RESPONSE OF COWPEA MUTANT LINES TO PLANTING DISTANCE AND SEASONAL VARIATION IN THE SEMI DECIDUOUS ECOZONE

BY

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DECLARATION

I, Musah Kweku Mensah, hereby declare that this thesis submitted to the Crop Science Department of the College of Basic and Applied Sciences (CBAS), University of Ghana, for the award of a Master of Philosophy Degree (Crop Science), is based on my own field work and has been composed under strict supervision. It has not been submitted previously, either wholly or partially for the award of a Master of Philosophy Degree in the University of Ghana or anywhere else. All sources of information have been duly acknowledged.

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ABSTRACT

Cowpea (*Vigna unguiculata*) is an important legume crop grown for its nutritional and economic benefits, particularly in the tropical and sub-tropical agro-ecological zones in Sub-Saharan Africa. However, optimizing cowpea production remains a challenge due to an inadequate knowledge on the ideal spacing and cowpea varieties suited for specific climatic conditions. This study aimed to evaluate the growth and yield potential of three cowpea mutant lines **(M1**:HansM9 (12) (3), **M2**:HansM9 (12) (5), and **M3**:HansM9 (12) (25) in referenced to two standard varieties (**Mi4**: Asontem (An improved variety) and **Mo5**: Hansadua (improved variety) in a semi-deciduous agro-ecological zone. The study employed a 3x5 factorial experiment laid out in a split-plot design with three (3) spacing intervals (**S1**; 60 cm × 20 cm, **S2**:60 cm × 30 cm, and **S3**:60cm × 40cm) during both the major and minor rainy seasons. There were fifteen treatment combinations with four (4) replications resulting in a total of sixty (60) plots. The spacing interval treatments were employed at the main plots (Block) with the three mutant lines and the two varieties on the subplots. Various vegetative and reproductive parameters, including plant height, number of branching, plant girth, canopy size, number of pods, seeds per pod, and total seed weight per hectare were studied. Results showed that the closest spacing **(60 cm × 20 cm)** led to the highest grain yield, particularly for the mutant line **HansM9 (12) (25)**, which outperformed other varieties in terms of **total seed weight** and **overall yield**. In contrast, the wider spacing **(60 cm × 40 cm)** promoted greater vegetative growth, making it suitable for practitioners aiming to maximize **biomass** production. The **major rainy** season was found to be the most **conducive** for growth and yield, while **irrigation** is recommended to enhance productivity during the **minor season**. In summary, **HansM9 (12) (25)** is recommended for **high-density planting (60 cm × 20 cm)** to maximize **grain yield**, especially during the **major season**. Asontem is more suited for biomass production, particularly at wider spacing **(60 cm × 40 cm)**

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DEDICATION

This thesis is dedicated to my family

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LIST OF ABBREVIATIONS

A.S.L	–	Above Sea Level
ANOVA	–	Analysis of Variance
CBAS	–	College of Basic and Applied Sciences
CPMOV	–	Cowpea Mottle Virus
CPMV	–	Cowpea Mosaic Virus
CRI	–	Crops Research Institute
CSIR	–	Council for Scientific and Industrial Research
DFT%E	–	Days to Fifty Percent Emergence
EC	–	Electrical Conductivity
FAO	–	Food and Agriculture Organization
FASDEP	–	Food and Agriculture Sector Development Policy
G	–	Gram
ha^{-1}	–	Per Hectare
IBPGR	–	International Board for Plant Genetics Resources
IITA	–	International Institute of Tropical Agriculture
kg ha^{-1}	–	Kilograms per Hectare
LAI	–	Leaf Area Index
m	–	Meter

Mm	–	Millimetre
MoFA	–	Ministry of Food and Agriculture
NPK	–	Nitrogen, Phosphorus, and Potassium
S.I. × S	–	Spacing Interval × Season Interaction
SPSS	–	Statistical Package for the Social Sciences
TSP	–	Triple Super Phosphate
USDA	–	United States Department of Agriculture
V × S.I. × S	–	Variety × Spacing Interval × Season Interaction
V × S.I.	–	Variety × Spacing Interval Interaction

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Cowpea (*Vigna unguiculata*), also known as black-eyed pea, is a legume crop originating from West Africa, specifically Nigeria, Niger, and Cameroon. Cowpea cultivation is widespread in Africa, Asia, Caribbean, Brazil, India, Australia, and the United States, accounting for 89% of global production (Oyewale & Bamaiyi, 2013). Its adaptability to arid and semi-arid conditions, having high nutritional value, and nitrogen-fixing properties making it a valuable crop for smallholder farmers and food security (Simon, 2018). West Africa, particularly Nigeria, Niger, Burkina Faso, and Mali, is the largest producer globally (Boukar *et al*., 2014). In East Africa, countries like Tanzania, Uganda, Kenya, and Ethiopia also cultivate cowpea (Owade *et al*., 2019).

It contains plenty of dietary fibre, vital minerals, amino acids, proteins, and carbohydrates, making it a great source of protein isolates and concentrates (Khalid & Elhardallou, 2016). Cowpeas can also be utilised as livestock feed, producing fodder, silage, and hay. Cowpea is also utilised to generate income, as it defines both formal and informal regional commerce in Sub-Saharan African market systems (Langyintuo *et al*., 2003). It is an ideal crop for food security due to its numerous benefits (Dube & Fanadzo, 2013). Cowpea can be used to control weeds and insect pests including *Striga hermonthica*, a parasite of millet, pearl sorghum, and maize (Sheahan 2012). It is also a good cover crop in orchards because of its big tap root and broad vegetative spread. Cowpea cultivation also helps in soil fertility through biological nitrogen fixation by nitrogen-fixing bacteria such as rhizobia, which promotes soil fertility and reduces demand (Audu *et al*., 2019).

In Ghana, grains can be cooked and eaten with "gari." It can also be combined with rice to form "waakye." The boiled seeds can also be served with fried ripe plantains (Quaye *et al*., 2009). Cowpea is officially classified as a key food security crop, especially in Ghana's coastal, savanna, and northern zones (MoFA, 2024).

Despite the numerous benefits derived from cowpea, its production is faced with so many constraints globally (Mbanya, 2011). Several conditions consisting of both biotic and abiotic factors act as barriers to higher grain yield and seed quality. Production is very low in Ghana with the area under cultivation decreasing significantly due to factors such as urbanization, land tenure issues, dwindling farmer interest, and the unavailability of preferred cultivars (Quaye *et al*., 2009; Egbadjor *et al*., 2013), as well as poor production practices (El Naim and Jabereldar, 2010).

Although cowpea is extremely important, on-farm yields are still low, ranging from 0.3 to 0.5 t ha−1 in West African savanna ecologies, especially Ghana (Boukar *et al*., 2019), compared to the crop's potential yield of about 2.0 t ha−1 (Owusu *et al*., 2018).

Low plant population density has been linked to low grain yield since most farmers grow cowpeas without following prescribed spacing and population density (Kamara *et al*., 2014). Cowpea cultivars require varying population densities to reach their maximum yield potential due to variations in plant morphology and growth habits (Ndiaga, 2001). As a result, new genotypes must be exposed to various ecozones and spatial arrangements in order to identify the most suited genotypes and optimum population density that will produce potential performance during a given season.

Development and evaluation of cowpea varieties that are well-adapted to particular agro ecological environments is vital for food security (Mason *et al*., 2015; FAO, 2019).

1.5. 0 Objectives of the study

The objectives of the study were to;

1. Determine the ideal spacing interval for cowpea mutant lines that maximizes growth and yield.
2. Determine the growth and yield of the mutant lines under both major and minor rainy seasons in the semi deciduous Agro-ecological zone.
3. Assess the relationship between plant population density and cowpea mutant lines.
4. Determine seasonal variations on the growth and yield of the cowpea lines.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution of the cowpea plant

Cowpea (Vigna unguiculata), also known as black-eyed pea, is an important legume crop widely cultivated in tropical and subtropical regions worldwide. Its origin can be traced back to West Africa, specifically in the region encompassing present-day Nigeria, Niger, and Cameroon (Herniter et al., 2020; Steele, 1976). Research suggests that cowpea domestication occurred around 5,000 years ago in this region (Coulibaly *et al*., 2002; Fatokun *et al*., 2012). Different wild and weedy cowpea varieties are abundant in West Africa on the boundaries of the forest zones as well as the savanna (Leaky & Wills, 1977) supporting the fact that, from around 300 BC, both origination and domestication took place in West Africa (Pratap & Kumar, 2011). Stahl (1985) argues that carbon dating of cowpea or wild relatives from the Kintampo rock shelter in central Ghana provides the oldest known archaeological evidence of cowpea in Africa. It is also a well-known fact that, West and Central Africa are associated with maximum variation in cultivated cowpea and landraces (Boukar *et al*., 2018).

The distribution of cowpea expanded from West Africa through trade routes, human migration, and cultivation practices. From its origins, cowpea spread across various continents, including Asia, the Americas, and parts of Europe, adapting to diverse climates and becoming a staple in many cuisines and agricultural systems (Coulibaly *et al*., 2002; Singh *et al*., 2017). Cowpea was brought to Europe through North-East Africa and India around 300 BC, reached South-Eastern Asia around 230 BC, and southern Europe by Greeks and Romans under the names *Phaseolus* and *Phaselus*. Cowpea has been cultivated in the southern United State of America since the early 18th century (Wolfe & Kipps, 1959).

Cowpea cultivation is widespread in Africa, Asia, Caribbean, Brazil, India, Australia, and the United State of America, with Western and Central African regions accounting for 89% of global production. Other regions include Kenya, Mozambique, Somalia, Sudan, Tanzania, Uganda, Egypt, Haiti, Myanmar, Serbia, and Sri Lanka (Oyewale & Bamaiyi, 2013). The crop's ability to thrive in arid and semi-arid conditions, coupled with its high nutritional value and nitrogen-fixing properties, has contributed to its popularity and widespread cultivation in regions with challenging agricultural environments (Fery and Singh, 2013).

2.2 Classification of cowpea plant

Cowpea is a member of the *Fabaceae* family, also known as the bean, pea, or legume family (Timko *et al*., 2007). The subfamily *Faboideae*, also referred to as the *Papilionoideae*, comprises several commercially significant legume crops. Cowpea is a vital annual herbaceous plant that grows in a climbing or trailing manner. Its complex leaves include three leaflets, each of which has a noticeable centre vein (Timko, 2007).

Cowpea is an annual crop, although those with indeterminate growth patterns are typically perennial (Haizel, 1972). Cowpea has a variety of growth traits with certain types having a canopy that may reach a height of 60 to 90 cm, and may be prostrate and vine-like, bushy and short, or tall. While the twining variants have significantly thinner stems, certain cowpea cultivars have erect, hollow, and hairless stems. The hairless, egg-shaped, three-parted leaves of cowpeas are around 10 cm long and 8 cm wide. Its leaves and leaf stems include tiny pores that function as floral nectar, secreting nectar to draw beneficial insects. The tap root system is well developed, with a significant number of globular, often grouped nodules and many laterals (Masangwa, 2012). The branchless inflorescence often produces stamens, which are purple or white in colour and are around 2.5 cm in length when they are formed along the main axis. The lowest leaf whorl is shaped like a bell. The flower's lobes are joined, and the lateral petals seem shorter than the upper ones. From the leaf axils arise two-valved pods, which are roughly 8 to 15 cm long and can be coiled, circular, crescent, or linear in form. Each pod contains about six to thirteen seeds, most of which are lodged in the spongy tissue (Sheahan, 2012). The majority of cowpea cultivars are categorized as indeterminate in nature since it takes a while for them to develop flowers and produce seeds (Oyewale & Bamaiyi, 2013). Certain varieties, known as determinate, produce flowers and produce seeds during a single season. The flowers are typically *Papilionaceous,* with five petals arranged in a distinctive butterfly-like shape (Badiane *et al*., 2014). Cowpea flowers come in various colours, including white, cream, purple, and red, depending on the cultivar (Kim *et al*., 2013). After pollination, cowpea plants produce elongated pods containing seeds, which are the edible portion of the plant (Abebe & Alemayehu, 2022). The seeds themselves vary in size, shape, and colour, with differences observed among cultivars (Nogueira *et al*., 2014). Cowpea seeds come in a variety of sizes, which are small, medium and large according to Abadassi (2015), with black, white, red, brown, cream, green, and buff being the most prevalent seed coat colours. The distinct textures of the seed coats include loose, wrinkled, rough, and smooth. The cowpea seeds vary in shape. Amongst the notable cowpea seed shapes include globose, kidney, crowder, rhomboid and ovoid (Abadassi 2015). Sheahan (2012) identified two cultivated cowpea sub-species, *V. sesquipedalis* and *V. catjang,* as distinct from *V. unguiculata* in pod length, shape, and seed characteristics, but notes nine variations that are difficult to isolate due to cross-fertilization.

2.3 Production trends of cowpea

Cowpea (Vigna unguiculata) is one of the world’s most significant leguminous crops, widely cultivated for its nutritional, agronomic, and economic value. In 2022, global cowpea cultivation covered approximately 15.1 million hectares, yielding 8.9 million tons (FAO, 2022). Africa is a major hub for cowpea production due to its adaptability and role in food security and economic sustainability (Walker *et al*., 2016). Projections indicate a growth in global production from 9.8 million tonnes in 2020 to 12.3 million tonnes by 2030 (Boukar *et al*., 2016). Cowpea is crucial not only in Africa and Asia but also in South America, where its environmental benefits and agronomic potential have made it one of the most cultivated legumes (Linguya *et al*., 2015; Goncalves *et al*., 2016).

Cowpea plays a central role in meeting nutritional needs, providing essential proteins, minerals, and vitamins. Every part of the plant—pods, leaves, and seeds—is consumed, especially as they are high in protein and low in fat (Gonçalves *et al*., 2016). It also supports soil health by enhancing beneficial microbial activity and reducing dependence on synthetic fertilizers (Bukovsky-Reyes *et al*., 2019; Sun *et al*., 2019).

Despite its benefits, cowpea production faces numerous constraints in Africa, including low-yielding varieties, poor seed quality, pest and pathogen pressures, nutrient-depleted soils, and climate change-induced drought and erratic rainfall (Barros *et al*., 2011; Afutu *et al*., 2017; Reed *et al*., 2022). Overcoming these barriers requires the use of high-quality, vigorous seeds and targeted breeding programs. Breeding focuses on desirable traits drawn from wild cowpea relatives to improve genotypes through hybridization and selection techniques.

Planting density and spacing are critical factors affecting cowpea yield. Studies show that wider spacing increases the number of pods and seeds per plant, while narrower row spacing can boost overall yield (Jakusko *et al*., 2013). Optimal spacing reduces competition for resources like light, nutrients, and water, while enhancing pod development and seed output (Sebetha *et al*., 2010; El Naim & Jabereldar, 2010; Kamara *et al*., 2018). However, low planting density remains a significant contributor to the poor average yields in sub-Saharan Africa—often under 450 kg/ha—

despite cowpea's yield potential of up to 6,000 kg/ha (Hutchinson *et al*., 2016; Lemma *et al*., 2009).

Multiple biophysical, technical, climatic, and socioeconomic factors—including poor rainfall, pests, inadequate farming practices, and limited access to credit or labour—contribute to these low yields (Abadassi, 2015). Implementing effective agronomic practices, particularly proper spacing and optimal planting density, is essential to improve productivity and close the yield gap (Lemma *et al*., 2009).

Cowpeas are harvested at different stages depending on intended use—green and tender at the pod stage, or fully dried for storage and grain purposes (Karanaja *et al*., 2008; Oyewale & Bachiyi, 2013). These diverse uses, along with cowpea's nutritional and ecological value, reinforce its importance as a staple food and income source for millions of smallholder farmers worldwide.

2.4 Cowpea production in Ghana

A key crop of Ghana's sustainable agricultural system is cowpea. Cowpea (Vigna unguiculata), the second most important leguminous crop grown in Ghana after maize, holds significant stature in terms of planted area, yield, and annual consumption (Karikari et al., 2023). At present, cowpea is officially classified as a key food security crop, especially in Ghana's coastal, savanna, and northern zones (MoFA, 2024). The bulk of cowpea production in Ghana takes place in the Guinea Savanna agro-ecological zone, with smaller amounts also being grown in the Sudan and Coastal Savanna zones (Asafo Adjei *et al*., 2005). Apart from the savanna agro-ecological zones, cowpea production is primarily subsistence in the other agro-ecological zones. According to Addo-Quaye *et al*. (2011), some cultivars are developed to thrive in particular agro-ecological zones. On 147,000 hectares, Ghana produced 206,380 Mt in 2016 (MoFA; SRID, 2017). Although the quantity of cowpeas produced has increased over time, the area under cultivation has decreased significantly, from over 163,000 hectares in 2003 to little over 163,000 hectares in 2010. There are a number of reasons for this decline in farm size, including urbanization, difficulties with land tenure, dwindling farmer interest, and the availability of cultivars that consumers prefer. Improved agronomic techniques and superior released varieties may be the cause of the rise in cowpea productivity. Ghana produces less cowpea than it consumes. The shortfall in cowpea yield is compensated for by imports from neighbouring West African nations. According to reports, Ghanaians (Egbadjor *et al*., 2013; Quaye *et al*., 2009) prefer big cream cowpea grains.

The release of varieties that consumers prefer may encourage more cowpea cultivation in Ghana. Although varieties such as "Asontem" and "Nhyira" have been released by the Council for Scientific and Industrial Research (CSIR) - Crops Research Institute (CRI), limitations arising from lengthy cooking time and crimson seed coat ("Asontem") and small gain size ("Nhyira") have significantly impacted consumer preference (Asafo-Adjei *et al*., 2005). Large, white, or cream-coated cowpea grains are the most popular, and are thus imported. Therefore, cultivars possessing these fundamental attributes are primarily imported and come at a high cost.

Reasonable indicators point to increasing cowpea productivity along Ghana's coastal savanna agro-ecological zone. According to Muchero *et al*. (2009), the cowpea crop has a short season and can withstand some amount of drought. Farmers with little resources cultivate the majority of the crop. As a result, cowpea grown in northern Ghana or other West African countries like Togo, Burkina Faso, Nigeria, and Niger flood the majority of southern markets. Once more, most imported kinds are not usually cultivated in Ghana due to genetic by environmental interactions (Langyintuo, 2004). Enhanced cultivation of consumer preferred varieties could go a long way to increase cowpea cultivation locally. This is expected to minimize rate of importation

Little improvement in cowpea yields have been reported since 1991, with Ghana producing 7,200 metric tons of cowpea (CRI, 1998). Cowpea yields prior to that ranged between 0.9and 2.0 metric tons per hectare. But in a few isolated locations with good agronomic and crop protection techniques (FASDEP, 2002), particularly on the loamy soils of Guinea's Savannah and Transition zones, yields of 2.0 metric tons per hectare have been reported (CRI, 1998).

Ghana's low cowpea tonnage output is caused by inadequate integrated management techniques, which include the use of vulnerable varieties, unimproved varieties, poor soils and cultural practices, pre-harvest diseases and pests, and post-harvest losses (FASDEP, 2002).

The weight of 100,000 seeds, the number of pods per plant per unit area, and the number of seeds per pod all positively correlate with cowpea output (Amoatey, 1987).

Secondary characteristics that affect seed output include days to blooming, days to maturity, peduncle length, and pod length (Doku, 1970).

Cowpea grain output was shown to be highly correlated with both the number of pods per plant and the weight of 100 seeds, as demonstrated by Ebong's (1972) research. Since there is a negative correlation between seeds per pod and pods per plant, recent research has focused more on the number of pods per plant as the primary yield component rather than the number of seeds per pod (Turk *et al*., 1980).

2.5 General uses of cowpea

Cowpea is well recognized for being a good source of dietary fibre. Cowpea also contains a number of essential nutrients that support good health, such as vitamins, minerals, and phytochemicals. Amino acids, proteins, and carbohydrate are also present. Due to its reduced cholesterol content, using cowpea in diets provides enhanced nutrition. Cowpea protein isolates and concentrates can be used to make textured meals and a variety of traditional food formulations (Khalid & Elhardallou, 2016).

Sometimes, full-sized cowpea pods harvested before dry up, could be shelled and cooked into fresh "southern peas" that may be eaten. This is commonly practiced in the semi-arid Sahel area of Africa during the "hungry period", which comes before the customary harvest of dry cowpea grains. In Ghana, the grains can be cooked and consumed with "Gari." It may also be cooked with rice to make "Waakye." It is also possible to serve the boiled seeds alongside a fried ripe plantain (Quaye *et al*., 2009).

Forage, silage, and hay may all be made from cowpea. Light grazing following blooming is recommended if it is to be used as feed. Should any buds remain unharmed during defoliation, the plant is capable of sprouting again. Cowpea foliage is regarded as a good source of premium hay used for animal feed worldwide (Audu *et al*., 2019). Studies have shown that older cowpea leaves have greater concentrations of carbohydrates and a protein content that is similar to that of seeds (Sebetha *et al*., 2010).

Cowpea, often referred to as the "poor man's crop" due to its versatile use as food, feed, and soil amendment, is highly resourceful (Dube and Fanadzo, 2013). In addition to being used as food, young cowpea pods, leaves, and grains are sold to farmers in order to make money (Kimiti *et al*., 2009). Hall (2012) reported that the sale of fresh southern peas provides the necessary funds during the lean period prior to harvests. In the Sub-Saharan African, cowpea is best suited as a crop for food security because of its many advantages (Dube & Fanadzo, 2013).

According to Hall (2012), certain cowpea lines can be used to supress the germination of Striga *hermonthica*, a parasite of millet, pearl sorghum, and maize. Nematode (*Scutellonema cavenessi*) is the primary pest that affects peanuts, sorghum, and pearl millet in the Sahelian zone. It has been observed that other lines can inhibit this pest. Allelopathic chemicals are the reason for cowpea's ability to control weeds, according to Sheahan (2012).

Cowpea is a cover crop that grows quickly. The large tap root and extensive, vegetative spread of cowpea make it a perfect crop for controlling weeds and preventing erosion. It has shown to be an effective groundcover in orchards (Sheahan, 2012). Timko & Singh, 2008 and Singh, 2002 mention the potential use of cowpea as a cover crop. Because of its resistance to drought, it may be grown on tropical soils when agricultural productivity is hampered by variables like as moisture, poor soil fertility, and erosion (Langyintuo *et al*., 2003).

Cowpea is considered an essential crop to rotate with grains. One of the main advantages is its contribution to the nitrogen condition of the soil (Hall, 2012). According to Gwata *et al*. (2016) and Yirzagla *et al*. (2016), cowpea cultivation increases soil fertility by means of biological nitrogen fixation by nitrogen-fixing bacteria such rhizobia.

Symbiotic nitrogen fixation makes this possible by increasing soil fertility and lowering the demand for N fertilizer application (Ndema *et al*., 2010). Nodulation occurs in cowpeas in the field. In Senegal and California, cowpeas have been shown to respond little to nil to nitrogen fertilizer of the soil. This may be related to its significant biological nitrogen fixation capacity (Hall, 2012).

2.6 Cowpea consumption in Ghana

According to Langyintuo *et al*. (2003) and Al-Hassan and Diao (2007), cowpea consumption in Ghana exceeds cowpea output. Ghanaians cook a variety of meals for consumption, which explains why the consumption rate is larger than the production rate.

Although Ghana imports cowpea, it is still regarded as one of the major producers of the crop (Singh *et al*., 2003; Egbadzor, 2014).

During the 2010–2011 fiscal year, 3,380 metric tons of cowpea were imported to complement Ghana's 219,257 metric tons of cowpea. Nonetheless, this accomplishment represented a considerable improvement from the about 113,000 metric ton 1990 shortfall (Al-Hassan and Diao, 2007). Ghana's output shortfall is a complex issue. Although it is possible to produce cowpeas in other agro-ecological zones, commercial cowpea production mostly takes place in the northern regions defined by Savannahs. For example, in 2010 when the national total was 219,300 metric tons, the Upper West and northern areas were reported to have produced 75,969 and 105,841 metric tons, respectively (Egbadzor, 2014).

In contrast to the north, the south mostly produces cowpeas for sustenance. Furthermore, Langyintuo *et al*. (2003) suggest that varietal choice might be a factor influencing cowpea cultivation and consumption in Ghana.

2.7. Cowpea establishment and weed management

2.7.1 Establishment of cowpea

The optimal period to plant is between late May and mid-June. Sowing involves placing seeds 2-4 cm deep. Cowpea seeds germinate quickly, the young plants are robust, and the crop can multiply from the previous crop. Cowpeas flower in around 48 days in older cultivars, while pod production takes about 60 days (Sheahan, 2012).

2.7.2 Weed management in cowpea

Though cowpea is a fast-growing weed suppressor, it is less effective at controlling perennial grasses. When cowpea is produced for dry seed, row culture is advised as a weed control method

(Sheahan, 2012). There are many weeds in the tropical zone that are known to cause serious cowpea losses of up to 86%. Examples of such weeds include *Cyperaceae*, *Scrofulariaceae, Gramineae* and *Euphorbiaceae* (Abadassi, 2015). Integrated weed management (IWM) is one of the several management techniques needed to reduce yield loss from weeds.

2.8 Climatic requirements

Cowpeas can grow in a wide range of environments. However, in regions with at least 600 mm of annual rainfall, it is often cultivated under rain-fed agriculture (Ndiso *et al*., 2016). According to Oyewale and Bamaiyi (2013), the best regions for cowpea production are those with 750–1500 mm of annual rainfall. Cowpea is not resilient to flooding and yields are impacted by water stress in different ways, depending on how severe it is (Sheahan, 2012).

Cowpea is resilient to severe heat, droughts, and other biotic stressors (Ndiso *et al*., 2016). According to Sheahan (2012), the optimal temperature for cowpea growth is 26.7°C throughout the day and a consistent soil temperature of 18.3°C on average.

Different types of soils can support cowpea development; very acidic to neutral soils are preferred, as more are low in fertility but well-drained soils (Sheahan 2012). Rich, sandy-loam soils with good drainage are ideal for cowpea cultivation (Oyewale & Bamaiyi, 2013). Cowpea grows best at a pH range of 5.5 to 6.5 (Ndiso *et al*., 2016).

2 .9 Fertility management

Cowpea requires less nitrogenous fertilizer since it fixes its own nitrogen from the air through its root nodules (Karikari *et al*., 2015). The crop supplies a significant amount of its own needs in addition to a fixed nitrogen deposit of up to 60–70 kg ha–1 in the soil (Singh *et al*., 2011). In places where the soil is deficient in nitrogen, a starting dose of around 15 kg of nitrogen is required for a healthy crop.

Cowpeas are susceptible to phosphorus levels in the soil. Cowpea growth is slowed down by low soil phosphorus, which is naturally low in many tropical soils (Kimiti, 2011). Phosphorus is a vital nutrient for crop productivity. It plays key roles in nodule formation, nitrogen fixation, enzyme regulation, energy metabolism, photosynthesis, respiration, and protein synthesis. It also supports rhizobium-legume symbiosis, rapid cell division, and the development of flowers, seeds, and fruits. Application of phosphorus has been observed to increase cowpea yields (Karikari *et al*., 2015). Soil phosphorus can be replenished by adding organic materials in the form of plant or animal debris, and inorganic fertilizers. Cowpea growth can be enhanced by adding inorganic phosphorus at rates of 13 to 25 Kgha-1 in the form of triple super phosphate (TSP) or di-ammonium phosphate (DAP) (Kimiti, 2011).

2.10 Cowpea pests and diseases and their management

In most regions, two to four species of important pests are present (Oyewale & Bamaiyi, 2013). Depending on the region, year, and cultivar, cowpea yield losses from field and storage pests can reach 95%. According to findings by Ilesanmi and Gungula (2010), bruchids are the primary pests in storage facilities, whereas aphids are the primary pests in fields. Losses in stored cowpea of up to 30–70% have been reported in the absence of insect pest management techniques (Bawa *et al*., 2012).

2.10.1 Insect pests of cowpea

Tiroesele *et al*., (2015) in their study of cowpea insect pests identified Aphids (*Aphis craccivora*), leafhoppers (*Empoasca sp*.), thrips (*Megalurothrips sp*.), and stinkbug infestations among the primary insect pests of cowpea that can cause significant financial losses. The most harmful of these pests include the legume pod borer, *Maruca vitrata Fab*. (Lepidoptera: *Pyralidae*), flower bud thrips, *Megalurothrips sjostedti Tryb*. (Thysanoptera: Thripidae), and a class of sucking bugs, which include *Aspavia sp*., *Clavigralla sp*., and *Riptortus sp*. Regular observation is essential because during the establishment period, birds and rats also consume the seeds (Oyewale & Bamaiyi, 2013).

2.10.2 Diseases of cowpea

There are several categories into which cowpea disease may be divided, including bacterial, viral, fungal, and nematode. Fungi are the cause of a number of cowpea disease. Damping off is one of these diseases, typically caused by the fungus *Pythium* (Oyewale and Bamaiyi, 2013). Oyewale and Bamaiyi (2013) further stated that, it affects plants that are crowded and exposed to moist conditions, particularly seedlings. It also affects plants that have stem rot (*Fusarium sp*.), root rot (*Verticillium sp*.), powdery mildew (*Erysiphe polyqoni*), anthracnose (*Colletotrichum lindemuthianum*), and Fusarium wilt (*Fusarium sp*.).

In regions where cowpea is grown, viral diseases pose a serious threat. There are more than twenty kinds of viruses that are known to impact cowpea production worldwide. These viruses can cause yield losses of up to 90% and, in certain situations, complete crop failure (Mbeyagala *et al*., 2014).

Cowpea mottle virus (CPMOV) and Cowpea mosaic virus (CPMV) are among the viruses that cause disease in cowpeas. Nematodes responsible for cowpea diseases include Dagger nematodes (*Xiphinema sp.),* Root lesion nematodes (produced by *Pratylenchus sp.),* and *Meloidogyne sp*., or root knot nematodes. Cowpea bacteria including (*Xanthomonas sp*. pv. *Vigna unguiculata*) and (*Xanthomonas sp. pv.*) are the two most common bacterial agents (Oyewale & Bamaiyi, 2013).

Store-related fungal infections are caused mainly by *Aspergillus fumigatus* and *Aspergillus flavus.*

Field fungus and their preservation fungus can cause infestations in foods and agricultural commodities that have been kept. The majority of storage fungus belong to the mould family, whose flora is mostly obtained in the field and after harvest. Poor storage conditions predispose grains to fungal deterioration, which is further worsened by insect damage. Molds are often dormant until they are exposed to environmental conditions that support their growth (Bawa *et al*., 2012). The capacity of seeds to germinate is affected when storage fungus infiltrates the embryo (Oyewale & Bamaiyi, 2013).

2.11 Management of cowpea pests and diseases

The utilization of synthetic pesticides for pest and disease management is essential in achieving significant cowpea yield increases.

A variety of synthetic compounds accessible on the market for cowpea grain storage, (Oyewale and Bamaiyi, 2013) include Actellic 2% dust, Phostoxin (Aluminium phosphide) tablet, and Actellic 25 E.C (Bawa *et al*. 2012). The FAO recommends applying actellic 2% dust at a rate of 25-50 g to a layer of 50-100 kg unthreshed cowpea and 10-12 ppm to threshed cowpea. Two to three months following the first treatment, the procedure is repeated Many cowpea producers in Africa do not pesticides because they can be expensive, non-unavailable, not having the right tools, or they are not trained on how to apply them.

Calls to reduce chemical usage to a minimum while looking into more practical, less hazardous, and cost-effective management measures in cowpea production have resulted in the use of botanicals (Egho *et al*., 2012). Botanical pesticides are made from plant extracts and decompose quickly in the soil, showing no signs of being stored in plant or animal tissue. Compared to synthetic pesticides, botanical pesticides offer a number of benefits. They are target specific, causing little to no harm to organisms that are not targeted, biodegradable and so safe for the environment, and less prone to cause pest resistance. Few plants have been identified as even though more than 2000 species have been found to have insecticidal properties after scientific evaluation. According to Oyewale and Bamaiyi (2013), the control of *Callosobruchus maculatus* has shown promise when using a low concentration of Cashew Nut Shell Liquid (CNSL), which includes active phenolic compounds, cardol, and anacardic acid, all of which have corrosive and abrasive qualities. Applying neem kernel powder (5–10 g per 100 g of seed), guava, eucalyptus, and lemon grass leaf powders, together with grape and orange peels at comparable ratios, can help reduce insect pests on stored cowpeas. The following substances have been shown to be beneficial in the management of stored cowpea insect pests: *Capsicum frutescens (L.), Ocimum basilicum*, *Sesamum indicum*, ash, and groundnut oil at 5 to 10 mls per kg, palm kernel oil, castor oil at 6 ml per kg, and cowpea seed. The majority of plant materials work by disrupting the regular activities of pests, which prevents them from multiplying, as well as by having antifeedant, insecticidal, and repellent qualities. Plant materials are inexpensive, widely accessible, and simple to employ (Bawa *et al*., 2012).

International Institute of Tropical Agriculture implemented the utilization of cowpea cultivars (Tvu123, VITA-3, Tvu59, and VITA -1) that possess resistance against leaf hoppers, negating the need for pesticides usage. Known by its popular abbreviation Bt, (*Bacillus thuringiensis*) is a widespread soil bacteria found all over the world that can generate Bt gene and Bt protein. According to Oyewale and Bamaiyi (2013), Bt proteins have the power to destroy specific insect species on their own without harming other living things. Laboratory research has also produced cowpeas that are resistant to pod borers, offering a great deal of promise for increased yields and bettering the nutritional and economic condition of small-holder farmers (Mohammed *et al*., 2014).

2.12 Cowpea drying and storage

For storage, cowpeas must be adequately dried to a moisture content of 13% or less. This is because high moisture levels can cause degradation and insect and fungal infestation. Grain that has been properly dried is less vulnerable to fungal and insect assault. Cowpeas should not be stored on bare floors to prevent moisture from migrating into the beans. Cowpeas that are diseased, broken, or both will promote infestation (Bawa *et al*., 2012).

2.13 Cowpea storage structures

Cowpeas can be kept in both threshed and unthreshed forms in buildings like silos, barrels and steel drums, earth ware type granaries (Rumbus), Earth ware-pit technique, and polythene bags.

Non-threshed cowpeas can be kept in hermetic storage. Heaped cowpeas are best stored in steel drums and bags made of polythene. Aluminum or Butyl rubber silos are suggested structures for storing threshed cowpeas in bulk. This type of storage is advised for large organizations such as firms, cooperatives, and businesses, where fumigation is required every three months starting two to three weeks after storage. Cowpea threshed can also be stored in 4x4x2 m polythene or mat-lined pits in regions with little yearly rainfall. The floor is cemented to keep moisture out of the pit. It is not, however, free of rodents, and termites often destroy the wall lining. The location and material availability affect maintenance costs (Bawa *et al*., 2012).

2 .14 Cowpea drought adaptation mechanism

Agriculture faces critical challenges due to factors such as population growth, water shortage, environmental degradation, and climate change. There are several biotic and abiotic factors that affect cowpea production; the main abiotic factor is drought. Cowpea is mostly farmed in the arid savanna and Sahel, which get sporadic rainfall and lack irrigation. Drought conditions typically weaken cowpea plants, making them more vulnerable to disease infestations and insect pest attacks

(Agbicodo *et al*., 2009). Many cowpea cultivars are susceptible to drought and high temperatures during the reproductive development stage (Ndiso *et al*., 2016). The capacity of a plant to survive, develop, and produce to a satisfactory level in the face of a limited water supply in the soil or an irregular water supply is known as drought tolerance. Plants adopt processes including drought avoidance, drought escape, and drought tolerance to deal with drought stress. Early maturing cowpea cultivars in Africa achieve maturity in many producing locations in 60 to 70 days. In addition to surviving droughts, early-maturing cultivars also resist insect infestations. Several studies on physiology, biochemistry, and genetics are on-going in Sub-Saharan Africa to identify cowpea drought coping mechanisms and develop varieties that may adjust to climate change (Agbicodo *et al*., 2009). When subjected to drought, cowpea leaves show little variations in their water potential and little osmotic adjustment. Owing to their sensitivity to soil dryness, their stomata partially shut before any changes in the leaf's water potential are felt. When cowpea leaves are subjected to dry conditions in the field, they track the sun by orienting more vertically, a tactic that helps to reduce solar energy interception. Through these mechanisms, cowpea is able to withstand extreme droughts during the vegetative stage that kills most of the other crop plants.

2.15 Mutagenesis of cowpea

Cowpea (*Vigna unguiculata*) plays a vital role in global agriculture, and the development of mutant lines has emerged as an important approach to enhance its productivity and resilience (Singh *et al*., 2017; Fatokun *et al*., 2020). Mutation breeding, a technique involving the induction of genetic variations through mutagenesis, has been employed to generate diverse mutant lines in cowpea. This approach aims to introduce desirable traits such as drought tolerance, disease resistance, and increased yield (Mba *et al*., 2012). Various mutagens, including chemical agents like ethyl methane sulfonate (EMS) and physical agents like gamma irradiation, have been utilized to induce mutations in cowpea (Mba *et al.,* 2012; Muchero *et al.,* 2013). These mutagens have been applied to seeds or tissues to create genetic variability.

Following mutagenesis, rigorous screening and selection methods are employed to identify desired traits in mutant populations. High-output phenotyping and genotyping techniques assist in the identification and characterization of promising mutant lines (Muchero *et al*., 2013; Lo *et al.,* 2018). Mutant lines exhibiting improved traits such as increased yield, resistance to pests and diseases, and enhanced nutritional content have shown promising results in field trials (Fatokun *et al.,* 2020; Lo *et al.,* 2018). These mutant lines hold potential for addressing challenges faced in cowpea cultivation, contributing to food security and sustainable agriculture.

Despite advancements, challenges persist in the efficient and rapid identification of desired mutations and their incorporation into elite varieties. Further research focusing on the understanding of genetic mechanisms underlying the observed traits and the development of efficient breeding strategies is crucial (Singh *et al.,* 2017). The production of mutant lines in cowpea through mutation breeding techniques offers a promising avenue for crop improvement. While significant progress has been made, on-going research efforts are necessary to harness the full potential of mutant lines in addressing global agricultural challenges in cowpea production.

2.16 Cowpea cropping systems

Cowpea (*Vigna unguiculata*) is a vital legume crop cultivated globally for its nutritional value and adaptability to diverse agro-ecological zones (Singh *et al.,* 2017). The crop is often grown in diverse cropping systems, including monoculture, intercropping, and rotations. Monoculture systems, while common, may lead to pest and disease buildup (Bado *et al.,* 2018). Intercropping strategies, such as cowpea-maize intercropping, have shown increased yield potential and resource use efficiency (Singh *et al*., 2020). Crop rotation involving cowpea, especially with cereals, benefits soil fertility and reduces pest pressure (Singh *et al*., 2017).

Agroforestry systems incorporating cowpea have gained attention for their multiple benefits. Studies suggest that integrating cowpea into agroforestry systems contributes to improved soil fertility, biodiversity, and ecosystem resilience (Franzel *et al.,* 2019). Alley cropping, where rows of trees are combined with cowpea cultivation in alleys, enhances sustainability by conserving soil moisture and improving microclimatic conditions for crop growth (Franzel *et al.,* 2019).

The choice of cropping system significantly influences pest and disease incidence. Monoculture systems may exacerbate pest pressure, leading to yield losses (Fatokun *et al.,* 2018). Intercropping and diversified systems often exhibit reduced pest severity due to decreased host availability and enhanced biodiversity (Bado *et al*., 2018). Integrated pest management practices, including crop diversification and biological control, play a crucial role in mitigating pest and disease outbreaks (Fatokun *et al.,* 2018).

Beyond yield considerations, cowpea cropping systems impact rural livelihoods and food security. Diverse cropping systems contribute to enhanced resilience against climate variability and market fluctuations, providing smallholder farmers with more stable incomes (Adebiyi *et al*., 2020). Sustainable cropping systems involving cowpea not only ensure food production but also preserve environmental resources and contribute to sustainable agricultural practices (Chikoye *et al.,* 2021).

Cowpea cropping systems encompass various approaches that significantly influence yield, sustainability, and socioeconomic aspects. While each system presents unique advantages, integrating diverse systems could offer a holistic approach to enhance productivity, resilience, and sustainability in cowpea cultivation. In industrialized nations, cowpea farming is automated (Fery, 2002). Mechanization in cowpea production is influenced by synchronized maturity, growth habit, and pod features.

2.17 Impact of plant spacing interval on cowpea growth and yield

The manipulation of plant spacing represents a critical agronomic practice influencing cowpea growth and yield.

2.17.1 Impact of plant spacing on cowpea emergence and early growth

Cowpea emergence is a critical stage influenced by various factors, including planting intervals (Diallo *et al*., 2020). Studies have shown that optimal planting intervals promote uniform germination and emergence, contributing to a more robust crop stand (Ibrahim *et al*., 2019). Adequate spacing between plants positively influences early root and shoot development, influencing subsequent growth stages. Studies by Ibrahim *et al*., (2019) indicated that shorter planting intervals resulted in quicker emergence of cowpea seedlings. The shorter intervals allowed for more uniform germination and establishment, leading to a higher initial growth rate. Conversely, longer intervals between planting delayed emergence and initial growth due to varied environmental conditions and competition for resources among seeds.

2.17.2 Impact of plant spacing on cowpea vegetative growth

The vegetative phase is crucial for biomass accumulation and canopy development. Research suggests that wider planting intervals may result in increased leaf area index, enhancing photosynthetic efficiency and overall growth (Adeyemo *et al*., 2021). Conversely, narrow planting intervals may lead to competition for resources, affecting individual plant size and branching patterns. Akande *et al*. (2019) suggested that moderate spacing facilitated an optimal leaf area index promoting better photosynthetic activity and overall plant growth.

Numerous studies have highlighted the influence of plant spacing on cowpea's vegetative growth. Wider spacing often allows for increased access to sunlight, reducing competition for resources such as light, water, and nutrients among plants. As a result, wider spacing tends to promote greater leaf area expansion, branching, and overall plant development compared to closer spacing (Egwurube, 2017).

According to the findings of Anjorin and Agboola (2017), closer plant spacing led to more prolific branching and leaf production in cowpea plants compared to wider spacings. Several other studies (Adejumo *et al*., 2018; Omoigui *et al*., 2019) have also investigated the influence of spacing intervals on cowpea growth parameters. Narrower spacing tends to promote competition among plants for resources, resulting in reduced plant height, smaller leaf area, and decreased branching. Conversely, wider spacing facilitates better light penetration, leading to taller plants with larger leaf canopies and increased branching. Wider spacing, as noted in the study by Abdullahi and Olufajo (2016), resulted in taller plants due to reduced competition for nutrients and sunlight. Singh and Singh (2018) highlighted that wider planting intervals often promote better vegetative growth in cowpea due to reduced intra-plant competition for resources. Conversely, narrower intervals may result in increased competition among plants for nutrients, water, and light, potentially limiting vegetative growth.

Ahmed *et al*. (2018) demonstrated that wider planting intervals resulted in increased branching and leaf area index. Conversely, narrower intervals exhibited higher plant density but reduced individual plant vigor, leading to limited canopy development (Singh *et al*., 2019). Furthermore, increased spacing between plants allowed for better nutrient utilization and root development, positively impacting vegetative parameters such as shoot biomass and plant height (Lal *et al*., 2020).

2.17.3 Impact of plant spacing on cowpea root development

Plant spacing significantly affects root architecture, thereby influencing nutrient uptake and water absorption. Ogundele *et al*. (2019) observed that wider spacing encouraged deeper root penetration and higher root biomass, enhancing the plant's ability to access water and nutrients in the soil profile compared to closer spacing. According to Abaidoo *et al*. (2016), wider planting intervals tend to encourage deeper and more extensive root systems in cowpea plants. This enhanced root development can facilitate better access to soil nutrients and moisture, contributing to overall plant vigor and stress tolerance. Adegbite and Yusuf (2020) demonstrated that closer spacing resulted in smaller girth due to competition for resources, while wider spacing allowed for thicker stems.

2.17. 4 Impact of plant spacing on flowering of cowpea

The reproductive phase of cowpea, including flowering, pod formation, and seed yield, is also intricately linked to planting intervals. Studies have shown that wider planting intervals promoted longer reproductive periods, allowing for extended flowering and pod-setting phases (Musa *et al*., 2021). Additionally, wider spacing enhanced pod number per plant due to reduced competition for resources, ultimately contributing to increased seed yield per hectare (Kamara *et al*., 2017).

Optimal plant spacing plays a crucial role in flowering and subsequent fruit set in cowpea. While excessively close spacing may lead to increased competition and reduced flower formation, wider spacing often facilitates better air circulation and pollination, resulting in higher flower retention and improved fruit set (Abdullahi & Mohammed, 2018)

Planting intervals impact the timing and synchronization of flowering in cowpea. Studies have demonstrated that specific planting intervals may enhance flower production and increase the likelihood of successful pollination (Moussa *et al*., 2017). Additionally, optimal planting intervals contribute to uniform pod development, influencing crop yield and quality.

2.17.5 Impact of plant spacing on cowpea pod formation and characteristics

Plant spacing influences pod development and characteristics, directly impacting cowpea yield. Adegbite and Olakojo (2016) revealed that wider spacing resulted in larger and heavier pods, contributing to increased overall yield, while closer spacing led to smaller pods but higher pod density per unit area.

Yusuf *et al*. (2019) demonstrated that optimal planting intervals significantly influence yield components such as pod number per plant, pod length, and seeds per pod in cowpea. Moderate intervals often strike a balance between resource availability and plant density, leading to improved yield components.

2.17.6 Impact of plant spacing on cowpea seed development and quality

The impact of plant spacing on cowpea seed development and quality has been a subject of interest in agricultural research. Cowpea (*Vigna unguiculata*), being a leguminous crop, is sensitive to spacing, which affects its growth, seed yield, and quality. Agyare *et al*. (2018) highlighted that wider plant spacing tends to encourage greater vegetative growth due to reduced competition among plants for resources like sunlight, nutrients, and water. Conversely, closer spacing can lead to more competition among plants, potentially resulting in smaller-sized plants but potentially higher seed yield per unit area.

Furthermore, research by Singh *et al*. (2017) suggested that wider plant spacing can result in larger seeds but lower seed yield per unit area. Conversely, closer plant spacing often leads to smaller seeds but a potentially higher overall yield per unit area due to more plants in a given space.

For instance, Li *et al*. (2020) have demonstrated that moderate plant spacing of cowpea resulted in an optimum balance between seed size and yield, suggesting that an intermediate spacing strategy may be ideal for achieving a good compromise between seed size and overall yield.

The impact of plant spacing on cowpea seed development and quality is significant. While wider spacing may contribute to larger seed size, it might come at the expense of overall yield per unit area. Conversely, closer spacing could lead to increased yield but smaller seed size. Finding the right balance in plant spacing is crucial to optimizing cowpea seed development and quality

2.17.7 Impact of plant spacing on cowpea yield

Relationship between spacing intervals and yield in cowpea cultivation has been extensively studied (Singh *et al*., 2017; Navoroh, 2022). Optimal spacing significantly impacts yield, with wider spacing generally associated with higher yields per plant. However, extremely wide spacing might lead to underutilization of available land and resources, potentially affecting overall yield at the field level. The relationship between plant spacing and cowpea seed yield is intricate and varies depending on environmental conditions and cultivar characteristics. Research conducted by Ibrahim *et al*. (2020) demonstrated that moderate plant spacing led to higher seed yield per plant compared to both excessively close and wide spacing. This finding suggests the existence of an optimum spacing range that maximizes cowpea seed yield.

The duration between planting and maturity is a key factor affecting cowpea yield. Appropriate planting intervals contribute to synchronized pod maturation, facilitating efficient harvesting (Kamara *et al*., 2018). Understanding the relationship between planting intervals and maturity is essential for devising strategies to manage crop cycles and optimize production. Ofori *et al*. (2017) suggests that wider planting intervals can result in higher yields per plant but may not necessarily translate to higher overall yields per hectare. Conversely, narrower intervals might achieve higher plant densities but could compromise individual plant productivity.

2.18 Impact of seasonal variations on cowpea vegetative and reproductive parameters

Cowpea is a key leguminous crop in several agro-ecological zones, serving as a source of protein-rich food and income for smallholder farmers. Yet, cowpea growth and yield are remarkably influenced by seasonal differences, mostly in agro-ecological zones with distinct dry (minor) and rainy (major) seasons (Timko *et al*., 2007).

Ajeigbe *et al*., (2017) and Fatokun *et al*., (2012) reported that dry seasons significantly delay cowpea days to emergence, flowering, and maturity. For example, days to 50% emergence, flowering, and maturity were recorded as 7.5, 35.5, and 55.6 days, respectively, during the rainy season, as compared to 12.5, 45.6, and 65.8 days during the dry season (Ajeigbe *et al*., 2017). Similar significant increases were found in plant girth, number of leaves, plant height, number of branches, and size of canopy during the rainy season (Ehlers & Hall, 1997; Singh *et al*., 2014).

According to research reports, rainy seasons greatly increase the number of seeds per pod, number of pods per plant, pod length, 100 seed weight, seed weight per plant, and total seed weight per plot for cowpeas (Fatokun *et al*., 2012; Ofori *et al*., 2015). Furthermore, significant increase in cowpea seed weight from (10% - 20%) (Adebisa *et al*., 2017) and (15%-30%) (Olaniyi *et al*., 2020) for dry and rainy seasons have also been reported.

A research conducted (Ofori *et al*., 2015) during the rainy season revealed a considerably larger pod length (23.4 cm), number of seeds per pod (12.5), and seed weight per plant (235.6 g) than during the dry season. Cowpea yields are often significantly lower during dry seasons (Singh *et al*., 2014), as a result of high temperatures, water stress, and increased pest and disease incidence.

In agro-ecological zones with different dry and wet seasons, breeding cowpeas for heat stress resistance and drought tolerance is important to increasing production (Hall *et al*., 2015).

2.19 Optimal spacing intervals in cowpea cultivation

Optimal spacing intervals play a crucial role in maximizing cowpea yield and quality. Determining the ideal planting intervals for cowpea necessitates a balance between vegetative and reproductive parameters. Kamara *et al*. (2016) suggested that intermediate planting intervals (e.g., 30–40 cm) struck a balance, fostering robust vegetative growth while ensuring sufficient spacing for optimal reproductive development. These intervals facilitated an adequate canopy cover for efficient photosynthesis, coupled with reduced intra-plant competition, leading to enhanced reproductive output.

Intra-spacing, the distance between plants within rows, significantly influences cowpea growth and yield. Ogundele *et al*. (2019) found that varying intra-spacing affects crop canopy development, influencing light interception and subsequent photosynthetic activity. Close spacing (around 10-15 cm between plants) may result in competition for nutrients and decreased yield due to overcrowding, while wider spacing (20-30 cm between plants) allows for better growth and yield potential.

Abdullahi *et al*. (2018) indicated that varying intra-row spacing significantly influences cowpea growth and yield. Narrower intra-row spacing (10-15 cm) resulted in competition among plants for resources, leading to reduced yield due to overcrowding. Conversely, wider intra-row spacing (20-30 cm) allowed for better light penetration, air circulation, and reduced competition, enhancing plant growth and yield.

Mohammed *et al*. (2020) suggested that an intra-row spacing of 15-20 cm between cowpea plants provided a balance between maximizing individual plant growth and optimizing overall yield. This spacing facilitated adequate plant development without excessive competition for resources. Inter-spacing, the distance between rows, is equally crucial. A study by Ntare *et al*. (2017) highlights that wider inter-spacing (around 50-75 cm) allows for better airflow and reduces disease incidence by preventing moisture retention. However, closer inter-spacing (25-40 cm) might lead to higher yields in certain cultivars by maximizing land use efficiency, particularly in regions with limited space.

Inter-row spacing influences canopy development, weed suppression, and nutrient availability for cowpea plants. Ogundele *et al*. (2019) highlighted that wider inter-row spacing (50-75 cm) allowed for better weed control and reduced competition for nutrients and moisture, resulting in enhanced cowpea growth. Abara *et al*. (2017) proposed that an inter-row spacing of 50-60 cm between cowpea rows promoted optimal growth conditions. This spacing facilitated efficient management practices, improved sunlight exposure, and minimized competition among plants, ultimately leading to increased yields.

Environmental factors such as soil fertility, rainfall patterns, and temperature also influence spacing decisions. In arid regions, wider spacing may be necessary to prevent moisture stress, while in fertile soils, closer spacing might optimize nutrient uptake. Optimal intra and inter-spacing intervals play a crucial role in maximizing cowpea yield. Balancing intra-row spacing between 15-20 cm and inter-row spacing within 50-60 cm appears to be beneficial for achieving higher yields by minimizing competition among plants, optimizing resource utilization, and facilitating efficient management practices.

2.20 Optimal climatic conditions in the semi deciduous agroecological zone for cowpea cultivation

Cowpea (*Vigna unguiculata*) is a versatile legume crop grown extensively in tropical and subtropical regions worldwide (Abebe eta al., 2022). Its adaptability to diverse agroecological conditions makes it a valuable crop for smallholder farmers, contributing to food security, soil fertility, and income generation (Simon, 2018). Temperature is a critical factor governing the growth and development of cowpea plants, exerting profound effects on various physiological processes essential for their lifecycle, including germination, flowering, and pod development (Maiti & Singh, 2016).As a warm-season crop, cowpea thrives within a specific temperature range that promotes optimal growth and productivity (Sokolnik, 2021). Typically, cowpea requires temperatures between 25°C and 35°C for optimal development, where the physiological processes are most efficiently carried out (Alves *et al*., 2023).

However, temperature extremes, both low and high, can have detrimental effects on cowpea growth and yield (Alves *et al*., 2023). Temperatures below 10°C can inhibit germination, delay flowering, and stunt plant growth, leading to reduced vigor and productivity. Conversely, temperatures exceeding 40°C can induce heat stress, causing physiological damage to the plants, including leaf scorching, flower abortion, and reduced pod set (Alves *et al*., 2023). These temperature extremes can significantly compromise cowpea yield and quality, posing challenges to its cultivation in regions prone to climatic fluctuations.

In semi-deciduous agroecological zones, where temperature variations are common, farmers must carefully time cowpea cultivation to coincide with the warmest months of the year (Baffour-Asare, 2018). For instance, in regions of West Africa characterized by a Sudanian climate, with distinct dry and wet seasons, cowpea planting is often scheduled at the onset of the rainy season when temperatures are favourable for germination and early growth. During this period, temperatures typically range between 25°C and 35°C, providing optimal conditions for cowpea establishment and development (Barros *et al*., 2021).

However, despite favourable daytime temperatures, semi-deciduous agroecological zones often experience significant fluctuations in temperature, particularly between day and night (Asare-Nuamah & Botchway, 2019). While daytime temperatures may exceed 35°C, nighttime temperatures can drop considerably, posing challenges to cowpea cultivation, especially during the cooler months (Asare-Nuamah & Botchway, 2019). These temperature differentials can disrupt physiological processes, such as flower development and pollination, leading to irregular pod set and reduced yields (Ofori-Kyereh *et al*., 2022).

To mitigate the adverse effects of temperature fluctuations, farmers in semi-deciduous agroecological zones employ various agronomic practices and management strategies (Antwi-Agyei *et al*., 2021). These may include selecting appropriate cowpea varieties with tolerance to temperature stress, planting during the optimal window of temperature conditions, implementing soil conservation measures to regulate soil temperature, and employing irrigation to mitigate heat stress during periods of extreme heat (Antwi-Agyei *et al*., 2021).

Rainfall is a pivotal factor shaping the cultivation of cowpea, exerting significant influence on its growth, development, and overall productivity (Mekonnen *et al*., 2022). As a crop with both drought and water sensitivity, cowpea's success is intricately tied to the availability and distribution of rainfall in its growing environment. In semi-deciduous agroecological zones, characterized by distinct dry and wet seasons, managing cowpea cultivation amidst fluctuating rainfall patterns is paramount for ensuring optimal yields (Carvalho *et al*., 2017).

Semi-deciduous agroecological zones typically experience seasonal variations in rainfall, with pronounced dry and wet periods. These fluctuations necessitate strategic planning and timing of cowpea planting to align with favourable moisture conditions while mitigating the risks associated with drought and excessive rainfall (Aliero *et al*., 2018). Cowpea's inherent adaptability to such conditions enables it to withstand short-term drought stress while still requiring sufficient moisture for sustained growth and development (Aliero *et al*., 2018).

In regions with bimodal rainfall patterns, such as parts of West Africa and East Africa, cowpea cultivation often aligns with the timing of the rainy seasons (Bello *et al*., 2017). Farmers capitalize on both the early and late rainy periods to maximize water availability and minimize the vulnerability of crop failure (Bello *et al*., 2017). For instance, in Ghana's semi-deciduous forest zone, where rainfall is predominant from April to October and December to March, farmers strategically schedule cowpea planting to coincide with these rainfall peaks. By planting in April and again in September, farmers optimize moisture availability, allowing cowpea plants to establish and thrive during periods of ample rainfall (Boukar *et al*., 2013).

However, the success of cowpea cultivation in semi-deciduous agroecological zones is not solely contingent on the presence of rainfall but also on its distribution and intensity (Boukar *et al*., 2013). Erratic rainfall patterns, characterized by prolonged dry spells or heavy downpours, can pose significant challenges to cowpea production, leading to yield losses and crop failure. Consequently, farmers must adopt adaptive strategies to cope with these uncertainties, such as water conservation techniques, drought-tolerant cultivars, and supplementary irrigation where feasible (Kamara *et al*., 2015).

Furthermore, sustainable cowpea production in semi-deciduous zones necessitates prudent water management practices to optimize water use efficiency and minimize resource wastage

(Houngnandan *et al*., 2019). Conservation tillage, mulching, and soil moisture monitoring are among the strategies employed to conserve soil moisture and enhance drought resilience Boukar *et al*., 2013). Additionally, the integration of water-efficient irrigation systems, such as drip or sprinkler irrigation, can complement rainfed cultivation and provide supplemental moisture during dry periods (Ouedraogo *et al*., 2020).

Photoperiod, the duration of daylight, plays a significant role in regulating the growth and development of cowpea plants, particularly in relation to key reproductive processes such as flowering and fruiting. Despite being categorized as a short-day plant, cowpea exhibits a relatively low sensitivity to photoperiod compared to some other crops such as rice or soya bean. Instead, its flowering response is primarily influenced by temperature and moisture conditions, with photoperiod playing a secondary role. Thus, it is well adapted to varying day lengths making it an advantage in areas with erratic weather or temperature (Boateng *et al*., 2012).

In semi-deciduous agro-ecological zones where day length fluctuates throughout the year, farmers must carefully select cowpea varieties adapted to local conditions to optimize flowering and fruit set (Asare *et al*., 2016). Early-maturing varieties are often preferred as they can rapidly transition to the reproductive phase, allowing farmers to take advantage of favourable growing conditions during the rainy season and minimize the risk of drought stress during the dry season (Boateng *et al*., 2012).

Farmers in semi deciduous agro-ecological zones may employ various strategies to optimize cowpea flowering and fruit set under changing photoperiod conditions. For instance, selecting cultivars with a broad adaptability range and early maturity traits can help mitigate the challenges posed by fluctuating day lengths. Additionally, timely planting and proper crop management practices, such as weed control and soil fertility management, can further enhance flowering and reproductive success.

In regions with pronounced dry and wet seasons, such as parts of West Africa and East Africa, the selection of appropriate planting dates is crucial for maximizing cowpea productivity. By aligning planting schedules with periods of favourable temperature and moisture conditions, farmers can ensure that cowpea plants enter the reproductive phase at the optimal time, thereby maximizing fruit set and yield potential.

Furthermore, advancements in breeding and biotechnology have enabled the development of cowpea varieties with enhanced flowering and reproductive traits, including improved stress tolerance and yield potential. By harnessing these innovations, farmers can access cultivars better suited to the specific agro-ecological conditions of their region, thereby enhancing overall crop performance and resilience (Boateng *et al*., 2012).

2.21 Characteristics of the cowpea planting materials used

The characteristics of the cowpea planting materials used in this study as recorded by Lumor (2022) are as follows;

a. **Hansadua**

Hansadua is an improved cowpea variety released by Crops Research Institute (CSRI), Fumesua, of Council for Scientific and Industrial Research (CSIR), Ghana. Hansadua has white seed coat colour and black eye. It has relatively large seeds with a potential yield of about 3500 kgha^{-1}. It has an indeterminate growth habit, a kidney-shaped seed, with a maturity period of between 65 and 67 days after sowing. Hansadua is known to be tolerant/resistant to insect pests such as thrips and diseases such as *Cercospora* leaf spot and anthracnose.

b. The **Hansadua** (Mother) were exposed to appropriate amount of gamma (radiation) doses to induce mutations in the three underlisted mutant lines. These cowpea lines are at the nineth generation. They have been screened and now are stable (Lumor, 2022). The three cowpea mutants: HansM9 (12) (3), HansM9 (12) (5), and HansM9 (12) (25) were sourced from the school of Agriculture, University of Cape Coast. The morphological traits of the mutants were recorded according to the International Board for Plant Genetics Resources (1983) standards as described below:

2.**HansM9 (12)(3),** it has Tan brown eye, cream seed coat, which is kidney shaped, High protein content. It exhibits semi erect and determinate growth. Percentage protein content is about 30.53. It has a slight twining tendency with a potential yield of 3134kgha^{-1} (Lumor, 2022)

3. **HansM9 (12)(5),** It has a black eye, with a cream seed coat. A globose seed shaped, determinate growth pattern and none twining tendency. Percentage protein content is about 19.09. It is a very high yielding mutant with a potential yield of about 3163kgha^{-1}. (Lumor, 2022)

4. **HansM9 (12)(25),** It has a black eye, cream seed coat, ovoid seed shape and a high yielding line with determinate growth pattern. It has a slight twining tendency with a yield potential of about 5796 kgha^{-1}. Percentage protein content is about 23.75 (Lumor, 2022).

c. **Asontem**

The Asontem variety was obtained from the Legumes Division of the Council for Scientific and Industrial Research (CSIR), Fumesua. Asontem has white seed coat colour and black eye. It has relatively small seeds with a potential grain yield ranging between 75.4 to 466.1 kgha^{-1}. It has an erect growth habit, a kidney-shaped seed, with a maturity period of between 64 and 66 days after sowing (Asafo-Adjei, B., *et al.*, 2005). Ravelombola, *et al.,* (2016), reported in their study that the

Asontem cowpea variety contains about 15.06% to 38% protein and was found to be climate smart. Asontem has indeterminate growth pattern.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site description

3.1.1 Location of study

The experiment was carried out at Kibi Presbyterian college of Education Demonstration farm, Kibi, in the Abuakwa South Municipality of the Eastern Region of Ghana between November, 2023 and July, 2024. Kibi Presbyterian college of Education is situated about 70 km to the North western side of Accra, the capital city of Ghana. The study area is located on the latitude of 6.2654'N, and longitude of 0.4609'W, and an elevation of 318m above sea level (A.S.L)

3.1.2 Relief and drainage

The land is generally undulating and rises about 240 metres to 300 metres above sea level. There are several different types of rock formation which give the different relief features ranging from flat bottom valleys to steep-sided highlands usually covered with iron pans, bauxite and kaolin. Also found are masses of granite which occur in parallel belts. Abuakwa South municipality is also drained by rivers such as the Birim, Densu, and Bompong most of which have their catchment areas within the Apedwa Forest Ranges. Several other seasonal streams are found in the municipality. The pattern is largely dendritic flowing in the north-south direction.

3.1.3 Climatic conditions

The study area is in the Semi deciduous agro-ecological zone characterized by humid conditions with relative humidity generally high throughout the year, ranging between 70%-80% in the dry season and 75% – 80% in the wet season. The total annual rainfall for the area is about 1450mm, with the mean annual rainfall figures between 125 mm and 175 mm. The dry seasons are really distinct, commencing in November and ending in late February. Temperature is found to be fairly uniform ranging between 26 ^oC in August and 30 ^oC in March. A monthly mean temperature ranging from 14.8 ^oC to 35.5 ^oC have been recorded over the years with distinct dry period (with occasional rains) observed between November and March (Bennet-Lartey and Ofori., 1999).

3.1.4 Soil conditions

The predominant soils in the study area are the Asikuma-Ansum/Oda Compound Association. Dominating this soil group is the series which are mainly red, well drained, deep gravel-free silty loams and silty- clay loams. The valley bottoms are occupied by the Oda series which are poorly drained alluvial silty clays. Bennet-Lartey and Ofori., (1999) reported in their study that soils at Kibi range from red clay loams on elevated ground to heavier alluvial soils near the Birim river. The soils are suitable for the cultivation of both food crops (cassava, plantain, yam, cocoyam, maize) and cash crops (cocoa, coffee, oil palm, citrus, cola) which are grown in the municipality. The land in this area is susceptible to soil erosion if laid bare of vegetation (Bennet-Lartey and Ofori., 1999). Soil samples from the experimental site were collected for evaluation on essential nutrients such as Nitrogen, Phosphorus, Potassium, salinity and pH levels. The soil analysis was done at the Soil Science Department research laboratory at the University of Ghana prior to the experimentation (Appendix 2)

3.2 Experimental procedure

The experiment was laid out in a Split plot Design (SPD), with 15 treatment combinations consisting of three (3) spacing intervals and five) (5) cowpea lines, with four (4) replications. The three spacing (3) spacing intervals used were 60 cm x 20 cm, 60 cm x 30 cm and 60 cm x 40 cm, designated as S1, S2 and S3, respectively. The three (3) cowpea mutant lines and two varieties used in the experiment were **HansM9 (12)(3), HansM9 (12)(5), HansM9(12)(25), Asontem and**

Hansadua, designated as M1, M2, M3, Mi4 and Mo5, respectively (Table 1). The land was first cleared and worked to medium tilth manually. Four main plots, each measuring 7 m wide and 12 m long with 1 m spacing between the plots were laid out using a tape measure, pegs and nylon twine. Each of the four main plots (blocks) was divided into 15 subplot plots measuring 2 m by 2 m with a 0.5 m spacing separating each plot from the other, making a total of 60 plots.

The Five (5) cowpea lines were planted at a depth of 4-5 cm as per the treatment combinations stated (Table 2). TSP fertilizer was applied according to the agronomic recommendation of 20 kg of P_2O_5 ha^{-1} and the experimental plots kept weed free by manual weeding. Five (5) cowpea lines were randomly selected and pre-tagged in each of the plots, excluding the border rows for the purpose of data collection. Days to 50% emergence, plant height, Number of leaves, leaf area index, plant girth, number of branches and plant canopy size were the vegetative parameters investigated. The reproductive or yield parameters investigated were days to 50% flowering, days to 50% maturity, number of pods per plant, pod length, number of seeds per pod, total seed weight per plant, total seed weight per plot and 100 seed weight per plot.

Table 1: Characteristics and sources of the cowpea planting materials

Cowpea line	Source	Growth Pattern	Twining Tendency	Maturity Days	Yield Potential
Hans (12)(3)	UCC	Determinate	Slight	63 to 67	3134kgha^{-1}
Hans (12)(5)	UCC	Determinate	None	63 to 67	3163kgha^{-1}
Hans (12)(25)	UCC	Determinate	Slight	63 to 67	5796 kgha^{-1}
Asontem	CSIR	Indeterminate	None	64 to 66	466.1 kgha^{-1}
Hansadua	CSIR	Indeterminate	None	65 to 67	3500 kgha^{-1}

Lumor, 2022

Table 2: Spacing and cowpea lines combinations

Factor 2	Spacing Interval (S cm) Factor 1		
Cowpea Lines	**S1 (60x20cm)**	**S2(60x30cm)**	**S3 (60x40cm)**
M1	M1S1	M1S2	M1S3
M2	M2S1	M2S2	M2S3
M3	M3S1	M3S2	M3S3
Mi4	Mi4S1	Mi4S2	Mi4S3
Mo5	Mo5S1	Mo5S2	Mo5S3

3.5 Data collection

i. **Days to 50% emergence** was obtained by counting a least half of the population of plants per plot that had emerged.

ii. **Plant height** was monitored on a fortnight basis. Measurement of the main stem from the base to the highest tip of the plant was taken from each of the five (5) randomly selected and pre-tagged plants per plot using a tape measure.

iii. **Days to 50% flowering** was obtained by counting a least half of the population of plants per plot that had flowered.

iv. **Days to 50 % maturity** was obtained by counting a least half of the population of plants per plot that had formed pods.

v. **Plant girth** was obtained from the five (5) randomly selected and pre-tagged plants per plot by using a caliper to determine girth on the stem at maturity.

vi. **Number of leaves per plant** from the five (5) randomly selected and pre-tagged plants per plot was determined through counting.

vii. **Canopy size per plant** from the five (5) randomly selected and pre-tagged plants per plot was determined by the use of tape Measure. The plant spread was measured as the diameter of the foliage from one end of the plant to the other.

viii. **Number of branches per plant** was obtained by counting the number of primary reproductive branches from each of the five (5) randomly selected and pre-tagged plants per plot at maturity.

ix. **Number of pods per plant** from the five (5) randomly selected and pre-tagged plants per plot was determined through counting at harvest.

x. **Pod length** from each of the five (5) randomly selected and pre-tagged plants per plot were determined by using a thread to take the length of the pods and then measured them on a 30 cm ruler at harvest.

xi. **Number of seeds per pod** from the five (5) randomly selected and tagged plants per plot was determined through counting at harvest.

xii. **Hundred (100) seed weight per plot** was estimated at harvest by counting 100 seeds at random from each plot and weighing them using an electronic balance.

xiii. **Seed weight per plant** was determined using the average of all harvested seeds from each of the five (5) randomly selected and pre-tagged plants per plot using an electronic balance.

xiv. **Seed weight per plot** was calculated at harvest using an electronic weighing scale to determine the seed weight per plot. To determine grain production per hectare, the gathered data was extrapolated.

3.6 Data analysis

The data collected were summarized using Excel package after which it was analysed using GenStat 12th Edition package. Analysis of variance (ANOVA) was carried out at 0.05 significance level to determine whether there were significant differences, where ANOVA indicated significant differences between the means ,Tukey's LSD was used to separate the mean differences which were statistically significant.

CHAPTER FOUR

4.0 RESULTS

4.1 Rainfall pattern for the experimental period

The monthly rainfall data obtained in the semi-deciduous agro-ecological zone is displayed in in Figure 1, with values ranging from 25.5 mm in December to 336 mm in July.

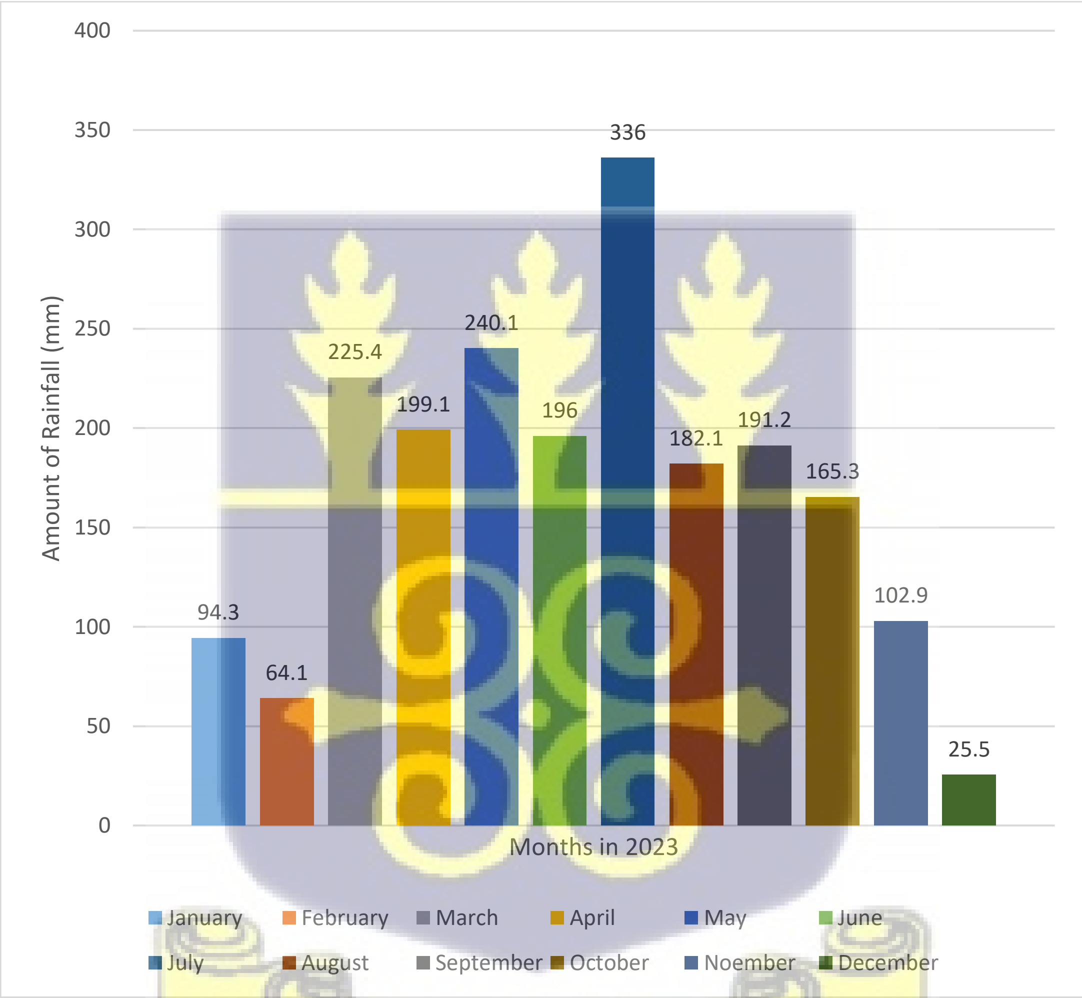


Figure 1: Rainfall Data for all months in 2023

4.2 Vegetative parameters

4.2.1 Days to 50% emergence of cowpea plant

The analysis for days to 50% emergence (DFT%E) revealed that the spacing intervals did not significantly affect the time it took for 50% of the cowpea lines to emerge ($p = 0.086$). Seasons had a highly significant impact on DFT%E ($p < 0.001$).The major season recorded faster emergence. Varieties did not significantly affect DFT%E ($p = 0.409$), These are presented in Figures 2 and 3.

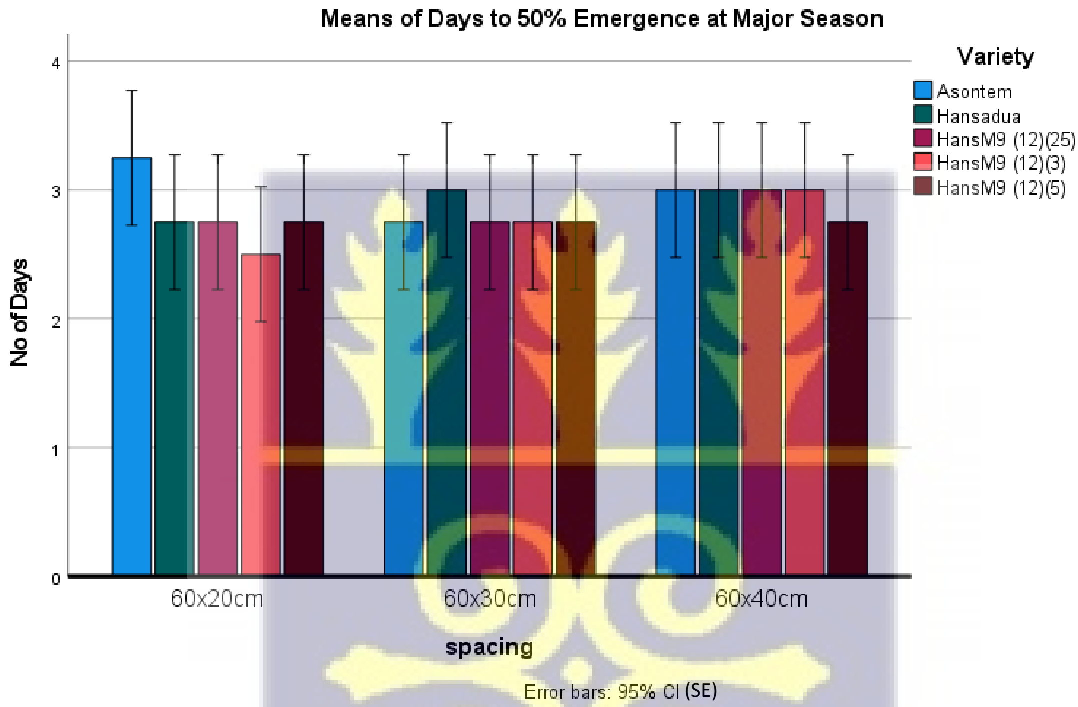


Figure 2:Mean days to 50% emergence of plant at different spacing (major season)

At major season, the days to 50% emergence was influenced by both the specific variety and the spacing at which they were planted. HansM9 (12)(3) exhibited a delayed emergence habit at closer spacing, while wider spacing intervals generally promoted earlier emergence. Hansadua and HansM9 (12)(25) generally showed intermediate DTF%E. Asontem and HansM9 (12)(3) typically had the lowest DTF%E, particularly at the 60 x 20 cm spacing. 60 x 20 cm spacing generally resulted in the highest DTF%E for most varieties.

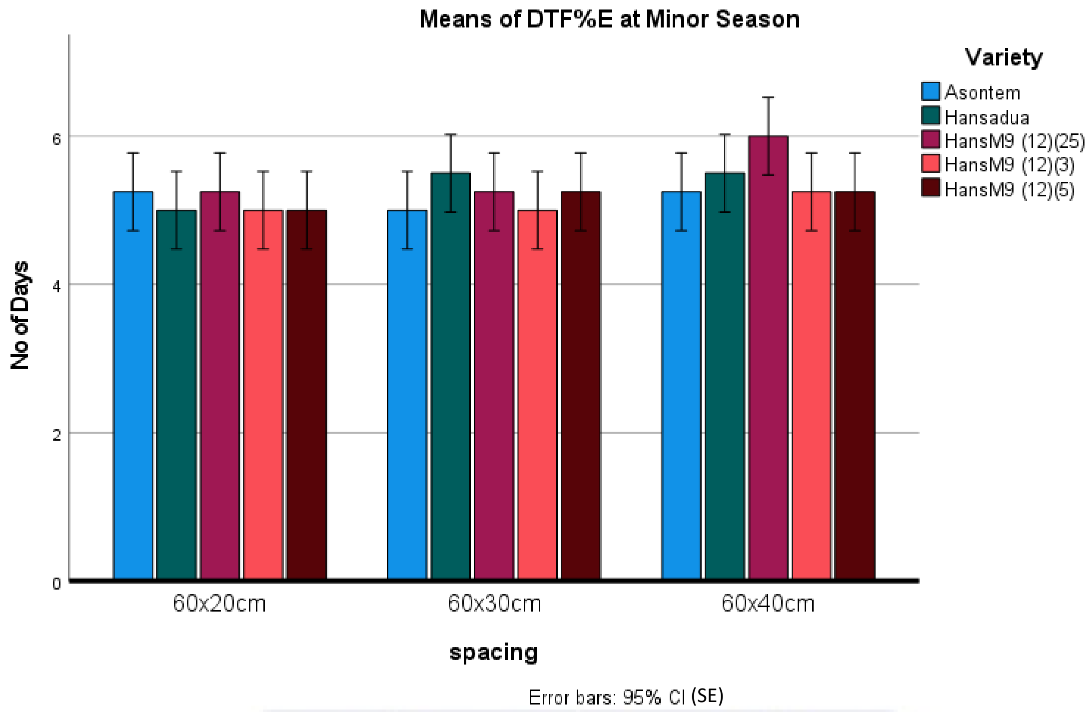


Figure 3:Mean days to 50% emergence of plant at different spacing (minor season)

4.2.2 Cowpea plant height

The analysis of variance (ANOVA) for plant height indicated highly significant differences between the seasons ($p < 0.001$), but not for the cowpea varieties or the spacing intervals (Table 3). There was significant interaction between spacing and seasons ($p = 0.034$). The cowpea varieties did not show a statistically significant difference in plant height ($p = 0.655$).

Table 3: Mean cowpea plant height at major and minor seasons

Variety	Major season			Mean (variety)	Minor season			Mean (variety)
	60x20cm	60x30cm	60x40cm		60x20cm	6ox30cm	60x40cm	
Hans M9 12 3	68.67	58.70	63.25	63.55	31.05	27.27	23.65	27.32
Hans M9 12 5	65.77	61.48	64.28	63.84	23.97	21.90	22.12	22.67
Hans 12 25	67.87	58.55	61.90	62.77	26.07	24.00	22.22	24.10
Asontem	65.95	58.02	61.50	61.82	17.62	24.80	20.77	21.07
Hansadua	65.15	58.04	62.57	62.04	23.97	29.32	21.45	24.92
Mean (spacing)	66.68	59.03	62.70		24.54	25.46	22.05	
LSD (P ≤ 0.05) Spacing	**4.02**	**NS**			**8.48**	**NS**		
Variety	**2.32**	**NS**			**4.55**	**NS**		
Spacing x Variety	**5.00**	**NS**			**10.22**	**NS**		

4.2.3 Number of leaves of cowpea plant

The analysis of variance (ANOVA) revealed that spacing intervals had a statistically significant effect on the Mean Number of Leaves ($p = 0.022$). 60 cm × 20 cm interval generally resulted in a lower number of leaves per plant. The 60 cm × 30 cm interval produced a higher number of leaves compared to the closest spacing (Table 4).

Table 4: Mean number of leaves of cowpea plant at major and minor seasons

Variety	Major season			Mean (variety)	Minor season			Mean (variety)
	60x20cm	60x30cm	60x40cm		60x20cm	6ox30cm	60x40cm	
Hans M9 12 3	90.20	108.20	104.20	100.90	102.00	93.20	133.80	109.70
Hans M9 12 5	104.00	94.20	77.80	92.20	92.00	113.20	71.20	92.20
Hans 12 25	100.8	73.50	106.20	93.50	82.50	97.80	111.80	97.30
Asontem	103.00	82.50	109.3	98.10	65.30	64.20	90.00	73.20
Hansadua	90.20	107.00	107.00	97.5	86.00	88.80	91.50	97.30
Mean (spacing)	97.50	90.70	100.90		85.60	91.5	99.70	
LSD ($P \leq 0.05$) Spacing	**20.47**	**NS**			**24.86**	**NS**		
Variety	**12.82**	**NS**			**20.82**			
Spacing x Variety	**26.49**				**38.29**	**NS**		

Seasons had a highly significant impact on the mean number of Leaves ($p < 0.001$). The major season recorded a higher number of leaves per plant

The cowpea varieties showed a statistically significant difference in the Mean Number of Leaves ($p = 0.044$). HansM9 (12)(3) was highest at 60x30cm spacing interval. Similar observations were made in the minor seasons where HansM9 (12)(3) was highest at 60 x 40 cm interval.

4.2.4 Leaf area index of cowpea plant at maturity

The analysis of variance (ANOVA) revealed that spacing intervals did not significantly affect the mean leaf area index per plant at maturity ($p = 0.652$). Seasons had a highly significant impact on mean LAI per plant at maturity ($p < 0.001$). The cowpea varieties did not show a statistically significant difference in mean LAI per plant at maturity ($p = 0.414$)

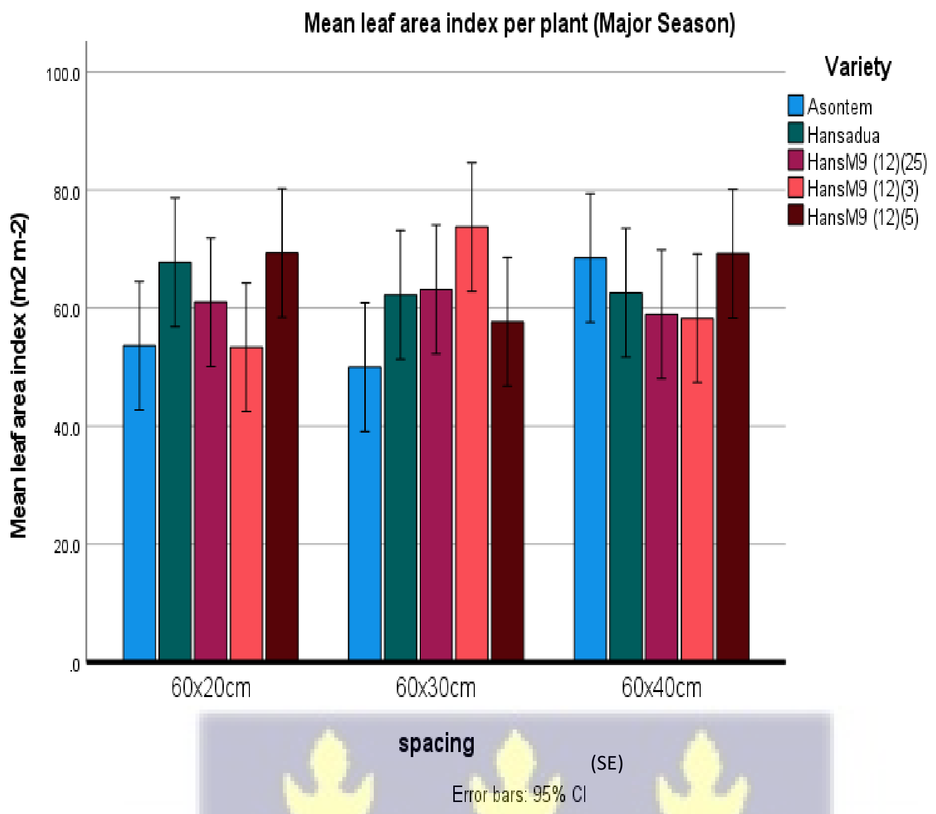


Figure 4: Mean leaf area index of cowpea plant at major season

In the major rainy season, Asontem and HansM9 (12)(25) consistently exhibited the largest leaf area index per plant, regardless of spacing. There was no clear consistent effect of spacing on leaf area index per plant across all cowpea varieties (Figure 4).

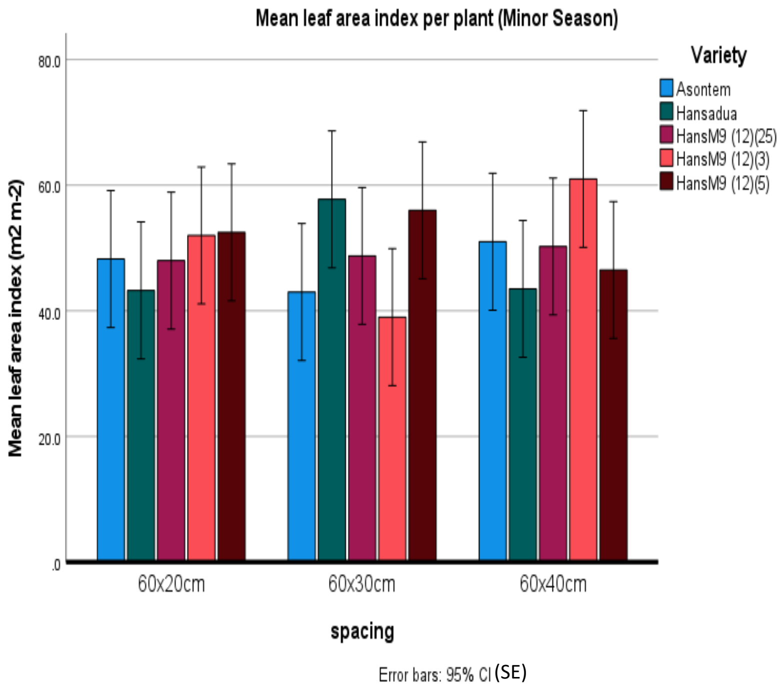


Figure 5: Mean leaf area index of cowpea plant at minor season

In the minor rainy season, HansM9 (12)(3) exhibited the largest leaf area index per plant, with wider spacing. There was no clear consistent effect of spacing on leaf area index per plant for Asontem variety, however, slight increase was observed at the widest plant spacing. Hansadua decreased as the spacing increased. Asontem and Hansadua recorded the lowest values across all spacing intervals (Figure 5).

4.2.5 Cowpea plant girth at maturity

The analysis of variance (ANOVA) revealed that spacing intervals had a statistically significant effect on plant girth at maturity ($p < 0.001$). Seasons had a significant impact on plant girth at maturity ($p < 0.001$). Significant difference was observed between the cowpea lines ($p < 0.001$). The interaction between variety and spacing interval showed significant differences. The major season recorded larger plant girth due to more favorable growing conditions. Smaller plant girth was observed during the minor season (Table 5).

Table 5: Mean cowpea plant girth at major and minor seasons

Variety	Major season			Mean (variety)	Minor season			Mean (variety)
	60x20cm	60x30cm	60x40cm		60x20cm	6ox30cm	60x40cm	
Hans M9 12 3	0.925	1.025	2.325	1.425	0.775	0.875	2.050	1.233
Hans M9 12 5	1.075	1.500	2.575	1.717	0.825	1.025	1.950	1.267
Hans 12 25	1.000	0.775	1.850	1.208	0.825	0.675	1.675	1.058
Asontem	0.800	0.800	1.000	0.867	0.625	0.600	0.700	0.642
Hansadua	1.300	1.025	1.125	1.150	1.050	0.850	0.952	0.942
Mean (spacing)	1.020	1.025	1.775		0.820	0.805	1.460	
LSD (P ≤ 0.05) Spacing	**0.1723**				**0.2495**			
Variety	**0.4145**				**0.2980**			
Spacing x Variety	**0.6561**				**0.5034**			

In the major season, the 60 x 40 cm spacing consistently resulted in the largest plant girth across most cowpea varieties. The 60 x 20 cm spacing consistently resulted in the smallest plant girth for most varieties . HansM9 (12)(3) and HansM9 (12)(25) consistently exhibited the largest plant girth, regardless of spacing and seasonal variations. Asontem consistently exhibited the smallest plant girth, regardless of spacing. HansM9 (12)(5) and showed a significant increase in plant girth with wider spacing (60 x 40 cm). HansM9 (12)(3) also showed increase in plant girth with wider spacing. The impact of spacing on plant girth was more pronounced for HansM9 (12)(25), HansM9 (12)(5) and HansM9 (12)(3) compared to Asontem and Hansadua. In the minor rainy season, the 60 x 40 cm spacing consistently resulted in the largest plant girth across all cowpea varieties. The 60 x 20 cm spacing consistently resulted in the smallest plant girth across all cowpea varieties. HansM9 (12)(3) consistently exhibited the largest plant girth. Asontem consistently exhibited the smallest plant girth, regardless of spacing. HansM9 (12)(5) showed a significant increase in plant girth with wider spacing (60 x 40 cm) although, Hansadua was highest at 60 x 20 cm. Asontem showed a slight increase in plant girth with wider spacing, but the difference was less pronounced.

4.2.6 Number of branches of cowpea plant at maturity

The number of branches per plant was significantly influenced by the spacing intervals (p = 0.006), but not by the cowpea varieties or seasons (Table 6).

Table 6: Mean number of branches of cowpea plant at major and minor seasons

Variety	Major season			Mean (variety)	Minor season			Mean (variety)
	60x20cm	60x30cm	60x40cm		60x20cm	6ox30cm	60x40cm	
Hans M9 12 3	4.00	4.25	5.00	4.42	3.25	3.75	4.25	3.75
Hans M9 12 5	3.50	3.75	4.50	3.92	2.50	3.75	3.75	3.33
Hans 12 25	3.50	3.75	3.50	3.50	3.75	3.50	3.75	3.65
Asontem	3.00	3.75	4.25	3.67	3.00	3.25	3.25	3.17
Hansadua	3.75	3.50	4.25	3.83	3.00	4.00	4.00	3.67
Mean (spacing)	3.50	3.80	4.30		3.10	3.65	3.80	
LSD (P ≤ 0.05) Spacing	**1.063**	**NS**			**0.97**	**NS**		
Variety	**0.73**	**NS**			**0.60**	**NS**		
Spacing x Variety	**1.45**	**NS**			**1.25**	**NS**		

The widest spacing interval, 60 x 40 cm, promoted the highest mean number of branches for most cowpea varieties. For instance, HansM9 (12)(3) and Hansadua recorded the highest branch counts at 60 x 40 cm, with means of 5.00 and 4.25, respectively. In the minor season, the trend remained similar, with wider spacing (60 x 40 cm) resulting in the highest branch counts. HansM9 (12)(3) reached 4.25 branches at 60 x 40 cm, while Hansadua showed a slightly lower branching rate of 4.00, consistent with the major season pattern. The closest spacing (60 x 20 cm) produced the lowest branch counts for most varieties, including HansM9 (12)(5) with a mean of 2.50 branches, indicating that higher plant density restricts branching.

4.2.7 Canopy size of cowpea plant at maturity

The analysis of variance (ANOVA) revealed that spacing intervals had no effect on mean canopy size per plant at maturity ($p = 0.098$). Seasons had no significant impact on mean canopy size per plant at maturity ($p = 0.103$). The cowpea varieties did not show a statistically significant difference in. mean canopy size per plant at maturity ($p = 0.380$). While not highly statistically significant, the interaction between some varieties and distance had some significant influence on the size of the canopy.

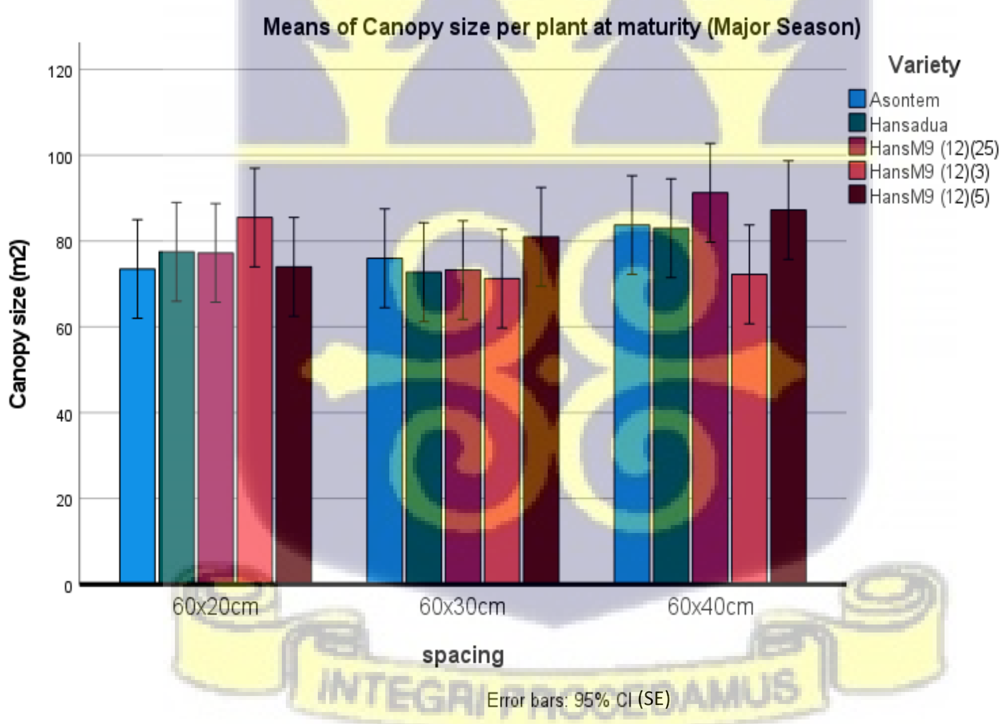


Figure 6: Mean canopy size of cowpea plant at major season

In the major rainy season, HansM9 (12)(3) consistently exhibited the largest canopy size, regardless of spacing. The 60 x 40 cm spacing resulted in the largest canopy size for all varieties. HansM9 (12)(5) and HansM9 (12)(25) consistently exhibited the smallest canopy size, regardless of spacing except at 60 x 40 cm spacing where HansM9 (12)(25) increased (Figure 6).

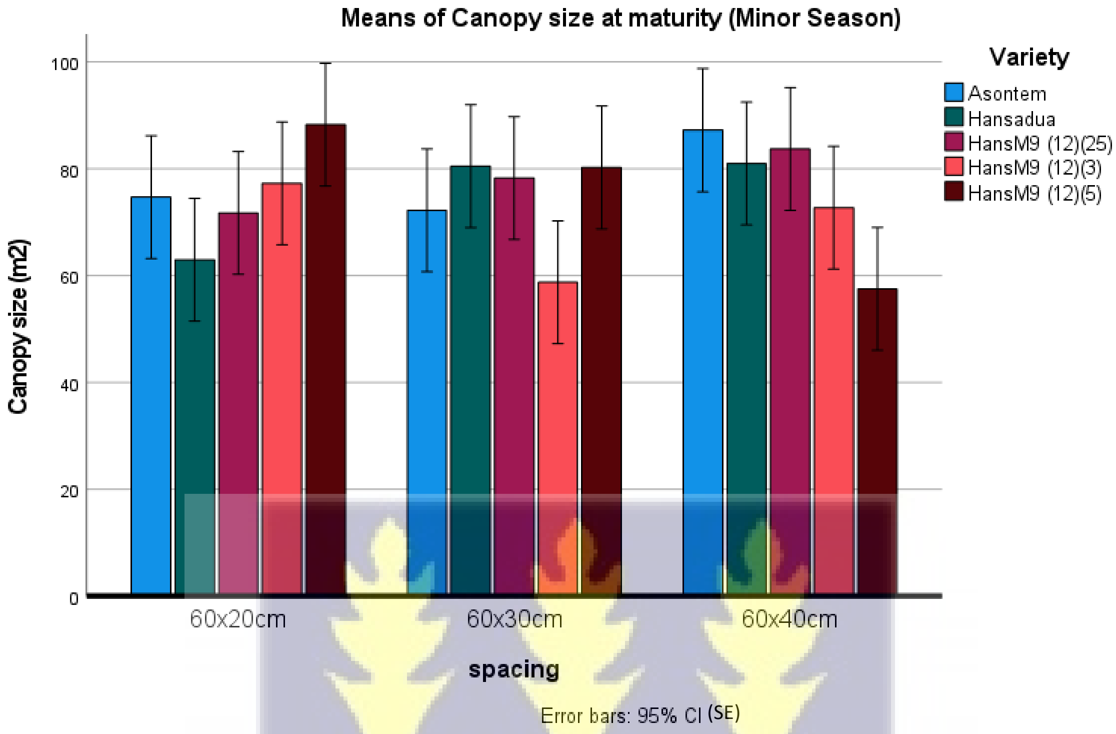


Figure 7: Mean canopy size of cowpea plant at minor season

In the minor rainy season, the 60 x 40 cm spacing consistently resulted in the largest canopy size per plant across most cowpea varieties. The 60 x 30 cm spacing consistently resulted in the smallest canopy size per plant across all cowpea varieties. HansM9 (12)(25) consistently exhibited the largest canopy size per plant, regardless of spacing (Figure 7).

4.3 Reproductive parameters

4.3.1 Days to 50% flowering of cowpea plant

The analysis of variance (ANOVA) revealed that the spacing intervals did not significantly influence the mean days to 50% flowering (p = 0.372), seasonal variation did not have a statistically significant effect on mean days to 50% flowering (p = 0.338). Also, the different cowpea varieties did not show significant differences in flowering time (p = 0.412) as indicated in figure 8 and 9.

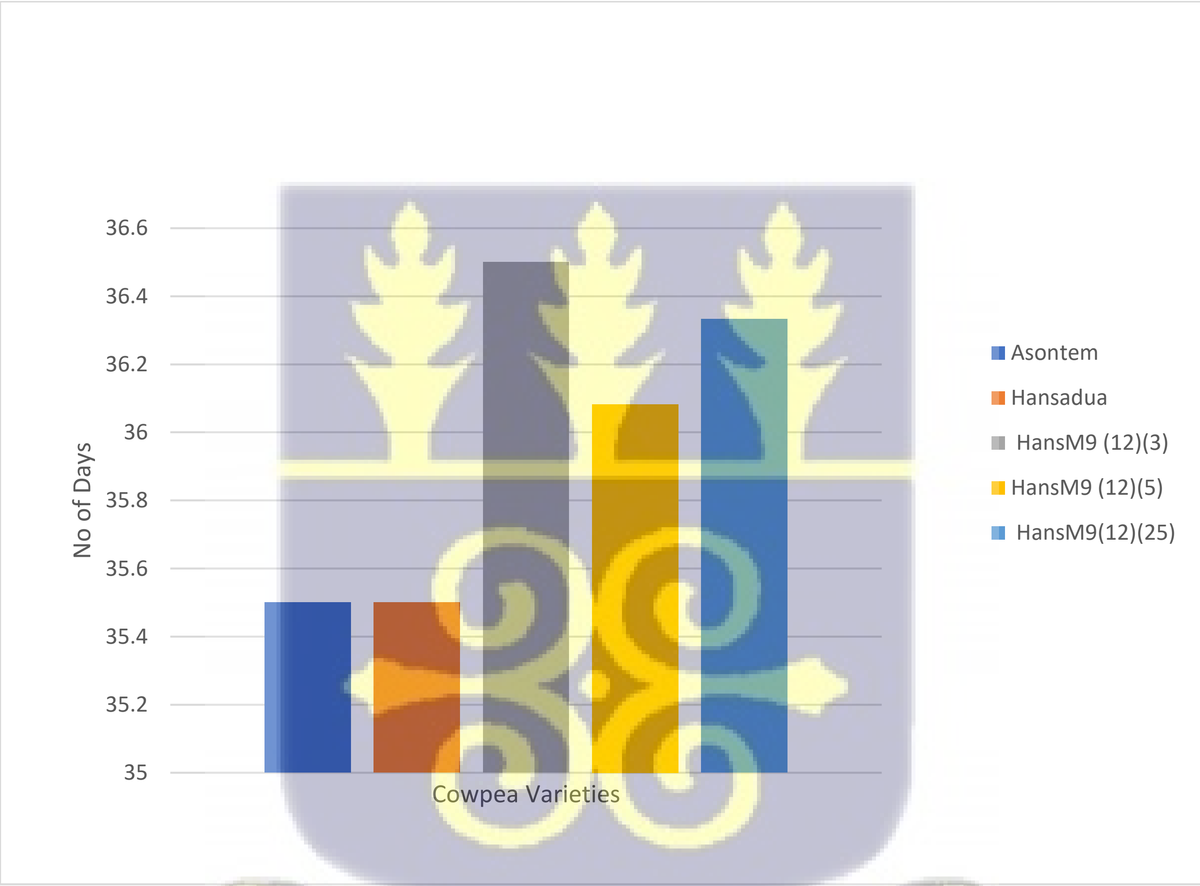


Figure 8: Mean days to 50% flowering of cowpea plant at major season

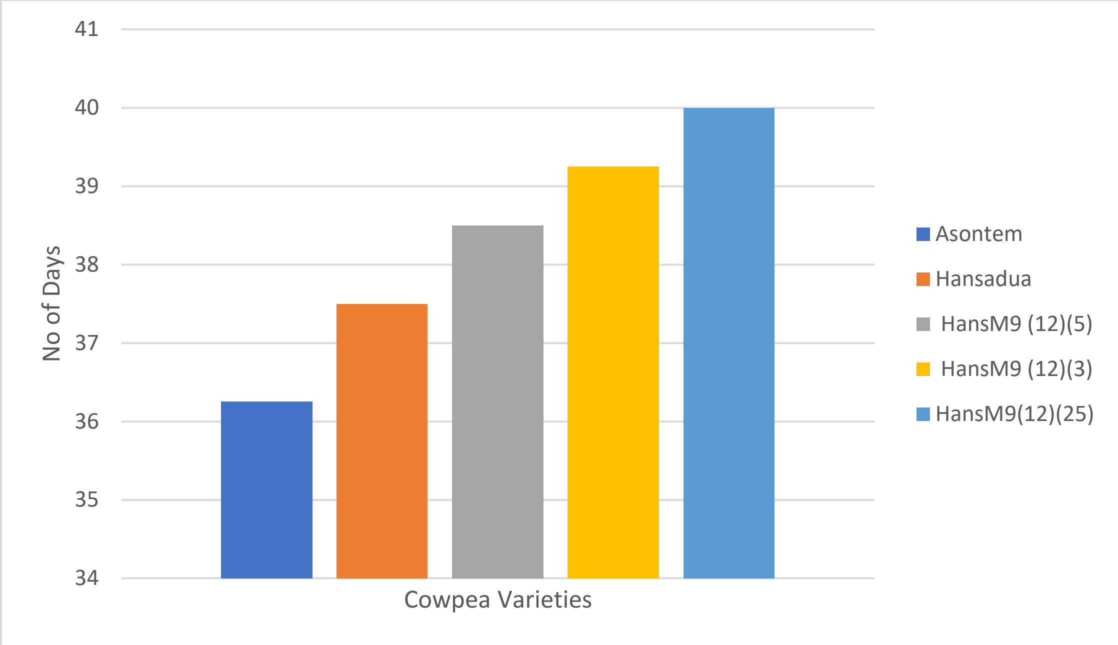


Figure 9: Mean days to 50% flowering of cowpea plant at minor season

4.3.2 Days to 50% maturity of cowpea plant

The analysis of variance (ANOVA) for days to 50% maturity indicated that the spacing intervals did not significantly affect the time it took for the cowpea plants to reach maturity ($p = 0.205$). Seasons had a significant impact on days to 50% maturity ($p < 0.001$). The major season recorded faster maturity rate while the minor season had a slower maturity. Additionally, the cowpea varieties did not significantly affect Days to 50% Maturity ($p = 0.979$).

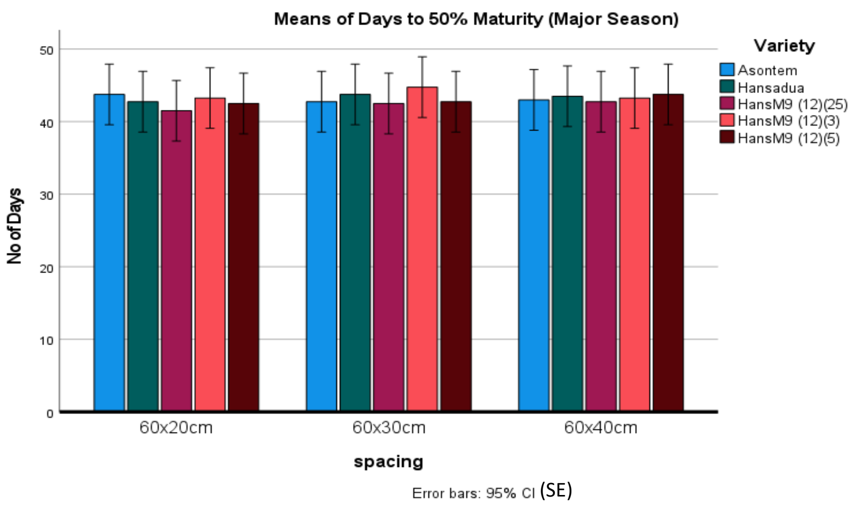


Figure 10: Mean days to 50% maturity of cowpea plant at major season

HansM9 (12)(5) and Asontem exhibited the highest DTF%M across all spacing intervals. Hansadua and HansM9 (12)(25) generally showed intermediate DTF%M at 60 x 30 cm and 60 x 40 cm but was the lowest at 60 x 20 cm interval. HansM9 (12)(3) typically had the lowest DTF%M, particularly at the 60 x 40 cm spacing. 60 x 20 cm spacing generally resulted in the lowest DTF%M for most varieties (Figure 10).

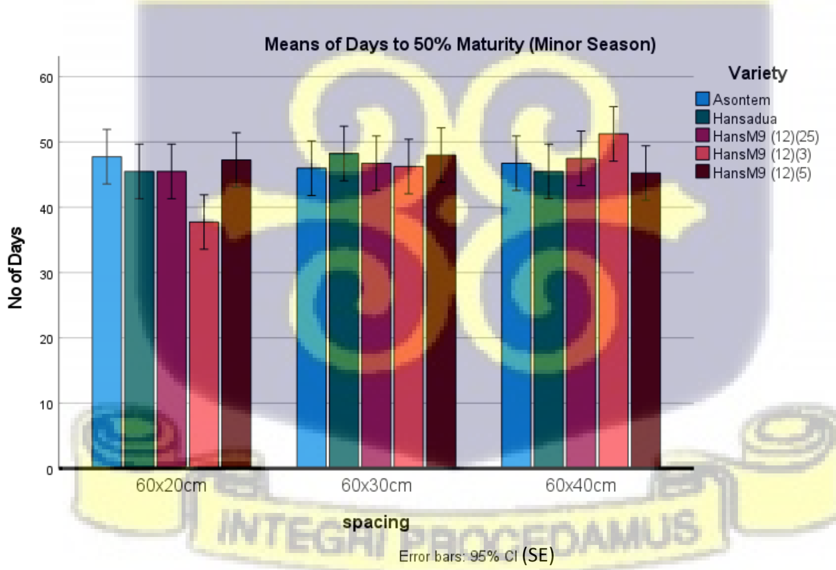


Figure 11: Mean days to 50% maturity of cowpea plant at minor season

The 60 x 20 cm spacing consistently resulted in the earliest maturity across all cowpea lines. Asontem consistently matured the earliest (43.5 to 48 days), regardless of spacing (Figure 6b).

However, HansM9 (12)(3) matured the earliest at 60 x 20 cm spacing interval. HansM9 (12)(5) and HansM9 (12)(25) consistently matured later than the other lines (45.5 to 51.5 days). Hansadua showed intermediate maturity times (45 to 48 days). The impact of spacing on maturity was more pronounced for Hansadua and the mutant lines than for Asontem. Hansadua showed a significant increase in maturity days with wider spacing (60 x 40 cm). The mutant lines exhibited a slight increase in maturity days with the wider spacing, but the differences were less pronounced compared to Hansadua. The mutant lines exhibited variable maturity times, with HansM9 (12)(3) maturing the earliest and HansM9 (12)(5) maturing the latest (Figure11).

4.3.3 Number of cowpea pods per plant

The analysis of variance (ANOVA) revealed that spacing intervals had a statistically significant effect on the mean number of pods per plant at maturity ($p < 0.001$) as indicated in Table 7.

Table 7: Mean number of cowpea pods per plant at major and minor seasons

Variety	Major season			Mean (variety)	Minor season			Mean (variety)
	60x20cm	60x30cm	60x40cm		60x20cm	6ox30cm	60x40cm	
Hans M9 12 3	16.20	16.20	21.80	18.10	19.00	17.75	17.50	18.08
Hans M9 12 5	21.80	31.20	25.00	26.00	10.75	22.75	20.50	18.00
Hans 12 25	18.70	24.5	26.50	23.20	13.00	28.00	26.75	22.58
Asontem	20.20	29.80	29.20	26.40	12.75	18.00	13.75	14.83
Hansadua	16.20	21.70	23.80	20.60	15.25	16.75	31.50	21.17
Mean (spacing)	18.60	24.70	25.20		14.15	20.65	22.00	
LSD (P ≤ 0.05) Spacing	**7.56**	**NS**			**5.32**			
Variety	**7.23**	**NS**			**4.60**			
Spacing x Variety	**12.80**	**NS**			**8.37**			

In the major season, the widest spacing interval (60 x 40 cm) generally produced average pod counts, with Asontem leading at 29.20 pods per plant, closely followed by HansM9 (12)(25) with 26.5 pods. At moderate spacing (60 x 30 cm), HansM9 (12)(5) achieved 31.2 pods, while Asontem reached 29.8. Close spacing (60 x 20 cm) yielded lower pod counts, with HansM9 (12)(3) and Asontem producing 16.2 and 20.2 pods, respectively. Seasonal differences were evident, with pod counts generally higher in the major season

Among varieties, HansM9 (12)(5) responded best to moderate spacing in the major season, though its pod count declined in the minor season. HansM9 (12)(5) performed well across both 60 x 30 cm and 60 x 40 cm in the major season, while Asontem performed best at 60 x 30 cm in the major season but saw a reduced count in the minor season. Hansadua excelled in the wider spacing at minor season.

4.3.4 Cowpea pod length at maturity

The results revealed that the spacing intervals did not significantly affect the pod length ($p > 0.05$). The major season, supported the growth of longer pods compared to the minor season.

During the major season, pod length across cowpea varieties was generally unaffected by spacing, though slight variations were noted. HansM9 (12)(5) achieved the longest pod length at 60 x 20 cm (19.57 cm). Moderate spacing (60 x 30 cm) showed no marked effect on pod length, while at 60 x 40 cm, varieties like HansM9 (12)(3) and HansM9 (12)(5) exhibited slightly longer pods, though differences were minimal. In the minor season, spacing effect on pod length remained limited, with HansM9 (12)(5) displaying consistent lengths across intervals (19.23 cm at 60 x 20 cm and 18.98 cm at 60 x 40 cm) as indicated in Table 8.

Table 8: Mean cowpea pod length at maturity for major and minor seasons

Variety	Major season			Mean (variety)	Minor season			Mean (variety)
	60x20cm	60x30cm	60x40cm		60x20cm	6ox30cm	60x40cm	
Hans M9 12 3	18.62	18.85	19.20	18.89	17.53	18.25	17.00	17.59
Hans M9 12 5	19.57	18.10	19.42	19.17	19.23	18.18	18.98	18.79
Hans 12 25	18.82	18.85	18.15	18.61	17.60	17.53	17.23	17.45
Asontem	18.75	18.50	18.60	18.56	17.98	16.68	17.18	17.28
Hansadua	18.52	17.12	18.52	18.06	16.60	15.55	16.93	16.36
Mean (spacing)	18.90	18.28	18.78		17.79	17.24	17.46	
LSD (P ≤ 0.05) Spacing	**0.79**	**NS**			**1.04**	**NS**		
Variety	**0.80**	**NS**			**2.37**	**NS**		
Spacing x Variety	**2.86**	**NS**			**3.77**	**NS**		

Cowpea pod lengths were longer in the major season, likely due to favorable rainfall and temperature. HansM9 (12)(5) emerged as the most consistent, with high pod lengths across seasons and spacing, particularly at closer intervals in the major season. Other varieties like HansM9 (12)(3) and Asontem had moderate lengths with minimal variation across spacing or season, indicating lower sensitivity to planting density and seasonal conditions

4.3.5 Number of cowpea seeds per pod at maturity

The analysis of variance (ANOVA) revealed that spacing intervals had marginal effect on the mean number of seeds per pod at maturity ($p = 0.115$), indicating that spacing did have some influence on seed production (Table 9).

Table 9: Mean number of cowpea seeds per pod at maturity for major and minor seasons

Variety	Major season			Mean (variety)	Minor season			Mean (variety)
	60x20cm	60x30cm	60x40cm		60x20cm	6ox30cm	60x40cm	
Hans M9 12 3	13.50	13.25	13.00	13.25	13.50	11.75	13.50	12.92
Hans M9 12 5	13.25	12.75	14.75	13.58	13.00	12.25	13.25	12.83
Hans 12 25	13.50	14.50	13.25	13.75	13.00	12.00	14.50	13.17
Asontem	13.25	13.50	13.00	13.25	11.00	11.00	11.00	11.00
Hansadua	14.25	13.50	14.25	14.00	12.75	13.75	14.00	13.50
Mean (spacing)	13.55	13.50	13.65		12.65	12.15	13.25	
LSD (P ≤ 0.05) Spacing	**0.75**	**NS**			**0.93**	**NS**		
Variety	**1.35**	**NS**			**0.88**			
Spacing x Variety	**2.18**	**NS**			**1.56**	**NS**		

In the major season, wider spacing (60 x 40 cm) produced the highest mean seed counts per pod, particularly for varieties like HansM9 (12)(5) and Hansadua, which recorded 14.75 and 14.25 seeds per pod, respectively. Moderate spacing (60 x 30 cm) also facilitated relatively high seed counts, with HansM9 (12)(25) reaching 13.25 seeds per pod. Close spacing (60 x 20 cm) saw reduced seed numbers, with HansM9 (12)(3) and Asontem producing 13.5 and 13.25 seeds per pod. Seasonal differences highlighted a trend toward higher seed counts per pod in the major season. Varieties such as HansM9 (12)(5) and Hansadua performed particularly well in the major season.

Among specific varieties, HansM9 (12)(5) and HansM9 (12)(25) consistently achieved its best seed counts at 60 x 40 cm in both seasons, with 13.5 seeds in the major and 14.5 in the minor season. HansM9 (12)(5) also maintained high seed counts across wider spacing intervals.

HansM9 (12)(25) recorded the highest seed counts overall, particularly at 60 x 40 cm. Asontem showed sensitivity to both closer spacing and seasonal changes, with lower seed counts across intervals, particularly at 11 seeds per pod at 60 x 20 cm in the minor season. Hansadua excelled at wider spacing in both seasons, achieving 14.25 seeds per pod in the major season and 14.0 in the minor season.

4.3.6 Total cowpea seed weight per plot at maturity (g)

The analysis of variance (ANOVA) revealed that spacing intervals did not significantly affect the total seed weight per plot ($p = 0.407$). Seasons had a highly significant impact on total seed weight per plot ($p < 0.001$. The major season recorded higher total seed weights due to more favorable growing conditions (Table 10).

Table 10: Mean total cowpea seed weight per plot at maturity (g)

Variety	Major season			Mean (variety)	Minor season			Mean (variety)
	60x20cm	60x30cm	60x40cm		60x20cm	6ox30cm	60x40cm	
Hans M9 12 3	662	695	613	657	507	532	467	502
Hans M9 12 5	886	761	617	755	681	575	474	576
Hans 12 25	1147	1109	860	1039	878	852	660	796
Asontem	814	518	784	705	624	397	601	541
Hansadua	410	644	614	556	304	494	469	422
Mean (spacing)	784	746	697		599	570	534	
LSD ($P \leq 0.05$) Spacing	**240.8**	**NS**			**185.1**	**NS**		
Variety	**232.8**				**178.7**			
Spacing x Variety	**411.0**	**NS**			**315.6**	**NS**		

In the major season, the closest spacing (60 x 20 cm) yielded the highest total seed weights across varieties, with HansM9 (12)(25) achieving 1147.0 grams per plot, followed by HansM9 (12)(5) with 886.0 grams. This suggests that denser spacing maximizes yield per unit area by leveraging favorable growing conditions. Moderate spacing (60 x 30 cm) also supported high yields for varieties like HansM9 (12)(25) at 1109.0 grams, though certain varieties, such as HansM9 (12)(3), showed reduced response to this density. At the widest spacing (60 x 40 cm), yields declined, as in HansM9 (12)(25) with 860.0 grams, likely due to fewer plants per area, indicating a suboptimal use of favorable conditions.

In the minor season, closer spacing continued to support the highest total seed weights. HansM9 (12)(25) reached 878.0 grams at 60 x 20 cm, while HansM9 (12)(5) followed with 681.0 grams, suggesting that dense planting sustains yield even under less favorable seasonal conditions. Moderate spacing (60 x 30 cm) showed slightly lower productivity, with HansM9 (12)(25) at 852.0 grams. The widest spacing (60 x 40 cm) saw further reductions, with HansM9 (12)(25) dropping to 660.0 grams, suggesting that lower density limits productivity in challenging conditions.

Across seasons, total seed weight was consistently higher in the major season. For instance, HansM9 (12)(25) reached 1147.0 grams at 60 x 20 cm in the major season, contrasting with 878.0 grams in the minor season, aligning with expectations that favorable rainfall and temperature boost growth. HansM9 (12)(5) mirrored this trend, with a peak of 886.0 grams at 60 x 20 cm in the major season, dropping to 681.0 grams in the minor season.

Variety-specific performance revealed HansM9 (12)(25) as the highest-yielding variety, particularly in denser plantings, achieving 1147.0 grams at 60 x 20 cm in the major season and 878.0 grams in the minor season, indicating strong adaptability. HansM9 (12)(5) also performed well at 60 x 20 cm in both seasons, though it fell short of HansM9 (12)(25)'s output.

HansM9 (12)(3) yielded lower overall, particularly at wider spacing, peaking at 613.0 grams in the major season at 60 x 40 cm, suggesting limited responsiveness to reduced competition. Asontem displayed moderate yields, with 814.0 grams at 60 x 20 cm in the major season and 624.0 grams in the minor season, showing moderate adaptability. Hansadua recorded the lowest yields across both seasons and spacing, especially with 303.8 grams at 60 x 20 cm in the minor season, indicating limited suitability for high-density planting.

4.3.7 Total cowpea seed weight per plot at maturity (kg ha-1)

The ANOVA indicated significant differences for total seed weight per plot across varieties ($p = 0.012$) and seasons ($p < 0.001$). However, spacing did not significantly affect the total seed weight ($p = 0.410$). The major seasons recording higher values than the minor seasons. Across the different spacing intervals, the variety HansM9 (12)(25) consistently recorded the highest mean total seed weight (Table 11). In the 60 cm × 20 cm spacing, it achieved a mean of 1.45 kg ha-1 during the major season, slightly decreasing to 1.20 kg ha-1 in the minor season. The interaction between the cowpea lines and seasons also exhibited significant differences.

Table 11: Mean total cowpea seed weight per plot at maturity (kg ha-1)

Variety	Major season			Mean (variety)	Minor season			Mean (variety)
	60x20cm	60x30cm	60x40cm		60x20cm	6ox30cm	60x40cm	
Hans M9 12 3	1652	2188	1532	1791	1267	1331	1168	1267
Hans M9 12 5	2214	1930	1542	1896	1703	1437	1184	1703
Hans 12 25	2868	2774	2149	2597	2195	2130	1649	2195
Asontem	2034	1295	1958	1762	1560	992	1502	1560
Hansadua	1026	1611	1535	1390	759	1234	1172	759
Mean (spacing)	1959	1960	1743		1497	1425	1335	
LSD (P ≤ 0.05) Spacing	**591.7**	**NS**			**462.5**	**NS**		
Variety	**647.4**				**446.8**			
Spacing x Variety	**1111.5**	**NS**			**788.9**	**NS**		

In the major season, the closest spacing interval (60 cm × 20 cm) produced the highest total seed weight per hectare across varieties, with HansM9 (12)(25) leading at 2,868 kg ha⁻¹. However, at the widest spacing (60 cm × 40 cm), yields decreased, with HansM9 (12)(25) achieving only 2,149 kg ha⁻¹, likely due to fewer plants per area.

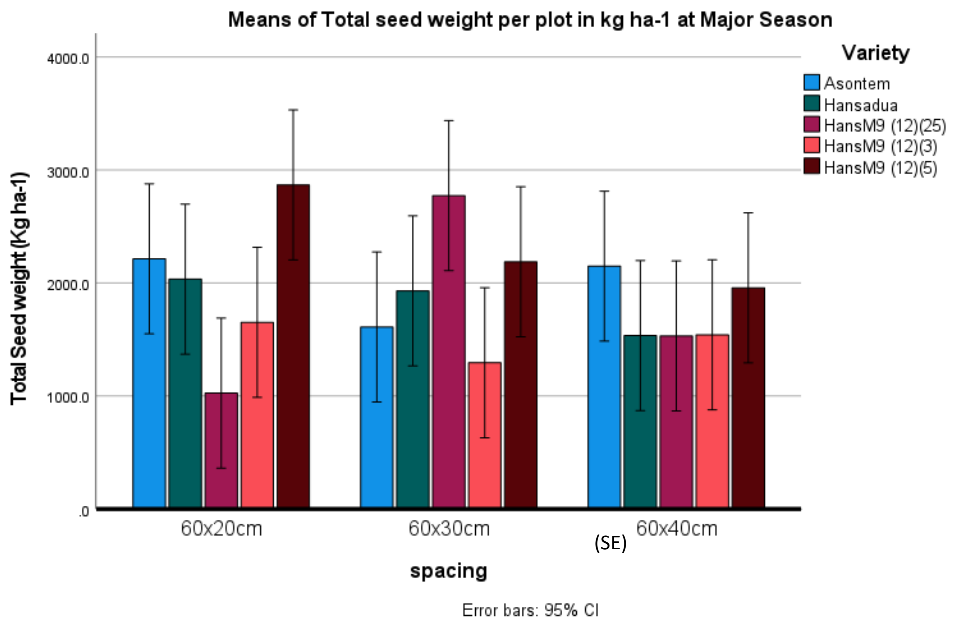


Figure 12: Mean total cowpea seed weight per plot (kg ha-1) at major season

In the minor season, the trend was similar, with 60 cm × 20 cm yielding the highest seed weights (Figure 12).

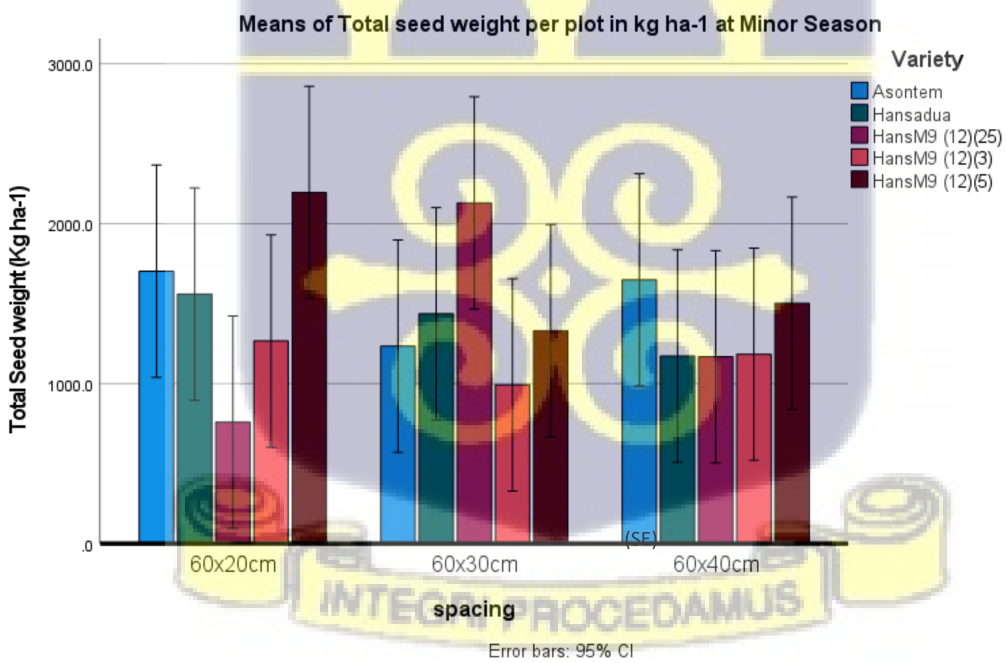


Figure 13: Mean total cowpea seed weight per plot (kg ha-1) at minor season

Variety-specific performance highlighted HansM9 (12)(25) as the top-yielding variety across seasons and spacing, with peak yields at closer spacing (60 cm × 20 cm), especially in the major season. HansM9 (12)(5) also showed high productivity at S1, particularly in the major season, though its yield was slightly lower than HansM9 (12)(25). Asontem displayed moderate yields, reaching 2,034 kg ha^{-1} at S1 in the major season, but did not match HansM9 (12)(25)'s yield potential under dense planting. Hansadua recorded the lowest yields, peaking at 1,026 kg ha^{-1} at S1 in the major season, suggesting limited adaptability to dense planting and lower yield potential (Figure13).

4.3.8 Hundred (100) cowpea seed weight per plot at maturity

Seasons had a highly significant impact on the 100-seed weight per plot ($p < 0.001$). The cowpea varieties did not show a statistically significant difference in 100-seed weight per plot ($p = 0.931$). Although not statistically significant, certain varieties exhibited more consistent seed weights across different intervals over the seasons. Varieties like Hansadua showed relatively stable performance across both seasons and spacing intervals.

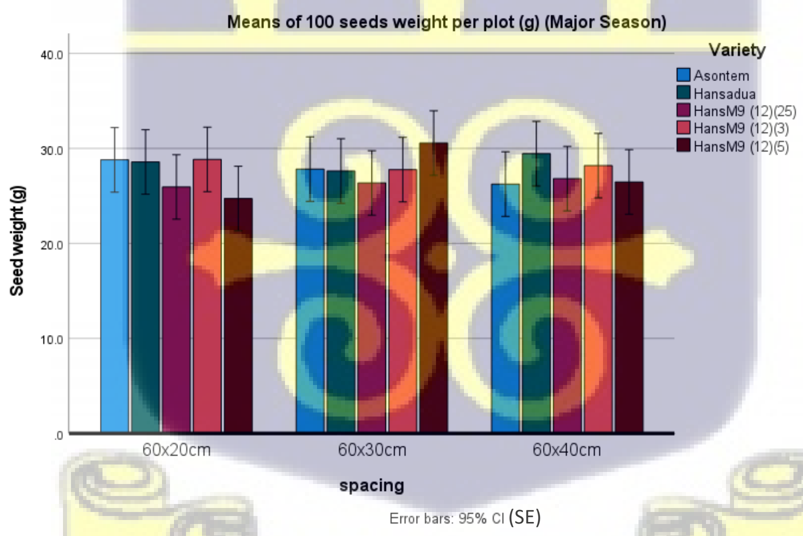


Figure 14: Mean hundred (100) cowpea seed weight per plot at major season

In the major rainy season, HansM9 (12)(3) consistently exhibited the largest 100 seed weight per plot at 60 x 30cm spacing interval but slightly decreased at the widest interval. Similarly, Asontem showed a slightly decreasing trend as spacing interval widened (Figure 14). Hansadua recorded an opposite trend where seed weight increased at the widest spacing interval. HansM9(12)(25) recorded the lowest seed weight across all spacing interval. The major season recorded high values than that of the minor season (Figure 14).

Figure 15: Mean hundred (100) cowpea seed weight per plot at minor season

There was no clear consistent effect of spacing on 100 seed weight per plot across all cowpea varieties (Figure 15). The 60 x 40 cm spacing resulted in the largest 100 seed weight per plot for HansM9(12)(25). HansM9 (12)(5) HansM9(12)(3), Asontem showed an increase in 100 seed weight per plot with 60 x 30 cm spacing but a decrease with 60 x 40 cm spacing((Figure15).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Rainfall pattern during the experimental period

The rainfall data indicated that the main rainy season began in March at an increase rate of around 100 mm, and it peaks in April with approximately 275 mm of precipitation. After that, there was a continuous downpour from May through July, with the maximum total of 336 mm rainfall in July. The rainfall distribution in the agro ecological zone is bimodal, with two separate peaks seen in the months of April and July. July had the highest recorded rainfall, with a peak value of about 336 mm. This signifies the major rainy season in this particular agro-ecological zone, which is characteristic of a tropical climate. The months with the least amount of rainfall are January, February, and December, with December having the lowest amount at 25.5 mm. The dry season, which is characterized by a sharp decline in precipitation, begins in these months. January signalled the beginning of a mild dry season, and February likewise saw minimal rainfall of 61.0 mm. Rainfall progressively decreases from August to October, keeping moderate values of 182.1 mm to 165.3 mm, following the peak of the rainy season in July. The amount of rain that falls in November also decreases to 102.9 mm, signalling the end of the minor rainy season and the start of the dry season. The rainfall data shows that a dry season, which lasts from December to February, ends and is followed by a wet season, which begins in March and sees a steady increase in precipitation. Consistent rainfall, with values exceeding 200 mm in May and September, was also observed during this period, facilitating crop growth.

5.1 Effect of spacing on days to 50% emergence of cowpea plant

The closest spacing (60 cm × 20 cm) resulted in slightly faster emergence across most varieties, though the differences were not statistically significant. This slight variation might be due to the increased soil moisture retention and microclimate effects in closely spaced plots, which can promote quicker emergence. HansM9 (12)(3) and HansM9 (12)(25) emerged slightly faster at closer spacing, possibly due to better soil moisture retention that facilitated quicker germination. Some studies suggest that closer spacing can slightly enhance emergence due to better moisture conservation and reduced soil surface exposure (Ngalamu *et al*., 2014). However, the effect is often minimal, as supported by the results of this study, where emergence times were relatively consistent across different spacing.

During the major rainy season, emergence was generally faster across all varieties, likely due to the more consistent and adequate moisture levels, which are critical for seed germination. The literature widely supports the notion that the major rainy season provides optimal conditions for rapid seed germination and emergence due to consistent moisture availability (Singh *et al*., 2017). The faster emergence observed in this study aligns with these findings, suggesting that the environmental conditions during the major season are ideal for early crop development.

5.2 Effect of spacing on cowpea plant height

The significant influence of seasonal variations on plant height aligns with existing literature, which consistently shows that environmental conditions such as temperature, rainfall, and sunlight during the growing season critically impact vegetative growth. For example, studies by Singh *et al*. (2017) and Kamara *et al*. (2018) have documented that cowpea growth, particularly in height, is sensitive to the amount of rainfall and the distribution of rainfall across the growing period. The higher plant heights observed during the major season in the study is attributed to more favourable growing conditions, including higher and more evenly distributed rainfall, which supports better vegetative growth.

The finding that spacing intervals did not significantly impact plant height differs from some studies, which suggest that closer spacing often leads to taller plants due to increased competition for light (Adeyemo *et al*., 2021). This discrepancy might be explained by the specific agro-ecological conditions of the study area or the genetic characteristics of the cowpea lines used. For instance, cowpea varieties with determinate growth habits might not exhibit the same degree of height increase under close spacing as indeterminate varieties, which continuously grow taller as they compete for light (Ahmed *et al*., 2018).

Although varietal differences were not statistically significant in the study, existing literature often highlights the role of genetic factors in determining plant height. According to Boukar *et al*. (2019), different cowpea varieties can exhibit varied growth patterns due to inherent genetic differences, especially when grown under similar environmental conditions. The observed lack of significant varietal differences in the study could be due to the relatively uniform growing conditions and the stability of the mutant lines used, which were selected for consistent performance across various conditions (Lumor, 2022). HansM9 (12)(25) demonstrated superior height during the major season across all spacing intervals but performed less well in the minor season. This line's significant height in favourable conditions suggests a robust growth response when environmental conditions are optimal. The high yield potential of HansM9 (12)(5) may contribute to its strong growth under favourable conditions. Studies like those of Boukar *et al*. (2019) have shown that cowpea varieties with high yield potentials often allocate resources towards both vegetative and reproductive growth when conditions permit, leading to greater overall plant height. Hansadua generally exhibited lower plant heights to Asontem, with slight variations across different spacing intervals. Its indeterminate growth habit could allow for continuous vegetative growth, making it less sensitive to spacing variations compared to determinate varieties. The adaptability of Asontem, as noted by Ravelombola *et al*. (2016), likely contributes to its consistent performance. Its resilience under varying conditions makes it a reliable choice for different planting strategies, explaining its stable height across different spacings.

5.3 Effect of spacing on the number of leaves of cowpea plant

The significant effect of wider spacing on leaf production aligns with studies by Adeyemo *et al*. (2021), who finds that, increased spacing reduces competition for light, nutrients, and water, allowing plants to develop more foliage. In denser plantings, competition can lead to reduced leaf production as plants allocate resources to vertical growth or reproductive structures instead of foliage. However, some studies (e.g., Ahmed *et al*., 2018) suggest that in certain environments, closer spacing might result in more leaves due to increased competition for light, which drives the plants to produce more leaves as they strive to outcompete neighbouring plants. The increase in leaf production with wider spacing can be attributed to reduced inter-plant competition. With more space, individual plants have better access to sunlight, nutrients, and water, which are critical for leaf development. The larger leaf area resulting from wider spacing likely enhances the plant's photosynthetic capacity, contributing to better growth and yield potential.

The higher number of leaves observed during the major season is consistent with the literature. Favourable environmental conditions, such as higher rainfall and optimal temperatures during the major rainy season, support more vigorous vegetative growth, leading to increased leaf production (Singh *et al*., 2017). This is in line with Kamara *et al*. (2018), who reported that cowpea plants tend to produce more leaves during periods of adequate moisture and favourable temperatures. The significant seasonal impact further supports the idea that environmental factors, particularly water availability and temperature, play a critical role in determining vegetative growth in cowpea. The stress conditions typically associated with the minor season, such as reduced rainfall, likely limited the plants' ability to produce leaves.

The literature often highlights that different cowpea varieties have varying capacities for vegetative growth depending on their genetic makeup (Boukar *et al*., 2019). For instance, varieties bred for higher yields or stress tolerance may allocate more resources to leaf production to support greater photosynthetic activity, which is essential for sustaining higher yields. In the study, HansM9 (12)(3) likely produced fewer leaves at closer spacing due to its determinate growth habits, which focus on reproductive growth over vegetative expansion (Adewale *et al*., 2018). In contrast, HansM9 (12) (25) and HansM9 (12)(5), with their more determinate growth, might have shown more consistent leaf production across different spacing intervals. The observed differences among cowpea varieties in leaf production are likely due to their inherent genetic traits. Varieties like HansM9 (12)(3) and HansM9 (12)(5), which are designed to optimize reproductive growth, might allocate fewer resources to leaf production compared to varieties like Asontem and Hansadua, which are more versatile in their growth habits and better at maintaining foliage production across varying conditions. The results suggest that wider spacing intervals (60 cm × 40 cm) are beneficial for maximizing leaf production in cowpea cultivation. This could have important implications for farmers looking to optimize their planting strategies for better vegetative growth and potentially higher yields.

5.4 Effect of spacing on cowpea leaf area index

The non-significant effect of spacing on LAI in the study contrasts with some findings in the literature. Adewale *et al*. (2018) and Ahmed *et al*. (2018) indicate that wider spacing intervals typically reduce competition for light, water, and nutrients, potentially leading to a higher LAI as plants can expand their leaf area more effectively. The discrepancy in the study could be attributed to the genetic stability of the cowpea lines, which might have been bred to maintain consistent leaf area development across different spacing. It is possible that the cowpea varieties used in the study have been selected for uniform LAI performance, regardless of planting density. This could be advantageous in maintaining stable photosynthetic efficiency across varying planting conditions, thereby ensuring consistent growth and yield outcomes.

The significant impact of seasons on LAI aligns with findings from Singh *et al*. (2017) and Kamara *et al*. (2018), who report that environmental factors such as rainfall, temperature, and sunlight during the growing season strongly influence leaf area development. The major rainy season likely provided more favourable conditions, such as higher and more consistent rainfall, which supported the development of a larger leaf area, leading to a higher LAI. The lower LAI observed during the minor season could be due to less favourable environmental conditions, such as reduced rainfall or suboptimal temperatures, which may have limited leaf expansion and vegetative growth.

The lack of significant differences in LAI among the cowpea varieties suggests that these lines are genetically similar in terms of their leaf area development. This might indicate that the varieties were bred or selected for consistent leaf area performance across different environmental conditions and spacing intervals. Previous studies (e.g., Boukar *et al*., 2019) often report significant varietal differences in LAI, reflecting the genetic diversity among cowpea lines. The uniformity observed in the study may reflect a breeding focus on minimizing variability in leaf area to ensure stable photosynthetic capacity across different environments. The lack of significant differences in LAI due to spacing or variety suggests that the cowpea lines used are genetically stable, particularly in their ability to maintain consistent leaf area development regardless of planting density. This stability ensures that the plants can sustain an efficient photosynthetic capacity, which is crucial for supporting growth and yield, even under varying planting conditions.

The findings suggest that the cowpea lines used in the study are likely to maintain a stable LAI across different planting densities and environmental conditions. This stability could be beneficial for farmers looking to optimize photosynthetic efficiency and ensure consistent growth, regardless of external factors like spacing or seasonal variations.

5.5 Effect of spacing on cowpea plant girth

The significant increase in plant girth with wider spacing intervals aligns with the findings of Adeyemo *et al*. (2021), who observed that reducing plant density allows individual plants to access more resources (light, nutrients, and water), which contributes to greater stem thickening. Wider spacing reduces competition, enabling the plants to develop thicker stems, which are essential for supporting larger canopies and potentially higher yields. This result is consistent with the work of Ahmed *et al*. (2018), who reported that closer spacing often leads to competition for resources, resulting in thinner stems as plants focus on vertical growth rather than lateral expansion. The significant effect of wider spacing on plant girth can be attributed to reduced competition for light, water, and nutrients. When plants are spaced further apart, they have more access to these resources, enabling them to develop thicker stems. This increased stem girth is crucial for supporting larger canopies and potentially higher reproductive yields.

The larger plant girth observed during the major rainy season is consistent with studies that highlight the role of favourable environmental conditions in promoting vegetative growth. According to Singh *et al*. (2017), higher rainfall and optimal temperatures during the major season provide ideal conditions for robust plant development, including increased stem girth. During the minor season, less favourable conditions, such as lower rainfall, might limit water availability, leading to reduced plant girth. Some studies suggest that under certain conditions, the minor season could lead to thicker stems if plants experience stress-induced growth responses. However, in this study, the major season's favourable conditions appear to have supported more consistent and robust girth development.

The significant differences in plant girth among the cowpea varieties reflect the impact of genetic factors. As noted by Boukar *et al*. (2019), different cowpea varieties exhibit varying growth habits and resource allocation strategies, which influence stem development. For example, varieties bred for high yield or drought tolerance might allocate more resources to developing thicker stems to support greater biomass. HansM9 (12)(5) consistently exhibited the largest plant girth, regardless of spacing or season, indicating its robust growth habit and possibly higher resource allocation to stem development. This could be linked to its determinate growth habit, which focuses on building a strong plant structure early in the growing season to support reproductive growth later.

The findings suggest that wider spacing intervals are beneficial for promoting stem thickening, which can enhance plant stability and support larger canopies. This is important for farmers aiming to maximize plant health and yield potential, especially in environments where robust vegetative growth is critical. Also, the significant differences in girth among cowpea varieties highlight the importance of selecting the right variety for specific growing conditions. Varieties like HansM9 (12)(5), which consistently develop thicker stems, may be better suited for environments where strong plant structure is necessary to support high yields.

5.6 Effect of spacing on the number of branches of cowpea plant

Wider spacing allows for more resources per plant, including light, nutrients, and water, which are critical for the development of lateral branches (Adewale *et al*., 2018). This finding aligns with studies by Adeyemo *et al*. (2021), who reported that cowpea plants grown with wider spacing intervals exhibited more branching due to reduced competition for resources. Some literature suggests that in certain environments, closer spacing might induce more branching as a competitive response, where plants strive to occupy available space and capture more light (Ahmed *et al*., 2018). However, in the study, the opposite was observed, likely due to the specific environmental conditions of the semi-deciduous agro-ecological zone, which might provide sufficient resources even at wider spacing, reducing the need for competitive branching.

While the effect of seasons on branching was not statistically significant, it was close to the threshold ($p = 0.062$). This suggests that environmental conditions such as temperature, rainfall, and day length, which vary between seasons, could influence branching to some extent. Kamara *et al*. (2018) reported that branching in cowpea can be influenced by environmental stress, with drought or suboptimal temperatures potentially limiting the plant's ability to produce branches. The non-significant seasonal effect could be due to the stability of the cowpea varieties used in the study, which were likely bred for consistent performance across different environmental conditions (Boukar *et al*. 2019).

The finding that cowpea varieties did not significantly differ in the number of branches might be explained by the genetic makeup of the specific lines used in the study. Varieties like HansM9 (12)(3) and HansM9 (12)(5), which exhibit determinate growth patterns, are genetically programmed to limit branching once they reach a certain stage of development (Lumor, 2022). This could result in similar branching patterns across different varieties, particularly in environments where resources are not a limiting factor. This finding contrasts with some studies (e.g., Singh *et al*., 2017), where genetic diversity in cowpea has been shown to significantly affect branching. The similarity in branching among the varieties in the study could be due to the selection of lines with similar growth habits, particularly determinate types, which are less prone to extensive branching compared to indeterminate varieties. The lack of significant differences among cowpea varieties suggests that the genetic makeup of these lines might limit their branching potential, particularly for the determinate varieties like HansM9 (12)(3) and HansM9 (12)(5). These varieties were likely bred to focus more on reproductive output rather than extensive vegetative growth, which could explain the similarity in branching across different spacing intervals.

5.7 Effect of spacing on canopy size of cowpea plant

The lack of a significant effect of spacing intervals on canopy size contrasts with some studies that suggest wider spacing generally allows for greater canopy expansion due to reduced competition for light and nutrients (Adewale *et al*., 2018). However, other studies (e.g., Ahmed *et al*., 2018) indicate that canopy size might not always increase with wider spacing, especially in varieties that prioritize vertical growth or reproductive structures over lateral expansion. The observed lack of a significant effect in the study could be due to the specific genetic traits of the cowpea lines used, which may have been selected for traits like yield or stress resistance rather than canopy expansion. Moreover, the environmental conditions in the semi-deciduous agro-ecological zone might have provided enough resources even at closer spacing, preventing significant variations in canopy size across different spacing intervals.

The non-significant seasonal effect on canopy size in the study is somewhat surprising, as existing literature often reports that environmental conditions during the major rainy season (such as higher rainfall and optimal temperatures) usually promote larger canopies (Singh *et al*., 2017). However, the lack of significance might suggest that the cowpea lines used in the study are genetically stable across different seasons, leading to consistent canopy development irrespective of seasonal changes. This stability could be linked to the breeding objectives for these lines, which might have focused on producing consistent growth patterns across varying environmental conditions, as noted by Boukar *et al*. (2019). The semi-deciduous agro-ecological zone where the study was conducted might provide sufficient resources (light, water, nutrients) even at closer spacing, leading to similar canopy sizes across different spacing intervals. The environmental stability in this zone might mitigate the expected effects of spacing and seasons on canopy size.

The absence of significant differences in canopy size among the cowpea varieties might be due to the similar growth habits of the lines studied. Asontem and Hansadua, being standard varieties, and the mutant lines (HansM9 (12)(3), HansM9 (12)(5), HansM9 (12)(25)), which were likely bred for specific traits like yield and stress resistance, may all exhibit similar canopy expansion patterns. In contrast, some studies, such as those by Adewale *et al*. (2018), suggest that different cowpea varieties often exhibit varied canopy sizes due to differences in growth habits, with more indeterminate varieties typically producing larger canopies. The uniformity observed in the study could indicate that the varieties were selected to minimize variability in canopy size, possibly to maintain consistent yield performance across different planting densities. The cowpea lines might be genetically predisposed to balance resource allocation between vegetative growth (like canopy expansion) and reproductive growth (yield). This could result in uniform canopy sizes across different conditions, as the plants focus on optimizing both vegetative and reproductive traits rather than excessively expanding their canopies.

5.8 Effect of spacing on days to 50% flowering of cowpea plant

The closest spacing of 60 cm × 20 cm generally resulted in slightly earlier flowering across most varieties, though the differences were not large. The increased competition at closer spacing might have induced earlier flowering as a stress response, where plants accelerate their reproductive phase in response to limited resources. Asontem and Hansadua flowered the earliest at closer spacing, though the effect was less pronounced compared to the mutant lines. The findings partially agree with studies such as Adewale *et al*. (2018) and Ahmed *et al*. (2018), which suggest that closer spacing can sometimes induce earlier flowering due to competition-induced stress. However, the effect in this study was minimal, indicating that while competition might influence flowering time, and the response can be variety-specific. The major rainy season led to earlier flowering across all varieties, likely due to the more favourable growing conditions, including consistent moisture and optimal temperatures, which promote faster development and earlier transition to flowering. The literature widely supports the notion that the major rainy season's optimal conditions promote quicker development, leading to earlier flowering (Kamara *et al*., 2018).

5.9 Effect of spacing on days to 50% maturity of cowpea plant

The days to 50% maturity is a critical parameter in agricultural research, particularly for determining the efficiency and adaptability of various crop lines under different environmental conditions. The findings align with previous research indicating that environmental factors, such as temperature and moisture availability, significantly influence crop maturation. For instance, studies have shown that favourable conditions in the major rainy season, characterized by adequate moisture and optimal temperatures, can enhance growth rates and hasten maturity (Adu-Gyamfi *et al*., 2018). The slower maturity observed in the minor rainy season may be attributed to less favourable conditions, including potential drought stress or suboptimal temperatures, which align with findings from Ravelombola *et al*. (2016) regarding cowpea's sensitivity to climatic variations.

Despite the lack of significant differences in maturity days across the spacing intervals, the cowpea lines exhibited varying maturity trends. For example, HansM9 (12)(5) and Asontem showed the highest days to maturity across all spacing combinations, while HansM9 (12)(3) typically matured earlier, particularly at the 60 x 20 cm spacing. This pattern suggests that genetic factors play a role in determining the maturity timing of cowpea lines, which is consistent with previous findings that emphasize the importance of genetic traits in crop maturation (Asafo-Adjei *et al*., 2005). Spacing interval did not influence days to maturity as they slightly varied across mutant lines.

5.10 Effect of spacing on the number of pods per cowpea plant

The significant effect of wider spacing on the number of pods per plant aligns with findings in the literature, which suggest that reduced competition for resources such as light, nutrients, and water at wider spacing allows plants to allocate more energy towards reproductive structures, including pod formation (Adewale *et al*., 2018; Ahmed *et al*., 2018). Wider spacing intervals, like 60 cm x 30 cm and 60 cm × 40 cm, typically provide each plant with more access to resources, facilitating the development of more pods. This finding is consistent with studies by Adegbite and Olakojo (2016) and Yusuf *et al*. (2019), which report that optimal spacing can enhance pod production by reducing intra-specific competition, allowing for better resource utilization and higher reproductive success.

The significant influence of seasons on pod production is well-supported by existing literature. Favourable environmental conditions during the major rainy season, such as higher rainfall and optimal temperatures, are critical for pod formation and development (Boukar *et al*., 2019). The higher number of pods observed in the major season likely reflects the better general growing conditions compared to the minor season, which may have experienced less consistent rainfall or lower temperatures, limiting pod development. The major season's favourable conditions likely provided sufficient moisture and temperatures conducive to flowering and pod setting, leading to a higher number of pods per plant. In contrast, the minor season's less favourable conditions could have caused stress, reducing the number of flowers that successfully developed into pods.

Studies (e.g., Adewale *et al*., 2018) have shown that different cowpea varieties can exhibit significant variability in pod production due to genetic differences. The uniformity observed in this study may suggest that the varieties were selected to minimize variability in pod production, ensuring stable yields across different growing conditions.

Asontem exhibited the highest number of pods per plant at wider spacing interval compared to closer spacing. Egbadzor *et al*. (2014) reported that Asontem performs well under varying densities, but optimal pod production is achieved at moderate to wide spacing. Similarly, Hansadua demonstrated increased pod numbers, benefiting from space for lateral growth. Asafo-Adjei *et al*. (2005) highlighted that Hansadua responds well to lower planting densities, maximizing yield through increased pod set. The performance of HansM9 (12)(25) agrees with Fatokun *et al*. (2012), who indicated that cowpea lines with twining tendencies benefit from wider spacing to fully express their growth and reproductive potential.

5.11 Effect of spacing on cowpea pod length

Seasonal variations had a no significant impact on pod length, although the major rainy season consistently resulted in slightly longer pods across all cowpea varieties and mutant lines.

HansM9 (12)(5) achieved the longest pod lengths at 60 cm × 20 cm across both seasons, indicating that this variety benefits significantly from reduced competition. Hansadua and Asontem also produced longer pods in the major season, reflecting their adaptability and vigorous growth habits. Singh *et al*. (2017) reinforced that optimal environmental conditions during critical growth stages, such as flowering and pod filling, lead to improved pod lengths in cowpea varieties.

While the study did not find significant differences among the cowpea varieties and mutant lines in terms of pod length, there were observable trends that highlight the influence of genetic traits on pod development. Both Asontem and Hansadua, with their indeterminate growth habits, generally produced longer pods across all spacing intervals, particularly when environmental conditions were favourable. These varieties are capable of continuous vegetative and reproductive growth, which allows for sustained pod development over time. The mutant lines, particularly HansM9 (12)(3) and HansM9 (12)(5), showed some variability in pod length depending on spacing and seasonal conditions. These lines are bred for specific traits like higher yield and disease resistance, but their determinate growth habit means they focus on maximizing pod length and seed development over a shorter period. HansM9 (12)(25), with its slightly twining growth habit, exhibited strong performance in terms of pod length, especially at wider spacing during the major season. This variety's genetic makeup allows it to exploit vertical and lateral space effectively, contributing to longer pod development even under moderate stress.

5.12 Effect of spacing on the number of cowpea seeds per pod

The study found that wider spacing (60 cm × 40 cm) generally supported a higher number of seeds per pod across most cowpea varieties. This finding is in line with studies by Adewale *et al*. (2018) and Ahmed *et al*. (2018), which report that reducing competition for light, water, and nutrients through wider spacing allows for more efficient resource allocation to reproductive growth, particularly seed development. HansM9 (12)(5) and HansM9 (12)(25) exhibited the highest seed counts per pod at wider spacing, agreeing with literature that suggests varieties with robust growth habits benefit significantly from reduced competition (Fatokun *et al*., 2012).

The major rainy season, characterized by higher rainfall, optimal temperatures, and longer daylight hours, resulted in a higher number of seeds per pod across all varieties. These favourable conditions support the full development of pods and seeds, leading to an increase in seed count.

5.13 Effect of spacing on the total cowpea seed weight per plot (g)

The major rainy season consistently resulted in higher total seed weights per plot across all varieties. This finding is strongly supported by literature, which emphasizes the importance of favourable environmental conditions, such as adequate rainfall and optimal temperatures, for maximizing seed yield (Singh *et al*., 2017). Contrary to what is often reported in the literature, the closest spacing of 60 cm × 20 cm led to the highest total seed weight per plot across all varieties, in both seasons. The HansM9 (12)(25) mutant line consistently performed best at the closest spacing (60 cm × 20 cm), regardless of the season, indicating that it is well-adapted to high-density planting and can efficiently use available resources even under competitive conditions. This suggests that in this study, the benefits of increased plant density outweighed the potential challenges of increased competition. The results diverge from many studies, such as those of Adewale *et al*. (2018) and Ahmed *et al*. (2018), who suggested that closer spacing can lead to reduced yields due to competition for resources. However, some studies. Singh *et al*., (2017) acknowledge that certain high-yielding or well-adapted varieties like HansM9 (12)(25) can perform better in closer spacing, especially if they have been bred for high-density planting conditions or if the environmental conditions are sufficiently supportive. Although uncommon, some research, such as that by Islam *et al*. (2014), has shown that under optimal environmental conditions and with varieties adapted to high-density planting, closer spacing can indeed lead to higher yields by maximizing the number of productive plants per unit area.

5.14 Effect of spacing on the total cowpea seed weight per plot in kg ha-1

The study showed that, the closest spacing of 60 cm × 20 cm resulted in the highest total seed weight per hectare across all cowpea varieties, indicating that higher plant density led to greater overall productivity. HansM9 (12)(25) achieved the highest total seed weight per hectare at this spacing, demonstrating its strong adaptability to dense planting conditions. The variety was able to efficiently utilize the available resources despite increased competition, resulting in higher yield per unit area. Asontem also performed well at this closest spacing, though its general yield was still lower than that of HansM9 (12)(25). These findings challenge conventional wisdom from studies such as Adewale *et al*. (2018) and Ahmed *et al*. (2018), which typically argue that closer spacing increases competition and reduces yield. However, this study's results align with findings of Islam *et al*. (2014), who reported that under optimal environmental conditions, certain high-yielding cowpea varieties can perform better under high-density planting by maximizing the number of productive plants per hectare. HansM9 (12)(25) has a slight twining tendency with a yield potential of about 5796 kgha^{-1}. Percentage protein content is about 23.75 (Lumor, 2022). The major rainy season produced the highest total seed weights per hectare across all varieties, with the 60 cm × 20 cm spacing being the most productive. The favourable conditions, such as consistent rainfall and optimal temperatures, allowed plants to achieve their maximum yield potential, especially under closer spacing. The results are consistent with studies such as those of Singh *et al*. (2017) and Kamara *et al*. (2018).

5.15 Effect of spacing on 100 cowpea seed weight per plot

The significant impact of seasons on 100-seed weight is consistent with findings in the literature, which emphasize the importance of environmental conditions during the growing season in determining seed size and weight. According to Singh *et al*. (2017) and Kamara *et al*. (2018), factors such as rainfall, temperature, and sunlight during the critical stages of pod filling and seed maturation can greatly influence the final seed weight. The major season, with more favourable growing conditions, likely supported better seed development, resulting in heavier seeds. The major season's likely higher and more consistent rainfall, combined with optimal temperatures, would have created ideal conditions for seed filling, leading to an increase in seed weight. The minor season might have experienced less favourable conditions, such as lower rainfall or suboptimal temperatures, which could have limited seed development and resulted in lighter seeds.

The lack of a significant effect of spacing intervals on 100-seed weight in the study contrasts with some studies that suggest closer spacing can lead to reduced seed size and weight due to increased competition for resources (Adewale *et al*., 2018). However, the uniformity in seed weight across different spacing might indicate that the cowpea lines used were bred to maintain consistent seed development, regardless of planting density. The stability of seed weight across different spacings could be due to the cowpea varieties' efficient resource utilization and genetic predisposition to prioritize seed development even under varying plant densities. This might reflect a breeding focus on ensuring high and consistent yield quality, regardless of spacing. The major rainy season's favourable conditions likely supported better seed filling and development, leading to heavier seeds. The minor season's potentially less favourable conditions might have limited the resources available for seed development, resulting in lighter seeds. However, HansM9 (12)(25) outperformed especially in the minor season.

The absence of significant varietal differences in 100-seed weight suggests that the cowpea lines used in the study have been selected for uniform seed development, likely to ensure consistent yield performance across different environments and planting densities. Some studies, often report significant differences in seed weight among cowpea varieties, reflecting genetic diversity in seed development. The near uniformity observed in the study may indicate that the varieties were bred to minimize variability in seed weight, which is crucial for maintaining consistent market quality and yield.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusions

- The study identified that closer spacing **(60 cm × 20 cm)** consistently optimized total seed weight per plot, suggesting that higher plant density is beneficial for maximizing yield across the cowpea lines, particularly for high-yielding mutant line **HansM9 (12)(25)**.
- For vegetative parameters such as branching and canopy size, wider spacing intervals **(60 cm × 40 cm)** were more effective, allowing plants to fully utilize available resources for vegetative growth. This indicates that closer spacing is preferable for yield-maximizing goals of the genotypes, while wider spacing benefits vegetative growth for high biomass yield.
- The **major season** consistently supported higher growth and yield across all cowpea lines, with **HansM9 (12)(25)** achieving the highest yields due to favourable conditions like adequate rainfall and optimal temperatures.
- Yields declined in the minor season due to less favorable conditions. However, **HansM9 (12)(25)** demonstrated resilience, maintaining relatively high performance compared to other mutant lines and the standard varieties used. This season-specific yield consistency highlights the mutant line's adaptability and potential for cultivation in varying seasonal conditions within the semi-deciduous agro-ecological zone.
- The study revealed that increased plant population density (closer spacing) was directly linked to higher yields for most cowpea lines, particularly in the high-yielding mutant lines and the standard varieties. The close spacing **(60 cm × 20 cm)** allowed for maximized grain production per hectare, suggesting that higher densities can enhance productivity in mutant lines when yield is prioritized.

- **HansM9 (12)(3)** and **HansM9 (12)(5)** exhibited better vegetative growth, including plant height and branching, at wider spacing intervals **(60 cm** × **40 cm),** where reduced competition allowed for enhanced development of these vegetative traits.
- Seasonal variations significantly influenced both growth and yield parameters. In the major season, favourable rainfall and temperature promoted higher growth, vegetative vigour, and yield potential across all the mutant lines and the standard varieties. This seasonal effect was most apparent in high-performing mutant line **HansM9 (12)(25),** which achieved the highest yields in the major season.
- In the minor season, growth and yield declined across all spacing intervals, though **HansM9 (12)(25)** and **HansM9 (12)(5)** maintained stable productivity compared to **HansM9 (12)(3),** showcasing their potential resilience and suitability for minor season planting. This adaptability to seasonal variations makes them viable options for all year-round production, with expected higher yields during the major season and moderate performance in the minor season.

6.2 Recommendation

From the study, the following recommendations can be made;

- When the primary objective is to maximize grain yield, the mutant line **HansM9 (12)(25)** is recommended. The most effective spacing for achieving maximum grain yield with this line is **60 cm** × **20 cm**.
- For agricultural practitioners focused on maximizing biomass yield, which includes general vegetative growth (stems, leaves, and pods), opt for **HansM9 (12)(5)** and **Asontem** and **use 60 cm** × **30 cm or 60 cm x 40 cm** spacing, also favoring the major season for planting, with measures to ensure consistent water supply during the minor season.

- The cost / benefit analysis of the mutant lines as against the improved varieties used in the study (Hansadua and Asontem) could be evaluated in future research.

REFERENCES

Abadassi, J. (2015). Cowpea (*Vigna unguiculata* (L.) Walp.) Agronomic traits needed in tropical zone. International Journal of Pure Applications, Bioscience, 3(4),158- 165 http://www.ijpab.com/ form/2015%20Volume%203, %20issue%204/IJPAB-2015-3-4-158-165.pdf.

Abaidoo, R. C., et al*et al*. (2016). Root growth, nodulation, and yield of cowpea as influenced by planting density and time of NPK application. Journal of Plant Nutrition, 39(10), 1482-1493.

Abara, G. et al*et al*. (2017). Response of Cowpea (*Vigna unguiculata* L. Walp) Genotypes to Different Plant Spacings in the Semi-Arid Savanna of Nigeria. International Journal of Agriculture and Biology, 19(5), 1001-1008.

Abdullahi, A. S., & Olufajo, O. O. (2016). Effect of Plant Spacing on the Growth and Yield of Cowpea (*Vigna unguiculata* L. Walp). Journal of Agriculture and Veterinary Science, 9(2), 11-17.

Abdullahi, M. et al*et al*. (2018). Effects of Intra-row Spacing on Growth and Yield of Cowpea (*Vigna unguiculata* L. Walp) Varieties in Semi-Arid Environment. Journal of Agricultural Science, 10(10), 1-9.

Abebe Belete Kuraz , Mulugeta Tesfaye Alemayehu, B (2022) The dietary use of pigeon pea for human and animal diets, the scientific world j 1–12, https://doi.org/10.1155/2022/4873008

Abebe, B. K., & Alemayehu, M. T. (2022). A review of the nutritional use of cowpea (*Vigna unguiculata* L. Walp) for human and animal diets. Journal of Agriculture and Food Research, 100383. A review of the nutritional use of cowpea (Vigna unguiculata L. Walp) for human and animal diets | Semantic Scholar.

Addo-Quaye, A. A., Darkwa, A. A., & Ampiah, M. K. P. (2011). Performance of three cowpea

(Vigna unguiculata (L) Walp) varieties in two agro-ecological zones of the Central Region of Ghana II: Grain yield and its components. ARPN Journal of agricultural and biological science, 6(2), 34-42.

Adebisa, M. A, and Ajala, M. O. (2017). Performance and stability of seed yield in rainfed sesame genotypes as influenced by plant population density. Tropical Agriculture, 83(2):47-53.

Adebiyi, J. A., et al*et al*. (2020). Economic importance and market trends of cowpea.

Adegbite, A. & Olakojo, S. (2016). Response of cowpea (Vigna unguiculata L. Walp) to plant population densities and intra-row spacing in two cropping seasons in Southwestern Nigeria. Notulae Scientia Biologicae, 8(4), 491-497.

Adegbite, K. A., & Yusuf, A. A. (2020). Influence of Plant Spacing on Growth and Yield of Cowpea (Vigna unguiculata L. Walp). Journal of Agricultural Sciences, 65(3), 245-254.

Adejumo, S. A., et al*et al*. (2018). Effects of plant population densities and intra-row spacings on growth and yield of cowpea in a semi-arid environment. Journal of Agricultural Science, 10(10), 65-73.

Adewale, B., Kehinde, O.B., Aremu, C.O., Popoola, J.O., & Dumet, D.J. (2018). Selection of cowpea genotypes based on grain mineral and total protein content. *Archives of Agronomy and Soil Science,* 64(11), 1533–1547. https://doi.org/10.1080/09064710.2018.1520290

Adeyemo, A. J., et al*et al*. (2021). Effects of plant spacing and planting interval on growth and yield of cowpea. International Journal of Agronomy, 2021, 6628431.

Adu-Gyamfi, J. J., et al*et al*. (2018). "Influence of Environmental Factors on Cowpea Yield and Quality." Journal of Agricultural Science.

Afutu, E., Agoyi, E.E., Amayo, R., Biruma, M., Rubaihayo, P.R. (2017a). Cowpea scab disease

(Sphaceloma sp.) in Uganda. Crop Protection. http://dx.doi.org/10.1016/j.cropro.2016.06.024.

Agbicodo, E. M., Fatokum, C. A., Muramaka, S., Visser, R. G. F. & Linden van der, C. G. (2009). Breeding drought tolerant cowpea: Constraints, accomplishments and future prospects. International Journal of Plant Breeding, 167(3), 353–370. https://link.springer.com/article/10.1007/s10681-009-9893-

Agyare, W. A., et al*et al*. (2018). Effects of plant spacing on growth and yield of cowpea (*Vigna unguiculata* (L.) Walp) at Kwame Nkrumah University of Science and Technology, Ghana. Journal of Experimental Agriculture International, 22(4), 1-10.

Ahmed, A. U., et al*et al*. (2018). Impact of Planting Density on Growth and Yield of Cowpea. Journal of Agriculture and Ecology Research International, 16(3), 1-9.

Ajeigbe, H. A., Eke-Okoro, O. N., & Akande, S. R. (2017). Growth and yield response of cowpea to varying rainfall patterns in the Nigerian savannahs. Journal of Agricultural Science, 9(2), 141-153

Akande SR, Olakojo S.A, Ajayi SA, Owolade O.F, Adetumbi JA, Adeniyan O.N, et al*et al*., (2019) Evaluation of Advanced Breeding Lines of Cowpea (Vigna unguiculata L. Walp) for High Seed Yield under Farmers' Field Conditions

Al-Hassan, R. M., & Diao, X. (2007). Regional disparities in Ghana: Policy options and public investment implications.

Aliero, B. L., Ouedraogo, O., Boukar, O., Kamara, A. Y., Bello, A., Houngnandan, P., ... & Carnide, V. (2018). Climate change adaptation strategies of cowpea farmers in North-West Nigeria. International Journal of Climate Change Strategies and Management, 10(2), 290-306. D https://doi 10.1108/IJCCSM-07-2017-0132

Alves Barros, J. R., Guimaraes, M. J. M., Simões, W. L., & Angelotti, F. (2023). Cowpea cultivation in Asia: A vital source of protein. Acta Scientiarum. Agronomy, 45(1), 56812. https://doi.org/10.4025/actasciagron.v45i1.56812

Amoatey, H. M. (1987). Genetic Studies in Some Cowpea (Vigna unguiculata (L) Walp.) Varieties in Ghana (Doctoral dissertation, University of Ghana

Anjorin, F.B., & Agboola (2017). Minerals and nutrients variability assessment in seeds and tubers of ten accessions of African yam bean (*Sphenostylis stenocarpa hoshst* ex a. rich). African Journal of Agriculture Technology and

Anonymous (2015). Catalogue of crop varieties released and registered in Ghana, 1: 10-13.

Antwi-Agyei, P., Wiafe, E. A., Amanor, K., & Codjoe, S. N. A. (2021). Determinants of choice of climate change adaptation practices by smallholder pineapple farmers in the semi-deciduous forest zone of Ghana. Indilinga: African Journal of Indigenous Knowledge Systems, 12(1), 100140. https://doi.org/10.1016/j.indic.2021.100140

Arabidopsis thaliana to Pseudomonas syringae infection. Frontiers in Plant Science, 7:808

Asafo-Adjei, B., et al*et al*. (2005). "Characterization of Cowpea Varieties for Performance in Varied Agro-ecological Conditions." African Journal of Agricultural Research.

Asafo-Adjei, B., et al*et al*., (2005) "Registration of 'Asontem' cowpea." Crop Science, vol. 45, no. 6, Nov.-Dec. 2005, p. 2649. Gale Academic OneFile, link.gale.com/apps/doc/A138996479/AONE?

Asafo-Adjei, B., Singh, B. B., & Atuahen-Amankwah, G. (2005). Registration of'Asontem'cowpea. Crop science, 45(6).

Asare, E., Asante, M. D., Boateng, S. K., & Mensah, J. K. (2016). Growth and yield response of cowpea (Vigna unguiculata) to planting date and variety in the forest-savanna transitional agro-ecological zone of Ghana. Agricultural and Biological Sciences Journal for Interchange (ABSJI), 2(2), 64-73. https://doi: 10.1002/jsfa.825

Asare-Nuamah, P., & Botchway, E. (2019). Understanding climate variability and change:

analysis of temperature and rainfall across agroecological zones in Ghana. Heliyon, 5(10), e02654. https://doi.org/10.1016/j.heliyon.2019.e02654

Audu, A., Gambo, F. M., Kingimi, M., & Wulgo, M. A. (2019). Bioactivity Of Essential Oils Of Selected Plants Against Callosobruchus maculatus (F.)(Coleoptera: Chrysomelidae) On Stored Cowpea Seeds (Vigna unguiculata L. Walp). Journal of Agriculture and Environment, 15(2), 103-115.

Badiane, F. A., Diouf, M., & Diouf, D. (2014). Cowpea. In Broadening the genetic base of grain legumes (pp. 95-114). New Delhi: Springer India.

Bado, B. V., et al*et al*. (2018). Intercropping cowpea with maize improves yield and economic performance.

Baffour-Asare, S. (2018). Environmental sustainability of smallholders' adaptation practices to weather variability and climate change in the forest-savannah transitional agro-ecological zone of Ghana (Master's thesis).

Barros, J. R. A., Guimaraes, M. J. M., Silva, R. M. E., Rêgo, M. T. C., de Melo, N. F., de Melo Chaves, A. R., & Angelotti, F. (2011). Selection of cowpea cultivars for high temperature tolerance: physiological, biochemical and yield aspects. Physiology and Molecular Biology of Plants, 27, 29-38. https://doi:10.1007/s12298-020-00919-7

Bawa, L. Y., Oparaeke, A. M. & Ainika, J. N. (2012). Cowpea (Vigna unguiculata) pest control methods in storage and recommended practices for efficiency: a review. Journal of Biology, Agriculture and Healthcare, 2(2), 27-33. https://www.cabdirect.org/cabdirect/abstract/20133057299.

Bello, A., Boukar, O., Kamara, A. Y., Aliero, B. L., & Codjoe, S. N. A. (2017). Selection of early maturing cowpea genotypes for adaptation to climate change in savanna agro-ecology of Nigeria. Agriculture & Food Security, 6(1), 1-11. https://doi: 10.1186/s40066-017-0101-8

Bennett-Lartey S. O. and Ofori I. (1999) Variability studies in some qualitative characters of cowpea(vigna unguiculata (L) walp) accession from four cowpea growing regions in Ghana. Ghana Agric Sci32:3…9

Boateng, S. K., Asante, M. D., Asare, E., & Mensah, J. K. (2012). Cowpea (Vigna unguiculata L. Walp) growth, yield and yield components as influenced by planting date and variety in the forest-savanna transitional agro-ecological zone of Ghana. Journal of Agricultural Science and Technology, 2(10), 1110-1121. https://do: 10.1016/j.indic.2021.100140.

Boukar, O, Fatokun, C. A., Huynh, B.-L., Roberts, P. A., and Close, T. J. (2016). Genomic Tools in Cowpea Breeding Programs: Status and Perspectives. Frontiers in Plant Science, 7, 757.

Boukar, O., Aliero, B. L., Kamara, A. Y., Houngnandan, P., & Carnide, V. (2013). Cowpea. In: Singh, B.B., Singh, S.R., & A. E. Hall (Eds.), Field Crop Manual. IITA.

Boukar, O., Belko, N., Chamarthi, S., Togola, A., Batieno, J., Owusu, E., Haruna, M., Diallo, S., Umar, M. L., Olufajo, O., et al*et al*. (2019). Cowpea (Vigna unguiculata): Genetics, genomics and breeding. Plant Breeding, 138(4):415–424.

Boukar, O., Fatokun, C., & Singh, B. B. (2014). Cowpea. In M. A. Pastor-Corrales & B. J. Porch (Eds.), Legumes in the Omic Era (pp. 227–247). Springer.

Boukar, O., Tamo, M., & Murdock, L. L. (2016). Cowpea (Vigna unguiculata): Genetics, genomics and breeding. *Plant Breeding Reviews*, 40, 315-356. https://doi.org/10.1111/pbr.12589

Boukar, O., Tamo, M., & Murdock, L. L. (2018). Cowpea (Vigna unguiculata): Genetics, genomics, and breeding. *Plant Breeding Reviews*, 40, 315-356. https://doi.org/10.1111/pbr.12589

Bukovsky-Reyes, M., Saleem, M., & Blanco-Canqui, H. (2019). Do cover crop mixtures improve soil physical health more than monocultures? *Plant and Soil*, 495, 99-112.

Carvalho AO, Machado OLT, Da Cunha M, Santos IS, Gomes VM (2001) Antimicrobial peptides and immunolocalization of a LTP in Vigna unguiculata seeds. Plant Physiology and Biochemistry 39: 137-146 Chen J, Mirocha CJ, Xie W, Hogge L, Olson D. (1992) Production of the mycotoxin fumonisin.

Chikoye D, Ellis-Jones J, Riches C, Kanyomeka L. (2021). Weed management in Africa: experiences, challenges and opportunities. XVI International Plant Protection Congress. p. 652–653. C

Costa, L. G., & Giordano, G. (2022). Developmental neurotoxicity of pyrethroid insecticides: critical review and future research needs. Environmental Health Perspectives, 115(1), 123-136. https://doi: 10.1289/ehp.9355

Coulibaly, S., Pasquet, R. S., Papa, R., Gepts, P. (2002). AFLP analysis of the phenetic organization and genetic diversity of Vigna unguiculata L. Walp. reveals extensive gene flow between wild and domesticated types. Theoretical and Applied Genetics, 104(2-3), 358-366.

Crops Research Institute (CRI). (1998). *Utilization of Cowpea Crop Residues to Reduce Fertilizer Nitrogen Requirements. Crop Science*, 38(3), 809-814. https://doi.org/10.2135/cropsci1998.0011183X003800030021x

Diallo, A., et al*et al*. (2020). Impact of planting date and plant density on cowpea productivity. Agronomy Journal, 112(4), 2839–2850.

Doku, E. V. (1970). Variability in local and exotic varieties of cowpea (Vigna unguiculata L. Walp.) in Ghana. Ghana Journal of Agricultural Science, 3, 139-43.

Dube, E., & Fanadzo, M. (2013). Maximising yield benefits from dual-purpose cowpea. Food Security, 5(6), 769–779. https://doi.org/10.1007/s12571-013-0307-3

Ebong, J. (1972). An analysis of yield components in cowpea (Vigna sinensis). Nig. J. Sci, 6, 185-189.

Egbadzor, K. F. (2014). Genetic Control and Breeding for Seed Size and Colour in Cowpea.

Egbadzor, K. F., Yeboah, M., Danquah, E. Y., Asante, I. K., Offei, S. K., & Ofori, K. (2013). Genetic control of seed coat color in cowpea (*Vigna unguiculata* L. Walp.): A case study of Ghanaian cowpea germplasm. *African Journal of Biotechnology*, 12(30), 4776–4784. https://doi.org/10.5897/AJB2013.12973

Eggleston, G., Blaine, A., & Jayaraman, K. S. (2012). Cowpea. In B. B. Singh, D. R. Mohan Raj, & L. E. N. Jackai (Eds.), Cowpea Research, Production, and Utilization (pp. 1–12). CABI.

Egho, E. O., & Enujeke E. C. (2012). Minimising insecticide application in the control of Insect Pests of Cowpea (Vigna Unguiculata (L) WALP) in Delta State, Nigeria, Sustainable Agriculture Research, 1 (1), 87-97. http://dx.doi.org/10.5539/sar.v1n1p87

Egwurube, J. (2017). Influence of plant spacing on growth and yield of cowpea (Vigna unguiculata L. Walp) varieties in Ebonyi State, Nigeria. International Journal of Agriculture Innovations and Research, 6(4), 769-773.

Ehlers, J. D., & Hall, A. E. (1997). Cowpea breeding for drought tolerance. Plant Breeding Reviews, 15, 215-274.

El Naim, A. M. & Jabereldar, A. A. (2010). Effect of plant density and cultivar on growth and yield of cowpea (Vigna unguiculata L.Walp). Australian Journal of Basic and Applied Sciences,4(8),3148-3153.

Environment, 8(1), 149-163.

Farias, R. de M., Woytke, M. R., & Petri, J. L. (2022). Chemical thinning of 'Sensação' peach trees in southern Brazil. *Acta Horticulturae*, 1343, 35-42. https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/1145428/1/Artigo-Chemical-thinning-of-Sensacao-peach-trees.pdf

Fatokun, C. A., Boukar, O., & Muranaka, S. (2018). Genetic diversity and population structure of a mini-core subset from the world cowpea (*Vigna unguiculata* [L.] Walp.) germplasm collection. *Scientific Reports*, 8(1), 16035. https://doi.org/10.1038/s41598-018-34555-9

Fatokun, C. A., Menancio-Hautea, D. I., Danesh, D., Young, N. D. (2012). Evidence for orthologous seed weight genes in cowpea and mung bean based on RFLP mapping. Genetics, 132(3), 841-846.

Fatokun, C. A., Tarawali, S. A., & Singh, B. B. (2012). Drought tolerance in cowpea: Genetic variation and breeding strategies. Journal of Food Legumes, 25(2), 131-144.

Fatokun, C.A., et al*et al*. (2020). "Cowpea Mutant Varieties and Their Potential in Enhancing Food and Nutritional Security in Sub-Saharan Africa." In R. Al-Khayri, et al*et al*. (Eds.), Advances in Plant Breeding Strategies: Legumes (pp. 255-287). Springer.

Fery, R. L. (2002). New opportunities in Vigna. Trends in new crops and new uses, 424-428.

Fery, R. L., Singh, B. B. (2013). Cowpea: The food legume of the 21st century. Crop Science, 53(3), 1041-1055.

Food and Agriculture Organization (FAO). (2019). The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns.

Food and Agriculture Organization (FAO). (2022). *FAOSTAT: Statistics database.* Retrieved from https://www.fao.org/statistics/en

Food and Agriculture Sector Development Policy (FASDEP) (2002).. Ministry of Food and Agriculture, Republic of Ghana.

Franzel, S., Kiptot, E., & Lukuyu, B. (2019). Developing sustainable farmer-to-farmer extension: experiences from the volunteer farmer–trainer approach in Kenya. *International Journal of Agricultural Sustainability*, 17(6), 401-412. https://doi.org/10.1080/14735903.2019.1679576

Gonçalves, A Goufo, P. Trindade, Rosa, H. Ferreira, L Dominguez-peris, R. *et alet al.*

Gwata, E. T., Shimels, H., & Motova, P. M. (2016). Potential of Improving Agronomic Attributes in Tropical Legumes Using Two Mutation Breeding Techniques in Southern Africa. In Alternative Crops and Cropping Systems (pp. 3–17). http://dx.doi.org/10.5772/62262

Haizel, K. A. (1972). The effects of plant density on lthe growth, development and grain yield of two varieties of cowpea, Vigna unguiculata (L) Walp. Ghana journal of agricultural science. ISSN : 0855-0042

Hall, A .E. (2012). Phenotyping cowpeas for adaptation to drought. Front Physiol. 3(1), 155. https://www.frontiersin.org/articles/10.3389/fphys.2012.00155/ful.

Hall, A. E. (2004). Breeding for adaptation to drought and heat in cowpea. *European Journal of Agronomy*, 21(4), 447-454.

Hall, A. E., Cisse, N., Thiaw, C., Elawad, M. A., & Ehlers, J. D. (2015). Breeding cowpea for drought tolerance: A review. Journal of Food Legumes, 28(1), 1-13.

Herniter, I. A., Muñoz-Amatriaín, M., Close, T. J., & Roberts, P. A. (2020). Genetic, textual, and archaeological evidence of the historical global spread of cowpea (Vigna unguiculata [L.] Walp.). Legume Science, 2(3), e57. https://doi.org/10.1002/leg3.57

Houngnandan, P., Kamara, A. Y., Boukar, O., Bello, A., & Lino-Neto, T. (2019). Assessing the impact of rainfall variability and management practices on cowpea yield: Evidence from northern Benin. Agricultural Water Management, 222, 51-59. https:// doi:: 10.1016/j.agwat.2019.05.008

Hutchinson, M. J., Muniu, F. K., Ambuko, J., Mwakangalu, M., Mwang'ombe, A. W., Okello, J. J., & Olubayo, F. (2016). Effect of cattle manure and calcium ammonium nitrogen on growth and leaf yield of local cowpea accessions in Coastal Kenya. International Journal of Plant & Soil Science 12(3), 1-12.

https://pdfs.semanticscholar.org/70e5/c9563054a4122e3d2e088c0dc839babb019 7.pd

Ibrahim, A. et al*et al*. (2020). Response of cowpea (Vigna unguiculata L. Walp) varieties to plant spacing in the Sudan Savanna of Nigeria. African Journal of Agricultural Research, 15(8), 1526-1533.

Ibrahim, S. K., et al*et al*. (2019). Influence of planting density on growth, yield, and yield components of cowpea (Vigna unguiculata (L.) Walp). International Journal of Plant Production, 13(2), 165–174.

IITA (International Institute of Tropical Agriculture). (2020.). Cowpea. Cowpea (iita.org)

Ilesanmi, J. O. & Gungula, D. T. (2010). Preservation of cowpea (Vigna unguiculata (L.) Walp) grains against cowpea bruchids (Callosobruchus maculatus) using neem and moringa seed oils. International Journal of Agronomy, 1(1), 8. https://www.hindawi.com/journals/ija/2010/235280/abs.

International Board for Plant Genetics Resources (IBPGR). Cowpea descriptors. Rome: IBPGR; 1983. Available from: http://www.bioversityinternational.org/ uploads/tx_news/Descriptors_for_cowpea_377.pd

Islam, M. T., Haque, M. A., & Akter, S. (2014). Assessment of genetic diversity in cowpea (*Vigna unguiculata* L. Walp.) germplasm. *Plant Genetic Resources: Characterization and Utilization*, 12(2), 170-177. https://doi.org/10.1017/S1479262114000222

J. Sci. Food Agric., 96 pp. 2941-2951

Jakusko, B. B., Anasunda, U. I., & Mustapha, A. B. (2013). Effect of inter-row spacing on some selected Cowpea (Vigna unguiculata (L). Walp) varieties in Yola, Adamawe State, Nigeria. Journal of Agriculture and Veterinary Science, 2(3), 30-35. http://www.iosrjournals.org/iosr-javs/papers/vol2- issue3/G0233035.pdf?id=1828.

Kamara, A., Tofa, A.I., Kyei-Boahen, S., Solomon, R., Ajeigbe, H.A. & Kamai, N. (2016). Effects of plant density on the performance of cowpea in Nigerian Savannas.

Experimental Agriculture, 1-13.

Kamara, A. Y., Boukar, O., Aliero, B. L., Houngnandan, P., & Codjoe, S. N. A. (2015). Management of cowpea production under drought: A review. Journal of Agriculture and Environment for International Development, 109(2), 287-311. https:// doi: 10.1002/jsfa.9074. Epub 2018 Jun 30. PMID: 29656381.

Kamara, A. Y., et al*et al*. (2017). Influence of Plant Spacing on the Yield and Yield Components of Cowpea (Vigna unguiculata L. Walp) Varieties in Northern Guinea Savanna of Nigeria. Journal of Experimental Agriculture International, 19(6), 1-9.

Kamara, A. Y., et al*et al*. (2018). Planting date and genotype effects on cowpea growth and yield components. Agronomy Journal, 110(4), 1345–1355.

Kamara, A. Y., Ewansiha, S. U., Boahen, S., and Tofa, A. I. (2014). Agronomic response of soybean varieties to plant population in the Guinea savannas of Nigeria. Agronomy Journal, 106(3):1051–1059.

Karanja, D. M., Ragwa, L., & M., M. (2008). Growing Cowpeas in Dry Areas. Kenya Agricultural Research Institute.

Karikari B., Arkorful E., & Addy S. (2015). Growth, Nodulation and Yield Response of Cowpea to Phosphorus Fertilizer Application in Ghana. Journal of Agronomy, 14(4), 234-240.

Karikari, B., Delle Maale, M., Anning, E., Akakpo, D. B., Abujaja, A. M., Addai, I. K., & Owusu, R. K. (2023). Cowpea cropping systems, traits preference and production constraints in the Upper West Region of Ghana: Farmers' consultation and implications for breeding. *CABI Agriculture and Bioscience, 4,* Article 17. https://doi.org/10.1186/s43170-023-00159-1

Kebede, E., & Bekoko, Z. (2020). Expounding the Production and Importance of Cowpea (Vigna unguiculata (L.) Walp.) in Ethiopia. *Cogent Food & Agriculture*, 6, Article ID:

1769805. https://doi.org/10.1080/23311932.2020.1769805

Khalid, A. M., & Elhardallou, S. B. (2016). Factors that compromise the nutritional value of cowpea flour and its protein isolates. *Food and Nutrition Sciences*, 7(12), 1202-1214. https://doi.org/10.4236/fns.2016.712118

Kim, D. K., Son, D. M., Choi, J. G., Shin, H. R., Choi, K. J., Lee, J., ... & Rim, Y. S. (2013). Agronomic characteristics and seed quality of cowpea (Vigna unguiculata L.) germplasm. Korean Journal of Crop Science, 58(1), 1-7. https://doi.org/10.1002/adma.201902743

Kimiti, J. M. (2011). Influence of integrated soil nutrient management on cowpea root growth in the semi-arid Eastern Kenya. African Journal of Agricultural Research, 6(13), 3084-3309. https://academicjournals.org/journal/AJAR/articlefull-text-pdf/5A7A2F23

Kimiti, J. M. (2011). Influence of integrated soil nutrient management on cowpea root growth in the semi-arid Eastern Kenya. African Journal of Agricultural Research, 6(13), 3084-3309. https://academicjournals.org/journal/AJAR/articlefull-text-pdf/5A7A2F236869

Kimiti, J. M., Odee, D. W., & Vanlauwe, B. (2009). Area under grain legume cultivation and problems faced by smallholder farmers in legume production in the semiarid Eastern Kenya. Journal of sustainable development in Africa, 11(4), 305- 315. http://www.jsdafrica.com/Jsda/V12NO2_Winter2009_B/Pdf/Area%20Under20Grain%20Legumes%20Cultivation.pd.

Kumar, S., & Pandita, M. (2016). Effect of integrated nutrient management on seed yield and quality in cowpea. *Legume Research*, 39(1), 80-85. https://doi.org/10.18805/lr.v0i0.4839

Kyei-Boahen, S., Savala, C. E. N., Chikoye, D., & Abaidoo, R. (2017). Growth and yield responses of cowpea to inoculation and phosphorus fertilization in different environments. *Frontiers in Plant Science*, 8, 646.

Lal, R., et alet *al*. (2020). Influence of Planting Density on the Growth and Yield of Cowpea (Vigna unguiculata L. Walp) Varieties in Nigeria. Journal of Plant Sciences, 8(2), 57-63.

Langyintuo, A. S., Lowenberg-DeBoer, J., Faye, M., Lambert, D., Ibro, G., Moussa, B., Kergna, A., Kushwaha, S., Musa, S., & Ntoukam, G. (2003). Cowpea supply and demand in West and Central Africa. Field Crops Research, 82(2–3), 215–231. https://doi.org/10.1016/S0378-4290(03)00039-X

Langyintuo, A. S., Ntoukam, G., Murdock, L., Lowenberg-DeBoer, J., & Miller, D. J. (2004). Consumer preferences for cowpea in Cameroon and Ghana. Agricultural Economics, 30(3), 203-213.

Leaky, C. L. A. and Wills, J. B. (1977). Food Crops of the Lowland Tropics. Great Britain: Oxford University Press lentil. Indian J. Genet. 64: 73-74.

Lemma, A., Worku, W., & Woldemichael, A. (2009). Moisture and planting density interactions affect productivity in Cowpea (Vigna unguiculata). Journal of Agronomy, 8(4), 117-123. https://www.cabdirect.org/cabdirect/abstract/2010317990

Li, X., et alet *al*. (2020). Effects of planting density on yield and quality of cowpea. Journal of Plant Nutrition, 43(9), 1346-1355.

Linguya, K. S. (2015). *Potential of Combining Host Plant Resistance and Intercropping In The Management of Root-Knot Nematodes And Insect Pests In The Indigenous Leafy Vegetables* (Doctoral Dissertation, Faculty Of Agriculture, University Of Nairobi).

Lo, S., et alet *al*. (2018). "High-Throughput Sequencing Reveals Genomic Variations in Response to Mutagenesis in a Cowpea Mutant Population." PLoS ONE, 13(7), e0199453.

Lumor, Prosper Deo Donne (2022) Mutagenesis of cowpea for high yield and resistance to some diseases. Ucc, Doctorial theisis.

Maiti, R. K., & Singh, V. P. (2016). Mechanisms of resistance to drought, temperature and salinity in bean crops-A review. Farming and Management, 1(2), 134-161. indianjournals.com/ijor.aspx?target=ijor:fam&volume=1&issue=2&article=004.

Masangwa, J. I. G. (2012). The effect of plant extracts on anthracnose of Phaseolus vulgaris L. and Vigna unguiculata (L.) Walp (Doctoral dissertation, University of Pretoria).

Mason, R. E., Mondal, S., Beecher, F. W., Pacheco, A., Jampala, B., Ibrahim, A., & Hays, D. B. (2015). QTL associated with heat susceptibility index in wheat (Triticum aestivum L.) under short-term reproductive stage heat stress. *Euphytica*, 203(1), 41-54.

Mba, C., et al*et al*. (2012). "Mutant Resources for Functional Genomics in Cowpea." Legume Perspectives, 1, 49-51.

Mbanya, A. (2011). Cowpea storage practices and factors that influence choice in Ghana. *International Journal of Agricultural Sustainability*, 5(3), 001-009. https://www.internationalscholarsjournals.com/articles/cowpea-storage-practices-and-factors-that-influence-choice-in-ghana.pdf

Mbeyagala E.k., Mukasa B.S.,Tukamuhabwa, P. & Bisikwa J. (2014). Evaluation of cowpea genotypes for virus resistance under natural conditions in Uganda. Journal of Agricultural Science, 6(10), 176-187. http://dx.doi.org/10.5539/jas.v6n10p176.

Mekonnen, T. W., Gerrano, A. S., Mbuma, N. W., & Labuschagne, M. T. (2022). Breeding of vegetable cowpea for nutrition and climate resilience in Sub-Saharan Africa: Progress, opportunities, and challenges. Plants (Basel, Switzerland), 11(12), 1583. https://doi.org/10.3390/plants11121583.

Ministry of Food and Agriculture (MoFA). (2024). *Crop production, food security, and extension services in Ghana's agro-ecological zones*. Ghana Ministry of Food and Agriculture.

MOFA (Ministry of Food and Agriculture) (2010). Medium-Term Agriculture Sector

Investment Plan (METASIP) document (2010). Ministry of Food and Agriculture, Accra, Ghana, September 2010.

MoFA; SRID. (2017). Agriculture in Ghana:Facts and Figures. In Agriculture in Ghana:Facts and Figures (Issue 911). https://doi.org/10.1126/science.35.911.927-a

Mohamed, B.S., Ishiyaku, M. F., Abdullahi., U.S., & Katung, M.D. (2014). Response of Bt cowpea lines and their hybrids under field conditions. Journal of plant breeding and crop science, 6(8), 91-96. http://www.academicjournals.org/journal/JPBCS/articlereferences/5F72FEE46830.

Mohammed, A. et al*et al*. (2020). Optimizing Intra-Row Spacing for Cowpea (Vigna unguiculata (L.) Walp.) Production in Northern Ghana. Journal of Experimental Agriculture International, 41(1), 14-22.

Moussa, M. S., et al*et al*. (2017). Effect of planting date on growth, yield and yield components of cowpea (Vigna unguiculata (L.) Walp). African Journal of Agricultural Research, 12(8), 605–611.

Muchero, W., Diop, N. N., Bhat, P. R., Fenton, R. D., Wanamaker, S., Pottorff, M., ... & Close, T. J. (2009). A consensus genetic map of cowpea [Vigna unguiculata (L) Walp.] and synteny based on EST-derived SNPs. Proceedings of the national academy of sciences, 106(43), 18159-18164.

Muchero, W., et al*et al*. (2013). "Genome Re-Sequencing Reveals Diverse Mutations and Evolutionary Potential in Cowpea." The Plant Genome, 6(3), 1-9.

Musa, S., et al*et al*. (2021). Effect of Plant Spacing on the Growth and Yield of Cowpea in the Sudan Savanna of Nigeria. Asian Journal of Soil Science and Plant Nutrition, 7(2), 1-9.

Navoroh, E. (2022). Effect of different planting distance on performance of two cultivars of cowpea (Vigna Unguiculata) (Doctoral dissertation, University of Education Winneba).

Ndema, N. E., Etame, J., Taffouo, V. D., & Bilong, P. (2010). Effects of some physical and chemical characteristics of soil on productivity and yield of cowpea (Vigna unguiculata L. Walp.) in coastal region (Cameroon). African Journal of Environmental Science and Technology, 4(3), 108-114. https://www.ajol.info/index.php/ajest/article/viewFile/56331/44772Ndema

Ndiaga, C. (2001). Genotype x row spacing and environment interaction of cowpea in semi-arid zones. *African Crop Science Journal*, 9(2), 27606. https://www.ajol.info/index.php/acsj/article/view/27606

Ndiso, J. B., Chemining'wa, G. N., Olubayo, F. M., & Saha, H. M. (2016). Effect of drought stress on canopy temperature, growth and yield performance of cowpea varieties. International Journal of plant and soil science, 9(3), 1-12 https://www.researchgate.net/profile/Hemedi_Saha/publication/283859029_Effect_of_Drought_Stress_on_Canopy_Temperature_Growth_and_Yield_Performance_of_Cowpea_Varieties/links/56a0d4f008aee4d26ad8b1f7.pd

Ngalamu, T., Guei, R., & Fatokun, C. (2014). *Cowpea Production Handbook*. International Institute of Tropical Agriculture (IITA).

Ntare, B. R., et al*et al*. (2017). Cowpea Production Guide. International Institute of Tropical Agriculture (IITA), 1-36.

Ofori, K., Amoah, A. A., & Gracen, V. E. (2015). Yield and yield components of cowpea as influenced by rainfall and sowing date in the Guinea savannas of Ghana. Journal of Agricultural Science, 7(2), 153-164.

Ofori, K., et al*et al*. (2017). Influence of planting intervals on cowpea yield and yield components in the forest-savanna transitional agro-ecological zone of Ghana. African Journal of Agricultural Research, 12(21), 1834-1841.

Ofori-Kyereh, B. E., Morton, J. F., & Chancellor, T. C. B. (2022). Constraints on farmers' adaptive capacity to climate variability and change. Climate and Development, 14(3),

Ogundele, D., Ojeniyi, S. O., Akinrinde, E. A., & Adediran, J. A. (2019). Effect of plant spacing on growth and yield of cowpea (Vigna unguiculata L. Walp) varieties in the Southern Guinea Savanna agroecology of Nigeria. Journal of Experimental Agriculture International, 28(5), 1–1.

Olaniyi, M. O., Akinyosoye, Eziashi, E. I., S. T., & Odebode, A. C. (2022). First report of *Colletotrichum cliviicola* causing anthracnose disease of cowpea (*Vigna unguiculata* L. Walp) in Nigeria. *Plant Disease*, 106(10), 2733. https://pubmed.ncbi.nlm.nih.gov/36541884/

Omoigui, L. O., et al*et al*. (2019). Influence of intra-row spacing on growth and yield of cowpea (Vigna unguiculata (L.) Walp) varieties in Sudan Savanna of Nigeria. African Journal of Agricultural Research, 14(9), 463-471.

Ouedraogo, O., Aliero, B. L., Boukar, O., Kamara, A. Y., & Codjoe, S. N. A. (2020). Determinants of cowpea yield variability and efficiency in Burkina Faso. Journal of Agriculture and Rural Development in the Tropics and Subtropics, 121(1), 77-88. https:// doi: 10.1002/jsfa.9074. Epub 2018 Jun 30. PMID: 29656381.

Owade, J. O., Abong', G., Okoth, M., & Mwang'ombe, A. W. (2019). A review of the contribution of cowpea leaves to food and nutrition security in East Africa. Food science & nutrition, 8(1), 36–47. https://doi.org/10.1002/fsn3.1337

Owusu, E. Y., Akromah, R., Denwar, N. N., AdjebengDanquah, J., Kusi, F., and Haruna, M. (2018). Inheritanceof Early Maturity in Some Cowpea (Vigna unguiculata (L.) Walp.) Genotypes under Rain Fed Conditions in NorthernGhana. Advances in Agriculture, 2018:1–10.

Oyewale, R. O., & Bamaiyi, L. J. (2013). Management of cowpea insect pests. Scholars Academic Journal of Biosciences, 1(5), 217-226.

https://staff.futminna.edu.ng/CRP/content/journal/PF1690/2.pd

Plant Breed. Biotech. 2019; 7:12-23

Pratap, A., & Kumar, J. (2011). History, origin and evolution. Biology and breeding of food legumes, 1-18.

Quaye, W., Adofo, K., Madode, Y., & Abdul-Razak, A. (2009). Exploratory and multidisciplinary survey of the cowpea network in the Tolon-Kumbungu district of Ghana: A food sovereignty perspective. African Journal of Agricultural Research, 4(4).

Rascovan, N., Carbonetto, B., Perrig, D., Díaz, M., Canciani, W., Abalo, M., Alloati, J., González-Anta, G., & Vazquez, M. P. (2016). Integrated analysis of root microbiomes of soybean and wheat from agricultural fields. *Scientific Reports*, 6, 28084. https://doi.org/10.1038/srep28084

Ravelombola, W. R., Sanders, P., & Fritschi, F. B. (2017). Evaluation and association analysis of cowpea salt tolerance. *Graduate Theses and Dissertations*. University of Arkansas. https://scholarworks.uark.edu/etd/1966

Ravelombola, W., et al*et al*. (2016). "Climate Adaptation and Cowpea Production: Assessing Genetic Diversity." International Journal of Plant Genetics.

Ravelombola, W.S., Shi, A., Weng, Y., Motes, D., Chen, P., Srivastava, V. and Wingfield, C. (2016) Evaluation of Total Seed Protein Content in Eleven Arkansas Cowpea (Vigna unguiculata (L.) Walp.). Lines American Journal of Plant Sciences, 7, 2288-2296.

Reed, R. M., Digrado, N. F., & Williamson, E. (2022). Cowpea leaf width correlates with above ground biomass across diverse environments. *Legume Science*, 4(1), e167. https://doi.org/10.1002/leg3.167

Sebetha, E. T., Ayodele, V. I., Kutu, F. R. & Mariga, I. K. (2010). Yields and protein content of two cowpea varieties grown under different production practices in Limpopo province, South Africa. African Journal of Biotechnology, 9(5), 628- 634.

https://www.ajol.info/index.php/ajb/article/download/78042/68435

Sheahan, C. M. (2012). Plant guide for cowpea (Vigna unguiculata). USDA-Natural Resources Conservation Service. Cape May Plant Materials Center. https://plants.usda.gov/plantguide/pdf/pg_viun.pd.

Simion, T. (2018). Adaptability performances of cowpea [Vigna unguiculata (L.) Walp] genotypes in Ethiopia. Food Science and Quality Management, 72, 43-47. Adaptability Performances of Cowpea [Vigna Unguiculata (L.) Walp] Genotypes in Ethiopia | Simion | Food Science and Quality Management (iiste.org)

Singh B. B., Ajeigbe H. A., Tarawali S. A., Fernandez-Rivera S., Abubakar M. (2003). Improving the production and utilization of cowpea as food and fodder. Field Crops Res. 84 169–177. 10.1016/S0378- 4290(03)00148-5.

Singh, A., & Singh, S. (2018). Influence of planting intervals on growth, yield, and quality of cowpea. Agricultural Science Research Journal, 8(6), 210-218.

Singh, B. B., Ehlers, J. D., & Sharma, B. (2011). Cowpea. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, & L. E. N. Jackai (Eds.), Advances in Cowpea Research (pp. 1–12). International Institute of Tropical Agriculture (IITA).

Singh, B. B., Ehlers, J. D., Sharma, B. (2017). Breeding cowpea for future climates. Critical Reviews in Plant Sciences, 36(2), 93-147.

Singh, B. B., Ehlers, J. D., Sharma, B., & Freire Filho, F. R. (2002). Recent progress in cowpea breeding. FATOKUN, CA; TARAWALI, SA; SINGH, BB; KORMAWA, PM, 22-40.

Singh, B. B., et al*et al*. (2018). Cowpea: The food legume of the 21st century. Crop Science, 58(2), 497–521.

Singh, B. B., Singh, V. P., & Singh, R. M. (2014). Drought tolerance in cowpea: Physiological and molecular mechanisms. Journal of Food Legumes, 27(1), 1-14.

Singh, B.B., et alet al. (2017). "Cowpea (Vigna unguiculata L. Walp) Breeding for Sustainable Production: Past, Present, and Future Prospects." Advances in Agronomy, 142, 89-155.

Singh, M., et alet al. (2017). Effect of plant spacing on growth, yield and economics of cowpea (Vigna unguiculata L. Walp). International Journal of Agriculture Sciences, 9(39), 3420-3422.

Singh, R. K., et alet al. (2019). Effect of Planting Space on Growth and Yield of Cowpea (Vigna unguiculata L. Walp). International Journal of Current Microbiology and Applied Sciences, 8(9), 2862-2870.

Singh, S. R., & Raghavendra, D. (2014). Cowpea Aphid, Aphis craccivora Koch: Biology, Ecology, and Management in a Global Context. Sustainable Management of Arthropod Pests of Tomato, 157-181. https://doi: 10.1007/978-81-322-1989-6_7.

Sokolnik, A. (2021). *Molecular Characterisation and Physiological Adaptations of Cowpea to Growth Temperature*. Master's thesis, Lancaster University. Available at: https://www.research.lancs.ac.uk/portal/en/publications/molecular-characterisation-and-physiological-adaptations-of-cowpea-to-growth-temperature%288c501a6b-88df-49f9-aaa0-2b6dc6c24512%29.html

Souza, P. C., Berto, S., & Biscaro, G. A. (2018). Cowpea. In M. M. Yamaguchi & H. J. Correa-Ferreira (Eds.), Cowpea: The Food Legume of the 21st Century (pp. 13–27). Springer

Stahl, A. B. (1985). Reinvestigation of Kintampo 6 rock shelter, Ghana: implications for the nature of culture change. African Archaeological Review, 3(1), 117-150.

Statista. (2022). Production volume of sesame seeds in Nigeria from 2010 to 2021. Nigeria: sesame seeds production volume | Statista

Steele, W. M. (1976). Cowpeas. In J. R. Smartt & N. W. Simmonds (Eds.), Evolution of crop plants (pp. 183–185). Longman.

Timko, M. P., & Singh, B. B. (2008). Cowpea, a Multifunctional Legume. In Genomics of

Tropical Crop Plants (pp. 227–258). Springer. https://doi.org/10.1007/978-0-387-71219-2_10.

Timko, M. P., Ehlers, J. D., & Roberts, P. A. (2007). Cowpea. In Pulses, sugar and tuber crops (pp. 49-67). Berlin, Heidelberg: Springer Berlin Heidelberg. Chicago

Timko, M. P., Ehlers, J. D., & Roberts, P. A. (2007). Cowpea. In: Kole, C. (Ed.), Genome Mapping and Molecular Breeding in Plants, Vol. 3, Pulses, Sugar and Tuber Crops. Springer, Berlin, pp. 1-13.

Tiroesele, B., Thomas, K., & Seketeme, S. (2015). Control of cowpea weevil, calloso bruchus Maculatus (F.) (Coleoptera: Bruchidae), using natural plant products. Insects, 6(1), 77-84. https://www.ncbi.nlm. nih.gov/pmc/articles /PMC4553528.

Tridge. (2024). Sesame exports as one of the main boosters of Nigerian foreign agricultural trade. Sesame exports as one of the main boosters of Nigerian foreign agricultural trade (tridge.com)

Turk, K. J., Hall, A. E., & Asbell, C. W. (1980). Drought adaptation of cowpea. I. Influence of drought on seed yield 1. Agronomy Journal, 72(3), 413-420.

Uguru, M. I. (2011). Evaluation of seventeen cowpea genotypes across years for grain yield, yield components, and yield stability in Nsukka, South-East Nigeria. *African Journal of Agricultural Research*, 6(22), 5145-5151. https://doi.org/10.5897/AJAR11.1351

Walker, T., McKenna, S., & Ecker, J. (2016) Assessing directions for cowpea R&D in USAID's Feed the Future program in Mozambique. *MEAS Evaluation Report*, 16. https://meas.illinois.edu/wp-content/uploads/2015/04/MEAS-EVAL-2016-Mozambique-Cowpea-RD-Walker-March-2016.pdf

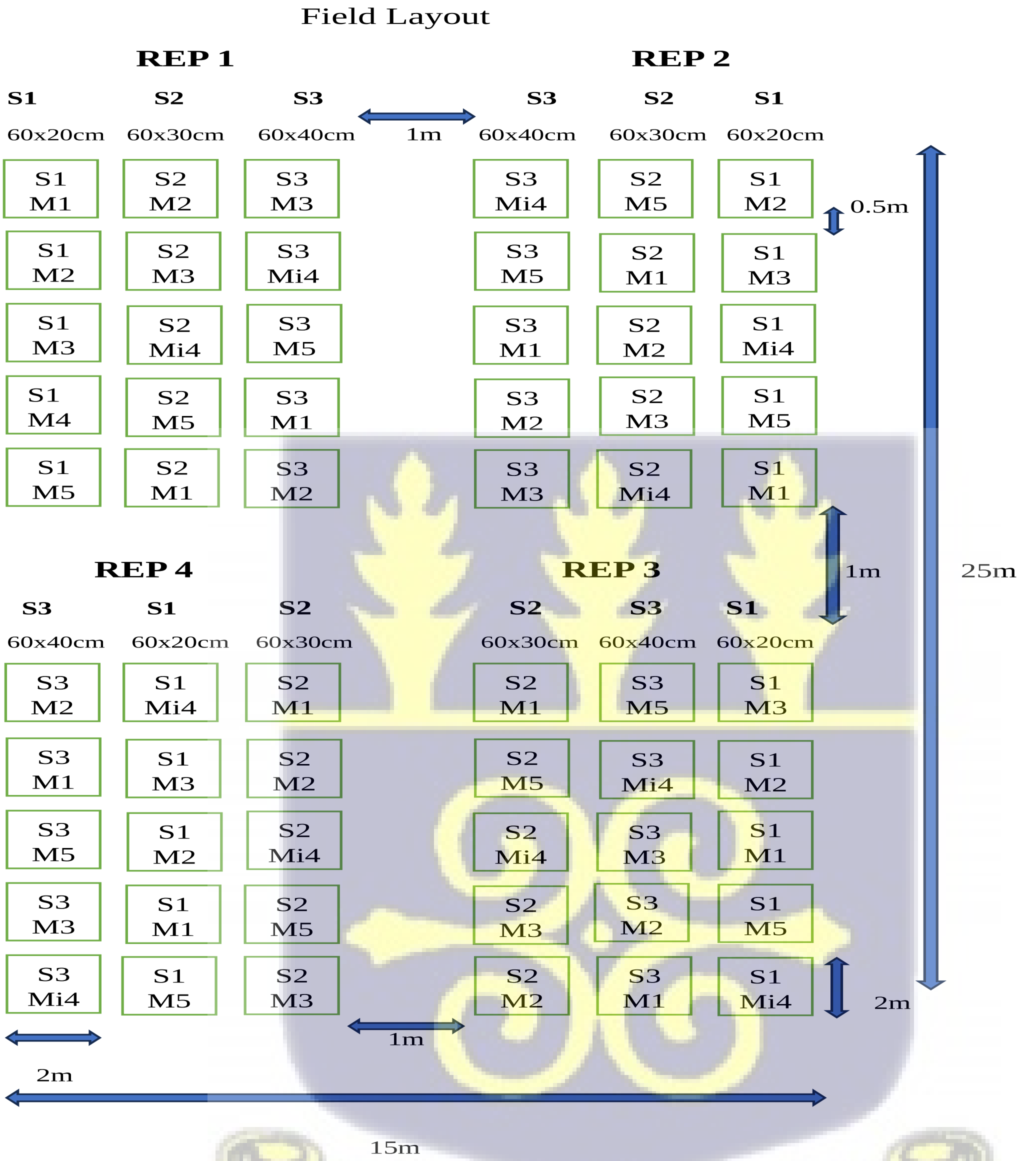
Wolfe, T. K., & Kipps, M. S. (1959). Production of Field Crop. McGraw-Hill Book Company.

Yirzagla, J., Atokple, I. D. K., Haruna, M., Kusi, F., & Muntari, A. (2016). Scaling out Cowpea Production in Northern Ghana , Community Seed Production Scheme Cowpea Out-scaling Project.

Yusuf, A. A., et al*et al*. (2019). Effect of planting interval on yield and yield components of cowpea (*Vigna unguiculata* (L.) Walp.) varieties in the Sudan Savanna of Nigeria. Nigerian Journal of Agriculture, Food and Environment, 15(2), 70-75.

APPENDICES

Appendix 1: Experimental field layout



APPENDIX 2

Results of soil analysis

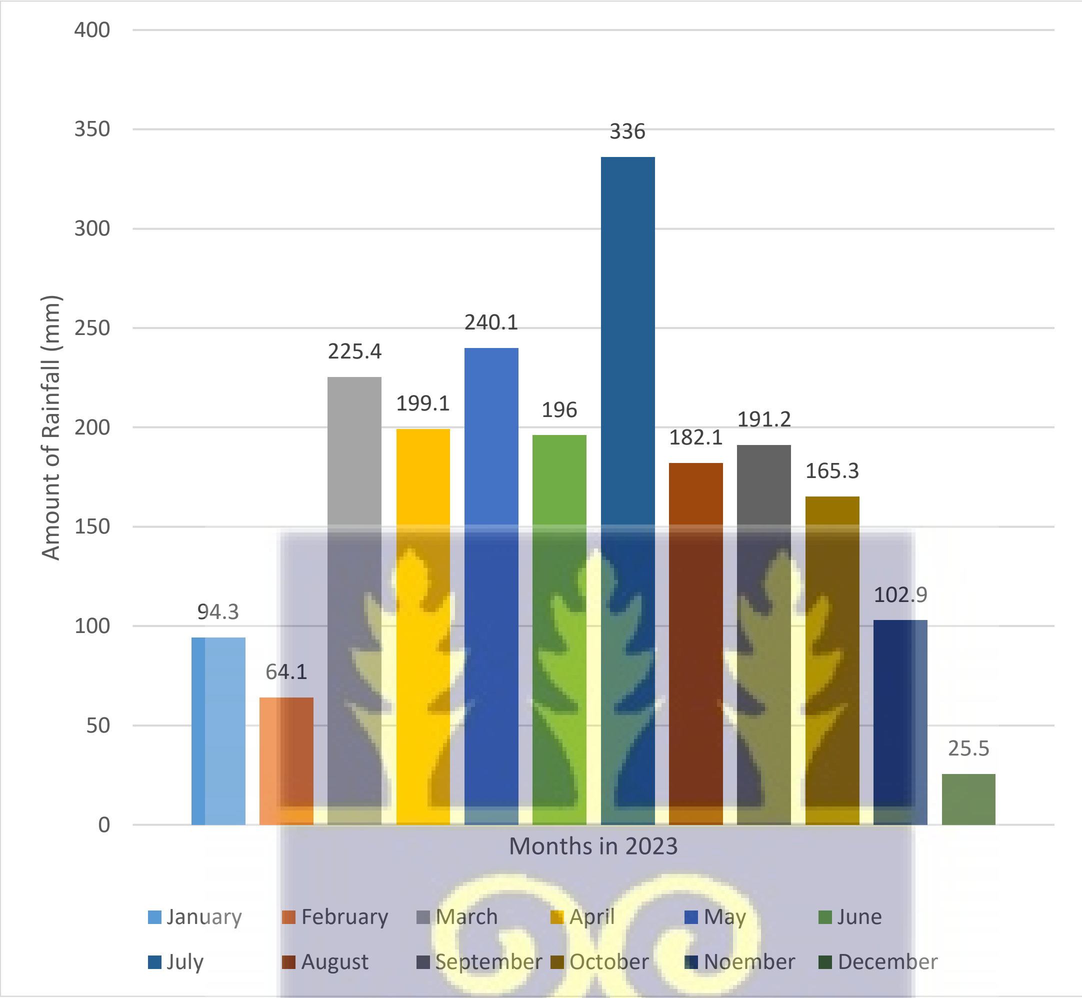
ID	pH water 1:1	E.C dm/m2	% N	% OC	Avail P mg/kg
1	5.39	0.156	0.18	1.92	1.395
2	5.42	0.199	0.18	2.31	1.555
3	6.70	0.394	0.17	2.17	0.716
4	6.70	0.209	0.17	2.10	0.992

Exchangeable bases Cmol/kg

ID	Ca	Mg	K	Na	CEC
1					
2	49.83	10.75	1.82	6.08	68.50
3					
4	50.0	11.2	0.44	1.31	63.0

APPENDIX 3

Rainfall pattern for the year 2023 / 2024



APPENDIX 4

Table 12:Analysis of variance (ANOVA) on Vegetative parameters

		Mean Squares								
Source of Variation	**df**	**Plant height**	**No of Leaves**	**No. of Branches**	**DTF%E**	**Days to 50% Flowering**	**Days to 50% Maturity**	**Mean Plant Girth**	**Mean Canopy size**	**Mean leaf area index**
Variety(V)	4	80.502	4587.750	1.492	0.279	114241.396	1.950	0.883 ***	142.596	119.928
Spacing (S.I)	2	338.014	7192.825	5.658 **	0.700	114176.608	28.575	6.534 ***	319.433	51.804
Seasons (S)	1	121437.856 ***	131605.63 ***	3.675	172.800 ***	105791.408	316.875 ***	1.801 ***	364.008	4750.20 ***
V * S.I	8	126.128	2867.919	0.335	0.242	114801.390	22.106	1.579 ***	361.152 **	137.506
V * S	4	119.509	2737.258	0.717	0.196	113498.804	8.083	0.019	44.946	33.891
S.I * S	2	460.598 **	1221.108	0.325	0.100	113592.998	11.875	0.038	102.633	1.903
V * S.I * S	8	42.647	1620.390	0.460	0.058	114053.258	22.865	0.047	338.102	349.634 **
Residual	90	131.544	1797.356	1.031	0.278	113592.998	17.692	.168	134.147	120.367

%=percent, ***=highly significant at P<.001, **= significant at <.01, NS= no significant at P>.05

APPENDIX 5

Table 13: Analysis of Variance (ANOVA) for Reproductive yield parameters

Analysis of Variance for Reproductive yield Parameters(Means Squares)

Source of variation	df	100 seeds weight per plot (g)	Total seed weight per plot (g)	Total seed weight per plot in kg ha-1	Mean No. of seeds per pod	Mean No. of Pods per plant	Mean pod length per plant
Variety	4	2.476	199000.992**	1535811.191**	3.417	96.117	0.730
Spacing	2	4.168	57386.008	402249.065	3.925	616.525***	3.483
Seasons	1	926.296***	915078.675***	6573762.352***	23.408***	464.133**	40.600
Variety * spacing	8	15.710	333301.592***	1928599.153***	4.029**	77.317	6.484
Variety * Seasons	4	11.454	3413.175	81651.899	3.283	32.550	0.972
spacing * Seasons	2	0.073	1184.725	40609.252	2.258	4.008	0.196
Variety * spacing * Seasons	8	34.979**	5296.287	35512.596	2.571	126.550	0.830
Residual	90	11.696	63122.297	446543.156	1.775	64.000	5.587

%=percent, ***=highly significant at P<.001, **= significant at <.01, NS= no significant at P>.05

APPENDIX 6

ANOVA TEST FOR MAJOR SEASON

Analysis of variance

Variate: %100_Seed_weight_per_plot_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	39.48	13.16	1.53	
Reps.spacing stratum					
spacing	2	5.24	2.62	0.30	0.748
Residual	6	51.73	8.62	0.44	
Reps.spacing.Variety stratum					
Variety	4	60.14	15.03	0.76	0.559
spacing.Variety	8	65.98	8.25	0.42	0.903
Residual	36	712.90	19.80		
Total	59	935.47			

Message: the following units have large residuals.

Reps 1 spacing 60x40cm Variety Asontem 9.54 s.e. 3.45

Tables of means

Variate: %100_Seed_weight_per_plot_g

Grand mean 27.62

spacing	60x20cm	60x30cm	60x40cm
	27.38	28.04	27.44

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	27.61	27.74	28.75	28.21

Variety	HansM9(12)(25)
	25.78

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		28.58	25.95	28.85	28.80
60x30cm		27.78	27.83	30.58	27.63
60x40cm		26.47	29.45	26.83	28.20

spacing	Variety	HansM9(12)(25)
60x20cm		24.73
60x30cm		26.38

60x40cm	26.25

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	2.272	3.684	5.984
d.f.	6	36	41.33
Except when comparing means with the same level(s) of spacing			6.382
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	27.38	a
60x40cm	27.44	a
60x30cm	28.04	a

Analysis of variance

Variate: Days_to_50%_Emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.4500	0.1500	0.53	
Reps.spacing stratum					
spacing	2	0.3000	0.1500	0.53	0.614
Residual	6	1.7000	0.2833	0.75	
Reps.spacing.Variety stratum					
Variety	4	0.9000	0.2250	0.60	0.668
spacing.Variety	8	0.7000	0.0875	0.23	0.982
Residual	36	13.6000	0.3778		
Total	59	17.6500			

Message: the following units have large residuals.

Reps 3 spacing 60x40cm	0.367	s.e.	0.168
Reps 3 spacing 60x40cm Variety Asontem	-1.200	s.e.	0.476
Reps 4 spacing 60x40cm Variety Hansadua	-1.050	s.e.	0.476

Tables of means

Variate: Days_to_50%_Emergence

Grand mean 2.850

spacing	60x20cm	60x30cm	60x40cm
	2.800	2.800	2.950

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	2.750	2.833	2.750	3.083

Variety	HansM9(12)(25)
	2.833

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		2.750	2.750	2.500	3.250
60x30cm		2.750	2.750	2.750	3.000
60x40cm		2.750	3.000	3.000	3.000

spacing	Variety	HansM9(12)(25)
60x20cm		2.750
60x30cm		2.750
60x40cm		3.000

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.4119	0.5089	0.8549
d.f.	6	36	41.92
Except when comparing means with the same level(s) of spacing			0.8814
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	2.800	a
60x30cm	2.800	a
60x40cm	2.950	a

Analysis of variance

Variate: Days_to_50%_Maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.800	0.600	0.77	
Reps.spacing stratum					
spacing	2	3.700	1.850	2.36	0.175
Residual	6	4.700	0.783	0.35	
Reps.spacing.Variety stratum					
Variety	4	13.733	3.433	1.53	0.215
spacing.Variety	8	14.467	1.808	0.80	0.603
Residual	36	81.000	2.250		
Total	59	119.400			

Message: the following units have large residuals.

Reps 1 spacing 60x30cm Variety HansM9 (12)(5)	-3.65	s.e.	1.16
Reps 4 spacing 60x20cm Variety Asontem	2.60	s.e.	1.16

Tables of means

Variate: Days_to_50%_Maturity

Grand mean 43.10

spacing	60x20cm	60x30cm	60x40cm
	42.75	43.30	43.25

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	43.75	42.58	42.92	43.58

Variety	HansM9(12)(25)
	42.67

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		42.75	41.50	43.25	43.75
60x30cm		44.75	42.75	42.75	43.75
60x40cm		43.75	43.50	42.75	43.25

spacing	Variety	HansM9(12)(25)
60x20cm		42.50
60x30cm		42.50
60x40cm		43.00

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.685	1.242	1.998
d.f.	6	36	40.69
Except when comparing means with the same level(s) of spacing			2.151
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	42.75	a
60x40cm	43.25	a
60x30cm	43.30	a

Analysis of variance

Variate: Mean_Days_to_50%_Flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2.983	0.994	0.30	
Reps.spacing stratum					
spacing	2	3.033	1.517	0.45	0.657
Residual	6	20.167	3.361	1.58	
Reps.spacing.Variety stratum					
Variety	4	10.400	2.600	1.22	0.319
spacing.Variety	8	7.800	0.975	0.46	0.877
Residual	36	76.600	2.128		
Total	59	120.983			

Message: the following units have large residuals.

Reps 1 spacing 60x30cm -1.20 s.e. 0.58

Tables of means

Variate: Mean_Days_to_50%_Flowering

Grand mean 35.98

spacing	60x20cm	60x30cm	60x40cm
	35.70	36.25	36.00

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	35.50	35.50	36.50	36.08

Variety	HansM9(12)(25)
	36.33

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		35.00	35.50	36.50	36.00
60x30cm		35.75	35.25	36.50	36.25
60x40cm		35.75	35.75	36.50	36.00

spacing	Variety	HansM9(12)(25)
60x20cm		35.50
60x30cm		37.50
60x40cm		36.00

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	1.419	1.208	2.209
d.f.	6	36	36.19
Except when comparing means with the same level(s) of spacing			2.092
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	35.70	a
60x40cm	36.00	a
60x30cm	36.25	a

Analysis of variance

Variate: Mean_No_leaves

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	332.4	110.8	0.16	
Reps.spacing stratum					
spacing	2	1105.3	552.6	0.79	0.496
Residual	6	4197.5	699.6	2.92	
Reps.spacing.Variety stratum					
Variety	4	600.8	150.2	0.63	0.647
spacing.Variety	8	5773.5	721.7	3.01	0.011
Residual	36	8637.3	239.9		
Total	59	20646.9			

Message: the following units have large residuals.

Reps 1 spacing 60x30cm Variety HansM9(12)(25)	27.5	s.e.	12.0
Reps 3 spacing 60x20cm Variety HansM9 (12)(5)	-35.3	s.e.	12.0

Tables of means

Variate: Mean_No_leaves

Grand mean 96.5

spacing	60x20cm	60x30cm	60x40cm
	97.8	90.7	100.9

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	98.1	97.5	100.9	92.2

Variety	HansM9(12)(25)
	93.5

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		103.0	90.2	90.2	104.8
60x30cm		82.0	95.2	108.2	94.2
60x40cm		109.3	107.0	104.2	77.8

spacing	Variety	HansM9(12)(25)
60x20cm		100.8
60x30cm		73.5
60x40cm		106.2

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	20.47	12.82	26.49
d.f.	6	36	25.69
Except when comparing means with the same level(s) of			
spacing			22.21
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	90.65	a
60x20cm	97.80	a
60x40cm	100.90	a

Analysis of variance

Variate: Mean_No_of_Seeds_per_Pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.867	0.289	0.31	
Reps.spacing stratum					
spacing	2	0.233	0.117	0.12	0.885
Residual	6	5.633	0.939	0.35	
Reps.spacing.Variety stratum					
Variety	4	5.067	1.267	0.47	0.756
spacing.Variety	8	14.433	1.804	0.67	0.712
Residual	36	96.500	2.681		
Total	59	122.733			

Message: the following units have large residuals.

Reps 2 spacing 60x40cm Variety Asontem	-3.55	s.e.	1.27
Reps 3 spacing 60x40cm Variety Hansadua	-3.00	s.e.	1.27

Tables of means

Variate: Mean_No_of_Seeds_per_Pod

Grand mean 13.57

spacing	60x20cm	60x30cm	60x40cm
	13.55	13.50	13.65

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	13.25	14.00	13.25	13.58

Variety	HansM9(12)(25)
	13.75

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		13.25	14.25	13.50	13.25
60x30cm		13.50	13.50	13.25	12.75
60x40cm		13.00	14.25	13.00	14.75

spacing	Variety	HansM9(12)(25)
60x20cm		13.50
60x30cm		14.50
60x40cm		13.25

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.750	1.356	2.181
d.f.	6	36	40.71
Except when comparing means with the same level(s) of spacing			2.348
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	13.50	a
60x20cm	13.55	a
60x40cm	13.65	a

Analysis of variance

Variate: Mean_No_of_pods_per_plt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	43.33	14.44	0.15	
Reps.spacing stratum					
spacing	2	536.43	268.22	2.81	0.138
Residual	6	572.77	95.46	1.25	
Reps.spacing.Variety stratum					
Variety	4	607.93	151.98	1.99	0.117
spacing.Variety	8	209.57	26.20	0.34	0.943
Residual	36	2746.90	76.30		
Total	59	4716.93			

Message: the following units have large residuals.

Reps 1 spacing 60x30cm Variety Asontem	17.6	s.e. 6.8
Reps 1 spacing 60x30cm Variety HansM9 (12)(5)	-14.9	s.e. 6.8

Tables of means

Variate: Mean_No_of_pods_per_plt

Grand mean 22.9

spacing	60x20cm	60x30cm	60x40cm
	18.7	24.7	25.2

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	26.4	20.6	18.1	26.0

Variety	HansM9(12)(25)
	23.2

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		20.3	16.2	16.2	21.8
60x30cm		29.8	21.7	16.2	31.2
60x40cm		29.2	23.8	21.8	25.0

spacing	Variety	HansM9(12)(25)
60x20cm		18.8
60x30cm		24.5
60x40cm		26.5

Least significant differences of means (5% level)

Table spacing Variety spacing

			Variety
rep.	20	12	4
l.s.d.	7.56	7.23	12.80
d.f.	6	36	39.09
Except when comparing means with the same level(s) of spacing			12.53
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	18.65	a
60x30cm	24.70	a
60x40cm	25.25	a

Analysis of variance

Variate: Mean_No_plt_Branches

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	6.6667	2.2222	1.18	
Reps.spacing stratum					
spacing	2	6.5333	3.2667	1.73	0.255
Residual	6	11.3333	1.8889	2.43	
Reps.spacing.Variety stratum					
Variety	4	5.7667	1.4417	1.85	0.140
spacing.Variety	8	2.6333	0.3292	0.42	0.899
Residual	36	28.0000	0.7778		
Total	59	60.9333			

Message: the following units have large residuals.

Reps 2 spacing 60x30cm Variety HansM9(12)(25) -1.55 s.e. 0.68

Tables of means

Variate: Mean_No_plt_Branches

Grand mean 3.87

spacing	60x20cm	60x30cm	60x40cm
	3.50	3.80	4.30

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	3.67	3.83	4.42	3.92

Variety	HansM9(12)(25)
	3.50

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		3.00	3.75	4.00	3.50
60x30cm		3.75	3.50	4.25	3.75
60x40cm		4.25	4.25	5.00	4.50

spacing	Variety	HansM9(12)(25)
60x20cm		3.25
60x30cm		3.75
60x40cm		3.50

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety

rep.	20	12	4
l.s.d.	1.063	0.730	1.446
d.f.	6	36	28.95
Except when comparing means with the same level(s) of			
spacing			1.265
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	3.500	a
60x30cm	3.800	a
60x40cm	4.300	a

Analysis of variance

Variate: Mean_Plant_Girth_at_maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.2893	0.0964	1.94	
Reps.spacing stratum					
spacing	2	7.5503	3.7752	76.10	<.001
Residual	6	0.2977	0.0496	0.20	
Reps.spacing.Variety stratum					
Variety	4	4.8523	1.2131	4.84	0.003
spacing.Variety	8	4.9447	0.6181	2.47	0.030
Residual	36	9.0230	0.2506		
Total	59	26.9573			

Message: the following units have large residuals.

Reps 4 spacing 60x40cm Variety HansM9 (12)(3)	-1.010	s.e.	0.388
Reps 4 spacing 60x40cm Variety HansM9(12)(25)	1.465	s.e.	0.388

Tables of means

Variate: Mean_Plant_Girth_at_maturity

Grand mean 1.273

spacing	60x20cm	60x30cm	60x40cm
	1.020	1.025	1.775

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	0.867	1.150	1.425	1.717

Variety	HansM9(12)(25)
	1.208

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		0.800	1.300	0.925	1.075
60x30cm		0.800	1.025	1.025	1.500
60x40cm		1.000	1.125	2.325	2.575

spacing	Variety	HansM9(12)(25)
60x20cm		1.000
60x30cm		0.775
60x40cm		1.850

Least significant differences of means (5% level)

Table	spacing	Variety	spacing

			Variety
rep.	20	12	4
l.s.d.	0.1723	0.4145	0.6561
d.f.	6	36	39.08
Except when comparing means with the same level(s) of spacing			0.7180
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	1.020	a
60x30cm	1.025	a
60x40cm	1.775	b

Analysis of variance

Variate: Mean_Plt_height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	17.415	5.805	0.21	
Reps.spacing stratum					
spacing	2	584.791	292.395	10.82	0.010
Residual	6	162.098	27.016	3.44	
Reps.spacing.Variety stratum					
Variety	4	38.091	9.523	1.21	0.322
spacing.Variety	8	48.424	6.053	0.77	0.630
Residual	36	282.569	7.849		
Total	59	1133.388			

Message: the following units have large residuals.

Reps 1 spacing 60x20cm Variety HansM9 (12)(3)	5.12	s.e.	2.17
Reps 2 spacing 60x20cm Variety HansM9 (12)(3)	-6.96	s.e.	2.17
Reps 4 spacing 60x30cm Variety HansM9 (12)(3)	5.21	s.e.	2.17

Tables of means

Variate: Mean_Plt_height

Grand mean 62.80

spacing	60x20cm	60x30cm	60x40cm
	66.68	59.03	62.70

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	61.82	62.04	63.55	63.84

Variety	HansM9(12)(25)
	62.77

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		65.95	65.15	68.67	65.77
60x30cm		58.02	58.40	58.72	61.48
60x40cm		61.50	62.57	63.25	64.28

spacing	Variety	HansM9(12)(25)
60x20cm		67.85
60x30cm		58.55
60x40cm		61.90

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	4.022	2.320	5.001
d.f.	6	36	22.90
Except when comparing means with the same level(s) of			
spacing			4.018
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	59.03	a
60x40cm	62.70	ab
60x20cm	66.68	b

Analysis of variance

Variate: Mean_canopy_Sizeatmaturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	97.93	32.64	0.17	
Reps.spacing stratum					
spacing	2	783.43	391.72	2.08	0.205
Residual	6	1127.77	187.96	2.15	
Reps.spacing.Variety stratum					
Variety	4	1072.43	268.11	3.06	0.029
spacing.Variety	8	337.07	42.13	0.48	0.861
Residual	36	3151.30	87.54		
Total	59	6569.93			

Message: the following units have large residuals.

Reps 3 spacing 60x30cm Variety HansM9(12)(25) 16.8 s.e. 7.2

Tables of means

Variate: Mean_canopy_Sizeatmaturity

Grand mean 78.6

spacing	60x20cm	60x30cm	60x40cm
	77.6	74.9	83.5

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	78.7	78.8	85.9	72.8

Variety	HansM9(12)(25)
	77.0

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		77.5	77.2	85.5	73.5
60x30cm		71.2	76.0	81.0	72.8
60x40cm		87.2	83.0	91.2	72.2

spacing	Variety	HansM9(12)(25)
60x20cm		74.0
60x30cm		73.2
60x40cm		83.8

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety

rep.	20	12	4
l.s.d.	10.61	7.75	14.96
d.f.	6	36	31.16
Except when comparing means with the same level(s) of spacing			13.42
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	74.85	a
60x20cm	77.55	a
60x40cm	83.50	a

Analysis of variance

Variate: Mean_leaf_area_index_per_pltatma

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	233.5	77.8	0.98	
Reps.spacing stratum					
spacing	2	73.2	36.6	0.46	0.652
Residual	6	477.4	79.6	0.46	
Reps.spacing.Variety stratum					
Variety	4	1852.3	463.1	2.66	0.048
spacing.Variety	8	688.9	86.1	0.49	0.852
Residual	36	6263.4	174.0		
Total	59	9588.6			

Message: the following units have large residuals.

Reps 4 spacing 60x40cm Variety HansM9(12)(25) 26.4 s.e. 10.2

Tables of means

Variate: Mean_leaf_area_index_per_pltatma

Grand mean 62.0

spacing	60x20cm	60x30cm	60x40cm
	61.0	61.4	63.5

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	70.2	57.9	56.7	58.0

Variety	HansM9(12)(25)
	67.0

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		67.7	61.0	53.3	53.6
60x30cm		73.7	50.0	57.7	62.2
60x40cm		69.2	62.6	58.9	58.3

spacing	Variety	HansM9(12)(25)
60x20cm		69.3
60x30cm		63.2
60x40cm		68.5

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety

rep.	20	12	4
l.s.d.	6.90	10.92	17.78
d.f.	6	36	41.45
Except when comparing means with the same level(s) of spacing			18.92
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	61.01	a
60x30cm	61.37	a
60x40cm	63.51	a

Analysis of variance

Variate: Mean_length_of_Pod_atmaturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	8.571	2.857	2.75	
Reps.spacing stratum					
spacing	2	4.300	2.150	2.07	0.207
Residual	6	6.228	1.038	0.22	
Reps.spacing.Variety stratum					
Variety	4	8.224	2.056	0.43	0.782
spacing.Variety	8	10.313	1.289	0.27	0.971
Residual	36	170.171	4.727		
Total	59	207.807			

Message: the following units have large residuals.

Reps 4 spacing 60x30cm	-0.65	s.e.	0.32
Reps 2 spacing 60x40cm Variety Asontem	-3.84	s.e.	1.68
Reps 4 spacing 60x30cm Variety HansM9 (12)(3)	-3.92	s.e.	1.68

Tables of means

Variate: Mean_length_of_Pod_atmaturity

Grand mean 18.66

spacing	60x20cm	60x30cm	60x40cm
	18.91	18.29	18.78

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	18.56	18.06	18.89	19.17

Variety	HansM9(12)(25)
	18.61

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		18.58	18.53	18.63	19.98
60x30cm		18.50	17.13	18.85	18.10
60x40cm		18.60	18.53	19.20	19.43

spacing	Variety	HansM9(12)(25)
60x20cm		18.83
60x30cm		18.85
60x40cm		18.15

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.788	1.800	2.856
d.f.	6	36	39.35
Except when comparing means with the same level(s) of spacing			3.118
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	18.29	a
60x40cm	18.78	a
60x20cm	18.91	a

Analysis of variance

Variate: Total_Seed_weight_per_plot_in_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.14862	0.04954	0.51	
Reps.spacing stratum					
spacing	2	0.07455	0.03728	0.38	0.697
Residual	6	0.58274	0.09712	1.23	
Reps.spacing.Variety stratum					
Variety	4	1.57748	0.39437	4.99	0.003
spacing.Variety	8	0.62069	0.07759	0.98	0.466
Residual	36	2.84532	0.07904		
Total	59	5.84941			

Message: the following units have large residuals.

Reps 1 spacing 60x20cm Variety HansM9(12)(25)	-0.533	s.e.	0.218
Reps 1 spacing 60x40cm Variety HansM9(12)(25)	-0.561	s.e.	0.218
Reps 4 spacing 60x20cm Variety HansM9(12)(25)	0.492	s.e.	0.218
Reps 4 spacing 60x40cm Variety HansM9(12)(25)	0.544	s.e.	0.218

Tables of means

Variate: Total_Seed_weight_per_plot_in_kg

Grand mean 0.742

spacing	60x20cm	60x30cm	60x40cm
	0.784	0.746	0.697

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	0.705	0.556	0.656	0.755

Variety	HansM9(12)(25)
	1.039

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		0.814	0.410	0.661	0.886
60x30cm		0.518	0.644	0.695	0.761
60x40cm		0.784	0.614	0.613	0.617

spacing	Variety	HansM9(12)(25)
60x20cm		1.147
60x30cm		1.109
60x40cm		0.860

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.2411	0.2328	0.4111
d.f.	6	36	39.28
Except when comparing means with the same level(s) of			
spacing			0.4032
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x40cm	0.6974	a
60x30cm	0.7455	a
60x20cm	0.7836	a

Analysis of variance

Variate: Total_seed_weight_per_plot_Kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1516537.	505512.	0.86	
Reps.spacing stratum					
spacing	2	623455.	311727.	0.53	0.612
Residual	6	3508802.	584800.	0.96	
Reps.spacing.Variety stratum					
Variety	4	9306066.	2326516.	3.81	0.011
spacing.Variety	8	4619909.	577489.	0.94	0.493
Residual	36	22007176.	611310.		
Total	59	41581945.			

Message: the following units have large residuals.

Reps 1 spacing 60x40cm	503.	s.e.	242.
Reps 1 spacing 60x40cm Variety HansM9(12)(25)	-1402.	s.e.	606.
Reps 3 spacing 60x30cm Variety HansM9 (12)(3)	1765.	s.e.	606.
Reps 4 spacing 60x40cm Variety HansM9(12)(25)	1360.	s.e.	606.

Tables of means

Variate: Total_seed_weight_per_plot_Kg_ha

Grand mean 1887.

spacing	60x20cm	60x30cm	60x40cm
	1959.	1960.	1743.

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	1762.	1390.	1791.	1896.

Variety	HansM9(12)(25)
	2597.

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		2034.	1026.	1652.	2214.
60x30cm		1295.	1611.	2188.	1930.
60x40cm		1958.	1535.	1532.	1542.

spacing	Variety	HansM9(12)(25)
60x20cm		2868.
60x30cm		2774.
60x40cm		2149.

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	591.7	647.4	1111.5
d.f.	6	36	41.15
Except when comparing means with the same level(s) of spacing			1121.3
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x40cm	1743	a
60x20cm	1959	a
60x30cm	1960	a

Analysis of variance

Variate: Total_seed_weight_per_plot_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	148271.	49424.	0.51	
Reps.spacing stratum					
spacing	2	75059.	37530.	0.39	0.695
Residual	6	581054.	96842.	1.22	
Reps.spacing.Variety stratum					
Variety	4	1577658.	394414.	4.99	0.003
spacing.Variety	8	620629.	77579.	0.98	0.466
Residual	36	2846403.	79067.		
Total	59	5849074.			

Message: the following units have large residuals.

Reps 1 spacing 60x20cm Variety HansM9(12)(25)	-534.	s.e. 218.
Reps 1 spacing 60x40cm Variety HansM9(12)(25)	-561.	s.e. 218.
Reps 4 spacing 60x20cm Variety HansM9(12)(25)	492.	s.e. 218.
Reps 4 spacing 60x40cm Variety HansM9(12)(25)	544.	s.e. 218.

Tables of means

Variate: Total_seed_weight_per_plot_g

Grand mean 742.

spacing	60x20cm	60x30cm	60x40cm
	784.	746.	697.

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	705.	556.	657.	755.

Variety	HansM9(12)(25)
	1039.

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		814.	410.	662.	886.
60x30cm		518.	644.	695.	761.
60x40cm		784.	614.	613.	617.

spacing	Variety	HansM9(12)(25)
60x20cm		1147.
60x30cm		1109.
60x40cm		860.

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	240.8	232.8	411.0
d.f.	6	36	39.31
Except when comparing means with the same level(s) of spacing			403.2
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x40cm	697.4	a
60x30cm	745.5	a
60x20cm	783.9	a

APPENDIX 7

ANOVA TEST FOR MINOR SEASON

Analysis of variance

Variate: %100_seeds_weight_per_plot_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	4.725	1.575	0.33	
Reps.spacing stratum					
spacing	2	3.236	1.618	0.33	0.728
Residual	6	29.029	4.838	0.81	
Reps.spacing.Variety stratum					
Variety	4	307.163	76.791	12.87	<.001
spacing.Variety	8	27.950	3.494	0.59	0.783
Residual	36	214.819	5.967		
Total	59	586.922			

Message: the following units have large residuals.

Reps 1 spacing 60x30cm Variety HansM9 (12)(5)	4.58	s.e.	1.89
Reps 3 spacing 60x40cm Variety Asontem	-4.22	s.e.	1.89
Reps 4 spacing 60x30cm Variety HansM9 (12)(5)	-4.30	s.e.	1.89
Reps 4 spacing 60x40cm Variety Hansadua	4.88	s.e.	1.89

Tables of means

Variate: %100_seeds_weight_per_plot_g

Grand mean 22.06

spacing	60x20cm	60x30cm	60x40cm
	21.90	22.39	21.89

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	20.07	20.37	20.95	22.73

Variety	HansM9(12)(25)
	26.19

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		19.77	20.62	20.27	22.35
60x30cm		21.17	19.25	22.05	23.75
60x40cm		19.25	21.22	20.52	22.10

spacing	Variety	HansM9(12)(25)

60x20cm	26.50
60x30cm	25.72
60x40cm	26.35

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	1.702	2.023	3.420
d.f.	6	36	41.78
Except when comparing means with the same level(s) of spacing			3.503
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x40cm	21.89	a
60x20cm	21.90	a
60x30cm	22.39	a

Analysis of variance

Variate: DTF%E

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2.5833	0.8611	5.34	
Reps.spacing stratum					
spacing	2	1.3000	0.6500	4.03	0.078
Residual	6	0.9667	0.1611	1.02	
Reps.spacing.Variety stratum					
Variety	4	0.8333	0.2083	1.32	0.283
spacing.Variety	8	1.8667	0.2333	1.47	0.201
Residual	36	5.7000	0.1583		
Total	59	13.2500			

Message: the following units have large residuals.

Reps 1 spacing 60x40cm Variety HansM9 (12)(3)	-0.750	s.e.	0.308
Reps 1 spacing 60x40cm Variety HansM9 (12)(5)	1.000	s.e.	0.308
Reps 4 spacing 60x40cm Variety HansM9 (12)(5)	-0.800	s.e.	0.308

Tables of means

Variate: DTF%E

Grand mean 5.250

spacing	60x20cm	60x30cm	60x40cm
	5.100	5.200	5.450

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	5.083	5.250	5.417	5.333

Variety	HansM9(12)(25)
	5.167

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		5.000	5.250	5.000	5.250
60x30cm		5.000	5.000	5.250	5.500
60x40cm		5.250	5.500	6.000	5.250

spacing	Variety	HansM9(12)(25)
60x20cm		5.000
60x30cm		5.250
60x40cm		5.250

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.3106	0.3295	0.5693
d.f.	6	36	40.80
Except when comparing means with the same level(s) of spacing			0.5706
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	5.100	a
60x30cm	5.200	a
60x40cm	5.450	a

Analysis of variance

Variate: Days_to_50%_Maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	112.98	37.66	1.70	
Reps.spacing stratum					
spacing	2	77.20	38.60	1.75	0.253
Residual	6	132.67	22.11	0.63	
Reps.spacing.Variety stratum					
Variety	4	149.57	37.39	1.07	0.386
spacing.Variety	8	222.13	27.77	0.79	0.611
Residual	36	1259.10	34.98		
Total	59	1953.65			

Message: the following units have large residuals.

Reps 3 spacing 60x20cm	-3.47	s.e. 1.49
Reps 2 spacing 60x20cm Variety HansM9 (12)(3)	13.00	s.e. 4.58
Reps 3 spacing 60x20cm Variety HansM9 (12)(3)	-24.00	s.e. 4.58

Tables of means

Variate: Days_to_50%_Maturity

Grand mean 46.35

spacing	60x20cm	60x30cm	60x40cm
	44.75	47.05	47.25

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	45.67	45.67	44.42	49.08

Variety	HansM9(12)(25)
	46.92

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		45.50	45.50	37.75	47.75
60x30cm		46.25	46.00	48.00	48.25
60x40cm		45.25	45.50	47.50	51.25

spacing	Variety	HansM9(12)(25)
60x20cm		47.25
60x30cm		46.75
60x40cm		46.75

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	3.638	4.897	8.123
d.f.	6	36	41.99
Except when comparing means with the same level(s) of			
spacing			8.481
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	44.75	a
60x30cm	47.05	a
60x40cm	47.25	a

Analysis of variance

Variate: Mean_Days_to_50%_Flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	5.733	1.911	1.31	
Reps.spacing stratum					
spacing	2	0.033	0.017	0.01	0.989
Residual	6	8.767	1.461	0.80	
Reps.spacing.Variety stratum					
Variety	4	97.567	24.392	13.41	<.001
spacing.Variety	8	0.133	0.017	0.01	1.000
Residual	36	65.500	1.819		
Total	59	177.733			

Message: the following units have large residuals.

Reps 4 spacing 60x40cm Variety Asontem 2.45 s.e. 1.04

Tables of means

Variate: Mean_Days_to_50%_Flowering

Grand mean 38.27

spacing	60x20cm	60x30cm	60x40cm
	38.25	38.25	38.30

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	36.25	37.50	39.25	38.50

Variety	HansM9(12)(25)
	39.83

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		36.25	37.50	39.25	38.50
60x30cm		36.25	37.50	39.25	38.50
60x40cm		36.25	37.50	39.25	38.50

spacing	Variety	HansM9(12)(25)
60x20cm		39.75
60x30cm		39.75
60x40cm		40.00

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety

rep.	20	12	4
l.s.d.	0.935	1.117	1.887
d.f.	6	36	41.80
Except when comparing means with the same level(s) of spacing			1.934
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	38.25	a
60x30cm	38.25	a
60x40cm	38.30	a

Analysis of variance

Variate: Mean_Canopy_size_per_pltatMaturi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1231.25	410.42	0.77	
Reps.spacing stratum					
spacing	2	60.70	30.35	0.06	0.945
Residual	6	3192.50	532.08	5.85	
Reps.spacing.Variety stratum					
Variety	4	4255.57	1063.89	11.70	<.001
spacing.Variety	8	679.13	84.89	0.93	0.501
Residual	36	3272.50	90.90		
Total	59	12691.65			

Message: the following units have large residuals.

Reps 4 spacing 60x30cm	-17.5	s.e.	7.3
Reps 1 spacing 60x20cm Variety HansM9 (12)(5)	-16.6	s.e.	7.4
Reps 1 spacing 60x40cm Variety HansM9 (12)(5)	-23.7	s.e.	7.4
Reps 2 spacing 60x30cm Variety Hansadua	-18.0	s.e.	7.4

Tables of means

Variate: Mean_Canopy_size_per_pltatMaturi

Grand mean 75.2

spacing	60x20cm	60x30cm	60x40cm
	75.0	74.0	76.5

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	59.8	75.0	80.4	76.0

Variety	HansM9(12)(25)
	84.6

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		63.0	71.8	77.2	74.8
60x30cm		58.8	72.2	80.2	80.5
60x40cm		57.5	81.0	83.8	72.8

spacing	Variety	HansM9(12)(25)
60x20cm		88.2
60x30cm		78.2
60x40cm		87.2

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	17.85	7.89	20.09
d.f.	6	36	15.77
Except when comparing means with the same level(s) of spacing			13.67
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	74.00	a
60x20cm	75.00	a
60x40cm	76.45	a

Analysis of variance

Variate: Mean_No_of_Branches_per_pltatMat

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	18.1833	6.0611	3.88	
Reps.spacing stratum					
spacing	2	5.4333	2.7167	1.74	0.253
Residual	6	9.3667	1.5611	2.93	
Reps.spacing.Variety stratum					
Variety	4	3.0667	0.7667	1.44	0.242
spacing.Variety	8	3.7333	0.4667	0.88	0.546
Residual	36	19.2000	0.5333		
Total	59	58.9833			

Message: the following units have large residuals.

Reps 4 spacing 60x30cm	-0.800	s.e.	0.395
Reps 1 spacing 60x30cm Variety Hansadua	1.250	s.e.	0.566
Reps 1 spacing 60x40cm Variety HansM9 (12)(5)	-1.750	s.e.	0.566

Tables of means

Variate: Mean_No_of_Branches_per_pltatMat

Grand mean 3.517

spacing	60x20cm	60x30cm	60x40cm
	3.100	3.650	3.800

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	3.167	3.667	3.750	3.333

Variety	HansM9(12)(25)
	3.667

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		3.000	3.000	3.250	2.500
60x30cm		3.250	4.000	3.750	3.750
60x40cm		3.250	4.000	4.250	3.750

spacing	Variety	HansM9(12)(25)
60x20cm		3.750
60x30cm		3.500
60x40cm		3.750

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.9668	0.6047	1.2503
d.f.	6	36	25.63
Except when comparing means with the same level(s) of spacing			1.0473
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	3.100	a
60x30cm	3.650	a
60x40cm	3.800	a

Analysis of variance

Variate: Mean_No_of_Pods_per_pltatMaturit

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1001.73	333.91	7.05	
Reps.spacing stratum					
spacing	2	704.63	352.32	7.44	0.024
Residual	6	284.17	47.36	1.53	
Reps.spacing.Variety stratum					
Variety	4	440.57	110.14	3.57	0.015
spacing.Variety	8	887.53	110.94	3.59	0.004
Residual	36	1111.10	30.86		
Total	59	4429.73			

Message: the following units have large residuals.

Reps 2 spacing 60x20cm Variety HansM9 (12)(3)	11.35	s.e.	4.30
Reps 3 spacing 60x30cm Variety HansM9 (12)(5)	-9.90	s.e.	4.30

Tables of means

Variate: Mean_No_of_Pods_per_pltatMaturit

Grand mean 18.93

spacing	60x20cm	60x30cm	60x40cm
	14.15	20.65	22.00

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	14.83	21.17	18.08	18.00

Variety	HansM9(12)(25)
	22.58

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		12.75	15.25	19.00	10.75
60x30cm		18.00	16.75	17.75	22.75
60x40cm		13.75	31.50	17.50	20.50

spacing	Variety	HansM9(12)(25)
60x20cm		13.00
60x30cm		28.00
60x40cm		26.75

Least significant differences of means (5% level)

Table	spacing	Variety	spacing

			Variety
rep.	20	12	4
l.s.d.	5.325	4.600	8.377
d.f.	6	36	36.60
Except when comparing means with the same level(s) of			
spacing			7.967
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	14.15	a
60x30cm	20.65	ab
60x40cm	22.00	b

Analysis of variance

Variate: Mean_No_of_seeds_per_podatMaturi

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	7.383	2.461	1.70	
Reps.spacing stratum					
spacing	2	12.133	6.067	4.20	0.072
Residual	6	8.667	1.444	1.28	
Reps.spacing.Variety stratum					
Variety	4	45.733	11.433	10.11	<.001
spacing.Variety	8	14.367	1.796	1.59	0.163
Residual	36	40.700	1.131		
Total	59	128.983			

Message: the following units have large residuals.

Reps 4 spacing 60x30cm	-0.80	s.e.	0.38
Reps 1 spacing 60x40cm Variety HansM9 (12)(5)	-2.20	s.e.	0.82
Reps 4 spacing 60x20cm Variety Asontem	1.85	s.e.	0.82
Reps 4 spacing 60x20cm Variety Hansadua	-1.90	s.e.	0.82

Tables of means

Variate: Mean_No_of_seeds_per_podatMaturi

Grand mean 12.68

spacing	60x20cm	60x30cm	60x40cm
	12.65	12.15	13.25

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	11.00	13.50	12.92	12.83

Variety	HansM9(12)(25)
	13.17

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		11.00	12.75	13.50	13.00
60x30cm		11.00	13.75	11.75	12.25
60x40cm		11.00	14.00	13.50	13.25

spacing	Variety	HansM9(12)(25)
60x20cm		13.00
60x30cm		12.00
60x40cm		14.50

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.930	0.880	1.563
d.f.	6	36	38.87
Except when comparing means with the same level(s) of spacing			1.525
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	12.15	a
60x20cm	12.65	a
60x40cm	13.25	a

Analysis of variance

Variate: Mean_Plant_Girth_at_maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.1818	0.0606	0.58	
Reps.spacing stratum					
spacing	2	5.5923	2.7962	26.90	0.001
Residual	6	0.6237	0.1039	0.80	
Reps.spacing.Variety stratum					
Variety	4	3.0810	0.7703	5.95	<.001
spacing.Variety	8	3.7410	0.4676	3.61	0.004
Residual	36	4.6620	0.1295		
Total	59	17.8818			

Message: the following units have large residuals.

Reps 4 spacing 60x40cm	0.242	s.e.	0.102
Reps 3 spacing 60x40cm Variety HansM9(12)(25)	-0.735	s.e.	0.279
Reps 4 spacing 60x40cm Variety HansM9(12)(25)	1.105	s.e.	0.279

Tables of means

Variate: Mean_Plant_Girth_at_maturity

Grand mean 1.028

spacing	60x20cm	60x30cm	60x40cm
	0.820	0.805	1.460

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	0.642	0.942	1.233	1.267

Variety	HansM9(12)(25)
	1.058

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		0.625	1.050	0.775	0.825
60x30cm		0.600	0.850	0.875	1.025
60x40cm		0.700	0.925	2.050	1.950

spacing	Variety	HansM9(12)(25)
60x20cm		0.825
60x30cm		0.675
60x40cm		1.675

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.2495	0.2980	0.5034
d.f.	6	36	41.80
Except when comparing means with the same level(s) of			
spacing			0.5161
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	0.805	a
60x20cm	0.820	a
60x40cm	1.460	b

Analysis of variance

Variate: Mean_leaf_area_index_per_pltatma

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2142.32	714.11	31.04	
Reps.spacing stratum					
spacing	2	34.23	17.12	0.74	0.514
Residual	6	138.03	23.01	0.52	
Reps.spacing.Variety stratum					
Variety	4	1382.43	345.61	7.88	<.001
spacing.Variety	8	588.77	73.60	1.68	0.138
Residual	36	1578.40	43.84		
Total	59	5864.18			

Message: the following units have large residuals.

Reps 3 spacing 60x20cm Variety HansM9 (12)(5)	11.55	s.e.	5.13
Reps 4 spacing 60x30cm Variety Asontem	-12.50	s.e.	5.13
Reps 4 spacing 60x30cm Variety HansM9 (12)(3)	15.50	s.e.	5.13

Tables of means

Variate: Mean_leaf_area_index_per_pltatma

Grand mean 49.38

spacing	60x20cm	60x30cm	60x40cm
	48.80	48.90	50.45

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	42.92	44.83	52.75	55.67

Variety	HansM9(12)(25)
	50.75

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		43.25	48.00	52.00	48.25
60x30cm		39.00	43.00	56.00	57.75
60x40cm		46.50	43.50	50.25	61.00

spacing	Variety	HansM9(12)(25)
60x20cm		52.50
60x30cm		48.75
60x40cm		51.00

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	3.711	5.482	8.990
d.f.	6	36	41.75
Except when comparing means with the same level(s) of spacing			9.496
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	48.80	a
60x30cm	48.90	a
60x40cm	50.45	a

Analysis of variance

Variate: Mean_no_of_leaves_perplts

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	14319.8	4773.3	4.62	
Reps.spacing stratum					
spacing	2	2005.7	1002.9	0.97	0.431
Residual	6	6193.9	1032.3	1.63	
Reps.spacing.Variety stratum					
Variety	4	8467.3	2116.8	3.35	0.020
spacing.Variety	8	8630.4	1078.8	1.71	0.131
Residual	36	22763.1	632.3		
Total	59	62380.2			

Message: the following units have large residuals.

Reps 4 spacing 60x30cm	-21.3	s.e.	10.2
Reps 2 spacing 60x30cm Variety HansM9 (12)(3)	62.8	s.e.	19.5
Reps 3 spacing 60x30cm Variety HansM9 (12)(3)	-44.0	s.e.	19.5

Tables of means

Variate: Mean_no_of_leaves_perplts

Grand mean 92.2

spacing	60x20cm	60x30cm	60x40cm
	85.6	91.5	99.7

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	73.2	88.8	109.7	92.2

Variety	HansM9(12)(25)
	97.3

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		65.3	86.0	102.0	92.0
60x30cm		64.2	88.8	93.2	113.2
60x40cm		90.0	91.5	133.8	71.2

spacing	Variety	HansM9(12)(25)
60x20cm		82.5
60x30cm		97.8
60x40cm		111.8

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	24.86	20.82	38.29
d.f.	6	36	35.70
Except when comparing means with the same level(s) of spacing			36.06
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x20cm	85.55	a
60x30cm	91.45	a
60x40cm	99.65	a

Analysis of variance

Variate: Mean_plt_height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	361.75	120.58	1.00	
Reps.spacing stratum					
spacing	2	124.50	62.25	0.52	0.620
Residual	6	720.37	120.06	3.97	
Reps.spacing.Variety stratum					
Variety	4	267.62	66.91	2.21	0.087
spacing.Variety	8	257.25	32.16	1.06	0.410
Residual	36	1089.58	30.27		
Total	59	2821.06			

Message: the following units have large residuals.

Reps 3 spacing 60x30cm	8.20	s.e. 3.46
Reps 1 spacing 60x20cm Variety HansM9 (12)(3)	15.73	s.e. 4.26
Reps 3 spacing 60x30cm Variety Hansadua	10.21	s.e. 4.26
Reps 3 spacing 60x30cm Variety HansM9 (12)(5)	-10.06	s.e. 4.26
Reps 3 spacing 60x30cm Variety HansM9(12)(25)	-9.96	s.e. 4.26

Tables of means

Variate: Mean_plt_height

Grand mean 24.02

spacing	60x20cm	60x30cm	60x40cm
	24.54	25.46	22.05

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	21.07	24.92	27.32	22.67

Variety	HansM9(12)(25)
	24.10

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		17.62	23.97	31.05	23.97
60x30cm		24.80	29.32	27.27	21.90
60x40cm		20.77	21.47	23.65	22.12

spacing	Variety	HansM9(12)(25)
60x20cm		26.07
60x30cm		24.00
60x40cm		22.22

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	8.478	4.555	10.221
d.f.	6	36	20.69
Except when comparing means with the same level(s) of			
spacing			7.890
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x40cm	22.05	a
60x20cm	24.54	a
60x30cm	25.46	a

Analysis of variance

Variate: Mean_pod_Length_per_pltatMaturit

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.161	0.387	0.21	
Reps.spacing stratum					
spacing	2	3.058	1.529	0.85	0.474
Residual	6	10.834	1.806	0.22	
Reps.spacing.Variety stratum					
Variety	4	36.397	9.099	1.10	0.370
spacing.Variety	8	10.387	1.298	0.16	0.995
Residual	36	296.840	8.246		
Total	59	358.677			

Message: the following units have large residuals.

Reps 1 spacing 60x20cm Variety HansM9(12)(25) -4.89 s.e. 2.22

Tables of means

Variate: Mean_pod_Length_per_pltatMaturit

Grand mean 17.49

spacing	60x20cm	60x30cm	60x40cm
	17.79	17.24	17.46

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	17.28	16.36	17.59	18.79

Variety	HansM9(12)(25)
	17.45

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		17.98	16.60	17.53	19.23
60x30cm		16.68	15.55	18.25	18.18
60x40cm		17.18	16.93	17.00	18.98

spacing	Variety	HansM9(12)(25)
60x20cm		17.60
60x30cm		17.53
60x40cm		17.23

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety

rep.	20	12	4
l.s.d.	1.040	2.378	3.772
d.f.	6	36	39.34
Except when comparing means with the same level(s) of			
spacing			4.118
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	17.24	a
60x40cm	17.46	a
60x20cm	17.79	a

Analysis of variance

Variate: Total_seed_weight_per_plot_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	84838.	28279.	0.49	
Reps.spacing stratum					
spacing	2	42082.	21041.	0.37	0.707
Residual	6	343262.	57210.	1.23	
Reps.spacing.Variety stratum					
Variety	4	943456.	235864.	5.06	0.002
spacing.Variety	8	376697.	47087.	1.01	0.445
Residual	36	1677180.	46588.		
Total	59	3467514.			

Message: the following units have large residuals.

Reps 1 spacing 60x20cm Variety HansM9(12)(25)	-410.	s.e.	167.
Reps 1 spacing 60x40cm Variety HansM9(12)(25)	-433.	s.e.	167.
Reps 4 spacing 60x20cm Variety HansM9(12)(25)	383.	s.e.	167.
Reps 4 spacing 60x40cm Variety HansM9(12)(25)	421.	s.e.	167.

Tables of means

Variate: Total_seed_weight_per_plot_g

Grand mean 568.

spacing	60x20cm	60x30cm	60x40cm
	599.	570.	534.

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	541.	422.	502.	576.

Variety	HansM9(12)(25)
	796.

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		624.	304.	507.	681.
60x30cm		397.	494.	532.	575.
60x40cm		601.	469.	467.	474.

spacing	Variety	HansM9(12)(25)
60x20cm		878.
60x30cm		852.
60x40cm		660.

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	185.1	178.7	315.6
d.f.	6	36	39.28
Except when comparing means with the same level(s) of			
spacing			309.5
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x40cm	534.1	a
60x30cm	569.9	a
60x20cm	598.9	a

Analysis of variance

Variate: Total_seed_weight_per_plant_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.004770	0.001590	1.34	
Reps.spacing stratum					
spacing	2	0.000601	0.000301	0.25	0.784
Residual	6	0.007119	0.001186	0.78	
Reps.spacing.Variety stratum					
Variety	4	0.010418	0.002605	1.72	0.167
spacing.Variety	8	0.010655	0.001332	0.88	0.543
Residual	36	0.054517	0.001514		
Total	59	0.088080			

Message: the following units have large residuals.

Reps 4 spacing 60x20cm	0.0259	s.e.	0.0109
Reps 4 spacing 60x20cm Variety HansM9(12)(25)	0.1767	s.e.	0.0301

Tables of means

Variate: Total_seed_weight_per_plant_kg

Grand mean 0.0256

spacing	60x20cm	60x30cm	60x40cm
	0.0289	0.0214	0.0267

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	0.0200	0.0159	0.0193	0.0213

Variety	HansM9(12)(25)
	0.0517

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		0.0155	0.0072	0.0125	0.0173
60x30cm		0.0143	0.0175	0.0217	0.0230
60x40cm		0.0302	0.0230	0.0235	0.0235

spacing	Variety	HansM9(12)(25)
60x20cm		0.0920
60x30cm		0.0302
60x40cm		0.0330

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	0.02665	0.03222	0.05432
d.f.	6	36	41.85
Except when comparing means with the same level(s) of			
spacing			0.05581
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x30cm	0.02135	a
60x40cm	0.02665	a
60x20cm	0.02890	a

Analysis of variance

Variate: Total_seed_weight_per_plot_in_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	531036.	177012.	0.50	
Reps.spacing stratum					
spacing	2	262262.	131131.	0.37	0.707
Residual	6	2143665.	357277.	1.23	
Reps.spacing.Variety stratum					
Variety	4	5901095.	1475274.	5.07	0.002
spacing.Variety	8	2355677.	294460.	1.01	0.445
Residual	36	10481668.	291157.		
Total	59	21675402.			

Message: the following units have large residuals.

Reps 1 spacing 60x20cm Variety HansM9(12)(25)	-1026.	s.e. 418.
Reps 1 spacing 60x40cm Variety HansM9(12)(25)	-1082.	s.e. 418.
Reps 4 spacing 60x20cm Variety HansM9(12)(25)	957.	s.e. 418.
Reps 4 spacing 60x40cm Variety HansM9(12)(25)	1052.	s.e. 418.

Tables of means

Variate: Total_seed_weight_per_plot_in_kg

Grand mean 1419.

spacing	60x20cm	60x30cm	60x40cm
	1497.	1425.	1335.

Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
	1352.	1055.	1255.	1441.

Variety	HansM9(12)(25)
	1991.

spacing	Variety	Asontem	Hansadua	HansM9 (12)(3)	HansM9 (12)(5)
60x20cm		1560.	759.	1267.	1703.
60x30cm		992.	1234.	1331.	1437.
60x40cm		1502.	1172.	1168.	1184.

spacing	Variety	HansM9(12)(25)
60x20cm		2195.
60x30cm		2130.
60x40cm		1649.

Least significant differences of means (5% level)

Table	spacing	Variety	spacing Variety
rep.	20	12	4
l.s.d.	462.5	446.8	788.9
d.f.	6	36	39.29
Except when comparing means with the same level(s) of			
spacing			773.8
d.f.			36

Tukey's 95% confidence intervals

spacing

	Mean	
60x40cm	1335	a
60x30cm	1425	a
60x20cm	1497	a