UNIVERSITY FOR DEVELOPMENT STUDIES

GRAIN YIELD AND PHYSIOLOGICAL RESPONSES OF COWPEA GENOTYPES UNDER CONSTRASTING SOIL MOISTURES IN THE SAVANNA AGRO-ECOLOGIES OF GHANA

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JANUARY, 2024

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DEPARTMENT OF CROP SCIENCE, FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES

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BY

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DECLARATION

I, Francis Abbas Senyabor hereby declare that this dissertation is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere. All sources of information cited and assistance received in the preparation of this work have been duly acknowledged and referenced.

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ABSTRACT

A two-year field experiment was carried out at the Golinga irrigation scheme to evaluate different cowpea genotypes under water deficit and well-watered conditions. The experiment was laid out in a split plot design with three replications of each treatment combination where the main plot was the water supply while the sub plot was the genotype. A non-stress (NS) treatment was based on the supply of irrigation every 3 days compared to a drought stress (DS) which involved the withdrawal of water supply at flowering and podding stage with ten (10) days stressed interval. The plot size for each experiment was 4m × 1.8m (7.2m^2), and the spacing between plots and replications were 1m and 2m respectively. Phenological, physiological, morphological and yield data were collected, the data was subjected to ANOVA using GENTAT 12 edition statistical software tool. Means were separated using the least significant difference (LSD) at 5% probability level. It was observed that soil moisture level, genotype and their interaction had significant effect ($P<0.05$) on the number of days it took for the cowpeas to reach their first flowering. There were significant differences ($p<0.05$) among the genotype effect of the biomass dry weight and 100 seed weight evaluated. IT17K-1367-2-3, KVx782-1, IT17K-1802-1, IT17K-1707-2-2, IT17K-849-2-1, IT17K-1095-2-2, IT14K-2030-2, UDS-CRS-F20-2, IT17K-1403-1-1 and UDS-CRS-F116-3 were among the outstanding cowpea genotypes with high pod yield, grain yield and harvest index than the rest of cowpea genotypes evaluated and the resistant check IT93K-503-1. The results also revealed that imposition of stress especially at the vegetative stage significantly ($p<0.05$) reduced the relative chlorophyll contents. The effects of drought were markedly observed in all the parameters studied. High chlorophyll content and high canopy temperature depression was found to be associated with high pod yield, grain yield and one hundred seed

weight**.** The high performing genotypes with high grain yield under drought stress should be evaluated on-farm in order to identify genotypes that are most adaptable to farmers' growing conditions for release as varieties.

Keywords: Drought tolerant, Genotype, Breeding, Cowpea.

DEDICATION

I dedicate this thesis to my late mother Mrs. Elizabeth Mariam Forson.

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LIST OF ACRONYMS

CT	Canopy Temperature
CTD	Canopy Temperature Depression
DNA	Deoxyribonucleic acid
HSW	Hundred Seed Weight
IITA	International Institute of Tropical Agriculture
LSD	Least Significant Difference
SARI	Savanna Agriculture Research Institute

CHAPTER ONE

INTRODUCTION

1.1 Background of study

Cowpea, scientifically known as *Vigna unguiculata L. Walp.,* is one of humanity's first recognized food sources, and it is highly cultivated to address food security. A part of the family Fabaceae and is known by a variety of names, such as the black-eyed pea, southern pea, lubia and crowder pea (Agbogidi, 2010). The crop is generally cultivated in both the wet and semi-dry agroecologies worldwide; the majority of its production takes place in low-input systems (Cisse' and Lobby, 2002). Millions of people living in the tropical regions have benefited a lot from cow pea which gives it great importance (Asiwe, 2009). The crop can be used as food, cash, animal feed, and manure for small-holder farmers who have limited access to other resources. Most resource-deprived people in developing nations, particularly in Africa, find employment in the agriculture industry. Cowpea grains have high protein content of between 20 and 30% (Fussel *et al.*, 1991). The grain is used to make a variety of snacks and meals, while the fresh, succulent leaves and peas are consumed as vegetables. The components of the plant that grow above ground can be harvested and made into food for animals (Gomez, 2004). The byproducts are utilized as animal feed in the season when the lands are dry, and they can also be put into the soil to increase its fertility (Carvalho *et al.*, 2012). Cowpea forms a crucial component in the majority of legume-cereal farming system due to the left behind nitrogen advantage that it provides to soil fertility. This benefit comes from the decomposition of cowpea's roots, root nodules and leaf litters (Asiwe, 2009). Due to cowpeas' resistance to shadow and flexibility as an intercrop, it has become the plant of choice in arid regions (Nagalakshmi *et al.* 2010). Cowpeas have been predicted to be one of the leguminous grains to have the

least yielding, coming in at 450 kg/ha on average across the world. It is grown in sub-Saharan Africa by an estimated 38 million households, which accounts for 194 million people; however, its productivity has not witnessed consistent development and the Consultative Group on International Agriculture Research (2011) have stated that the overall area over the past decade was at 4.3% whiles yield was 1.5% and production was 5.8%. The crop, on the other hand, produces yields that are among the lowest in the world (Ofosu-Budu *et al.*, 2008). In the meantime, cowpea is notable for being grown extensively, particularly in Ghana's transition and savannah zones (Crop Research Institute, 2006). It has been shown that the crop's genotypes have a significant amount of variability, which enables them to be adapted to a wide variety of agricultural practices that are used in their respective areas of production.

On the other hand, it was believed that environmental factors exerted a significant amount of control over the manifestation of its full genetic potential (Jansen and Vellena, 2010). Soil water content is a vital component that forms part in crop development. The amount of water in the soil can have a considerable impact on the performance of crops, and if these crops survive, they may face substantial challenges, including shifts in the morphological, physiological, and metabolic functioning of the plant, which would result in a lower yield. Mayaki *et al*. (2016) found that drought has an effect, either directly or indirectly, on the process of photosynthesis in plants and how it is distributed across the various plant organs. The stages in which drought can affect cowpea production include seedling, vegetative and pod filling. Vegetative stage is affected when there is no adequate water to develop the root, stem, leaves and flowers. Adequate water is required to develop the seeds in the pods which will result in the standard seed size of the genotype. Hence drought affects plants in the above stages that affect the yield outcome of crop production (Alidu, 2018).Cowpea yields

have improved over the years as a result of the introduction of improved cowpea varieties. Due to the changing climate, developing varieties wit with robust more will be needed. Previously, the goals were focused on improving cowpea yields.

1.2 Problem statement

Cowpea yields in sub-Saharan Africa (SSA), particularly Ghana, is far lower than it could be due to a wide variety of biotic and abiotic stressors as well as socio-economic constraints such as drought (Naidu *et al.,* 2001).When there is an insufficient amount of rainfall, the soil may not have sufficient moisture, causing plants to suffer from either drought stress or moisture stress. The development of drought stress is caused by excessive water loss that is not restored by water taken in by the roots of the plant (Ramanjulu and Sudhakar, 2000). This results in a diminish water potential of plants (Szegletes*et al.,* 2000; Aharoni et *al.,* 2004) and comparative water content (Naidu *et al.,* 2001), which in turn leads to a reduction in cell turgor (Szegletes *et al.,* 2000). The yield of crops is negatively impacted by both intermittent and terminal droughts, albeit in very different ways. When selecting the appropriate genotypes for the various agroecological settings, it is essential to have an understanding of the ways in which the biotic factors and different soils influence the development and growth of the newer varieties. This is necessary to properly construe the yields that are observed in these environments.

1.3 Justification

It is possible to improve yield and growth performance by evaluating methods in order to advance the performance of novel variety for a number of distinct agroecological zones in order to gain a deeper comprehension of the biochemical, morphological and physiological responses of these species to their surrounding environment. It's a crop that can be grown in a variety of environments. Consequently, one of the most important things that have to be done to increase cowpea production in the producing area is to breed improved varieties of cowpea that incorporate the characteristics that farmers value most. Cowpea is better able than other crops to adapt to ecological conditions such as high temperatures and drought which can have a harmful effect on crop production. A few assortments have a small creation cycle and mature early, giving food during the time of yearning when food turns out to be very scant in semi-dry districts of sub-Saharan Africa (Cisse' and Lobby, 2002). As well as being dry season open minded, a few assortments have a short creation cycle and mature early. Due to the fact that it may be used for a variety of purposes, it presents an appealing alternative for farmers who live in locations that are prone to drought. Such regions are typically characterised by minimal rainfall, high temperatures, and irrigation systems that are either less developed or nonexistent altogether. This highlights how important it is to evaluate the agronomic performance of cowpea varieties as a food security crop under current and anticipated future situations.

Therefore, the purpose of this study was to evaluate the grain yield and physiological responses of cowpea under different levels of soil moisture in Ghana's Guinea Savannah agroecology.

1.2 Objectives

1.2.1 Main Objective

The main objective of this study was to evaluate cowpea genotypes under water deficit and well-watered conditions.

1.2.2 Specific objectives

- To investigate the effect of different moisture regimes on growth parameters of cowpeas.
- To determine the effect of water deficit on crop physiological characteristics and their relationships with yield.
- To rank cowpea genotypes based on their agronomic, physiological characteristics and yield in response to drought stress.

CHAPTER TWO

LITERATURE REVIEW

2.1 Cowpea

2.1.1 Botany, Origin and Distribution of Cowpea

Vigna unguiculata (L.) Walp, as the plant is scientifically known, is categorized as a vascular plant (Tracheobionta), a member of the order cosmopolitan, the class of dicotyledon (Magnoliopsida), the sub-class nitrogen-fixing (Rosidae), the division of flowering plants (Spermatophyte), and the super-division of seed plants (Spermatophyte) (United State Department of Agriculture, 2009).

Cowpea is grown on over 156,000 hectares of land in Ghana (International Institute of Tropical Agriculture [IITA], 2009). In Ghana, it's the second most significant grain legume after peanut, and it plays a vital part in both the urban and rural lives of the country's needy (SARI, 2015). It is generally agreed that the origin of cowpea can be traced back to Africa. *V. unguiculata* has two subspecies: *missenses*, which are found in humid and sub humid zones, and *dekindtiana*, which are located in seasonally desert places. The undomesticated cowpea can only be located in the West and Central Africa. Due to a paucity of archaeological evidence, there are conflicting theories that support Asia, South America and Africa as the original centers of human genesis (Department of Agriculture, Forestry, and Fisheries 2011). If you take into account the fact that Africa is home to both wild and cultivated cowpea species, you can deduce that the continent has the greatest variety of cowpea varieties. Certain locations inside Africa have been put forward as candidates for the role of the centre of variety and foundation of *Vigna unguiculata*. West Africa, Southern Africa, Ethiopia are among these (Cook *et al.*, 2005). There is still much debate on the particular country or area in which cowpea was originally cultivated for human consumption. The widespread

geographical distribution of the cultivar *dekindtiana* across the entirety of sub-Saharan Africa lends credence to the notion that the it could have been possible to domesticate the species in any one of the regions Zhang et *al.* (2005). To this day, *Vigna unguiculata* can be grown in the transition and savanna agroecology everywhere from 35 degrees north and 30 degrees south, all across Oceania, Asia, southern Europe, the Middle East, Africa, and Central and South America and the southern United States of America (Cook *et al.,* 2005). Over two-thirds of the developing world is currently engaged in the cultivation of cowpea as a relay or cohort crop with key cereals. The area that includes the tropical regions of southern Niger, Burkina Faso, northern Benin, the northwestern parts of Cameroon, Nigeria, and Togo is nonetheless the centre of the highest variety of planted cowpea. This centre can be found in West Africa Zhang et *al.* (2005).

2.1.2 Plant Morphology

Cowpea is an annual herb that can grow in a variety of different forms. Depending on the cultivar, it can grow in a climbing, erect, or prostrate position. It can also creep along the ground (Eco-crop, 2009). It contains a deep taproot as well as several lateral roots that extend out from it. The root system is distinguished from that of soybeans by its expansiveness and the presence of big nodules. Brady rhizobium species are the unique symbiotic nodular bacteria that they host (Gomez, 2004). The first pair of leaves on the plant are simple and opposing, while the remaining leaves are trifoliate and grouped in an alternate pattern (with three leaflets). The leaves often have a dark green colour, are smooth, might be dull or lustrous, and very rarely have pubescence. Depending on the kind, they can range from having an elongated and pointed shape to an oval form. Their size also varies significantly. The length of the leaf petiole can range anywhere from 5 to 25 centimetres (Department of Agriculture, Forestry, and

Fisheries, 2009). The stems can be ridged, smooth, or even slightly hairy, and they can have a hint of purple (Gomez, 2004). At the distal ends of peduncles that are anywhere from 5 to 60 centimetres in length, the flowers are grouped in racemes or intermediate inflorescences. In most cases, there are only two or a few flowers produced by each inflorescence. They are born in alternate pairs. They stand out, are capable of pollinating themselves, are carried on undersized corollas and pedicels can be any of the following colours: dirty yellow, white, pale blue, purple or pink (Department of Agriculture, Forestry, and Fisheries, 2011). The size, shape, and colour of seeds can vary quite a bit from one another. There is a wide range of possible seed colours, including black, spotted, red, green, white, and brown varieties. The quantity of seeds contained in each pod might range anywhere from 8 to 20. The seeds themselves are quite sizeable (0.2–1.6 cm in diameter). The testis can have a smooth or wrinkled surface, and its colour can be white, green buff, red brown, black, spotted, blotched, eyed (in which the hilum is white and ringed by a dark ring), mottled, or speckled. The testis may also have a smooth or wrinkled surface. The pods of different fruits can range in size, shape, colour, and texture. They typically range in length from 6.5 to 25 cm and in width from 3 to 12 mm. They can be upright, in the shape of a crescent, or coiled. Yellow in colour when fully mature, but sometimes brown or even purple in hue as well (Department of Agriculture, Forestry, and Fisheries, 2009).

2.1.3 Genetic Development of Cowpea

The subspecies *Vigna catjang* and *Vigna sesquipedalis* are the other two cultivated variants of the cowpea species. However, *Vigna unguiculata* is not the same as any of these. The differences lie in the size, shape, and length of the pods, as well as the properties of the seeds (Sheahan, 2012). Due to the fact that the plant is able to quickly cross-pollinate and create fertile hybrids, these traits are highly changeable and

difficult to distinguish (Sheahan, 2012). Cowpea genetic and morphological research (Ogbonnaya et *al.,* 2003) identifies the species Vigna unguiculata as consisting of domesticated forms (Vigna unguiculata species unguiculata cultivar unguiculata), wild annual forms (Vigna unguiculata species unguiculata cultivar spontanea), and ten wild domesticated animals (Ba et *al.*, 2004). The five so-called cultivar groups (cv.-gr. or "cultigroups" are used to classify cultivated cowpea (Cooket *al.,* 2005).

The extremely variable nature of the species has resulted in the development of a number of commercial cultivars, which can be categorized according to the bean's differences in form, size, and colour (Ogbonnaya et *al.,* 2003). Take, for instance,

- Brown-eyed peas — The length of the pods and the colours they come in vary from green to lavender. When cooked, the immature seeds turn a brown colour ranging from medium to dark, have a flavour that is subtle, and are quite soft.

- Crowder peas — The seeds are dark in colour, spotted with brown, and brown-eyed. The seeds are "packed" within the pod, and the pods themselves tend to have a round, globe-like form.

2.1.4 Economic Importance of Cowpea

Cowpea is grown largely for the purpose of its seed; however, it is also used as a vegetable (for leafy greens, green pods, fresh shelled green peas, and shelled dried peas), as a cover crop, and for fodder (Thomas Jefferson Agricultural Institute, 2013). This crop has the potential to offer feed of a higher quality than cereals and forage grasses (Akyeampong, 2012). According to Aharoni *et al*. (2004), cowpea seed is an essential source of a variety of nutrients, including protein, fat, fibre, carbs, and vitamins, making it a valuable addition to both the human diet and the diet of animals.

The leaves are an excellent source of a variety of minerals and vitamins. In terms of total nitrogen, their protein composition varies from 29 to 43 percent on a dry mass basis; younger leaves have the highest nitrogen content (Ogbonnaya et *al.*, 2003), and they have the highest percentage of protein in their calories when compared to other vegetative foods (Shaw and Monica, 2007).

People living in rural areas and the surrounding peri-urban areas are the most likely to consume it (Asiwe 2009). Cowpea, in addition to being a nutrient-dense crop, also has the ability to "fix" nitrogen from the atmosphere, which in turn lowers the amount of nitrogen that the crop requires. Because of this, cowpea is extremely well-liked and important in Africa, particularly in the more remote parts of the continent where land is scarce and farmers do not have access to fertilisers. According to research carried out by Jansen and Vellena (2010), the quantity of nitrogen that cowpea can organically fix each year ranges anywhere from 65 to 335 kg N/ha. The ability of the crop to restore soil fertility for cereal crops grown in rotation with it makes it a valuable component of farming systems in many different regions. This ability makes the crop a valuable component of farming systems in many different regions (Timko and Singh 2007). Additionally, it spreads rapidly and covers the ground, both of which serve to prevent soil erosion (IITA 2009).

2.1.5 Ecology

Cowpea is a species that is native to savannahs and is highly adaptable to conditions of depleted soil and marginal habitats, both of which are unfavourable to the growth of other types of crops. According to D'Andréa*et al*. (2006), it is a crop that is

cultivated extensively in the semi-arid and sub-humid zones of Africa and Asia. Germination of the crop can only occur at temperatures higher than 10 °C, and optimal vegetative growth occurs at temperatures ranging from 21°C to 33°C. Warmer temperatures can trigger blooming and abscission of flowers earlier than normal, which can lead to poor pod set (Agriculture Research Council 2008). The plant can thrive in a wide range of soil conditions, from sandy soils to heavy clay soils and clays with good drainage; however, it grows best in lighter soils that promote healthy root development. It is able to thrive in low-fertility, heavy-textured, and strongly alkaline soils and can endure a wide variety of pH levels, including extremely acidic soils (pH 4). On the other hand, it is said to have a low tolerance for saltiness (Cook *et al.,* 2005).

Cowpea is able to withstand modest amounts of drought, but an excessive amount of water in the soil can be detrimental; it slows growth and increases the risk of infection by fungal diseases (Cook *et al.*, 2005). It is able to successfully adapt to a diverse range of precipitation types (650–2000 mm). When planted for the purpose of using it as feed, annual rainfall regimes of 750 to 1100 millimetres are preferred. As a human food crop, it is frequently cultivated in areas with annual rainfall regimes as low as 400 millimetres (Cook *et al.,* 2005). The crop, as compared to other legumes, is sensitive to waterlogging, and it cannot endure flooding for an extended period of time (Cook *et al.,* 2005). The process of nitrogen fixation, which is unique to legumes, is hampered in soils that are saturated with water (Ajetomodi and Abiodum 2010). It is possible to cultivate it using either irrigated or non-irrigated methods (Aharoni et *al.*, 2004)

2.2 Cowpea Production Trends and Agronomic Procedures for Increased Production

Pulses can be grown all over the world, with the cowpea being only one variety. Cowpea is cultivated on 14 million hectares, with a productivity of 387 kg per ha and a production of 4.5 million metric tonnes, according to Halemani (2009). Ninety-four percent of this amount comes from Africa. The cowpea is mostly grown and consumed in Nigeria, the world's largest producer and consumer of the crop. In 2010, Nigeria produced 2.2 million metric tons of dry grain. Niger was the second-highest producer, behind Burkina Faso, Myanmar, Cameroon, and Mali, with 1,800,900, 432,400, 169,900, 135,000, and 109,000 metric tonnes produced, respectively. As per FAO 2011 (cited by Wiley and Sons 2013), Niger held the second-largest position in terms of production. Out of all the major tropical grain legumes, cowpea is predicted to yield the least, 450 Kg/ha on average globally. In sub-Saharan Africa, an estimated 38 million families, or 194 million people, grow cowpea. However, over the last 20 years, productivity has not improved consistently; according to the Consultative Group on International Agricultural Research (2011), overall area, yield, and production have increased by 4.3%, 1.5%, and 5.8%, respectively.

According to Timko et al. (2007), it is the most widely grown food crop of all the beans grown in sub-Saharan Africa (SSA). According to Tan et al. (2012), cowpea farming is estimated to occupy 12.5 million hectares of land globally, producing three million metric tons of product in total. 64% of the world's total production is accounted for by West and Central Africa alone (Singh et *al.*, 2014). In sub-Saharan Africa, Nigeria and Niger, two countries in West Africa, are the main producers of cowpea. Approximately 80% of the total cowpea production in the West African region comes from the combined cowpea output of these two countries (Aboki and Yuguda, 2013).

Nigeria is the world's largest producer and consumer of cowpeas, where the crop is mostly farmed and consumed. Nigeria generated 2.2 million metric tons of dry grain in 2010.

2.2.1 Planting

Growing cowpeas from seed is the only method. The type of variety and growing pattern will dictate not only the distance between rows but also the spacing between rows. Because they do so much better in close quarters, cultivars that have upright growth patterns can support a greater number of plants per acre than trailing or semi-trailing ones (Shiringani, 2007). The ecological potential of the land that will be used is one of the factors that can be used to determine the cowpea plant population that will be most successful (Shiringani 2007). When it comes to grain production, a plant population of between 200,000 and 300,000 plants per hectare with an inter-row spacing of between 30 and 50 centimetres is recommended over broader rows that range from 70 to 100 centimetres and could be ideal for trailing types (Department of Agriculture, Forestry, and Fisheries 2011). Regarding the time of planting, farmers frequently engage in the practice of manipulation for a variety of reasons. The reasons for this include avoiding high insect infestation periods or planting cowpeas at a time that allows harvesting to coincide with periods of dry weather. Both of these reasons are important considerations (Department of Agriculture, Forestry, and Fisheries, 2011).

2.2.2 Fertilization

Cowpea is a legume, and legumes are known for their ability to fix their own nitrogen through a symbiotic interaction with certain types of Rhizobium bacteria that live in the soil. It's likely due to this factor that cowpea has a relatively low demand for

supplemental nitrogen. If you want to have a successful crop in regions that have soils that are low in nitrogen, you will need to apply a relatively small amount of nitrogen fertilizer—about 15 kg N per hectare—as a foundational treatment. The plant will have excessive vegetative growth and a low grain yield if an excessive amount of nitrogen fertiliser is put on it. This will cause the plant to flourish luxuriantly (Dugje*et al*. 2009). Phosphate fertiliser is typically useful when applied to a plant. The pH of the soil must be between 5.6 and 6.5 for cowpea to thrive there (Dugje *et al.*, 2009).

2.2.3 Irrigation

In comparison to a great number of other crops, cowpea is exceptionally resistant to drought. It is able to thrive with annual precipitation ranging from 400 to 700 millimetres (Department of Agriculture, Forestry, and Fisheries 2011). It is more common for it to be cultivated in dryland conditions than in irrigated ones. However, a study that was conducted by Ahmed and Suliman (2010) demonstrated that a lack of water during the flowering and pod-filling stages (sensitive growth stages) can result in decreased yields. This indicates that the plant may require supplemental irrigation during dry spells, particularly those that coincide with vital crop growth stages like flowering and yield creation. Ample watering is very important during these times.

2.2.4 Pests and Diseases

The cowpea plant is susceptible to a rather wide variety of pests, and almost every area of the plant is infested with a pest species that is adapted to inflict significant damage (Adu-Dapaah et *al.*, 2008). Due to their capacity to uproot just sprouted seedlings and feed on the emerging green pods, birds—especially those of the parrot family—can be a nuisance (Department of Agriculture, Forestry, and Fisheries 2011). Aphid-borne mosaic virus is the most prevalent disease, followed by rust, powdery mildew,

bacterial canker, fusarium wilt, and Cercospora leaf spot. Aphid-borne mosaic virus is the second most common virus, Xanthosomonasvignicola causes bacterial blight, Phytophtoravignae causes stem rot, and cowpeas cause fusarium wilt. As with other susceptible crops, cowpeas should not be planted right after another susceptible crop on the same plot of land (Wang and Sorley, 2012).

2.2.5 Weed Control

One persistent issue that lowers agricultural production and yields is weeds. They have significant negative effects on crop quality and yield, particularly when weed populations are allowed to spread unchecked. They generate large losses in certain places as they fight for light, space, and nutrients (Madukweet *al.*, 2012). Weed management can be achieved chemically (with the use of herbicides) or manually. The method that farmers use the most frequently in cowpea production is manual weed control. To maintain a clean field, it is recommended that cowpea be weeded twice using a hand hoe.

The first time should be done two weeks after planting, and the second time should be done four to five weeks after planting. A drastic drop in yield is the result of ineffective weed control or a delay in weeding (Dugje *et al.*, 2009). When it comes to chemical weed management, the herbicide that is used is often selected based on the main weed species as well as the availability of the herbicide. The spraying of herbicides is not suggested in areas where the leaves are consumed (Dugje *et al.*, 2009). *Striga gesnerioides* and several species of Alectra are the most common parasitic weeds that infect cowpea, especially in semiarid environments (Department of Agriculture, Forestry, and Fisheries, 2009).

2.2.6 Harvesting

Cowpeas have a variety of growth habits, from erect or semi-erect types with a short (100 day) growth duration, which are grown primarily for grain, to longer (> 120 day) durations in semi-erect or trailing plants, which are normally grown primarily for forage. The average growth duration for cowpeas is between 100 and 120 days (Department of Agriculture, Forestry, and Fisheries 2011). At maturity, the leaves will become more brittle, but they might not fall off entirely. Cowpea is ready to harvest when the seed moisture level is between 12 and 14 percent, minimising cracking and seed damage (Mullen *et al.*, 2003).

Cowpeas are able to be collected at all three stages of their maturation, which include while they are still young and green, when they are fully ripe, and when they are completely dried (Aharoni et *al.,* 2004). The vast majority of cowpeas grown in the United States are harvested using machinery. However, cowpeas that are harvested by hand sustain significantly less damage, and the harvesting season can last anywhere from one to three weeks (Gomez 2004). Because the quality of the seed is vital for the cowpea seed market, it is necessary to take extra precautions during harvesting and post-harvest handling in order to avoid cracked or split seed (Department of Agriculture, Forestry, and Fisheries, 2009).

2.3 Constraints to Cowpea Production

In Ghana, cowpea production faces significant challenges, including insect pests, diseases, drought, and poor soil quality (ICRISAT, 2013). Additionally, researchers like Almekinder *et al*. (2010) and Zhange *et al.* (2005) have highlighted the absence of suitable rhizobia strains in the soil as a major constraint. Other obstacles include inadequate access to essential inputs like fertilizes, insecticides, and improved seeds,

as well as suboptimal farming practices and lack of suitable machinery to expand cultivation. Despite cowpea's drought tolerance, farmers in sub-Saharan Africa's dry regions typically achieve low yields, averaging around 350 kg per hectare, due to reliance on rainfall. Cowpea production, on the other hand, is limited due to a number of variables, both biotic and abiotic. Insect pest, in particular, cause damage to the crop at every stage, from the appearance of the seedlings through their storage. In addition, yield losses caused by diseases can be quite large. These diseases might be caused by viruses, fungi, or bacteria. Its output and productivity in Ghana are both significantly impacted by a variety of abiotic variables, including but not limited to heat stress, drought, and low fertility. It was discovered through the use of quantitative approaches to identify the inheritance of heat tolerance in cowpea during pod set that heat tolerance is conditioned by a single dominant gene. This was discovered after attempting to assess the inheritance of heat tolerance in cowpea.

2.4 Drought and its Effects on Cowpea Production

When there is an insufficient amount of rainfall, the soil may not have sufficient moisture, causing plants to suffer from either drought stress or moisture stress. The development of drought stress is caused by excessive water loss that is not restored by water taken in by the roots of the plant. This results in a decrease in plant water potential (Szegletes *et al.*, 2000) and relative water content (Naidu *et al.*, 2001) which in turn leads to a reduction in cell turgor (Aharoni *et al.*, 2004; Szegletes *et al.*, 2000). Cells with low turgor cannot expand to their full potential, which in turn stunts plant growth. The physiology of the plant can be altered by drought, which has direct repercussions on the growth and development of the crop, the accumulation of biomass, and the production of seed yield. The severity of a drought can be classified as mild, moderate, or severe, and its length of time can be broken down into either

short or lengthy periods. Droughts can also be categorised according to the frequency with which they occur, which can be either intermittent or terminal. Intermittent drought is a type of drought that can strike at any point throughout the vegetative growth stage of a crop. This type of drought is notoriously difficult to forecast from one year to the next, despite the fact that a general pattern can be identified for a given area (Chauhan *et al.,* 2002). Terminal drought is the type of drought that happens near the end of the crop growth stage, and it mostly affects the reproductive stage, which includes flowering and the generation of seeds (Nigam *et al.,* 2002). A crop can experience either an intermittent or terminal drought, depending on whether or not the rains stop falling too soon during the crop growth stage. Intermittent drought occurs when the amount and distribution of rainfall during this period vary. Crops that have been engineered to withstand drought will be efficient against particular forms of drought (Asare et *al.,* 2010). For this reason, it is essential to have a crystal-clear awareness of the sort of drought that occurs in the habitat that is being targeted in order to design cultivars that are appropriate. In environments that are characterised by terminal droughts, short-cycle and synchronous varieties are suitable, whereas indeterminate and long-cycle varieties with sequential flowering are suitable for environments that have a long but unpredictable water supply. Jansen and Patel (2010) gave the examples of short-cycle and synchronous varieties as being appropriate.

The yield of crops is negatively impacted by both intermittent and terminal droughts, albeit in very different ways. The buildup of biomass is directly impacted by intermittent dryness in the form of a loss in leaf area (Zhang et *al.*, 200) and an increase in stem length. There is a reduction in leaf area as a result of reduced leaf area initiation (Clarke and Durdley, 1981), reduced leaf expansion as a result of the extreme sensitivity of cell expansion to reduced turgor (Akeampong, 2012), and/or enhanced

leaf senescence (Clarke and Durdley, 2006). All of these factors contribute to the reduction in leaf area (Asare et *al.*, 2010). A smaller leaf area means that less radiation is intercepted (Mollier and Pellerin, 1999), which in turn leads to a lower biomass output (Akeampong, 1986). In intermittent drought, maintaining a large leaf area would improve yield stability due to improved radiation interception when water is available. However, in a terminal drought, maintaining a large leaf area would lead to yield instability because it would result in an increased rate of water use. Maintaining a large leaf area would increase the rate of water use. Because of this, there is a greater chance that the crop will run out of water before it reaches maturity (Ludlow and Muchow, 2002). Therefore, cultivars intended to withstand periodic dryness would be a good fit for leaf care, but not cultivars developed to withstand terminal drought. Genetic diversity for leaf area maintenance (also known as stay-green in sorghum and delayed leaf senescence (DLS) in cowpea) has been observed in a number of different crops. This trait is most typically seen in cowpea and sorghum (Hall, 2004). In cowpea, a delayed-leaf senescence trait was found to give some tolerance to reproductive stage drought in cultivars of erect cowpea (Hall, 2004). Cowpea plants can produce a second flush of flowers and pods thanks to a phenomenon known as delayed leaf senescence, which compensates for the loss of the initial flush of flowers brought on by drought. It was shown that a single gene was responsible for controlling this characteristic (Hall, 2004). DLS cowpea cultivars in Senegal began flowering 35 days after sowing, produced around 2000 kgha-1 of grain by 60 days, and then had a second flush of pods that had the potential to produce an additional 1000 kgha-1 by 100 days after sowing (Hall *et al.*, 2003).

Little work has been done to incorporate this characteristic into better cultivars, despite the fact that DLS appears to be effective in increasing production and yield stability of

cowpea in situations that are characterised by periodic dryness. Terminal drought has a direct detrimental impact on seed yield because it interferes with the creation and development of reproductive organs as well as the translocation of photoassimilates to the grain. This ultimately results in a lower seed yield. Research has shown that drought stress has the most severe impact on crops when it occurs during the critical stages of meiosis and early grain formation (Asare *et al.,* 2010). Additionally, drought during the flowering stage can disrupt the development of flowers and the formation of reproductive cells, leading to reduced fertility (Asare *et al.,* 2013). According to Aspinall (2012), once the grain has been initiated, the susceptibility to drought decreases gradually with grain development. This occurs as the grain matures. There are no studies that specifically indicate which stage of cowpea development is the most sensitive, but Turk *et al*. (2010) found that drought stress during flowering and grain filling caused a reduction in the number of pods and seed weight. This was due to the drought-induced sensitivity of pod initiation and pod filling.

2.4.1 Agronomic and Meteorological Drought and their Effect on Plant Growth and Development

A significant environmental stress that has an effect on the expansion and maturation of plants is drought (Harb *et al.,* 2010). There are two different ways to define drought: a meteorological definition and an agronomic definition. A stretch of exceptionally dry weather that lasts for a significant amount of time to generate a serious hydrological imbalance in the region that is being affected by the drought is what meteorologists mean when they talk about a drought (Asare *et al.,* 2013). The term "agronomic drought" refers to a situation in which there is an insufficient amount of water in the soil to support the growth of crops (World Meteorological Organisation, 2006). There are a number of factors that can contribute to agronomic drought,

including meteorological drought, an uneven distribution of precipitation, and improper management of soil water, which can lead to insufficient soil water (World Meteorological Organisation, 2006, Mabhaudhi 2009). The ability of a plant to survive for an extended time with inadequate access to water is one of the criteria used by specialists to determine whether or not the plant is drought-resistant. This does not indicate that a plant that is drought-tolerant enjoys hot, dry circumstances or that the plant will not suffer any negative effects as a result of the drought (Fair, 2009). In general, drought has a detrimental effect on the growth and development of crops, particularly during the reproductive period of plant life. The effect of drought stress on the reproductive stage was also confirmed by a study that was carried out by de Souza *et al*. (2015). In that study, water deficit was observed to reduce yield by reducing seed size and number and shortening the grain filling period. Additionally, the grain filling period was observed to be shortened. A period of dryness that lasts for an extended period of time will have a detrimental impact on plant growth since it will reduce the plant's ability to control its temperature. In addition, if there is a lack of available water, the plant may also suffer from a lack of nutrients, which will result in a reduction in photosynthesis. If the plant's ability to produce photosynthesis is hindered, the plant may run out of energy and be unable to maintain all of its functions (Fair, 2009).

Drying soil has been demonstrated in a number of studies to reduce the amount of water that plants are able to take in, leading to dehydration of plant tissues, a decrease in photosynthesis and storage capacity (Xu*et al.,* 2010), damage to the root system, and disturbance of the integrity of cell membranes (Kujawski, 2010). It was shown that the growth and symbiotic properties of the majority of rhizobia bacteria can be inhibited in legume crops, in particular when subjected to harsh environmental

conditions such as drought stress. This was one of the conditions studied. However, it was observed that many strains of rhizobia, which were spread throughout several different species, were resistant to the effects of stress (Zannou, 2006). This was proven to be true once again by Serraj (2003), who found evidence that nitrogenase activity was inhibited in soybeans that had been cultivated in drought-like conditions.

2.4.2 Drought Tolerance

The instruments of drought tolerance have been studied by a number of researchers (Aharoni et *al.,* 2004), and these mechanisms can be categorised into the following three groups: leakage, tolerance and avoidance (Mitra, 2001; Agbicodo*et al.,* 2009). The capability of a plant to finish its life cycle before substantial soil and plant water deficiencies arise is what we mean when we talk about drought escape. This system requires quick phenological development, developmental plasticity (change in duration of growth according to the level of water deprivation), and remobilization of pre-anthesis photo assimilation in order to function properly. The capacity of plants to keep their tissue water potential relatively high despite a reduction in available soil moisture is known as drought avoidance. Plants have developed several tactics to conserve water and maintain internal pressure. These strategies include:

- Expanding their root systems to absorb more water
- Reducing water loss by:
  - Limiting gas exchange through tiny openings on leaves and stems
  - Reflecting sunlight to reduce heating
- Curling or folding leaves to minimize exposure
- Producing smaller leaves to decrease water loss through transpiration

These adaptations enable plants to efficiently manage water and maintain cellular turgor pressure.

These strategies all work together to help plants maintain turgor (Mitra, 2001). The capability of plants to survive periods of water deprivation while maintaining alow tissue water potential is referred to as drought tolerance (Mitra, 2001). Plants that make use of tolerance mechanisms are able to maintain their turgor through osmotic adjustment (the buildup of compatible solutes in the cell), increase cell flexibility, decrease cell volume, and raise their resistance to desiccation through protoplasmic resistance (Zannou, 2006). In order to survive drought, plants typically employ more than one defence mechanism at the same time. It has been said that cowpea is a crop that can survive in dry conditions (Zannou, 2006; Zhang et *al.*, 2005a). The crop uses a variety of techniques, such as escape, avoidance, and tolerance, to protect itself from the pest. Cowpea is able to avoid and tolerate drought because of its deep roots, strong stomatal sensitivity, reduced growth rate, leaf area reduction, and selective moisture remobilization with major dedication to the upper leaves and growing tips (Turk et *al.*, 2013; Zhang et *al.*, 2005). Cowpea can escape drought because of its ability to hasten or delay its reproductive cycle (Chiulele and Agenbag, 2004). In spite of the significant efforts that have been put into determining the mechanisms that contribute to cowpea's drought tolerance, the utilisation of this information in breeding has been almost nonexistent. The only significant advance that has been made so far is the creation of early-maturing varieties, such as IT84S-2246 and Bambey-21, which have since been made available to farmers and have received widespread adoption, notably in West Africa (Agbicodo *et al.*, 2009). These types have the ability to grow and produce a crop prior to the beginning of the end-of-offseason drought that happens in a number of different locales.

2.5 Chlorophyll Content

In 1816, Joseph Bienaime 'Caventou and Joseph Pelletier made the discovery that led to the discovery of chlorophyll. The term chlorophyll comes from the Greek words chroma, which means green, and phullon, which means leaf (Anon, 2013). Chlorophyll is a collection of green pigments that are found in the chloroplast cells of plants as well as in other photosynthetic organisms such as cyanobacteria and algae. Chlorophyll is responsible for the green colour of these species (Oxford Dictionary, fourth edition, 2000). These pigments are an exceedingly significant type of biomolecule that plays an essential role in the process of photosynthesis. They enable plants to take in energy from the sun. The amount of chlorophyll in a leaf offers extremely helpful information regarding the physiological state of a plant (Gitelson *et al.*, 2002). For instance, determining a plant's chlorophyll concentration can also be used as a proxy for determining its nitrogen content due to the fact that nitrogen is an integral component of chlorophyll. This measurement contributes to the determination of a more effective programme for applying fertiliser (Analyseur de Teneur en Chlorophylle, France, 2011). There is evidence in the scientific literature to suggest that water deficit can result in a decrease in chlorophyll content (Turk *et al.*, 2013). It has been claimed that the damage to chloroplasts that occurs as a result of reactive oxygen species is the cause of the decrease in chlorophyll that occurs under drought stress (Mafakheri *et al.*, 2010). However, high chlorophyll content is an indicator of a low degree of photo-inhibition of photosynthetic machinery since it lowers carbohydrate losses for grain growth. This is because chlorophyll absorbs more light than other pigments (Quaye *et al.*, 2009).

2.6 The Role of Moisture and Biological Nitrogen Fixation (BNF)

The conversion of nitrogen gas into ammonia is what Takishima *et al*. (2004) mean when they talk about biological nitrogen fixation. In order to break the nitrogen bonds and allow them to mix with hydrogen, the procedure requires sixteen molecules of ATP and a complex collection of enzymes. Plants are able to access the nitrogen that has been fixed either as a result of the lysis and death of free nitrogen-fixing bacteria or as a result of the symbiotic interaction that some nitrogen-fixing bacteria have with plants (Chenn, 2009). There are many different kinds of microorganisms that can be found in soil, including bacteria, actinomycetes, fungus, algae, and others. When associated with legume plants, a certain type of soil bacteria known as rhizobia has a positive impact on the growth of legumes. Rhizobia are able to biologically convert otherwise unavailable atmospheric nitrogen into a form that plants may use for growth and development (Chenn, 2009). Rhizobia can exist in the soil as saprophytic organisms or in conjunction with host legumes by developing plant-derived growths on the roots known as nodules. Either way, rhizobia can live. The legumes initiate the process of nodule formation by initiating communication with suitable rhizobia through the release of chemical molecules known as flavonoids from their roots. This, in turn, causes the bacteria to produce nod factors (Hutton, 2010). The root undergoes a number of biochemical and morphological changes in response to the detection of the nod factor, which in turn causes cell division in the root cortex, which results in the formation of the nodule. Subsequently, the root hair development is redirected, encircling the bacteria multiple times until it encases one or more of them entirely. Encased within the capsule, the bacteria multiply multiple times until they form a microcolony. The bacteria from this microcolony penetrate the growing nodule by way of an entity called an infection thread. This structure extends into the basal region of

the epidermal cell, past the root hair, and into the root cortex. After that, the bacteria grow into bacteroids that fix nitrogen and are encased in a membrane that comes from the plant (Watanabe, 2000).

In bacteria, distinct sets of genes are responsible for controlling different aspects of the nodulation process. Genes of specificity are what determine which strain of Rhizobium infects a particular type of bean. Even in the event that the strain is able to infect a legume, there is a possibility that the nodules that are created will not be able to fix nitrogen. Only the strains that are effective are able to cause the formation of nodules that fix nitrogen. The Nod genes are responsible for nodulation, which determines effectiveness. Because it ensures a steady supply of nitrogen for the development of plants, the biological process of nitrogen fixation is one of the most important factors in the enhancement of the fertility and productivity of low-nitrogen soils (Lindemann and Glover, 2003). Because the fixed nitrogen is directly available to the host plant, this not only enables the plant to grow in situations that are deficient in nitrogen, but it also helps to prevent losses caused by denitrification, volatilization, and leaching. According to a number of studies, grain legumes can fix anywhere from 15 to 210 kg Nha^{-1} in Africa, depending on the season (Chenn, 2009).

2.6.1 Factors Affecting BNF

The nitrogen that legumes need can be obtained from the soil, from rhizobia that are already present in the soil, or from rhizobia that have been introduced as an inoculant. Even if they fix large amounts of nitrogen into the atmosphere, legumes still get some of their nitrogen from the soil in the majority of cases (Mpepereki and Makonase, 2004). The amount of nitrogen that legume plants are able to fix is contingent upon the density and duration of the root nodules, the efficiency of the rhizobia that live

within the root nodules, and the quantity of nitrogen that is present in the soil (Singleton et *al.*, 2006). Nodulation and nitrogen fixation are both affected by a variety of factors, some of which include soil pH, soil moisture, temperature, and mineral nutrients. Other considerations include these as well. One of the elements that can have an effect on nodulation and nitrogen fixation is the presence of an excessive amount of moisture and/or water logging. In addition to this, it hinders the growth of root hair and sites of nodulation, and it disrupts the normal diffusion of oxygen throughout the root systems of plants. The nitrogen-fixing bacteria Sesbaniarostrata and Aeschynomene sp. can thrive in these conditions due to their location on plant stems rather than roots (Mohammadi *et al.,* 2012). The number of rhizobia in soils is known to decrease when they are subjected to water deficit, which also prevents nodulation and the fixation of nitrogen. A prolonged drought will hasten the decomposition of nodules, which will have an adverse effect on nitrogen fixation (Graham, 1992). When the surface soil is drying out, nitrogen can still be fixed by deep-rooted legumes that take advantage of the moisture in lower soil layers (Singleton et *al.,* 2006).

Another component that plays a role in nitrogen fixation is the pH of the soil. According to Mohammadi *et al*. (2012), a low soil pH is more often seen as a signal of situations in which some other soil qualities may limit crop growth than as the major cause of poor growth on its own. In addition to the direct effects that soil acidity has, it may also have an indirect effect on the growth of legumes by inhibiting the processes of nodulation and nitrogen fixation. Nodulation and BNF are both affected in a unique manner by extremes of the soil's pH. Rhizobia are susceptible to a wide variety of impacts based on the pH of the soil, but in general, very few rhizobia can grow and survive at pH levels that fall below 4.5 to 5.0. (Hungria and Vargas, 2000). The infection process and the growth of the bean plant can both be slowed down by an

increase in acidity. This effect is most likely the result of a breakdown in signal exchange between macro- and micro-symbionts, as well as a suppression of nodulation gene expression and the excretion of nod factor in the rhizobia (Singleton et *al.,* 2006). The level of acidity in the soil is another factor that inhibits the growth and existence of rhizobia. Rhizobia that have a rapid rate of growth are typically thought to be more sensitive than bradyrhizobia. Not only are there fewer rhizobia in acid soils, but the acidity also makes it difficult for roots to attach themselves to the soil. As a result, nodulation problems are widespread in these types of soils (Andrade, 2002). Brockwell *et al*. (2009) found that the quantity of *S. meliloti* rhizobia in soils with a pH less than 6 was roughly three times lower than the number of rhizobia in soils with a pH greater than 7.0, which had an effect on nodulation.

Mineral nitrogen slows the process of rhizobia infection and also inhibits the process of nitrogen fixation in the sense that it is more cost-effective for the plant to consume nitrogen from the soil rather than fix nitrogen (Mohammadi *et al.,* 2012). On the other hand, for the plant to take up nitrogen from the soil, it requires less energy than for it to fix nitrogen. Nitrogen fixation increases when there is a decrease in the amount of nitrogen in the soil, and vice versa. This is a general rule. When there is a lot of nitrogen in the soil, plants might not create any nodules at all, or the nitrogen-fixing activity in the nodules they have already formed might slow down or stop entirely (Mohammadi *et al.,* 2012). Nitrogen fixation can be inhibited by the use of high quantities of nitrogen fertiliser, although the early growth of legumes can be stimulated by low doses (less than 30 kg N ha1) of nitrogen fertiliser, which can also boost the legumes' total rate of nitrogen fixation. The quantity of this beginning nitrogen needs to be determined in relation to the amount of nitrogen that is already present in the soil (Singleton et *al.,* 2006).

Additionally, high temperatures have a deleterious impact on the process of nitrogen fixation. Variations in temperature can have a significant impact on enzyme activity, and this is because the process of nitrogen fixation is an enzymatic one. According to the findings of Singleton and colleagues (1990), the ideal temperature range for nodulation and nitrogen fixation in soil is between 25 and 30 degrees Celsius. However, Mohammadi *et al*. (2012) found that the effect of temperature on rhizobia seems to vary depending on the strain as well as the soil.

2.7 Socio-economic and Environmental Impacts of Drought

2.7.1. Socio-economic Impacts of Drought

In the most underdeveloped nations, a large number of people rely on rain-fed agriculture and work in small businesses. For example, a hydrological drought will inevitably reduce hydropower production, which could lead to a national electricity shortfall and, as a result, unemployment. Although a lack of rainfall is the root cause of all droughts, agriculture is typically the first to be impacted because it is the most sensitive industry (Garca-León *et al.*, 2021). A drought can have the following social and financial effects:

- The economic consequences of the drought seemed to be the most severe, with a major impact on household income.
- The nation's economy is suffering due to food shortages, inadequate sanitation, the spread of new diseases that cause fatalities, and other factors.
- A rise in the unemployment rate as a result of decreased crop yields and the failure of business-related endeavors; a decline in employment in the agricultural industry or other jobs in rural areas.

- There may be an increase in crime and pollution as a result of temporary family dispersal to areas with economic opportunity, subpopulations, and urban expansion.
- When there may be numerous catastrophes, such as soil erosion, wildfires, and heat waves, that complement droughts, livestock are driven to lower numbers due to a lack of water and a de-vegetated landscape. Both public health and wealth are impacted by all of this.

2.8 Indicators Drought Stress

Variables and drought indicators are necessary to define the level of drought reaction and timing, as well as to measure, monitor, and identify drought circumstances, in order to describe and signal the aforementioned aspects of drought (Temam *et al.*, 2019). Indicators of drought are frequently divided into two groups: meteorological and hydrological (Bowell *et al.*, 2021). Meteorological indicators include climatic factors like precipitation, temperature, and evapotranspiration, while hydrological factors include stream flow, soil moisture, snowpack, groundwater, and reservoir levels.

2.9 Drought Tolerant Indices

Drought indices are numerical measures of the intensity of a drought that are derived from climatic or hydro-meteorological inputs. The size, location, timing, and duration of drought occurrences are all measured using drought indicators. The severity of an index is the amount by which it deviates from the mean. By giving practitioners, the

general public, and other interested parties important information tools, drought indices can assist in making the composite correlation simpler (Kim *et al.*, 2021).

CHAPTER THREE

MATERIALS AND METHODS

3.1: Location of the study

The study was carried out at Golinga irrigation in the Tolon district within the Guinea Savannah agroecology in the northern region of Ghana. Planting of the cowpea genotypes was done on 10th February, 2022 and 13th December, 2022 during the dry season. The Golinga irrigation scheme has a water source covering a 124-kilometer squarearea and irrigation facilities, allowing different levels of irrigation treatments to be conducted at the same site with gravity being the mode of water delivery. It has aPotential Irrigable Area of 100 ha but currently has a developed irrigable area of 40 ha.The scheme is managed by the Ghana Irrigation Development Authority. The region has a one-off precipitation of 1100 mm for every annum which happens among May and October every year (SARI, 2015). The soil being a sandy topsoil doesn't hold water well. The harvests filled in the plans incorporate onions, cowpea, rice, roselle and okra. The Golinga water system plot was initially worked in 1965, with an arranged limit of 100 ha of flooded land).

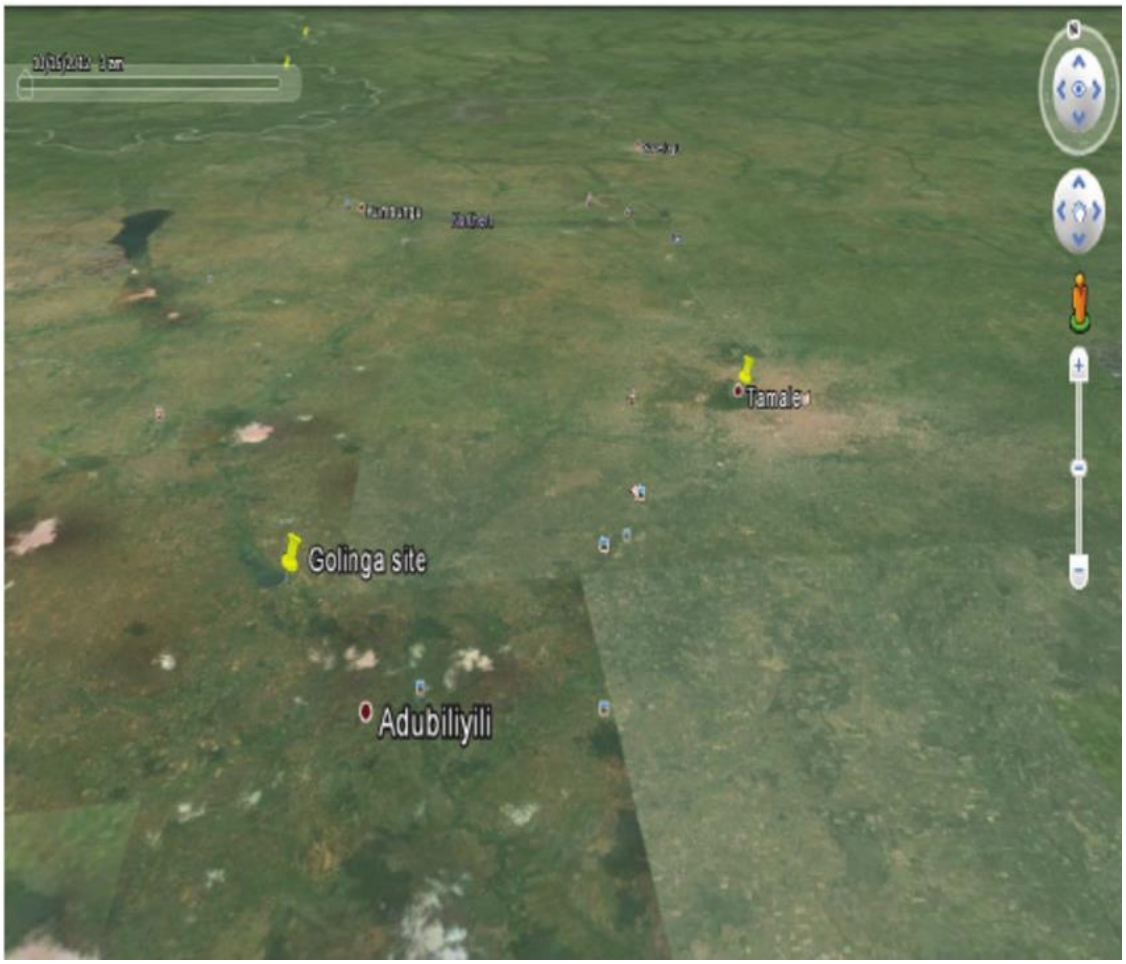

Figure 1: A 3D view of the Golinga Irrigation site (Avornyo, 2014)

3.2: Sources of cowpea

Twenty (20) cowpea genotypes were used in this study. Thirteen (13) were obtained from the Cowpea ImprovementProgramme, CSIR-SARI and seven (7) were obtained from the Department of Crop Science, University for Development Studies. IT93K-503-1 served as the resistant check.

Table 1: Sources of cowpea genotype

Genotype	Biological status	Source
UDS-CrS-UDS-CRS-F116-3-3	Advanced breeding line	UDS
UDS-CrS-UDS-CRS-F142-1-1	Advanced breeding line	UDS
UDS-CrS-UDS-CRS-F186-6-6	Advanced breeding line	UDS
UDS-CrS-UDS-CRS-F20-2-2	Advanced breeding line	UDS
UDS-CrS-F325-4	Advanced breeding line	UDS
UDS-CrS-UDS-CRS-F55-5-5	Advanced breeding line	UDS
UDS-CrS-UDS-CRS-F84-7-7	Advanced breeding line	UDS
IT93K-503-1	Advanced breeding line	UDS
IT10K-837-1	Advanced breeding line	CSIR-SARI
IT14K-2030-2	Advanced breeding line	CSIR-SARI
IT16K-1966-1	Advanced breeding line	CSIR-SARI
IT16K-1970-1	Advanced breeding line	CSIR-SARI
IT17K-1095-2-2	Advanced breeding line	CSIR-SARI
IT17K-1367-2-3	Advanced breeding line	CSIR-SARI
IT17K-1403-1-1	Advanced breeding line	CSIR-SARI
IT17K-1707-2-2	Advanced breeding line	CSIR-SARI
IT17K-1802-1	Advanced breeding line	CSIR-SARI
IT17K-1809-4	Advanced breeding line	CSIR-SARI
IT17K-849-2-1	Advanced breeding line	CSIR-SARI
KVX782-1	Advanced breeding line	CSIR-SARI

3.3: Experimental design, levels of irrigation and experimental layout on the field

The experiment was laid out in a split plot design with three replications for each treatment combination where the main plot is the watering regime, while the sub-plot is the genotype.

A non-stress (NS) treatment was based on the supply of irrigation every 3 days compared to a drought stress (DS) which involved the withdrawal of water supply at flowering and podding stage for 10 days interval.

The plot size for each experimental plot was 4m × 1.8m (7.2m^2), and the spacing between plots and replications were 1m and 2m respectively. The field was laid out taking into consideration measurements for the plot size, size of replication and alley. The experimental plots and its respective alley to form three replications for each treatment was properly demarcated using lines and pegs. These enable you to make calculation involving area and to determine yield with respect to the area calculated.

3.4: Soil data

Soil samples were randomly collected from the experimental site at different depths foranalysis to determine the nutrient composition of the site.

3.5: Land preparation

3.5.1: Clearing of land

The experimental site was cleared with cutlasses, the field was harrowed using a tractor to loosen the soil compartment and a harrower was used to remove gullies on the field.

3.5.2: Levelling

After laying out the field as described above, the field was levelled with a rake and a hoe. This was to achieve an even and effective field level that could prevent the stagnation of water on the field.

3.5.3: Labelling

Labelling of the field was necessary the initial stage to help in preventing errors during planting.

3.6: Planting

Sowing was done with the required soil moisture level. The cowpea genotypes were planted at a distance of 60 cm ×20 cm and at a depth of 5 cm.

The packaged seeds were placed by the respective labels on each plot prior to planting.

3.7: Weed control and fertilizer application

A post-emergence herbicide with active ingredient Glyphosate [(Sunphosate (480 g/L)] was sprayed at 3.2 L/ha to eliminate any weed that emerged fast before the plant. A pre-emergence herbicide with active ingredient Pendimethaline [Alligator (400g/L)] was sprayed 3.2 L/ha to suppress the emergence of weed seeds whilst the experimental fields were weeded once, since pre- and post-emergence herbicides were applied to supress the growth of weeds. Manual weeding was done with a hoe. Ridges were reshaped to conserve moisture and also to control weeds at 2-3 weeks after weeding.

3.8 Data collection

3.8.1: Phenological Data

Phenological data were taken on parameters such as plant stand per plot, days to first flowering, days to 50% flowering, days to 95% flowering, days to first pod maturity, and days to 95% pod maturity.

3.8.2: Morpho-physiological data

The morpho-physiological data recorded on each of the genotypes were

- Average number of pods per peduncle
- Number of pods per plant

3.8.3: Physiological Data

- **Chlorophyll Content:** SPAD meter was used to determine the green nature of the plants which made it possible to determine the chlorophyll content of the plants.
- **Canopy temperature Depression:** The deviation of temperature of plant canopies from ambient temperature was calculated as = air temperature (TA) – canopy temperature.
- **Soil moisture:** Moisture meter was used to determine the moisture lost in the soil during the stress period.

3.8.4: Yield and yield components

Data on yield and yield components were determined in the following parameters;

- **Pod weight:** The pods were picked at harvest and further dried sufficiently in the sun on a concrete floor to obtain their dry weights.

- **Grain weight:** After shelling, the seeds of the harvested pods of each genotype were weighed and recorded.
- **Hundred seed weight:** After sun-drying the harvested pods, it was shelled and from each genotype, 100 seeds were randomly selected and weighed. The values were recorded as 100-seed weights which is an indicator to determine the seed size of each genotype.
- **Biomass weight:** Ten plants were carefully scooped out from the soil with a hoe and collected in envelopes together with the biomass and oven-dried at 60 $^{\circ}$C for 48 hours prior to subsequent weighing and data collection.

3.9: Data Analysis

The data was subjected to ANOVA using GENTAT 12 edition statistical software tool. Means were separated using the least significant difference (LSD)at 5% probability level.

A correlation analysis was done using the R Software (De Meniburu *et al.*, 2020). Principal component analysis was also conducted to understand the contribution of each trait to the total variation observed among the genotypes. The average of the two-year data was used in determining the principal components. Cluster analysis was performed using Hierarchical Clustering on Principal Components function of the FactoMine (Lê *et al.*, 2008) in R statistical software version 4.2.2.

CHAPTER FOUR

RESULTS

There were significant differences ($p<0.05$) between the stresses, stress by genotype effect and significant genotype effect of days to flowering of cowpea genotypes (Appendix 1). Days to first flowering ranged from 32 DAP in UDS-CRS-F142-1 to 44DAP in IT16K-1966-1 under well-watered conditions whiles it ranged from 36 DAP in UDS-CRS-F142-1 to 49DAP in IT16K-1966-1 under water deficit conditions. Only UDS-CRS-F142-1, UDS-CRS-F186-6, IT17K-1367-2-3 had significantly lower days to first flowering than the resistant check IT93K-503-1 (Table 1).

Table 2. Days to first flowering of stressed and non-stressed cowpea genotypes. Different letters in a column denotes significant differences at $p<0.05$.

	Days to first flowering	
Genotype	**Well-watered**	**Water deficit**
UDS-CRS-F116-3	36.33 bcd	42 de
UDS-CRS-F142-1	32 e	36 f
UDS-CRS-F186-6	34.33 de	43 cde
UDS-CRS-F20-2	39.67 bc	48 ab
UDS-CRS-F325-4	37.33 bcd	45.33 a-d
UDS-CRS-F55-5	40.33 ab	46.33 abc
UDS-CRS-F84-7	39 bc	43 cde
IT10K-837-1	39.33 bc	45.67 a-d
IT14K-2030-2	38 bcd	43.67 cde
IT16K-1966-1	**44.33 a**	**49 a**
IT16K-1970-1	40.33 ab	46.33 abc
IT17K-1095-2-2	40 bc	43 cde
IT17K-1367-2-3	36 cde	41 e
IT17K-1403-1-1	39.67 bc	43.33 cde
IT17K-1707-2-2	37.33 bcd	42 de
IT17K-1802-1	36.67 bcd	42 de
IT17K-1809-4	40 bc	44 b-e

IT17K-849-2-1	39.67 bc	43 cde
IT93K-503-1	39 bc	42.67 cde
KVX782-1	37.33 bcd	42 de
p value		**0.0139**
CV (%)		**3.4**

There were significant differences ($p<0.05$) between the stresses and significant genotype effect of days to 50% flowering of cowpea genotypes (Appendix 2). Genotype UDS-CRS-F142-1 had the lowest days to 50% flowering than the resistant check, IT93K-503-1 and other cowpea genotypes evaluated (table 2).

There were significant differences ($p<0.05$) among the genotype effect of days to first pod maturity and days to 95% pod maturity of the cowpea genotype evaluated (Appendix 3 and 4). Genotype UDS-CRS-F142-1 had the lowest days to first pod maturity than the resistant check, IT93K-503-1 and other cowpea genotypes evaluated (table 2). Only UDS-CRS-F142-1 and IT17K-1367-2-3 had lower days to 50% flowering, days to first pod maturity and days to 95% pod maturity than the resistant check IT93K-503-1 (Table 2). The maturity period of UDS-CRS-F116-3, UDS-CRS-F84-7, IT14K-2030-2, IT17K-1095-2-2, IT17K-1367-2-3, IT17K-1403-1-1, IT17K-1707-2-2, IT17K-1802-1, IT17K-1809-4, IT17K-849-2-1, IT93K-503-1 and KVX782-1 were not significantly different.

Table 3. Days to 50% flowering, days to first pod maturity and days to 95% pod maturity of cowpea genotypes evaluated under well-watered and water deficit conditions in 2022. Different letters in a column denotes significant differences at $p<0.05$.

Genotype	Days to 50% flowering	Days to first pod maturity	Days to 95% pod maturity
UDS-CRS-F116-3	44.33cd	54cd	**60.67ef**
UDS-CRS-F142-1	**39.5e**	**50e**	**59.5f**
UDS-CRS-F186-6	45.33cd	54.67cd	**64.33cdef**
UDS-CRS-F20-2	48.5ab	57.5bc	68.5bc
UDS-CRS-F325-4	45.9bc	56.5bc	67.5bcd
UDS-CRS-F55-5	48.5ab	58.83ab	67.67bcd
UDS-CRS-F84-7	45.5cd	55.67bcd	**62.83def**
IT10K-837-1	46bc	56.33bc	67.67bcd
IT14K-2030-2	45.5cd	57bc	**65.17cde**
IT16K-1966-1	50.33a	61.33a	73.67a
IT16K-1970-1	48.48ab	57.67abc	70.83ab
IT17K-1095-2-2	45.33cd	56.17bc	**62.83def**
IT17K-1367-2-3	**43d**	**52.33de**	**59.5f**
IT17K-1403-1-1	45.01cd	55.67bcd	**60.67ef**
IT17K-1707-2-2	44.5cd	55.5bcd	**63.33def**
IT17K-1802-1	43.67cd	54.5cd	**61ef**
IT17K-1809-4	45.67bcd	56.5bc	**64.67cde**
IT17K-849-2-1	44.83cd	57.33bc	**63.83cdef**
IT93K-503-1	**44.83cd**	**56.33bc**	**64.83cde**
KVX782-1	44.17cd	54.33cd	**60.5ef**
P Value	**0**	**0**	**0**
CV (%)	**2.96**	**3.16**	**3.74**

There were significant differences ($p<0.05$) among genotype effect of the pod yield of cowpea genotypes evaluated (Appendix 5). KVX782-1, IT17K-1367-2-3, IT17K-1707-2-2, IT17K-849-2-1, IT17K-1802-1, IT17K-1095-2-2, IT10K-837-1, UDS-CRS-F20-2, UDS-CRS-F116-3, IT14K-2030-2, UDS-CRS-F84-7 and UDS-CRS-F186-6 had the highest pod yield than the resistant check IT93K-503-1 as shown in table 3. Furthermore, KVX782-1 had a significant higher pod yield with 2947.67 among all the genotypes evaluated.

There were significant differences ($p<0.05$) between the stresses and genotype effect of the grain yield of cowpea genotypes (Appendix 6).

The top 10 genotypes with high grain yield were IT17K-1367-2-3, KVX782-1, IT17K-1802-1, IT17K-1707-2-2, IT17K-849-2-1, IT17K-1095-2-2, IT14K-2030-2, UDS-CRS-F20-2, IT17K-1403-1-1 and UDS-CRS-F116-3. They are among genotypes that have yields significantly higher than the resistant check variety (IT93K-503-1) (Table 3).

There were significant differences ($p<0.05$) among the genotype effect of biomass dry weight evaluated (Appendix 7). UDS-CRS-F20-2 and UDS-CRS-F55-5 had a significantly high biomass dry weight than the remaining cowpea genotypes and the resistant check (IT93K-503-1) evaluated (Table 3).

There were significant differences ($p<0.05$) between the stressed and unstressed genotypes as well as stress and genotype effect of harvest index of cowpea genotypes evaluated (Appendix 8). IT17K-1367-2-3, IT17K-1802-1, IT17K-1707-2-2, IT17K-1095-2-2, IT17K-1403-1-1, KVX782-1 and UDS-CRS-F116-3, UDS-CRS-F142-1

and UDS-CRS-F186-6 have harvest index ranging from 0.25-0.35 while the resistant check has a harvest index of 0.18.

There were significant differences ($p<0.05$) among the genotype effect with respect to the hundred seed weight of the cowpea genotypes evaluated (Appendix 9).KVX782-1 had a higher hundred seed weight($p<0.05$) among the cowpea genotypes evaluated and the resistant check the (Table 3). IT14K-2030-2 had the highest 100 seed-weight of 25 g which is not significantly different from IT17K-1707-2-2 (23.67), KVX782-1 (22 g), IT93K-503-1 (21 g), IT16K-1966-1 (21 g) and IT17K-1809-4(21 g).

Table 4. Yield characteristics of cowpea under well-watered and water deficit conditions. Different letters in a column denotes significant differences at p<0.05.

Genotype	Pod yield	Grain yield	Biomass dry weight	Harvest index	100-seed weight
UDS-CRS-F116-3	2073.48 a-e	1480.36 a-e	3922.22 a-d	**0.25 a-e**	17.17 f
UDS-CRS-F142-1	1600.23 c-g	1084.13 c-f	2606.67d	**0.25 a-e**	**20.17 b-f**
UDS-CRS-F186-6	1808.52 b-f	1373.27 a-e	3904.44 a-d	**0.25 a-e**	19.17 c-f
UDS-CRS-F20-2	2092.11 a-e	1484.65 a-e	**5088.89 a**	0.21 b-f	19.5 c-f
UDS-CRS-F325-4	1455.92 d-g	957.26 def	4082.22 a-d	0.16 def	18.17 def
UDS-CRS-F55-5	1568.49 c-g	1177.76 b-f	**5015.56 ab**	0.19 c-f	18.83 c-f
UDS-CRS-F84-7	1849.8 b-f	1320.58 a-e	3857.78 a-d	0.23 b-e	17.5 ef
IT10K-837-1	2128.76 a-e	1349.27 a-e	4602.22 abc	0.20 b-f	19.67 b-f
IT14K-2030-2	1876.99 b-f	1491.35 a-e	4373.33 abc	0.24 b-e	**25 a**
IT16K-1966-1	745.9 g	552.35 f	4151.11 abc	0.12 f	**21.83 a-d**
IT16K-1970-1	1262.74 efg	922.71 def	4315.56 abc	0.17 c-f	**20.83 b-f**
IT17K-1095-2-2	2246.38 a-e	1561.85 a-d	3553.33 bcd	**0.27 a-d**	18.5 def
IT17K-1367-2-3	2722.3 ab	**2013.53 a**	3137.78 cd	**0.35 a**	19.33 c-f
IT17K-1403-1-1	2073.99 a-e	1481.86 a-e	3704.44 a-d	0.26a-e	**20.83 b-f**
IT17K-1707-2-2	2473.4 abc	**1826.08 ab**	4328.89 abc	**0.27 abc**	**23.67 ab**

	2376.01				
IT17K-1802-1	a-d	**1854.69 ab**	4042.22 a-d	**0.29 ab**	**20.17 b-f**
IT17K-1809-4	958.57 fg	834.02 ef	4102.22 a-d	0.16 ef	**21.33 a-e**
	2468.61				
IT17K-849-2-1	a-d	**1693.15 abc**	3806.67a-d	**0.27 abc**	17.5 ef
	1778.66				
IT93K-503-1	**b-f**	**1164.12 b-f**	**4511.11abc**	**0.18 c-f**	**21.92 a-d**
KVX782-1	**2947.67 a**	**1917.82 a**	4540 abc	0.26 a-e	**22.67 abc**
p value	**0**	**0**	**0**	**0**	**0**
CV (%)	**24.82**	**24.02**	**17.66**	**21.57**	**9.61**

There were significant differences ($p<0.05$) among the genotype effect of Chlorophyll contents at 36DAP and 46DAP of cowpea genotypes evaluated (Appendix 10 and 11). IT17K-1367-2-3 also had the highest Chlorophyll contents at 36DAP and 46 DAP than the cowpea genotypes and the resistant check evaluated (Table 4).

There were significant differences ($p<0.05$) among the genotype effect of Chlorophyll contents at 76DAP of cowpea genotypes evaluated (Appendix 12). IT17K-1802-1 had the higher Chlorophyll contents at 76DAP than the resistant check (IT93K-503-1) and the other cowpeas evaluated (Table 4). Likewise, IT17K-1367-2-3, F325, UDS-CRS-F84-7 and IT17K-1707-2-2.

Table 5. Chlorophyll contents of cowpea genotypes at 36, 46 and 76 days after planting. Different letters in a column denotes significant differences at $p<0.05$.

Genotype	SPAD 36 DAP	SPAD 46DAP	SPAD 76 DAP
UDS-CRS-F116-3	57.8ab	57.57cd	53.9a
UDS-CRS-F142-1	**70.47 ab**	**72.38 ab**	52.25a

UDS-CRS-F186-6	**62.27 ab**	61.18bcd	**64.62 a**
UDS-CRS-F20-2	**59.23 ab**	62.68a-d	**62.27 a**
UDS-CRS-F325-4	**59.13 ab**	63.67a-d	**67.82 a**
UDS-CRS-F55-5	**66.1 ab**	**64.9 a-d**	**62.85 a**
UDS-CRS-F84-7	**62.22 ab**	**66.98 a-d**	**67.4 a**
IT10K-837-1	56.67b	62.22a-d	**58.58 a**
IT14K-2030-2	**67.13 ab**	**68.32 a-d**	**59.53 a**
IT16K-1966-1	**65.48 ab**	56.15d	**63.67 a**
IT16K-1970-1	**60.73 ab**	62.95a-d	55.2a
IT17K-1095-2-2	**58.4 ab**	**71.53 ab**	**59.35 a**
IT17K-1367-2-3	**74.07 a**	**75.68 a**	**67.28 a**
IT17K-1403-1-1	**62.07 ab**	**67.95 a-d**	52.13a
IT17K-1707-2-2	**65.92 ab**	**67.13 a-d**	**66.77 a**
IT17K-1802-1	**62.87 ab**	**70.02 abc**	**68 a**
IT17K-1809-4	**71.18 ab**	**70.2 abc**	**62.47 a**
IT17K-849-2-1	63.33ab	**66.28 a-d**	**57.13a**
IT93K-503-1 (Resistant check)	**59.4 ab**	64.05a-d	57.3a
KVX782-1	**65.9 ab**	**64.6 a-d**	56.35a
p value	**0.0176**	**0.0001**	**0.0135**
CV (%)	**12.91**	**9.82**	**14.86**

Soil moisture during the trials were significantly higher for non-stressed than stressed (Table 5 and (Appendix 13). Although soil moisture around IT16K-1970-1 was relatively high averagely, at 56DAP, it was not significantly different from the rest of the genotypes (Table 5).

There were significant ($p<0.05$) genotype by stress effect of soil moisture at 76DAP for the cowpea genotypes evaluated (Appendix 14). Soil moisture at 76DAP of the cowpea genotypes evaluated ranges from 29 in IT10K-837-1 to 46 in IT17K-1707-2-

2 under non-stressed conditions, and only soil moisture for IT10K-837-1 and IT17K-1707-2-2 were significantly different from each other while soil moisture for the remaining genotypes were not significantly different.

Soil moisture for genotypes under water-stressed conditions ranged from 11 in UDS-CRS-F20-2 to 20 in IT17K-849-2-1. Soil moisture for the cowpea genotypes under water deficit conditions were not significantly different (Table 5).

Table 6. Soil moisture content of cowpea genotypes under two moisture regimes at 56 and 76 days after planting. Different letters in a column denotes significant differences at p<0.05.

	Soil	Soil Moisture_76 DAP	
Genotype	**Moisture_56DAP**	**NS**	**S**
UDS-CRS-F116-3	10.47ab	29.8b	12.5a
UDS-CRS-F142-1	12.65ab	30.13b	13.3a
UDS-CRS-F186-6	12.72ab	30.8b	13.8a
UDS-CRS-F20-2	9.9b	35.2ab	**11.17a**
UDS-CRS-F325-4	16.08ab	41.47ab	19.77a
UDS-CRS-F55-5	9.07b	40.93ab	15.87a
UDS-CRS-F84-7	13.95ab	34.5ab	12.3a
IT10K-837-1	11.55ab	**29b**	18.8a
IT14K-2030-2	9.2b	29.3b	13.17a
IT16K-1966-1	10.72ab	36.07ab	13.17a
IT16K-1970-1	**18.1a**	39.53ab	15.3a
IT17K-1095-2-2	10.75ab	29.17b	14.37a
IT17K-1367-2-3	11.7ab	39.17ab	15.5a
IT17K-1403-1-1	12.08ab	33.4ab	16.5a
IT17K-1707-2-2	12.8ab	**46.63a**	14.1a
IT17K-1802-1	14.02ab	31.4b	19.83a
IT17K-1809-4	11.1ab	35.93ab	13.37a
IT17K-849-2-1	12.98ab	35ab	**20.07a**
IT93K-503-1 (Resistant check)	**10.17b**	**35.7ab**	**12.33a**
KVX782-1	11.53ab	33.93ab	15.13a
p value	**0.007**	**0.0099**	
CV (%)	**30.31**	**19.17**	

There were significant differences ($p<0.05$) between the stresses, stress by genotype effect and significant genotype effect of days to flowering of cowpea genotypes (Appendix 15). Days to flowering ranged from 31 DAP in UDS-CRS-F142-1 to 40 DAP in IT17K-849-2-1 under well-watered conditions whiles it ranged from 32 DAP in UDS-CRS-F142-1 and UDS-CRS-F84-7 to 42DAP in UDS-CRS-F20-2, IT10K-837-1 and F325 under water deficit conditions. Only UDS-CRS-F142-1 and UDS-CRS-F116-3 had significantly lower days to first flowering than the resistant check IT93K-503-1 under well-watered condition whiles UDS-CRS-F142-1 and UDS-CRS-F84-7 had significantly lower days to first flowering than the resistant check IT93K-503-1 under water deficit conditions (Table7).

There were significant differences ($p<0.05$) between the stressed and unstressed genotypes for days to 50% flowering of cowpea genotypes (Appendix 16). Days to 50% flowering also ranges from 36DAP in UDS-CRS-F142-1 and 48DAP in IT16K-1966-1 and IT16K-1970-1 under well-watered conditions whiles it ranged from 39DAP in IT17K-1367-2-3 to 50 DAP in IT16K-1966-1 and IT16K-1970-1 under water-deficit condition. Only UDS-CRS-F142-1 had significantly lower days to 50% flowering under well-watered condition than the resistant check IT93K-503-1 whiles IT17K-1367-2-3 had significantly lower days to 50% flowering under water deficit condition than the resistant check IT93K-503-1(Table7).

There were significant differences ($p<0.05$) between the stresses, stress by genotype effect and significant genotype effect of days to first pod maturity of cowpea genotypes (Appendix 17). Days to first pod maturity ranged from 52DAP in UDS-CRS-F142-1 and 62DAP in UDS-CRS-F55-5 under well-watered conditions whiles it ranged from 48DAP in UDS-CRS-F142-1 and 59DAP in IT16K-1966-1 under water deficit condition. Only UDS-CRS-F142-1 had significantly lower days to first pod maturity in both well-watered

conditions and water deficit condition than the resistant check IT93K-503-1(Table7). There were significant differences ($p<0.05$) between the stresses, stress by genotype effect and significant genotype effect of days to 95% pod maturity of cowpea genotypes (Appendix 18). Days to 95% pod maturity ranges from 60DAP in UDS-CRS-F142-1 and 75DAP in UDS-CRS-F55-5 under well-watered condition whiles it ranges from 57DAP in IT17K-1367-2-3 to 72DAP in IT17K-1809-4 under water deficit condition. Only UDS-CRS-F142-1 and IT17K-1367-2-3 had significantly lower days to 95% pod maturity in both well-watered conditions and water deficit conditions respectively than the resistant check IT93K-503-1(Table7).

Table 7. Flowering and maturity parameters of cowpea genotypes under well-watered and water deficit conditions in 2023. Different letters in a column denotes significant differences at p<0.05.

	Days to first flowering		Days to 50% flowering		Days to first pod maturity		Days to 95% pod maturity	
Genotypes	**Well-watered**	**Water deficit**	**Well-watered**	**Water deficit**	**Well-watered**	**Water deficit**	**Well-watered**	**Water deficit**
UDS-CRS-F116-3	**33.67 f**	41 a-e	40 f	46.33 def	55.67 fgh	53 fg	61.33 f	60.67 j
UDS-CRS-F142-1	**31.33 g**	**32 g**	**36 g**	40.5 hi	52.67 j	**48.5 h**	**60.67 f**	65 hi
UDS-CRS-F186-6	38.67 cd	41 a-e	45.33 bc	45 efg	55 ghi	55 def	66 bc	69 bcde
UDS-CRS-F20-2	40 bc	**42.33 ab**	**48.33 a**	48 bcd	57.67 c-f	56.3333 b-e	65 b-e	70 a-d
UDS-CRS-F325-4	35.33 ef	**42.67 a**	43.33 cd	45 efg	54.67 hij	58 ab	65.67 bcd	67.33 d-h
UDS-CRS-F55-5	43 a	40 cde	46 ab	45 efg	**62.33 a**	58 ab	**75.67 a**	67.67 d-h
UDS-CRS-F84-7	40 bc	**32 g**	43 cde	41 hi	58.33 cd	56.5 b-e	62.33 ef	67.5 d-h
IT10K-837-1	39.67 bcd	**42.33 ab**	44 bcd	47.33 cde	58 cde	57 a-d	65 b-e	69 b-e
IT14K-2030-2	39 bcd	39.33 e	44.33 bcd	44 fg	57.33 c-f	56.6667 bcde	66 bc	68.67 b-e
IT16K-1966-1	43 a	41 a-e	**48.33 a**	**50.5 a**	61.33 ab	**59a**	74.67 a	71.5 ab
IT16K-1970-1	40 bc	40.33 cde	**48 a**	**50.33 ab**	59.33 bc	55.3333 cde	74.67 a	70.67 abc
IT17K-1095-2-2	40.67 b	41.33 a-d	43 cde	45 efg	54.67 hij	56 b-e	63 def	68 c-g
IT17K-1367-2-3	**35.67 e**	36.33 f	40.67 ef	**39 i**	53.33 ij	52 g	62.67 ef	**57 k**
IT17K-1403-1-1	39.33 bcd	41.5 abc	43.33 cd	46 def	56.33 d-h	57.5 abc	61 f	59 jk
IT17K-1707-2-2	36 e	39.5 de	44 bcd	41 hi	55 ghi	54.5 ef	67 bc	66.5 e-i
IT17K-1802-1	39.33 bcd	41.33 a-d	42 def	45.33 ef	56.67 d-h	56 b-e	62.67 ef	64.33 i
IT17K-1809-4	40.33 bc	41.33 a-d	45.33 bc	49 abc	57 d-g	56 b-e	67.67 b	72.33 a
IT17K-849-2-1	40.67 b	40.5 b-e	44.33 bcd	44.5 fg	57.67 c-f	58 ab	66 bc	65.5 f-i
IT93K-503-1	39.33 bcd	40.67 b-e	43 cde	44.67 fg	58 cde	56 b-e	67 bc	68.33 c-f
KVx782-1	38 d	41.67 abc	42 def	42.67 gh	56 e-h	55 def	64.33 cde	65.33 ghi
p value	**0**		**0**		**0**		**0**	
Cv	**1.7**		**1.8**		**1.37**		**1.46**	

There were significant differences ($p<0.05$) among the genotype effect of pod yield of cowpea genotypes evaluated (Appendix 19). IT17K-1367-2-3, UDS-CRS-F20-2, UDS-CRS-F84-7, IT17K-1095-2-2 and KVx782-1 had a high pod yield than the cowpea genotypes evaluated and the resistant check IT93K-503-1(Table 8).

There were significant differences ($p<0.05$) between the stresses and the genotype effect of grain yield of cowpea genotypes evaluated (Appendix 20). IT17K-1095-2-2 and IT17K-1367-2-3 had a significant high grain yield than cowpea genotypes evaluated and the resistant check IT93K-503-1(Table 8).

Table 8. Yield component of cowpea genotype evaluated under well-watered and water deficit condition in 2023. Different letters in a column denotes significant differences at p<0.05.

Genotypes	Pod yield	Grain yield
UDS-CRS-F116-3	1164.97a	778.65a
UDS-CRS-F142-1	1325.2a	967.43a
UDS-CRS-F186-6	1023.92a	751.6a
UDS-CRS-F20-2	**1405.16a**	954.7a
UDS-CRS-F325-4	937.37a	618.03a
UDS-CRS-F55-5	**1325.93a**	965.15a
UDS-CRS-F84-7	**1439.76a**	948.04a
IT10K-837-1	1033.15a	744.1a
IT14K-2030-2	868.92a	596.73a
IT16K-1966-1	1102.2a	724.06a
IT16K-1970-1	1018.89a	681.91a
IT17K-1095-2-2	**1393.42a**	**1026.91a**
IT17K-1367-2-3	**1470.06a**	**1021.88a**
IT17K-1403-1-1	1203.7a	738.53a
IT17K-1707-2-2	1264.63a	878.65a
IT17K-1802-1	1079.68a	721.53a
IT17K-1809-4	1222.89a	807.11a
IT17K-849-2-1	1240.94a	809.93a
IT93K-503-1	**1117.73a**	**896.06a**
KVx782-1	**1363.27a**	963.84a
p value	**0.0248**	**0.004**
CV (%)	**25.69**	**25.41**

There were significant differences (p<0.05) between stresses and the genotype effect of chlorophyll contents at 46DAP of cowpea genotypes (Appendix 21). UDS-CRS-F142-1 had a significant high chlorophyll content at 46DAP than the resistant check IT93K-503-1(Table 9).

There were significant differences ($p<0.05$) among the genotype effect of chlorophyll contents at 56DAP of cowpea genotypes evaluated (Appendix 22). IT17K-1707-2-2 had the highest chlorophyll contents at 56DAP than the resistant check IT93K-503-1 and the cowpea genotypes evaluated (Table 9).

There were significant differences ($p<0.05$) among the stress by genotype effect of chlorophyll contents at 76DAP of cowpea genotypes evaluated (Appendix 23). Chlorophyll contents of cowpea genotypes evaluated at 76DAP ranges from 57 in IT17K-1403-1-1 to 81 in UDS-CRS-F186-6 and had the highest chlorophyll content than the resistant checkIT93K-503-1 under the well-watered condition whiles it ranges from 56 in IT17K-1809-4 to 94 in IT17K-1403-1-1 which is significantly higher than the resistant check IT93K-503-1 under the water deficit condition (Table 9).

Table 9. Chlorophyll contents of cowpea genotypes evaluated in 2023 at 46, 56 and 76 days after planting under well-watered and water deficit condition. Different letters in a column denotes significant differences at p<0.05.

Genotypes	SPAD 46DAP	SPAD 56 DAP	SPAD76	
			Well-watered	Water deficit
UDS-CRS-F116-3	**70.72 a**	64.28 a	71.67a	64.53ab
UDS-CRS-F142-1	**75.53 a**	62.44 a	58.3 a	**70.4 ab**
UDS-CRS-F186-6	61.95 a	72.9 a	**81.1 a**	64.4 ab
UDS-CRS-F20-2	60.45 a	53.55 a	70.3 a	64.8 ab
UDS-CRS-F325-4	**69.17 a**	64.07 a	51.2 a	**78.73 ab**
UDS-CRS-F55-5	58.53 a	59.72 a	**80.67 a**	**69.3 ab**
UDS-CRS-F84-7	61.85 a	64.31 a	63.83 a	62.1 ab
IT10K-837-1	66.9 a	57.4 a	**78.6 a**	57.9 ab
IT14K-2030-2	67.22 a	65.85 a	77.7 a	66.03 ab
IT16K-1966-1	**77.94 a**	61.35 a	75.53 a	**71.8 ab**
IT16K-1970-1	**74.1 a**	71.97 a	70.23 a	66.17 ab
IT17K-1095-2-2	**82.95 a**	67.3 a	75.27 a	**67.37 ab**
IT17K-1367-2-3	**82.15 a**	71.15 a	67.17 a	**70.07 ab**
IT17K-1403-1-1	56.33 a	51.88 a	**57.13 a**	**94.9 a**
IT17K-1707-2-2	**72.79 a**	**76.91 a**	57.03 a	65.5 ab
IT17K-1802-1	61.27 a	**74.57 a**	69.9 a	**72.4 ab**
IT17K-1809-4	57.88 a	71.32 a	68.67 a	**56.97 b**
IT17K-849-2-1	68.42 a	65.86 a	64.3 a	**68 ab**
IT93K-503-1	**68.73 a**	**73.25 a**	**78.07 a**	**67.87 ab**
KVx782-1	63 a	69.13 a	74 a	**75.1 ab**
p value	**0.0274**	**0.0226**	**0.6694**	
			17.2	
CV (%)	**20.69**	**128.41**		

There were significant differences (p<0.05) between the stress by genotype effect and the significant genotype effect of canopy temperature at 56DAP of cowpea genotypes

evaluated (Appendix 24). Canopy temperature at 56DAP ranges from 33 in UDS-CRS-F55-5 to 35 in UDS-CRS-F186-6 under the well-watered condition whiles it ranges from 32 in IT17K-1707-2-2 to 36 in UDS-CRS-F142-1 under the water deficit condition of the cowpea genotypes evaluated. Genotype UDS-CRS-F55-5 had the lowest canopy temperature which is not significantly different from the canopy temperature of the resistant check IT93K-503-1 under well-watered condition. IT17K-1707-2-2 had the lowest canopy temperature which is significantly ($p < 0.05$) lower than the resistant check IT93K-503-1 under water deficit condition (Table 10).

The genotype with the highest CTD was IT17K-1095-2-2 followed by UDS-CRS-F116-3, IT14K-2030-2, IT14K-1403-1-1 and KVX782-1.

There were significant differences ($p<0.05$) between the stress by genotype effect and the significant genotype effect of canopy temperature depression at 56DAP of cowpea genotypes evaluated (Appendix 25). Canopy temperature depression at 56DAP ranges from 1.13 in UDS-CRS-F186-6 to 3.9 in UDS-CRS-F55-5 under well-watered condition whiles it ranges from 0.7 in UDS-CRS-F142-1 to 4.2 in IT17K-1707-2-2 under water deficit condition of the cowpea genotypes evaluated (Table 10).

Table 10. Canopy temperature and canopy temperature depression of cowpea genotypes under well-watered and water deficit condition in 2023.

Different letters in a column denotes significant differences at p<0.05.

Genotypes	CT56		CTD56	
	NS	S	NS	S
UDS-CRS-F116-3	34.33ab	**33.53bc**	2.67ab	**3.47ab**
UDS-CRS-F142-1	**33.3b**	36.3a	**3.7a**	0.7c
UDS-CRS-F186-6	35.87a	33.7bc	1.13b	**3.3ab**
UDS-CRS-F20-2	34.43ab	34.27abc	2.57ab	2.73abc
UDS-CRS-F325-4	33.3b	33.93abc	**3.7a**	**3.07abc**
UDS-CRS-F55-5	**33.1b**	34.57abc	**3.9a**	2.43abc
UDS-CRS-F84-7	35.17ab	35.15abc	1.83ab	1.85abc
IT10K-837-1	35.37ab	34.43abc	1.63ab	2.57abc
IT14K-2030-2	34.1ab	**33.6bc**	2.9ab	**3.4ab**
IT16K-1966-1	34.67ab	33.75bc	2.33ab	**3.25ab**
IT16K-1970-1	34.63ab	33.73bc	2.37ab	**3.27ab**
IT17K-1095-2-2	**33.57ab**	**33.67bc**	**3.43ab**	**3.33ab**
IT17K-1367-2-3	34.77ab	**33.3bc**	2.23ab	**3.7ab**

IT17K-1403-1-1	**33.73ab**	33.85abc	**3.27ab**	**3.15abc**
IT17K-1707-2-2	34.13ab	**32.8c**	2.87ab	**4.2a**
IT17K-1802-1	35.33ab	**33.63bc**	1.67ab	**3.37ab**
IT17K-1809-4	34.3ab	**33.4bc**	2.7ab	**3.6ab**
IT17K-849-2-1	35ab	34.3abc	2ab	2.7abc
IT93K-503-1	35.63ab	35.67ab	1.37ab	1.33bc
KVx782-1	**33.97ab**	**33.37bc**	**3.03ab**	**3.63ab**
p value		**0.0005**		**0.0005**
CV (%)		**2.47**		**30.72**

Table 11: Genetic correlation of variables combined across locations. Different asterix in a column denotes significant differences at p<0.05.

Traits	DFF	D50F	D1PM	D95PM	PY	GY	HSW	BY	SPAD 46DAP	SM 46DAP	CT 56DAP	CTD 56DAP	SPAD 56DAP	SM 56DAP	CT 76DAP
D50F	0.96***														
D1PM	0.98***	0.95***													
D95PM	0.78***	0.9***	0.83***												
PY	-0.4	-0.65***	-0.51*	-0.83***											
GY	-0.4	-0.7***	-0.56**	-0.85***	1***										
HSW	0.08	0.21	0.024	0.34	-0.4	-0.3									
BY	0.94***	0.65***	0.73***	0.46*	0.5*	0.4	-0.08								
SPAD 46DAP	-0.6*	-0.46*	0.57***	-0.11	0.3	0.2	**0.53***	-1***							
SM 46DAP	-0.2	-0.3	-0.09	-0.23	-0.2	-0.1	-0.2	-0.1	0.081						
CT 56DAP	-0.2	-0.07	0.14	0.19	**-0.4**	**-0.5***	**-0.99*****	0.16	-0.2	0.66**					
CTD 56DAP	0.24	0.11	-0.07	-0.14	**0.2**	**0.5***	**0.99*****	0.13	0.23	-0.63**	-1***				
SPAD 56DAP	-0.7***	-0.67***	-0.62**	-0.55**	**0.6****	**0.8*****	**0.64****	-0.7***	0.8***	0.81***	**-0.5***	**0.39**			
SM 56DAP	-0.1	-0.23	-0.09	-0.34	-0	0.1	0.09	0.83***	-0.17	0.65**	-1***	**0.99*****	**0.96*****		
CT 76DAP	0.1	-0.35	-0.16	-0.62	0.1	-0	0.8***	0.21	-0.51*	0.07	1***	-1***	-0.2	-1***	
CTD 76DAP	0.12	0.58***	0.38*	0.8***	0.1	0.2	-0.91***	-0.1	**0.48***	0.02	-1***	0.99***	0.32	1***	-1***

Note: DFF = days to first flowering; D50%F = days to 50% flowering; DIPM = days to first pod maturity; D95%PM = Days to 95% pod maturity; PY = pod yield; HSW = hundred seed weight; BY = Biomass yield; SM = soil moisture; CT = canopy temperature; CTD = canopy temperature depression; DAP = days after planting

Significant positive association was found between the number of days until 50% flowering and the number of days until first flowering. The days to 50% flowering grow in tandem with the days to first flowering. The days to first flowering, first pod maturity, and 95% pod maturity showed a highly significant positive connection. Early maturing genotypes were found to blossom early. The amount of chlorophyll at 46 and 56 days before flowering showed a strong negative connection. The cowpea genotypes took longer to blossom as the chlorophyll content increased. Days to initial blooming and biomass dry weight showed a substantial and positive association. Long-flowering plants exhibited increased dry biomass. Days to initial blooming and harvest index showed a substantial and negative association (Table 11). This suggests that plants with shorter flowering times have better harvest indices. Days to 50% flowering and grain yield showed a modest negative connection that was significant, suggesting that early mature genotypes produced more grain. Between 50% blooming and biomass dry weight, there was a highly significant difference accompanied by a strong positive connection. Between the days to 50% flowering and harvest index, there was a highly significant difference and a strong negative connection (Table 11). Pod yield and grain yield showed a substantial positive connection with a highly significant difference, suggesting that genotypes with more pods also had more grains. Pod yield and harvest index showed a strong positive link with a very significant difference; this suggests that when pod output rises, so does the harvest index. The harvest index and grain yield showed a very significant difference and a strong positive association, indicating that an increase in grain output is accompanied by an increase in the harvest index. A noteworthy positive connection was observed between SPAD46DAP and HSW. While there was a large negative association between CT56DAP and HSW, there was only a minor correlation between PY and GY. HSW, grain yield, and pod yield are all

negatively correlated with high canopy temperature at 56DAP. CTD56DAP and PY had a positive relationship, while CTD56DAP and GY had a positive but significant relationship. A noteworthy positive connection was observed between CTD56DAP and HSW. Elevated canopy temperature depression is linked to increased grain and pod yields as well as high 100-seed weight.

A noteworthy positive connection was observed among SPAD56DAP, grain yield, pod yield, and 100 seed weight. High grain yield, 100 seed weight, and pod yield are correlated with higher SPAD chlorophyll meter values. Along with SPAD56DAP, there was a substantial positive association between SM56DAP and CTD56DAP. This suggested that increased soil moisture is linked to higher chlorophyll content and higher canopy temperature depression.

Principal component analysis and cluster analysis

Principal component analysis (PCA) was used to identify the traits that showed the most variation between genotypes in the data. Principal components (PC) one, two, and three contributed 38.29%, 53.25%, and 65.99%, respectivly, to the complete variety (Appendix 4). Aggregately, PC one and two represented 53.25% of the complete variety saw among the genotypes, while head parts one to three represented 65.99% (Appendix 5). The genotypes were sorted into five distinct color-coded clusters using the hierarchical cluster analysis dendrogram (Figure 1).

UDS-CRS-F142-1 belonged to cluster 1. IT17K-1707-2-2 and IT17K-1367-2-3 belong to cluster 2. IT17K-1095-2-2, UDS-CRS-F116-3, IT17K-1403-1-1, KVx782-1 and IT14K-2030-2 were grouped in cluster 3.

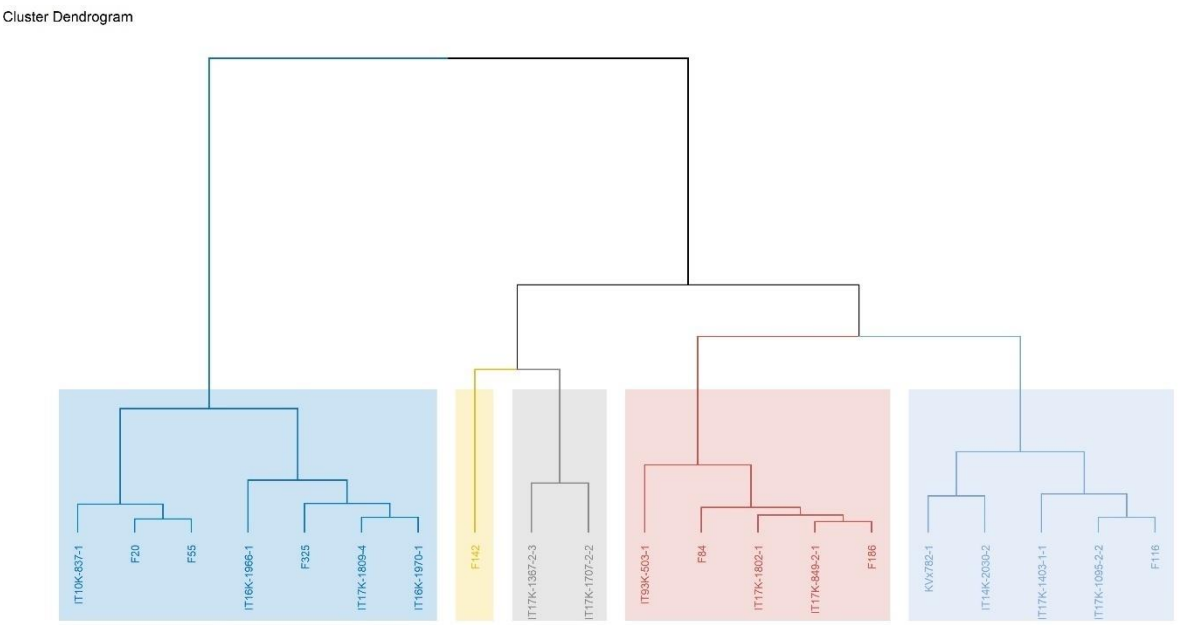

Figure 2: Cluster dendrogram

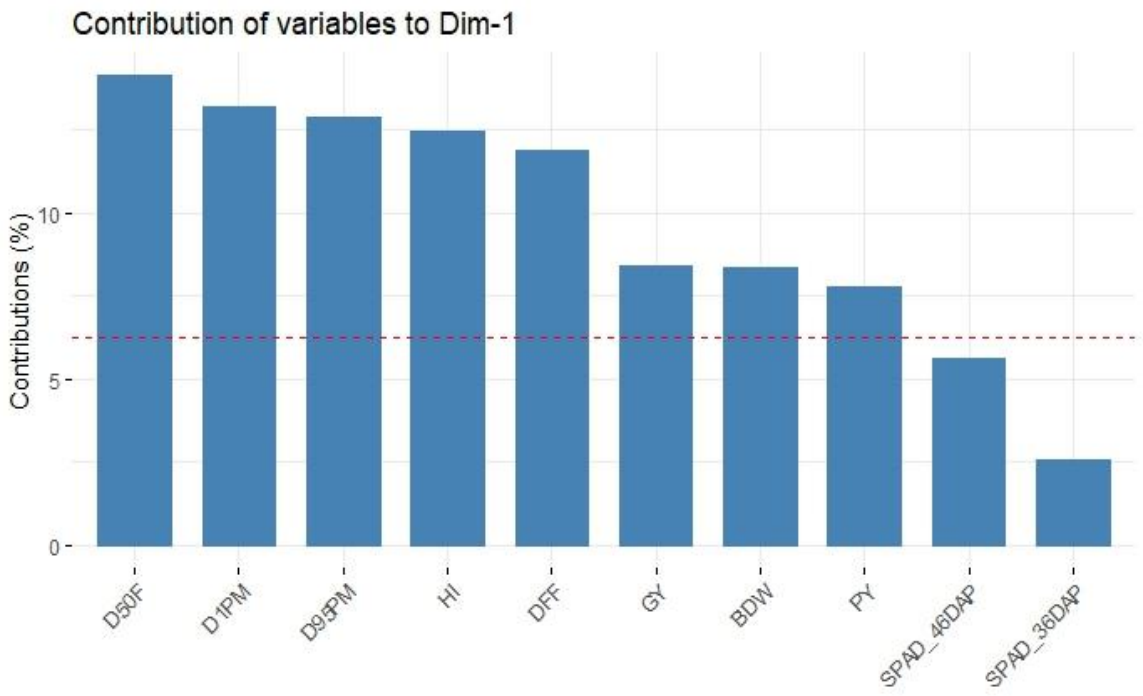

Figure 3: Principal component 1

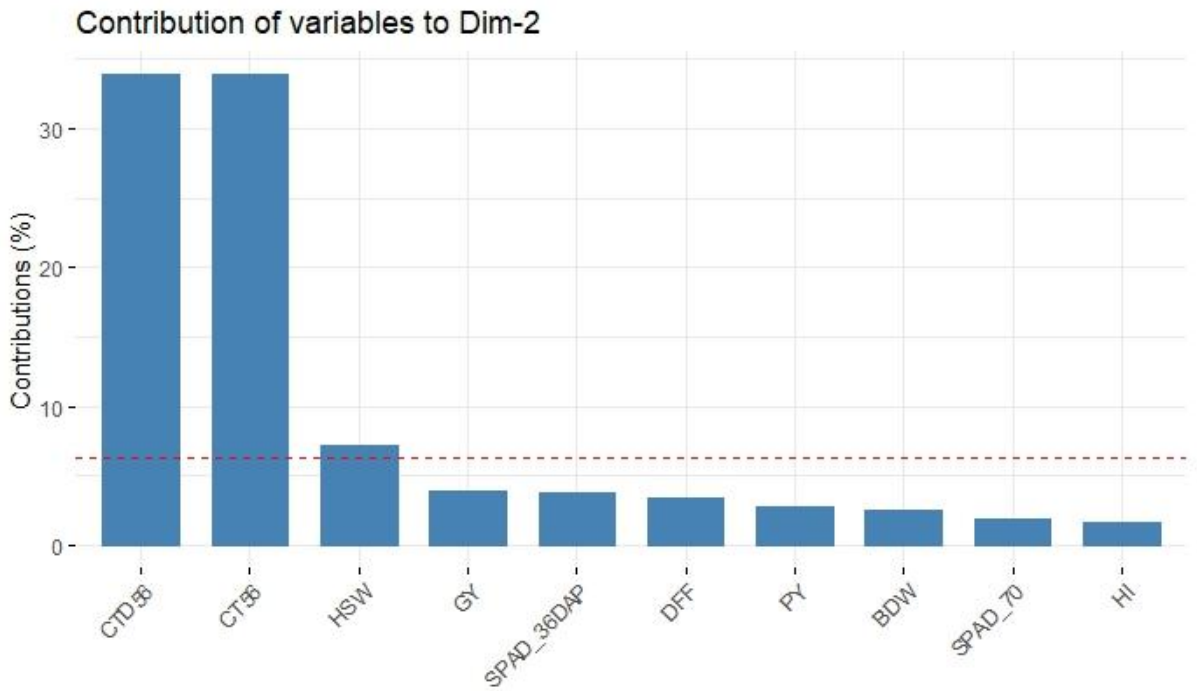

Figure 4: Principal component 2

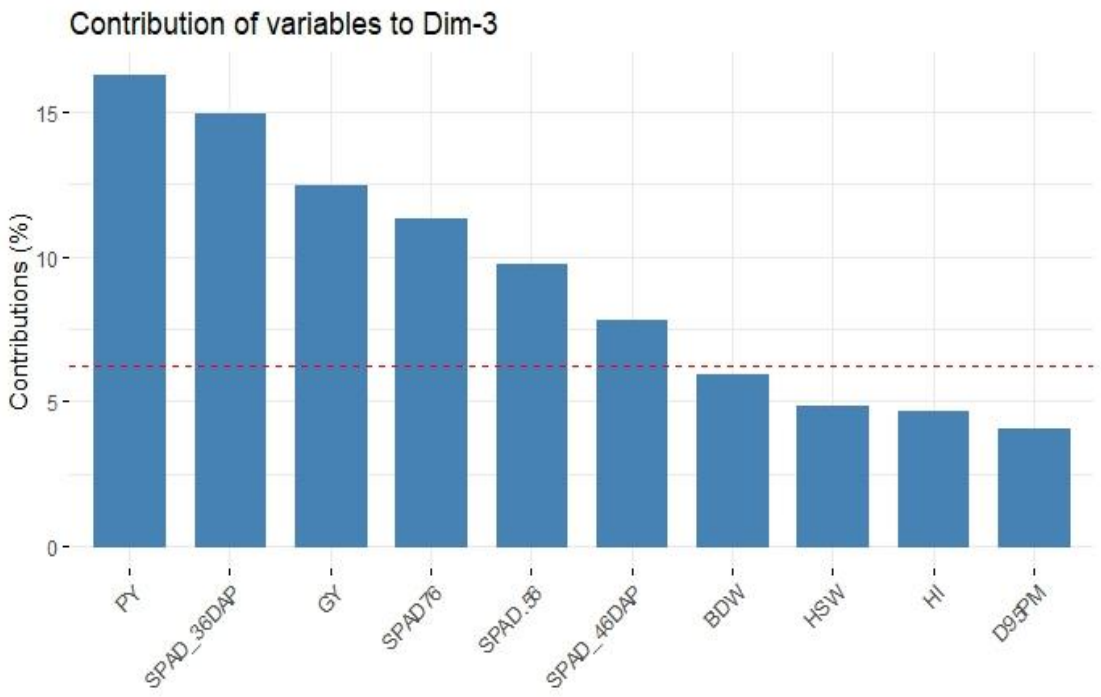

Figure 5: Principal component 3

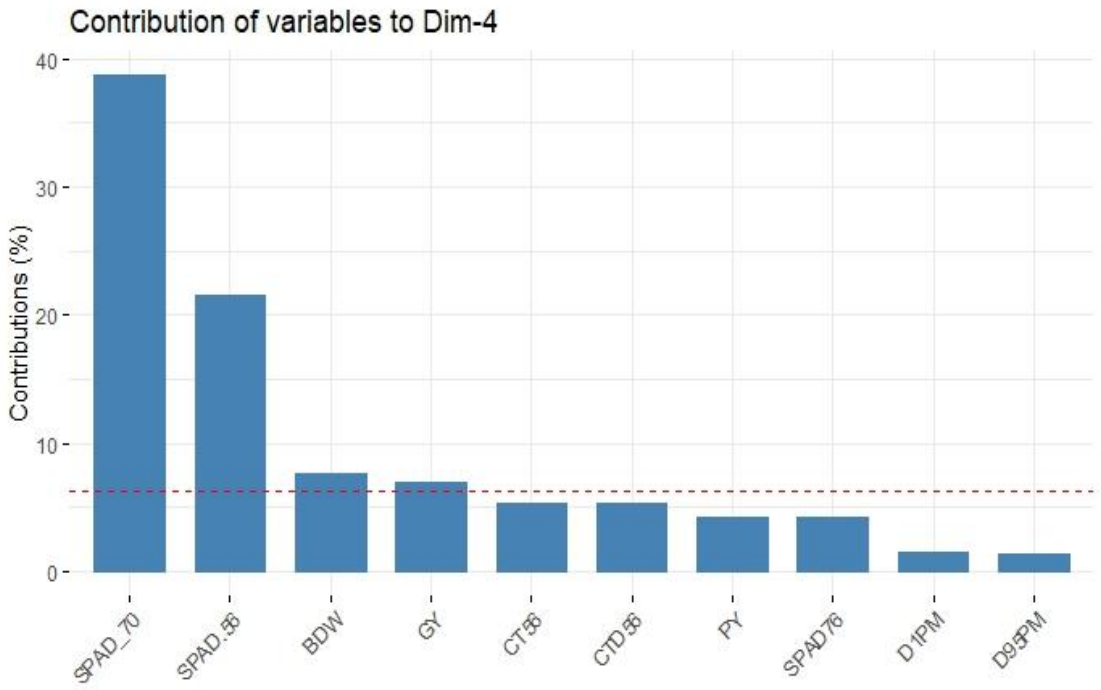

Figure 6: Principal component 4

CHAPTER FIVE

DISCUSSIONS

5.1 Physiological and morphological response of cowpea genotype under water deficit and well-watered conditions

Effect of water deficit on crop phenology (flowering and pod maturity)

In the northern and savannah regions of Ghana what would be vital to achieving maximum food security will be to produce field crops that are tolerant to moisture stress since production is mainly rainfed and the occurrence of drought is difficult to predict and to manage (Alidu, 2018). Throughout the two-year trial soil moisture was significantly higher for well-watered than water deficit fields. In 2022, although, IT16K-1970-1 appeared to have relatively higher soil moisture around it, this value was not significantly different from the soil moisture around the rest of the genotypes. Generally, soil moisture under stressed conditions was not significantly different for the genotypes from plot to plot.

Soil moisture level, genotype and their interaction had significant effect on the number of days it took for the cowpeas to reach their first flowering. Cowpea genotypes were observed to flower early under well-watered conditions while they flowered late under water deficit conditions during the two years evaluation. Differences in soil moisture are one of the reasons for the differences in flowering time. According to Galen (2000) where soil moisture is enough, plants channel resources into flower and seed production.

Genotypic differences in flowering time, first pod maturity and 95% pod maturity were also observed. UDS-CRS-F142-1, UDS-CRS-F186-6 and IT17K-1367-2-3 were

found to be earliest in flowering. UDS-CRS-F142-1 and IT17K-1367-2-3 took the least days to reach 50% flowering, days to first pod maturity and days to 95% pod maturity than the resistant check IT93K-503-1. However, maturity period of UDS-CRS-F116-3, UDS-CRS-F84-7, IT14K-2030-2, IT17K-1095-2-2, IT17K-1403-1-1, IT17K-1707-2-2, IT17K-1802-1, IT17K-1809-4, IT17K-849-2-1, IT93K-503-1 and KVX782-1, compared with IT17K-1367-2-3 were not significantly different from each other.Studies have reported that growth, development and yield of a crop is due to its genetic potential interacting with its environment (Sjamsijah *et al.*, 2016) this effect has been seen in this study. Genotypes that used fewer days to reach 1st flowering, reached 50% flowering early and took the shortest time to reach 1st pod maturity and 95% of their pod maturity. This explains the strong and significant positive correlation between days to 1st flowering, days to 50% flowering, days to 1st pod maturity and days to 95% pod maturity. This agrees with Rahman *et al*. (2011) who asserted that within certain limits, the longer it took a plant to reach its first flowering resulted in prolonged number of days to 50% flowering and 1st pod maturity.

5.2 Chlorophyll content of cowpea genotypes under water deficit and well-watered conditions

It was discovered that there was a substantial ($p<0.05$) interaction between the genotypes and stress levels in the two distinct water regimes. Significant variations were seen in the genotype performances under the water deficit regime. The investigated genotypes' chlorophyll concentrations were impacted by the water deficiency condition, which continuously decreased photosystem efficiency (Table 4). Similar water deficit research was carried out on winter wheat by Zhao et al. (2020), who found that photosynthetic parameters are impacted by water shortage. Under moderate and severe stress, it was shown that photosynthetic metrics such as net

photosynthetic rate (Pn), intercellular carbon concentration (Ci), stomatal conductance (Gs), and transpiration (E) dramatically decreased. Reduced readings from the SPAD chlorophyll meter indicate how plants are affected by drought stress. Water deficiency has also been reported to lower photosynthesis of tomato substantially as a result of both stomatal limitation and nonstomatal limitation (Liang et *al.*, 2020).The SPAD chlorophyll meter reading increases with increased soil moisture (SPAD56DAP positively connected with SM_56DAP).

Under drought stress in both assessment years, IT17K-1367-2-3, IT17K-1095-2-2, IT17K-1802-1, IT17K-1707-2-2, and UDS-CRS-F142-1 showed high chlorophyll contents. In both the stressed and non-stressed circumstances, the mean chlorophyll content (SPAD) readings were 56.7 and 69.5, respectively (Table 9). Stress, particularly during the vegetative stage, dramatically ($p<0.05$) decreased the relative chlorophyll contents. These outcomes align with the findings of (Nyachiro, 2001). When wheat leaves are exposed to extreme dryness, Fotovatet al. (2007) similarly found a considerable drop in the amount of chlorophyll in the leaves. According to Smirnoff (1995), damaged chloroplasts brought on by active oxygen species may be the reason of the genotypes under stress treatment's ongoing decline in chlorophyll content. For the purpose of choosing cowpea genotypes resistant to drought, chlorophyll content can be a trustworthy benchmark.

Under conditions of water deficiency, the genotypes IT17K-1095-2-2, IT17K-1367-2-3, IT16K-1966-1, UDS-CRS-F142-1, IT17K-1707-2-2, F325, IT17K-1802-1IT17K-1403-1-1, and KVx782-1 were able to maintain a high level of SPAD chlorophyll.The substantial and significant positive connection between high chlorophyll content and high pod and grain production as well as high 100 SW was found.

5.3 Canopy temperature depression of cowpea genotypes under water deficit and well-watered conditions

IT17K-1095-2-2, KVx782-1, IT17K-1403-1-1, IT17K-1707-2-2, IT17K-1367-2-3, IT17K-1802-1, IT14K-2030-2, IT17K-1809-4 and UDS-CRS-F116-3 were identified to have the lowest canopy temperature and therefore high canopy temperature depression under drought stress conditions simplifies that genotypes with high canopy temperature depression are more drought tolerant. The top five genotypes with the highest canopy temperature depression were IT17K-1707-2-2, IT17K-1367-2-3, KVX782-1, IT14K-2030-2 and UDS-CRS-F116-3, respectively. The difference between air temperature and plant canopy temperature, known as canopy temperature depression, is a key indicator of drought tolerance in plants (Tuberosa, 2014). Canopy temperature is closely linked to the plant's genetic ability to develop roots that efficiently absorb soil moisture (Blair et *al.*, 2010; Hammer et *al.*, 2019). Plants with cooler canopy temperatures tend to have deeper roots, allowing them to access more water, leading to increased yields (Lopes and Reynolds, 2010). In fact, studies have shown that certain bean varieties with cooler canopy temperatures produced 30% higher yields, attributed to a 40% increase in root growth at depths of 60-120 cm (Blum, 2005).There is therefore a high possibility that these genotypes have deeper root systems that allow them to explore soil moisture to access water. This finding is affirmed by the fact that a high CTD was highly associated with high soil moisture (CTD 56DAP and SM 56DAP).

5.4 Yield response of cowpea genotypes under water deficit and well-watered conditions

IT17K-1367-2-3, KVx782-1, IT17K-1802-1, IT17K-1707-2-2, IT17K-849-2-1, IT17K-1095-2-2, IT14K-2030-2, UDS-CRS-F20-2, IT17K-1403-1-1 and UDS-CRS-F116-3 were among the outstanding cowpea genotypes with high pod yield, grain yield and harvest index than the rest of cowpea genotypes evaluated and the resistant check variety, IT93K-503-1.High grain yield during drought is any breeder's preferred and primary trait for selection in any crop improvement program (Sariah, 2010). Several physiological and morphological traits combine for higher grain yield. Understanding the relationship between yield and the components that constitute grain yield is as good as improving the efficiency of selection in breeding programs. It is reported that moisture stress had a significant effect on grain yield and number of pods per plant (Alidu, 2018).

According to Luo et al. (2013), the yields from this study compare favorably to those from earlier studies conducted in other Sub-Saharan nations under similar environmental conditions. According to Anantharaju and Muthiah (2008), the drought stress greatly decreased grain productivity. The savannah ecology of sub-Saharan Africa is prone to severe drought conditions. According to Rizza *et al*. (2004), the best suited genotypes should retain high yield under both favourable and stressful conditions. Based on the evaluation of twenty genotypes, IT17K-1095-2-2 and IT17K-1367-2-3 were found to be among the best in both stressed and non-stressed situations. As such, they are considered to be genotypes with strong potential for yield and stability. Out of all the genotypes, UDS-CRS-F20-2 and UDS-CRS-F55-5 performed better in terms of dry biomass weight. These genotypes may be possibilities for dual-purpose cowpeas, which are fed to animals as fodder and grains that people eat. The

resistant check and cowpea genotypes exhibited a substantially lower hundred seed weight (25 g) than IT14K-2030-2.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Water deficit delays the time of flowering. Genotypes that reached first flowering early matured early. Genotypes which were identified to have high pod and grain yield, and high harvest index (IT17K-1367-2-3, KVx782-1, IT17K-1802-1, IT17K-1707-2-2, IT17K-849-2-1, IT17K-1095-2-2, IT14K-2030-2, UDS-CRS-F20-2, IT17K-1403-1-1 and UDS-CRS-F116-3) also had high chlorophyll content under drought stress and high canopy temperature depression under drought stress. These genotypes can therefore be classified as drought tolerant materials. Chlorophyll content and canopy temperature depression can be used to indirectly to select cowpea genotypes that are drought tolerant. High chlorophyll content and high canopy temperature depression was found to be associated with high pod yield, grain yield and one hundred seed weight. Reduced soil moisture resulted in reduced chlorophyll content.

6.2 Recommendation

The following cowpea genotypes, IT17K-1367-2-3, KVx782-1, IT17K-1802-1, IT17K-1707-2-2, IT17K-849-2-1, IT17K-1095-2-2, IT14K-2030-2, UDS-CRS-F20-2, IT17K-1403-1-1 and UDS-CRS-F116-3, should be evaluated under farmers field and best performing ones proposed for release as drought tolerant cowpea varieties.

Further studies should be conducted to assess root architecture of the above-mentioned genotypes which have also been identified to have high SPAD Chlorophyll meter readings and low canopy temperature depression under drought stressed conditions. Mechanisms of resistance to low canopy temperatures can be determined.

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Appendix

Appendix 1

DFF

Source	DF	SS	MS	F	P
REP	2	3.95	1.975	0.69	0.5914
Stress	**1**	**821.6333**	**821.6333**	**287.45**	**0.0035**
Error(a)	2	5.7167	2.8583		
GENOTYPE	**19**	**752.3667**	**39.5982**	**20.38**	**0**
Stress:GENOTYPE	**19**	**76.3667**	**4.0193**	**2.07**	**0.0139**
Error(b)	**76**	**147.6667**	**1.943**		
Total	**119**	**1807.7**			

Appendix 2

D50F

Source	DF	SS	MS	F	P
REP	2	0.2316	0.1158	0.02	0.9799
Stress	**1**	**839.2189**	**839.2189**	**148.62**	**0.0067**
Error(a)	2	11.2938	5.6469		
GENOTYPE	**19**	**609.4269**	**32.0751**	**17.7**	**0**
Stress:GENOTYPE	19	54.5152	2.8692	1.58	0.084
Error(b)	**73**	**132.3233**	**1.8126**		
Total	**116**	**1647.01**			

Appendix 3

D1PM

Source	DF	SS	MS	F	P
REP	2	10.0667	5.0333	4.19	0.1925
Stress	1	9.075	9.075	7.56	0.1107
Error(a)	2	2.4	1.2		
GENOTYPE	**19**	**633.4917**	**33.3417**	**10.67**	**0**
Stress:GENOTYPE	19	43.425	2.2855	0.73	0.7756
Error(b)	**76**	**237.5333**	**3.1254**		
Total	**119**	**935.9917**			

Appendix 4

D95PM

Source	DF	SS	MS	F	P
REP	2	6.45	3.225	0.34	0.7461
Stress	1	1.875	1.875	0.2	0.6999
Error(a)	2	18.95	9.475		
GENOTYPE	**19**	**1708.758**	**89.9346**	**15.44**	**0**
Stress:GENOTYPE	19	111.2917	5.8575	1.01	0.4647
Error(b)	**76**	**442.6**	**5.8237**		
Total	**119**	**2289.925**			

Appendix 5

PY

Source	DF	SS	MS	F	P
REP	2	1077058	538528.9	3.6	0.2175
Stress	1	810438.5	810438.5	5.41	0.1454
Error(a)	2	299346.8	149673.4		
GENOTYPE	**19**	**35739545**	**1881029**	**8.23**	**0**
Stress:GENOTYPE	19	4892896	257520.9	1.13	0.3428
Error(b)	**76**	**17362853**	**228458.6**		
Total	**119**	**60182137**			

Appendix 6

GY

Source	DF	SS	MS	F	P
REP	2	139839.1	69919.55	1.99	0.3349
Stress	**1**	**963664.2**	**963664.2**	**27.37**	**0.0347**
Error(a)	2	70425.28	35212.64		
GENOTYPE	**19**	**17041018**	**896895.7**	**8.19**	**0**
Stress:GENOTYPE	19	2586939	136154.7	1.24	0.2471
Error(b)	**76**	**8318127**	**109449**		
Total	**119**	**29120014**			

Appendix 7

BDW

Source	DF	SS	MS	F	P
REP	2	660986.7	330493.3	0.41	0.7092
Stress	1	3637761	3637761	4.51	0.1676
Error(a)	2	1611879	805939.3		
GENOTYPE	**19**	**38582191**	**2030642**	**3.91**	**0**
Stress:GENOTYPE	19	4766239	250854.7	0.48	0.9623
Error(b)	**76**	**39518779**	**519983.9**		
Total	**119**	**88777836**			

Appendix 8

HI

Source	DF	SS	MS	F	P
REP	2	0.003	0.0015	44.3	0.0221
Stress	**1**	**0.0105**	**0.0105**	**307.07**	**0.0032**
Error(a)	2	0.0001	0		
GENOTYPE	**19**	**0.3384**	**0.0178**	**7.43**	**0**
Stress:GENOTYPE	19	0.0536	0.0028	1.18	0.2994
Error(b)	**76**	**0.1823**	**0.0024**		
Total	**119**	**0.5879**			

Appendix 9

HSW

Source	DF	SS	MS	F	P
REP	2	14.9625	7.4813	2.59	0.2786
Stress	1	0.1021	0.1021	0.04	0.8683
Error(a)	2	5.7792	2.8896		
GENOTYPE	**19**	**504.6563**	**26.5609**	**7.06**	**0**
Stress:GENOTYPE	19	84.7729	4.4617	1.19	0.2913
Error(b)	**76**	**285.7583**	**3.76**		
Total	**119**	**896.0313**			

Appendix 10

		SPAD_36DAP			
Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	156.3352	78.1676	0.59	0.6302
Stress	1	6.4403	6.4403	0.05	0.8464
Error(a)	2	266.4622	133.2311		
GENOTYPE	**19**	**2563.76**	**134.9347**	**2.01**	**0.0176**
Stress:GENOTYPE	19	1447.34	76.1758	1.13	0.3377
Error(b)	**76**	**5110.483**	**67.2432**		
Total	**119**	**9550.82**			

Appendix 11

		SPAD_46DAP			
Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	214.3985	107.1992	9.39	0.0962
Stress	1	3.9241	3.9241	0.34	0.617
Error(a)	2	22.8222	11.4111		
GENOTYPE	**19**	**2688.921**	**141.5222**	**3.39**	**0.0001**
Stress:GENOTYPE	19	1068.944	56.2602	1.35	0.1809
Error(b)	**76**	**3174.899**	**41.775**		
Total	**119**	**7173.909**			

Appendix 12

		SPAD_76DAP			
Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	1847.459	923.7293	3.74	0.2111
Stress	1	963.3333	963.3333	3.9	0.1871
Error(a)	2	494.3207	247.1603		
GENOTYPE	**19**	**3212.528**	**169.0804**	**2.07**	**0.0135**
Stress:GENOTYPE	19	1091.787	57.4625	0.71	0.8025
Error(b)	**76**	**6193.747**	**81.4967**		
Total	**119**	**13803.17**			

Appendix 13

		SM_56DAP			
Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	265.2527	132.6263	3.15	0.2412
Stress	1	234.0813	234.0813	5.55	0.1426
Error(a)	2	84.3327	42.1663		
GENOTYPE	**19**	**571.6913**	**30.089**	**2.25**	**0.007**
Stress:GENOTYPE	19	345.322	18.1748	1.36	0.1754
Error(b)	**76**	**1018.195**	**13.3973**		
Total	**119**	**2518.875**			

Appendix 14

		SM_76DAP			
Source	**DF**	**SS**	**MS**	**F**	**P**
REP	2	12726.09	6363.045	0.95	0.512
Stress	1	11804.8	11804.8	1.77	0.315
Error(a)	2	13350.63	6675.315		
GENOTYPE	**19**	**935.8097**	**49.2531**	**2.16**	**0.0099**
Stress:GENOTYPE	**19**	**804.163**	**42.3244**	**1.85**	**0.0314**
Error(b)	**76**	**1736.74**	**22.8518**		
Total	**119**	**41358.23**			

Appendix 15

		DFF			
Source	**DF**	**SS**	**MS**	**F**	**P**
REP.1	2	1.1792	0.5896	1.62	0.3821
Stress	**1**	**47.5021**	**47.5021**	**130.29**	**0.0076**
Error(a)	2	0.7292	0.3646		
Genotypes	**19**	**695.6063**	**36.6109**	**84.51**	**0**
Stress:Genotypes	**19**	**314.4563**	**16.5503**	**38.2**	**0**
Error(b)	**76**	**32.925**	**0.4332**		
Total	**119**	**1092.398**			

Appendix 16

		D50F			
Source	**DF**	**SS**	**MS**	**F**	**P**
REP.1	2	2.45	1.225	3.42	0.2263
Stress	**1**	**50.0521**	**50.0521**	**139.68**	**0.0071**
Error(a)	2	0.7167	0.3583		

Genotypes	**19**	**888.8563**	**46.7819**	**73.56**	**0**
Stress:Genotypes	**19**	**160.5729**	**8.4512**	**13.29**	**0**
Error(b)	**76**	**48.3333**	**0.636**		
Total	**119**	**1150.981**			

Appendix 17

D1PM

Source	**DF**	**SS**	**MS**	**F**	**P**
REP.1	2	3.0042	1.5021	3.32	0.2313
Stress	**1**	**38.5333**	**38.5333**	**85.24**	**0.0115**
Error(a)	2	0.9042	0.4521		
Genotypes	**19**	**559.8667**	**29.4667**	**49.3**	**0**
Stress:Genotypes	**19**	**102.6333**	**5.4018**	**9.04**	**0**
Error(b)	**76**	**45.425**	**0.5977**		
Total	**119**	**750.3667**			

Appendix 18

D95PM

Source	**DF**	**SS**	**MS**	**F**	**P**
REP.1	2	25.1542	12.5771	25.47	0.0378
Stress	**1**	**16.875**	**16.875**	**34.18**	**0.028**
Error(a)	2	0.9875	0.4938		
Genotypes	**19**	**1620.292**	**85.2785**	**91.04**	**0**
Stress:Genotypes	**19**	**410.2917**	**21.5943**	**23.05**	**0**
Error(b)	**76**	**71.1917**	**0.9367**		
Total	**119**	**2144.792**			

Appendix 19

PY

Source	**DF**	**SS**	**MS**	**F**	**P**
REP.1	2	382974.9	191487.5	8.37	0.1067
Stress	1	111969.7	111969.7	4.89	0.1575
Error(a)	2	45766.64	22883.32		
Genotypes	**19**	**3460620**	**182137.9**	**1.92**	**0.0248**
Stress:Genotypes	19	797743.8	41986.52	0.44	0.9763
Error(b)	**76**	**7226045**	**95079.54**		
Total	**119**	**12025120**			

Appendix 20

GY

Source	DF	SS	MS	F	P
REP.1	2	242727.7	121363.8	2.69	0.2713
Stress	**1**	**535936.8**	**535936.8**	**11.86**	**0.075**
Error(a)	2	90376.61	45188.31		
Genotypes	**19**	**2019552**	**106292.2**	**2.39**	**0.004**
Stress:Genotypes	19	555709.9	29247.89	0.66	0.8472
Error(b)	**76**	**3377353**	**44438.85**		
Total	**119**	**6821655**			

Appendix 21

SPAD_46DAP

Source	DF	SS	MS	F	P
REP.1	2	403.7988	201.8994	14.1	0.0662
Stress	**1**	**2214.502**	**2214.502**	**154.64**	**0.0064**
Error(a)	2	28.6403	14.3201		
Genotypes	**19**	**7082.258**	**372.7504**	**1.89**	**0.0274**
Stress:Genotypes	19	4235.434	222.9176	1.13	0.3407
Error(b)	**76**	**14999.18**	**197.3576**		
Total	**119**	**28963.81**			

Appendix 22

SPAD_56DAP

Source	DF	SS	MS	F	P
REP.1	2	675.1558	337.5779	1.52	0.3962
Stress	1	362.7902	362.7902	1.64	0.329
Error(a)	2	443.0636	221.5318		
Genotypes	**19**	**5437.496**	**286.184**	**1.94**	**0.0226**
Stress:Genotypes	19	2472.019	130.1062	0.88	0.6052
Error(b)	**76**	**11211.09**	**147.5144**		
Total	**119**	**20601.62**			

Appendix 23

SPAD_76DAP

Source	DF	SS	MS	F	P
REP.1	2	353.598	176.799	2.84	0.2606
Stress	1	20.0083	20.0083	0.32	0.6281
Error(a)	2	124.6527	62.3263		
Genotypes	19	2220.118	116.8483	0.83	0.6694
Stress:Genotypes	**19**	**5714.052**	**300.7396**	**2.13**	**0.011**
Error(b)	**76**	**10741.38**	**141.3339**		
Total	**119**	**19173.81**			

Appendix 24

CT_56DAP

Source	DF	SS	MS	F	P
REP.1	2	4.3404	2.1702	0.65	0.6074
Stress	1	4.5047	4.5047	1.34	0.3664
Error(a)	2	6.7149	3.3574		
Genotypes	**19**	**39.7837**	**2.0939**	**2.92**	**0.0005**
Stress:Genotypes	**19**	**37.7799**	**1.9884**	**2.77**	**0.0009**
Error(b)	**76**	**54.5798**	**0.7182**		
Total	**119**	**147.7033**			

Appendix 25

CTD_56DAP

Source	DF	SS	MS	F	P
REP.1	2	4.3404	2.1702	0.65	0.6074
Stress	1	4.5047	4.5047	1.34	0.3664
Error(a)	2	6.7149	3.3574		
Genotypes	**19**	**39.7837**	**2.0939**	**2.92**	**0.0005**
Stress:Genotypes	**19**	**37.7799**	**1.9884**	**2.77**	**0.0009**
Error(b)	**76**	**54.5798**	**0.7182**		
Total	**119**	**147.7033**