SS	MS	F	P
REP	2	271354	135677		
VARIET	13	1078196	82938	1.24	0.3075
Error	26	1736913	66804		
Total	41	3086464			

Grand Mean 822.17 CV 31.44

Randomized Complete Block AOV Table for NB

Source	DF	SS	MS	F	P
REP	2	1.000	0.5000		
VARIET	13	178.952	13.7656	2.26	0.0372
Error	26	158.333	6.0897		

Total	41	338.286

Grand Mean 8.5714   CV 28.79

Randomized Complete Block AOV Table for NP

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	213.19	106.595		
VARIET	13	3635.14	279.626	4.82	0.0003
Error	26	1508.14	58.005		
Total	41	5356.48			

Grand Mean 33.476   CV 22.75

Randomized Complete Block AOV Table for NS

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	0.2976	0.14881		
VARIET	13	9.7440	0.74954	0.61	0.8278
Error	26	32.2024	1.23855		
Total	41	42.2440			

Grand Mean 6.3452   CV 17.54

Randomized Complete Block AOV Table for PH

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	34.905	17.4524		
VARIET	13	121.143	9.3187	0.61	0.8230
Error	26	396.429	15.2473		
Total	41	552.476			

Grand Mean 55.190   CV 7.08

Randomized Complete Block AOV Table for SW

Source	DF	SS	MS	F	P
REP	2	7672	3836.2		
VARIET	13	405740	31210.7	1.95	0.0717
Error	26	416552	16021.2		
Total	41	829964			

Grand Mean 497.55   CV 25.44

Randomized Complete Block AOV Table for WS

Source	DF	SS	MS	F	P
REP	2	21.000	10.5000		
VARIET	13	634.286	48.7912	5.74	0.0001
Error	26	221.000	8.5000		
Total	41	876.286			

Grand Mean 14.429   CV 20.21

VARIETY EVALUTION EXPERIMENT – TOMPI SELEKA 2007/8 GROWING SEASON

Randomized Complete Block AOV Table for SW

Source	DF	SS	MS	F	P
REP	2	137339	68669		
VARIET	13	8832452	679419	8.03	0.0000
Error	26	2199122	84582		
Total	41	1.116E+07			

Grand Mean 1382.9   CV 21.03

Randomized Complete Block AOV Table for DM

Source	DF	SS	MS	F	P
REP	2	394.48	197.238		
VARIET	13	1581.14	121.626	1.08	0.4139
Error	26	2920.86	112.341		
Total	41	4896.48			

Grand Mean 73.524   CV 14.42

Randomized Complete Block AOV Table for DMF

Source	DF	SS	MS	F	P
REP	2	578622	289311		
VARIET	13	2.270E+08	1.746E+07	6.94	0.0000
Error	26	6.537E+07	2514168		
Total	41	2.929E+08			

Grand Mean 7488.0   CV 21.18

Randomized Complete Block AOV Table for DMM

Source	DF	SS	MS	F	P
REP	2	2223502	1111751		
VARIET	13	2.316E+08	1.782E+07	6.67	0.0000
Error	26	6.947E+07	2671896		
Total	41	3.033E+08			

Grand Mean 7996.7   CV 20.44

Randomized Complete Block AOV Table for DMV

Source	DF	SS	MS	F	P
REP	2	527925	263962		
VARIET	13	2.305E+08	1.773E+07	7.12	0.0000

Error	26	6.471E+07	2488913
Total	41	2.957E+08	

Grand Mean 6772.0   CV 23.30

Randomized Complete Block AOV Table for NB

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	8.190	4.0952		
VARIET	13	186.952	14.3810	2.05	0.0580
Error	26	182.476	7.0183		
Total	41	377.619			

Grand Mean 8.2381   CV 32.16

Randomized Complete Block AOV Table for NP

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	6995	3497.5		
VARIET	13	193952	14919.4	15.85	0.0000
Error	26	24477	941.4		
Total	41	225425			

Grand Mean 172.61   CV 17.78

Randomized Complete Block AOV Table for NS

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	4.219E-29	2.109E-29		
VARIET	13	7.23810	0.55678	0.49	0.9084
Error	26	29.3333	1.12821		
Total	41	36.5714			

Grand Mean 6.2857   CV 16.90

Randomized Complete Block AOV Table for PH

Source	DF	SS	MS	F	P
REP	2	268.05	134.024		
VARIET	13	1534.50	118.038	0.81	0.6497
Error	26	3809.29	146.511		
Total	41	5611.83			

Grand Mean 65.833   CV 18.39

VARIETY RESPONDS TO PHOSPHORUS LEVELS AND INOCULATION- SYFERKUIL EXPERIMENT -2006/7 GROWING SEASON

Analysis of Variance Table for DF

Source	DF	SS	MS	F	P
REP	3	3889306	1296435		
VARIET	1	433770	433770	19.88	0.0210
Error REP*VARIET	3	65447.4	21815.8		
FERT	2	1.044E+08	5.224E+07	82.77	0.0000
VARIET*FERT	2	1616663	808331	1.28	0.3132
Error REP*VARIET*FERT	12	7574045	631170		
INOC	1	2643755	2643755	4.06	0.0591
VARIET*INOC	1	114368	114368	0.18	0.6801
FERT*INOC	2	1362529	681264	1.05	0.3717
VARIET*FERT*INOC	2	287902	143951	0.22	0.8038
Error REP*VARIET*FERT*INOC	18	1.172E+07	651276		
Total	47	1.341E+08			

Grand Mean 4616.9
CV(REP*VARIET) 3.20
CV(REP*VARIET*FERT) 17.21
CV(REP*VARIET*FERT*INOC) 17.48

Analysis of Variance Table for DMM

Source	DF	SS	MS	F	P
REP	3	5565920	1855307		

VARIET	1	82088.0	82088.0	1.69	0.2849
Error REP*VARIET	3	146014	48671.4		
FERT	2	1.063E+08	5.320E+07	98.77	0.0000
VARIET*FERT	2	1472649	736324	1.37	0.2918
Error REP*VARIET*FERT	12	6462876	538573		
INOC	1	2329805	2329805	2.99	0.1010
VARIET*INOC	1	101844	101844	0.13	0.7220
FERT*INOC	2	811999	406000	0.52	0.6028
VARIET*FERT*INOC	2	1169546	584773	0.75	0.4866
Error REP*VARIET*FERT*INOC	18	1.403E+07	779756		
Total	47	1.386E+08			

Grand Mean 4735.8

CV(REP*VARIET) 4.66

CV(REP*VARIET*FERT) 15.50

CV(REP*VARIET*FERT*INOC) 18.65

Analysis of Variance Table for DV

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	3	46166	15389		
VARIET	1	403	403	0.17	0.7097
Error REP*VARIET	3	7206	2402		
FERT	2	1438955	719478	185.29	0.0000
VARIET*FERT	2	9068	4534	1.17	0.3441
Error REP*VARIET*FERT	12	46597	3883		
INOC	1	86615	86615	14.53	0.0013
VARIET*INOC	1	78	78	0.01	0.9105
FERT*INOC	2	43388	21694	3.64	0.0471
VARIET*FERT*INOC	2	18698	9349	1.57	0.2357
Error REP*VARIET*FERT*INOC	18	107333	5963		
Total	47	1804506			

Grand Mean 463.52

CV(REP*VARIET) 10.57

CV(REP*VARIET*FERT) 13.44

CV(REP*VARIET*FERT*INOC) 16.66

Analysis of Variance Table for NB

Source	DF	SS	MS	F	P
REP	3	3.958	1.3194		
VARIET	1	0.521	0.5208	0.33	0.6042
Error REP*VARIET	3	4.688	1.5625		
FERT	2	61.698	30.8490	41.52	0.0000
VARIET*FERT	2	18.885	9.4427	12.71	0.0011
Error REP*VARIET*FERT	12	8.917	0.7431		
INOC	1	11.021	11.0208	3.82	0.0664
VARIET*INOC	1	1.333	1.3333	0.46	0.5053
FERT*INOC	2	1.135	0.5677	0.20	0.8231
VARIET*FERT*INOC	2	6.323	3.1615	1.10	0.3556
Error REP*VARIET*FERT*INOC	18	51.938	2.8854		
Total	47	170.417			

Grand Mean 6.5417

CV(REP*VARIET) 19.11

CV(REP*VARIET*FERT) 13.18

CV(REP*VARIET*FERT*INOC) 25.97

Analysis of Variance Table for NS

Source	DF	SS	MS	F	P
REP	3	2.7292	0.9097		
VARIET	1	1.6875	1.6875	3.63	0.1530
Error REP*VARIET	3	1.3958	0.4653		
FERT	2	60.6667	30.3333	56.00	0.0000
VARIET*FERT	2	1.5000	0.7500	1.38	0.2877
Error REP*VARIET*FERT	12	6.5000	0.5417		
INOC	1	0.0208	0.0208	0.05	0.8270
VARIET*INOC	1	0.1875	0.1875	0.44	0.5143
FERT*INOC	2	2.1667	1.0833	2.56	0.1053
VARIET*FERT*INOC	2	0.5000	0.2500	0.59	0.5646
Error REP*VARIET*FERT*INOC	18	7.6250	0.4236		
Total	47	84.9792			

Grand Mean 6.3542

CV(REP*VARIET) 10.73

CV(REP*VARIET*FERT) 11.58

CV(REP*VARIET*FERT*INOC) 10.24

VARIETY RESPOND TO PHOSPHORUS LEVELS AND INOCULATION-SYFERKUIL EXPERIMENT 2007/8 GROWING SEASON

Analysis of Variance Table for WS

Source	DF	SS	MS	F	P
REP	3	5347	1782		
VARIET	1	7550	7550	0.90	0.4117
Error REP*VARIET	3	25034	8345		
FERT	2	1016054	508027	58.06	0.0000
VARIET*FERT	2	30633	15316	1.75	0.2153
Error REP*VARIET*FERT	12	105002	8750		
INOC	1	48260	48260	10.63	0.0043
VARIET*INOC	1	800	800	0.18	0.6795
FERT*INOC	2	10524	5262	1.16	0.3361
VARIET*FERT*INOC	2	1431	715	0.16	0.8554
Error REP*VARIET*FERT*INOC	18	81704	4539		
Total	47	1332340			

Grand Mean 365.08

CV(REP*VARIET) 25.02

CV(REP*VARIET*FERT) 25.62

CV(REP*VARIET*FERT*INOC) 18.45

Analysis of Variance Table for NS

Source	DF	SS	MS	F	P
REP	3	2.167	0.7222		

VARIET	1	0.750	0.7500	2.08	0.2452
Error REP*VARIET	3	1.083	0.3611		
FERT	2	88.292	44.1458	51.68	0.0000
VARIET*FERT	2	3.125	1.5625	1.83	0.2026
Error REP*VARIET*FERT	12	10.250	0.8542		
INOC	1	0.333	0.3333	0.57	0.4595
VARIET*INOC	1	0.750	0.7500	1.29	0.2717
FERT*INOC	2	2.042	1.0208	1.75	0.2021
VARIET*FERT*INOC	2	0.375	0.1875	0.32	0.7292
Error REP*VARIET*FERT*INOC	18	10.500	0.5833		
Total	47	119.667			

Grand Mean 6.5833

CV(REP*VARIET) 9.13

CV(REP*VARIET*FERT) 14.04

CV(REP*VARIET*FERT*INOC) 11.60

Analysis of Variance Table for NP

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	3	80.3	26.78		
VARIET	1	3.0	3.00	0.11	0.7584
Error REP*VARIET	3	79.3	26.44		
FERT	2	7867.0	3933.52	290.33	0.0000
VARIET*FERT	2	18.4	9.19	0.68	0.5260
Error REP*VARIET*FERT	12	162.6	13.55		
INOC	1	6674.1	6674.08	312.24	0.0000
VARIET*INOC	1	0.8	0.75	0.04	0.8535
FERT*INOC	2	1497.0	748.52	35.02	0.0000
VARIET*FERT*INOC	2	5.4	2.69	0.13	0.8826
Error REP*VARIET*FERT*INOC	18	384.8	21.38		
Total	47	16772.7			

Grand Mean 40.833

CV(REP*VARIET) 12.59

CV(REP*VARIET*FERT) 9.01

CV(REP*VARIET*FERT*INOC) 11.32

Analysis of Variance Table for NB

Source	DF	SS	MS	F	P
REP	3	31.063	10.3542		
VARIET	1	4.687	4.6875	4.35	0.1282
Error REP*VARIET	3	3.229	1.0764		
FERT	2	1.542	0.7708	0.15	0.8651
VARIET*FERT	2	26.375	13.1875	2.51	0.1230
Error REP*VARIET*FERT	12	63.083	5.2569		
INOC	1	3.521	3.5208	0.69	0.4159
VARIET*INOC	1	0.021	0.0208	0.00	0.9496
FERT*INOC	2	16.792	8.3958	1.65	0.2191
VARIET*FERT*INOC	2	8.792	4.3958	0.87	0.4375
Error REP*VARIET*FERT*INOC	18	91.375	5.0764		
Total	47	250.479			

Grand Mean 6.7708

CV(REP*VARIET) 15.32

CV(REP*VARIET*FERT) 33.86

CV(REP*VARIET*FERT*INOC) 33.28

Analysis of Variance Table for DMV

Source	DF	SS	MS	F	P
REP	3	17574	5858		
VARIET	1	35	35	0.00	0.9766
Error REP*VARIET	3	103976	34659		
FERT	2	1890984	945492	35.91	0.0000
VARIET*FERT	2	18386	9193	0.35	0.7122
Error REP*VARIET*FERT	12	315960	26330		
INOC	1	425069	425069	24.06	0.0001
VARIET*INOC	1	81428	81428	4.61	0.0457
FERT*INOC	2	20524	10262	0.58	0.5695
VARIET*FERT*INOC	2	13289	6644	0.38	0.6918
Error REP*VARIET*FERT*INOC	18	317976	17665		
Total	47	3205200			

Grand Mean 714.90

CV(REP*VARIET) 26.04

CV(REP*VARIET*FERT) 22.70

CV(REP*VARIET*FERT*INOC) 18.59

Analysis of Variance Table for DMM

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	3	26443	8814		
VARIET	1	4107	4107	0.10	0.7779
Error REP*VARIET	3	129452	43151		
FERT	2	2578773	1289386	32.66	0.0000
VARIET*FERT	2	97238	48619	1.23	0.3262
Error REP*VARIET*FERT	12	473712	39476		
INOC	1	559872	559872	12.35	0.0025
VARIET*INOC	1	12160	12160	0.27	0.6108
FERT*INOC	2	323211	161606	3.57	0.0496
VARIET*FERT*INOC	2	16510	8255	0.18	0.8350
Error REP*VARIET*FERT*INOC	18	815754	45320		
Total	47	5037231			

Grand Mean 976.17

CV(REP*VARIET) 21.28

CV(REP*VARIET*FERT) 20.35

CV(REP*VARIET*FERT*INOC) 21.81

Analysis of Variance Table for DMF

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	3	26004	8668		
VARIET	1	18605	18605	0.29	0.6265
Error REP*VARIET	3	191219	63740		
FERT	2	1921509	960755	32.19	0.0000
VARIET*FERT	2	24983	12491	0.42	0.6672
Error REP*VARIET*FERT	12	358135	29845		

INOC	1	308001	308001	13.41	0.0018
VARIET*INOC	1	122513	122513	5.33	0.0330
FERT*INOC	2	108269	54135	2.36	0.1233
VARIET*FERT*INOC	2	8179	4090	0.18	0.8384
Error REP*VARIET*FERT*INOC	18	413518	22973		
Total	47	3500933			

Grand Mean 867.40

CV(REP*VARIET) 29.11

CV(REP*VARIET*FERT) 19.92

CV(REP*VARIET*FERT*INOC) 17.47

VARIETY RESPOND TO PHOSPHORUS LEVELS AND INOCULATION- TOMPI SELEKA EXPERIMENT 2007/8 GROWING SEASON

Analysis of Variance Table for SW

Source	DF	SS	MS	F	P
REP	3	46091	15364		
VARIET	1	4780	4780	0.21	0.6807
Error REP*VARIET	3	69582	23194		
FERT	2	3261082	1630541	41.55	0.0000
VARIET*FERT	2	277119	138560	3.53	0.0622
Error REP*VARIET*FERT	12	470868	39239		
INOC	1	915493	915493	14.03	0.0015
VARIET*INOC	1	31776	31776	0.49	0.4943
FERT*INOC	2	309544	154772	2.37	0.1219
VARIET*FERT*INOC	2	9805	4903	0.08	0.9279
Error REP*VARIET*FERT*INOC	18	1174948	65275		
Total	47	6571087			

Grand Mean 1155.7

CV(REP*VARIET) 13.18

CV(REP*VARIET*FERT) 17.14

CV(REP*VARIET*FERT*INOC) 22.11

Analysis of Variance Table for NS

Source	DF	SS	MS	F	P
REP	3	1.500	0.5000		
VARIET	1	6.750	6.7500	5.93	0.0930
Error REP*VARIET	3	3.417	1.1389		
FERT	2	44.792	22.3958	9.74	0.0031
VARIET*FERT	2	2.625	1.3125	0.57	0.5796
Error REP*VARIET*FERT	12	27.583	2.2986		
INOC	1	30.083	30.0833	27.07	0.0001
VARIET*INOC	1	0.333	0.3333	0.30	0.5906
FERT*INOC	2	4.542	2.2708	2.04	0.1585
VARIET*FERT*INOC	2	7.042	3.5208	3.17	0.0662
Error REP*VARIET*FERT*INOC	18	20.000	1.1111		
Total	47	148.667			

Grand Mean 7.3333

CV(REP*VARIET) 14.55

CV(REP*VARIET*FERT) 20.67

CV(REP*VARIET*FERT*INOC) 14.37

Analysis of Variance Table for NP

Source	DF	SS	MS	F	P
REP	3	787	262.5		
VARIET	1	65	65.3	2.09	0.2441
Error REP*VARIET	3	94	31.3		
FERT	2	61332	30666.1	86.70	0.0000
VARIET*FERT	2	832	415.8	1.18	0.3418
Error REP*VARIET*FERT	12	4245	353.7		
INOC	1	38081	38081.3	138.64	0.0000
VARIET*INOC	1	169	168.8	0.61	0.4433
FERT*INOC	2	7443	3721.5	13.55	0.0003
VARIET*FERT*INOC	2	374	186.8	0.68	0.5191
Error REP*VARIET*FERT*INOC	18	4944	274.7		
Total	47	118366			

Grand Mean 172.79

CV(REP*VARIET) 3.24

CV(REP*VARIET*FERT) 10.88

CV(REP*VARIET*FERT*INOC) 9.59

Analysis of Variance Table for NB

Source	DF	SS	MS	F	P
REP	3	3.958	1.3194		
VARIET	1	0.521	0.5208	0.33	0.6042
Error REP*VARIET	3	4.688	1.5625		
FERT	2	61.698	30.8490	41.52	0.0000
VARIET*FERT	2	18.885	9.4427	12.71	0.0011
Error REP*VARIET*FERT	12	8.917	0.7431		
INOC	1	11.021	11.0208	3.82	0.0664
VARIET*INOC	1	1.333	1.3333	0.46	0.5053
FERT*INOC	2	1.135	0.5677	0.20	0.8231
VARIET*FERT*INOC	2	6.323	3.1615	1.10	0.3556
Error REP*VARIET*FERT*INOC	18	51.938	2.8854		
Total	47	170.417			

Grand Mean 6.5417

CV(REP*VARIET) 19.11

CV(REP*VARIET*FERT) 13.18

CV(REP*VARIET*FERT*INOC) 25.97

Analysis of Variance Table for DMV

Source	DF	SS	MS	F	P
REP	3	2381173	793724		
VARIET	1	946408	946408	0.51	0.5261
Error REP*VARIET	3	5550696	1850232		
FERT	2	1.059E+08	5.299E+07	95.73	0.0000
VARIET*FERT	2	1912865	956432	1.73	0.2190
Error REP*VARIET*FERT	12	6642281	553523		
INOC	1	5.432E+07	5.432E+07	72.52	0.0000
VARIET*INOC	1	354664	354664	0.47	0.5002
FERT*INOC	2	9318867	4659433	6.22	0.0088
VARIET*FERT*INOC	2	1155428	577714	0.77	0.4771
Error REP*VARIET*FERT*INOC	18	1.348E+07	749048		
Total	47	2.021E+08			

Grand Mean 6427.7

CV(REP*VARIET) 21.16

CV(REP*VARIET*FERT) 11.57

CV(REP*VARIET*FERT*INOC) 13.46

Analysis of Variance Table for DMM

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	3	7090616	2363539		
VARIET	1	222360	222360	0.20	0.6840
Error REP*VARIET	3	3311434	1103811		
FERT	2	1.375E+08	6.874E+07	125.33	0.0000
VARIET*FERT	2	1387315	693657	1.26	0.3174
Error REP*VARIET*FERT	12	6581449	548454		
INOC	1	5.039E+07	5.039E+07	44.86	0.0000
VARIET*INOC	1	2112183	2112183	1.88	0.1872
FERT*INOC	2	9958314	4979157	4.43	0.0272
VARIET*FERT*INOC	2	755164	377582	0.34	0.7189
Error REP*VARIET*FERT*INOC	18	2.022E+07	1123389		
Total	47	2.395E+08			

Grand Mean 7639.4

CV(REP*VARIET) 13.75

CV(REP*VARIET*FERT) 9.69

CV(REP*VARIET*FERT*INOC) 13.87

Analysis of Variance Table for DMF

Source	**DF**	**SS**	**MS**	**F**	**P**
REP	3	1883322	627774		
VARIET	1	2015151	2015151	1.47	0.3121
Error REP*VARIET	3	4111567	1370522		
FERT	2	1.178E+08	5.894E+07	77.24	0.0000
VARIET*FERT	2	1220679	610340	0.80	0.4720
Error REP*VARIET*FERT	12	9157703	763142		
INOC	1	4.898E+07	4.898E+07	69.99	0.0000
VARIET*INOC	1	7828.52	7828.52	0.01	0.9169
FERT*INOC	2	1.308E+07	6540983	9.35	0.0016
VARIET*FERT*INOC	2	1190436	595218	0.85	0.4437

Error REP*VARIET*FERT*INOC	18	1.259E+07	699849
Total	47	2.121E+08	

Grand Mean 6958.9

CV(REP*VARIET) 16.82

CV(REP*VARIET*FERT) 12.55

CV(REP*VARIET*FERT*INOC) 12.02

APPENDIX- B

Guar bean study questionnaire

Aim of the study: Survey on guar bean utilization in South African mining and food processing industries

Name of company:…………………………………………………

Type of business:…………………………………………………

1. How many tons of guar bean does the company use in a year ?

………………………………………………………………………………………

2. What specific variety (ies) of guar bean does the company use?

………………………………………………………………………………………..

3. In what form do you receive raw guar material (Raw grain, gum or powder form.

…………………………………………………………………………………………

4. What could be the projected future quantity usage of guar bean gum in the company?(tons/year)

………………………………………………………………………………………

5 Who presently supplies the company with raw guar material?

……………………………………………………………………………………….

6. Where does the supplier source the material of guar bean?

……………………………………………………………………………………….

7. What is the price of the raw material per ton?

………………………………………………………………………………………

8. What is the standard requirement of quality does the company use?

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9 How can the company assist small-scale producers to produce guar?

………………………………………………………………………………………

10. What challenges does the company experience in sourcing guar bean material?

………………………………………………………………………………………

11. What usage does your company utilize the guar bean material?

………………………………………………………………………………………………