UNIVERSITY FOR DEVELOPMENT STUDIES

EVALUATION OF SOYBEAN (*Glycine max* (L.) Merrill) GERMPLASM FOR IMPROVED AGRONOMIC TRAITS FOR POTENTIAL MECHANICAL HARVESTING

IDDI TABDEEN

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EVALUATION OF SOYBEAN (*Glycine max* (L.) Merrill) GERMPLASM FOR IMPROVED AGRONOMIC TRAITS FOR POTENTIAL MECHANICAL HARVESTING

BY

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(UDS/MCS/0002/21)

DISSERTATION SUBMITTED TO THE DEPARTMENT OF CROP SCIENCE, FACULTY OF AGRICULTURE, FOOD, AND CONSUMER SCIENCES, IN PARTIAL FULFILMENT FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

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DECLARATION

I, hereby declare that this thesis is the result of my original work and that no part of it has been presented for another degree in this University or elsewhere.

Iddi Tabdeen ………………………….. ……………………...

(**Name of student**) (Signature) (Date)

We hereby declare that the preparation and presentation of the thesis were supervised per the guidelines on supervision laid down by the University for Development Studies.

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(**Principal supervisor**) (Signature) (Date)

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ABSTRACT

Soybean (*Glycine max* (L.) Merrill) is an emerging commercial crop in Ghana with a diversity of uses including being an important oil crop, nutritional security in low-income communities and income generation in Northern Ghana. However, harvesting operations are still done manually which is tedious and time-consuming with high yield losses due to shattering resulting from late harvesting. A two-phase study was conducted in 2022. In phase 1, a survey was conducted in April 2022 using a random sampling method to identify and ascertain the challenges confronting commercial soybean farmers in Northern Ghana. In phase 2, a field experiment was carried out during the cropping season to assess morphological architecture of foreign and local soybean germplasm for possible mechanical harvesting. The field experiment was a single factor experiment using a randomised complete block design with three replications. The treatment consisted of four (4) foreign soybean germplasm (G39, G83, G90, and G119) and three (3) farmers preferred local varieties (Afayak, Favour, and Jenguma). Results from the field survey revealed that difficulty in harvesting (from uprooting to threshing) soybeans was the most prevalent constraint confronting commercial soybean farmers in northern Ghana. It was also revealed that Favour variety was the choice soybean variety used by commercial soybean farmers due to lower shattering ability, while sole cropping was the major cropping system practised by farmers. The field experiment showed that the foreign soybean germplasm significantly ($P < 0.05$) increased plant height, plant girth, number of pods per plant, first pod height from the ground level by 20% and grain yield compared to the local varieties. The foreign soybean germplasm averagely recorded higher lodged plants and was also more prone to shattering compared to the local varieties. Notably, the local soybean germplasms exceeded the recommended height

of 12 cm for mechanical harvesting, whereas one of the foreign germplasms, G119, fell short of the recommended height. The foreign soybean germplasm (G39, G83, and G90), and local soybean germplasm (Afayak Favour and Jenguma) can be harvested mechanically using a combined harvester following the recommendation of 12 cm above ground to the first pod for soybean mechanical harvesting. The results from this study lay the foundation for further studies to commence soybean mechanical harvesting in Ghana.

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DEDICATION

I dedicate this work to my wife, children, family, and friends for their spiritual, moral, and financial support throughout the course of this study. May Almighty Allah bless and protect you all.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Soybean (*Glycine max* (L) Merrill) is a major source of oil and protein in the world (Mandić *et al*., 2020). In terms of global harvested area and production, soybean ranks as the fourth most significant crop, after rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.) (Fried *et al*., 2019). Soybeans possess a wide range of advantages, including their use as a source of food for humans and feed for animals. The crop is classified as an oilseed and provides a substantial amount of vitamins, minerals, and amino acids that are essential for human nutrition (Dogbe *et al*., 2013). In the year 2019, the total world production of soybeans was approximately 350 million metric tonnes, with Africa contributing around 3.5 million metric tons (Adjei-Nsiah *et al*., 2021). Notably, West Africa accounted for almost a third (920,000 metric tons) of the total African soybean production (Adjei-Nsiah *et al*., 2021). The prominence of soybean as the fourth-largest crop globally, combined with its diverse uses and nutritional benefits, underscores the importance of this legume crop. The significant contribution of Africa, and particularly West African countries to global soybean production highlights the crop's growing significance in the region and the potential for further expansion and optimization of soybean cultivation.

According to Mbanya (2011), the government of Ghana through the Ministry of Food and Agriculture (MoFA), Non-Governmental Organizations (NGOs), and other development partners are helping to promote the production of soybean to enhance household nutrition and cash income for farmers, especially in the Northern Ghana where both soils and climatic conditions are favourable for the production of soybean (Asodina *et al*., 2021). Studies have indicated that most of the agricultural interventions in the Northern region of Ghana such as the Youth in Agriculture Program, Northern Rural Growth Program (NRGP), Savannah Accelerated Development Authority (SADA), ReMI Official, and many others, focus on promoting the production and utilization of soybean through the food value chain (Dogbe *et al*., 2013). According to the Statistics, Research and Information Directorate, (SRID) of the Ministry of Food and Agriculture (Gyan, 2018), seventy-seven percent (77 %) of soybean produced in Ghana is from the north of Ghana. The region is therefore a target for most soybean-related interventions including the Agricultural Value Chain Mentorship Project (AVCMP), funded by DANIDA through AGRA which was jointly implemented by CSIR-SARI, International Fertilizer Development Centre, (IFDC), and Ghana Agricultural Associations Business Centre, (GAABIC).

Soybean also plays an important role in nitrogen fixation by symbiosis, which reduces the application of nitrogen to other cereal crops when rotation is carried out (Carsky *et al*., 2003; Kermah *et al*., 2017). Current domestic production is anticipated to be two-thirds behind domestic demand, necessitating considerable imports of soybean grain, meal, and oil (Gage *et al*., 2012; Eshun *et al*., 2018). Martey (2018) reported that soybean output has increased since 2012. Despite the increment, the grain yield is at 1.3 t ha^{-1} which is still below the potential yield of 3 t ha^{-1} (Buah *et al*., 2020). Nevertheless, 80 % of Ghana's soybean production comes from northern Ghana with an average yield of less than 0.8 t/ha (Awuni *et al*., 2020). The low yield is attributed to challenges such as lack of machinery operations in production (including harvesting), poor seed varieties, low soil nutrients, high cost of inputs, poor agronomic practices, and inadequate rainfalls (Buah *et al*., 2020; Kanton *et al*., 2017; Ulzen *et al*., 2016).

However, increasing the yield of soybean per unit area by increasing the plant population with the modification of plant architecture, improving yield per unit area in soybeans production is not that simple as compared to the other crops because of its unique plant architecture (Rincker *et al*., 2014; Kim *et al*., 2022). Efforts to boost soybean production resulted in a 13 times increase to 340 million metric tonnes from 1961 to 2017 (Foyer *et al*., 2019). The yields of soybeans increase globally as a result of increasing planting area.

Soybean production is increasing as a source of income, particularly for smallholder farmers. Soybean output increased by 27% between 2018 and 2020, according to the Statistics, Research, and Information Directorate (Mabaya *et al*., 2022). Soybean output increased by 27 % between 2018 and 2020, to 116,000 acres in 2020 with 116,000 acres of soybean production planned for 2020.

1.2 Problem statement

In Ghana, soybean is a non-native, non-staple crop that is mostly utilized as animal feed (Martey *et al*., 2020). Soybean production assistance activities in Ghana have historically been donor-driven, but the crop is increasingly gaining commercial significance as more growers become aware of the benefits of cultivating soybeans as a cash crop (Gage *et al*., 2012; Mabaya *et al*., 2022). With the introduction of Planting for Food and Jobs (PFJ) by the government in 2017, yields do not appear to have increased considerably in comparison to previous years. Whereas average yields ranged between 1.6 and 1.7 metric tons per hectare (MT ha^{-1}) between 2013 and 2016, yields rose only to 1.7 to 1.8 MT ha^{-1} during the PFJ era

(MoFA-IFPRI, 2020). This is much lower than the MoFA's estimated possible yield of 3.0 MT ha^{-1} in 2017 (MoFA-IFPRI, 2020).

One of the major challenges that Ghana suffers in agriculture is mechanization particularly in soybean production (Rahaman, 2018). Harvesting and threshing of soybeans in Ghana are still done manually which is tedious and time-consuming with high losses (Yamba *et al*., 2017) whereas mechanical harvesting is widely used in countries such as the USA, Canada, and Australia (Singh *et al*., 2019) while in Ghana, the efforts made to increase soybean plant height for mechanized harvesting through architectural modifications have not been successful (Yamba *et al*., 2017) and it is a limiting factor to achieving higher yield. Soybean harvesting has traditionally involved cutting the crop from the field using hand sickles and knives. Work rates for crop cutting in the field range between 100 and 200 man-hours per hectare (Hutchinson *et al.*, 2017). Human labour is the most expensive component in the manual harvesting and basic processing of soybeans. At $4 per man-day, labour for cutting the crop (with sickles) equates to $50 per ha in Zimbabwe (Musoni *et al*., 2013). Harvesting soybeans by hand produces low work rates and is tedious, requiring large labour forces and increasing operating expenses, thereby limiting the amount of land under cultivation, which lowers national agricultural production.

It is reported by Hutchinson *et al*. (2017) that shattering together with pests, high temperatures, precipitation, and heavy wind could lead to 35 % yield loss. This loss is facilitated by delaying in manual harvesting (Musoni *et al*., 2013). However, the lack of a mechanical harvesting method for small-scale farmers has resulted in significant losses and a delayed start to the following farming season. These disadvantages cause bottlenecks in Ghanaian soybean production. According to Mbanya (2011), many farmers in the northern part of Ghana are not able to get high yields because the soybeans shatter on the field due to the difficulty in harvesting. Sidhoum *et al*. (2021) indicated that the lack of labourers for effective harvesting of soybeans in the five northern regions of Ghana is the major cause of low yield because of its complicated plant architecture. The grain of soybeans is situated in pods distributed along the entire stem's height, making cutting height a crucial factor in soybean harvesting. However, incorrect cutting heights can result in significant yield losses. When harvesting too high, crop elements formed at lower parts of the plant are left untouched, leading to harvest failure. Conversely, harvesting too low complicates the process by causing excessive stem mass penetration into the threshing apparatus and grain separation parts of the harvester.

1.3 Justification

Reducing soybean shattering will reduce food losses resulting in less expansion of agricultural production onto uncultivated land, therefore reducing greenhouse gas emissions, and less waste of water, fuel, and fertilizer (Shafiee-Jood and Cai, 2016; Galford *et al*., 2020). Soybean pod shattering can sufficiently be reduced by early mechanized harvesting, as combine harvester may do numerous operations at once, such as cutting, threshing, cleaning, and separation, considerably improving grain harvesting efficiency.

Two of the most critical traits for the mechanical harvesting of soybeans are the plant's erectness and the height of the first pod from the ground (Singh *et al*., 2019). Similar to peas, the height of soybean plants can also be improved through modifications to architectural traits, such as a determinate growth habit accompanied by synchronized and early maturity, abundant branching, top pod bearing, longer pods, and an increase in seed number and size

(Nadarajan and Gupta, 2010). Typically, soybean plants range in height from 60 to 110 cm, depending on the specific variety and cultivation methods. The biological characteristics of soybeans lead to the formation of crop elements primarily in the lower portion of the plant. As such, evaluating the architecture of foreign germplasm and local soybean varieties for mechanical harvesting can help improve yields in northern Ghana. The optimal harvesting height for soybeans is crucial to ensure maximum yield and streamline harvesting operations. By focusing on traits like plant erectness and first pod height, as well as architectural modifications that promote synchronized maturity and pod distribution, soybean breeders and farmers can optimize the crop for mechanical harvesting. This is particularly important in northern Ghana, where evaluating germplasm and local varieties for their suitability to mechanical harvest can help increase overall soybean yields.

1.4 Objectives

1.4.1 Main Objective

This study is to evaluate new soybean germplasm on shoot architecture for possible mechanical harvest.

1.4.2 Specific Objectives

This study was aimed specifically at;

i. Identify soybean production constraints confronting commercial soybean farmers in Northern Ghana,

ii. Determine the soybean germplasm of a good height with a good distance between the ground level and the first pod on the soybean at maturity,

iii. Assessing foreign and local soybean germplasm for their shattering response, and

iv. Assess the soybean germplasm for lodging resistance

The above specific objectives were formulated to test the following hypotheses;

Hypothesis 1:

H_0: Soybean height, shattering, and lodging cannot be influenced by mechanical harvesting.

H_a: Soybean height, shattering, and lodging can be influenced by mechanical harvesting.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution of soybean

Soybeans originated in East Asia, primarily China, Japan, and Korea, from where they spread to America, Europe, and other parts of the world in the 18th century (Okwany *et al*., 2010). Chinese history has it that soy existed for over 5,000 years and was used as a food and as an ingredient in medicines (Norman *et al*., 1995). Research has shown that East Africa and Australia are another possible centre of origin for the genus Glycine (Cobbinah *et al*., 2011). Soybeans are commonly grown in commercial quantities in both tropical and temperate regions such as China, Thailand, Indonesia, Brazil, the US, and Japan; However, it has emerged as an important crop and major export (Evans, 1996). Soy first became known in Africa in the early 19th century through southern Africa (Okwany *et al*., 2010) and is now widespread across the continent. However, Shurtleff and Aoyagi, (2015) indicated that harvesting should take place earlier in East Africa, as this region had long-established deals with the Chinese. Similar reports indicated that the plant continued to be popular and cultivated in Tanzania in 1907 and Malawi in 1909. Soy was first introduced to Ghana in 1909 by Portuguese missionaries. This initial introduction failed because the plant originated from temperate climates (Abdul-Karim, 2020; Avornyo *et al.*, 2020). However, soybean cultivation in Ghana began in the early 1970s. This was possible due to the concerted breeding efforts of the Ghana Ministry of Food and Agriculture (MOFA) and the International Institute of Tropical Agriculture (IITA) (Rahaman, 2018).

2.2 World production of soybean

Soybean (*Glycine max* L. Merr.) is the fourth most widely grown and produced crop globally in terms of harvested area (Fried *et al*., 2018). It is the most important oilseed and one of the most significant and cost-effective protein sources produced worldwide (Fried *et al*., 2019). World soybean production has increased dramatically, rising from 117 million metric tons in 1992 to 316 million metric tons in 2015. The countries with the highest soybean yields are the United States, Brazil, Argentina, and China (Qin *et al*., 2017). Soybean yields have increased substantially over the past century in several major producing countries. In the United States, soybean yields have increased linearly by 16.8 kg ha^{-1} per year for cultivars released from 1928 to 2008, and by 26.5 kg ha^{-1} per year for cultivars released from 1923 to 2007 (Rogers *et al*., 2015; Koester *et al*., 2014). Similarly, in Canada, yields of short-season soybean cultivars have increased by approximately 0.5 % annually (Morrison *et al*., 2000). Significant yield improvements have also been observed in India (Ramteke *et al*., 2011) and China (Jin *et al*., 2010; Wu *et al*., 2015; Wang *et al*., 2016). These yield increases in major soybean-producing nations can be attributed to advancements in breeding, crop management, and agricultural technologies, which have enabled farmers to achieve higher and more consistent soybean yields over time.

2.3 Soybean Production in Ghana

Soybean is a non-native and non-essential crop in Ghana, primarily used as animal feed (Martey *et al*., 2020). The crop was first brought to the country in the early 1900s, to enhance the nutritional content of traditionally consumed foods (Mbanya, 2011). Initially, soybean was grown for household use and as a rotational crop with maize, taking advantage of its nitrogen-fixing properties. In the past, soybean production in Ghana has largely been supported by external donor initiatives. However, the crop is gradually gaining commercial significance as more farmers recognize the potential of growing soybeans as a cash crop (Gage *et al*., 2012). Soybean has become one of the most economically significant grain legume crops for export in Ghana, with many farmers in northern Ghana generating substantial income from its cultivation (Mbanya, 2011). In recent years, there has been a growing interest among Ghana's agricultural development programs to promote soybean not only as a protein source for human consumption but also as a valuable feed for the expanding global livestock and aquaculture industries (Dogbe *et al*., 2013). As a result, soybean is now viewed as a potential new income source for smallholder farming communities. Additionally, many Sub-Saharan African countries, including Ghana, see domestic soybean production as a way to reduce reliance on imported raw soybean and soybean meal. In 2014, a significant depreciation of the Ghanaian Cedi, around 40%, led to a substantial increase in the cost of imported soy products for domestic buyers, such as the poultry industry. Furthermore, the unmet domestic demand for soybeans in Ghana leaves little, if any, for export to neighbouring countries (Baker *et al*., 2017). Within this context, increasing domestic soybean production can be an important policy tool for reducing foreign currency outflows and promoting regional and national economic development. The strong demand for soybeans in Ghana, combined with its potential to contribute to smallholder farmer incomes, has led to increased promotion, awareness-building, and extension and outreach efforts by agricultural development and government actors. As a result, soybean is gaining popularity and acceptance among smallholder farmers in Ghana (Dogbe *et al*., 2013). However, average soybean yields in Ghana remain well below global averages. Dogbe *et al*. (2013) found that average soybean yields in the Northern Region of Ghana, which contributes approximately

70 % of the national soybean area and 77 % of national production, range from 509 to 642 kilograms per hectare (kg ha^{-1}). These yield figures represent only 30 % of the national average of 1,910 kg ha^{-1} and 25 % of the global average of 2,310 kg ha^{-1} (Masuda and Goldsmith, 2009). The low yields can be attributed to a low-input, low-output production scenario. Awuni and Reynolds (2016) reported that yields of currently available soybean varieties can be doubled using improved agricultural management strategies and inputs. Yet, Mbanya (2011) and Dogbe *et al*. (2013) observe that very few smallholder farmers are using rhizobium inoculants and other improved agricultural technologies, such as fertilizer application, herbicide and pesticide use, and good management practices (e.g., row planting and using the correct plant population).

2.4 Production Constraints in Ghana

Soybeans have experienced a production increase in the past decade in Ghana due to the government interventions in encouraging its production, development, utilization, and export through the framework of the Medium-Term Agriculture Development Programme. However, in the past two decades, Plahar, (2006), reported a plethora of challenges such as a lack of soybean processing facilities, poor utilization of soybeans in preparation of local cuisines, poor marketing facilities, unattractive production packages for farmers and the difficulty in harvesting the crop manually that retarded the growth of the soybean industry in Ghana. Despite the government intervention, soybean output is still low (<1 t ha^{-1}) in Ghana (Matusso *et al*., 2013) mainly because the improved varieties of soybean have not reached many soybean growers (Moses, 2012). The accomplishment of optimal soybean yields in Africa is restricted by some biotic, abiotic, and economic issues. Yield losses due to pod shattering in sensitive and intermediate susceptible soybean cultivars range from 57 to 175 kg ha^{-1} and 0 to 186 kg ha^{-1}, respectively (Tukamuhabwa *et al*., 2002). Due to the lack of processing equipment for soybeans, knowledge, and lower prices for the crop, many farmers feel reluctant to devote time and energy to soybean cultivation (Okwany *et al.*, 2010). Furthermore, biotic stresses that limit soybean production include frog-eye leaf spot (*Cercospora sojina*), red leaf blotch (*Phoma glycinicola*), soybean rust (*Phakopsora pachyrhizi*), bacterial pustule (*Xanthomonas campestris* pv. *glycines*), bacterial blight (*Pseudomonas amygdali pv. glycinea*), and soybean mosaic virus disease. In many farmers' fields, overlapping disease infections during soybean development are a regular occurrence. The following insect pests are the main ones that affect soybeans: armyworm (*Pseudaletia unipuncta*), blister beetles (*Epicauta funebris*, *Epicauta vittata*), saltmarsh caterpillar (*Estigmene acre*a), soybean looper (*Pseudoplusia includens*), bean leaf beetle (*Cerotoma trifurcate*), and velvet bean caterpillar (*Anticarsia gemma*) (Kachala, 2018). By far, soybean rust (*Phakopsora pachyrhizi*) has the most stress-causing yield losses of up to 80 % (Miles *et al*., 2003). Soybean production is also still low because improved varieties of soybean have not reached many soybean growers to increase production (Tefera *et al.*, 2009) and many still grow landraces or obsolete varieties. Research has shown that most farmers in Ghana are not interested in soybean production because of the difficulties in harvesting (Yamba *et al*., 2017).

2.5 Determinate and Indeterminate soybean cultivars

Determinate and indeterminate are the two categories into which soybean growth habits have historically been classified. Determinate types stop growing vegetatively and start producing nodes on the main stem soon after blooming starts, according to studies by Toshiro *et al.* (1998) and Purcell *et al*. (2014). On the other hand, indeterminate types keep producing nodes on the main stem until the beginning of the seed fill phase (growth stage R5). However, until seed fill begins, indeterminate cultivars will keep producing nodes on branches. Although determinate kinds blossom for just about three weeks at the nodes on the main stem, the overall flowering time, including the branches, is similar to that of indeterminate varieties of the same age. The entire flowering phase might last anywhere from three to six weeks, depending on the maturity and planting date. A terminal raceme that produces a cluster of pods at the topmost main stem node under suitable growth circumstances is the defining feature of determinate cultivars. In times of stress, the terminal raceme which resembles a notched spine at the apex of the plant appears as some or all of the pods may abort. The leaves of determinate kinds are usually identical in size and located at the highest three or four nodes. On the other hand, indeterminate cultivars do not have a terminal raceme, and their nodes tend to be arranged in a zigzag pattern toward the top of the plant. Indeterminate varieties display a pattern of diminishing leaf size from the top to the terminal node, typically beginning around the fifth node.

2.6 Effect of plant height on harvest

The three-dimensional arrangement of the plant body is known as plant architecture. This involves the branching pattern, leaf size, shape, and location of the sections of the plant that are above ground. Plant architecture is still the most reliable way to identify a species of plant and has long been the single standard for systematic and taxonomic categorization. However, it also has a significant impact on agronomic importance, since it may greatly affect a plant's suitability for cultivation, yield, and harvesting efficiency. The production of soybean in Sub-Saharan Africa particularly in Ghana is hand-harvested and production is impeded by a mechanized cropping system. Mechanical harvesting is a challenge because the plant is too close to the ground thus, a better understanding of the molecular-genetic regulation of plant form will help us to modify specifically agronomically relevant traits. Delay harvesting due to difficulty in harvesting may cause great losses in both grains and quality and present extreme problems in harvesting operations. It can cause lower yields and diminish nutrient density. According to Berry *et al*. (2004), lodging in wheat can make it more vulnerable to pests and diseases and have a detrimental impact on crop growth, resulting in a decrease in grain per m^2 and average grain weight. Breeding has reduced lodging losses by lowering plant height, which reduces the chance of lodge (mostly due to retrogression of dwarfing genes). However, lodging still affects grain production. (Acreche and Slafer, 2011). Reducing the seed rate or adding less nitrogen can result in strong-stemmed plants with wide stem bases and thick walls (Crook and Ennos, 1995). Environmental factors and morphological (structural) plant features affect lodging in grain and legume crops. Inadequate crop standing power and unfavourable meteorological factors, such as rain, wind, and/or hail, can lead to lodging in grain crops. Additionally, lodging depends on variety (cultivar). A semi-dwarf wheat cultivar with stiffer straw is less likely to lodge than a tall, weak-stemmed wheat cultivar. Medium-high soybean plants are more likely to lodge than semi-dwarf ones when there are high levels of moisture and nitrogen fertility. When good conditions prevail, plants that are initially resistant to lodging may remain upright; nevertheless, when very unfavourable weather, like intense rain or wind, occurs, these plants may collapse. Early lodging of the crop will result in "elbow joints" forming at the lowest stem nodes, which will aid in recovery. The stem is forced to stand upright by the elongating cells on the node's bottom side. The stem cells of mature plants are no longer able to elongate and support the recovery of the plant.

2.7 Effect of lodging on harvest

The permanent repositioning of a stem from its upright posture is known as lodging. Plants are considered to have lodged when the stems of ordinarily erect plants droop over and do not straighten out (Pinthus, 1974; Dahiya *et al*., 2018). Another symptom of abundance that limits the use of factors that increase yield is lodging. Lodging has also been referred to as bending at the base of the peduncle (Patterson *et al*., 1957; Dahiya *et al*., 2018). There are two categories of plant lodging: stem lodging and root lodging, according to Dahiya *et al*. (2018). Given the increase in the intensity and frequency of extreme weather events, the potential for harm from wind-induced root lodging is growing internationally (Lindsey *et al*., 2021). A weak root system, root injury, or unfavourable soil conditions can cause stalks to fall without breaking, a situation known as "root lodging" (Barnes *et al*., 1992). Several drench events in the early 2010s had an impact on crop production in the United States from May through August (Corfidi *et al.*, 2016; Lindsey *et al*., 2021). The distribution of lodging in an impacted field is frequently uneven, with some areas or sites having more lodging than others. Uncertainty in the climate and weather could lead to lodging. Lodging is one of the major obstacles to increasing mean yields and improving the quality of cereal harvests, whether it results from the adoption of tall cultivars, insufficient nitrogen management, or unfavourable climatic circumstances (Floss, 2004; Dahiya *et al*., 2018). Generally speaking, lodging was sparked by high-velocity winds in May and June (71, 69, and 72 km h^{-1}) together with rainfall, particularly in July and August (143 and 115 mm) at the crop's milky stage (Khakwani *et al*., 2010). The problem was made worse by the soil's textural type (silty clay), which led to a brief period of flooding and encouraged the crop's roots to lodge. It is crucial to have a better grasp of how to manage lodging-induced difficulties or to increase cereals' resistance to lodging since it is a chronic limitation that significantly reduces crop plants' productivity. The amount of lodging, or the angle at which the culms deviate from perpendicular, can vary depending on where in the pitch and what stage of development it occurs at. Depending on how severe it is and when it occurs, lodging can affect grain yield (Dahiya 2018). While lodging near harvest cannot directly reduce grain output, it may result in losses owing to harvest interference. Grain yield was reduced by 27 – 40% due to artificially induced lodging during the heading stage, however, only in one area was it more than 24 % (Dahiya *et al*., 2018). According to Khakwani *et al*. (2010), lodging plays a significant role in lowering wheat crop yield by up to 38%. According to Kelbert *et al.* (2004) and Dahiya *et al*. (2018), accommodation can result in yield losses of up to 40 % if it occurs within the first 10 days of departure. Lodging affects all cereal species and many other crops, such as oilseed rape and sunflowers, throughout the world (Telkar *et al*., 2017).

2.8 Effect of soybean germplasm on yield

In The testing of soybeans in various environments, genotype performance varies significantly due to the interplay between genotype and environment (Gauch and Zobel, 1997; Yan *et al*., 2010). Every year, soybean multi-environment trials (MET) are carried out all over the world to help identify superior genotypes and evaluate environment interactions, such as identifying mega environments, to better understand the impacts of genotype and environment on soybean performance (Yan *et al.*, 2000). When 12 different soybean genotypes were examined, Rao *et al*. (2002) discovered substantial genotype, year, and location (GYL) impacts on grain production. Increasing soybean acreage and output requires the development of high-yielding, early-maturing cultivars in a variety of conditions (Alghamdi, 2004). In plant improvement efforts, understanding genetic variability is crucial.

Also, the breeding stock should be assessed in various situations since, in the lack of knowledge about genotype x environment interactions (GE), heritability estimation and genetic advance prediction become inaccurate (Comstock and Moll, 1963; Alghamdi, 2004) Alghamdi (2004) also stated that the ideal genotype is one that continuously performs well across a variety of environments . The phenotypic performance of any cultivar and the success of any breeding efforts for the creation of genetic material, adaptable to a wide variety of environments are significantly influenced by the genotype x environment interaction. Using agricultural techniques and technology is necessary to utilize soybeans' genetic potential fully. The right planting period is crucial to soybean production and does not increase costs (Mandić *et al*., 2020). Due to variations in the climatic conditions (precipitation, temperature, relative humidity, soil moisture, and photoperiod), sowing time impacts the phenological phase of the plant and, consequently, impacts the growth, development, and output of soybeans. According to Jumrani and Bhatia, (2018), adverse weather during the soybean development stage can lower seed yield by up to 74% compared to unstressed circumstances.

2.9 Effect of shattering on yields

In the tropics, flowering plants developed a variety of new seed dispersion systems during their immense radiation, which Darwin dubbed an abhorrent enigma (Wang *et al*., 2020). Because of shifting symbioses and selection pressures, flowering plants have undergone repeated modifications in seed distribution throughout history. Legumen, or pods in Latin, are unicarpellate fruits that develop seeds along a single ventral suture. This is one of the main characteristics that define the legume family, or Fabaceae (Yang *et al*., 2021). Pod cracking is a significant issue with legume cultivation in tropical and subtropical environments, specifically with soybeans. Pod shattering is the result of the pods splitting open too soon and releasing their seeds, which reduces yield. Because of Ghana's unimodal rainfall pattern, soybeans are grown throughout the wet season, especially in the north, and they mature during the driest portion of the year. Bara *et al*. (2013) reported that high temperature and low humidity cause soybean pod cracking. When crops mature in hot, dry weather, there may be significant reductions in seed production. When the fruit reaches maturity, the pod explodes, a process known as pod-shattering, which disperses seeds (Parker *et al*., 2020; Simpson, 2019). For wild species, this method of dissemination has proven to be quite effective. With at least 19,300 species, the legume family ranks third among all flowering plant families in terms of species count (Hughes and Group, 2017). Legume pod dehiscence can result in severe output losses in farming settings. Therefore, in domesticated legumes, humans have aggressively selected against pod breaking (Ogutcen *et al*., 2018; Di-Vittori *et al*., 2019). Pod cracking, which can result in up to 100% of the seed being lost, is considered the biggest obstacle to soybean production in tropical and sub-tropical areas (Adeyeye *et al*., 2014; Kataliko *et al*., 2019). The majority of the cultivars found in the tropics are direct imports from other areas where soybeans have long been farmed. Pod dehiscence in legumes can lead to devastating yield losses in agricultural environments. Humans have, therefore, selected strongly against pod shattering in domesticated legumes (Ogutcen *et al*., 2018; Di-Vittori *et al*., 2019). With losses of up to 100% of seed, pod shattering has been recognized as the most important constraint to soybean production in tropical and sub-tropic regions (Adeyeye *et al*., 2014; Kataliko *et al*., 2019). The majority of the cultivars found in the tropics are direct imports from other regions where soybeans have long been cultivated. Furthermore, it has been discovered that the appropriate use of plant growth regulators might control a few of the morphological and physiological functions of the plant, particularly in hot and dry climates to reduce rapid drying and, as a result, lessen pod-shattering (Gulluoglu *et al*., 2006; Adeyeye *et al*., 2014). Genetic studies have shown that two genes, one dominant and the other non-dominant gene, control pod shattering in soybeans. These findings highlight the importance of genetic variability in the selection of diverse parental characters for crop improvement initiatives (Tukamuhabwa *et al*., 2000; Sujata *et al*., 2012). But in the tropics, resistant cultivars imported from other regions of the world frequently die from pod-shattering (Tukamuhabwa *et al*., 2000), most likely as a result of environmental variations and genotype x environment interactions.

2.10 Effect of pod height from ground level at maturity on harvest

On soybean plants, the height of the bottom pods can have a significant impact on seed loss during harvest. When employing a mechanical combine harvester, the height to the first pod (HFP), or the distance from the soil at the base of the plant to the first pod, is a crucial characteristic (Kowalczuk, 1999; Fratini *et al*., 2007). The distribution of pods along a legume plant's stem is highly significant, maybe even more significant than the height of the first pod when it comes to the overall loss of pods containing seeds during combined harvesting. The reason for this is that plants with comparatively low HFP will produce minimal seed loss provided the remaining pods are primarily distributed in the middle to upper section of the stem. Conversely, if the bulk of pods are gathered in the lower-medium region of the stem, other plants with greater HFP may experience a much bigger effect and seed loss (Eckert *et al*., 2011). Even with sophisticated harvesters, if the cutter bar level is too low, stones or other detritus on the soil surface might physically damage it. However, lower pods won't be harvested if the residual stubble height is greater than 15 cm, as has been observed in several soybean cultivars, leading to a reduction in net yield (Kang *et al*., 2017).

If pods are below the combined cutter bar's cutting height, seeds will be lost. In the US Mid-West, researchers have found that yield losses range from 3 to 14 % for four cultivars at a 15 cm cutter bar height (Allen *et al*., 2012), in double-cropped soybeans, yield losses are 0.4, 2, and 6.6 % for cutter bar heights of 5, 10, and 15 cm, respectively (Grabau and Pfeiffer, 1990). Researchers have also found that yield losses occur for every 2.5 cm increase in cutter bar height from 2.5 to 40 cm. Recently, there has been a rise in the use of more productive cultivars, whose plant architecture makes mechanized harvesting and cultural activities easier (Souza *et al*., 2021). Contemporary cultivars often grow more vertically, have a type II growth habit, resist lodging, and mature consistently. However, according to Alves *et al*. (2001), there is a negative correlation between yield and more upright plant crops, which might be a challenge for contemporary cultivars. Souza *et al*. (2010) further stated that superior architecture is found in plants with larger average plant heights at harvest as well as larger hypocotyl and epicotyl diameters. Nonetheless, a negative linear correlation has been noted between the diameters of the hypocotyl and epicotyl and grain output, suggesting that plants with more upright architecture yield less (Zilio *et al*., 2013).

2.11 Harvesting of soybean

According to the American Heritage Dictionary (2000) and Musoni *et al*. (2013), harvesting is the act of gathering or collecting physiologically matured crops from the fields. When harvesting soybeans, it is important to harvest them at the ideal time with the right technique to maximize grain output and reduce grain losses and quality degradation. Removing the soybean grain from the plants and pods is the main goal. It takes 100–200 man-hours to harvest a single hectare using the old-fashioned methods, which involve using sickles and scythes. (FAO, 1997). According to the Regional Network for Agricultural Machinery in

1983, harvesting and threshing activities in underdeveloped countries can account for as much as 40 % of the manpower needed to raise a crop (Musoni *et al*., 2013). In addition to raising production prices, this high labour required creates a major labour availability issue during the busiest harvesting seasons. Because of this, farmers in developing nations frequently face difficulties recruiting enough workers to do these jobs on time, which can result in crop losses and lower yields. By lowering labour costs and raising total production, farmers in these areas may gain a great deal from the discovery of more effective and automated harvesting and threshing techniques.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The work was carried out in two stages, a field survey conducted to identify soybean commercial farmers' challenges within Northern Ghana and a field assessment conducted on soybean germplasm for mechanical harvesting.

3.1 Part I: Field survey to identify challenges in soybean commercial farming in Northern Ghana

3.1.1 Description of study areas

The survey work was conducted in eleven (11) districts or municipals including; West Mamprusi Municipal (longitude 0 ° 35 ' W and 1˚ 45'; latitude 9˚ 55' N and 10˚ 35' N), Nanton (longitude 0 ˚ 43' 9 W; latitude 9 ˚ 33' 9 N), Mion (longitude 0 ˚ 16' 33 W; latitude 9 ˚ 25' 2 N), Savaligu (longitude 0 ˚ 49' 41 W; latitude 9 ˚ 37' 26 W), Sissala East (longitude 1 ˚ 58' 49 W; latitude 10 ˚ 52' 22 N) , Wa East (longitude 1 ˚ 57' 36 W; latitude 10 ˚ 17' 6 N), North Gonja (longitude 1 ˚ 22' 56 W; latitude 9 ˚ 31' 49 N), North East Gonja (longitude 0 ˚ 33' 1 W; latitude 9 ˚ 6' 56 N), Wa Municipal (longitude 2 ˚30' 35 W; latitude 10˚ 33' 36 N), Kasena Nankana Municipal (longitude 1 ˚ 5' 25 W; latitude 10˚ 53' 5 N), and Karaga (longitude 0 ˚ 25' 49 W; latitude 9 ˚ 55' 29 N) in the five (5) regions in Northern Ghana to identify the challenges confronting commercial soybean farmers. All these districts or municipals have a natural vegetation and classified as guinea savanna woodland comprising short trees of varying sizes and density, growing over a dispersed cover of perennial grassland shrubs. About 80 % of the population of these districts or municipals are engaged in agriculture.

Table 1: Randomly identified commercial soybean farmers in selected districts/municipals

District/Municipal	**Frequency**	Percentage
West Mamprusi Municipal	8	10.96
Nanton	7	9.59
Mion	8	10.96
Savaligu	11	15.07
Sissala East	4	5.48
Wa East	3	4.11
North Gonja	4	5.48
North East Gonja	11	15.07
Wa Municipal	4	5.48
Kasena Nankana Municipal	4	5.48
Karaga	9	12.33
Total:	73	100.00

3.1.2 Sampling methods and size of survey

Among the 70 districts and Municipals in Northern Ghana, a simple random sampling (lottery method) was employed to select eleven districts or municipals while the snowball sampling method was used to identify and select seventy - three (73) respondents that cultivate soybeans for commercial purposes. The districts and municipals were represented with numbers (1 to 70) on a piece of paper, folded, kept in a bowl, and shaken vigorously. 11 out of 70 districts and municipals were picked one after the other without replacement. Snowball sampling where farmers located from districts or municipals were made to recommend their colleague commercial soybean farmers in other chosen districts or municipals for the selection procedure. The districts or municipals were selected based on the scale of commercial soybean production in these eleven districts or municipals. The number of respondents varied among the eleven districts/municipals depending on the number of commercial soybean farmers operating in that district or municipal.

3.1.3 Data collection procedure

Qualitative and Quantitative data were structured using Google survey forms and were collected using closed and open-ended structured questionnaires. Respondents were identified in each of the districts and reached out for willingness to participate in the study. In total, 73 respondents from the 11 Districts were identified and questionnaires were answered by logging into the Google survey platform. Google link for the questionnaire was created and forwarded to respondents through WhatsApp. Follow-up checks were done on each respondent to ensure successful completion of the questionnaire. After the survey, the Google survey account was logged in and data were accessed and analysed.

3.1.4 Data analysis

Statistical Package for Social Sciences (SPSS) version 17.0 and Microsoft Excel were used to analyze the data collected. Descriptive statistics in the form of frequencies and percentages were used to present data in graphs and pie charts. Cross-tabulations were also done.

3.2 Part II: field screening of soybean germplasm

3.2.1 Description of the experimental site

The experiment was carried out at the Farming for the Future field at Nyankpala campus in the University for Development Studies, Tamale Ghana. It is located on the longitude 9° 58 W and latitude 9 ° 25 N. The area of study has one farming season usually starting in June and ending in September depending on rainfall pattern. The area has unimodal rainfall ranging from 1000 - 1200 mm per annum usually starting in April – May with its peak occurring in the month of July/August. However, it drastically reduces in October with no rain at all in the months of November (Abdul-Karim, 2020). Averagely, minimum and maximum temperatures are 23.4℃ and 34.5℃ respectively with relative humidity ranging from 46 to 76.8 % (Abel *et al*., 2020). Vegetatively, it is a grassland with characteristics of the Guinea Savanna Agroecological Zone which is sparse with trees. The soil profile is loamy sand with origin emanating from the Voltarian sandstone and characterized as the Nyankpala series (Adu *et al*., 2018).

3.2.2 Land preparation

A tractor was used to plough the land after the first two rains in May 2022 and was allowed to fallow for two weeks before harrowing to break the lumpy soils. Pegging and Lining was done to get an accurate land size of 50 × 50 m^2. A plot size of 50 cm by 50 cm was used. 1 m of space was provided between blocks and within blocks.

3.2.3 Soil sampling and analysis

Before the commencement of the field trial, the soil was sampled from various sections of the field at a depth of 0 – 20 cm using a zigzag method with a standard auger. The soil samples were sent to the Council for Scientific and Industrial Research Kumasi. The parameters analyzed included; Soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases, exchangeable acidity, ammonium acetate, particle size distribution, Percentage Base Saturation (PBS), and soil micronutrients.

3.2.3.1 Soil pH

It was measured in a 1:2.5 (w:v) soil-water ratio using a glass electrode (H19017 Microprocessor) pH meter.

3.2.3.2 Soil organic carbon

Soil organic carbon was determined by the modified dichromate oxidation method of Walkley-Black as described by Nelson and Sommers (1982).

3.2.3.3 Total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described by Bremner and Mulveney (1982).

3.2.3.4 Potassium determination

The readily acid-soluble forms of phosphorus were extracted with HCl: NH4F Mixture (Bray's No. 1 extract) and determined calorimetrically by ascorbic reduction as described by Bray and Kurtz (1945) and Olsen and Sommers (1982) and potassium was determined by flame photometer.

3.2.3.5 Exchangeable bases

Calcium, magnesium, potassium, and sodium were determined in 1.0 M ammonium acetate (NH4OAc) extract (Thomas, 1982). Calcium and magnesium were determined by EDTA titration. Potassium and sodium were determined by flame photometry.

3.2.3.6 Cation Exchange Capacity

Effective cation exchange capacity (ECEC) was determined by the sum of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and exchangeable acidity (Al^{3+} + H^{+}).

3.2.4 Experimental design

The soybean germplasm was arranged in a Randomized Complete Block Design (RCBD) with three replications. The study involved seven germplasm both foreign and local soybean germplasm. Among the seven genotypes were four (4) foreign soybean germplasm and three (3) local germplasm (Afayak, Favour, and Jenguma). The foreign germplasms were obtained from different countries where soybeans are one of their major cereal-legume crops. Below are some details of the soybean germplasms. Soybean germplasm with their days to maturity is presented in Table 2 below.

Table 2: Preliminary information on soybean germplasm used

S/N	Name	Origin	Days to maturity	Yield potential (t/ha)	Potential plant height (cm)
G39	IAC-4	Brazil	81	2.6 – 3.5	60 – 70
G83	M – 9	Madhya Pradesh, India	104	2.89 - 3.2	60 – 65
G90	Kiro Aki Daizu	Japan	105	2.5 - 3.63	75 – 85
G119	Koban Mame (Zairai)	Japan	68	3.0 – 3.8	50 – 65
G183	Afayak	Ghana	115	2 – 3	40 – 45
G185	Favour	Ghana	115	Not specified	Not specified
G186	Jenguma	Ghana	115	2 – 3	50 – 55

3.2.5 Planting

During the cropping season that commenced on June 10th, 2021, planting activities involved placing ten seeds per hill for each soybean line. The seeds were spaced at intervals of 50 cm between rows and 5cm between individual plants within the rows.

3.2.6 Cultural practices

3.2.6.1 Weeding

Manual hand weeding was done four times before harvesting with a hoe. Each weeding was done within a day for all blocks and weeds gathered together to avoid sprouting of already cleared weeds.

3.2.6.2 Thinning

Thinning was carried out at 15 days after planting when seedlings were fully established. Seedlings were thinned to seven due to overcrowding of plants per hill.

3.2.6.3 Pest management

Leaf miners and pod suckers were managed using a mixture of Cypermethrin and Dimethoate 10 emulsion concentration at 100 ml in 15 L of water in a knapsack sprayer. Both Cypermethrin and Dimethoate are synthetic insecticides for the control of insect pests.

3.2.7 Parameters studied

3.2.7.1 Leaf chlorophyll content

At the vegetative stage, a spad meter was used to take the chlorophyll content. Three selected and tagged plants for each soybean germplasm in each plot were measured. The spad meter was turned on by pressing the power button on the device. Selected and tagged leaves were measured by placing the leaf between the clamps of the spad meter ensuring it covers the entire sensor area then reading the chlorophyll content of the leaf.

3.2.7.2 Plant height

At maturity, a long metal meter rule was used to measure the height of the plant from the base to the highest point of the plant. On each plot, three plants were chosen and marked with tags to record their height. The average was calculated and recorded in centimetres as plant height per plot.

3.2.7.3 Plant girth

At maturity, plant girth was determined using Vernier callipers. Three tagged plants on each of plot was measured for the plant girth. The plant stem was selected for measure and ideally, the stem is representative of the overall girth and is free from irregularities like nodes or branches. The jaws of the callipers are widely open enough to fit around the plant stem. The callipers are placed around the stem at the desired height and the jaws of callipers are close until they just make contact with the plant stem surface without compressing the stem and ensure the jaws are perpendicular to the stem for an accurate measurement. The primary reading was taken by checking on the Vernier scale that exactly aligns with the line on the main scale. The readings were combined from the main scale and the Vernier scale to get the final measurement.

3.2.7.4 Number of branches

Three soybean plants of each soybean germplasm at vegetative stage branches were counted. On each plot, three plants were chosen and marked with tags to record their branches. The average was calculated and recorded as the number of branches per plot.

3.2.7.5 Days to 50% flowering

When the soybean plants began to flower, a daily walk around the field was done to count the number of plants that had flowered. The number of days it took for 50 % of the total plant population per plot to produce flowers relative to the day of sowing was used to calculate the number of days to 50 % flowering per plot.

3.2.7.6 First pod height from the ground

At physiological maturity, selected and tagged plants' first pod height from the ground level was measured using a long metre rule. The metre rule was straightened and placed on the ground below the soybean plant and the distance between the first pod and the ground level was measured. The total of the three plants' first pod heights were summed and divided by the three plants measured to determine the average first pod height from the ground level.

3.2.7.7 Plants at harvest

At maturity, the total number of plants were counted in each plot and the percentage was computed to represent the percentage of plants per plot at harvest.

3.2.7.8 Lodging resistance

At maturity, plants in individual plots that were lodged were counted. The average number of plants lodged per plot was computed by dividing the plants lodged by the total number of plants in that plot. This estimation was done on each of the plots and then averaged to get the lodged plants per each of the soybean germplasm. Lodging resistance was determined by the method used by Sarkar *et al*. (2023) with some modifications where rating 1 showed that plants are erect representing 0 % lodged, 2 showed slight lodging representing 25 % of plants lodged, 3 showed plants lodged at 45 degrees angle representing 50 % plants lodged, 4 showed severe lodging representing 75 % plants lodged and 5 showed all plants lodged flat representing 100 % of plants lodged.

3.2.7.9 Number of pods per plant

Three plants at maturity, from each soybean germplasm were selected on each row and the pods were detached from the plant manually and counted. The average number of pods per plant was calculated by dividing the total number of pods of the three plants by three.

3.2.7.10 Assessing soybean germplasm shattering ability

At physiological maturity, shattering ability was assessed on each soybean germplasm. Soybean germplasm was visually inspected for shattering at physiological maturity. The number of shattered pods per plant was determined by the method used by Shete *et al*. (2023) where the rating of 1 showed very resistant representing 0 %, 2 showed resistance representing 1 – 10 % shattering, 3 showed moderate resistance representing 11 – 25 % of shattering, 4 showed moderate susceptible representing 26 – 50 % of shattering and 5 showed very susceptibility representing ≥ 50 % then dividing it by the total number of soybean pods on a plant.

3.2.7.11 Number of seeds per pod

At physiological maturity, three plants from each soybean plot were selected, and the number of seeds found in each pod was counted and recorded. The average was computed to represent the number of seeds per pod.

3.2.7.12 100 seed weight

The weight of 100 seeds was determined by randomly collecting 100 seeds from the lot harvested per soybean plot. The weight of the 100 seeds was recorded in grams (g) using a digital scale.

3.2.8 Data analysis

Data collected were analysed using ANOVA from GenStat Statistical Package Software edition 12. Averages were separated using Least Significant differences (LSD) at a 5 % probability level and results were presented in graphs and tables.

CHAPTER FOUR

4.0 RESULTS

4.1 Field Survey of soybean commercial farmers in Northern Ghana

4.1.1 Age distribution

Figure 1 represents the age group of commercial soybean farmers in the 11 districts and Municipals in the 5 Northern regions that are into commercial soybean farming. The age of respondents was in the range of 18 – 54 years with 42 % in the 25 - 44 age bracket. The lowest age bracket was 54 years and above representing 8 % of soybean commercial farmers. Commercial soybean farming decreased in the selected eleven (11) districts in northern Ghana with persons from an age range of 25 to 54 years.

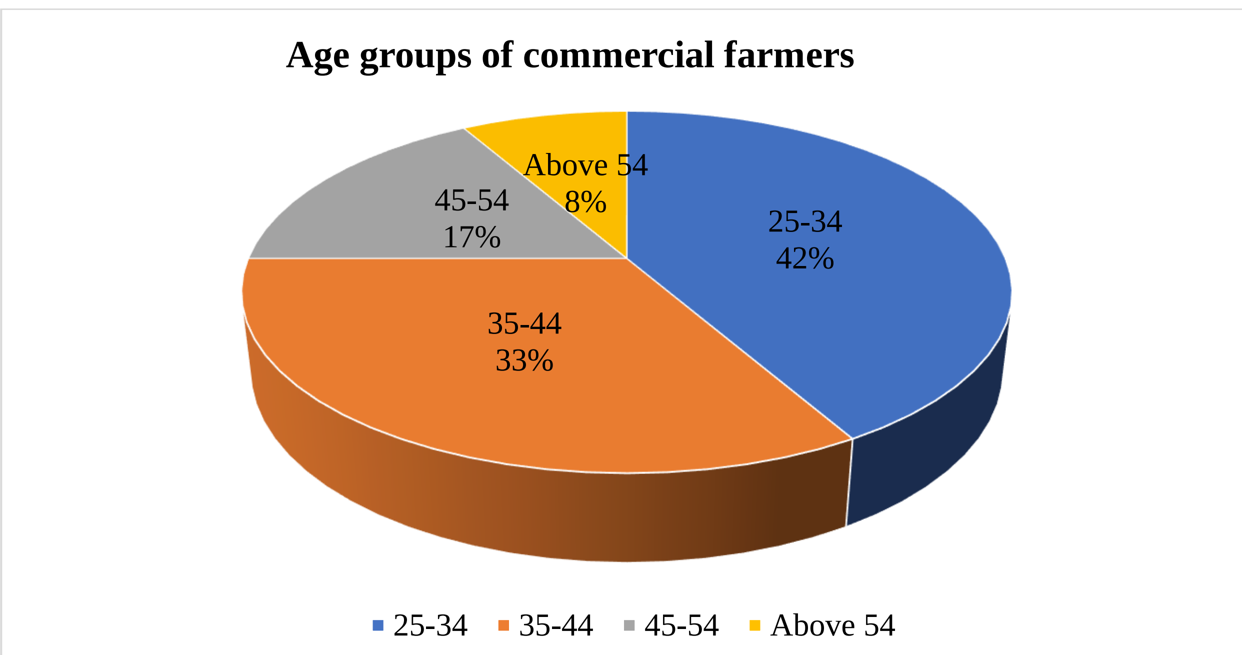

Figure 1: Age distribution of soybean commercial farmers in Northern Ghana.

4.1.2 Cropping system

Figure 2, below shows the cropping systems the commercial soybean farmers are engaged in the Northern part of Ghana. The majority of the respondents practice sole cropping systems (79 %) for commercial soybean production while 21 % of the respondents practice multiple cropping systems for their soybean production.

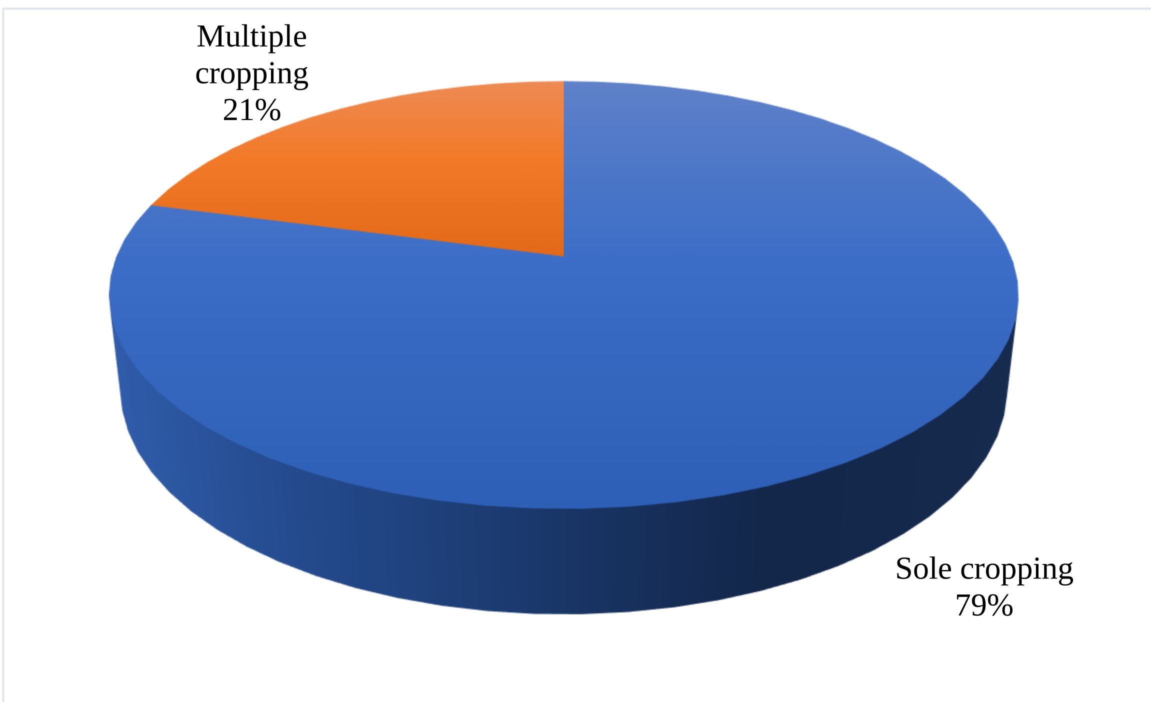

Figure 2: Cropping system used by commercial soybean farmers in the 11 districts surveyed.

4.1.3 Soybean varieties used by commercial farmers

The survey revealed that Favour was the most widely soybean genotype preferred among the commercial soybean farmers in the 11 Districts and Municipals in the 5 Northern regions in Ghana. However, Favour (36 %) was closely followed by Afayak (31 %) and Jenguma (28 %) while Anidaso (3 %) and Toodana (2 %) were rarely used by commercial soybean farmers in the surveyed zone (Figure 3).

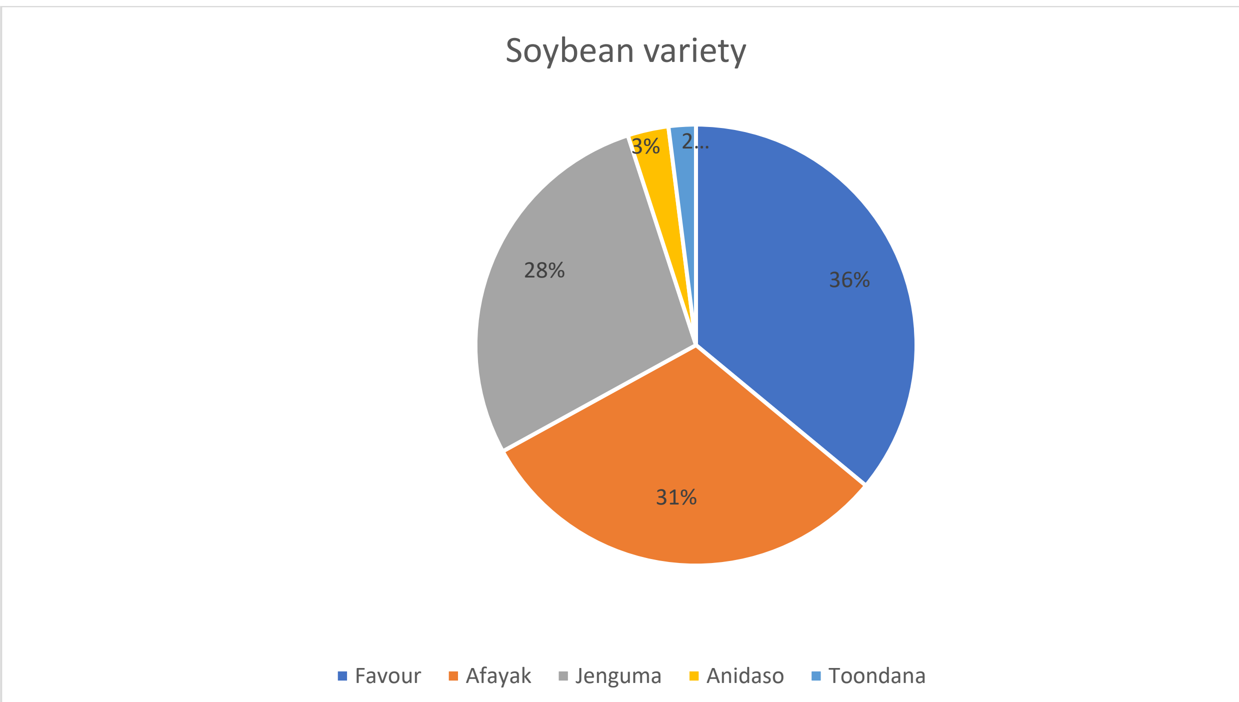

Figure 3: soybean varieties used by commercial farmers in Northern Ghana.

4.1.4 Constraints associated with commercial soybean production

The findings show that the biggest problem for commercial soybean farmers in Northern Ghana is the difficulty in harvesting, with 75 % of commercial soybean farmers facing this issue. Following closely behind are problems like poor seed viability (50 %), high seed costs (46 %), and low yields (42 %). These challenges decrease in significance, with inadequate access to improved soybean varieties being the least problematic, affecting only 4 % of farmers. Figure 4 below shows the challenges in soybean commercial farming in Northern Ghana

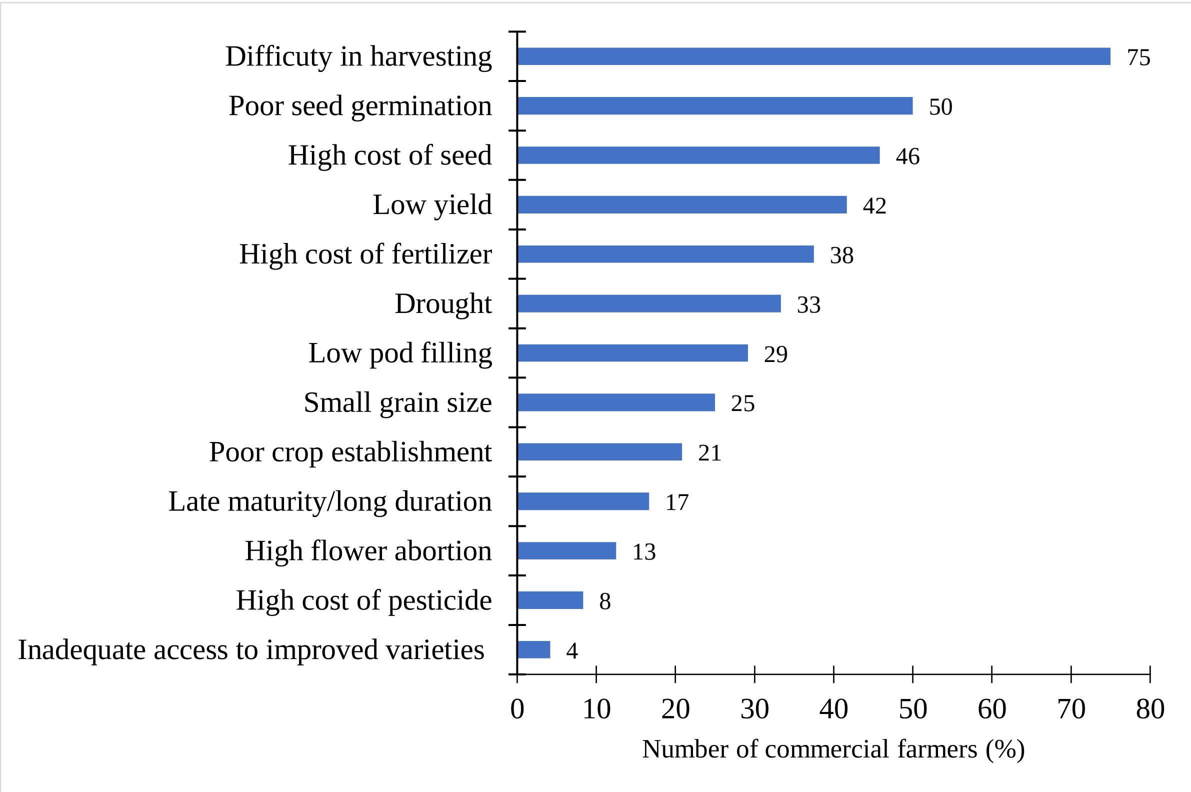

Figure 4: Challenges confronting commercial soybean farmers in eleven (11) selected districts or municipals in five (5) regions in northern Ghana.

4.2 Fieldwork of soybean germplasm evaluation

4.2.1 Soil Analysis

Table 4.2 below shows the soil chemical analysis from 2021 to 2022cropping season. The results revealed that the soil was acidic with a pH of 5.85 in the 2021 and 2022 cropping seasons. The soil was low in organic carbon and total N before planting with 0.52 for organic carbon and 0.04 for total N respectively, in the 2021 and 2022 cropping seasons. Similarly, the soil analysis revealed 3.42 mg/kg of available phosphorus in the soil before planting. The exchangeable bases analysis also revealed that potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg)—were found to be quite low. The values ranged from 0.04 to 1.52 with 0.04 for potassium, 0.05 for sodium, 1.52 for calcium, and 0.50 for magnesium as shown in Table 3 below.

Table 3: Soil chemical properties before the experiment

Soil chemical property	Before planting (2021)
Soil pH to (1:2.5: HO)	5.85
Soil organic carbon (%)	0.52
Total N (%)	0.04
Available P (mg/kg)	3.42
Exchangeable bases (Cmol/kg)	
Potassium (K)	0.04
Sodium (Na)	0.05
Calcium (Ca)	1.52
Magnesium (Mg)	0.50

4.2.2 Leaf chlorophyll content (spad units)

There were significant ($P < 0.05$) differences in leaf chlorophyll content at 40 days after planting. The soybean germplasm G119 produced the highest (39.87 spad units) chlorophyll content but it was not significantly different ($P > 0.05$) from Jenguma (37.50 spad units) and G83 (37.07). However, they were significantly different from Afayak (29.87 spad units) with the least chlorophyll content. The soybean germplasm G119, Jenguma, G83, G39, G90, Favour, and then Afayak produced chlorophyll in decreasing trend with 39.87, 37.5, 37.07, 33.8, 33.07 30.2 and 29.87 respectively, at 40 days after planting. Table 4 below shows the chlorophyll content of soybean germplasm

Table 4: Chlorophyll content of soybean germplasm

Leaf chlorophyll (spad units)	
Soybean germplasm	Means
G39	33.80^{c}
G83	37.07^{b}
G90	33.07^{c}
G119	39.87^{a}
Afayak	29.87^{d}
Favour	30.20^{d}
Jenguma	37.50^{ab}
P value	<.001
LSD %	2.45
CV %	0.4

Values with the same letters are not significant ($P > 0.05$) while letters with different values indicate significant differences ($P < 0.05$).

4.2.3 Soybean plant height at physiological maturity

Plant height was significantly ($P \leq 0.05$) affected by soybean germplasm. Among the foreign soybean germplasm, G90 recorded the tallest plant height (80 cm) and was statistically significant ($P \leq 0.05$) compared to the local soybean germplasm. The foreign soybean germplasm G119 however, produced the shortest (34.9 cm) plant height among both the foreign and local soybean germplasm tested. The local soybean germplasm, Afayak produced the tallest plant height of 45.3 cm and was not significantly different ($P \geq 0.05$) from the rest of the local soybean germplasm with values of 45.2 cm and 42.3 cm for Favour and Jenguma respectively as shown below in Figure 5.

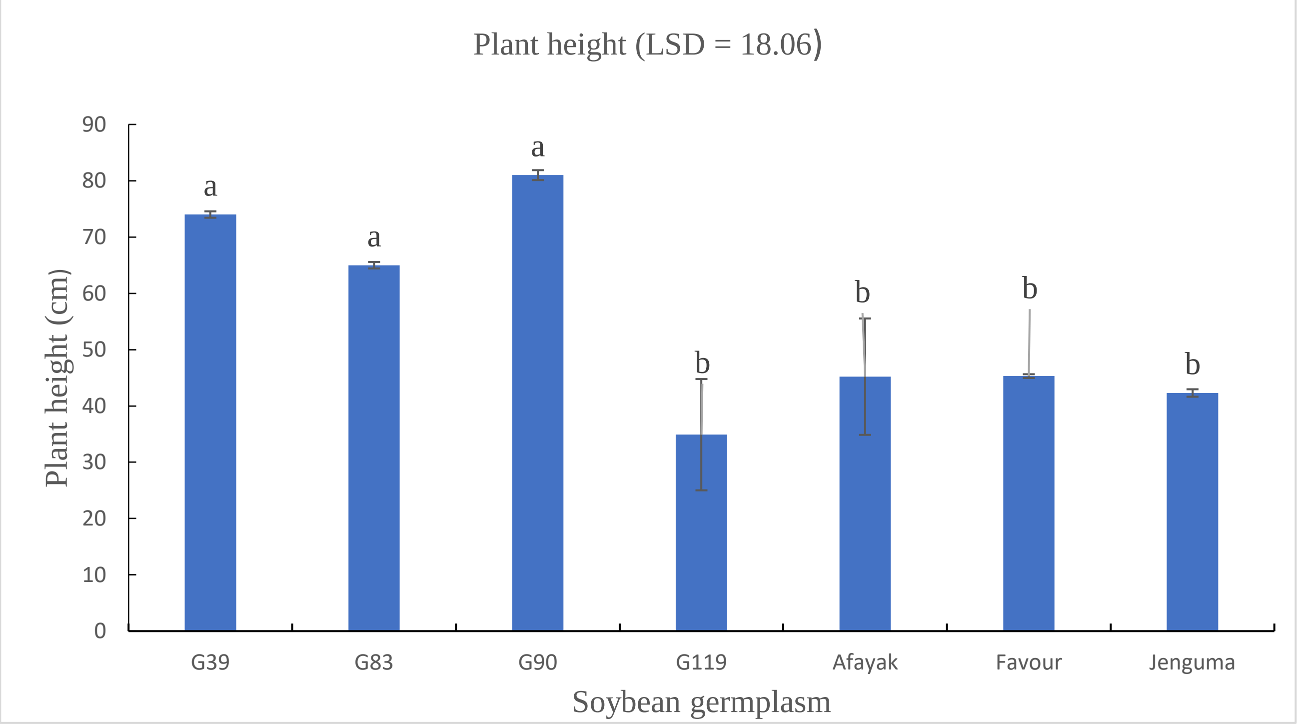

Figure 5: Plant height of soybean germplasm at physiological maturity. Bars with different letters are significantly different at ($P < 0.05$) by the least significance difference test while bars with the same letters are not significantly different ($P < 0.05$).

4.2.4 Plant girth of soybean germplasm

As shown in Table 5 below, the plant girth was significantly ($P < 0.05$) affected by the soybean germplasm with G83 having the broadest and sturdier plant girth of 11.51 mm. This, though, was not significantly different ($P > 0.05$) from G39 (11.07 mm). The lowest (8.37 mm) plant girth was produced by Jenguma which was significantly different from G83 (11.51 mm). Generally, plant girth for both foreign and local soybean germplasm did not follow any pattern.

Table 5: Plant girth of soybean germplasm

Soybean germplasm	Means
G39	11.07^{ab}
G83	10.17^{abc}
G90	10.33^{abc}
G119	8.81^{c}
Afayak	11.51^{a}
Favour	9.36^{bc}
Jenguma	8.37^{c}
P value	0.03
LSD %	1.89
CV %	7.7

Values with the same letters are not significant ($P > 0.05$) while letters with different values indicate significant differences ($P < 0.05$).

4.2.5 Number of soybean germplasm branches

Soybean germplasm presented below (Table 6) recorded a significant (*P* < 0.05) difference in the number of branches among soybean germplasm. The soybean germplasm G39 produced the highest number of branches with an average of 8.67 and was not statistically significant (*P* > 0.05) from G119 (8.33). The lowest (5.67) number of branches was recorded by the soybean germplasm Jenguma and Afayak.

Table 6: Number of branches

Soybean germplasm	Mean
G39	8.67^{a}
G83	7.33^{bc}
G90	6.67^{cd}
G119	8.33^{ab}
Afayak	5.67^{d}
Favour	6.67^{cd}
Jenguma	5.67^{d}
P value	<.001
LSD`	1.04
CV %	6.1

LSD=Least Significant Difference Values with the same letters are not significant (*P* > 0.05) while letters with different values indicate significant difference (*P* < 0.05).

4.2.6 Days to 50% flowering of soybean germplasm

Days to 50 % flowering were significantly (*P* < 0.05) different among soybean germplasm. Soybean germplasm G39 recorded the earliest days to 50 % flowering and was not significantly different from the rest of the soybean's germplasm except for G119 (36.67).

With decreasing order, G90, Jenguma, G83, Afayak, and Favour produced plants that had more days to 50 % flowering with 43, 42.33, 42.33, 42, 41.67, and 41.33 respectively as indicated in Fig. 6 below. Comparatively, there was no trend between the foreign and local soybean germplasm.

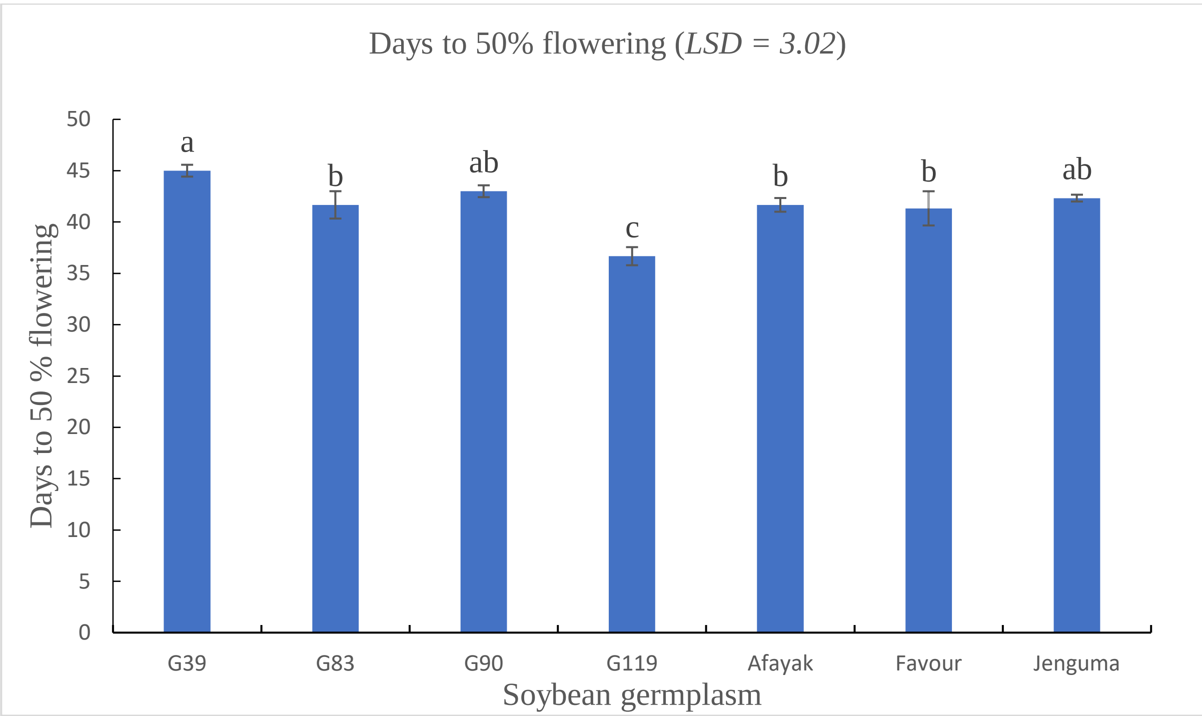

Figure 6: Days to 50 % flowering of soybean germplasm. Bars with different letters are significantly different at ($P < 0.05$) by the least significance difference test while bars with the same letters are not significantly different ($P < 0.05$).

4.2.3 First Pod height from the ground of the soybean germplasm

The first pod height from the ground was significantly ($P \leq 0.05$) different between foreign and local soybean germplasm (Figure 7). The first pod's height from the ground level ranged between 10.83 - 24.5cm with the foreign soybean germplasm (G90) producing the highest (24.5 cm) from the ground to the first pod and was significantly different as compared to all the local soybean germplasm planted. The shortest close to the ground level was recorded by a foreign soybean germplasm G119 with 10.83. However, the local soybean germplasm produced moderate first pod height at a range of 12.33± 0.88 to 16±0.58 cm, with Favour recording the highest first pod height at 16±0.58 cm, while the lowest to the ground level was recorded by Afayak with 12.33±0.88 cm, respectively.

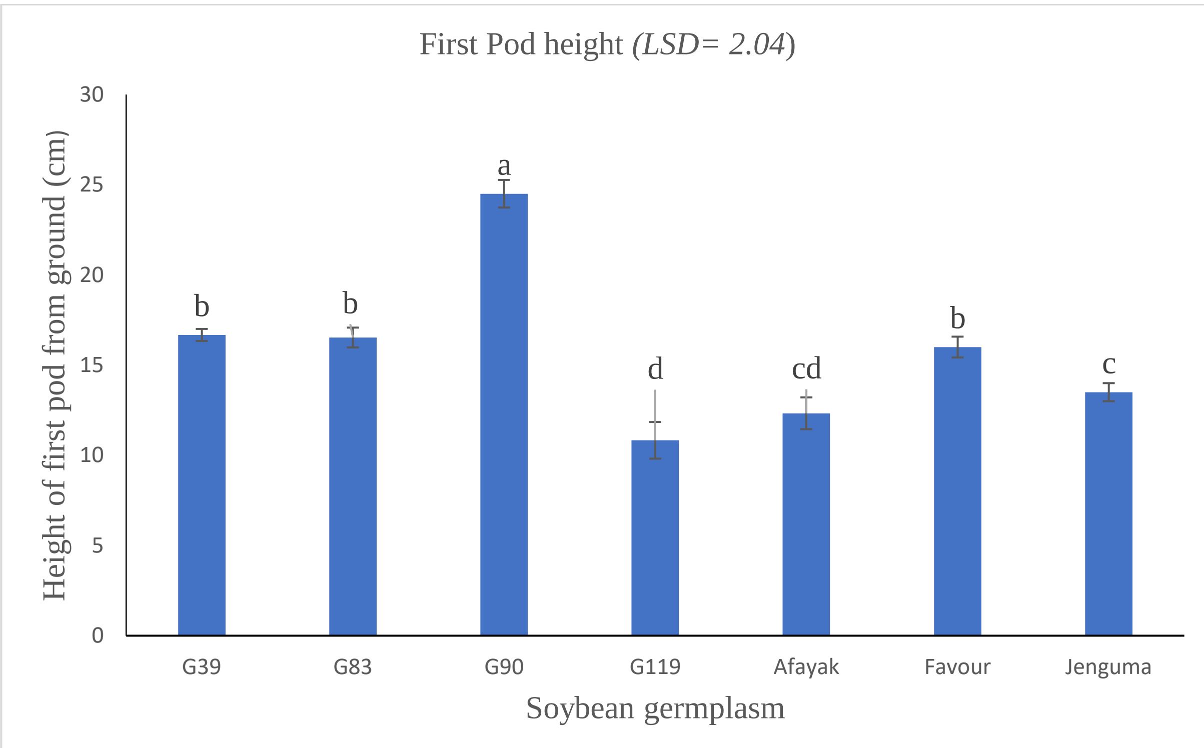

Figure 7: Soybean first pod height from the ground. Bars with different letters are significantly different at ($P < 0.05$) by the least significance difference test while bars with the same letters are not significantly different ($P < 0.05$).

4.2.7 Soybean germplasm resistance to lodging

The results indicated a significant ($P < 0.05$) difference in the number of plants lodged at physiological maturity. The soybean germplasm G83 and Favour performed best with the least (1) number of lodged plants. However, G90 recorded the highest (2.33) number of lodged plants, followed by Jenguma (2) while the soybean germplasm Afayak, G119 and G39 all recorded the same number (1.33) of lodged plants at physiological maturity (Table 7).

Table 7: Assessing Soybean germplasm resistance to lodging

	Lodged plants
Soybean germplasm	Means
G39	1.33^{bc}
G83	1.00^{c}
G90	2.33^{a}
G119	1.33^{bc}
Afayak	1.33^{bc}
Favour	1.00^{c}
Jenguma	2.00^{ab}
P value	0.03
LSD %	0.82
CV %	5.4

LSD = Least Significant Difference in Different Letters. Values with the same letters within columns are not significant ($P > 0.05$) while letters with different values indicate significant differences ($P < 0.05$).

4.2.8 Days to physiological maturity

As shown in Table 8 below, physiological maturity was significantly ($P < 0.05$) affected by the soybean germplasm. The foreign soybean germplasm G119 produced plants that took fewer days (68) to reach physiological maturity and were significantly lower as compared to other soybean germplasm (Jenguma) which took more days (106) to reach physiological maturity. In ascending order, the physiological maturity of soybean germplasm Favour, Afayak, G39, and G90 recorded 85, 90, 95, and 101 days, respectively. The foreign soybean germplasm was early to mature with 51.36 % of them maturing at 100 days after planting while 48.64 % of the local soybean germplasm maturing late after 100 days of planting.

Table 8: Days to physiological maturity of soybean germplasm

	Days to physiological maturity
Soybean germplasm	Days
G39	95.00^{c}
G83	92.00^{d}
G90	100.67^{b}
G119	68.00^{f}
Afayak	90.00^{d}
Favour	85.00^{e}
Jenguma	106.00^{a}
P value	<.001
LSD %	2.2
CV %	0.5

Values with the same letters are not significant ($P > 0.05$) while letters with different values indicate significant differences ($P < 0.05$).

4.2.9 Number of nodes per plot

The number of nodes per plot was significantly ($P < 0.05$) affected by the soybean germplasm (Table 9). The soybean germplasm Afayak produced the highest (22.33) number of nodes which was significantly higher than any of the soybean germplasm. The soybean germplasm Favour recorded the least (6.67) number of nodes and was not significantly ($P > 0.05$) different from the soybean germplasm Jenguma (8.87) and there was not also significant ($P > 0.05$) different between Jenguma (8.87) and G119 (9.97). In decreasing order of the number of nodes produced G39 and G90 produced the same number of nodes of 15, after Afayak and was then followed by G83, G119, Jenguma, and Favour.

Table 9: Node number at podding per plot

Soybean germplasm	Nodes
G39	15.00[b]
G83	10.00[c]
G90	15.00[b]
G119	9.97[c]
Afayak	22.33[a]
Favour	6.67[d]
Jenguma	8.87[cd]
P value	<.001
LSD %	2.2
CV %	0.7

Values with the same letters are not significant ($P > 0.05$) while letters with different values indicate significant differences ($P < 0.05$).

4.2.10 Number of seeds per pod

The results showed a significant (P < 0.05) difference in the number of seeds per pod as indicated in Table 10 below. Among the soybean germplasm, number of seeds per pod ranged between 2.17 to 4.33. The soybean germplasm G39 had the highest (4.33) number of seeds per pod and was statistically different from G90 (3.5) and G119 (3.33). The least number of seeds per pod was produced by the local soybean germplasm with Favour producing the lowest with 2.17, followed by Afayak (2.33), Jenguma (2.5), and the foreign germplasm G119 (3.33) in ascending order of the number of seeds produced per pod by the soybean germplasm planted. The foreign soybean germplasm averagely produced 23 % more seeds per pod than the local soybean germplasm.

Table 10: Number of seeds per pod of soybean germplasm

Number of seeds per pod	
Soybean germplasm	Means
G39	4.33^{a}
G83	3.67^{a}
G90	3.50^{b}
G119	3.33^{b}
Afayak	2.33^{c}
Favour	2.17^{c}
Jenguma	2.50^{c}
P value	<.001
LSD %	0.66
CV %	3.5

Values with the same letters are not significant ($P > 0.05$) while letters with different values indicate significant differences ($P < 0.05$).

4.2.11 Node number at podding per plant

At podding, the node number per plant was significantly ($P \leq 0.05$) affected by the soybean germplasm. The soybean germplasm G90 and G83 produced greater nodes with 6.67 and 5.33 respectively, followed by G39 (4.33). G90 was statistically significant ($P \leq 0.05$) than any of the local soybean germplasm (Afayak, Favour, and Jenguma). Among the local soybean germplasm, Jenguma produced the least (3) node number at podding whereas G119 produced the least among the foreign germplasm. Afayak recorded the highest number of nodes at podding with 3.67 among the local soybean germplasm. The foreign soybean germplasm (G39, G83, G90, and G119) averagely increased node number by 30 % compared to the local soybean germplasm as shown in Table 11 below.

Table 11: Scoring the nodding ability of soybean germplasm per plant

Node number after podding	
Soybean germplasm	Means
G39	4.33^{bc}
G83	5.33^{b}
G90	6.67^{a}
G119	2.67^{d}
Afayak	3.67^{cd}
Favour	3.33^{cd}
Jenguma	3.00^{d}
P value	<.001
LSD %	1.23
CV %	3.4

Values with the same letters are not significant ($P > 0.05$) while letters with different values indicate significant differences ($P < 0.05$).

4.2.12 Number of pods per plant

The study revealed significant ($P < 0.05$) differences in the number of pods per plant among soybean germplasm. The number of pods per plant ranged between 20 to 30 among the soybean germplasm. The soybean germplasm G39 recorded the highest (30.33) number of pods per plant and was not statistically significant from G90 (30) and G119 (28). The least number of pods per plant was recorded by the soybean germplasm Favour with 20 pods per plant, followed by Afayak (21), Jenguma (24), G83 (24), and then G119 recording 28 pods per plant. (Table 12). Comparatively, the foreign soybean germplasm averagely produced a 15 % higher number of pods per plant compared to the local counterparts.

Table 12: Number of pods per plant of soybean germplasm

	Number of pods per plant
Soybean germplasm	Means
G39	30.33[a]
G83	24.33[c]
G90	30.00[a]
G119	27.67[b]
Afayak	21.33[d]
Favour	20.00[d]
Jenguma	23.67[c]
P value	<.001
LSD %	1.85
CV %	0.7

Values with the same letters are not significant ($P > 0.05$) while letters with different values indicate significant differences ($P < 0.05$).

4.2.13 Soybean germplasm shattering ability

Pods per plant that shattered before physiological maturity was significantly ($P \leq 0.05$) different as presented in Table 13 below. Shattering ranged between 1 to 3.67 in both foreign and local soybean germplasm. Generally, the foreign soybean germplasm G83 shattered more seeds before harvesting than any of the soybean germplasm planted with a value of 3.67 and was significantly ($P \leq 0.05$) different from the rest of the soybean germplasm. The least shattered soybean germplasm was recorded by both foreign and local soybeans including G39, Afayak, and Favour with the same value of 1. The highest shattering among the local soybean germplasm was recorded by Jenguma with 1.33.

Table 13: Number of shattered pods per plant

Number of shattered pods per plant	
Soybean germplasm	Means
G39	1.00[b]
G83	3.67[a]
G90	1.33[b]
G119	1.67[b]
Afayak	1.00[b]
Favour	1.00[b]
Jenguma	1.33[b]
P value	<.001
LSD %	0.69
CV %	15.7

Values with the same letters are not significant ($P > 0.05$) while letters with different values indicate significant differences ($P < 0.05$).

4.2.14 100-seed weight

100-seed weight was significantly ($P < 0.05$) affected by the soybean germplasm. The foreign soybean germplasm G119 recorded the greatest 100 seed weight with 22.29 g which was significantly higher than any of the other soybean germplasm evaluated. The second best-performed soybean germplasm was G39 with 19.08 g followed by G90, G83, Jenguma, and then Favour with 17.62, 16.83, 14.15, and 12.37 respectively. The least 100 seed weight was however recorded by the soybean germplasm Afayak with 9.21 g (Table 14).

Table 14: Hundred seed weights of soybean germplasm

Hundred seed weight (g)	
Soybean germplasm	Weight (g)
G39	19.80^{b}
G83	16.83^{c}
G90	17.62^{bc}
G119	22.29^{a}
Afayak	9.21^{f}
Favour	12.37^{e}
Jenguma	14.15^{d}
P value	<.001
LSD %	1.64
CV %	3.4

Values with the same letters are not significant ($P > 0.05$) while letters with different values indicate significant difference ($P < 0.05$).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Field survey

5.1.1 Age distribution of respondents

In a developing country like Ghana for that matter, its economy heavily depends on agriculture, and age is a significant factor in agriculture productivity (Abdul-Karim, 2020). Much of the youth and middle age are the major stakeholders in agriculture, especially in northern Ghana. Majority (42%) of commercial soybean farmers are young and fall within the age bracket of 24 – 35 years. It was deduced that there is a decreasing pattern from the age bracket 25 – 34 to 54 years and above. This is promising for a developing country like Ghana since more energetic young people will spend more time on field activities which will lead to higher productivity as compared to the elderly in agricultural activities. Soybean farming is gaining momentum in the Ghanaian market due to its numerous uses and exports. This might have encouraged the youth to go into commercial soybean production. This finding is in agreement with that of Addae-Frimpomaah *et al*. (2021) who reported that farming is patronized by the youth in the Guinea Savanna Ecology Zone because it is the main occupation in Northern Ghana. Contrary to their report, Asodina *et al*. (2021) stated that the old are more efficient soybean farmers than the youth in the Chereponi and Saboba districts in the northern region of Ghana. They further concluded that young people's engagement in soybean production may create sustainability of the crop as an employment avenue in northern Ghana.

5.1.2 Respondent's choice of cropping system and soybean variety

Cropping system in the tropics plays a major role to the choice of selecting good crop for cultivation. Sole cropping practice by commercial soybean farmers is attributed to many factors including mechanization, pest and disease control, and water management. The preference for sole cropping of soybeans was suggested by commercial farmers to be more compatible with mechanical harvest, as manual activities in soybean cultivation are difficult. However, 21% of respondents preferred multiple cropping patterns as they can efficiently utilize the land. The study found out that 36% of soybean commercial farmers cultivate the Favour variety as their main choice as shown in Figure 3. The criteria for variety selection by commercial soybean farmers in the 11 districts or municipals are based on good yield, large seed size, and non-shattering ability, which agrees with Addae-Frimpomaah *et al.* (2021) and Abdul-Karim (2020).

However, contrary to Abdul-Karim's (2020) report that 58% of soybean farmers choose the Jenguma variety due to its desirable characteristics, including high yield, low shattering ability, high oil content, and colour characteristics, our study found that the Favour variety is the most preferred. In this study Afayak Jenguma, Anidaso, and Toondana were the choice of commercial soybean farmers with 31 %, 28 %, 3 %, and 2 % respectively in northern Ghana after Favour (36 %) variety. This agrees with Addae-Frimpomaah *et al*. (2021) who conducted similar studies and found that Jenguma, Favour, and Afayak are the most commonly used soybean varieties in Northern Ghana. Dugje *et al*. (2009) as referenced by Abdul-Karim, (2020) reported that Jenguma soybean variety is recommended for cultivation in the Guinea savanna and agroecological zones of West Africa because of its favourable traits, such as moderate maturity rate, high yield, little shattering, and great grain colour.

Based on maturity, production potential, lodging, drought tolerance, and pest and disease resistance, producers choose different soybean cultivars. Based on the maturation time, a farmer should select a variety that is appropriate for his or her geographic weather conditions. Early-maturing soybean genotypes are often preferred in areas with little rainfall. Although late-maturing soybean varieties gives higher yields but associated with risk such as poor yield performance due to late-dry spelled climatic conditions especially in Guinea Savanna Agroecological Zone of Ghana.

5.1.3 Challenges in soybean cultivation in Northern Ghana

Difficulty in harvesting soybeans has been the most prominent constraint in soybean cultivation in northern Ghana. This corroborates with that of Addae-Frimpomah *et al*. (2022) who reported difficulty in harvesting soybean as the most important constraint confronting soybean farmers in the Guinea Savanna ecological zone after the late maturity of soybean varieties. The commercial soybean farmers attributed time constraints; a reason that the harvesting season is short-lasting from October to December, physical strains in carrying out manual harvesting activities, and lower productivity involving manual harvesting activities making manual harvesting of soybeans the main constraint in the cultivation of soybean in Northern Ghana. From the experience of the farmers, they also indicated that due to harvesting constraints, they are restricted to cultivating a few hectares of soybean with the fear that late harvesting will lead to shattering. This conforms with Asodina *et al*. (2021) report that soybean output increased with an increase in farm size as well as that of Mbanya (2011) and Yamba *et al*. (2017) who also reported that delay in soybean harvesting led to shattering in Northern Ghana. This reduces the soybean farming efficiency in Northern Ghana due to the small farm size (Asodina *et al*., 2021). Poor seed viability was the next major constraint in soybean production in Northern Ghana. This conforms with the findings of Abdul-Karim (2020) who reported that soybean viability has been the major challenge in Northern Ghana that hinders soybean cultivation. This might stem from poor storage conditions of soybean seeds practiced by the soybean farmers. Mbanya (2011) reported that poor seed viability occurs due to a lack of proper storage practised in northern Ghana. He further concluded that soybean farmers tend to store their soybean seeds in airtight polythene sacks to avoid moisture absorption and seed deterioration in hopes of using them for planting in the coming season. Aside from the constraints confronting soybean commercial farmers in these 11 districts and municipals, respondents equally stated the high cost of agricultural inputs such as fertilizer, seeds, and pesticides while the least concern of the farmers interviewed was inadequate access to improved soybean varieties.

5.2 Field Assessment of soybean germplasm

5.2.1 Shoot architecture in soybean plants

According to Clark and Ma, (2023), soybean shoot architecture is an inherent plastic that is influenced by available soil moisture, nutrient resources, competition, wind, and environmental stresses. The number of branches produced varied among the soybean germplasm. However, the foreign soybean germplasm had more branches compared to their local counterparts. The differences in the branch number between the foreign and local soybean germplasm could be attributed to their genetic modification and favourable weather conditions (Yang *et al*., 2021) where the soybean germplasm was planted. For instance, crops tend to grow vegetatively with plenty of sunlight at their disposal hence producing more branches (Loomis and Williams, 1969) which otherwise is the opposite in countries where sunlight is scarce via these foreign soybean germplasms were produced. However, the production of more branches by the foreign soybean germplasm could be the reason behind the higher yields produced compared with the local germplasm as the number of branches is a prerequisite for higher yield as pods per plant seen in correlates to a higher number of branches (Clark and Ma, 2023).

Plant girth is an important trait in soybeans (Clark and Ma, 2023). Soybean stem growth is greatly impacted by vegetative growth and is the major contributor to soybean height. Generally, the stems produced by the foreign soybean germplasm were sturdier as in Table 5 which could be a result of them being indeterminate germplasm contrary to the local soybean germplasm producing sturdier stems with fewer nodes. Clark and Ma (2023) reported that the difference between determinate and indeterminate soybean varieties is the geographical climatic conditions.

The duration to 50 % flowering varied among the foreign germplasm than that of the local soybean germplasm. However, on average the local soybean germplasm relatively had a shorter duration to flower than the foreign soybean germplasm as shown in Figure 6. This corroborates with the reports of Abel *et al*. (2020) who screened soybean germplasm with fertilization and rhizobia inoculant and found that the local germplasm Jenguma and the new germplasm N119 and N135 were earlier to flower and he attributed this to their genetic make-up. This study supports this assertion with the fact that the local soybean germplasm is well adapted to the growing conditions of the Guinea savanna agroecological zone of Northern Ghana which could be said otherwise for the foreign soybean germplasm. The variability in the duration of flowering between the foreign soybean germplasm and local soybean germplasm could also be due to the day length variations as different soybean varieties react differently to changing day length (Shurtleff and Aoyagi, 2015).

5.2.2 Soybean plant height at physiological maturity

In the mechanization of soybean, plant height at maturity is one of the important characteristics to consider hence the height of the soybean germplasm was determined by measuring the distance from the ground to the uppermost part of the plant. The differences in height between the foreign soybean germplasm and that of the local germplasm could be attributed to many factors including; varietal characteristics, genetic makeup, soil quality, drought stress. Because de Carvalho Ribeiro *et al*. (2016) and Souza *et al*. (2021) suggested that temperature, soil water content, rainfall, and relative humidity are the prominent environmental factors that influences soybean height. However, plant height is dependent on genetic differences among the soybean varieties (Lambon *et al*., 2018) and this claim is supportive of this study. All the foreign soybean germplasm and the local germplasm observed in the study gave a steady plant height at maturity as reported in the preliminary information of the soybean germplasm used (Figure 5). The genetic makeup of the germplasm might have also enabled G90 and G39 at 8WAP to utilize light, water, and nutrients more efficiently, resulting in significantly greater heights at maturity. However, height ranged between 34.9 cm to 81 cm as recorded by both foreign and local germplasm which is in accord with the reports of Bhuiyan *et al*. (2022) who recorded similar soybean germplasm height between 32.69 cm – 90.97 cm. Based on the height observed from the foreign soybean germplasm and the local germplasm as well as the recommended height for mechanical harvesting of at least 12 cm of the first pod above ground level at maturity as reported by Ramteke *et al*. (2012), both foreign and local germplasm are ideal for mechanical harvesting with combine harvester except G119 (10.83).

5.2.3 First pod height from the ground of soybean germplasm

The height of the first pod from the base of the plant is a crucial agricultural trait when using a mechanical combine harvester (Fratini *et al*., 2007; Kowalczuk, 1999). The foreign soybean germplasm G39, G83, and G90 produced the highest first pod height from the base as the results indicated. This could be linked to environmental factors that affected the foreign soybean germplasm to produce more flowers as compared to the local soybean germplasm. The variation in the first pod from the base for the foreign soybean germplasm could also be due to the results of late planting which affected the local germplasm while the foreign soybean germplasm was not affected as they were determinate germplasm (Toshiro *et al.*, 1998*)*. This conforms with the reports of Kang *et al*. (2017) who stated that soybean first pod height from the ground is affected by the environment such as seeding rate and planting distance. Indeterminate varieties that are usually grown in the Midwest require shorter growing seasons (Purcell *et al*., 2014) while the determinate varieties grown in the Southwest due to the longer growing season needed, hence late planting of the local genotypes could have affected the pod production. Proper pod placement on a legume plant's stem is key, particularly when it comes to maximizing yield during combined harvesting. All the soybean germplasm planted (both foreign and local germplasm') first pod height ranged between 10.83 – 24.50 cm. This report is similar to that of Souza *et al*. (2021) who reported the first pod height of soybean cultivars in a range of 13.37 $\pm$ 0.21 cm (BMX Opus) to 14.24 $\pm$ 0.34 cm (BRS 9383). This suggested that the soybean germplasm evaluate could be harvested with a combine harvester except G119 (10.83) since the recommended first pod should be 12 cm above ground level (Ramteke *et al*., 2012). However, this was contrary to the report by Pereira Junior *et al*. (2010) who reported that for mechanical harvesting the first pod height of the soybean plant should be 15 cm. The relationship between the first pod height and various aspects of the plant has been explored in multiple studies (Fratini *et al*., 2007; Kang *et al*., 2017; Ramteke *et al*., 2012). Observations have shown that first pod height has a positive correlation with plant height, but a negative correlation with the number of pods, seeds per plant, seeds per pod, and seed weight (Oz *et al*., 2009). Ramteke *et al*. (2012) reported a positive correlation between plant height, number of nodes, and stem diameter. However, Ghodrati *et al*. (2013) found that first pod height was negatively correlated with seed yield, which could be attributed to the high ratio of first pod height to plant height and potentially reduced the number of pods.

5.2.4 Assessing soybean germplasm resistance to lodging

Stem lodging refers to the permanent displacement of the above-ground parts of the crop (Wu and Ma 2018). Lodging could be a major hindrance to the mechanical harvesting of soybeans. It creates difficulty in gathering and separating pods from the lodged plants. Table 7 indicated that the number of lodged plants statistically varied among foreign soybean germplasm and local soybean germplasm with the foreign soybean germplasm averagely giving higher lodged plants. The reason behind the local soybean germplasm lodging less could be attributed to the adaptability to environmental and weather factors. This assertion corroborates the reports of Ramteke *et al*. (2012) who suggested that environment and variety are the cause of soybean lodging. He further reported that frequent rain continuously in a week is a prerequisite for soybean lodging. The high lodging of the foreign soybean germplasm could also be attributed to the height attained by the foreign soybeans because Ramteke *et al*. (2012) reported that taller plants are highly susceptible to lodging due to their thinner stem and are prone to be affected by wind action. It was observed that more of the lodging occurred shortly after harvesting.

5.2.5 Number of seeds per pod

The results in Table 10 showed that the foreign soybean germplasm displayed a higher number of pods per plant as compared to the local germplasm, and this difference was statistically significant. This suggests that the quantity of pods produced during the vegetative growth stage is directly related to the genetic makeup of the soybean germplasm. This relationship is also supported by the positive correlation between pods per plant and the soil conditions and nodes produced. This finding is consistent to the report by Peters *et al*. (2005) who reported that soil pH below 5.2 does not support the growth and development of soybean pods and this is evident in the soil chemical analysis with a pH of 5.85. However, Desclaux *et al*. (2000) rather attributed the number of pods produced per plant to the number of flowers produced by a soybean plant. He further linked low pods per plant to poor flower production, potentially resulting in seed abortion. Nevertheless, the nodes produced by the foreign soybean germplasm could have also played a role in the number of pods per plant. The nodes on the soybean plant serve as an initial point for the establishment and development of pods (Egli, 2013). Also, Abel (2020) reported that soybean growth habits and genetic makeup improve the superiority in the number of pods per plant. In pigeon peas, inherent genetic differences were recorded in the number of seeds per pod (Ahmad and Mohammed 2004). Similarly, in the Guinea Savanna Zone in Nigeria, Umeh *et al*. (2011) recorded differences in the number of pods per plant among different soybean varieties tested. This suggested that the foreign soybean lines are superior for growth habits as well as a genetic improvement compared to the local soybean germplasm used by farmers in Northern Ghana.

5.2.6 Assessment of soybean germplasm shattering ability

Soybean pod-shattering can lead to a significant reduction in yield, with estimates ranging from 50 - 100%. Factors such as the timing of harvest, harsh environmental conditions, and the genetic makeup of the soybean genotype have been identified as contributing to this problem (Bara *et al*., 2013). It was observed that foreign soybean germplasm was more prone to shattering compared to local germplasm as recorded in Table 13, which may be attributed to differences in genetic makeup or exposure to harsh environmental conditions. In the Guinea savanna agroecological zone, high temperatures exacerbated by dry conditions are a major contributor to soybean pod shattering. Bara *et al*. (2013) reported that conditions such as high temperature, low humidity and rapid temperature changes play a vital role in soybean pod shattering after maturity. The late harvesting could also have contributed to the higher pod-shattering of the foreign soybean lines because as initially established determinate soybean varieties have a shorter growing period hence the faster maturity of the foreign soybeans may be attributed to pod-shattering of the foreign soybean lines. Adverse environmental conditions and late-to-harvest soybean pods result in pod shattering due to the impact of a combined harvester (Kuai *et al*., 2016).

5.2.7 100-grain weight

On 100 grain weight, the situation was not different as the foreign soybean germplasm gave a greater 100 grain weight as compared to the local germplasm as shown in Table 14. The lower grain weight exhibited by the local germplasm might be attributed to the effect of late maturity. This was exacerbated by dry climatic conditions which affected the local germplasm at the pod filling stage. This was contrary to the case of the foreign soybean germplasm as they might have passed the pod-filling stage before the draught set in because of their early maturing ability. Water availability is an important factor in the soybean pod-filling stage. 100-grain weight was greatly impacted by water stress in soybean germplasm at the pod-filling stage in the work of Konlan *et al*. (2013). However, Abel (2020) and Turk *et al*. (1980) claimed in their works that genetic makeup affects soybean seed weight but is limited to extreme drought as well as desiccated hot winds resulting in forcible maturity.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study involved two phases. The first phase was a survey to find out the constraints confronting commercial soybean farmers in five regions in northern Ghana and the second phase was a fieldwork to evaluate foreign and local soybean germplasm for appropriate height for mechanized harvesting of soybeans in Northern Ghana.

From the survey, lack of harvesting soybeans mechanically was the most prominent constraint confronting soybean commercial farmers in Northern Ghana. Afayak, Favour, and Jenguma were the most used varieties by commercial soybean farmers in northern Ghana while Toondana and Anidaso varieties were the least used. The majority of commercial soybean farmers practised sole cropping systems while a handful of them practised multiple cropping systems. Due to the difficulty in harvesting soybeans manually, they are restricted to the number of hectares to cultivate. Time constraints, physical strain, and lower productivity were the key drivers of the manual harvesting of soybeans in Northern Ghana.

The germplasm assessment revealed that the foreign soybean germplasm had more branches and sturdier plants as compared to the local soybean germplasm. The first pod height from the base was significantly higher in foreign soybean germplasm though the local soybean germplasm had the first pod height above the recommended 12 cm from the ground for mechanized harvesting by a combine harvester. Plant height at harvest was also significantly higher in the foreign soybean germplasm than the local germplasm but moderately giving the recommended 50 cm height required for combine harvester operation. The foreign soybean germplasm had a lodging rate of 20%, which was higher than the 10 % lodging rate observed in the local soybean germplasm. The foreign soybean germplasm had a shattering rate of 10%, which was higher than the 4% shattering rate observed in the local soybean germplasm. Number of pods per plant was higher in the foreign soybean germplasm as compared to the local soybean germplasm. The foreign germplasm 100 seed weight was greater than the local soybean germplasm.

6.2 Recommendations

- Commercial soybean farmers should adopt foreign soybean germplasm (G39, G83, G90, and G119) in their farming for higher yields.
- For reduced lodging and shattering in soybean production, the local soybean germplasm is recommended.
- Mechanized harvesting is recommended for both foreign soybean germplasm and local soybean germplasm except G119 (10.83) since both attained the recommended first pod height of 12 cm for mechanized harvesting.
- It is also recommended that; further work be carried out in different locations to confirm the response of these foreign soybean germplasm and the local soybean germplasm for possible mechanized harvest.

REFERENCES

Abdul-Karim, Y. (2020). *O*n-station evaluation of soybean (*Glycine max* (L.) merill) mutant genotypes for improved agronomic traits in northern ghana. University for Develoment Studies.

Abel, C. L., Lamptey, S., & Kugbe, J. X. (2020). Growth and yield response of screened soybean (Glycine max L. Merrill) genotypes to fertilization and rhizobia inoculation in northern Ghana. *Nigeria Agricultural Journal*, *51*(3), 36–44.

Acreche, M. M., & Slafer, G. A. (2011). Lodging yield penalties as affected by breeding in Mediterranean wheats. *Field Crops Research*, *122*(1), 40–48.

Addae-Frimpomaah, F., Denwar, N. N., Adazebra, G. A., Adjebeng-Danquah, J., Kanton, R. A. L., Afful, N. T., & Duut, M. (2021). Assessment of genetic diversity among 32 pigeon pea genotypes using morphological traits and simple sequence repeat markers in Northern Ghana.

Adeyeye, A. S., Togun, A. O., Akanbi, W. B., Adepoju, I. O., & Ibirinde, D. O. (2014). Pod shattering of different soybean varieties, Glycine max (L) Merrill, as affected by some growth and yield parameters. *International Journal of Agricultural Policy and Research*, *2*(1), 10–15.

Adu, G. B., Alidu, H., Amegbor, I. K., Abdulai, M. S., Nutsugah, S. K., Obeng-Antwi, K., Kanton, R. A. L., Buah, S. S., Kombiok, M. J., & Abudulai, M. (2018). Performance of maize populations under different nitrogen rates in northern Ghana. *Annals of Agricultural Sciences*, *63*(2), 145–152.

Alghamdi, S. S. (2004). Yield stability of some soybean genotypes across diverse environments. *Pakistan Journal of Biological Sciences*, *7*(12), 2109–2114.

Asodina, F. A., Adams, F., Nimoh, F., Asante, B. O., & Mensah, A. (2021). Performance of smallholder soybean farmers in Ghana ; evidence from Upper West Region of Ghana. *Journal of Agriculture and Food Research*, *4*(February), 100120. https://doi.org/10.1016/j.jafr.2021.100120

Avornyo, V. K., Manu, A., & Adu-Gyamfi, R. (2020). Response of soybean (Glycine max (L.) Merr) to PS-Foundation 1-0-1 biostimulant, triple super phosphate, and rhizobium inoculant. *Communications in Soil Science and Plant Analysis*, *51*(7), 985–996.

Awuni, G. A., Reynolds, D. B., Goldsmith, P. D., Tamimie, C. A., & Denwar, N. N. (2020). Agronomic and economic assessment of input bundle of soybean in moderately acidic Savanna soils of Ghana. *Agrosystems, Geosciences and Environment*, *3*(1), 1–15. https://doi.org/10.1002/agg2.20085

Barnes, R. F., Beard, J. B., Luellen, W. R., & Korsts, G. (1992). *Glossary of crop science terms*. Crop Science Society of America Madison.

Bhuiyan, M. S. H., Malek, M. A., Emon, R. M., Khatun, M. K., Khandaker, M. M., & Alam, M. A. (2022). Increased yield performance of mutation induced Soybean genotypes at varied agro-ecological conditions. *Brazilian Journal of Biology*, *84*.

Buah, S. S. J., Denwar, N. N., Kanton, R. A. L., & Kombiok, J. M. (2020). *Participatory Approach to Variety Selection Using Soybean Production in Ghana as a Model*. *28*(2), 14–30.

Carsky, R. J., Douthwaite, B., Manyong, V. M., Sanginga, N., Schulz, S., Vanlauwe, B., Diels, J., & Keatinge, J. D. H. (2003). Amélioration de la gestion des sols par l'introduction de légumineuses dans les systèmes céréaliers des savanes africaines. *Cahiers Agricultures*, *12*(4), 227–233.

Clark, C. B., & Ma, J. (2023). The genetic basis of shoot architecture in soybean. *Molecular Breeding*, 1–16. https://doi.org/10.1007/s11032-023-01391-3

Cobbinah, F. A., Addo-Quaye, A. A., & Asante, I. K. (2011). Characterization, evaluation and selection of cowpea (Vigna unguiculata (L.) walp) accessions with desirable traits from eight regions of Ghana. *Journal of Agricultural and Biological Science*, *6*(7), 21–32.

Comstock, R. E., & Moll, R. H. (1963). *Genotype environment interactions. Statistical genetics and plant breeding.*

Corfidi, S. F., Coniglio, M. C., Cohen, A. E., & Mead, C. M. (2016). A proposed revision to the definition of "derecho." *Bulletin of the American Meteorological Society*, *97*(6), 935–949.

Dahiya, S., Kumar, S., Chaudhary, C., & Chaudhary, C. (2018). Lodging: Significance and preventive measures for increasing crop production. *Int. J. Chem. Stud*, *6*(2), 700–705.

de Carvalho Ribeiro, F., Colombo, G. A., Silva, P. O. S., da Silva, J. I. C., Erasmo, E. A. L., & Peluzio, J. M. (2016). Desempenho agronômico de cultivares de soja na região central do Estado do Tocantins, safra 2014/2015. *Scientia Plena*, *12*(7).

Desclaux, D., Huynh, T., & Roumet, P. (2000). Identification of soybean plant characteristics that indicate the timing of drought stress. *Crop Science*, *40*(3), 716–722.

Di Vittori, V., Gioia, T., Rodriguez, M., Bellucci, E., Bitocchi, E., Nanni, L., Attene, G., Rau, D., & Papa, R. (2019). Convergent evolution of the seed shattering trait. *Genes*, *10*(1), 68.

Dogbe, W., Etwire, P. M., Etwire, J. C., Baba, I. I. Y., & Siise, A. (2013). *Economics of Soybean Production Evidence from Saboba and Chereponi Districts of Northern Region of Ghana*.

Dugje, I. Y., Omoigui, L. O., Ekeleme, F., Kamara, A. Y., & Ajeigbe, H. (2009). Production du niébé en Afrique de l'Ouest: Guide du paysan. *IITA, Ibadan, Nigeria*, *20*.

Egli, D. B. (2013). The relationship between the number of nodes and pods in soybean communities. *Crop Science*, *53*(4), 1668–1676.

Eshun, J. K., Kwame, O., Boateng, E., & Kwaku, H. (2018). A comprehensive study on the activities of soy processing facilities in Kumasi and its environs. *University of Cape Coast Youthmappers, Department of Geography and Regional Planning*.

Floss, E. L. (2004). Fisiologia das plantas cultivadas. *Passo Fundo: UPF*, *204*.

Foyer, C. H., Siddique, K. H. M., Tai, A. P. K., Anders, S., Fodor, N., Wong, F., Ludidi, N., Chapman, M. A., Ferguson, B. J., & Considine, M. J. (2019). Modelling predicts that soybean is poised to dominate crop production across A frica. *Plant, Cell & Environment*, *42*(1), 373–385.

Fratini, R., Durán, Y., García, P., & De La Vega, M. P. (2007). Identification of quantitative trait loci (QTL) for plant structure, growth habit and yield in lentil. *Spanish Journal of Agricultural Research*, *5*(3), 348–356.

Gage, D., Bangnikon, J., Abeka-Afari, H., Hanif, C., Addaquay, J., Antwi, V., & Hale, A. (2012). The market for maize, rice, soy, and warehousing in Northern Ghana. *This Report Was Produced by USAID's Enabling Agricultural Trade (EAT) Project*.

Gauch Jr, H. G., & Zobel, R. W. (1997). Identifying mega-environments and targeting genotypes. *Crop Science*, *37*(2), 311–326.

Gyan, K. (2018). Farmers'willingness to pay for soya bean production inputs in northern Ghana. A Thesis Submitted In Partial Fulfilment of the Requirements for The Award ….

Hutchinson, M. J., Muniu, F. K., Ambuko, J., Mwakangalu, M., Olubayo, F., Kirimi, J., Sciences, V., & Kilifi, P. O. (2017). Morphological and Agronomic Characterization of Local Vegetable Cowpea Accessions in Coastal Kenya *M.J. March*, 47–58.

Jumrani, K., & Bhatia, V. S. (2018). Impact of combined stress of high temperature and water deficit on growth and seed yield of soybean. *Physiology and Molecular Biology of Plants*, *24*(1), 37–50.

Kachala, B. M. (2018). Study on grain yield stability, molecular diversity and multi-trait relationships among elite soybean lines. University of KwaZulu-Natal.

Kang, B.-K., Kim, H.-T., Choi, M.-S., Koo, S.-C., Seo, J.-H., Kim, H.-S., Shin, S.-O., Yun, H.-T., Oh, I.-S., & Kulkarni, K. P. (2017). Genetic and environmental variation of first pod height in soybean [*Glycine max* (L.) Merr.]. *Plant Breeding and Biotechnology*, *5*(1), 36–44.

Kataliko, R. K., Kimani, P. M., Muthomi, J. W., Wanderi, W. S., Olubayo, F. M., & Nzuve, F. M. (2019). Resistance and correlation of pod shattering and selected agronomic traits in soybeans. *Journal of Plant Studies; Vol*, *8*(2).

Kelbert, A. J., Spaner, D., Briggs, K. G., & King, J. R. (2004). Screening for lodging resistance in spring wheat breeding programmes. *Plant Breeding*, *123*(4), 349–354.

Kermah, M., Franke, A. C., Adjei-Nsiah, S., Ahiabor, B. D. K., Abaidoo, R. C., & Giller, K. E. (2017). Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea savanna of northern Ghana. *Field Crops Research*, *213*, 38–50.

Khakwani, A. A., Baloch, M. S., Nadim, M. A., Zubair, M., Shah, I. H., & Khan, A. W. (2010). Lodging: A determining factor in reducing yield and yield structure of wheat. *Sarhad J. Agric*, *26*(2), 235–239.

Kim, J., Scaboo, A., Pantalone, V., Li, Z., Bilyeu, K., & Bilyeu, K. (2022). Utilization of Plant Architecture Genes in Soybean to Positively Impact Adaptation to High Yield Environments. *13*(May), 1–17. https://doi.org/10.3389/fpls.2022.891587

Kowalczuk, J. (1999). Pattern of seed losses and damage during soybean harvest with grain combine harvesters. *International Agrophysics*, *13*(1).

Kuai, J., Sun, Y., Liu, T., Zhang, P., Zhou, M., & Wu, J. (2016). Physiological Mechanisms behind Differences in Pod Shattering Resistance in Rapeseed (Brassica napus L .) Varieties. *PLoS ONE*, *11*(6), 1–12. https://doi.org/10.1371/journal.pone.0157341

Lambon, J. B., Sarkodie-Addo, J., & Kombiok, J. M. (2018). Growth and yield response of soybean [Glycine max (L.) Merrrill] to inoculation and starter N fertilizer applications in the Tolon District of the Northern Region of Ghana. *Ghana Journal of Agricultural Science*, *52*, 55–67.

Lindsey, A. J., Carter, P. R., & Thomison, P. R. (2021). Impact of imposed root lodging on corn growth and yield. *Agronomy Journal*, *113*(6), 5054–5062.

Loomis, R. S., & Williams, W. A. (1969). Productivity and the morphology of crop stands: patterns with leaves. *Physiological Aspects of Crop Yield*, 27–47.

Mabaya, E., Adzivor, S. Y., Wobil, J., Waithaka, M., Mugoya, M., Damba, B., & M'Balou Camara, K. T. (2022). *Ghana Country Report 2022*.

Mandić, V., Đorđević, S., Đorđević, N., Bijelić, Z., Krnjaja, V., Petričević, M., & Brankov, M. (2020). Genotype and sowing time effects on soybean yield and quality. *Agriculture*, *10*(11), 502.

Martey, E., Gatti, N., & Goldsmith, P. (2020). Assessing the performance of regional soybean prices in Ghana. *International Food and Agribusiness Management Review*, *23*(2), 267–282. https://doi.org/10.22434/IFAMR2019.0138

Matusso, J. M. M., Mugwe, J. N., & Mucheru-Muna, M. (2013). Effects of different maize (Zea mays L.) soybean (Glycine max (L.) Merrill) intercropping patterns on yields and land equivalent ratio. *Journal of Cereals and Oilseeds*, *4*(4), 48–57.

Mbanya, W. (2011). Assessment of the constraints in soybean production: A case of Northern Region, Ghana. *Journal of Developments in Sustainable Agriculture*, *6*(2), 199–214.

Miles, M. R., Frederick, R. D., & Hartman, G. L. (2003). Soybean rust: Is the US soybean crop at risk. *APS Net Plant Pathology Online*.

Moses, A. (2012). Evaluation of new soybean varieties for market traits and adaptation in Uganda. *Magister Thesis, University Kampala*.

Musoni, S., Raymond, M., & Nazare, M. L. (2013). Mechanisation Of Soya Bean Harvesting

For Small And Medium Scale Farmers In Zimbabwe. *IOSR Journal Of Agriculture And Veterinary Science (IOSR-JAVS)*, *2*(3), 51–53.

Norman, H. A., Pillai, P., & Baker, M. E. (1995). Licorice-derived compounds inhibit linoleic acid (C: 18: 2ω6) desaturation in soybean chloroplasts. *FEBS Letters*, *368*(1), 135–138.

Ogutcen, E., Pandey, A., Khan, M. K., Marques, E., Penmetsa, R. V., Kahraman, A., & Von Wettberg, E. J. B. (2018). Pod shattering: a homologous series of variation underlying domestication and an avenue for crop improvement. *Agronomy*, *8*(8), 137.

Okwany, Z. A., Njoka, F. M., & Githui, E. (2010). *Genotype variant of soybean cultivars around Lake Victoria region, East Africa*.

Patterson, F. L., Schafer, J. F., Caldwell, R. M., & Compton, L. E. (1957). Lodging by Node-bending in Wheat and Barley 1. *Agronomy Journal*, *49*(9), 518–519.

Pinthus, M. J. (1974). Lodging in wheat, barley, and oats: the phenomenon, its causes, and preventive measures. *Advances in Agronomy*, *25*, 209–263.

Plahar, W. A. (2006). Overview of the soybean industry in Ghana. CSIR-food research institute, PO Box m. 20, Accra, Ghana. *Workshop on Soybean Protein for Human Nutrition and Health. Www. Csir. Org. Gh/Fri. Html*.

Purcell, L. C., Salmeron, M., & Ashlock, L. (2014). Arkansas soybean production handbook. *MP197. Purcell, LC, Ed.(Little Rock, AR: University of Arkansas Cooperative Extension Service) Pp*, 1–8.

Rahaman, K. A. (2018). Farmers' practices in soybean (*Glycine max* (L) Merrill) storage and their effects on viability and vigour of seeds. University for Development Studies.

Ramteke, R., Singh, D., & Murlidharan, P. (2012a). *Selecting soybean (Glycine max) genotypes for insertion height of the lowest pod ,*. *82*(June), 39–43.

Ramteke, R., Singh, D., & Murlidharan, P. (2012b). Selecting soybean (Glycine max) genotypes for insertion height of the lowest pod, the useful trait for combine harvester. *Indian Journal of Agricultural Sciences*, *82*(6), 511–515.

Rao, M. S. S., Mullinix, B. G., Rangappa, M., Cebert, E., Bhagsari, A. S., Sapra, V. T., Joshi, J. M., & Dadson, R. B. (2002). Genotype× environment interactions and yield stability of food-grade soybean genotypes. *Agronomy Journal*, *94*(1), 72–80.

Rincker, K., Nelson, R., Specht, J., Sleper, D., Cary, T., Cianzio, S. R., Casteel, S., Conley, S., Chen, P., & Davis, V. (2014). Genetic improvement of US soybean in maturity groups II, III, and IV. *Crop Science*, *54*(4), 1419–1432.

Sarkar, S., Zhou, J., Scaboo, A., Zhou, J., Aloysius, N., & Lim, T. T. (2023). Assessment of Soybean Lodging Using UAV Imagery and Machine Learning. *Plants*, *12*, 1–20. https://doi.org/https://doi.org/10.3390/ plants12162893

Shete, R., Borale, S., Andhale, G., & Girase, V. (2023). Screening of soybean genotypes for pod shattering tolerance and association of different traits with seed yield. *The Pharma Innovation*, *12*(1), 1548–1551.

Shurtleff, W., & Aoyagi, A. (2015). *History of soybeans and soyfoods in Sweden, Norway, Denmark and Finland (1735-2015): Extensively annotated bibliography and sourcebook*. Soyinfo Center.

Sidhoum, A. A., Vrachioli, M., & Sauer, J. (2021). 7. Agricultural mechanization and farm labor development. *Handbook on the Human Impact of Agriculture*, 102.

Singh, U., Gaur, P. M., Chaturvedi, S. K., Hazra, K. K., & Singh, G. (2019). Changing plant architecture and density can increase chickpea productivity and facilitate for mechanical harvesting. *International Journal of Plant Production*, *13*, 193–202.

Souza, J. B. C., Lages Vieira Passos, M., da Silva, E. A., Filho, A. L. de B., de Almeida, S. L. H., Oliveira, A. K. da S., Ferreira, L. de S., Sousa, W. da S., Almeida, E. I. B., & Silva, R. P. da. (2021). Estimated losses in soybean ('Glycine max'(L.) Merril) harvest according to the speed and rotation of the trail system. *Australian Journal of Crop Science*, *15*(4), 559–563.

Tefera, H., Kamara, A. Y., Asafo-Adjei, B., & Dashiell, K. E. (2009). Improvement in grain and fodder yields of early-maturing promiscuous soybean varieties in the Guinea savanna of Nigeria. *Crop Science*, *49*(6), 2037–2042.

Toshiro, K., Saitoh, K., Mahmood, T., & Yanagawa, K. (1998). Differences in Flowering Habit between Determinate and Indeterminate Types of Soybean. *Plant Prod. Sci.*, *1*(1), 18–24.

Tukamuhabwa, P., Dashiell, K. E., Rubaihayo, P., & Nabasirye, M. (2002). *Determination of field yield loss and effect of environment on pod shattering in soybean*.

Wu, W., & Ma, B.-L. (2018). Assessment of canola crop lodging under elevated temperatures for adaptation to climate change. *Agricultural and Forest Meteorology*, *248*, 329–338.

Yamba, P., Larson, E. A., Issaka, Z., & Akayeti, A. (2017). Design, Manufacture and Performance Evaluation of a Soybean Paddle Thresher with a Blower. *Life*, *7*, 8.

Yan, W., Hunt, L. A., Sheng, Q., & Szlavnics, Z. (2000). Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Science*, *40*(3), 597–605.

Yan, Z., Lauer, J. G., Borges, R., & De Leon, N. (2010). Effects of genotype× environment interaction on agronomic traits in soybean. *Crop Science*, *50*(2), 696–702.

Yang, Q., Lin, G., Lv, H., Wang, C., & Yang, Y. (2021). *Environmental and genetic regulation of plant height in soybean*. 1–15.

Zilio, M., Souza, C. A., Coelho, C. M. M., Miquelluti, D. J., & Michels, A. F. (2013). Cycle, canopy architecture and yield of common bean genotypes (Phaseolus vulgaris) in Santa Catarina State. *Acta Scientiarum. Agronomy*, *35*, 21–30.

Abdul-Karim, Y. (2020). *On*-station evaluation of soybean (*Glycine max* (L.) Merill) mutant genotypes for improved agronomic traits in northern Ghana. Dissertation submitted to the Department of Crop Science, University for Development Studies.

Abel, C. L., Lamptey, S., & Kugbe, J. X. (2020). Growth and yield response of screened soybean (*Glycine max* L. Merrill) genotypes to fertilization and rhizobia inoculation in northern Ghana. *Nigeria Agricultural Journal*, *51*(3), 36–44.

Acreche, M. M., & Slafer, G. A. (2011). Lodging yield penalties as affected by breed ing in Mediterranean wheats. *Field Crops Research*, *122*(1), 40–48.

Addae-Frimpomaah, F., Denwar, N. N., Adazebra, G. A., Adjebeng-Danquah, J., Kanton, R. A. L., Afful, N. T., & Duut, M. (2021). Assessment of genetic diversity among 32 pigeon pea genotypes using morphological traits and simple sequence repeat markers in Northern Ghana.

Adeyeye, A. S., Togun, A. O., Akanbi, W. B., Adepoju, I. O., & Ibirinde, D. O. (2014). Pod shattering of different soybean varieties, *Glycine max* (L) Merrill, as affected by some growth and yield parameters. *International Journal of Agricultural Policy and*

Research, *2*(1), 10–15.

Adjei-Nsiah, S., Ahiakpa, J. K., Gyan, K., & Kanampiu, F. (2021). Influence of phosphorus fertilizer blends on grain yield, nutrient concentration, and profitability of soybeans in the southern Guinea Savannah of Ghana. *South African Journal of Plant and Soil*, *38*(5), 381–389.

Adu, G. B., Alidu, H., Amegbor, I. K., Abdulai, M. S., Nutsugah, S. K., Obeng-Antwi, K., Kanton, R. A. L., Buah, S. S., Kombiok, M. J., & Abudulai, M. (2018). Performance of maize populations under different nitrogen rates in northern Ghana. *Annals of Agricultural Sciences*, *63*(2), 145–152.

Alghamdi, S. S. (2004). Yield stability of some soybean genotypes across diverse environments. *Pakistan Journal of Biological Sciences*, *7*(12), 2109–2114.

Alves, G. F., Ramalho, M. A. P., & Abreu, A. (2001). de FB Desempenho de cultivares antigas e modernas de feijão avaliadas em diferentes condições ambientais. *Ciência e Agrotecnologia*, *25*(4), 863–870.

Asodina, F. A., Adams, F., Nimoh, F., Asante, B. O., & Mensah, A. (2021). Performance of smallholder soybean farmers in Ghana ; evidence from Upper West Region of Ghana. *Journal of Agriculture and Food Research*, *4*(February), 100120. https://doi.org/10.1016/j.jafr.2021.100120

Avornyo, V. K., Manu, A., & Adu-Gyamfi, R. (2020). Response of soybean (*Glycine max* (L.) Merr) to PS-Foundation 1-0-1 biostimulant, triple super phosphate, and rhizobium inoculant. *Communications in Soil Science and Plant Analysis*, *51*(7), 985–996.

Awuni, G. A., Reynolds, D. B., Goldsmith, P. D., Tamimie, C. A., & Denwar, N. N. (2020).

Agronomic and economic assessment of input bundle of soybean in moderately acidic Savanna soils of Ghana. *Agrosystems, Geosciences and Environment*, *3*(1), 1–15. https://doi.org/10.1002/agg2.20085

Awuni, G., & Reynolds, D. (2016). Two (2) Year Activity Review Summary Report of SMART Farm In Ghana (2014–2015). *Mississippi State, MS: Feed the Future Innovation Lab for Soybean Value Chain Research (Soybean Innovation Lab, SIL)*.

Baker, D., Jayadev, A., & Stiglitz, J. (2017). Innovation, intellectual property, and development. *Available at Accessibsa. Org [Date Last Accessed 1 November 2023]*.

Barnes, R. F., Beard, J. B., Luellen, W. R., & Korsts, G. (1992). *G*lossary of crop science terms. Crop Science Society of America Madison.

Bhuiyan, M. S. H., Malek, M. A., Emon, R. M., Khatun, M. K., Khandaker, M. M., & Alam, M. A. (2022). Increased yield performance of mutation-induced Soybean genotypes at varied agroecological conditions. *Brazilian Journal of Biology*, *84*.

Buah, S. S. J., Denwar, N. N., Kanton, R. A. L., & Kombiok, J. M. (2020). *Participatory Approach to Variety Selection Using Soybean Production in Ghana as a Model*. *28*(2), 14–30.

Carsky, R. J., Douthwaite, B., Manyong, V. M., Sanginga, N., Schulz, S., Vanlauwe, B., Diels, J., & Keatinge, J. D. H. (2003). Amélioration de la gestion des sols par l'introduction de légumineuses dans les systèmes céréaliers des savanes africaines. *Cahiers Agricultures*, *12*(4), 227–233.

Clark, C. B., & Ma, J. (2023). The genetic basis of shoot architecture in soybean. *Molecular Breeding*, 1–16. https://doi.org/10.1007/s11032-023-01391-3

Cobbinah, F. A., Addo-Quaye, A. A., & Asante, I. K. (2011). Characterization, evaluation and selection of cowpea (*Vigna unguiculata* (L.) walp) accessions with desirable traits from eight regions of Ghana. *Journal of Agricultural and Biological Science*, *6*(7), 21–32.

Comstock, R. E., & Moll, R. H. (1963). Genotype environment interactions. *Statistical genetics and plant breeding.*

Corfidi, S. F., Coniglio, M. C., Cohen, A. E., & Mead, C. M. (2016). A proposed revision to the definition of "derecho." *Bulletin of the American Meteorological Society*, *97*(6), 935–949.

Crook, M. J., & Ennos, A. R. (1995). The effect of nitrogen and growth regulators on stem and root characteristics associated with lodging in two cultivars of winter wheat. *Journal of Experimental Botany*, *46*(8), 931–938.

Dahiya, S., Kumar, S., Chaudhary, C., & Chaudhary, C. (2018). Lodging: Significance and preventive measures for increasing crop production. *Int. J. Chem. Stud*, *6*(2), 700–705.

de Carvalho Ribeiro, F., Colombo, G. A., Silva, P. O. S., da Silva, J. I. C., Erasmo, E. A. L., & Peluzio, J. M. (2016). Desempenho agronômico de cultivares de soja na região central do Estado do Tocantins, safra 2014/2015. *Scientia Plena*, *12*(7).

Desclaux, D., Huynh, T., & Roumet, P. (2000). Identification of soybean plant characteristics that indicate the timing of drought stress. *Crop Science*, *40*(3), 716–722.

Di Vittori, V., Gioia, T., Rodriguez, M., Bellucci, E., Bitocchi, E., Nanni, L., Attene, G., Rau, D., & Papa, R. (2019). Convergent evolution of the seed-shattering trait. *Genes*, *10*(1), 68.

Dogbe, W., Etwire, P. M., Etwire, J. C., Baba, I. I. Y., & Siise, A. (2013). *Economics of Soybean Production Evidence from Saboba and Chereponi Districts of Northern Region of Ghana*.

Dugje, I. Y., Omoigui, L. O., Ekeleme, F., Kamara, A. Y., & Ajeigbe, H. (2009). Production du niébé en Afrique de l'Ouest: Guide du paysan. *IITA, Ibadan, Nigeria*, *20*.

Eckert, F. R., Kandel, H. J., Johnson, B. L., Rojas-Cifuentes, G. A., Deplazes, C., Vander Wal, A. J., & Osorno, J. M. (2011). Row spacing and nitrogen effects on upright pinto bean cultivars under direct harvest conditions. *Agronomy Journal*, *103*(5), 1314–1320.

Egli, D. B. (2013). The relationship between the number of nodes and pods in soybean communities. *Crop Science*, *53*(4), 1668–1676.

Eshun, J. K., Kwame, O., Boateng, E., & Kwaku, H. (2018). A comprehensive study on the activities of soy processing facilities in Kumasi and its environs. *University of Cape Coast Youthmappers*, Department of Geography and Regional Planning.

Floss, E. L. (2004). Fisiologia das plantas cultivadas. *Passo Fundo: UPF*, *204*.

Foyer, C. H., Siddique, K. H. M., Tai, A. P. K., Anders, S., Fodor, N., Wong, F., Ludidi, N., Chapman, M. A., Ferguson, B. J., & Considine, M. J. (2019). Modelling predicts that soybean is poised to dominate crop production across A frica. *Plant, Cell & Environment*, *42*(1), 373–385.

Fratini, R., Durán, Y., García, P., & De La Vega, M. P. (2007). Identification of quantitative trait loci (QTL) for plant structure, growth habit and yield in lentils. *Spanish Journal of Agricultural Research*, *5*(3), 348–356.

Fried, H. G., Narayanan, S., & Fallen, B. (2019). Evaluation of soybean [*Glycine max* (L.) Merr.] genotypes for yield, water use efficiency, and root traits. *PLoS ONE*, *14*(2), 1–18. https://doi.org/10.1371/journal.pone.0212700

Gage, D., Bangnikon, J., Abeka-Afari, H., Hanif, C., Addaquay, J., Antwi, V., & Hale, A. (2012). The market for maize, rice, soy, and warehousing in Northern Ghana. *This Report Was Produced by USAID's Enabling Agricultural Trade (EAT) Project*.

Gauch Jr, H. G., & Zobel, R. W. (1997). Identifying mega-environments and targeting genotypes. *Crop Science*, *37*(2), 311–326.

Grabau, L. J., & Pfeiffer, T. W. (1990). Management Effects on Harvest Losses and Yield of Double-Crop Soybean. *Agronomy Journal*, *82*(4), 715–718.

Gulluoglu, L., Arioglu, H., & Arslan, M. (2006). Effects of some plant growth regulators and nutrient complexes on pod shattering and yield losses of soybean under hot and dry conditions. *Asian Journal of Plant Sciences*.

Gyan, K. (2018). Farmers'willingness to pay for soya bean production inputs in northern *Ghana*. A Thesis Submitted In Partial Fulfilment of the Requirements for The Award of MPhil in Crop Science. University for Development Studies

Hughes, C. E., & Group, L. P. W. (2017). A new subfamily classification of the Leguminosae based on a taxonomically comprehensive phylogeny. *Taxon*, *66*(1), 44–77.

Hutchinson, M. J., Muniu, F. K., Ambuko, J., Mwakangalu, M., Olubayo, F., Kirimi, J., Sciences, V., & Kilifi, P. O. (2017). Morphological and Agronomic Characterization of Local Vegetable Cowpea Accessions in Coastal Kenya. *M.J. March*, 47–58.

Jin, J., Liu, X., Wang, G., Mi, L., Shen, Z., Chen, X., & Herbert, S. J. (2010). Agronomic and physiological contributions to the yield improvement of soybean cultivars released from 1950 to 2006 in Northeast China. *Field Crops Research, 115*(1), 116–123.

Jonathan C. Allen, J., D Corbitt, A., P Maloney, K., S Butt, M., & Truong, V.-D. (2012). Glycemic index of sweet potato as affected by cooking methods. *The Open Nutrition Journal*, *6*(1).

Jumrani, K., & Bhatia, V. S. (2018). Impact of combined stress of high temperature and water deficit on growth and seed yield of soybean. *Physiology and Molecular Biology of Plants*, *24*(1), 37–50.

Kachala, B. M. (2018). Study on grain yield stability, molecular diversity and multi-trait relationships among elite soybean lines. Doctoral dissertation, University of KwaZulu-Natal.

Kahlon, C. S., Board, J. E., & Kang, M. S. (2011). An analysis of yield component changes for new vs. old soybean cultivars. *Agronomy Journal*, *103*(1), 13–22.

Kang, B.-K., Kim, H.-T., Choi, M.-S., Koo, S.-C., Seo, J.-H., Kim, H.-S., Shin, S.-O., Yun, H.-T., Oh, I.-S., & Kulkarni, K. P. (2017). Genetic and environmental variation of first pod height in soybean [*Glycine max* (L.) Merr.]. *Plant Breeding and Biotechnology*, *5*(1), 36–44.

Kataliko, R. K., Kimani, P. M., Muthomi, J. W., Wanderi, W. S., Olubayo, F. M., & Nzuve, F. M. (2019). Resistance and correlation of pod shattering and selected agronomic traits in soybeans. *Journal of Plant Studies; Vol*, *8*(2).

Kelbert, A. J., Spaner, D., Briggs, K. G., & King, J. R. (2004). Screening for lodging resistance in spring wheat breeding programs. *Plant Breeding*, *123*(4), 349–354.

Kermah, M., Franke, A. C., Adjei-Nsiah, S., Ahiabor, B. D. K., Abaidoo, R. C., & Giller, K. E. (2017). Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea savanna of northern Ghana. *Field Crops Research*, *213*, 38–50.

Khakwani, A. A., Baloch, M. S., Nadim, M. A., Zubair, M., Shah, I. H., & Khan, A. W. (2010). Lodging: A determining factor in reducing yield and yield structure of wheat. *Sarhad J. Agric*, *26*(2), 235–239.

Kim, J., Scaboo, A., Pantalone, V., Li, Z., Bilyeu, K., & Bilyeu, K. (2022). Utilization of Plant Architecture Genes in Soybean to Positively Impact Adaptation to High Yield Environments. *13*(5), 1–17. https://doi.org/10.3389/fpls.2022.891587

Koester, R. P., Skoneczka, J. A., Cary, T. R., Diers, B. W., & Ainsworth, E. A. (2014). Historical gains in soybean (*Glycine max* L. Merr.) seed yield are driven by linear increases in light interception, energy conversion, and partitioning efficiencies. *Journal of Experimental Botany*, *65*(12), 3311–3321.

Kowalczuk, J. (1999). Pattern of seed losses and damage during soybean harvest with grain combine harvesters. *International Agrophysics*, *13*(1).

Kuai, J., Sun, Y., Liu, T., Zhang, P., Zhou, M., & Wu, J. (2016). Physiological Mechanisms behind Differences in Pod Shattering Resistance in Rapeseed (*Brassica napus* L.) Varieties. *PLoS ONE*, *11*(6), 1–12. https://doi.org/10.1371/journal.pone.0157341

Lambon, J. B., Sarkodie-Addo, J., & Kombiok, J. M. (2018). Growth and yield response of soybean [*Glycine max* (L.) Merrill] to inoculation and starter N fertilizer applications in the Tolon District of the Northern Region of Ghana. *Ghana Journal of Agricultural Science*, *52*, 55–67.

Lindsey, A. J., Carter, P. R., & Thomison, P. R. (2021). Impact of imposed root lodging on corn growth and yield. *Agronomy Journal*, *113*(6), 5054–5062.

Mabaya, E., Adzivor, S. Y., Wobil, J., Waithaka, M., Mugoya, M., Damba, B., & M'Balou Camara, K. T. (2022). *Ghana Country Report 2022*.

Mandić, V., Đorđević, S., Đorđević, N., Bijelić, Z., Krnjaja, V., Petričević, M., & Brankov, M. (2020). Genotype and sowing time effects on soybean yield and quality. *Agriculture*, *10*(11), 502.

Martey, E., Gatti, N., & Goldsmith, P. (2020). Assessing the performance of regional soybean prices in Ghana. *International Food and Agribusiness Management Review*, *23*(2), 267–282. https://doi.org/10.22434/IFAMR2019.0138

Masuda, T., & Goldsmith, P. D. (2009). World soybean production: area harvested, yield, and long-term projections. *International Food and Agribusiness Management Review*, *12*(1030-2016–82753), 1–20.

Matusso, J. M. M., Mugwe, J. N., & Mucheru-Muna, M. (2013). Effects of different maize (*Zea mays* L.) soybean (Glycine max (L.) Merrill) intercropping patterns on yields and land equivalent ratio. *Journal of Cereals and Oilseeds*, *4*(4), 48–57.

Mbanya, W. (2011). Assessment of the constraints in soybean production: A case of Northern Region, Ghana. *Journal of Developments in Sustainable Agriculture*, *6*(2), 199–214.

Miles, M. R., Frederick, R. D., & Hartman, G. L. (2003). Soybean rust: Is the US soybean crop at risk. *APS Net Plant Pathology Online*.

Morrison, M. J., Voldeng, H. D., & Cober, E. R. (2000). Agronomic changes from 58 years of genetic improvement of short-season soybean cultivars in Canada. *Agronomy Journal*, *92*(4), 780–784.

Moses, A. (2012). Evaluation of new soybean varieties for market traits and adaptation in Uganda. *Magister Thesis, University Kampala*.

Musoni, S., Raymond, M., & Nazare, M. L. (2013). Mechanisation Of Soya Bean Harvesting For Small And Medium Scale Farmers In Zimbabwe. *IOSR Journal Of Agriculture And Veterinary Science (IOSR-JAVS)*, *2*(3), 51–53.

Nadarajan, N., & Gupta, S. (2010). Role of classical breeding in the improvement of pulse crops. *Electronic Journal of Plant Breeding*, *1*(4), 1099–1106.

Norman, H. A., Pillai, P., & Baker, M. E. (1995). Licorice-derived compounds inhibit linoleic acid (C: 18: 2ω6) desaturation in soybean chloroplasts. *FEBS Letters*, *368*(1), 135–138.

Ogutcen, E., Pandey, A., Khan, M. K., Marques, E., Penmetsa, R. V., Kahraman, A., & Von Wettberg, E. J. B. (2018). Pod shattering: a homologous series of variation underlying domestication and an avenue for crop improvement. *Agronomy*, *8*(8), 137.

Okwany, Z. A., Njoka, F. M., & Githui, E. (2010). *Genotype variant of soybean cultivars around Lake Victoria region, East Africa*.

Patterson, F. L., Schafer, J. F., Caldwell, R. M., & Compton, L. E. (1957). Lodging by Node-bending in Wheat and Barley 1. *Agronomy Journal*, *49*(9), 518–519.

Pinthus, M. J. (1974). Lodging in wheat, barley, and oats: the phenomenon, its causes, and preventive measures. *Advances in Agronomy*, *25*, 209–263.

Plahar, W. A. (2006). Overview of the soybean industry in Ghana. CSIR-food research institute, PO Box m. 20, Accra, Ghana. *Workshop on Soybean Protein for Human Nutrition and Health. Www. Csir. Org. Gh/Fri. Html*.

Purcell, L. C., Salmeron, M., & Ashlock, L. (2014). Arkansas soybean production handbook. *MP197. Purcell, LC, Ed.(Little Rock, AR: University of Arkansas Cooperative Extension Service) Pp*, 1–8.

Qin, X., Feng, F., Li, D., Herbert, S. J., Liao, Y., & Siddique, K. H. M. (2017). Changes in yield and agronomic traits of soybean cultivars released in China in the last 60 years. *Crop and Pasture Science*, *68*(11), 973–984.

Rahaman, K. A. (2018). Farmers' practices in soybean *(Glycine max (*L) Merrill*)* storage and their effects on viability and vigour of seeds. Dissertation submitted to the Department of Crop Science for the award of MPhil in Crop Science, University for Development Studies.

Ramteke, R., Gupta, G. K., Murlidharan, P., & Sharma, S. K. (2011). Genetic progress of soybean varieties released during 1969 to 2008 in India. *Indian Journal of Genetics and Plant Breeding*, *71*(04), 333–340.

Ramteke, R., Singh, D., & Murlidharan, P. (2012). Selecting soybean (Glycine max) genotypes for insertion height of the lowest pod, the useful trait for combine harvester. *Indian Journal of Agricultural Sciences*, *82*(6), 511–515.

Rao, M. S. S., Mullinix, B. G., Rangappa, M., Cebert, E., Bhagsari, A. S., Sapra, V. T., Joshi, J. M., & Dadson, R. B. (2002). Genotype× environment interactions and yield stability of food-grade soybean genotypes. *Agronomy Journal*, *94*(1), 72–80.

Rincker, K., Nelson, R., Specht, J., Sleper, D., Cary, T., Cianzio, S. R., Casteel, S., Conley, S., Chen, P., & Davis, V. (2014). Genetic improvement of US soybean in maturity groups II, III, and IV. *Crop Science*, *54*(4), 1419–1432.

Rogers, J., Chen, P., Shi, A., Zhang, B., Scaboo, A., Smith, S. F., & Zeng, A. (2015). Agronomic performance and genetic progress of selected historical soybean varieties in the southern USA. *Plant Breeding*, *134*(1), 85–93.

Sarkar, S., Zhou, J., Scaboo, A., Zhou, J., Aloysius, N., & Lim, T. T. (2023). Assessment of Soybean Lodging Using UAV Imagery and Machine Learning. *Plants*, *12*, 1–20. https://doi.org/https://doi.org/10.3390/ plants12162893

Shete, R., Borale, S., Andhale, G., & Girase, V. (2023). Screening of soybean genotypes for pod shattering tolerance and association of different traits with seed yield. *The Pharma Innovation*, *12*(1), 1548–1551.

Shurtleff, W., & Aoyagi, A. (2015). *History of soybeans and soyfoods in Sweden, Norway, Denmark and Finland (1735-2015): Extensively annotated bibliography and sourcebook*. Soyinfo Center.

Sidhoum, A. A., Vrachioli, M., & Sauer, J. (2021). 7. Agricultural mechanization and farm labor development. *Handbook on the Human Impact of Agriculture*, 102.

Singh, U., Gaur, P. M., Chaturvedi, S. K., Hazra, K. K., & Singh, G. (2019). Changing plant architecture and density can increase chickpea productivity and facilitate for mechanical harvesting. *International Journal of Plant Production*, *13*, 193–202.

Souza, C. A., Coelho, C. M. M., Guidolin, A. F., Engelsing, M. J., & Bordin, L. C. (2010). Influência do ácido giberélico sobre a arquitetura de plantas de feijão no início de desenvolvimento. *Acta Scientiarum. Agronomy*, *32*, 325–332.

Souza, J. B. C., Lages Vieira Passos, M., da Silva, E. A., Filho, A. L. de B., de Almeida, S. L. H., Oliveira, A. K. da S., Ferreira, L. de S., Sousa, W. da S., Almeida, E. I. B., & Silva, R. P. da. (2021). Estimated losses in soybean ('*Glycine max*'(L.) Merril) harvest according to the speed and rotation of the trail system. *Australian Journal of Crop Science*, *15*(4), 559–563.

Sujata, B., Basavaraja, G. T., & Salimath, P. M. (2012). Analysis of variability in segregating generation of soybean [*Glycine max* (L.) Merrill]. *Karnataka Journal of Agricultural Sciences*, *25*(2), 176–178.

Tefera, H., Kamara, A. Y., Asafo-Adjei, B., & Dashiell, K. E. (2009). Improvement in grain and fodder yields of early-maturing promiscuous soybean varieties in the Guinea savanna of Nigeria. *Crop Science*, *49*(6), 2037–2042.

Toshiro, K., Saitoh, K., Mahmood, T., & Yanagawa, K. (1998). Differences in Flowering Habit between Determinate and Indeterminate Types of Soybean. *Plant Prod. Sci.*, *1*(1), 18–24.

Tukamuhabwa, P., Dashiell, K. E., Rubaihayo, P., & Nabasirye, M. (2002). Determination of field yield loss and effect of environment on pod shattering in soybean.

Tukamuhabwa, P., Rubaihayo, P. R., Dashiell, K., & Adipala, E. (2000). Inheritance of resistance to pod shattering in soybean. *Afr Crop Sci J*, *8*(3), 203–211.

Wang, B., Xu, K., Wang, Y., Parker, T., & Wang, Q. (2020). Using soybean isoflavone to prevent hydrogen production reaction of aluminium dust and water in wet dust removal systems. *Journal of Loss Prevention in the Process Industries*, *67*, 104233.

Wang, C., Wu, T., Sun, S., Xu, R., Ren, J., Wu, C., Jiang, B., Hou, W., & Han, T. (2016). Seventy-five years of improvement of yield and agronomic traits of soybean cultivars released in the Yellow-Huai-Hai River Valley. *Crop Science*, *56*(5), 2354–2364.

Wu, T., Sun, S., Wang, C., Lu, W., Sun, B., Song, X., Han, X., Guo, T., Man, W., & Cheng, Y. (2015). Characterizing changes from a century of genetic improvement of soybean cultivars in Northeast China. *Crop Science*, *55*(5), 2056–2067.

Wu, W., & Ma, B.-L. (2018). Assessment of canola crop lodging under elevated temperatures for adaptation to climate change. *Agricultural and Forest Meteorology*, *248*, 329–338.

Yamba, P., Larson, E. A., Issaka, Z., & Akayeti, A. (2017). Design, Manufacture and Performance Evaluation of a Soybean Paddle Thresher with a Blower. *Life*, *7*, 8.

Yan, W., Hunt, L. A., Sheng, Q., & Szlavnics, Z. (2000). Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Science*, *40*(3), 597–605.

Yan, Z., Lauer, J. G., Borges, R., & De Leon, N. (2010). Effects of genotype× environment interaction on agronomic traits in soybean. *Crop Science*, *50*(2), 696–702.

Yang, Q., Lin, G., Lv, H., Wang, C., & Yang, Y. (2021). *Environmental and genetic regulation of plant height in soybean*. 1–15.

Zilio, M., Souza, C. A., Coelho, C. M. M., Miquelluti, D. J., & Michels, A. F. (2013). Cycle, canopy architecture and yield of common bean genotypes (Phaseolus vulgaris) in Santa Catarina State. *Acta Scientiarum. Agronomy*, *35*, 21–30.

APPENDICES

Appendix 1: Questionnaire for field survey among commercial soybean farmers

SECTION A: Socio-economic characteristics of farmers

1. District name *

2. Community name *

3. Age (years) *

4. Sex/gender *

○ Male

○ Female

5 Religion *

○ Islam

- Christianity
- Traditionalist
- Others

6 Highest educational level *

- Tertiary
- SHS/SSS JHS/JSS
- Professional training
- No formal education
- No formal training

7 Marital status *

- Married
- Single
- Divorced
- Separated
- Widow

8 Main occupation *

- Farming
- Trading
- Government worker
- Artisan
- Agro-processor

9 Do you own your farm land? *

- Yes
- No

10 If yes, how did you acquire the land?

- ◯ Owned land
- ◯ Gift
- ◯ Leased/rented Sharecropping

11 What type of cropping system do you practice on your soya bean farm? *

- ◯ Sole cropping
- ◯ multiple cropping

12 If multiple cropping, what type do you pracitice? (only for multiple)

- ☐ Sequential cropping system (this is where two or more crops are grown on the same piece of land per year)

☐ Mixed Cropping (Two or more crops without a distinct row arrangement)

☐ Ridge or Row Intercropping (this is the same as mixed cropping but with a distinct row arrangement or crops are grown on ridges

☐ Relay Intercropping (Growing two or more crops simultaneously during part of the life cycle of each)

☐ Phased Planting (Here the planting dates of the intercrops are systematically arranged to ensure continuous sequence of growth and harvesting)

☐ Strip Intercropping (involves growing two or more crops in separate strips wide enough for independent cultivation)

☐ Alley Cropping (In this system, food crops are grown in alleys or strips)

13 If intercropped, what crops do you intercrop soya bean with? (solely for mixed cropping in Q10)

☐ Maize

☐ Sorghum

☐ Any cereal and groundnut

☐ Millet

☐ Any cereal and cowpea

☐ Cowpea

☐ Yam

☐ Sweet potato

14 Roughly, what is your annual income (Gh¢) *

: SECTION B: Soya bean varieties in Ghana and their popularity

15 Where do you get information on soya bean production from? *

- ☐ Ministry of Food and Agriculture (MoFA)
- ☐ Farmer-based organization (FBO)/Community based organization (CBO)
- ☐ Non-governmental organization (NGO)
- ☐ Media (TV/radio)
- ☐ Mosque/church
- ☐ Print media
- ☐ Others

16 Information from Farmer-based organization (FBO)/Community based organization (CBO), name the FBO/CBO

Information from Non-governmental organization, please name them.

17 So far, 14 soya bean varieties have been released in Ghana, how many of these have you heard (multiple answers allowed) *

☐ Salintuya-I ☐ Salintuya-II ☐ Anidaso ☐ Bengbie ☐ Jenguma ☐ Quarshie ☐ Nangbaar ☐ Ahoto ☐ Afayak ☐ Songda ☐ Suong-Pungun ☐ Gyidie ☐ Latara ☐ Favour ☐ Toondana ☐ Anigyes

☐ No idea

18 Which of these varieties do you cultivate (multiple answers)? *

☐ Salintuya-I ☐ Salintuya-II ☐ Anidaso ☐ Bengbie ☐ Jenguma ☐ Quarshie ☐ Nangbaar ☐ Ahoto ☐ Afayak ☐ Songda ☐ Suong-Pungun ☐ Gyidie ☐ Latara ☐ Favour ☐ Toondana ☐ Anigyes ☐ No idea

19 Where do you obtain seeds for planting (multiple answers allowed)? *

☐ Ministry of Food and Agriculture (MoFA)

☐ Agro-chemical shop

☐ Certified Seed grower

☐ Chief farmer

☐ Own saved seed

☐ Non-governmental organization

☐ Friend/family member saved seed

SECTION C: Soya bean production constraints

This section seeks to identify challenges associated with soya bean production.

20 Which of the following are soya bean production constraints you face? *

- ☐ Poor seed germination
- ☐ Poor crop establishment
- ☐ High cost of seed
- ☐ Late maturity/long duration
- ☐ Small grain size
- ☐ Poor seed colour
- ☐ High cost of fertilizer
- ☐ High cost of pesticide
- ☐ High pest incidence
- ☐ No access to improved variety seeds
- ☐ High disease incidence
- ☐ Low yield
- ☐ Difficulty in harvesting
- ☐ Drought
- ☐ Low pod filling
- ☐ Poor taste
- ☐ Low recovery/shelling percentage
- ☐ Not fit into cropping system
- ☐ Poor fodder quality
- ☐ Susceptible to storage pest
- ☐ High flower abortion
- ☐ High incidence of pod dropping
- ☐ Others (Please specify)

21 If others to question 20 above, please specify

SECTION D: FARMER PREFERRED SOYA BEAN TRAITS

This section seeks to identify soya bean traits preferred by farmers

22 What characteristics of soya bean do you prefer for its production value? *

- ☐ Early maturing variety (specify maturity days)
- ☐ Pest resistance
- ☐ Disease resistance
- ☐ High yield
- ☐ Big seed size
- ☐ Small seed size
- ☐ Fit into existing cropping system
- ☐ improve soil fertility by higher nitrogen fixing ability
- ☐ More recovery/shelling %
- ☐ Drought resistance
- ☐ High biomass/good for fodder
- ☐ White/cream seed colour
- ☐ Red seed colour
- ☐ Black seed colour
- ☐ Mottled seed colour
- ☐ Better taste
- ☐ Less cooking

Appendix 2: Analysis of variance for plant girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	8.167	4.084	3.61	
Replication. *Units* stratum					
Soybean lines	6	24.030	4.005	3.54	0.030
Residual	12	13.568	1.131		
Total	20	45.766			

CV % 7.7
LSD 1.892

Appendix 3: Analysis of variance for lodging

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.0952	0.0476	0.22	
Replication. *Units* stratum					
Soybean lines	6	4.5714	0.7619	3.56	0.029
Residual	12	2.5714	0.2143		
Total	20	7.2381			

CV % 5.6
LSD 0.824

Appendix 4: Analysis of variance for plant height at physiological maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2.6	1.3	0.01	
Replication. *Units* stratum					
Soybean lines	6	5727.2	954.5	9.26	<.001
Residual	12	1236.7	103.1		
Total	20	6966.5			

CV % 0.8
LSD 18.06

Appendix 5: Analysis of variance for shattering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.8571	0.4286	2.84	
Replication. *Units* stratum					
Soybean lines	6	16.4762	2.7460	18.21	<.001
Residual	12	1.8095	0.1508		
Total	20	19.1429			

CV % 15.7
LSD 0.6908

Appendix 6: Analysis of variance for first pod height from the ground level

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	4.487	2.243	1.70	
Replication. *Units* stratum					
Soybean lines	6	356.960	59.493	45.13	<.001
Residual	12	15.820	1.318		
Total	20	377.267			

CV % 3.6
LSD 2.043

Appendix 7: Analysis of variance for the number of branches of soybean germplasm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2.5714	1.2857	3.77	
Soybean_lines	6	25.3333	4.2222	12.37	<.001
Residual	12	4.0952	0.3413		
Total	20	32.0000			

Appendix 8: Analysis of variance for leaf chlorophyll content at 40 days after planting.

Variate: LCC40

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.310	0.155	0.08	
Soybean_lines	6	260.666	43.444	22.99	<.001
Residual	12	22.677	1.890		
Total	20	283.652			

Appendix 9: Analysis of variance for number of pods per plant

Variate: NPP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.381	0.190	0.18	
Replication.*Units* stratum					
Soybean_lines	6	301.333	50.222	46.53	<.001
Residual	12	12.952	1.079		
Total	20	314.667			

Appendix 10: Analysis of variance for the number of seeds per pod per plant

Variate: NSPP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.1667	0.0833	0.60	
Replication.*Units* stratum					
Soybean_lines	6	11.6190	1.9365	13.94	<.001
Residual	12	1.6667	0.1389		
Total	20	13.4524			

Appendix 11: Analysis of variance for Hundred Seed weight

Variate: HSW

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	3.9807	1.9903	2.33	
Replication.*Units* stratum					
Soybean_lines	6	343.1856	57.1976	67.10	<.001
Residual	12	10.2292	0.8524		
Total	20	357.3955			