AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND
ENTREPRENEURIAL DEVELOPMENT

FACULTY OF AGRICULTURE EDUCATION

EFFECT OF PLANT SPACING ON GROWTH AND YIELD PERFORMANCE OF TWO NEWLY RELEASED VARIETIES (ADOYE AND ENNEPA) OF COMMON BEANS (*Phaseolus vulgaris)*

ELIZABETH AJAO

2025

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A THESIS IN THE DEPARTMENT OF CROP AND SOIL EDUCATION, FACULTY OF AGRICULTURE EDUCATION, SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF MASTER OF PHILOSOPHY IN CROP SCIENCE (AGRONOMY)

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DECLARATION

Candidate's Declaration

I hereby declare that, except for references to other people's work, which have been cited and duly acknowledged, this research is the result of my own original work and that no part or whole of it has been presented for another degree in this university or elsewhere.

Elizabeth Ajao

Signature……………………………… Date……………………….………

Supervisors' Declaration

We hereby declare that the preparation and presentation of this dissertation were supervised in accordance with guidelines on supervision of thesis laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

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DEDICATION

I dedicate this thesis to my mother, Mad. Agnes Boateng and my Father Apostle Reuben Ajao (Late).

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LIST OF ABBREVIATIONS/ACRONYMS

ANOVA	Analysis of Variance
BCMV	Bean Common Mosaic Disease
CM	Centimeters
CSIR-CRI	Council for Scientific And Industrial Research- Crops Research
CV	Coefficient of Variation
DAP	Days After Transplanting
G	Grams
HSD	Honestly Significant Difference
IPM	Integrated Pest Management
KG	Kilograms
LAI	Leaf Area Index
NS	Not Significance
PAR	Photosynthetic Active Radiation
RGR	Crop Growth Rate
RGR	Relative Growth Rate
VCU	Value for Cultivation And Use

ABSTRACT

Two field trials were conducted at two different sites at the Multipurpose Crop Nursery field of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Asante Mampong from March to July and August to December 2023 in the major and minor cropping seasons, respectively to assess the growth and yield performance of two newly released common beans varieties to different plant spacings. A 2 x 4 factorial experiment arranged in a Randomized Complete Block Design with eight treatments and each replicated four times was used for the study. The treatments were two common bean varieties [(i) Adoye and (ii) Ennepa] and four Plant Spacing [(i) 60 cm x 20 cm; (ii) 50 cm x 20 cm; (iii) 40 cm x 20 cm and (iv) 30 cm x 20 cm]. The results showed that Ennepa flowered and podded earlier than Adoye across both seasons, with variety × spacing interaction significantly influencing days to 50% podding. Adoye had greater plant height and stem diameter during the major season, while Ennepa had superior branch number, leaf count, and biomass accumulation, particularly under wider spacings (60 cm × 20 cm) in both cropping seasons. 50–60 cm × 20 cm significantly enhanced growth parameters across both seasons than 30 cm – 40 cm x 20 cm. Ennepa grown at 50 cm × 20 cm and 30 cm × 20 cm produced greater pod number, pod weight and longer pod length and grain yield than Adoye in the minor season. Grain yield ranged from 1.05 -2.47 t/ha and 1.20-1.58 t/ha for the major and minor season, respectively. On the average across both seasons the 30 x 20 cm produced the highest grain yield, while the 60 x 20 cm had the lowest grain yield. Ennepa also produced higher grain yields than Adoye in both seasons. It is recommended that Ennepa and Adoye should be planted at a spacing of 50 cm × 20 cm or 30 cm × 20 cm for higher yield, while wider spacings of 50–60 cm × 20 cm are ideal for maximizing vegetative growth.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Common bean (Phaseolus vulgaris L.) is a significant cereal legume that is a member of the Fabaceae family. It is the primary legume crop, accounting for 85% of global bean production (Machiani et al., 2019; Masa et al., 2017). Currently, the crop is cultivated on all continents except Antarctica and is extensively distributed worldwide, occupying over 90% of the production areas that are planted to Phaseolus species (Shamseldin & Velázquez, 2020). Diverse morphological, agronomic, and adaptability characteristics are demonstrated by numerous Phaseolus varieties (Loko et al., 2018). The crop is a warm-season, herbaceous annual that is highly polymorphic. It has two growth habits: erect herbaceous shrubs (determinate) that can reach a height of 20 to 60 cm and twining, ascending vines (indeterminate) that can reach a length of 2 to 5 m (Ecocrop, 2013).

According to FAOSTAT (2018), common beans are cultivated on 29 million hectares worldwide, resulting in an annual global yield of over 27 million tons. This yield is sufficient to feed over 300 million individuals who are linked to agricultural economies worldwide. Arega (2019) notes that it is one of the most significant legume commodities that are cultivated on all continents, with a total production exceeding 27 million metric tons (MT). Of this total, 7 million MT were produced in Latin America and Africa. It is estimated that the common bean provides over 50% of the dietary protein needs of households in Sub-Saharan Africa (Shumi et al., 2018). Among low-income individuals who are unable to purchase nutritious food items, such as proteins and fish, the annual per capita consumption of common bean is higher (Beebe et al., 2013; Singh et al., 2020). The average annual consumption of common beans in Latin America is 10–18 kg per person, while in East Africa, it can reach as high as 50 kg per person (Celmeli et al., 2018).

For its palatable seeds and stalks, the common bean is a significant grain legume that is consumed globally. The plant is cultivated for its green leaves, green clusters, and embryonic and/or desiccated seeds (Musana et al., 2020). Approximately 57% of the recommended dietary protein and 23% of energy consumption are provided by common legumes, which are important for the nutritional well-being of African populations (Nchanji & Ageyo, 2021). The potential to reduce the risk of a variety of diseases, such as cancer, diabetes, and coronary heart disease, has led health organizations to actively promote the regular consumption of common legumes and other pulses (McDermott & Wyatt, 2017). Beans are a key component of the diet in numerous developing countries, as they are a rich source of fiber, vitamins, and minerals (Tumsa et al., 2014). According to Grela et al. (2017), it is an exceptional source of sodium, potassium, selenium, molybdenum, thiamine, vitamin B6, and folic acid, and is also high in carbohydrate and dietary fiber. Throughout Africa, common legumes are essential for maintaining nutritional food security. Yeboah et al. (2021) have demonstrated that these legumes are not only a valuable source of protein, calories, vitamins, and minerals, but they also have the potential to provide improved nutritional benefits through biofortification. As it has the capacity to sequester nitrogen, it is crucial in agricultural systems, as it can improve soil fertility. (Alemu et al., 2018) It serves as an alternative source of income for smallholder producers.

Furthermore, the rapid growth and early maturation of common legumes render them an appropriate option for climate-smart agriculture. In addition, their extensive temperature tolerance renders them a promising alternative for future agri-food systems in the context of climate change (Yeboah et al., 2021). Depending on the varieties, common beans are cultivated in the majority of agro-ecological zones in Ghana. Most farmers in the country highly prefer its production due to its rapid maturation characteristics, which allow households to obtain the currency necessary for the purchase of food and other household necessities when other crops have not yet reached maturity (Tumsa et al., 2014). Masa et al. (2017) assert that bean is a critical element in the intensification of production in small-scale agricultural systems due to its rapid maturation and ability to be cultivated under a variety of cropping systems for a variety of purposes.

1.2 Problem Statement and Justification

Common beans (*Phaseolus vulgaris* L.) are important crops globally, Particularly in developing countries, where they satisfy over 50% of the dietary protein needs of households in Sub-Saharan Africa (Shumi et al., 2018). Despite the increasing interest in bean production in Ghana, the actual yield attained by farmers is 0.8 tons per hectare, which is significantly lower than the potential yield of 2 tons per hectare (Karavidas et al., 2022). Regrettably, this circumstance has persisted without any improvement. The primary causes of the low yield are biotic and abiotic factors, including the prevalence of pests and diseases, drought, low soil fertility, poor cultural practices (e.g., untimely and inappropriate field operations), inappropriate plant density, and weed infestation (Liliane & Charles, 2020). Sustainable bean production necessitates the creation of novel varieties that exhibit enhanced characteristics, including disease resistance, high yield potential, and tolerance to abiotic stress (Karkanis et al., 2018).

The release of new common bean varieties with enhanced traits has been the result of recent plant breeding efforts. Nevertheless, the optimal cultivation practices for these novel varieties have not yet been thoroughly established. Plant spacing is a critical factor that influences the development and yield of plants. The extent of the canopy, the efficiency of photosynthesis, the distribution of resources, and the growth rate are all factors that can be influenced by plant spacing (Gokavi et al., 2021). The competition for resources between plants can lead to stunted growth, reduced yields, and an increased susceptibility to pests and diseases when they are spaced too closely together. Conversely, the potential for yield may not be fully realized when plants are spaced excessively apart, as this results in an inefficient utilization of resources.

The crop's early ground coverage, ability to compete with vegetation, surface soil evaporation, light interception, lodging, and the development of an optimal number of fruiting sites within the crop canopy are all significantly influenced by the appropriate distance between plants (Deressegn & Telele, 2017). It is crucial to determine the optimal row spacing in order to enhance crop productivity, as plants that are grown in close proximity to one another may not be able to effectively utilize nutrient, water, and light resources (Lamichhane et al., 2023). Nevertheless, crops that are cultivated in rows that are too narrow may experience severe interrow competition. In addition, dry matter partitioning, photosynthetic competence of leaves, and plant architecture are also influenced by row spacing in numerous field crops (Hussain et al., 2012). The growth and yield of common legumes can be substantially influenced by plant spacing, as demonstrated by numerous studies. According to a study conducted by Masa et al. (2017), the height of the plant, physiological maturation, and grain yield decreased as the interrow increased from 30 cm to 50 cm. However, the number of pods per plant and the weight of 100 seeds increased. Essubalew (2014), who worked on green bean, reported that the longest number of days to 50% flowering was observed at a wider plant spacing, while the least number of days to 50% flowering was documented at a narrow plant spacing (40 cm x 10 cm).

Mulatu et al. (2017) found that plant spacing had a highly significant impact on physiological maturity. Specifically, plants with the narrowest spacing matured earlier, while those with the widest spacing matured later. Different planting patterns can be employed to ensure that the appropriate plant population is maintained, thereby ensuring an increase in yield. The utilization of moisture from soil and the interception of radiation are both influenced by the planting pattern (Musana et al., 2020). Variations in the distribution and dispersion of light energy, both in terms of quality and quantity, among plants are the primary function of sowing patterns in the process of plant growth. This ultimately results in an increase in the absorption ratio, which in turn leads to an increase in biological yield and cereal yield.

Merga (2020) conducted a study that demonstrated that the Nasir common bean variety produced higher crop yields at a spacing of 40 cm x 10 cm than at wider spacings of 50 cm x 10 cm and 60 cm x 10 cm. In the same vein, Tehulie et al. (2021) discovered that the MH-97 mungbean variety, when combined with a spacing of 40 cm x 10 cm (inter and intra-row), was the most effective method for obtaining a higher cereal yield in the study area than a spacing of 50 cm x 10 cm. Mulika (2022) confirmed these findings by demonstrating that a plant spacing of 45 cm x 20 cm resulted in a substantially higher grain yield in green gram varieties than the narrowest spacing of 45 cm x 5 cm, which yielded the lowest grain yield.

The majority of research on plant spacing has concentrated on conventional common bean varieties, and there is limited information regarding the impact of plant spacing on newly introduced common bean varieties in Ghana. In terms of grain yield, marketability, and processing quality, the recently released common bean varieties, Adoye and Ennepa, provide substantial advantages over their older counterparts (GVRC, 2019). Both varieties are highly desirable for commercial and processing markets due to their homogenous seed morphologies, white seed coatings, and excellent canning quality (GVRC, 2019). Disease tolerance is demonstrated by older varieties like Nsoroma, while Adoye and Ennepa compensate with superior yield potential, market adaptability, and disease resistance, thereby increasing their profitability for producers. The optimal plant spacing for common beans can vary depending on the variety, soil type, climate, and other environmental factors, as demonstrated by previous research. It is imperative to address these issues in order to enhance the security of food in developing countries such as Ghana and promote sustainable common bean production. Consequently, there is a knowledge vacuum in the area of the impact of plant spacing on the growth and yield performance of recently released common bean varieties.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of the study was to assess the growth and yield performance of two newly released common beans varieties (Adoye and Ennepa) to different plant spacings.

1.3.2 Specific Objectives

The specific objectives of the study were:

1. Evaluate the effects of plant spacing on phenological development of Adoye and Ennepa.
2. Assess the most appropriate plant spacing on vegetative growth of Adoye and Ennepa.
3. Evaluate the effects of plant spacing on yield and yield components of Adoye and Ennepa.

CHAPTER TWO: LITERATURE REVIEW

2.1 Origin and Distribution of Common Beans

The precise origin of the common bean (Phaseolus vulgaris L.) remains a topic of debate among scientists worldwide (Rendón-Anaya et al., 2017). The feral P. vulgaris is of Mesoamerican provenance and has been dispersed from northern Mexico, through Central America and the Andes highlands, to north-western Argentina since its expansion (Bellucci et al., 2014). It is uncertain when the complete transition from wild beans to cultivated beans occurred, as there are voids in the archaeological record. However, it is believed to have occurred in Peru around 6000 BC, and in Mexico around 5000 BC (Wen et al., 2019).

Beans have been disseminated worldwide by the Portuguese and the Spanish since their domestication thousands of years ago. It is widely distributed in subtropical, temperate, and tropical regions of Africa, Asia, America, and Europe (Wortmann et al., 2006). During the 16th century, Spanish explorers and Portuguese merchants respectively transported the legumes from North America to Europe and Africa. Beans have since become an indispensable produce in numerous African nations. Common beans are cultivated by both smallholder producers and large-scale commercial plantations in sub-Saharan Africa.

2.2 Botany of Common Beans

The common bean is an annual herbaceous plant that is extremely polymorphic and warm-seasonal. There are two distinct varieties of this plant: an erect perennial shrub that can reach a height of 20 to 60 centimeters and a twinning with ascending tendrils that can reach a height of 2 to 5 meters. Artificial supports are required to facilitate the harvesting process when the ascending variety is cultivated for its embryonic pods, such as green beans. It is a terrestrial plant that is composed of a tap root and a variety of adventitious roots (Ecocrop, 2013). The stems of common bean bushy types are slender, pubescent, and branched, whereas the stems of twinning types are prostrate for the majority of their length and rise towards the end. The common bean is an annual herbaceous plant that generates compound leaves with three leaflets (Mwanauta et al., 2015).

The leaves are composed of two or more distinct leaflets and are green in color. The leaf arrangement is alternating, with one leaf per node along the stem. The leaflets range in size from 6 to 15 centimeters in length and 3 to 11 cm in width. The inflorescences are terminal or axillary, with racemes that measure 15 to 35 cm in length. The flowers are papillonaceous, bilaterally symmetrical, and range in color from white to purple (Wortmann et al., 2006). After pollination, each blossom generates a single fruit that is either green, yellow, purple, or black. The flower is composed of five petals and sepals. The common bean flower is characterized by the arrangement of 10 stamens in a diadelphous pattern. The fruit is desiccated, but it does not rupture when it ripens. The fruit is length ranges from 80 to 200 millimeters (mm). The pods are edible as green beans before ripening or after maturation. The dried seeds are obtained from dry edible beans after ripening (McNaughton et al., 2015). The majority of edible-podded legumes yield relatively low yields of mature seeds, or seeds of low culinary quality. Clark (2019) has identified a wide variety of seed colors, including white, green, yellow, sienna, pink, red, brown, and purple, as well as black, in both solid and contrasting patterns.

2.3 Uses and Nutritional Value

Grain legume food crops are frequently cultivated to supply high-protein diets. It is crucial to note that the harvest residues of grain legume crops are typically more nutritious, particularly in terms of nitrogen, than those of cereal crops. The haulm (stem and leaf) and pod wall crop residues of early harvested common beans are of high nutritive value to ruminants (Dejene et al., 2021). Traditionally, common legumes are employed in the production of soups and salads, and they are occasionally combined with cereals. However, the utilization of beans in the preparation of ready-to-eat bakery food products, meat-type derived products (Mecha et al., 2021), and traditional recipes in certain countries that are typically prepared with other ingredients could potentially increase the global consumption of bean protein (Cominelli et al., 2022).

Common beans are the primary source of protein and micronutrients, particularly Fe and Zn, for more than 200 million individuals in rural and impoverished urban communities in Africa. These individuals are unable to afford alternative sources of these nutrients on a regular basis (Huertas et al., 2022). A high nutritive value is attributed to the balance of carbohydrates to proteins in beans, as well as the high amino acid diversity in comparison to cereals (Sa et al., 2020). Beans not only supply energy, but they can also contribute up to 35% of daily protein requirements, with 340 calories per 100 g (Huertas et al., 2022). Common legumes are low in calories, sodium, and lipids (Kibar & Kibar, 2019). Common beans are a significant additional value due to the presence of group B vitamins, the consistent amounts of minerals and trace elements (Celmeli et al., 2018), the high quantities of starch and fiber, and the specific protein fractions (Fujiwara et al., 2017). Lastly, the regular consumption of beans has been associated with the prevention and/or regulation of chronic diseases, as evidenced by the presence of a variety of bioactive compounds in beans, including polyphenols, flavonoids, anthocyanins, and carotenoids (Kibar & Kibar, 2019).

Common bean (Phaseolus vulgaris L.) is cultivated as a sustenance legume crop in numerous global regions (Beebe et al., 2013). The majority of the crop is harvested at seed maturity, but a small portion is harvested early during the green pod fill growth stage to provide a vegetable during times of scarcity and to provide seasonal dietary variety. Beans are the primary source of dietary protein for over 300 million individuals in rural and urban communities in Eastern Africa and Latin America (Petry et al., 2015).

2.4 Production Estimates

Dried beans are the most abundantly produced in developing countries, and the common bean (Phaseolus vulgaris L.) is the most widely consumed cereal grain legume globally (Nassary et al., 2020). Globally, 33 million hectares of land are allocated for bean production, with 7.9 million hectares of this land located in Africa (FAOSTAT, 2019). In Africa, smallholder farmers, primarily women, cultivate an estimated 5 million hectares of land in a single stand or in conjunction with other legumes, cereals, root crops, and tree crops (Huertas et al., 2022). In 2019, the global production of dried grains was 23.9 million tonnes, vegetable or snap bean production was 20.7 million tonnes, and string or common bean production was 1.9 million tonnes (Nigatie, 2021). The demand for this crop is anticipated to rise in response to the present trends in population growth and bean consumption (Bellucci et al., 2014).

The common bean is a significant crop in sub-Saharan Africa and is therefore expected to become a more significant food source in Africa, where it is expected to play a critical role in nutritional security (Philipo et al., 2021b). In order to accommodate the increase in demand, annual yields in primary African production centers in Eastern, Southern, and Western Africa have been increasing by more than 2% annually between 2006 and 2018 (Huertas et al.,2022). This results in annual production increases of nearly 8% in Western Africa, where productivity increases have been matched by substantial expansion of the production area (>5% per year) (Farrow & Muthoni-Andriatsitohaina, 2020). The output in Northern Africa is 4 tonnes per hectare, while the yield in Middle Africa is only 0.68 tonnes per hectare (FAOSTAT, 2019). Kenya is the primary producer of beans in both Eastern and Western Africa, with a land area extending from 300,000 to 500,000 hectares. The annual production of approximately 40,000 to 150,000 metric tons is the result of this extensive cultivation (Barkutwo et al., 2020).

2.5 Varieties

The size, shape, color, and fibrousness or tenderness of the embryonic pods of common bean varieties vary significantly. In general, varieties that are cultivated for desiccated mature seeds yield pods that are too fibrous to consume at any stage of development. The Council for Scientific and Industrial Research-Crops Research Institute, which is situated in Kumasi, has released a variety of unique common bean varieties in Ghana. From white to black, seed colors encompass a wide variety of solid colors and myriad contrasting patterns, including green, yellow, tan, pink, red, brown, and purple. The characteristics of certain common bean varieties that are cultivated in the different regions of Ghana are illustrated in Table 2.1 below.

Table 2. 1: Some varieties of Common Beans grown in Ghana

Variety	Distinctness Uniformity and Stability (DUS)	Value for Cultivation and Use (VCU)	Preferred Ecology
Adoye	Seed coat color: white; seed shape: oval. Seed coat patterns are nonexistent; Helium coloration is nonexistent. White is the standard color of the flower. Four flower buds are present in each inflorescence. Green pigmentation of the hypocotyl; The color of the hypocotyl that is emerging is a very translucent green. Leaf Persistence: Intermediate; Pod Color: A standard shade of green; Pod Curvature: A slight curve; Pod Suture String: A limited number of strings	Canning quality: good; Early maturing (60-65 days after sowing); Grain yield- 1.3 ton/ha.	Transition and Forest
Ennepa	Seed coat color: white; seed shape: kidney; seed coat patterns: absent; helium color: absent; standard flower color: white; three flower buds per inflorescence; hypocotyl pigmentation: green; hypocotyl color: very pale green; leaf persistence: intermediate; pod color: normal green; pod curvature: slightly curved; pod suture string: few strings	Canning quality: good; Early maturing (60-65 days after sowing); Grain yield- 2.1 tons/ha.	Transition and Forest

Semanhyia	Seed coat color: Brown; seed shape: Cuboid; seed coat patterns: Absent; helium color: White with a yellow circle; standard flower color: White; inflorescence has three flower buds; hypocotyl pigmentation: Green; hypocotyl: Very pale green; leaf persistence: Intermediate; pod color: Normal green; pod curvature: Curved; pod suture string: Stringless	Early maturing (60-65 days after sowing); High iron and zinc content (Iron :77 ppm and Zinc 37 ppm); Grain yield:1.9 ton/ha.	Transition and Forest
Nsoroma	Brown seed coat color; Cuboid seed shape; Absent seed coat patterns; Helium color: White with yellow circle; Standard flower color: White; Three flower buds per inflorescence; Hypocotyl pigmentation: Green; Hypocotyl: Very pale green; Leaf persistence: Intermediate; Pod color: Normal green; Pod curvature: Curved; Pod suture string: Stringless	Early maturing (60-65 days after sowing) Tolerant to diseases; Grain yield: 1.3 ton/ha.	Transition and Forest

Source: CSIR, 2019

2.6 Climatic and Soil Requirements

Common bean thrives in environments with temperatures ranging from 15°C to 30°C and rainfall between 300 mm and 600 mm (Chibarabada et al., 2018). Extreme environmental conditions, such as intermittent and terminal droughts (< 300 mm or > 600 mm), have been reported to have an impact on the crop. This results in a reduction in plant sugars, energy, quality, and yield, which is caused by a negative impact on photosynthesis (Philipo et al., 2021a). Water saturation, which is the result of an excessive amount of rainfall, leads to a reduction in yield, as well as foliar diseases and root decay, as a result of inadequate gas exchange between the root and soil pore spaces (Beebe et al., 2013). Once more, high temperatures, such as a daytime temperature exceeding 30 °C and a nighttime temperature exceeding 20 °C, are responsible for the abortion of flower buds, flowers, and pods, which leads to a decrease in seed yield (De Ron et al., 2016). The nitrogen fixation activities and photosynthesis are both impeded by poor soil fertility, which is characterized by low nitrogen and available phosphorus (Philipo et al., 2021a). Consequently, the yield of common beans is reduced. Aluminum toxicity may result from excessively acidic soils, which can also diminish legume yields (Chekanai et al., 2018).

Common beans are capable of being grown in a diverse array of soil types; however, they are more suited to loamy soils that are well-drained and have a pH between 5.5 and 7.0 (Kelly, 2018). They are capable of enduring soils that are slightly acidic to slightly alkaline; however, nutrient availability may be compromised by extreme pH levels. Loam soils possess a balanced texture that ensures adequate drainage while retaining an adequate amount of moisture and nutrients. Clay soils can become compacted and impede root growth, while sandy soils discharge rapidly and may necessitate more frequent irrigation. Common beans necessitate sufficient soil moisture throughout their growth cycle. It is essential for common beans to have adequate soil drainage, as waterlogged conditions can result in root decay and other maladies. The common bean plant is susceptible to adverse soil and climate conditions as a result of its high nutritional demand and brief growth cycle (Manzeke et al., 2019). Root development and nutrient absorption can also be impeded by soils that are inadequately exhausted. Proper soil aeration is crucial for common beans, as it enables the absorption of nutrients and the respiration of roots. Plant vigor can be diminished and root growth can be impeded by compacted soils. Common beans necessitate soils that possess a high water-holding capacity in order to maintain sufficient moisture levels for plant growth. Soils with a higher organic matter content have a greater capacity to retain water, which is essential for the rapid growth and development of common beans.

2.7 Crop Propagation

There is a widespread dissemination of common legumes through seed. It is always advisable to cultivate common bean seedlings that have been certified. According to Kimaru et al. (2019), certified vegetable seedlings exhibit an exceedingly high germination rate, with a range of 95% to 100%. As a result, the high success rate of seedling establishment necessitates a reduced quantity of seeds for cultivation (Peluffo et al., 2016). The CSIR-Crops Research Institute's distribution of common bean seedlings is widely recommended for the commencement of common bean production in Ghana's diverse regions.

Once the soil has warmed and the risk of frost has passed, the crop should be sown, as it prefers mild weather. Common beans are cultivated twice annually in the Transitional Zone. The initial season, which is the primary rainy season, spans from March to June, while the subsequent season, which is classified as a minor season, occurs from September to December. It is advisable to cultivate common beans during the main precipitation season between mid-March and mid-June. This schedule enables the crop to capitalize on mild weather and adequate precipitation during its initial growth phase (Darabi, 2016). Conversely, it is recommended to plant common beans between mid-September and mid-October for dry season production. This guarantees arid and mild conditions that are conducive to the growth, maturation, harvesting, and podding of the crop, resulting in a high-quality yield and high-quality seeds (Darabi, 2016).

When sowing common beans (Phaseolus vulgaris), it is important to consider a variety of factors, such as planting methods, varieties, and patterns. Common beans can be sown as a single crop at inter and intra row spacing of 45-75 cm and 15-30 cm, respectively, with two seeds per hill, depending on the cultivar. The optimal sowing density is adjusted in accordance with the guidelines provided on seed packets or local agricultural resources and the varieties to be planted. Turuko and Mohammed (2014) suggest that the majority of bean varieties should be seeded with a 40 cm spacing between rows and a 10 cm spacing between supports.

2.8 Weed and Disease Control

Weed control in Its (Phaseolus vulgaris) is a critical component of crop management that is designed to reduce the proliferation and impact of undesirable plant species within the bean crop. It is susceptible to the detrimental consequences of vegetation competition, particularly during the initial phases of its growth and development (Fried et al., 2017). During this critical period, the growth and productivity of common beans are more susceptible to weeds. The notion that the duration of weed presence following the emergence of crop seedlings is positively correlated with reductions in yield potential is substantiated by numerous studies. Furthermore, these studies suggest that yield potential is not restored even after vegetation removal (Horvath et al., 2018).

The optimal growth and yield of common beans are promoted by the implementation of effective vegetation control practices, which reduce competition for resources such as water, nutrients, and light. To manage vegetation in its production, a variety of scientific techniques and approaches are implemented. Weed management for common legumes is significantly influenced by cultural practices. Kaur et al. (2015) have demonstrated that the use of clean seeds, crop rotation, punctual planting, and appropriate spacing are effective cultural practices for controlling weeds in the production of common beans. Mechanical, chemical, and mulching methods of vegetation control have been found to have a substantial impact on yield and growth in numerous studies.

Sims et al. (2018) also posited that the application of herbicides to common beans necessitates meticulous attention to the crop stage, herbicide selectivity, and compliance with label instructions. Pre-emergent herbicides are applied prior to the emergence of weeds, whereas post-emergent herbicides are applied subsequent to the emergence of weeds. Mechanical methods involve the physical removal or suppression of weeds, while organic mulches, such as fiber or compost, can help suffocate weeds and conserve soil moisture. Synthetic mulches, such as plastic film, prevent weed emergence by obstructing sunlight (Attri et al., 2022).

The annual population growth rate, which is estimated to be over 2 percent, has not been matched by the rate of crop production. This is predominantly the result of a variety of constraints, including biotic (related to living organisms), abiotic (related to non-living factors), and socio-economic factors (Katungi et al., 2009). Crop yields have been substantially diminished as a consequence of these constraints. Insect pests have evolved as a significant factor contributing to the reduction of yields in legumes, among other biotic constraints (Mwanauta et al., 2015). Stem maggot (Ophiomyia phaseoli), ootheca (Ootheca bennigseni), and aphids (Aphis fabae) are the most significant insect parasites that affect common beans. According to Munyasa (2013) and Ochilo and Nyamasyo (2011), these pests can result in yield losses that range from 37% to 100% for stem maggot, 18% to 31% for ootheca, and 37% for aphids.

The most significant field parasite affecting legumes in Africa are bean stem larvae, also known as bean flies. They are accountable for yield losses that range from 80% to 100% (Ochilo & Nyamasyo, 2011). O. phaseoli, O. spencerella, and O. centrosematis are the most prevalent species of bean stem maggots that infest bean crops in all regions (Ambachew et al., 2015). Ophiomyia phaseoli, in particular, is extensively distributed and poses a substantial hazard to seedling beans in Eastern and Western Africa. Eggs are laid by the adult bean stem maggot in the foliage, stems, and hypocotyls of immature seedlings. The emerging larvae tunnel their way to the root zone, where they endure pupation (Marjanović-Jeromela & Prodanović, 2021). They confine their nutrition between the woody stem and the epidermal tissue, disrupting water and nutrient transport and establishing entry sites for disease-causing organisms (Ochilo & Nyamasyo, 2010).

Bean stem maggots cause the most significant harm to the bean plant during the seedling stage. The plant is attacked by the parasites as the first pair of leaves unfurl, and they continue to target new leaves as they emerge (Yadav et al., 2019). The adult maggots deposit their eggs directly into the plant tissue, while the emerging maggots feed on the stem, thereby disrupting the flow of water and nutrients. Yellowing and withering of leaves are signs of infestation, which ultimately results in plant mortality (Mahesha et al., 2022). The financial constraints of small-scale farmers in obtaining costly chemical pesticides, as well as the substantial yield losses caused by these insects, necessitate the development of sustainable pest control strategies (Oben et al., 2015). These strategies may involve the implementation of botanical approaches, biological control methods, and agronomic practices.

Ootheca bennigseni is endemic to mainland Africa and is predominantly found on bean plants (Phaseolus vulgaris L.) (Mwanauta et al., 2015). After a period of 2 to 3 weeks, the larvae of Ootheca bennigseni emerge and are able to suckle on the roots of bean plants. These larvae undergo three instars, and the teneral adults enter diapause until the commencement of the monsoon season the following year. When they emerge, they commence grazing on the foliage of newly planted bean crops (Togola et al., 2017). In the event of a severe infestation, the adult beetles have the potential to completely decimate a crop and cause significant defoliation (Sherwani et al., 2016). Togola et al. (2017) have also identified Ootheca spp. as a substantial parasite in sub-Saharan Africa. O. bennigseni has caused foliar injury to the juvenile bean plants of African producers, which has been observed to increase over time. Nevertheless, they were unaware of the larval harm caused by the same insect until they discovered the larvae on the roots of the bean plants.

The primary aphid parasite that affects common legumes in Africa is Aphis fabae, which is commonly referred to as bean aphids. Many aphid taxa have evolved biologically complex life cycles as a consequence of their adaptations to their host plants (Jousselin et al., 2010). Bean aphids are typically observed in colonies that surround the plant's stem, leaves, and growth sites (Duric et al., 2022). The aphids' feeding and suction activities cause injury and discoloration to the foliage that are infested. The vegetation may inevitably succumb to dehydration. Aphids can cause early plant mortality by indirectly transmitting common mosaic viruses, in addition to directly damaging the host plant by drawing fluid from various plant parts (Fingu-Mabola et al., 2021). Black bean aphids (Aphis fabae) are among the most prevalent insect pests that inflict damage on common beans in the field, resulting in a yield loss of approximately 37% (Mwanauta et al., 2015). Aphids also secrete honeydew, which inhibits the photosynthetic capacity of plants and encourages the growth of sooty fungi (Singh & Singh, 2021). The responses of plants to aphid nutrition are unique to specific combinations of aphids and plants. Aphid attacks have been demonstrated to decrease the biomass, leaf area, and relative growth rate of legumes, including cowpea, faba bean, pea, mung bean, groundnut, and soybean, in a variety of combinations (Mofokeng & Gerrano, 2021).

As numerous researchers have observed, bean common mosaic disease (BCMD) poses a substantial hazard to the global production of common beans. The most prevalent viral disease affecting common beans is Bean common mosaic virus (BCMV), which is related to the necrotic species Bean common mosaic necrotic virus (BCMNV) (Mangeni, 2016). The incidence of BCMV and BCMNV infections has been observed to reach as high as 100%, resulting in yield losses spanning from 35% to 100% (Mangeni et al., 2020). Viruses are transmitted through seeds and aphids, with the latter serving as non-persistent carriers (Wamonje et al., 2020). BCMV and BCMNV are Potyvirus genus members of the

Potyviridae family that are closely related (Muute et al., 2021). Numerous researchers have visually identified the typical symptoms of BCMD, including puckered or distorted leaves, curled leaves, a light green or yellow and dark green mosaic pattern on leaves, and wilting, in contrast to healthy bean plants (Muute et al., 2021). Buruchara et al. (2010) had previously observed these symptoms.

2.9 Control Measures for Common Bean Pests and Diseases

2.9.1 Chemical Pesticides

Approximately 1.8 billion individuals worldwide are engaged in agriculture, and a significant number of them depend on pesticides to protect the food and commercial products they produce (Mwanauta et al., 2015). Etana (2022) has identified specific chemicals, such as endosulfan, diazinon, or lindane, that can be applied in low doses as seed dressings to protect germinating plants, particularly during the vulnerable stage when they are susceptible to attacks, such as those from the bean stem maggot, by various national bean programs and research organizations worldwide. This parasite has been effectively managed by pesticides such as cypermethrin, carbaryl, and karate (Chaudhary et al., 2022). In integrated pest management (IPM) programs for faba beans, a relatively novel insecticide known as imidacloprid has demonstrated substantial potential (Sani et al., 2020). imidacloprid has been shown to be effective against the broad bean weevil Bruchus rufimanus, aphids, wireworms, and thrips, despite the fact that ongoing research is still being conducted on its use (Khan et al., 2020). Faba bean necrotic yellows virus, soybean dwarf virus, and bean leaf roll virus infection rates can be substantially diminished through imidacloprid control of aphids (Abraham, 2019). Imidacloprid effectively reduces populations of the leaf miner Liriomyza huidobrensis (Blanchard) when administered as a foliar application during podding.

2.9.2 Biological Control

Biocontrol, also referred to as biological control, is a method that employs the natural enemies of undesirable insects, parasites, vegetation, animals, or plant diseases to reduce or manage their populations (Nega, 2019). This method entails the deliberate introduction, promotion, or augmentation of these natural enemies to sustain their populations at levels that are economically insignificant. For the past two millennia, biological control has been employed to manage insect pests in the majority of commodities that are below the economic threshold (Joop et al., 2018). This method is predicated on natural mechanisms such as herbivory, parasitism, predation, and other biological interactions (Nega, 2019).

Parasites, predators, and pathogens can all be employed to combat the primary pests of common beans, such as aphids (Hrček et al., 2016). Aphids are consumed by both larvae and adult predators from the Coccinellidae family, which are commonly referred to as ladybird beetles or ladybugs, in the context of aphid control (Skouras et al., 2015). The Aphidiinae subfamily of braconids is composed of species that develop as endoparasitoids, with a single larva concluding its development within each aphid host. Singh and Singh (2016) Aphids are ultimately killed by certain entomopathogenic fungi, which infest them through their cuticles. Ladybirds are capable of attacking multiple hosts within a brief period of time due to their larger, stronger, and often more intelligent than their prey (Peterson et al., 2016). Spinosad is an additional biological control agent that is employed to combat aphids. It is an insecticide that was isolated from soil and is derived from the bacterium Saccharopolyspora spinosa. Spinosad operates by poisoning the pests through nerve and gastrointestinal action (Mwanauta et al., 2015). The fungus Trichoderma viride is currently being developed as a biological control for the treatment of plant diseases (Nega, 2019).

2.9.3 Botanical Pesticides

Pyrethrum, which is the most widely used botanical insecticide globally, has been commercially successful for more than a century and is derived from the desiccated flowers of Tanacetum cinerariifolium (Asteraceae) (Isman, 2020). The natural insecticides can be chemical, mineral, extract, or biological. The overarching objective of all of these is to eliminate, discourage, or otherwise disrupt the detrimental conduct of insect pests (Oguh et al., 2019).

In agriculture, botanical pesticides or biopesticides are regarded as environmentally benign and human health-friendly alternatives to conventional chemical pesticides (Damalas & Koutroubas, 2020). These botanical insecticides are typically composed of a combination of bioactive compounds and provide a variety of benefits, such as the capacity to prevent the development of resistance, brief persistence, and high efficacy (Chowański et al., 2016). In addition, they are frequently more cost-effective for producers than synthetic products, and their expenses can be quantified in terms of the time required for harvest and processing (Dinesh et al., 2014). Pesticidal plants derive their value by utilizing the natural defense strategies of plants, which involve the production of compounds with repellent, antioxidant, growth-retarding, and noxious properties that are specifically designed to target insect pests and microorganisms (Chowański et al., 2016). These compounds are one of the most critical lines of plant defense against parasites, and they are generated by a wide diversity of plant species in nearly all of their organs.

Furthermore, the brief half-life of natural insecticides in the environment is one of their most significant characteristics (Chowanski et al., 2014). Additionally, pests are unable to develop resistance to them due to their extensive physiological activity and pleiotropy. According to Bernardi et al. (2017), recent research has identified seed extracts from other species that exhibit increased bioactivity, which suggests their potential for the development of more potent botanical insecticides for the control of vegetable pests. These studies have focused on the Annonaceae family.

2.10 Plant Spacing

The overall health and productivity of plants are significantly impacted by plant spacing, which is a fundamental component of crop management. Many researchers have identified plant spacing as a critical component of plant cultivation, as it is a critical factor in determining the growth, development, and overall yield of plants. Plant spacing contributes to the economic productivity of crops by influencing the duration of vegetative growth, light conversion efficiency, dry matter production, seed yield, and canopy architecture, as per Welbaum (2015). Ladaniya et al. (2021) also stated that the optimal spacing of plants is crucial for the optimal utilization of sunlight, air circulation, nutrient availability, and water absorption for each plant.

Too close spacing can result in competition for resources such as light, water, and nutrients, which can lead to stunted growth, reduced productivity, and increased susceptibility to diseases and parasites. Conversely, too wide spacing can result in underutilization of space and diminished crop yield (Tokatlidis, 2013). Nevertheless, Ashraf et al. (2014) reported that adequate spacing enables a more efficient distribution of nutrients in the soil, thereby reducing nutrient competition among plants. Ashraf et al. (2014) also maintained that sufficient spacing guarantees that each plant has access to the essential minerals and elements required for optimal yield and healthy growth. The spacing of plants can differ based on the specific crop that is being cultivated. In order to accommodate their growth patterns, certain crops necessitate a wider spacing, while others can be cultivated more densely. The primary factors that influence the determination of appropriate spacing are plant size, growth rate, and branching pattern, as per Thomas (2013).

Farmers and gardeners frequently depend on plant spacing guidelines that are tailored to the specific crop or plant variety. As per Balliu et al. (2017), it may be necessary to reduce or transplant seedlings in order to maintain the appropriate spacing and guarantee the optimal development of the plant. It is imperative to conduct consistent surveillance of plant growth, health, and spacing in order to optimize productivity and preserve plant vigor. The success of a crop is significantly influenced by the number of plants that are cultivated per unit area of land, which is referred to as plant population density. A variety of factors influence the relationship between crop yield and plant population density. Individual groundnut plants typically have more space and available resources when plant population densities are lower. The development of larger and more robust plants is frequently the result of this favorable environment, which ultimately results in a higher yield per plant. Conversely, the concentration of groundnut plants within a specific area increases as the density of the plant population increases (Kumar et al., 2019). This may result in an increased total pod count per unit area. Nevertheless, it is imperative to achieve a balance, as exceedingly high plant densities can result in increased competition for resources, which can subsequently decrease overall yields (Brown & Green, 2017).

The advantage of lower plant populations is that each plant can allocate a greater amount of resources to pod development. As a result, the quality of the harvest is not only improved, but also its market value is bolstered by the larger size of groundnut kernels (Smith et al., 2017). The optimal spacing for maximizing growth and yield in leguminous commodities, such as common beans, has been suggested by various studies. The choice of plant spacing can have a significant impact on these factors. (Vanvanhossou et al., 2021). The majority of research has demonstrated that the spacing of plants can influence a variety of characteristics in common legumes and groundnuts. For instance, the accumulation of plant dry matter, test weight, pod yield, kernel yield, and stover yield was enhanced by maintaining a spacing of 40 cm × 15 cm (Yadav et al., 2021). Mare et al. (2018) also found that a spacing of 30 x 10 cm resulted in a higher plant height, dry matter accumulation, leaf area index (LAI), and number of branches, while a spacing of 60 x 10 cm resulted in a higher number of groundnut branches.

2.10.1 Effect of Plant Spacing on Growth and Yield of Common Beans

The growth and yield of common bean (Phaseolus vulgaris) crops are significantly influenced by plant spacing. Numerous studies have been conducted to examine the impact of plant spacing on the performance of common bean, with an emphasis on elements such as plant density, inter-row spacing, and intra-row spacing. Lema and Tekalign (2012) noted that bean yields were higher when plant densities were higher than those of lower densities. Nevertheless, overcrowding, increased competition for resources, and reduced yields can also result from excessively high plant densities. The inter-row spacing, which is the distance between rows, is a critical factor in the cultivation of common beans. Various studies have suggested that yields are generally higher when interrow spacing is wider. Mohammed et al. (2018) discovered that bean yields were significantly higher when inter-row spacing was wider (e.g., 60 cm) than when it was narrower (e.g., 40 cm). This is due to enhanced air circulation, improved light penetration, and decreased competition for water and nutrients.

Kahlon et al. (2019) conducted a study that demonstrated that yields were significantly higher when the intra-row spacing was wider (e.g., 10 cm) than when it was narrower (e.g., 5 cm). This enables enhanced nutrient uptake, improved root development, and reduced competition among plants within the row. The growth and yield of a common bean can be influenced by the choice of cultivar and the spacing of the plants. According to a study conducted by Hassan et al. (2017), specific cultivars exhibit superior performance under specific plant spacing conditions. In comparison to a narrower spacing of 25 cm × 10 cm, they discovered that specific cultivars and a wider plant spacing of 50 cm × 10 cm resulted in higher bean yields of common beans.

Moha et al. (2018) also showed that the control of weeds in common bean crops can be influenced by the proper spacing of plants. Furthermore, they stated that the wider inter-row spacing enables the implementation of more effective weed management strategies, such as inter-row hoeing or mechanical cultivation, which results in reduced weed competition and enhanced bean yields. The influence of plant spacing on common bean extends beyond its impact on growth and produce. Researchers have also investigated its effects on pest and disease management. Alves et al. (2016) found that wider inter-row spacing can reduce the incidence of foliar diseases in common bean, as improved air circulation helps to minimize humidity and create a less favorable environment for disease development. Plant spacing has been linked to resource-use efficacy. Al-Kaisi et al. (2013) reported that optimal plant spacing in common bean can contribute to enhanced nutrient assimilation and utilization, resulting in higher nitrogen use efficiency and reduced fertilizer requirements. This not only benefits the economic bottom line but also contributes to sustainable agricultural practices by minimizing nutrient discharge and its environmental impact.

A study on tomato plants demonstrated that a 20 cm interrow spacing resulted in a 35.96% increase in marketable produce yield compared to a 30 cm spacing (Amare & Gebremedhin, 2020). Similarly, a study on Egyptian cotton found that a planting spacing of 40 cm significantly increased seed cotton yield, lint cotton yield, and other yield attributes

(Ibrahim et al., 2022). Gebru (2015) found that plant spacing affects the growth of root crops by creating competition for nutrients, water, and light among the plants. Abrha et al.(2015) reported that the minimum fruit length was recorded from a closer intra-row spacing of 20 cm. Contrary to the findings of Abrha et al. (2015), Ogundare et al. (2015) also reported that highest fruit length was recorded from a wider spacing of 75 × 60 cm than closer spacing.

According to Haque & Sakimin (2022) wider spacing resulted in larger fruit size, while closer spacing resulted in smaller fruit size of sweet cherry trees. Singh et al. (2020) revealed that various sowing systems exhibited significant effects on the growth, yield, and quality parameters of produce. In general, yield components and productivity are affected by the spatial arrangement of the crop, which is determined by a combination of row spacing and plant spacing within the row (Bezerra et al., 2016). Proper plant spacing can improves harvest efficiency. The produce is more easily accessible due to the appropriate spacing, which enhances the efficiency of the harvest and decreases labor costs. However, when plants are spaced too closely together, their root systems can become overcrowded, leading to intense competition for nutrients and water. Subsequently, the capacity to absorb critical nutrients from the soil may be impaired, and root growth may be restricted. Ultimately, this can significantly impact the overall growth and yield of the crop (Nyambati & Kioko, 2018). By ensuring that there is an adequate amount of space between plants, their root systems can flourish, thereby facilitating the efficient absorption of nutrients and water. This, in turn, supports robust plant growth and enhances the crop's yield potential.

Research results suggest that the growth and yield of common bean (Phaseolus vulgaris) can be significantly influenced by the precise spacing of plants. For instance, specific plant spacing configurations, such as 50 x 20 cm, have been associated with notable improvements in growth and yield parameters. Studies have reported increased plant height, longer arrowroot length, and higher tuber weight per plant when using this particular spacing arrangement (Qodliyati & Nyoto, 2018). Nevertheless, it is crucial to acknowledge that the impact of plant spacing on common bean is multifaceted and is influenced by a variety of factors. The relationship between plant spacing and common bean performance has been the subject of numerous studies, and a consensus has been reached regarding a suitable compromise for achieving optimal growth and yield. Most research indicates that a plant spacing of approximately 20-30 cm between individual plants within a row and 40-60 cm between rows is generally considered favorable (Karavidas et al., 2022). This spacing arrangement strikes a balance between promoting robust plant growth and attaining satisfactory crop yields. It is important to recognize that, although precise plant spacing is crucial, it is only one element of a comprehensive crop management strategy. Farmers should also consider other factors, such as nutrient availability, irrigation practices, and pest and disease management, to ensure the overall health and productivity of common bean crops (Karavidas et al., 2022).

2.11 Effect of Variety on Yield of Common Beans

The yield potential of common beans (Phaseolus vulgaris L.) is significantly influenced by varietal selection, as the genetic variability among cultivars directly affects a variety of physiological and agronomic characteristics. Variations in attributes such as pod number, seed size, biomass accumulation, and resource use efficiency are the primary factors driving the observed differences in yield among common bean varieties, as demonstrated by numerous studies.

The genetic variation among common bean varieties substantially influenced variables such as leaf area index (LAI), number of pods per plant, seeds per pod, primary branches, and above-ground dried biomass, as reported by Masa et al. (2017). Their results indicated that the Hawassa Dume variety outperformed Ibbado in all of these parameters, which led to a higher grain yield as a result of its superior capacity to accumulate biomass and effectively translocate assimilates to reproductive organs. In the same vein, Kouyaté et al. (2012) underscored the fact that varietal differences have a substantial impact on nodulation, which can subsequently affect plant development and yield by affecting nitrogen fixation capacity.

Begna & Asrat (2021) also discovered that genotype DAB564 has a substantially higher yield than DAB520, which they attribute to its superior genetic potential for biomass production and resource utilization. This corroborates the results that genotypic variations influence the efficiency with which varieties convert photosynthates into cereal yield in response to specific environmental conditions. Kazemi et al. (2012) observed a substantial interaction between cultivar and plant density on the harvest index of white bean in a separate study. This suggests that certain varieties may perform better under specific agronomic practices as a result of their inherent development patterns and resource requirements.

Furthermore, Kumar et al. (2023) revealed a considerable positive correlation between grain yield and yield per plant in bread wheat, thereby confirming that varietal traits that improve yield components, such as seeds per plant, also have a substantial impact on total grain yield. The broader principle that genetic factors significantly influence yield outcomes in field commodities, including common beans, is underscored by this study, despite its focus on wheat. Significant variations in the hundred-seed weight of common bean cultivars in response to phosphorus (P) administration were reported by Amare et al. (2014) and Dereje et al. (2016) in a comparable study. A study conducted by Alemu et al. (2018) in Jimma, Southwest Ethiopia, found that the Tatu cultivar produced a yield advantage of 31.12% over Ibbado and 20.57% over Remeda when grown with an application rate of 69 kg/ha P_2O_5. The study examined the growth and yield of common bean (Phaseolus vulgaris L.) cultivars as influenced by phosphorus rates.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Experimental Site Description

The Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Mampong-Ashanti campus, located in the forest-savannah transitional zone of Ghana, conducted two field experiments at the research field during the major rainy season (March to July 2023) and the minor rainy season (August to December 2023). Geodatos (2020) notes that the region is situated at an elevation of 457.5 meters above sea level and is situated within 7° 8 N of the equator and 1° 24 W of Greenwich.

Major rainfall occurs between March and July, while minimal rainfall occurs from August to December. The region experiences a bimodal rainfall pattern. The monthly average is 91.2 mm, and the total annual rainfall ranges from 1270 mm to 1534 mm. The annual temperature averages 27 oC, and the mean monthly temperature ranges from 25 oC to 32 oC (Kotei et al., 2016). According to the FAO/UNESCO (2008) legend system of classification, the soil at the experimental site is classified as Chromic Luvisol. The soil is classified as a deep red sandy loam that is concretion and stone-free, and it is derived from the Voltaian Sandstone. It is a member of the Savannah Ochrosol class of the Bediese Series and has an excellent texture and structure. It is appropriate for the cultivation of tuber, cereal, vegetable, and legume crops due to its high water retention capacity and well-drained nature (Asiamah, 1988).

3.2 Experimental Design and Treatments

The experimental design used was a 2 x 4 factorial experiment arranged in a Randomized Complete Block Design with eight treatments and each replicated four times. There were two Factors; (A) Common Bean varieties:- [(i) Adoye and (ii) Ennepa] and (B) Plant Spacing:- [(i) 60 cm x 20 cm; (ii) 50 cm x 20 cm; (iii) 40 cm x 20 cm and (iv) 30 cm x 20 cm]. The total number of treatment combinations is presented in Table 3.1.

Table 3. 1: Treatment Combinations

Treatment	Variety	Planting distance
T1	Adoye	60 cm x 20 cm
T2	Adoye	50 cm x 20 cm
T3	Adoye	40 cm x 20 cm
T4	Adoye	30 cm x 20 cm
T5	Ennepa	60 cm x 20 cm
T6	Ennepa	50 cm x 20 cm
T7	Ennepa	40 cm x 20 cm
T8	Ennepa	30 cm x 20 cm

3.3 Cultural and Management Practices

3.3.1 Land Preparation

The experimental field size of 414.4 square meters was marked out, disc ploughed, and harrowed to a fine tilth. The eight treatments were replicated four times with 2.0 m left between blocks and 1.0 m between plots. Each plot size consisted of six rows resulting in four different plot sizes of 3.6 m x 2.0 m, 3.0 m x 2.0 m, 2.4 m x 2.0 m and 1.8 m x 2.0 m.

3.3.2 Planting Materials and Planting

The seeds of both common bean varieties (Adoye and Ennepa) were obtained from the Council for Scientific and Industrial Research- Crops Research Institute, Kumasi, Ghana (CSIR-CRI). Adoye and Ennepa are early maturing varieties (60 – 65 days) with yield potential of 1.3 t/ha and 2.1 t/ha, respectively. Sowing was done on 5h June 2023 and 7th September 2023 during the major and minor rainy seasons, respectively.

The seeds were sown at the varying inter-row spacings of 60 cm, 50 cm, 40 cm and 30 cm with a constant intra row spacing of 20 cm at two (2) seeds per hill and seedlings were thinned to 1 plant per hill one week after seedling emergence.

3.3.3 Pest and Disease Control

The whiteflies outbreak was controlled by spraying Cyperforce insecticide (a.i cypermethrin) at a rate of 15 ml per 15 L Knapsack sprayer. Hoeing of weeds was done two weeks after sowing and every two weeks. The common weed found on the field was *Cyperus rotundus.*

3.3.4 Harvesting

Leaf and stalk senescence, pod colour change from green to yellow or brown, dried and brittle pods that produce a rattling sound when shaken, pod dehiscence, and hardened seeds were the key indicators of maturity in both common bean varieties across both cropping seasons. Harvesting was carried out manually by handpicking dried pods, which were then sun-dried before threshing.

3.4 Data Collected

3.4.1 Phenological data

3.4.1.1 Days to 50% Seedling Emergence

This was determined by counting the number of days from the first day after sowing till 50% of the seeds within the four central rows of each plot had emerged.

3.4.1.2 Percentage Plant Establishment

Plants within the four middle rows that had successfully established were counted 3 weeks after sowing and expressed as a percentage (Dapaah, 2014). This was expressed as;

$$\%\text{ Plants Establishment} = \frac{Number\ of\ established\ plants}{Number\ of\ plants\ within\ the\ four\ middle\ rows}\ x\ 100\%$$

3.4.1.3 Days to 50% Flowering and Podding

This was done by counting the number of days from sowing till 50% of the plants within the four central rows has flowered or fruited.

3.4.2 Vegetative Growth Data

3.4.2.1 Plant Height

Five plants per plot were randomly selected from the four middle rows and tagged for data collection. Plant height was measured from the soil surface to the apex of the main vine at 21 DAP and at 10 days interval till 51 DAP and the mean estimated. The plant height was determined using the meter rule.

3.4.2.2 Number of Leaves Per Plant

The total number of leaves per plant was counted on the five sampled plants from the four middle rows at 21 DAP and at 10 days interval till 51 DAP and the mean estimated.

3.4.2.3 Number of Branches Per Plant

The total number of branches from the five randomly selected and tagged plants from the four middle rows were counted at 21 DAP and at 10 days interval till 51 DAP and the mean estimated.

3.4.2.4 Stem Diameter

The stem diameter was measured on the five randomly selected and tagged plants from the four middle rows at 21 DAP and at 10 days interval till 51 DAP and the mean estimated. It was measured at about 7cm above the soil surface using a digital vernier caliper.

3.4.2.5 Shoot and Root Dry Weight

Two plants were randomly selected and uprooted from the row outside the harvestable area per plot and were separated into shoot and root. Fresh sub-sample each of shoot and root weighing 200 g was weighed using electronic weighing scale. Each subsample was placed in a paper bag and put in an oven at 78 degrees Celsius for 72 hours until a constant weight was attained. Each sub-sample was then immediately weighed using an electronic weighing scale and recorded as shoot and root dry weight. The mean dry weight was estimated.

3.4.3 Physiological Growth Parameters

3.4.3.1 Crop Growth Rate

This was measured in g m^{-2} day^{-1} using the formula below as adopted by Essilfie *et al.* (2023); CGR =$(\frac{\mathbf{1}}{\boldsymbol{GA}})\ \boldsymbol{X}\ (\frac{\boldsymbol{W2-W1}}{\boldsymbol{T2-T1}})$, Where CGR= Crop growth rate; W_1=total dry matter at first harvest; W_2= Total dry matter at second harvest; T_1 = Days of observation at first harvest; T_2= Days of observation at second harvest.

3.4.3.2 Relative Growth Rate

This was measured in g m^{-2} day^{-1} using the formula below as adopted by Essilfie *et al.* (2023); RGR =$(\frac{LnW2-LnW1}{T2-T1})$, Where RGR = Relative growth rate; W_1=Total dry matter at first harvest; W_2= Total dry matter at second harvest; T_1= Days of observation at first harvest; T_2=Days of observation at second harvest; In=Natural log.

3.4.4 Yield and Yield Components

3.4.4.1 Number of Plants Harvested

This was achieved by counting the total number of plants within the four middle rows per plot at harvest and the mean recorded.

3.4.4.2 Number of Pods Per Plant

Total number of pods from the five randomly selected and tagged plants within the four middle rows were counted and used to estimate the pods per plant. The mean pods per plant was estimated.

3.4.4.3 Pod Weight Per Plant

All pods from the five randomly selected and tagged plants in each treatment plot were collected, weighed using an electronic weighing scale and the mean weight was estimated in grams (g).

3.4.4.4 Pod Weight Per Plot

All pods from the four middle rows of each treatment plot were weighed using an electronic weighing scale and the mean weight was estimated in grams (g).

3.4.4.5 100-seed Weight

The 100-seed weight was estimated from three lots of 100 seeds selected from pods from the central rows and weighed using an electronic weighing scale and the mean weight was estimated in grams.

3.4.4.6 Pod Length

Five pods were randomly selected from the four middle rows of each plot for the pod length. The pod length was measured with a meter rule from the base to the tip of the pod and the mean length was estimated in centimeters (cm).

3.4.4.7 Haulm Weight Per Plot

After harvesting of pods, plants from the four middle rows of each treatment plot were cut above the soil surface. The haulm weight was determined by weighing the total biomass of stems and leaves by using an electronic weighing scale, and the average weight was recorded in grams (g).

3.4.4.8 Harvest Index

Harvest index was estimated as the ratio of total seed yield to biological yield of each treatment plot. The formula was adopted from Shabani & Sepaskhah (2019).

$$\text{Harvest index} = \frac{Seed\ yield\ (kg)}{Biological\ yield\ (Seed\ yield + stover\ yield)}$$

3.4.4.9 Active Nodules Count Per Plant

Five plants from the two boarder rows of each plot were uprooted and the active nodules were physically counted from the root at 71 DAP and the mean was estimated. Active nodules are firm, spherical, and display a distinct pink or reddish colour inside when cut open. Inactive nodules are often small, soft, and white or greenish internally (Sharma *et al.*, 2023).

3.4.4.10 Seed Weight Per Plot

The seed weight per plot was determined from the four middle rows of each plot with an electronic weighing scale and mean recorded in grams (g).

3.4.4.11 Grain yield per plot

The total yield was estimated by weighing the grains from the four middle rows of each plot and the result was then used to compute the yield in kg/ha. The formula used as described below was adopted from Shabani & Sepaskhah (2019).

$$\text{Yield (kg/ha)} = \frac{Seed\ yield\ (kg)}{Harvestable\ area\ (m^2)} \text{ x } \frac{10{,}000\ m^2}{1000}$$

3.5 Data Analysis

Data collected were subjected to Analysis of Variance (ANOVA) using GenStat Release Version 18.1 statistical package. Significant differences between treatment means were separated using Tukey's Honestly Significant Difference (HSD) at 5% significance level. Correlation matrix analysis was used to determine the relationship between some vegetative growth parameters and yield and yield components.

CHAPTER FOUR: RESULTS

4.1 Climatic conditions at the Experimental Sites

The climatic variables measured during the experimental period were total rainfall, relative humidity and mean temperature which stretched from March, 2023 to Julyn2023 and August 2023 to December 2023 during the major and minor cropping seasons respectively (Table 4.1). In the 2023 major cropping season, 784 mm of rainfall was recorded from March, 2023 to July, 2023 with the highest peak in April and July. Mean monthly relative humidity of 90.4 % and 63.0% was recorded for 6:00 hrs and 15:00 hrs respectively. The average minimum and maximum temperature were 22.76 ^{O}C and 31.72 ^{O}C, respectively (Table 4. 1).

In the 2023 minor cropping season, a total rainfall of 786.9 mm was recorded from August 2023 to December 2023 with the peak in August and October . However, no amount of rainfall was recorded in December. The average relative humidity for 6: 00 hrs and 15:00 hrs was 88.0% and 61.6%, respectively from August 2023 to December 2023 (Table 4.1). The mean minimum and maximum temperature were 22.82 ^{O}C and 31.84 ^{O}C, respectively.

Table 4. 1: Climatic conditions at the experimental site

Month	**Total Rainfall (mm)**	**Relative Humidity (%)**		**Mean Temperature (^{O}C)**	
		6:00 hrs	**15:00hrs**	**Min**	**Max**
		2023 minor rainy season			
March, 2023	57.8	88	55	23.1	33.8
April	258.8	91	59	22.7	33.3
May	71.3	90	60	23.2	32.8
June	198.0	92	70	23.0	30.3
July	198.9	91	71	21.8	28.4
Total	784				
		2023 minor rainy season			
August, 2023	213.4	93	74	22.5	29.0
September	196.0	92	69	22.4	30.6
October	286.4	90	62	23.0	32.0
November	91.1	91	59	23.5	33.1
December	0.00	74	44	22.7	34.5
Total	786.9				

(Ghana Meteorological Agency– Asante Mampong, 2023)

4.2 4.2 Phenology of Common Bean

4.2.1 Days to 50% Emergence

The days to 50% emergence ranged from 9-11 days and 10 - 13 days during 2023 major and 2023 minor cropping seasons respectively (Table 4.2). In 2023 major cropping season, Adoye emerged almost two (2) days earlier than Ennepa. There were no significant ($P \geq 0.05$) differences among plant spacing and the interaction between variety and plant spacing in days to 50% emergence. There were no significant ($P \geq 0.05$) differences between varieties, plant spacing and the interaction between variety and plant spacing in number of days to 50% seedling emergence in 2023 minor cropping season (Table 4.2). In 2023 major cropping season, the seedlings emerged significantly earlier as compared to 2023 minor cropping season.

4.2.2 Percentage Crop Establishment

There were no significant (P≥0.05) differences between varieties, plant spacing and the interaction between variety and plant spacing in plant establishment in both cropping seasons (Table 4.2). Plant establishment ranged from 90.63- 96.88% and 77.74% to 82.82% for the major and minor rainy seasons, respectively. In 2023 major cropping season, significantly higher established plants were recorded as compared to those obtained during 2023 minor cropping season (Table 4.2). In the major season Adoye had a higher percentage plant establishment, while in the minor season Ennepa had a higher percentage plant establishment (Table 4.2).

Table 4. 2: Effect of variety and plant spacing on number of days to 50% emergence and percentage crop establishment during 2023 major and 2023 minor cropping seasons

Treatment	Days to 50% emergence		Percentage plant establishment	
	Major season	Minor season	Major season	Minor season
Variety (V)				
Adoye	9b	11	94.92	77.74
Ennepa	11a	12	91.41	82.82
HSD (P≤ 0.05)	**1.44**	**NS**	**NS**	**NS**
Spacing (S)				
60 cm x 20 cm	10	12	90.63	78.52
50 cm x 20 cm	9	10	91.80	82.42
40 cm x 20 cm	10	12	93.36	82.43
30 cm x 20 cm	11	13	96.88	77.74
HSD (P≤ 0.05)	**NS**	**NS**	**NS**	**NS**
CV (%)	**19.61**	**22.43**	**6.58**	**10.74**
Variety (HSD=0.05)	*1.13***		*NS*	
Spacing (HSD=0.05)	*NS*		*NS*	
Season (HSD=0.05)	*1.13***		*3.87***	
Variety x Spacing (HSD=0.05)	*NS*		*NS*	
Variety x Season (HSD=0.05)	*NS*		*7.25***	
Spacing x Season (HSD=0.05)	*NS*		*NS*	

4.2.3 Days to 50% Flowering

Across both cropping seasons, Ennepa flowered almost three (3) days earlier than Adoye (Table 4.3). Days to 50% flowering ranged from 35-40 days for both major and minor rainy season. Plant spacing and the interaction between variety and plant spacing had no significant effect on days to 50% flowering across both cropping seasons. Season had no significant effect on days to 50% flowering. The interaction between variety x spacing, variety x season, spacing x season as well as variety x season x spacing did not significantly influenced number of days to 50% flowering (Table 4.3).

4.2.4 Days to 50% Podding

Table 4.3 shows the result of days to 50% podding as influenced by variety and plant spacing during 2023 major and 2023 minor cropping seasons. The days to 50% podding ranged from 41.00 days to 47.00 days and 41.00 days to 51.00 days during 2023 major and 2023 minor cropping seasons respectively. Ennepa fruited almost three (3) days and four (4) days earlier than Adoye during 2023 major and 2023 minor cropping seasons respectively. Plant spacing had no significant effect on days to 50% podding across both cropping seasons. In 2023 major cropping season, Ennepa grown at a spacing of 50-30 cm x 20 cm had the least and same number of days to 50% podding (41.00 days) and was insignificantly ($P \geq 0.05$) different from all the interactive effects, except Adoye (50 cm x 20 cm) interaction which podded 6 days later.

In 2023 minor cropping season, Ennepa grown at a spacing of 60 cm x 20 cm and 30 cm x 20 cm had the same least days to 50% podding (41.00 days) and was insignificantly ($P \geq 0.05$) different from all the interactive effects except Adoye (50 cm x 20 cm) interaction which fruited 10 days later. Variety x spacing interaction significantly influenced days to 50% podding. The interaction between variety x season, spacing x season as well as variety x season x spacing interaction did not significantly influenced number of days to 50% fruiting (Table 4.3). Season had no significant effect on days to 50% podding.

Table 4. 3: Effect of variety and plant spacing on number of days to 50% flowering and days to 50% fruiting during 2023 major and 2023 minor cropping seasons

Treatment	Days to 50% flowering		Days to 50% podding	
	Major season	Minor season	Major season	Minor season
Variety (V)				
Adoye	39a	39a	44a	46a
Ennepa	35b	36b	41b	42b
HSD (P≤ 0.05)	**2.14**	**2.28**	**1.41**	**2.59**
Spacing (S)				
60 cm x 20 cm	38	38	42	42
50 cm x 20 cm	37	37	44	46
40 cm x 20 cm	36	37	42	45
30 cm x 20 cm	37	37	42	43
HSD (P≤ 0.05)	**NS**	**NS**	**NS**	**NS**
Interaction (V x S)				
Adoye (60 cm x 20 cm)	40	39	42b	42b
Adoye (50 cm x 20 cm)	40	40	47a	51a
Adoye (40 cm x 20 cm)	37	38	43ab	45ab
Adoye (30 cm x 20 cm)	38	39	43b	44ab
Ennepa (60 cm x 20 cm)	36	37	42b	41b
Ennepa (50 cm x 20 cm)	35	35	41b	41b
Ennepa (40 cm x 20 cm)	35	35	41b	44ab
Ennepa (30 cm x 20 cm)	36	36	41b	41b
Mean	**37**	**37**	**43**	**44**
HSD (P ≤ 0.05)	**NS**	**NS**	**4.54**	**8.34**
CV (%)	**7.85**	**8.33**	**4.50**	**8.05**
Variety (HSD=0.05)	*1.46***		*1.43***	
Spacing (HSD=0.05)	*NS*		*NS*	
Season (HSD=0.05)	*NS*		*NS*	
Variety x Spacing (HSD=0.05)	*NS*		*4.52***	
Variety x Season (HSD=0.05)	*NS*		*NS*	
Spacing x Season (HSD=0.05)	*NS*		*NS*	

4.3 Vegetative Growth

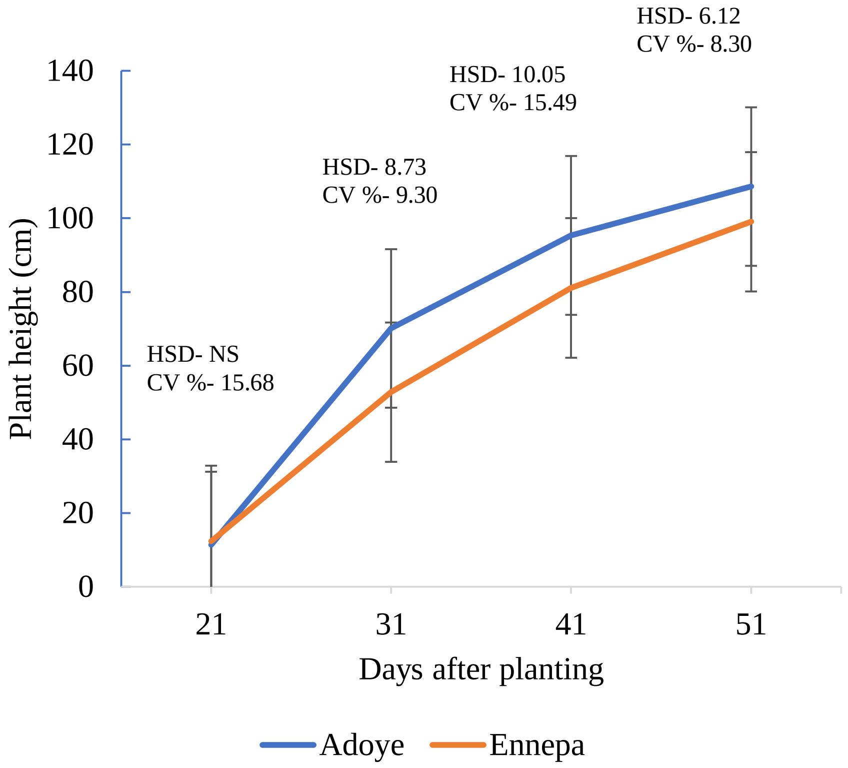
4.3.1 Plant Height

During 2023 major cropping season, variety had no significant effect on plant height at 21 DAP. Adoye produced significantly taller plants than Ennepa from 31 DAP to 51 DAP. In 2023 minor season, Ennepa produced the tallest plant at 21, 31 and 41 DAP, respectively, and was 13.86%, 10.50% and 9.49% taller than Adoye. Variety had no significant effect on plant height at 51 DAP (Figure 4.1).

Plant spacing had no significant effect on plant height at 21-51 DAP except at 41 DAP. For plant spacing in the minor season, there were no significant differences between plant spacing in plant height from 21 to 31 DAP (Figure 4.2).

Ennepa grown at a spacing of 60 cm x 20 cm recorded the highest plant height and was significantly different from Adoye grown at the same space at 21 DAP in the major season. Adoye grown at a spacing of 40 cm x 20 cm produced the tallest plants and was significantly taller plants than Ennepa grown at 60 cm x 20 cm from 31 to 51 DAP (Figure 4.3). In the minor season, the interaction between Ennepa and (60 cm x 20 cm) recorded significantly taller plants than Adoye grown at a spacing of 40 cm x 20 cm from 21 to 31 DAP. Ennepa and (50 cm x 20 cm) interactions recorded significantly taller plants (27.30 cm) than Adoye and (50 cm x 20 cm) interactions which produced the least plant height of 15.60 cm. The interactive effects did not significantly influence plant height at 51 DAP (Figure 4.3).

(A) 2023 major season



(B) 2023 minor season

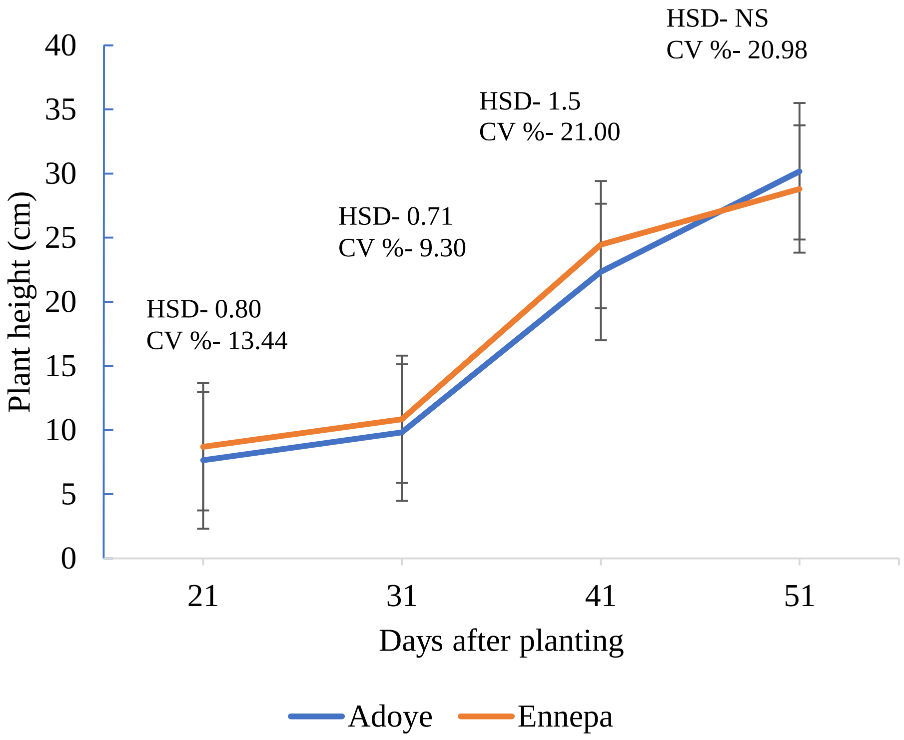
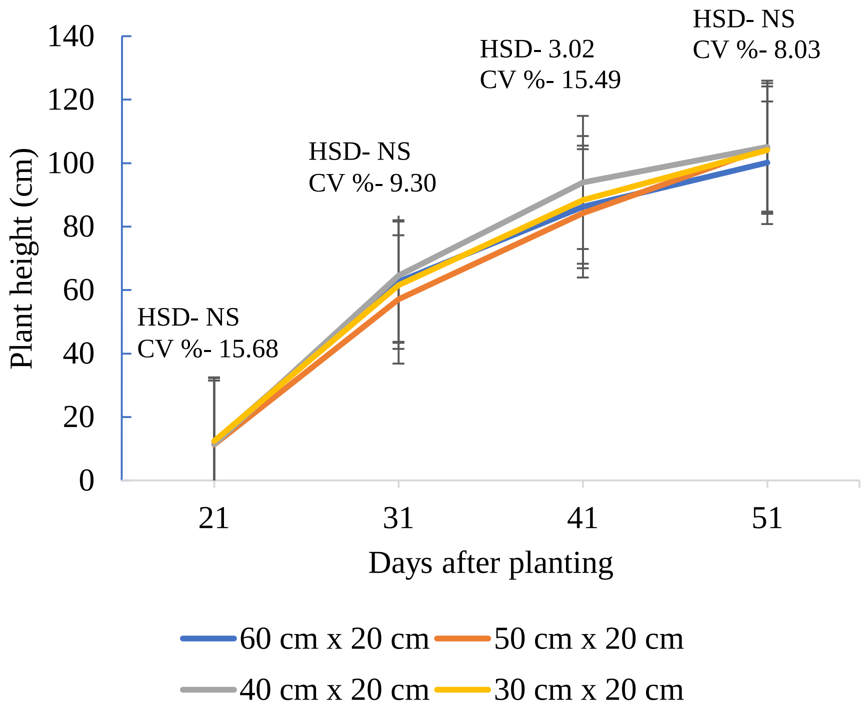


Figure 4. 1: Effect of common variety on plant height

(A) 2023 major season



(B) 2023 minor season

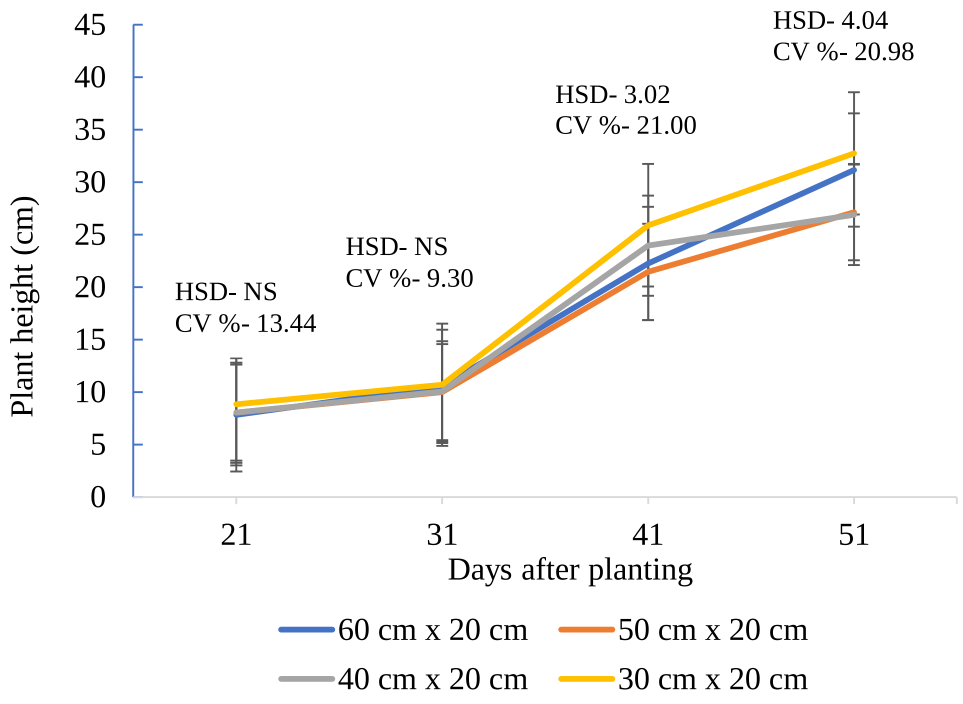
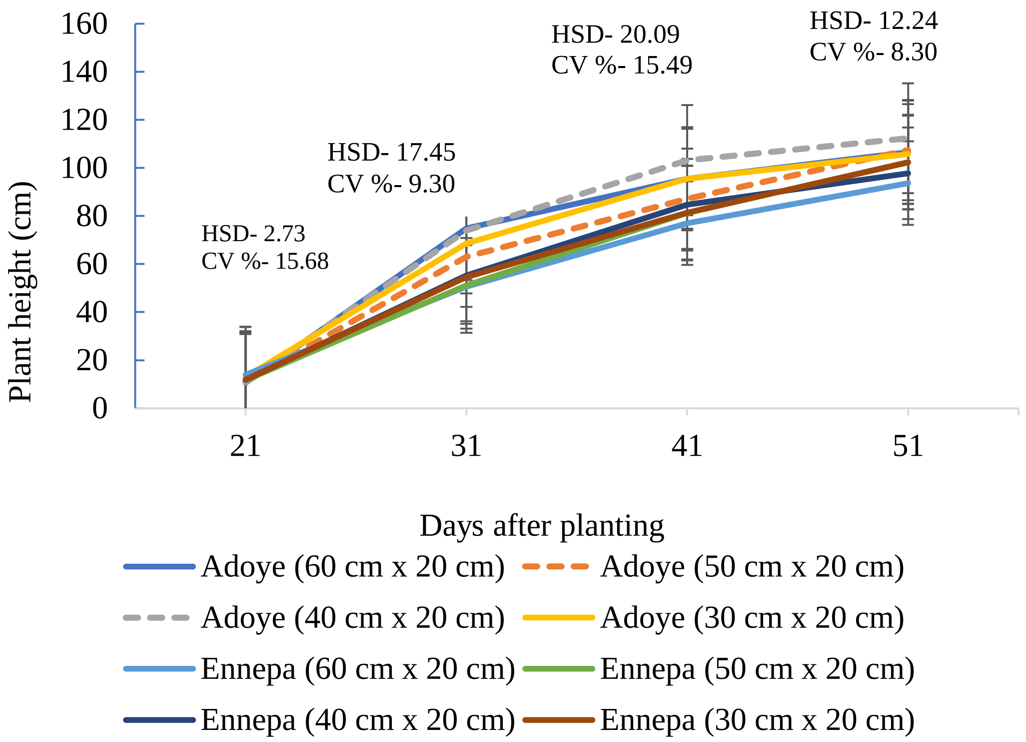


Figure 4. 2: Effect of plant spacing on plant height

(A) 2023 major season



(B) 2023 major season

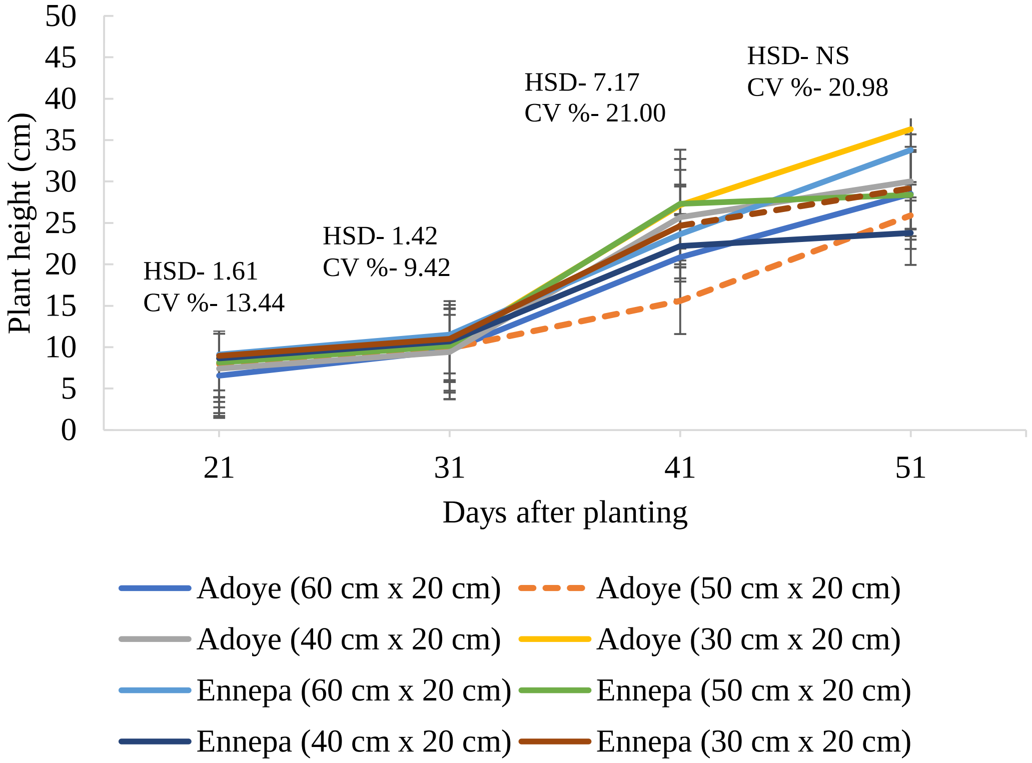


Figure 4. 3: Effect of variety x plant spacing interaction on plant height

4.3.2 Number of Branches Per Plant

Tables 4.4 and 4.5 show number of branches per plant as influenced by variety and plant spacing during 2023 major and 2023 minor cropping seasons. Variety had no significant effect on number of branches per plant at 21 and 51 DAP during 2023 major cropping season. Adoye produced significantly higher number of branches per plant than Ennepa from 31 to 41 DAP during 2023 major cropping season. Common bean plants grown at a spacing of 60 cm x 20 cm recorded significantly greater number of branches per plant than plants grown at a spacing of 30 cm x 20 cm throughout the entire growing period except at 51 DAP where plant spacing had no significant effect on number of branches per plant (Table 4.4). Adoye grown at a spacing of 60 cm x 20 cm recorded significantly higher number of branches per plant than plant than both varieties grown at a spacing of 30 cm x 20 cm throughout the entire growing period (Table 4.5).

During 2023 minor cropping season, Ennepa produced significantly higher number of branches per plant than Adoye from 21 to 41 DAP except at 51 where variety had no significant effect on number of branches per plant (Table 4.5). Common bean plants grown at a spacing of 30 cm x 20 cm recorded significantly greater number of branches per plant than plants grown at a spacing of 40 cm x 20 cm at 21 and 51 DAP. Varieties had no significant effect on number of branches per plant from 31 to 41 DAP. Adoye and (60 cm x 20 cm) interactions recorded significantly greater number of branches per plant than same variety grown at a spacing of 40 cm x 20 cm at 21 DAP. Ennepa and (60 cm x 20 cm) interactions produced significantly higher number of branches per plant than Adoye grown at a spacing of 50 cm x 20 cm from 31 to 41 DAP. Ennepa and (60 cm x 20 cm) interactions recorded significantly higher number of branches per plant than Adoye grown at a spacing of 40 cm x 20 cm at 51 DAP.

Table 4. 4: Effect of variety and plant spacing on number of branches per plant during 2023 major cropping season

Treatment	Number of branches per plant			
	21 DAP	31 DAP	41 DAP	51 DAP
Variety (V)				
Adoye	7	16a	22a	24
Ennepa	6	14b	19b	24
HSD (P≤ 0.05)	**NS**	**2.07**	**1.83**	**NS**
Spacing (S)				
60 cm x 20 cm	8a	17a	22a	25
50 cm x 20 cm	7b	15ab	21ab	24
40 cm x 20 cm	6b	14ab	19b	25
30 cm x 20 cm	6b	13b	20ab	23
HSD (P≤ 0.05)	**1.13**	**2.93**	**2.58**	**NS**
Interaction (V x S)				
Adoye (60 cm x 20 cm)	9a	20a	25a	27a
Adoye (50 cm x 20 cm)	7b	17ab	24ab	24ab
Adoye (40 cm x 20 cm)	6b	14b	19c	23b
Adoye (30 cm x 20 cm)	7b	13b	18c	23b
Ennepa (60 cm x 20 cm)	7ab	14b	19c	23b
Ennepa (50 cm x 20 cm)	7b	14b	18c	23b
Ennepa (40 cm x 20 cm)	6b	15b	19c	26ab
Ennepa (30 cm x 20 cm)	6b	13b	21bc	23b
HSD (P≤ 0.05)	**1.60**	**4.14**	**3.65**	**3.61**
CV (%)	**15.90**	**18..78**	**12.08**	**10.22**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

Table 4. 5: Effect of variety and plant spacing on number of branches per plant during 2023 minor cropping season

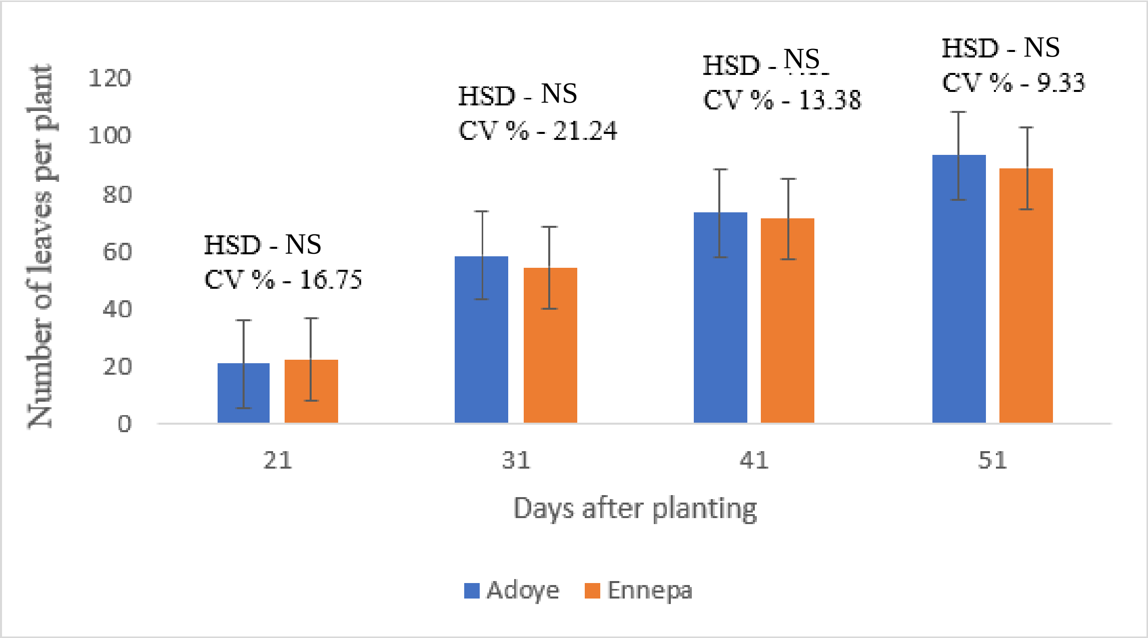
Treatment	Number of branches per plant			
	21 DAP	31 DAP	41 DAP	51 D AP
Variety (V)				
Adoye	4b	6b	12b	17
Ennepa	5a	8a	17a	20
HSD (P≤ 0.05)	**0.78**	**1.35**	**2.88**	**NS**
Spacing (S)				
60 cm x 20 cm	5.85b	7	15	19a
50 cm x 20 cm	5.73b	7	15	21a
40 cm x 20 cm	4.45b	6	12	13b
30 cm x 20 cm	5.43a	7	15	21a
HSD (P≤ 0.05)	**0.60**	**NS**	**NS**	**6.49**
Interaction (V x S)				
Adoye (60 cm x 20 cm)	6a	6ab	11b	16ab
Adoye (50 cm x 20 cm)	4ab	5b	10b	20ab
Adoye (40 cm x 20 cm)	4b	6ab	10b	12b
Adoye (30 cm x 20 cm)	5ab	7ab	15ab	21a
Ennepa (60 cm x 20 cm)	5ab	8a	19a	24a
Ennepa (50 cm x 20 cm)	6a	8a	19a	22a
Ennepa (40 cm x 20 cm)	5ab	7ab	13b	15ab
Ennepa (30 cm x 20 cm)	6a	8a	16ab	20ab
HSD (P≤ 0.05)	**1.81**	**2.70**	**5.75**	**9.18**
CV (%)	**24.15**	**26.92**	**27.74**	**33.39**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

4.3.3 Number of Leaves Per Plant

In 2023 major cropping season, there were no significant (P≥0.05) differences between variety in number of leaves per plant from 21 to 51 DAP (Figure 4.4A). In the same season, plant spacing produced no significant effect on number of leaves per plant from 21 to 51 DAP (Figure 4.5A). In 2023 minor cropping season, there were no significant (P≥0.05) differences in both variety and plant spacing in number of leaves per plant from 21 DAP to 31 DAP (Figure 4.4B and Figure 4.5B respectively). From 41 to 51 DAP, plants grown at a spacing of 60 cm x 20 cm followed by 50 cm x 20 cm and 30 cm x 20 cm produced significantly higher number of leaves per plant than plants grown at 40 cm x 20 cm.

(A) 2023 Major Season



(B) 2023 Minor Season

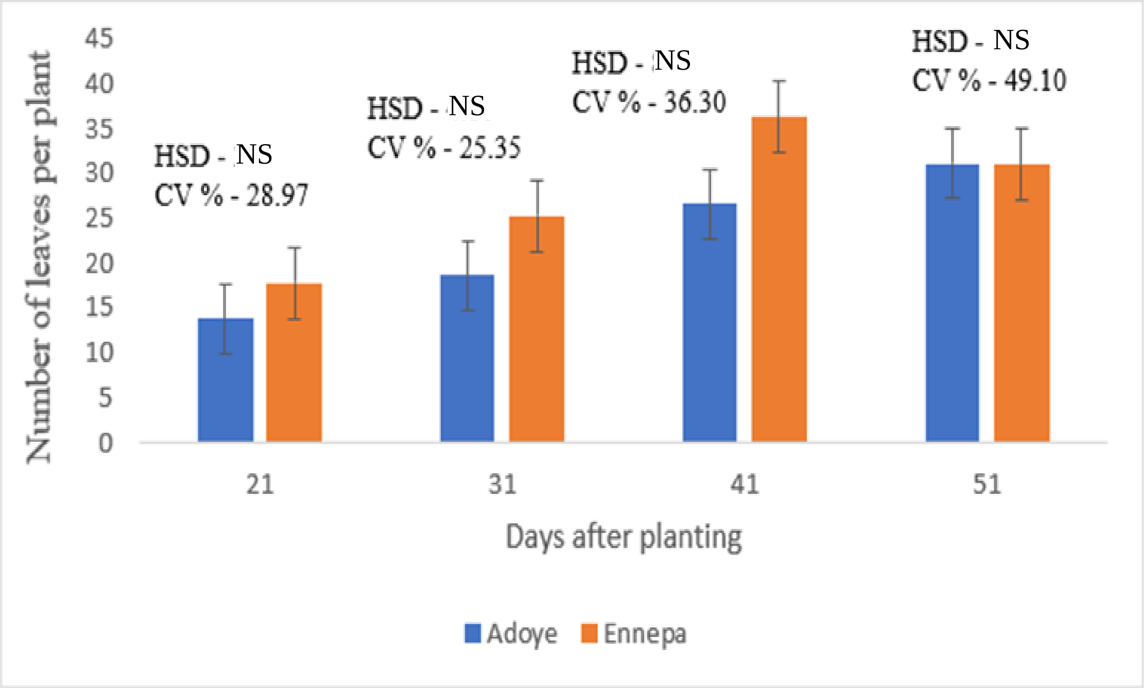
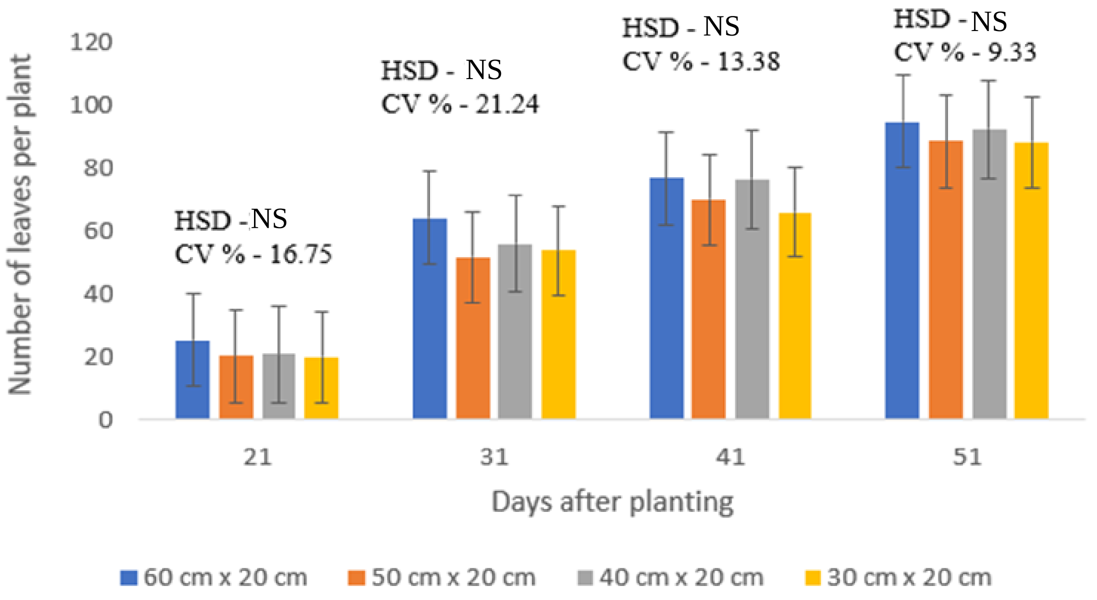


Figure 4. 4: Effect of common bean variety on number of leaves per plant

2023 Major Season



2023 Minor Season

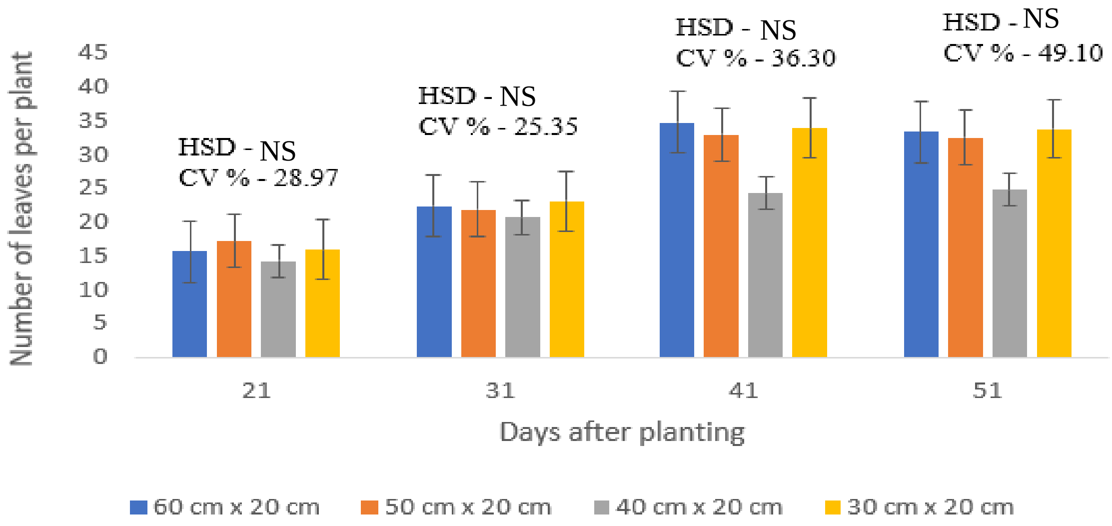


Figure 4. 5: Effect of plant spacing on number of leaves per plant

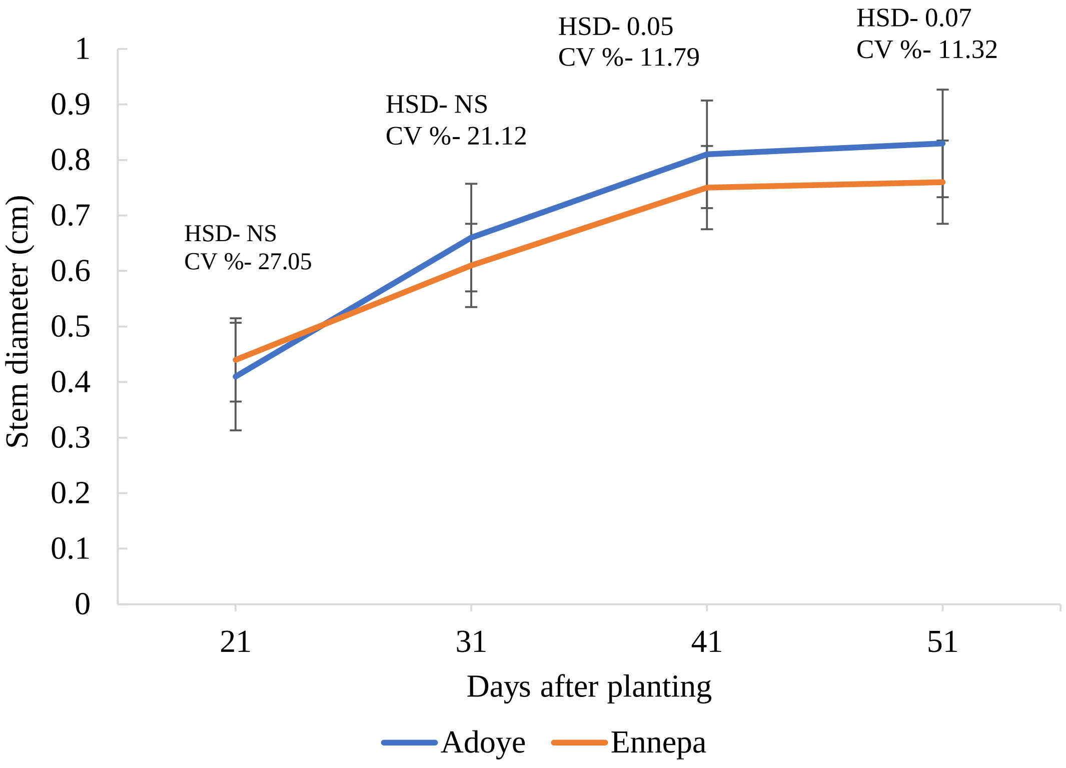
4.3.4 Stem Diameter

Figure 4.6 shows stem diameter as influenced by common bean variety during 2023 major and 2023 minor cropping seasons. Variety had no significant effect on stem diameter per plant from 21 and 31 DAP during 2023 major cropping season. Adoye produced significantly wider stem diameter than Ennepa from 41 to 51 DAP. During the 2023 minor cropping season, Ennepa produced significantly wider stem diameter than Adoye from 21 to 51 DAP except at 41 DAP where variety had no significant effect stem diameter.

Common bean plants grown at a spacing of 60 cm x 20 cm recorded significantly wider stem diameter than plants grown at a spacing of 40 cm x 20 cm throughout the entire growing period except at 31 DAP in the major season (Figure 4.7). Plant spacing had no significant effect on stem diameter from 21 to 41 DAP except at 51 DAP where 60 cm x 20 cm had significantly wider stem diameter than plants grown at a spacing of 40 cm x 20 cm in the minor season (Figure 4.7).

Adoye grown at a spacing of 60 cm x 20 cm recorded significantly wider stem diameter than same variety grown at a spacing of 30 cm x 20 cm throughout the entire growing period except from 31 to 41 DAP in the major season (Figure 4.8). Ennepa and (60 cm x 20 cm) interactions recorded significantly wider stem diameter than Adoye grown at a spacing of 50 cm x 20 cm throughout the growing period except from 31 to 41 DAP in the minor season (Figure 4.8).

(A) 2023 major season



(B) 2023 minor season

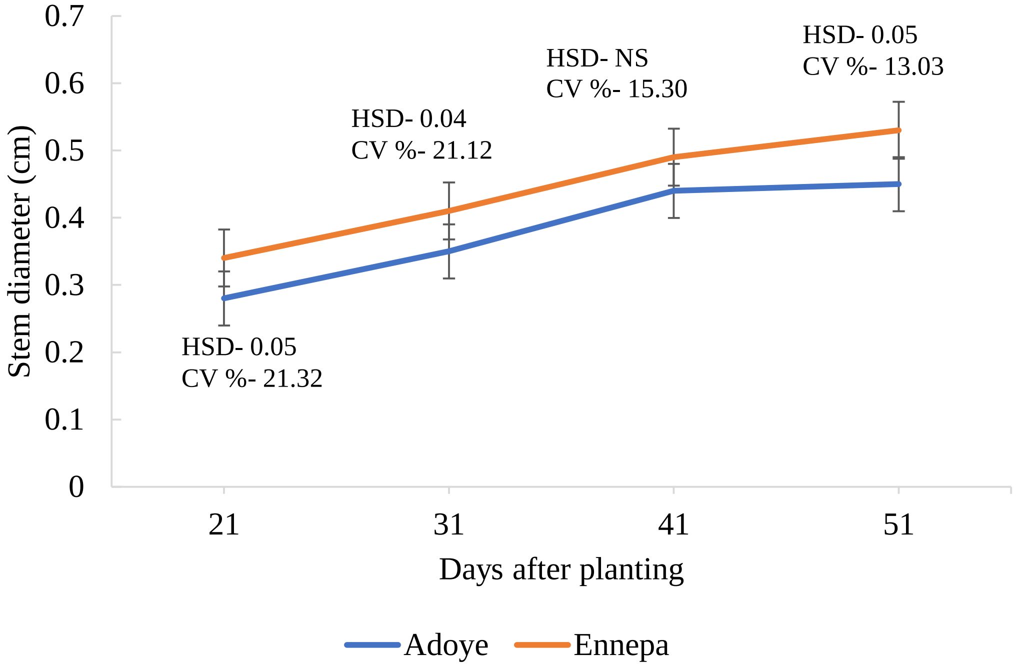
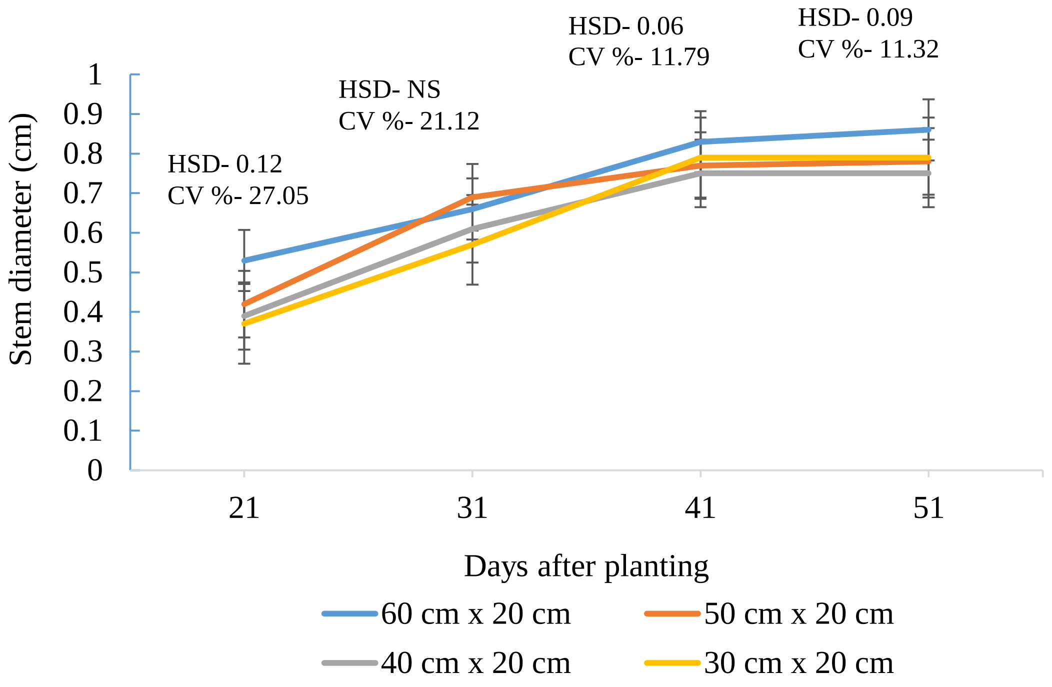


Figure 4. 6: Effect of common bean variety on stem diameter

(A) 2023 major season



(B) 2023 minor season

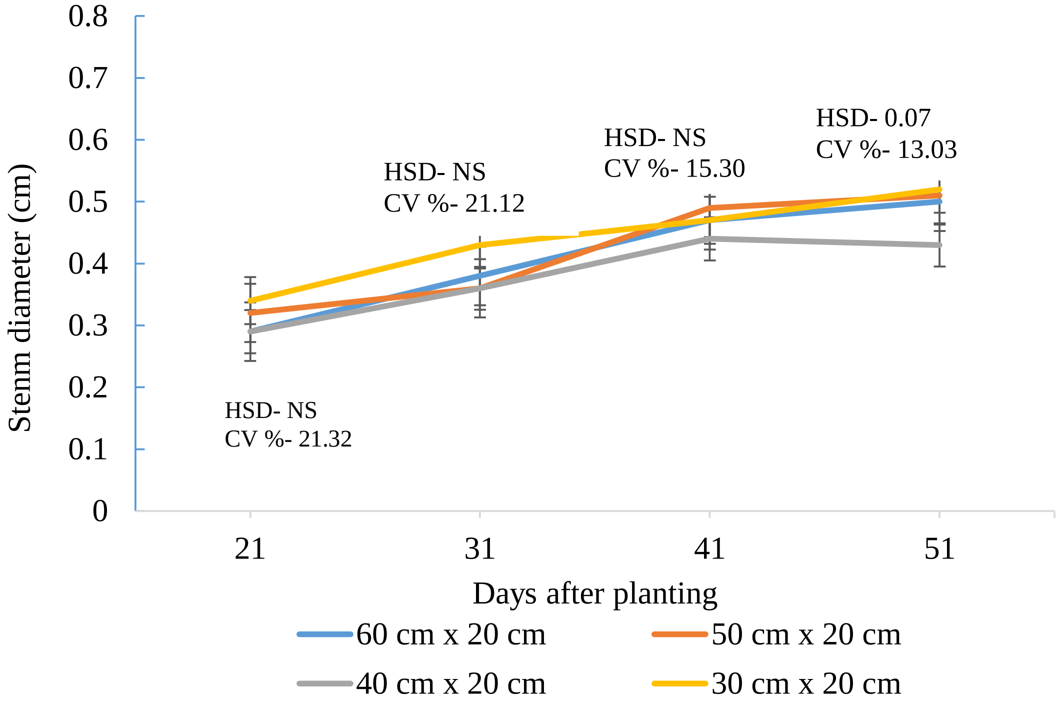
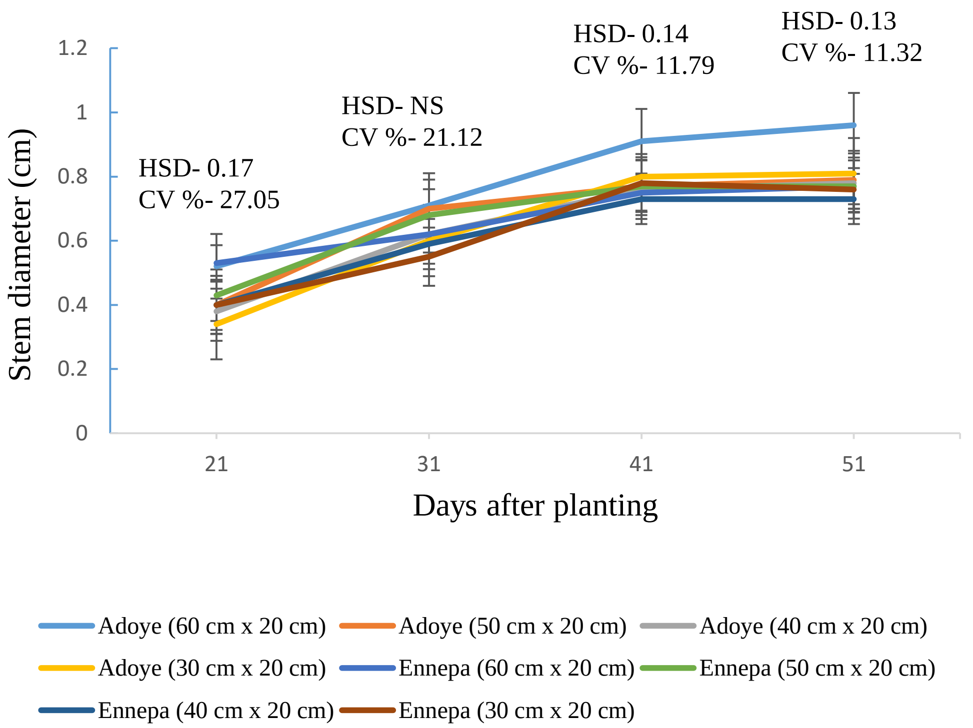


Figure 4. 7: Effect of plant spacing on stem diameter

(A) 2023 major season



(B) 2023 minor season

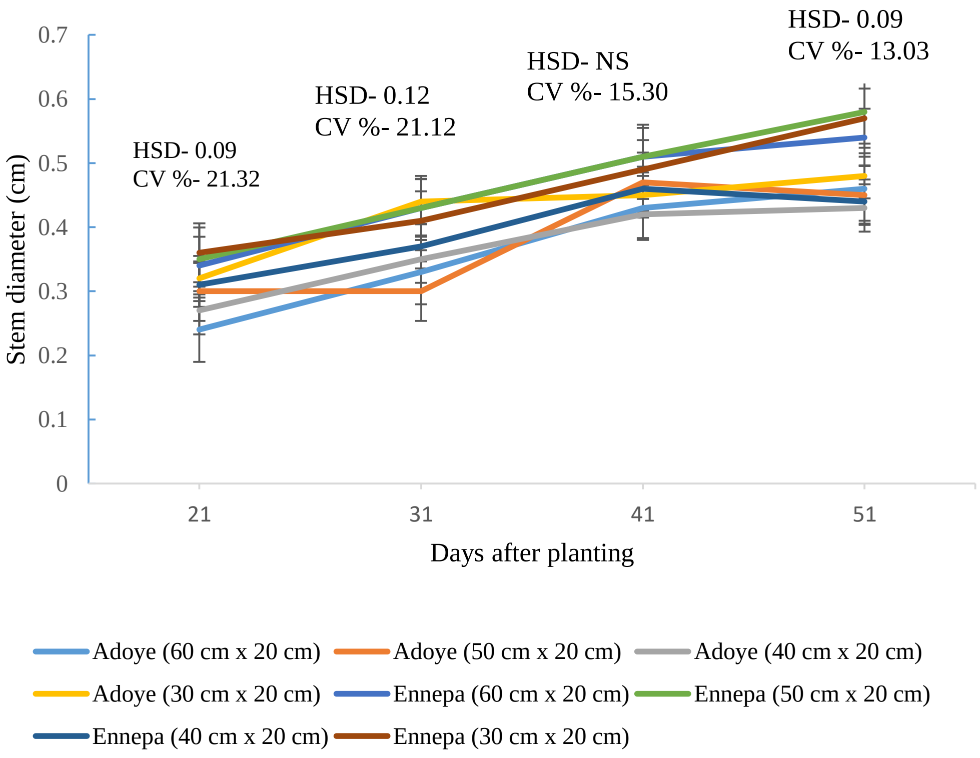


Figure 4. 8: Effect of variety x plant spacing interaction on plant height

4.3.5 Shoot Dry Weight Per Plant

Ennepa produced significantly heavier shoot dry weight per plant than Adoye from 21 to 41 DAP (Table 4.6). Plant spacing had no significant effect on shoot fresh weight at from 21 to 31 DAP except at 41 DAP where common bean plants grown at a spacing of 50 cm x 20 cm had significantly higher shoot dry weight per plant than plants grown at a spacing of 40 cm x 20 cm. Ennepa grown at a spacing of 30 cm x 20 cm recorded the heaviest shoot dry weight per plant and was significantly different from Adoye grown at a spacing of 60 cm x 20 cm from 21 and 31 DAP (Table 4.6). At 41 DAP, Ennepa grown at a spacing of 60 cm x 20 cm recorded significantly higher shoot dry weight per plant than Adoye grown at a spacing of 60 cm x 20 cm which recorded the least mean value of 30.25 g. During 2023 minor cropping season, variety, plant spacing and the interaction between variety and plant spacing had no significant effect on shoot dry weight per plant from 21 to 41 DAP (Table 4.7).

Table 4. 6: Effect of variety and planting on shoot dry weight per plant during 2023 major cropping season

Treatment	Shoot dry weight per plant (g)		
	21 DAP	31 DAP	41 DAP
Variety (V)			
Adoye	5.44b	15.56b	34.19b
Ennepa	7.50a	24.31a	42.44a
HSD (P≤ 0.05)	**1.03**	**3.51**	**7.68**
Spacing (S)			
60 cm x 20 cm	5.50	20.00	39.00ab
50 cm x 20 cm	6.25	18.38	40.63a
40 cm x 20 cm	7.25	21.38	36.38b
30 cm x 20 cm	6.88	20.00	37.25b
HSD (P≤ 0.05)	**NS**	**NS**	**3.00**
Interaction (V x S)			
Adoye (60 cm x 20 cm)	4.25b	15.25b	30.25b
Adoye (50 cm x 20 cm)	6.25ab	16.75b	36.75ab
Adoye (40 cm x 20 cm)	6.50ab	17.00b	35.50ab
Adoye (30 cm x 20 cm)	4.75b	13.25b	34.25ab
Ennepa (60 cm x 20 cm)	6.75ab	24.75a	47.75a
Ennepa (50 cm x 20 cm)	6.25ab	20.00ab	44.50ab
Ennepa (40 cm x 20 cm)	8.00ab	25.75a	37.25ab
Ennepa (30 cm x 20 cm)	9.00a	26.75a	40.25ab
HSD (P≤ 0.05)	**4.15**	**7.01**	**NS**
CV (%)	**20.58**	**23.93**	**27.25**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

Table 4. 7: Effect of variety and plant spacing on shoot dry weight per plant during 2023 minor cropping season

Treatment	Shoot dry weight per plant (g)		
	21 DAP	31 DAP	41 DAP
Variety (V)			
Adoye	1.22	2.84	7.06
Ennepa	1.09	3.66	9.39
HSD (P≤ 0.05)	**NS**	**NS**	**NS**
Spacing (S)			
60 cm x 20 cm	0.95	3.05	9.38
50 cm x 20 cm	1.40	3.29	8.37
40 cm x 20 cm	1.17	3.26	5.60
30 cm x 20 cm	1.11	3.40	9.54
HSD (P≤ 0.05)	**NS**	**NS**	**NS**
Interaction (V x S)			
Adoye (60 cm x 20 cm)	0.93	2.50	6.90
Adoye (50 cm x 20 cm)	1.57	3.01	7.76
Adoye (40 cm x 20 cm)	1.18	2.30	4.92
Adoye (30 cm x 20 cm)	1.22	3.56	8.65
Ennepa (60 cm x 20 cm)	0.97	3.61	11.87
Ennepa (50 cm x 20 cm)	1.24	3.57	8.98
Ennepa (40 cm x 20 cm)	1.16	4.21	6.28
Ennepa (30 cm x 20 cm)	1.00	3.25	10.43
HSD (P≤ 0.05)	**NS**	**NS**	**NS**
CV (%)	**25.08**	**20.54**	**21.48**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

4.3.6 Root Dry Weight Per Plant

Tables 4.8 and 4.9 show effect of variety and plant spacing on root dry weight per plant during 2023 major and 2023 minor cropping seasons. During 2023 major cropping season, Ennepa produced significantly heavier root dry weight per plant than Adoye at 21 and 41 DAP. Plant spacing had no significant effect on root dry weight per plant from 21 to 41 DAP (Table 4.8). Ennepa grown at a spacing of 30 cm x 20 cm recorded the heaviest root dry weight per plant and was significantly different from Adoye grown at a spacing of 40 cm x 20 cm from 21 to 41 DAP (Table 4.8).

During 2023 minor cropping season, Ennepa produced significantly heavier root dry weight per plant than Adoye at 21 DAP. Variety had no significant effect on root dry weight per plant from 31 to 41 DAP (Table 4.9). Plant spacing had no significant effect on root dry weight per plant from 21 to 41 DAP. Ennepa grown at a spacing of 40 cm x 20 cm recorded the heaviest root dry weight per plant and was significantly different from Adoye grown at a spacing of 40 cm x 20 cm which recorded the least at 21 DAP. Variety and plant spacing interactions had no significant effect on root dry weight per plant from 31 to 41 DAP.

Table 4. 8: Effect of variety and plant spacing on root dry weight per plant during 2023 major cropping season

Treatment	Root dry weight per plant (g)		
	21 DAP	31 DAP	41 DAP
Variety (V)			
Adoye	0.36b	1.36b	2.30b
Ennepa	1.09a	0.94a	2.96a
HSD (P≤ 0.05)	**0.24**	**0.51**	**0.61**
Spacing (S)			
60 cm x 20 cm	0.81	1.45	2.60
50 cm x 20 cm	0.59	1.49	2.54
40 cm x 20 cm	0.69	1.69	2.64
30 cm x 20 cm	0.79	1.95	2.75
HSD (P≤ 0.05)	**NS**	**NS**	**NS**
Interaction (V x S)			
Adoye (60 cm x 20 cm)	0.52cd	1.52abc	2.90ab
Adoye (50 cm x 20 cm)	0.43cd	1.27bc	2.22ab
Adoye (40 cm x 20 cm)	0.22d	1.11c	1.90b
Adoye (30 cm x 20 cm)	0.25d	1.53abc	2.17ab
Ennepa (60 cm x 20 cm)	1.11ab	1.37abc	2.30ab
Ennepa (50 cm x 20 cm)	0.75bc	1.71abc	2.85ab
Ennepa (40 cm x 20 cm)	1.16ab	1.28bc	3.37a
Ennepa (30 cm x 20 cm)	1.34a	2.38a	3.33a
HSD (P≤ 0.05)	**0.48**	**1.02**	**1.23**
CV (%)	**22.45**	**21.16**	**19.86**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

Table 4. 9: Effect of variety and plant spacing on root dry weight per plant during 2023 minor cropping season

Treatment	Root dry weight per plant (g)		
	21 DAP	31 DAP	41 DAP
Variety (V)			
Adoye	0.16b	0.36	0.59
Ennepa	0.21a	0.38	0.77
HSD (P≤ 0.05)	**0.05**	**NS**	**NS**
Spacing (S)			
60 cm x 20 cm	0.22	0.39	0.74
50 cm x 20 cm	0.17	0.35	0.73
40 cm x 20 cm	0.16	0.35	0.62
30 cm x 20 cm	0.19	0.37	0.63
HSD (P≤ 0.05)	**NS**	**NS**	**NS**
Interaction (V x S)			
Adoye (60 cm x 20 cm)	0.23a	0.35	0.70
Adoye (50 cm x 20 cm)	0.13bc	0.37	0.64
Adoye (40 cm x 20 cm)	0.09c	0.27	0.51
Adoye (30 cm x 20 cm)	0.19ab	0.45	0.52
Ennepa (60 cm x 20 cm)	0.21ab	0.43	0.78
Ennepa (50 cm x 20 cm)	0.21ab	0.34	0.81
Ennepa (40 cm x 20 cm)	0.24a	0.44	0.74
Ennepa (30 cm x 20 cm)	0.19ab	0.29	0.74
HSD (P≤ 0.05)	**0.09**	**NS**	**NS**
CV (%)	**20.04**	**21.34**	**23.41**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

4.4 Physiological Growth Parameters

4.4.1 Crop Growth Rate

There were significant (P≤0.05) differences between variety, plant spacing and their interactions on crop growth rate (CGR) during 2023 major cropping (Table 4.10). There was a gradual increase in CGR from 0-21 DAP to 41-51 DAP across both cropping seasons. During 2023 major cropping season, Ennepa recorded significantly higher CGR than Adoye throughout the entire growing period except at 31-41 DAP where varieties did not significantly influence CGR. Wider plant spacing specifically 60 cm x 20 cm recorded significantly higher CGR than plants grown at a spacing of 30 cm x 20 cm with the least mean values from 21 DAP to 51 DAP. Ennepa grown at a spacing of 60 cm x 20 cm recorded the highest CGR values and was significantly different from Adoye grown at a spacing of 30 cm x 20 cm from 0- 21 DAP to 41-51 DAP.

There were no significant (P≥0.05) differences between variety and plant spacing in CGR from 0-21 DAP to 41-51 DAP during 2023 minor cropping season (Tables 4.11). However, at 0-21 DAP plant spacing at 50 cm x 20 cm was 91.7% significantly higher than plant spacing at 30 cm x 20 cm.

Table 4. 10: Effect of variety and plant spacing on crop growth rate during 2023 major cropping season

	Crop growth rate (g/m^2/day)			
Treatment	0-21 DAP	21-31 DAP	31-41 DAP	41-51 DAP
Variety (V)				
Adoye	0.78b	3.14b	7.53	21.45b
Ennepa	1.12a	4.96a	9.29	24.73a
HSD (P≤ 0.05)	**0.24**	**1.07**	**NS**	**2.59**
Spacing (S)				
60 cm x 20 cm	1.15a	5.67a	9.74	25.99a
50 cm x 20 cm	1.04ab	4.17ab	9.56	24.35ab
40 cm x 20 cm	0.91ab	3.63b	6.96	20.88b
30 cm x 20 cm	0.70b	2.74b	7.38	21.15ab
HSD (P ≤ 0.05)	**0.34**	**2.03**	**NS**	**4.91**
Interaction (V X S)				
Adoye (60 cm x 20 cm)	0.87ab	4.33ab	8.01	22.71ab
Adoye (50 cm x 20 cm)	1.02ab	3.63ab	10.03	23.52ab
Adoye (40 cm x 20 cm)	0.77ab	2.73b	5.64	18.97b
Adoye (30 cm x 20 cm)	0.46b	1.88b	6.43	20.62b
Ennepa (60 cm x 20 cm)	0.44a	7.04a	11.47	29.26a
Ennepa (50 cm x 20 cm)	1.07ab	4.71ab	9.08	25.18ab
Ennepa (40 cm x 20 cm)	1.05ab	4.53ab	8.28	22.79ab
Ennepa (30 cm x 20 cm)	0.95ab	3.61ab	8.33	21.68ab
HSD (P ≤ 0.05)	**0.79**	**3.46**	**NS**	**8.36**
CV (%)	**21.84**	**19.01**	**22.45**	**15.25**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

Table 4. 11: Effect of variety and plant spacing on crop growth rate during 2023 minor cropping season

Treatment	Crop growth rate (g/m^2/day)			
	0-21 DAP	21-31 DAP	31-41 DAP	41-51 DAP
Variety (V)				
Adoye	0.18	1.54	2.37	12.28
Ennepa	0.18	2.11	2.96	13.21
HSD (P≤ 0.05)	**NS**	**NS**	**NS**	**NS**
Spacing (S)				
60 cm x 20 cm	0.21ab	2.70	3.89	13.12
50 cm x 20 cm	0.23a	1.77	2.92	13.35
40 cm x 20 cm	0.15ab	1.45	1.90	11.70
30 cm x 20 cm	0.12b	1.39	1.95	12.81
HSD (P ≤ 0.05)	**0.11**	**NS**	**NS**	**NS**
Interaction (V X S)				
Adoye (60 cm x 20 cm)	0.21	1.83	2.92	13.26
Adoye (50 cm x 20 cm)	0.24	1.56	2.69	12.41
Adoye (40 cm x 20 cm)	0.15	1.61	2.11	11.76
Adoye (30 cm x 20 cm)	0.13	1.19	1.76	11.70
Ennepa (60 cm x 20 cm)	0.21	3.57	4.86	12.98
Ennepa (50 cm x 20 cm)	0.22	1.99	3.14	14.29
Ennepa (40 cm x 20 cm)	0.16	1.28	1.69	11.64
Ennepa (30 cm x 20 cm)	0.11	1.59	2.14	13.93
HSD (P ≤ 0.05)	**NS**	**NS**	**NS**	**NS**
CV (%)	**23.04**	**25.04**	**24.18**	**14.75**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

4.4.2 Relative Growth Rate

There were significant (P≤0.05) differences between variety, plant spacing and their interactions on relative growth rate (RGR) at 0-21 DAP and 41-51 DAP during 2023 major cropping season (Table 4.12). Generally, there was a gradual reduction in RGR from 0-21 DAP and 41-51 DAP among all the treatments. Ennepa recorded 8.33% and 25% RGR more than Adoye at 0-21 DAP and 41 -51 DAP respectively. Ennepa grown at a spacing of 60 cm x 20 cm had significantly higher RGR than Adoye grown at the same space (60 cm x 20 cm) at 0-21 DAP and 41-51 DAP. There were no significant (P≥0.05) differences between variety, plant spacing and their interactions on RGR from 21-31 DAP to 31-41 DAP. Again, plant spacing had no significant difference on RGR at 0-21 DAP and 41-51 DAP.

There was gradual reduction in relative growth rate (RGR) among all the treatments from 0-21 DAP to 41-51 DAP (Table 4.13). There were no significant ($P \geq 0.05$) differences between variety and plant spacing in RGR from 0-21 DAP to 41 -51 DAP during 2023 minor cropping season.

Table 4. 12: Effect of variety and plant spacing on relative growth rate during 2023 major cropping season

	Relative growth rate (g/m^2/day)			
Treatment	0-21 DAP	21-31 DAP	31-41 DAP	41-51 DAP
Variety (V)				
Adoye	0.36b	0.08	0.11	0.08b
Ennepa	0.39a	0.06	0.12	0.10a
HSD ($P \leq 0.05$)	**0.02**	**NS**	**NS**	**0.01**
Spacing (S)				
60 cm x 20 cm	0.37	0.07	0.12	0.08
50 cm x 20 cm	0.37	0.08	0.11	0.09
40 cm x 20 cm	0.36	0.06	0.11	0.09
30 cm x 20 cm	0.36	0.06	0.12	0.10
HSD ($P \leq 0.05$)	**NS**	**NS**	**NS**	**NS**
Interaction (V X S)				
Adoye (60 cm x 20 cm)	0.35b	0.07	0.13	0.07bc
Adoye (50 cm x 20 cm)	0.36ab	0.08	0.09	0.09abc
Adoye (40 cm x 20 cm)	0.36ab	0.07	0.11	0.08abc
Adoye (30 cm x 20 cm)	0.35ab	0.09	0.11	0.07bc
Ennepa (60 cm x 20 cm)	0.39a	0.07	0.12	0.10a
Ennepa (50 cm x 20 cm)	0.38ab	0.08	0.11	0.09abc
Ennepa (40 cm x 20 cm)	0.37ab	0.04	0.12	0.10a
Ennepa (30 cm x 20 cm)	0.37ab	0.04	0.12	0.10a
HSD ($P \leq 0.05$)	**0.04**	**NS**	**NS**	**0.03**
CV (%)	**17.50**	**27.29**	**23.01**	**21.80**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

Table 4. 13: Effect of variety and plant spacing on relative growth rate during 2023 minor cropping season

Treatment	Relative growth rate ($g/m^2/day$)			
	0-21 DAP	21-31 DAP	31-41 DAP	41-51 DAP
Variety (V)				
Adoye	0.54	0.43	0.24	006
Ennepa	0.48	0.39	0.28	0.07
HSD (P≤ 0.05)	**NS**	**NS**	**NS**	**NS**
Spacing (S)				
60 cm x 20 cm	0.51	0.40	0.24	0.06
50 cm x 20 cm	0.51	0.38	0.29	0.04
40 cm x 20 cm	0.49	0.43	0.27	0.06
30 cm x 20 cm	0.52	0.43	0.25	0.09
HSD (P ≤ 0.05)	**NS**	**NS**	**NS**	**NS**
Interaction (V X S)				
Adoye (60 cm x 20 cm)	0.54	0.41	0.20	0.03
Adoye (50 cm x 20 cm)	0.55	0.40	0.28	0.03
Adoye (40 cm x 20 cm)	0.53	0.48	0.25	0.08
Adoye (30 cm x 20 cm)	0.53	0.43	0.24	0.09
Ennepa (60 cm x 20 cm)	0.48	0.40	0.29	0.09
Ennepa (50 cm x 20 cm)	0.46	0.37	0.29	0.05
Ennepa (40 cm x 20 cm)	0.47	0.38	0.30	0.04
Ennepa (30 cm x 20 cm)	0.50	0.43	0.26	0.09
HSD (P ≤ 0.05)	**NS**	**NS**	**NS**	**NS**
CV (%)	**26.21**	**27.36**	**25.75**	**22.58**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

4.5 Yield and Yield Components

4.5.1 Number of Plants Harvested

There were no significant (P≥0.05) differences between variety and plant spacing in number of plants harvested across both cropping seasons. Significantly higher number of plants harvested was recorded in 2023 major cropping season as compared to those obtained during 2023 minor cropping season (Table 4.14).

Table 4. 14: Effect of variety and plant spacing on number of plants harvested during 2023 major and 2023 minor cropping seasons

Treatment	Number of plants harvested	
	Major season	Minor season
Variety (V)		
Adoye	30	25
Ennepa	29	27
HSD (P≤ 0.05)	**NS**	**NS**
Spacing (S)		
60 cm x 20 cm	29	25
50 cm x 20 cm	29	26
40 cm x 20 cm	30	26
30 cm x 20 cm	31	25
HSD (P ≤ 0.05)	**NS**	**NS**
CV (%)	**6.58**	**10.74**

Means bearing the same letters within a column are not significantly different at 5% level of significance; DAP = Days after planting; x = interaction.

4.5.2 Number of Pods Per Plant

Variety, plant spacing and the interaction between variety and plant spacing had no significant effect on number of pods per plant during 2023 major cropping season. In 2023 minor season, there were significant (P≤0.05) differences between variety and the interaction between variety and plant spacing on number of pods per plant. Adoye and the interaction between Adoye and 30 cm x 20 cm was superior in number of pods per plant, which was 13.60% and 58.18% higher than Ennepa grown at a spacing of 40 cm x 20 cm respectively. Plant spacing had no significant effect on number of pods per plant (Table 4.15). Significantly higher number of pods per plant was recorded in 2023 major cropping season as compared to those obtained during 2023 minor cropping season.

4.5.3 Pod Weight Per Plant

In 2023 major cropping season, variety, plant spacing and their interaction had no significant effect on pod weight per plant (Table 4.15).

In 2023 minor cropping season, Ennepa recorded significantly heavier pod weight per plant (207.75g) than Adoye (189.94 g). Plant spacing had no significant effect on pod weight per plant. Ennepa grown at a spacing of 50 cm x 20 cm had the highest (222.75 g) pod weight per plant and was significantly ($P \leq 0.05$) different from Adoye grown at a spacing of 40 cm x 20 cm with the least mean of 179.75 g (Table 4.15). Seasons had no significant effect on pod weight per plant.

Table 4. 15: Effect of variety and plant spacing on number of pods per plant and pod weight per plant during 2023 major and 2023 minor cropping seasons

Plant Spacing	Number of pods per plant						Pod weight per plant (g)					
	Major season			Minor season			Major season			Minor season		
	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean
30 cm x 20 cm	22	23	23	22	20	21	203.25	201.75	203	207	197.75	202
40 cm x 20 cm	29	36	33	14	21	18	189	217	203	179.75	198.25	189
50 cm x 20 cm	26	27	27	19	20	20	193.25	172	183	187	222.75	205
60 cm x 20 cm	32	27	30	17	21	19	225	215	220	186	212.25	199
Mean	**27**	**28**		**18**	**21**		**202.63**	**201.44**		**189.94**	**207.75**	
CV (%)	= 23.95			= 13.80			= 21.38			= 18.28		
Variety (V) HSD (0.05)	= NS			= 1.94			= NS			=9.337		
Spacing (S) HSD (0.05)	= NS			= NS			= NS			= NS		
V x S HSD (0.05)	= NS			= 6			= NS			= NS		
Season HSD (0.05)	= 2.46			= 2.46			= NS			= NS		

4.5.4 Pod Weight Per Plot

During 2023 major cropping season, variety significantly influenced pod weight per plot where Ennepa produced 184.75 g higher than Adoye. Plant spacing and the interaction between variety and plant spacing had no significant effect on pod weight per plot.

During 2023 minor cropping season, variety, plant spacing and their interaction had no significant effect on pod weight per plot (Table 4.16). However, Ennepa recorded higher (579.00 g) pod weight per plot than Adoye (562.81 g). Common bean plants that were grown at a spacing of 50 cm x 20 cm recorded the highest pod weight per plot whereas Ennepa x (60 cm x 20 cm) interactions recorded the highest pod weight per plot. Pod weight per plot recorded during 2023 major cropping season was significantly higher than those obtained during 2023 minor cropping season.

4.5.5 100- Seed Weight

Table 4.19 shows 100-seed weight as influenced by variety and plant spacing during 2023 major and 2023 minor cropping seasons. During 2023 major cropping season. Ennepa produced the greatest (25.00 g) 100-seed weight and was 51.94% higher than Adoye which recorded the least (23.13 g). Plant spacing and the interaction between variety and plant spacing had no significant effect on 100-seed weight.

Variety, plant spacing and their interaction had no significant effect on 100-seed weight in 2023 minor season (Table 4.16). 100-seed weight recorded during 2023 major cropping season was significantly higher than those obtained during 2023 minor cropping season.

Table 4. 16: Effect of variety and plant spacing on pod weight per plot and 100-seed weight during 2023 major and 2023 minor cropping seasons

Plant Spacing	Pod weight per plot (g)						100-seed weight (g)					
	Major season			Minor season			Major season			Minor season		
	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean
30 cm x 20 cm	594	766.75	680	567.5	570.5	569	23.25	24	24	27.25	27.25	27
40 cm x 20 cm	648.25	771.5	710	562.75	550.75	557	23	25.75	24	18.25	18.25	18
50 cm x 20 cm	584	896.75	740	575.75	610.5	593	23.5	24.25	24	19.5	17	18
60 cm x 20 cm	763	893.25	828	541.25	584.25	563	22.75	26	24	22.75	25.5	24
Mean	**647**	**832**		**562**	**579**		**23.13**	**25.00**		**21.94**	**22.00**	
CV (%)	= 29.46			= 28.53			= 6.37			= 10.28		
Variety (V) HSD (0.05)	= 160.28			= NS			= 1.13			= NS		
Spacing (S) HSD (0.05)	= NS			= NS			= NS			= NS		
V x S HSD (0.05)	= NS			= NS			= NS			= NS		
Season HSD (0.05)	= 77.92			= 77.92			= 2.67			= 2.67		

4.5.6 Pod Length

From Table 4.17, Ennepa produced significantly longer pod (11.50 cm) than Adoye (10.32 cm) in 2023 major cropping season. Plant spacing and the interaction between variety and plant spacing had no significant effect on pod length.

During 2023 minor season, Ennepa recorded the longest pods (11.78 cm) longer than Adoye (10.61). Plant spacing had no significant effect on pod length. Ennepa under 60 cm x 20 cm interactions recorded the longest (12.20 cm) pod length and was significantly different from Adoye by 60 cm x 20 cm interaction with the least (9.70 cm). Pod length was not significantly influence by season.

4.5.7 Haulm Weight Per Plot

During 2023 major cropping season, varieties had no significant effect on haulm weight per plot (Table 4.17). For plant spacing, common bean plants grown at 30 cm x 20 cm recorded the heaviest (339.87 g) and was 61.55% significantly higher than plants grown at a spacing of 60 cm x 20 cm (212.28 g). Variety and plant spacing interaction had no significant effect on haulm weight per plot.

During 2023 minor cropping season, Ennepa was significantly higher than Adoye in terms of haulm weight per plot. Plant spacing had no significant effect on haulm weight per plot. Ennepa under 60 cm x 20 cm interactions recorded the heaviest (328.75 g) haulm weight per plot and was significantly higher than Adoye under 40 cm x 20 cm (198.50 g). Season had no significant effect on haulm weight per plot.

Table 4. 17: Effect of variety and plant spacing on pod length and haulm weight per plot during 2023 major and 2023 minor cropping seasons

Plant Spacing	Pod length (cm)						Haulm weight per plot (g)					
	Major season			Minor season			Major season			Minor season		
	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean
30 cm x 20 cm	10.17	11.74	10.95	11.68	11.78	11.75	336.51	343.24	339.87	277.25	328.75	303.00
40 cm x 20 cm	10.04	11.21	10.62	11.03	11.40	11.21	312.50	207.28	259.88	198.50	268.00	233.25
50 cm x 20 cm	10.77	11.68	11.22	10.03	11.75	10.89	250.11	285.27	267.69	221.75	307.25	264.50
60 cm x 20 cm	10.31	11.39	10.85	9.70	12.20	10.95	208.50	216.06	212.28	202.00	320.25	261.13
Mean	**10.32**	**11.50**		**10.61**	**11.78**		**276.91**	**262.96**		**224.88**	**306.06**	
CV (%)	= 9.43			= 7.98			= 21.69			= 19.50		
Variety (V) HSD (0.05)	= 0.76			= 0.65			= NS			= 38.08		
Spacing (S) HSD (0.05)	= NS			= NS			= 119.24			= NS		
V x S HSD (0.05)	= NS			= 2.09			= NS			= 122.78		
Season HSD (0.05)	= NS			= NS			= 38.29			= 38.29		

4.5.8 Seed Weight Per Plot

Table 4.18 shows seed weight per plot as influenced by variety and plant spacing during 2023 major and 2023 minor cropping seasons. During 2023 major cropping season, Ennepa recorded the heaviest (497.44 g) seed weight per plot and was significantly heavier than Adoye (375.37 g). Plant spacing and the interaction between variety and plant spacing had no significant effect on seed weight per plot.

During 2023 minor cropping season, variety, plant spacing and their interaction had no significant effect on seed weight per plot. However, Ennepa recorded higher seed weight per plot than Adoye. Seed weight per plot recorded during 2023 major cropping season was significantly higher than those obtained during 2023 minor cropping season.

4.5.9 Active Nodule Count Per Plant

Table 4.18 shows active nodule count per plant as influenced by variety and plant spacing during 2023 major and 2023 minor cropping seasons. During 2023 major cropping season, variety, plant spacing and their interaction had no significant effect on active nodule count. However, Ennepa recorded higher active nodule count per plant than Adoye.

During 2023 minor cropping season, Ennepa was higher than Adoye in active nodule count per plant, but the difference was not significant. Plant spacing and the interaction between variety and plant spacing had no significant effect on active nodule coupnt per plant (Table 4.18). Season had no significant effect on active nodule count.

Table 4. 18: Effect of variety and plant spacing on seed weight per plot and active nodule count per plant during 2023 major and 2023 minor cropping seasons

Plant Spacing	Seed weight per plot (g)						Active nodule counts per plant					
	Major season			Minor season			Major season			Minor season		
	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean
30 cm x 20 cm	357.5	474.8	416.1	474.8	357.5	416.1	25.5	28.0	26.8	23.9	30.2	27.1
40 cm x 20 cm	350.8	489.8	420.3	489.8	350.8	420.3	16.5	18.8	17.6	17.9	25.9	21.9
50 cm x 20 cm	336.3	551.5	443.9	551.5	336.3	443.9	22.8	22.8	22.8	17.7	24.4	21.1
60 cm x 20 cm	457.0	473.8	465.4	473.8	457.0	465.4	21.3	26.0	23.6	16.7	25.2	20.9
Mean	**375.4**	**497.4**		**497.4**	**375.4**		**21.5**	**23.9**		**19.1**	**26.4**	
CV (%)	= 26.40			= 22.75			= 24.86			= 23.13		
Variety (V) HSD (0.05)	= 116.84			= NS			= NS			= NS		
Spacing (S) HSD (0.05)	= NS			= NS			= NS			= NS		
V x S HSD (0.05)	= NS			= NS			= NS			= NS		
Season HSD (0.05)	= 60.62			= 60.62			= NS			= NS		

4.5.10 Harvest Index

Table 4.19 shows harvest index as influenced by variety and plant spacing during 2023 major and 2023 minor cropping seasons. During 2023 major cropping season, Ennepa recorded the highest (0.65) harvest index and was significantly different from Adoye (0.56), vice versa in 2023 minor cropping season. Across both cropping seasons, plant spacing and the interaction between variety and plant spacing had no significant effect on harvest index. Harvest index recorded during 2023 major cropping season was significantly higher than those obtained during 2023 minor cropping season.

4.5.11 Grain Yield

Grain yield as influenced by variety and plant spacing during 2023 major and 2023 minor cropping seasons is shown in Table 4. 19. Grain yield ranged from 1.05 -2.47 t/ha in the major season and 1.20-1.58 t/ha in the minor season. Varieties had significant effect on grain yield during 2023 major cropping season, but not in the minor season. Ennepa recorded significantly higher grain yield, 57.31% higher than Adoye during the major cropping season. Across both cropping seasons, common bean plants grown at a spacing of 30 cm x 20 cm recorded significantly higher grain yield (2.17 t/ha and 1.99 t/ha, respectively) than when grown at a spacing of 60 cm x 20 cm (1.21 t/ha and 1.68 t/ha, respectively). The 40cm x 20cm and 50cmx 20cm spacings produced intermediate grain yields in both seasons. During both cropping seasons, planting Ennepa at a spacing of 30 cm x 20 cm recorded significantly heavier grain yield per plot than Adoye grown at a spacing of 50 cm x 20 cm and Adoye grown at a spacing of 60 cm x 20 cm in the major and minor cropping seasons respectively but differed insignificantly from the other interactive effects. There was no significant difference in grain yield between the seasons. (Table 4.19).

Table 4. 19: Effect of variety and plant spacing on harvest index and grain yield per plot during 2023 major and 2023 minor cropping seasons.

Plant Spacing	Harvest index						Grain yield (t/ha)					
	Major season			Minor season			Major season			Minor season		
	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean	Adoye	Ennepa	Mean
30 cm x 20 cm	0.51	0.58	0.55	0.58	0.51	0.55	1.86	2.47	2.17	1.98	2.01	2.00
40 cm x 20 cm	0.52	0.68	0.60	0.68	0.52	0.60	1.46	2.04	1.75	1.86	1.83	1.85
50 cm x 20 cm	0.56	0.66	0.61	0.66	0.56	0.61	1.05	1.72	1.39	1.79	1.91	1.85
60 cm x 20 cm	0.67	0.69	0.68	0.69	0.67	0.68	1.19	1.23	1.21	1.63	1.74	1.69
Mean	**0.57**	**0.65**		**0.65**	**0.57**		**1.39**	**1.87**		**1.82**	**1.87**	
CV (%)		= 18.27			= 25.16			= 22.52			= 9.28	
Variety (V) HSD (0.05)		= 0.08			= 0.10			= 0.43			= NS	
Spacing (S) HSD (0.05)		= NS			= NS			= 0.81			= 0.18	
V x S HSD (0.05)		= NS			= NS			= 1.37			= 0.31	
Season HSD (0.05)		= 0.07			= 0.07			= NS			= NS	

4.6 Correlation Matrix Analysis

Tables 4.20 and 4.21 show correlation matrix analysis among vegetative and yield and yield components parameters of common bean during 2023 major and 2023 minor cropping seasons respectively. During 2023 major cropping season, seed weight per plot and grain yield were strong, highly and positively correlated (0.78***). There were strong, moderately and positive correlation between plant height and number of leaves per plant (0.52**) and number of pods per plot and seed weight per plot (0.45**). Most of the parameters correlated showed no significant differences among each other (Table 4.20).

During the 2023 minor cropping season (Table 4.21), there was strong, high and positive correlation between seed weight per plot and grain yield (0.72***). There was a moderate and positive correlation between plant height haulm weight per plot (0.49**), number of pods per plot and grain yield (0.45**), number of leaves per plant and grain yield (0.44**) and haulm weight per plot and grain yield (0.43**). About 19% of the parameters measured showed a low and positive correlation between each other whereas 4.8% showed no significant correlation (Table 4.24). The number of pods per plot and haulm weight per plot (0.83***), number of leaves per plant and haulm weight per plot (0.80***), number of leaves per plant and stem diameter (0.78***), stem diameter and haulm weight per plot (0.77***), number of leaves per plant and number of pods per plot (0.75***), stem diameter and number of pods per plot (0.71***), number of pods per plot and haulm weight per plot (0.62***) were highly and positively correlated.

Table 4. 20: Correlation matrix analysis among vegetative and yield and yield components of common bean during 2023 major cropping season

	1	2	3	4	5	6	7
1. Plant height	1	0.52**	0.40*	-0.17ns	-0.19ns	0.21ns	-0.06ns
2. Number of leaves per plant		1	0.40*	-0.001ns	-0.16ns	-0.04ns	-0.21ns
3. Stem diameter			1	-0.12ns	-0.33ns	0.05ns	-0.24ns
4. Number of pods per plot				1	0.45**	-0.13ns	0.22ns
5. Seed weight per plot					1	0.02ns	0.78***
6. Haulm weight per plot						1	0.25ns
7. Grain yield (kg/ha)							1

Numbers against the parameters in columns correspond with variables in rows; NS – Not significant ***** *= Significant at P≤0.05* ****** *= Significant at P≤0.01* ******* *= Significant at P≤0.001*

Table 4. 21: Correlation matrix analysis among vegetative and yield and yield components of common bean during 2023 minor cropping season

	1	2	3	4	5	6	7
1. Plant height	1	0..68***	0.57***	0.53***	0.33ns	0.49**	0.36*
2. Number of leaves per plant		1	0.78***	0.75***	0.63***	0.80***	0.44**
3. Stem diameter			1	0.71***	0.41*	0.77***	0.38*
4. Number of pods per plot				1	0.62***	0.83***	0.45**
5. Seed weight per plot					1	0.42*	0.72***
6. Haulm weight per plot						1	0.43**
7. Grain yield (kg/ha)							1

Numbers against the parameters in columns correspond with variables in rows; NS – Not significant ***** *= Significant at P≤0.05* ****** *= Significant at P≤0.01* ******* *= Significant at sP≤0.001*

CHAPTER FIVE: DISCUSSION

5.1 Effect of Variety and Plant Spacing on Phenology of Common Bean

During the 2023 main cropping season, the Adoye variety emerged nearly two days earlier than the Ennepa variety. Additionally, Ennepa flowered and podded substantially earlier than Adoye in both cropping seasons. The earliest emergence of Adoye implies that this variety may have characteristics such as increased seed vigor or faster germination rates, which can be influenced by genetic factors and seed coat characteristics that facilitate radicle protrusion and faster water absorption (Basu & Groot, 2023). Due to its genetic predisposition for early maturation, Ennepa's earlier flowering and podding suggest a shortened vegetative growth phase and a more rapid transition to reproductive development. This was consistent with the findings of Kamai et al. (2014), who discovered that the Kannanado White and Borno Brown varieties of cowpea exhibited substantially prolonged periods to attain first and 50% flowering compared to the other varieties they researched.

In both cropping seasons, the percentage of plants established was not substantially influenced by plant spacing and varieties. The days to 50% emergence during the 2023 minor cropping season was not significantly influenced by varieties, plant spacing, or their interaction. The days to 50% emergence during the 2023 main cropping season was not significantly influenced by plant spacing or the interaction between variety and plant spacing. This is consistent with the results of Masa et al. (2017), who found that the days to emergence of two common bean varieties were not substantially influenced by the main effects of inter- and intra-row spacing or the interactions between common variety and spacing. Emergence is also significantly influenced by soil conditions, including soil moisture, texture/structure, soil temperature, the depth of sowing, and the hardness of the soil covering. The interaction between variety and plant spacing did not significantly influence the Days to 50% blossoming and fruiting across both cropping seasons. The significant difference in days to 50% flowering and days to 50%

fruiting may have been attributed to the genetic variability between Adoye and Ennepa, as well as their response to plant spacing. This is consistent with the findings of Appiah (2023), who noted that the genetic composition of the varieties and their response to environmental conditions were the reasons for the disparities between two maize varieties in days to 50% tasseling and days to 50% silking.

5.2 Effect of Variety and Plant Spacing on Vegetative Growth of Common Bean

The Adoye variety produced considerably taller plants than the Ennepa variety from 31 to 51 days after sowing (DAP) during the 2023 main cropping season. Nevertheless, this trend was reversible in the minor season, as Ennepa outperformed Adoye in terms of plant height during the same growth period. The growth patterns and development of the two varieties are likely to be influenced by their distinct genetic backgrounds. This was consistent with Koli (2013), who noted substantial variations in plant height between two black cumin cultivars. In comparison to those cultivated at wider spacings, the varieties Adoye and Ennepa, as well as a closer plant spacing of 30-40 cm x 20 cm, substantially facilitated the development of taller plants during both crop production seasons. The competition for light was likely exacerbated by the increased density, which in turn encouraged plants to grow taller in an effort to access sunlight. This closer spacing may also produce a more favorable microenvironment by enhancing moisture retention and regulating temperatures as a result of early canopy closure, which can further support vertical growth. These results are in direct opposition to the findings of Gholinezhad & Abdolrahimi (2014), who determined that the plant height of black seed (Nigella sativa) was not substantially influenced by the variety x spacing interaction.

The genetic potential differences between Adoye and Ennepa, particularly in the minor cropping season, may be the cause of the substantial differences in stem diameter and the number of branches per plant. In comparison to the closer spacing of 30-40 cm x 20 cm, the branch and stem diameter were substantially increased by the wider inter-row spacing of 50-60 cm x 20 cm. This result indicates that the wider spacing afforded by the additional space reduced competition among plants for critical resources, including light, water, space, and nutrients. Each plant had increased access to these resources due to the reduced congestion, which in turn facilitated the development of branches and leaves, thereby fostering lateral growth (Madisa et al., 2014). Furthermore, the increased spacing likely enabled plants to develop thicker stems, as they had more space to expand and grow without the restrictive pressure of neighboring plants. This increased vegetative growth, particularly in stem thickness and branching, suggests that a wider spacing can support more robust and potentially resilient plant structures. This may be advantageous under specific growing conditions where plant size and structural integrity are critical (Edgar et al., 2017).

The genetic variability between the two varieties and their varying responses to plant spacing are likely the cause of the substantially higher shoot and root dry weight recorded by the Ennepa variety for the entire cropping period compared to Adoye during the 2023 main cropping season. Ennepa's genetic composition may provide it with an advantage in biomass accumulation, allowing it to cultivate more resilient roots and branches (Rasul et al., 2012). The highest shoot and root dry weights were achieved during the 2023 main cropping season when the Ennepa variety was planted at the same spacing as the closer inter-row spacing of 30-40 cm. This was in contrast to the wider spacing of 50-60 cm. The increased plant density likely facilitated competition, which in turn encouraged plants to grow more vigorously, resulting in a greater accumulation of biomass (Fischer et al., 2019). This growth was further bolstered by the more favorable microenvironment that was established by the closer spacing, which included enhanced soil conditions and greater moisture retention. Zhang et al. (2021) assert that plants were able to optimize their growth potential by utilizing available resources, including light, water, and nutrients, in a more compact planting configuration. The increased plant height that Ennepa produced when planted in close proximity to those with broader spacing may have been advantageous for plants to optimize sunlight interception for crop growth.

During the 2023 main cropping season, there were substantial variations in the relative growth rate (RGR) and crop growth rate (CGR) of the various varieties. Ennepa demonstrated the greatest CGR from 0-21 DAP to 41 DAP at harvest, as well as the highest RGR at 0-21 DAP and 41 DAP at harvest. Variations in genetic compositions among the varieties may account for these discrepancies. This observation is consistent with the results of Islam et al. (2019) in Bangladesh, who reported substantial variations in the relative growth rate (RGR) and crop growth rate (CGR) of eight maize varieties. The increase in CGR among all treatments was consistent until the period between 41 DAP and harvest, which was primarily attributed to the plants' increased accumulation of dry matter during this stage.

In general, the RGR experienced a significant increase during the initial growth stage and progressively decreased as the plant matured. The plants during this period prioritize the allocation of photosynthetic assimilates to the developing pod, which are the economically significant components of the bean plant. As the plant redirects its energy and nutrients toward capsule development, the progressive senescence of leaves and stalks is the result of this reallocation of resources (Tanveer et al., 2014). Bell (2010) observed a significant increase in RGR during the initial phase, particularly during the 30 days after planting (DAP) period until 90 days after planting, after which it gradually decreased.

The total crop growth rate (CGR) and relative growth rate (RGR) from 0-21 DAP to 41 DAP to harvest during the 2023 minor cropping season were not significantly influenced by the genetic variations between the two common bean varieties general, plant spacing, or the interaction between variety x plant spacing. This implies that the two varieties, despite their distinct genetic backgrounds, exhibited comparable patterns in their overall growth dynamics and the efficacy of biomass accumulation during the growing periods. This was consistent with the findings of Essilfie et al. (2023), who found no significant differences in CGR and RGR between two maize varieties.

5.3 Effect of Variety and Plant Spacing on Yield and Yield components of Common Bean

The number of plants harvested in both cropping seasons did not exhibit any substantial differences between the interactions between variety and plant spacing. This implies that the number of plants harvested was uniformly affected by the common bean varieties and plant spacing, indicating that neither factor had a significantly impact on this outcome. This uniformity may be attributed to the varieties' similar growth behaviors and adaptability to the specified spacing, which result in consistent plant survival and harvestability irrespective of the treatment combinations (Rasul et al., 2012). Masa et al. (2017) reported substantial discrepancies in the number of plants harvested for common bean varieties (Ibbado and Hawassa Dume), which is in stark contrast to the current findings.

During the 2023 main cropping season, the number of pods per plant, the number of pods per plot, and the pod weight per plant were not significantly influenced by the interactions between common bean varieties and plant spacing. In the minor cropping season, the highest pod production per plant and per plot, as well as the greatest pod weight per plot, were achieved by sowing Ennepa at 50 cm x 20 cm. It is possible that the wider plant spacing likely optimized the balance between plant density and resource availability, enabling each plant to access sufficient sunlight, nutrients, and water without excessive competition for effective translocation of assimilate to the pod (Kirimi, 2019).

Pod weight per plot, 100-seed weight, and seed weight per plot were not significantly influenced by variety x plant spacing interactions during either cropping season. Nevertheless, the highest means in those variables were recorded by Ennepa when grown at a 60 cm x 20 cm spacing, in contrast to Adoye when grown at the same spacing. The variations may be attributed to genetic variability and other environmental factors, such as climatic and edaphic factors, that are present in the cultivars (Melaku, 2012).

Pod length was not substantially influenced by the interaction of plant spacing and variety during the 2023 main cropping season. The significantly longer pod length observed in Ennepa sown at a 60 cm x 20 cm spacing during the 2023 minor cropping season may be attributed to the wider inter-row spacing, which may have reduced competition for space, nutrients, and water, as well as to improved resource availability for photosynthesis (Bekele & Geleta, 2021). In the same vein, Koirala et al. (2020) reported the maximal cob length of maize in a row spacing of 60 cm × 25 cm.

During the 2023 main cropping season, the haulm weight per plot was not substantially influenced by the interaction between variety and plant spacing. The haulm weight was substantially increased by the 30 cm x 20 cm spacing. This is due to the fact that denser planting, which encourages early canopy closure, reduces vegetation competition by shading the soil surface and enhances the crop's access to resources. During the 2023 minor cropping season, Ennepa grown at a spacing of 60 cm x 20 cm exhibited a substantially higher haulm weight per plot than Adoye x (30 cm x 20 cm). This may be due to the fact that the wider inter-row spacing facilitates improved light penetration, photosynthetic active radiation (PAR) absorption, and air circulation, which can improve the overall health of the plant and improve photosynthesis.

Across both cropping seasons, the active nodule count was not substantially influenced by the interaction between variety and plant spacing. It is possible that the formation of nodules was not significantly influenced by plant spacing and variety. Other factors, such as soil health, microbial activity, or overall environmental conditions, may have had a greater impact on nodule formation, which is essential for nitrogen fixation in leguminous plants, than the specific bean variety or planting configuration. Variations in variety and their response to spacing may account for the substantially higher active nodule count produced by Ennepa than Adoye when the same spacing is employed. In like manner, the harvest index was not significantly influenced by the interaction between plant spacing and variety in either of the cropping seasons. In contrast to this discovery, Kazemi et al. (2012) maintained that the harvest index was substantially influenced by the interactions between wheat bean cultivar and plant spacing.

In comparison to both varieties that were cultivated at a wider inter-row spacing, Ennepa sown at an inter and intra-row spacing of 30 cm x 20 cm exhibited a significantly higher grain yield. By optimizing resource utilization and establishing favorable conditions for crop development, closer inter-row spacing can improve plant growth and cereal yield. Ali et al. (2017) posited that plants can enhance their photosynthesis, which in turn leads to an increase in biomass production, by capturing light more efficiently and closing the canopy more effectively. The Nasir and Goberesha common bean varieties were sown with a 30- 40 cm inter-row spacing, as Merga (2020) discovered, resulting in higher crop yields. In the same vein, Mashiqa et al. (2019) reported that Genotype DAB564 of common bean generated a substantially higher yield than DAB520, which is likely attributable to its superior genetic potential.

A firm and positive correlation between the cereal yield in the main season and the seed weight per plot suggests that a higher seed weight could effectively enhance the seed weight. This is consistent with the findings of Kumar et al. (2023), who observed a highly significant positive correlation between cereal yield and yield per plant in bread wheat. In the same vein, Zewdu et al. (2024) discovered that grain yield exhibited positive and highly significant ($p<0.01$) genotypic and phenotypic correlations with a variety of characteristics, such as plant height, number of seeds per spike, head weight, yield per head, and biomass yield. In contrast, Chimdesa et al. (2017) reported non-significant correlations between grain yield and the number of seeds per spike (positive) and peduncle length (negative) at both the genotypic and phenotypic levels in bread wheat. In the 2023 minor cropping season, the strong positive correlation between the number of pods per plot and the haulm weight per plot indicates that plants with greater vegetative growth tend to produce more pods. This is likely due to the increased photosynthetic capacity that supports pod development. Several important traits in wheat have been positively and significantly correlated with grain yield in previous studies. Baye et al. (2020) and Getachew et al. (2021) both noted that grain yield was positively and substantially correlated with plant height, test weight, biomass yield, and harvest index at both genotypic and phenotypic levels.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Based on the findings of the study it can be concluded that:

Phenology

- Adoye emerged earlier than Ennepa during the 2023 major cropping season where varieties had no significant effect on days to 50% emergence in 2023 minor cropping season. Plant spacing and the interaction between variety and plant spacing had no significant effect on days to 50% emergence across both cropping seasons.
- Variety, plant spacing and their interactions had no significant effect on percentage plant establishment across both cropping seasons. Ennepa common bean variety was the earliest to flower and pod as compared to Adoye common bean variety across both cropping seasons. Plant spacing as well as the interaction between variety and plant spacing had no significant effect on number of days to 50% flowering across both cropping seasons.
- Different plant spacing had no significant effect on days to 50% podding in both cropping seasons. However, Ennepa grown at a spacing of 50 x 20 cm was the earliest to pod as compared to Adoye grown at the same spacing across both cropping seasons.

Vegetative Growth

Variety, plant spacing and their interactions significantly influenced the vegetative growth across both cropping seasons.

- Generally, Adoye common bean variety significantly enhanced vegetative growth parameters namely plants height, number of branches per plant, stem diameter than Ennepa common bean variety during 2023 major cropping season vice versa in 2023 minor cropping season. Varieties had no significant effect on shoot fresh weight per plant and root fresh weight per plant across both cropping seasons. Ennepa common bean variety produced significantly higher root dry weight than Adoye across both cropping seasons.

- Wider plant spacing of 50 – 60 cm x 20 cm significantly enhanced the vegetative growth parameters (number of branches per plant, number of leaves per plant, stem diameter, shoot and root fresh and dry weight) across both cropping seasons. However, different plant spacing had no significant effect on shoot and root fresh and dry weight during 2023 minor cropping season.
- Both Ennepa and Adoye grown at a spacing of 60cm x 20 cm and 50 cm × 20 cm enhanced the vegetative growth parameters (such as plant height, number of branches per plant, number of leaves per plant and stem diameter) across both cropping seasons than the other interactive treatments.
- Ennepa and Ennepa grown at a spacing of 60 cm x 20 cm significantly enhanced the physiological growth parameters (crop growth rate and relative growth rate) as compared to Adoye and Adoye planted at the same spacing during 2023 major cropping season. However, in 2023 minor cropping season, variety, plant spacing and their interactions had no physiological growth name crop growth rate and relative growth rate.

Yield and Yield Components

- Variety and plant spacing interactions had no significant effect on number of plants harvested, number of pods per plant, pod weight per plant and nodule count during 2023 major cropping season. Again, the interaction between variety and plant spacing did not significantly influenced pod weight per plot, 100-seed weight, pod length, seed weight per plot, and harvest index during 2023 major cropping season.
- In 2023 minor cropping season, Ennepa grown at a spacing of 50 cm x 20 cm as well as Ennepa and 30 cm x 20 cm interactions produced the highest number of pods per plant and per plot, pod weight per plant and longer pod length as compared to Adoye planted at the same spacing. Ennepa grown at spacing of 30 cm x 20 cm produced the highest grain yield than Adoye grown at the same spacing across both cropping seasons.

6.2 Recommendations for Adoption

It is recommended that;

- Farmers should grow Ennepa common bean variety at a spacing of 50 x 20 cm for early flowering and fruiting due to reduce impact of erratic rainfall on the crop as compared Adoye.
- Ennepa grown at a spacing of 50 x 20 cm was the earliest to fruit as compared to Adoye grown at the same spacing across both cropping seasons.
- For higher vegetative growth that will translate into yield, both Ennepa and Adoye common bean varieties should be grown at a wider plant spacing of 50-60 cm x 20 cm.
- Farmers should consider adopting Ennepa and Adoye common bean varieties at a spacing of 30 cmx 20 cm or 50 cm x 20 cm for higher yield and yield components such as number of pods per plant, active nodule count, longer pod length, haulm weight and grain yield.

6.3 Recommendation for Further/Future Studies

- Further studies should look at wider intra-row spacing on growth and yield of common beans; and other agro-ecological zones; and intercropping with cereals and root and tuber crops.

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