

EVALUATION OF F₄ GENERATION OF COWPEA (*VIGNA UNGUICULATA*)
GENOTYPES FOR DROUGHT TOLERANCE AND HIGH YIELD



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DECLARATION

I do hereby declare that except for citations to findings of other researchers, duly cited, this work is my original research and that neither part nor whole has been presented elsewhere for the award of a degree.



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ABSTRACT

Globally, demand for improved agricultural production has increased as a result of an increasing human population. Drought and heat stress brought on by climate change exacerbate the difficulties of increasing crop production. Drought stress has a primary consequence of lowering crop output by reducing biomass and seed weight. Irrigation and breeding are two strategies for minimizing the consequence of drought or addressing the problem of drought stress. Irrigation, on the other hand, necessitates a significant upfront investment and the availability of water throughout the growing season, particularly during flowering and pod filling. This makes it more difficult, particularly for African small-scale farmers. The study was aimed at increasing cowpea yield through improved tolerance to drought. There was high diversity among the genotypes for days to first flowers, chlorophyll content, plant healthiness, stem greenness, number of seeds per pod, number of pods per plant, number of days to maturity, and ultimately the yield of the genotypes across all the treatments applied. The most decline was observed in the pod filling stage drought treatments across all measured parameters. Pearson correlation was conducted to observe the relationships between the parameters measured. The correlation analysis revealed a strong relationship was established between chlorophyll content and plant healthiness. Number of pods per plant was positively correlated to number of seeds per pod and similarly, seed size and pod length, revealing that the size of seeds and number of seeds in a pod determines the length of the pod. The ranking of genotypes based on the three drought tolerant parameters revealed some genotypes that performed better than Danila, a known drought tolerant line and Hewale the high yielding local cultivar. High yielding and drought tolerant genotypes for the vegetative and pod filling stage drought showed true drought tolerance.

DEDICATION

I dedicate this thesis to God Almighty and also to my cherished parents.



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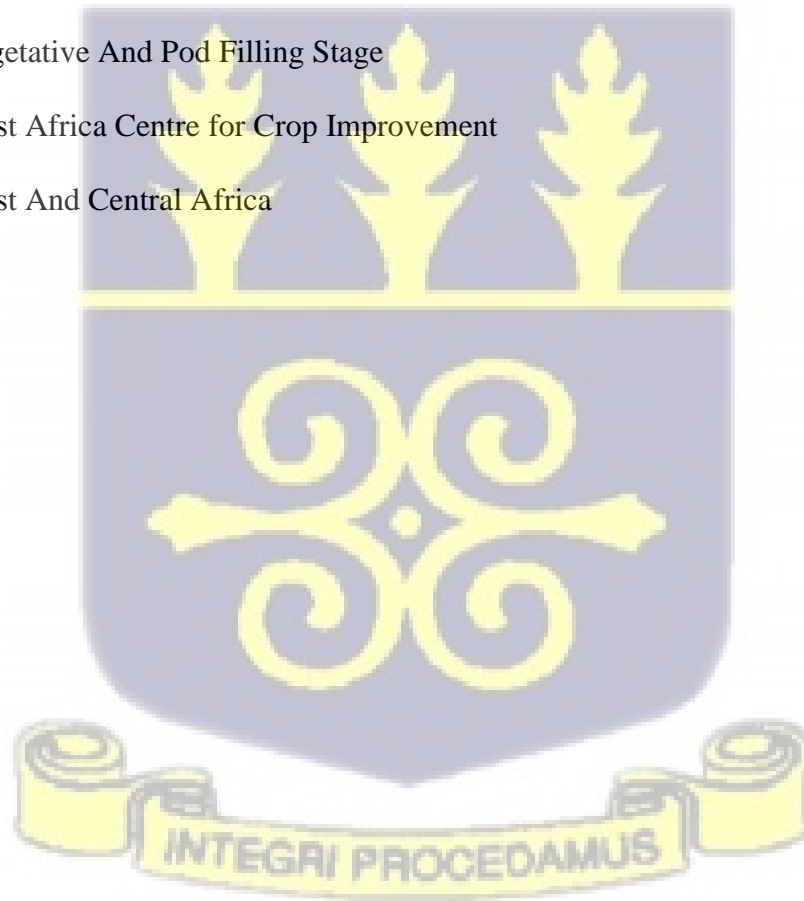
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LIST OF ABBREVIATIONS

AFLPs	Amplified Fragment Length Polymorphisms
CABMV	Cowpea Aphid Borne Mosaic
CII	Chlorophyll Inflect Index
CMV	Cucumber Mosaic Virus
CPMMV	Cowpea Moderate Mottle Virus
DAS	Days After Sowing
DMRT	Duncan's Multiple Range Test
FAO	Food And Agricultural Organization of The United Nations
GCA	General Combining Ability
GDP	Gross Domestic Product
HII	Healthiness Inflect Index
IITA	International Institute of Tropical Agriculture
MAS	Marker-Assisted Selection
MoFA	Ministry Of Food and Agriculture
PF	Pod Filling Stage
PUFA	Polyunsaturated Fatty Acids
QTL	Quantitative Trait Loci
RAPDs	Random Amplified Polymorphic DNAs
RCBD	Randomized Complete Block Design
RFLPs	Restriction Fragment Length Polymorphisms
RuBP	Ribulose-1,5-Bisphosphate

SARI	Savannah Agricultural Research Institute
SCA	Specific Combining Ability
SSA	Sub-Saharan Africa
SSRs	Simple Sequence Repeats
UNCCD	United Nations Convention to Combat Desertification
VEG	Vegetative Stage
VP	Vegetative And Pod Filling Stage
WACCI	West Africa Centre for Crop Improvement
WCA	West And Central Africa



CHAPTER 1

1.0 INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp) is a significant legume crop that is grown extensively in arid and semi-arid agroecologies around the world under low input production techniques. It belongs to the family Fabaceae and sub-family Faboideae (Horn & Shimelis, 2020). It is a vital crop for Africa. It holds a high quantity of protein (19 to 35%) (Horn & Shimelis, 2020), 64% carbohydrates, and significant amounts of fiber, minerals, and vitamins (Yahaya *et al.*, 2019a). Cowpea is a vital element of the diet of many individuals in Africa and other underdeveloped countries, where it provides a key source of protein. It is a healthfully advantageous dietary protein source and compliments low protein staple cereals and tuber crops. It is also a reliable and valuable resource that generates revenue for farmers and merchants (Timko *et al.*, 2007; Singh *et al.*, 2007; Langyintuo *et al.*, 2003). In addition to nutrients, cowpea contains dietary fibre, antioxidants, polyunsaturated fatty acids (PUFA), and polyphenols (Nkomo *et al.*, 2021a) with the grains also high in lysine and tryptophan, two important amino acids (Horn & Shimelis, 2020). It is mainly a self-fertilizing crop. Cowpea is a crop that has the ability to fix nitrogen in the soil, restoring soil fertility. Farming households profit financially from the sale of the grains, leaves, or fodder as well as food processing by-products (Yahaya *et al.*, 2019b). The crop is known as a hunger crop because it matures early, allowing the edible leaves to be used during a time of year when food stores from earlier harvests have been depleted and newly planted seeds of other agricultural crops are not yet available for harvest (Yahaya *et al.*, 2019a). As a plant-based diet, it boosts fiber consumption, which lowers the risk of bowel disorders, including cancer, as well as the incidence of osteoporosis (Khalid & Elhardallou, 2016). With the exception of Nigeria, which yearly produces the most

cowpea grains (3.57 million metric tonnes), the United States, Peru, Serbia, Sri Lanka, and China were all named as the top producers throughout the previous three years (2014-2016) (FAOSTAT, 2017). Cowpea is cultivated on around 14.5 million hectares worldwide, yielding roughly 8.9 million metric tons per year (FAOSTAT, 2019). West Africa is the largest producer of cowpeas in Sub-Saharan Africa (SSA), with 80% of the region's entire production over the previous 14 years being produced by Nigeria and Niger (Boukar *et al.*, 2018). Cowpea is an important crop in Ghana because of its impact on the country's GDP, household earnings, and food and nutritional security. In terms of consumption, cowpea comes second after peanuts (Egbadzor, 2013; MOFA/SRID, 2011), and it is crucial for the economy and diet of urban and rural poor (SARI, 2014). Cowpea production is predominant in five regions of Ghana, namely, Northern, Upper West, Upper East, Brong Ahafo, and Ashanti regions (MOFA, 2016). The northern parts of Ghana are the major producers of cowpea. Although there is seasonal variation in rainfall, the main cowpea producing region is characterized by the unpredictable nature of this change. Cowpea has a short crop cycle and integrates well into cropping niches where other crops do not. In particular, cowpea production is gaining prominence in the hydromorphic lowlands between April and June before rice is produced. In the northern Savanna zones of West Africa, average farm level yields of cowpea are still within 0.8 t/ha on farmers' fields even though varieties with grain yield potentials are in excess of 3.0 tonnes per hectare (t/ha) have been developed for such ecologies (SARI, 2014). Because of its multiple advantages, cowpea is practically cultivated by all smallholder farmers in most of Ghana's agro-ecological zones. Unfortunately, the complex nature of the abiotic and biotic stress usually leads to low grain yield of cowpea. According to MOFA (2016), typical yields in farmer's fields in Ghana range between 400 and 600 kg/ha, equated to potential yields of 1600 to 2500 kg/ha in research fields. The usage of unimproved local cultivars, poor soil fertility, drought, and

other biotic and abiotic stressors are all linked to low yield. The reduced potential yield of cowpeas in sub-Saharan Africa is caused by a number of biotic and abiotic causes, including insect pests, diseases (fungal, viral, and bacterial), inadequate soil fertility, metal toxicity, and drought (Sala *et al.*, 2008; Boukar *et al.*, 2018; Gomes *et al.*, 2019.). A plant may become tolerant to drought by a variety of methods, including drought escape, drought avoidance, or drought tolerance. Plants might employ a combination of mechanisms for dealing with drought (Ludlow, 1989; Mitra, 2001; Yue *et al.*, 2006). The capacity of a plant to finish its life cycle prior to the commencement of a severe water deficit is known as drought escape. (Yue *et al.*, 2006; Bhatnagar-Mathur *et al.*, 2010). This mechanism comprises speedy phenological growth (early flowering, early podding and early maturity) (Gaur *et al.*, 2008). Despite the fact that studies have shown there is a production penalty for any crop maturity time reduction below the ideal (Caliskan *et al.*, 2008), a prominent approach in breeding crops for drought tolerance is the choice of earliness. This is because, early cultivars offer immediate income at the start of the cropping seasons, is produced in varied cropping systems and can escape some insect infestation (Ehlers and Hall, 1997). Drought avoidance is the ability of plants to maintain a high-water status or cellular hydration while experiencing the impacts of drought (Blum, 2005). Plants use this method to reduce water loss by closing their stomata and increasing lenticular conductivity (Chaves *et al.*, 2003), limiting absorption of solar radiation by leaf rolling or folding/Para heliotropism (Fatokun *et al.*, 2012) and decreasing the area of the leaf where water is lost through evaporation, as well as creating a thick trichome layer that improves reflectivity (Yue *et al.*, 2006; Taiz and Zeiger, 2006). They boost the roots' systems ability to take up water (Jackson *et al.*, 2000) and root traits including thickness, depth, length, and density, for example in rice (Ekanayake *et al.*, 1985). This mechanism affects how efficiently water is used as well as how evapotranspiration is controlled. The capacity of plants to survive water shortages

with low tissue water potential is known as drought tolerance. The approach includes the creation of various stress-relieving substances, the preservation of turgor via osmotic adjustment (concentration of solutes in the cell), enhanced cell flexibility and reduced cell size, and desiccation tolerance via protoplasmic resistance (Agbicodo *et al.*, 2010). It deals with the recovery and survival of genotypes following a protracted and severe internal water deprivation. In the event of a 95% loss of leaf water, these genotypes can still exist (Scott *et al.*, 2000). Dehydration tolerance allows plants to withstand lengthy and difficult water deficits and recover when it rains. Additionally, it enables plants to extend the duration of their metabolic processes and transfer assimilates to the storage tissues (Fukai and Cooper, 1995). Plants escape dehydration as a result of biochemical mechanisms that entail the build-up of compatible solutes, primarily nitrogen molecules (McCue and Hanson, 1990). These antioxidants and solutes are present in plants in various forms and concentrations. These solutes collaborate with antioxidants, which function to reduce reactive oxygen species (ROS), safeguard cellular components by osmotic adjustment, and maintain the proper balance between the creation and destruction of free radicals (McCue and Hanson, 1990; Lin *et al.*, 2006; Brosché *et al.*, 2010). By displaying delayed leaf senescence (DLSC), which is comparable to the stay-green traits in cereals, the cowpea exhibits a tolerance mechanism (Gwathmey and Hall 1992; Hall *et al.*, 1997). According to research, cowpea plants with the delayed leaf senescence (DLSC) trait were capable of surviving the mid-season drought brought on by sporadic rains and produce a second flush of pods for an increase in grain output (Hall *et al.*, 2003). It is possible for there to be a drought at the start of the growth season, when rain stops soon after planting, or in the middle of the season, just before the plants flower, or from the reproductive to the pod-filling stage. Early maturity is a strategy for escaping drought, however drought tolerance at the seedling stage and DLSC will increase the plants' capacity to endure

drought during the early and mid-season as well as the pod filling stages. For sorghum, it has been reported that genotypes with DLSC (stay green) can maintain physiological activity during the latter phases of grain filling in conditions of terminal drought (van Oosterom *et al.*, 1996).

Globally, demand for improved agricultural production has increased as a result of an increasing human population (Lesk *et al.*, 2016). Drought and heat stress brought on by climate change exacerbate the difficulties of increasing crop production (Fahad *et al.*, 2017). Droughts, both terminal and intermittent, reduce crop yields significantly because of their detrimental effects on plant development, physiology, and reproduction (Barnabás *et al.*, 2008). Drought stress has a primary consequence of lowering crop output by reducing biomass and seed weight (Dellal & McCarl, 2010). Irrigation and breeding are two strategies for minimizing the consequence of drought. Irrigation, on the other hand, necessitates a significant upfront investment and water supply for the entire planting season, particularly during flowering and pod filling. Due to this, it is harder, particularly for African small-scale farmers. As a result, genotypes that can withstand water stress should be selected. Developing drought-tolerant cultivars is a more long-term solution to drought management because farmers will not incur any additional charges once drought-tolerant seeds are accessible. Drought tolerance and grain yield, on the other hand, are complicated to breed since they are governed by minor genes whose impacts are usually confounded by interactions between the crop's morphological, physiological, and biochemical features and the environment, making genetic enhancement of these traits in crops a lengthy a challenging procedure (Fatokun *et al.*, 2012; Mir *et al.*, 2012). Tsamenyi (2018), in evaluating F₂ populations of cowpea showed some genotypes with drought tolerance potential. Ngalamu *et al.*, (2019) also

identified some genotypes with stability for drought tolerance and high grain yield. Drought tolerance is polygenic, making it difficult to find tolerant genotypes in drought-prone areas (Ngalamu *et al.*, (2019).

The goal of breeding programs is to create cultivars that outperform previously available cultivars (Daniele Lustosa Silva Jéssica DA *et al.*, 2017). However, getting access to cultivars with these advantages is possible if the new cultivar simultaneously has several phenotypes of interest, such as high grain yield and quality, a plant growth habit that allows for mechanization, high pest and disease resistance, tolerance to high temperatures and water stress, good nutritional quality, high production stability, and adaptation to different environments (Daniele Lustosa Silva Jéssica DA *et al.*, 2017). The failure of a cultivar can be caused by the identification of superior genotypes based on only one attribute, especially when economic and commercial characteristics, as well as customer preferences, are ignored (Cruz *et al.*, 2004). Selection is a crucial phase in genetic improvement that must be carried out with extreme caution. As a result, due to the difficulty of simultaneous selection, selection indices are utilized as a substitute for identifying superior genotypes for various features. Low heritability, polygenic control, epistasis, considerable genotype by environment (G x E) and quantitative trait loci (QTL) by environment (QTL x E) interactions have all hindered straight selection for grain yield under water-stress conditions (Piepho, 2000). The delayed progress in yield enhancement in drought-prone regions can be attributed to the complexity of drought tolerance mechanisms. Cowpea cultivars with improved drought and heat tolerance, as well as high biological nitrogen fixation, have been identified by researchers and plant breeders (Singh, 2014). Estimating the genetic gain can be used to quantify the increase in a population's average performance after each selection cycle due to an increase in the frequency of beneficial alleles. The calculation of genetic gain helps breeders to

assess the efficacy of their breeding strategies and direct them toward the formation of superior populations (Cruz *et al*, 2004; FERH, 1987).

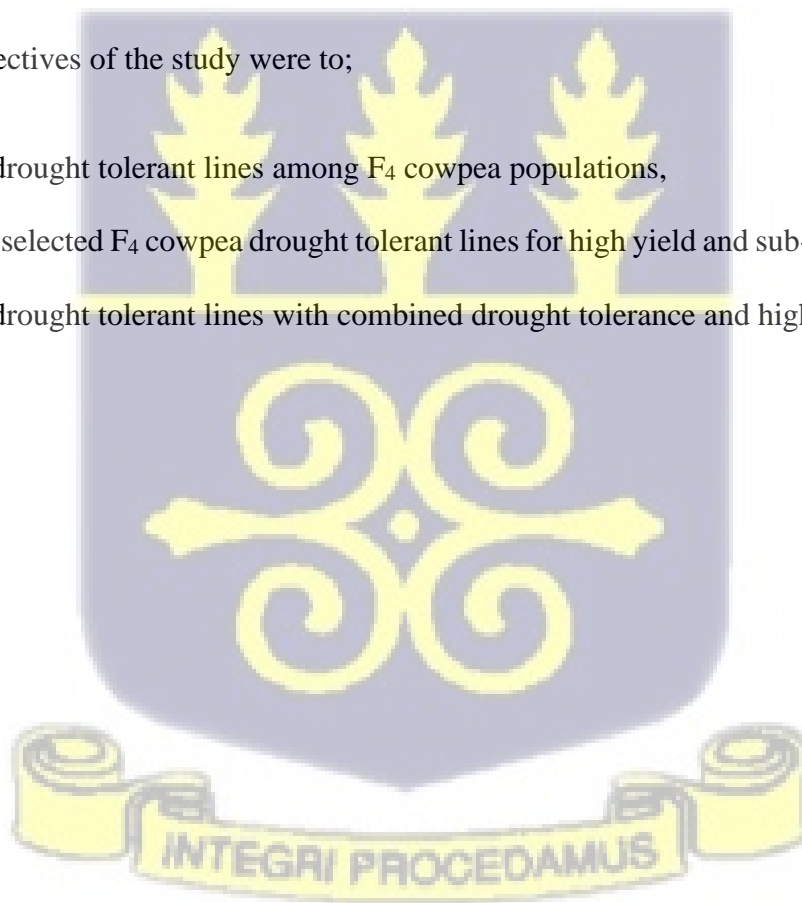
1.1 Main Objective of the study

The main objective of the study was to increase cowpea yield through improved tolerance to drought.

Specific objectives

The specific objectives of the study were to;

1. identify drought tolerant lines among F₄ cowpea populations,
2. Evaluate selected F₄ cowpea drought tolerant lines for high yield and sub-yield components
3. identify drought tolerant lines with combined drought tolerance and high grain yield.



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cowpea taxonomy, origin, domestication

Cowpea [*Vigna unguiculata* (L.) Walp.] was originally named for the fact that it was used as hay to feed cows in some parts of the world, such as the southeastern United States (Timko *et al.*, 2007). It is a diploid ($2n = 2x = 22$) whose genome size is over 620Mb (Timko and Singh, 2008), and is one of the oldest human food sources with evidence of its use as a crop plant dating back to the Neolithic period (Summerfield *et al.*, 1974). It belongs to Fabaceae family (Jayathilake *et al.*, 2018) and sub-family Faboideae (Agbogidi, 2010). Sharma *et al.*, (2016), states that all cowpeas grown, are included under the species *Vigna unguiculata*, that is also categorized into four cultivar groups: *Unguiculata* (common cowpea for food and fodder), *Biflora* (*catjang*), *Sesquipedalis* (yard long or asparagus bean used as a vegetable), and *Textilis* (used for fibres). *Unguiculata* is the most diversified amongst the cultivar groups, and it is extensively farmed in Africa, Asia, and Latin America (Fang *et al.*, 2007). The only cultivated cowpea is subspecies *unguiculata*, while the other three are wild relatives.

It's tough to pinpoint where a species' center of origin actually is (B. B. Singh *et al.*, 1997). Botanical and cytological evidence, information on geographical dispersion, along with cultural practices and historical records, have been referenced to make assumptions of the genesis and naturalization of cowpea [*Vigna unguiculata* (L.) Walp.] (Ng, 1995). According to Huynh *et al.*, (2013), cowpea was first transported from West Africa with African people at the time of the slave trade to other parts of the globe. However, there were no documents to back the extent of

movement extent. Cowpea is thought to have originated in West Africa by other scholars, while the specific site of the species' origin is unknown. A thorough examination of a crop's physical and genetic variation in connection to its geographical distribution could aid in speculating on the origin of cultivated plants (B. B. Singh *et al.*, 1997). Huynh *et al.*, (2013) utilized SNP makers to investigate the gene pool structure of the African wild annual cowpea *V. unguiculata subsp. dekindtiana* from East and West Africa, as well as their kinship to African wild cowpeas and non-African domesticated cowpeas. Two gene pools were created from the genetic material., according to these researchers. The two gene pools were dispersed across two main geographic regions, which were divided by the vast and dense Congo River basin rainforests according to Batiemo (2016) in a related study. Cowpea remnants were unearthed in Ghana's Kintampo and carbon dated to around 1400-1480 BC, making it the earliest archaeological confirmation of this crop (Flight, 1976). Due to the existence of the most primitive wild varieties, var. *rhomboidea*, var. *protracta*, var. *tenuis*, and var. *stenophylla*, the Transvaal region of the Republic of South Africa was most likely the focus of *V. unguiculata* diversification (B. B. Singh *et al.*, 1997). By 2000 BC, the West African collection reached India, as revealed in a study carried out using more than 10,000 accessions from the global collection at the International Institute of Tropical Agriculture's (IITA) (Padulosi and Ng, 1997). The Greeks and Romans brought it to Europe, and called it Phaseolus. It was very recently made known to the Americas. IITA's research revealed that West African germplasm were more diverse than East African germplasm (Padulosi and Ng, 1997). These discoveries added to the growing body of evidence indicating West Africa was the principal breeding ground for domesticated animals. The Savanna regions of Nigeria, southern Benin, Togo, and the north-western section of Cameroon are home to the greatest diversity of

farmed cowpeas (Ng and Marechal, 1985). According to Verdcourt (1970), *Vigna* has multiple species, however the precise number differs depending on the author.

2.2 Cultivation and utilization of cowpea in Africa

Legume crops play an essential role in agricultural sustainability, household income, and nutritional systems. Cowpea is grown across Africa, and in portions of Southeast Asia and Latin America. Cowpea is currently farmed in the tropics and subtropics all over the world within a latitudinal range of 35⁰N and 30⁰S of the equator, with low rainfall (300-600 mm) (Fatokun *et al.*, 2012). Sub-Saharan Africa, Asia, South America, Central America, the Caribbean, Oceania, South of the United States of America, and the Mediterranean Sea region are all part of this zone where cowpea is grown (Padulosi and Ng, 1997; OECD, 2015; Onuh and Donald, 2009). It is mostly a warm-weather crop (Alidu, 2019) that is more suited to drought, high temperatures, and other biotic stresses compared to most other crops (Onuh and Donald, 2009). It is grown primarily for its seeds, which have high protein (20–32%), carbohydrate (50–60%) (Gomes *et al.*, 2020) and dry matter content and is mostly eaten as a dry grain or as a raw vegetable. The grain which has a high protein content is also high in lysine and tryptophan which are two important amino acids (Abadassi, 2015). Cowpea is thus an important part of the human diet in many poorer nations, earning it the nickname "poor man's meat." (Jayathilake *et al.*, 2018). Because rhizobium facilitates the fixing of atmospheric nitrogen, contributing to soil fertility enhancement in leguminous plants, cowpea has become a key component of traditional cropping systems as a legume, notably in farming systems used by smallholder farmers where little or no fertilizer is used (Bado *et al.*, 2006) and many of these smallholder farmers in Africa and the developing countries depend on it for food, cash, animal feed, and fertiliser (Menssena *et al.*, 2017). Cowpea is the most valuable native

African legume crop, with diverse applications as a nutrient-dense component of human and cattle diets (Langyintuo *et al.*, 2003). Because it is frequently harvested prior to maturity of the cereal crops, it is called a "hungry-season crop." Cowpea grain has a high protein content, which makes it ideal for use in new born and children's meals (Agyeman *et al.*, 2014). It also has a low-fat content, which is beneficial in preventing a variety of metabolic and cardiovascular illnesses (Gonçalves *et al.*, 2016). The mature pods are picked, and the haulms are chopped and rolled into little bundles with the leaves and vines while still green (Agbicodo, 2009). Cowpea haulms can bring up to 50% of the grain price (dry weight basis). Over 70% of Ghana's population depend on it as their source of minerals and vegetable protein.

The season for cowpeas in Ghana varies depending on the types the farmer wishes to sow and their goals. The major rainy season (May) and the minor rainy season (August) are the two main seasons in Ghana, but the crop can be planted at any time throughout the major season. When used as cattle fodder, the crop can be intercropped with some cereal crops (MoFA, 2002). The majority of Ghanaian cowpea is grown in the Sudan savanna, one of Ghana's agro-ecological savanna zones. Cowpea seeds for planting are available in Ghana through market/traders, farmers' stock seeds, and farmers who save seeds for sale (MOFA, 2005). Despite its origins in West Africa, this bean has found its way into the diets of over 110 million people worldwide (Ogbuinya, 1997).

2.3 World Cowpea Production

According to FAOSTAT (2020), cowpea was grown on an about 15 million ha worldwide with 14.8ha in Africa in 2020 with majority of production limited to West Africa (12.7 million ha), especially in Nigeria, Niger, Burkina Faso, Senegal, Ghana and Mali. A little over 8.9 million tons

of cowpeas are produced globally, with Africa generating almost 8.6 million tons. West and Central Africa (WCA) account for more than 64% of the area – 9.2 million hectares followed by roughly 2.4 million hectares in Central and South America, 1.3 million hectares in Asia and about 0.8 million hectares in Eastern and South Africa (Olubunmi, 2015). Nigeria is the largest producer and user of cowpeas and accounts for 46.3% of the production in Africa and 41% globally (FAOSTAT, 2020) as compared to 1% of the production in Africa and 58%

Worldwide (Baysah, 2013). 52% of total African production of cowpeas is utilized as food, 13% as animal feed, 10% for seeds, 9% for other uses, and 16% being wasted (Nkomo *et al.*, 2021b).

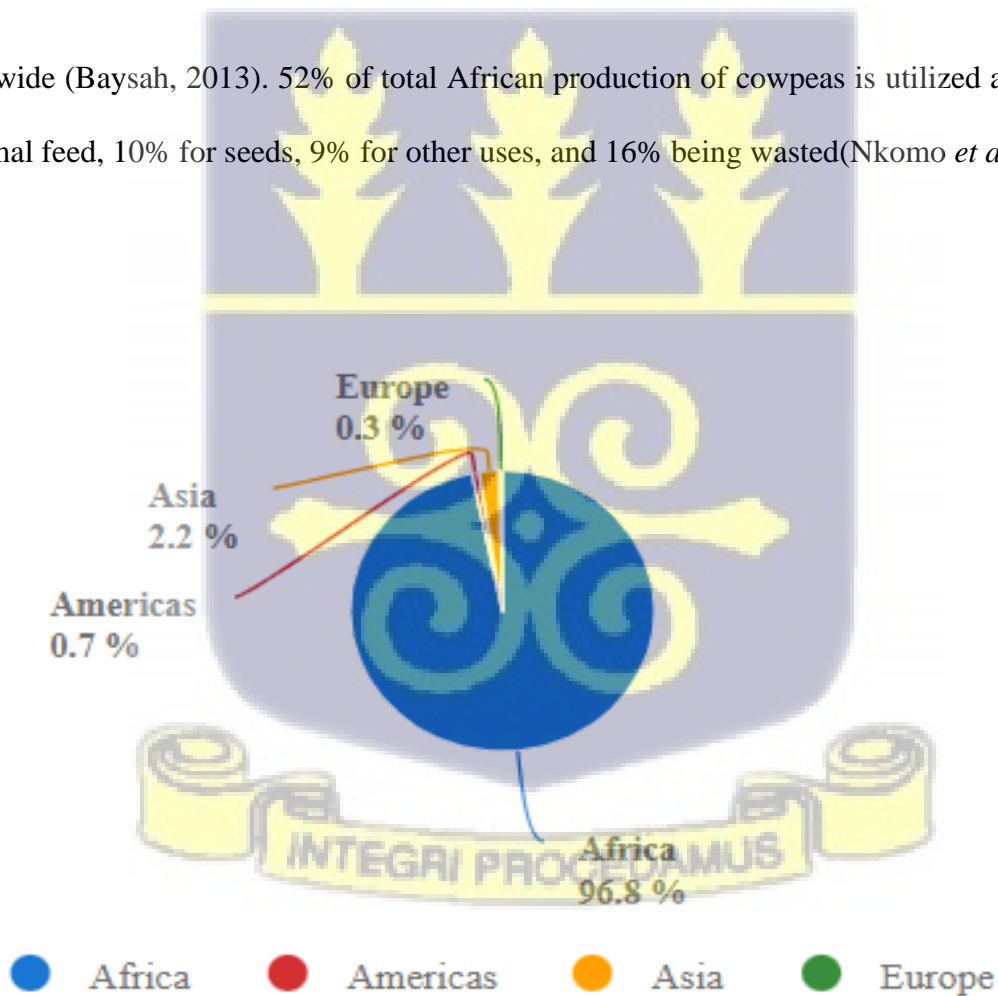


Figure 1: Share of Africa in world cowpea production.

Source: FAOSTAT (2020)

2.4 Constraints to Cowpea Production

Even though for its numerous characteristics, cowpea is among the most popular crops and a vital element in the farming systems of numerous rural SSA households with little access to resources (Molosiwa *et al.*, 2016). Poor yields, ranging from 100 to 599 kg ha⁻¹ compared to expected yields of 1500 to 3000 kg ha⁻¹ have been seen in cowpea. This can be attributed to biotic and abiotic stressors. Insect pests (aphid, flower thrips, maruca, pod sucking bugs, bruchid), diseases (bacterial, fungal, and viral), Striga (*S. gesnerioides*), and Alectra can cause yield loss ranging from 15% to 100% depending on the extent and intensity of infestation, variety vulnerability/resistance, drought, and low soil fertility. Other obstacles include shortage of inputs such as fertilizers, pesticides, and improved seeds, as well as poor cultural practices and a lack of appropriate technology for expanding cultivated area (Tropical Legume II, 2012). Over 40 species of fungi have been identified as causing disease in cowpea. These fungi cause leaf smut, stem rot, and root rot in the plant with losses ranging from 20%-100%. Sources of fungal pathogen resistance have been identified, and screening approaches have been refined (Pujari, 2015). There are over 20 viruses reported to have detrimental effects on cowpea productivity globally. In other locations, these viruses have been linked to 90% output reduction or even total crop failure (Mbeyagala *et al.*, 2014). Cowpea aphid borne mosaic (CABMV), cucumber mosaic virus (CMV), cowpea moderate mottle virus (CPMMV), and cowpea severe mosaic virus are the most common viral infections in cowpea, according to Mbeyagala *et al.*, (2014). (CPSMV). In certain years, aphid infestation on cowpea causes a 100% yield loss (Horn *et al.*, 2015). The red mosaic virus inhibits the growth and development of rhizobium bacteria. Root nodulation had decreased by 20 to 45 percent as a result of this (Taiwo *et al.*, 2014). The red mosaic virus stops the expansion and advancement of rhizobium bacteria and as a result, root nodulation is decreased by 20 to 45

(Taiwo *et al.*, 2014). Bacteria pathogens on the other hand, cause yield losses of up to 71%, 68% and 53% in pod, seed and fodder of susceptible varieties respectively (Viswanatha *et al.*, 2011). During mild infection, usual signs include a gradual yellowing of the leaves with irregular to circular dots. This causes senescence and leaf drooping (Horn & Shimelis, 2020). The two principal parasitic weeds influencing cowpea production in SSA are *Striga gesnerioides* (Wild.) Vatke and *Alectra vogelii* Benth. Weeds spread and attach themselves to the host's root surfaces, where they receive nutrition (Horn *et al.*, 2015). In Ghana, *Striga gesnerioides* causes significant yield losses in cowpea.

Drought stress is the most devastating abiotic stress in cowpea production. Despite the fact that cowpea is mostly grown in arid areas of Sub-Saharan Africa and can tolerate soils with low levels of moisture, drought is still one of the major climatic conditions that determines whether a crop is productive and profitable (Horn & Shimelis, 2020).

2.5 Effect of drought on agriculture and food security

The primary means of support for people living in rural areas continues to be agriculture, in Sub-Saharan Africa, giving cash, food, and employment to farmers, as well as contributing to a country's GDP. Climate and weather conditions have a significant impact on agricultural production and productivity. Due to unpredictable rainfall at the start and conclusion of the rainy season, drought has been noted as a serious restriction in semi-arid tropics (Olajide, 2017). Drought can strike in the middle of the planting season or near the end, and it has been shown to have a devastating effect on cowpea yield regardless of when it occurs. Cowpea can suffer from both heat and drought stress in West Africa's Sahelian and dry savanna zones with early flowering kinds surviving dryness in select places and years to produce useful grain yields. (Ajayi *et al.*, 2018). Drought is a regular hazard in Ghana's northern region, although the country as a whole is prone

to it (UNCCD, 2015). Droughts in Ghana often tend to have parallels in the past within a 30 year or so time frame. However, they have become increasingly common in recent years, as World Bank research (2010) on precipitation forecasting showed a cyclical trend for all parts of the country over the period 2010-50, with high rainfall levels followed by drought every decade or two (UNCCD, 2015). Drought stress affects cowpea at both the seedling and terminal growth phases, reducing grain yield and biomass production significantly (Nkomo *et al.*, 2021b). Droughts can be intermittent, occurring at one or more times during the growth season of the crops, or terminal, resulting in a steady decline in available soil moisture content and severe drought (Ibitoye, 2015). Due to a combination of high temperatures, drought, and longer daylengths, floral bud development might be slowed or inhibited, resulting in fewer flowers and poorer cowpea output (Ndiso *et al.*, 2016). Drought stress's effects on crop output can have a considerable negative influence on farmer income and, as a result, on GDP growth (Mou *et al.*, 2018). Drought-related yield losses in agricultural crops have been estimated at 17% (Ashraf *et al.*, 2008).

2.6 EFFECTS OF DROUGHT ON COWPEA

Severe or even slight water drought conditions is able to result in some biochemical limitation of photosynthesis in cowpea plants in a genotype-dependent manner. These biochemical limitations include decreases in phosphorylation, ribulose-1,5-bisphosphate (RuBP) regeneration, and Rubisco activity (Rivas *et al.*, 2016; S. K. Singh & Raja Reddy, 2011), damage to the membranes and abnormalities in the functioning of several enzymes, including those involved in CO₂ fixation and adenosine triphosphate synthesis (Tetteh *et al.*, 2019). Drought events restrict the performance of cowpea plants at numerous developmental stages and biological processes, ranging from embryo to reproductive and maturity (Kapoor *et al.*, 2020) Despite the fact that cowpea is a drought-tolerant crop (Carvalho *et al.*, 2019; Goufo *et al.*, 2017; Horn & Shimelis, 2020; Mou *et*

al., 2018; Olubunmi, 2015; Timko & Singh, 2008). According to Farooq *et al.*, (2017), cowpea yields can decline from 34% to 68% dependent on the time of drought stress development. Seedling stage drought mostly led to a reduction in plant height owing to reduced turgor, which affects cell division, expansion and elongation, reduction in leaf, stem, root, total plant dry mass and root to shoot ratio of genotypes under study (Tetteh *et al.*, 2020). Number of flowers per plant which is positively correlated to number of pods produced, is also greatly affected due to increased soil moisture deficit (Abayomi and Abidoye, 2009). Higher soil moisture stress levels also caused a considerable delay in the beginning and date of full flowering, according to the same study. The drop in leaf number and plant growth was ascribed to a decrease in cellular expansion as a result of reduced plant water potential and turgor as a result of decreased soil water potential. The decreased metabolic activity to compensate for the increased moisture shortage resulted in a loss in growth (Otwe *et al.*, 2013). The crop's sensitivity to extreme drought conditions in the soil, particularly during flowering, pod setting, and pod filling stages, intensifies the frequency of flower abortion and immature pods, as well as reducing the size of the legume's seeds (Horn & Shimelis, 2020; Toudou *et al.*, 2018). Increased leaf senescence, abscission of reproductive structures, restriction of dry matter partition to the reproductive sink or seed forming variables, and a shortening of the seed filling period due to the effect of soil water deficits are all factors that contribute to the decrease in pod numbers and seed size (Ahmed *et al.*, 2010; Toudou *et al.*, 2018). Drought can strike in the middle of the planting season or near the end, and it has been shown to have a devastating effect on cowpea yield regardless of when it occurs.

2.7 Understanding Drought: Meteorological, Agricultural, Hydrological and Socioeconomic Drought.

2.7.1 Definition of Drought

The main abiotic restriction to cowpea production is drought. Unpredictable rainfall, particularly at the onset of the season, has a negative impact on cowpea growth due to cultivation without irrigation particularly in the dry savanna and Sahelian regions (Agbicodo, 2009). Droughts are defined by their spatial extent (Wisner *et al.*, 1974): national, regional, or local, as well as the type of the drought. A drought is considered national if it affects more than 10% of the population and lasts for two or more growing seasons. If output loss is significant in most ecological zones and occurs once every ten years, it is considered national. A regional drought impacts less than 10% of the population's production and lasts one or two seasons in medium and low-potential locations (UNCCD, 2015). Regional occurrence varies depending on the types of crops planted, livestock populations, and grazing patterns. Every year, in marginal agricultural zones, there is a local drought. Because the area is plagued by drought stress during the growing season, the majority of the droughts encountered in northern Ghana can be classed as local and regional (UNCCD, 2015).

Droughts can be intermittent, occurring at one or more intervals during the growth season of the crops, or terminal, resulting in a steady reduction in available soil moisture content and severe drought (Ibitoye, 2015). According to Iwuagwu *et al.*, (2017), the impacts of drought vary and are dependent on the intensity, developmental stage, and length of stress, as well as the plant's adaptive strategy for coping with the stress.

2.7.2 Types of Droughts

Four basic approaches have been categorized to measure drought: meteorological, hydrological, agricultural, and socioeconomic.

When rainfall falls below the long-term average, a meteorological drought ensues (UNCCD, 2015) or when dry weather patterns dominate an area (*Drought Basics, n.d.*). The extent of dryness (in relation to some "normal" or average quantity) and the length of the dry period are commonly used to define meteorological drought. Because the atmospheric circumstances that cause a lack of precipitation vary greatly from place to region, meteorological drought definitions must be regarded region specific (*Types of Droughts - JournalsOfIndia, 2021*). For example when mean monthly precipitation fell below 900mm in 1983, 1992, and 2001 in Ghana, there was a meteorological drought across the country (UNCCD, 2015). It is hydrological when rainfall is much below average, causing surface and ground water reserves to be insufficient to meet all needs (UNCCD, 2015). When low water supply becomes evident in the water system (*Drought Basics, n.d.*). The implications of precipitation periods (including snowfall) shortage on surface or underground water supplies are known as hydrological drought (i.e., streamflow, reservoir and lake levels, groundwater). Watershed or river basin scales are frequently used to explain the frequency and severity of hydrological drought. Although all droughts begin with a lack of precipitation, hydrologists are primarily interested with how that lack of precipitation manifests itself in the hydrologic system. Hydrological droughts are frequently out of sync with meteorological and agricultural droughts, or they arrive later. Drought in agriculture occurs when evapotranspiration loss exceeds total rainfall throughout the growing season (UNCCD, 2015). It can also be when crops are affected by drought. Agricultural drought should be defined in a way that takes into consideration the varying vulnerability of crops at different stages of development,

from emergence through maturity (*Types of Droughts - JournalsOfIndia, 2021*). Lack of moisture in the topsoil at the time of planting may hinder plant germination, resulting in low plant populations per hectare and a reduced yield. If topsoil moisture is sufficient for early development requirements, however, shortages in subsoil moisture at this point may not affect eventual output if subsoil moisture is replaced as the growing season develops or if plant water needs are met by rainfall. Drought is defined in socioeconomic terms as a condition in which the supply and demand of certain economic items are linked to components of meteorological, hydrological, and agricultural drought (*Types of Droughts - JournalsOfIndia, 2021*). It varies from the other types of droughts in that its occurrence is determined by supply and demand mechanisms that occur throughout time and space. This makes it difficult to define or classify droughts. Weather affects the supply of various economic items, including water, pasture, food grains, fish, and hydroelectric power (UNCCD, 2015). Water supply is abundant in some years but insufficient to meet human and environmental needs in others due to natural climate variability. When demand outpaces supply of an economic good, socioeconomic drought results, from a weather-related shortage in water supplies.

2.8 Drought coping Mechanisms in plants

Drought conditions can be characterized according to their intensity (mild, moderate, and severe), the time they occur (intermittent and terminal), and the duration (short and long). Intermittent drought can occur at any point of the cowpea's vegetative growth cycle, and it's difficult to predict on an annual basis, though a general environmental trend can be identified (Chauhan *et al.*, 2002). Terminal dryness happens at the end of a crop's growth cycle, interfering with reproductive stages such as flowering and seed formation (Nigam *et al.*, 2002). The ability of a crop to respond to drought at different phases of development is determined by the stage of development, crop

species, stress intensity and duration, and the crop's economic value (Shouse, 1979, 1981). To allow plants to deal with drought conditions, several elements and mechanisms work separately or in concert. As a result, drought resistance is a multifaceted characteristic (Krishnamurthy *et al.*, 1996). Drought tolerance is traditionally defined as a plant's ability to live, grow, and produce well with insufficient soil water availability or under persistent water shortages (Ashley 1993). Drought escape, drought avoidance, and drought tolerance are the three types of strategies that plants adopt to handle with drought stress, according to Mitra (2001). Crop plants, on the other hand, utilize multiple mechanisms to cope with drought at the same time.

2.8.1 Drought Escape in Cowpea

A plant's capacity to complete its life cycle before substantial soil and plant water deficiencies occurs is known as drought escape. Rapid phenological development (early flowering and early maturity), developmental plasticity (change in growth phase duration reliant on the level of water deprivation), and remobilization of pre-anthesis assimilates are all part of this system. Although research has proven that against a genotype with a normal life cycle, typically, a genotype with a shorter life cycle produces less (Agbicodo, 2009), drought has induced a shift to early maturing cultivars in several cowpea farming areas (Mortimore *et al.*, 1997). Early maturity of cowpea cultivars is looked-for, and their ability to withstand drought has proven advantageous in some dry regions and years. In addition, early maturing cultivars can escape some insect infestation and severe damage caused by diseases. Cowpea cultivars adapted to low rainfall locations have been developed successfully by selection for early flowering and maturity, as well as yield testing of breeding lines under drought circumstances (Hall and Patel 1985; Cisse *et al.*, 1997). Early maturity cowpea cultivars that withstand terminal drought (i.e., Vallenga, bengpla etc.) have been released

and extensively embraced by Ghanaian farmers. These genotypes, on the other hand, fared badly when put through periodic drought during the vegetative or reproductive stages. As a result, efforts are being made to produce cowpea types that are more drought tolerant in the early, mid, and late seasons.

2.8.2 Drought Avoidance in Cowpea

Plants' ability to endure high water status or cellular hydration during water stress is referred to as drought avoidance. These plants have created specialized tissues with reduced water potential sensitivity to cope in this situation. Their responses under avoidance are characterized by maximizing water uptake through the development of deep roots, minimizing water loss through stomatal control & lenticular conductance, Leaf movements, smaller leaves, the shedding older leaves and decreasing solar radiation absorption by rolling or folding leaves/paraheliotropism (Fatokun *et al.*, 2012) and the growth of a dense trichome layer that improves reflectivity, as well as decreasing evapotranspiration surface (leaf area) (Yue *et al.*, 2006; Taiz and Zeiger, 2006). They improve root system capacity (Jackson *et al.*, 2000) and root properties like as thickness, depth, length, and density (e.g., in rice) to maximize water uptake (Ekanayake *et al.*, 1985). This mechanism has an impact on efficient water utilization and evapotranspiration regulation. To assist sustain high water potentials in plant tissues, some plants grow xeromorphic features such as hairy leaves and cuticles. (Seleiman *et al.*, 2021). Overdevelopment of these xeromorphic features reduces the production of the plants.

2.8.3 Drought Tolerance in Cowpea

Drought tolerance refers is a plant's ability to cope with water scarcity and reduced tissue water potential. The method involves osmotic adjustment (solute accumulation in the cell), enhanced cell flexibility and decreased cell size, the creation of various stress-relieving chemicals, and protoplasmic resistance to desiccation (Agbicodo *et al.*, 2010). It entails the revival and survival

of genotypes following a prolonged and severe internal water shortage. Tolerant genotypes still survive when water loss in the plant is up to 95% (Scott *et al.*, 2000). Mai-Kodomi *et al.*, used a wooden box approach to identify two types of drought tolerance in cowpea seedlings (1999) namely the “TYPE1” and “TYPE 2”. He argued that cowpea genotypes acquired various ways to cope with extended drought in the semi-arid parts of Africa where the crop is thought to have originated, based on the two forms of tolerance responses of seedlings to drought stress. In Mai-Kodomi *et al.*, (1999) experiment, all of the seedlings of two vulnerable lines, TVu 7778 and TVu 8256, were completely dead 15 days after the watering was stopped in Mai-Kodomi *et al.*, (1999) trials. After the commencement of drought stress, TVu 11979 stopped growing but showed a decline in turgidity in all plant tissues, including the unifoliate and emerging tiny trifoliate, for nearly two weeks. All plant parts, including the growing tip, unifoliate, and epicotyls, died practically simultaneously. This he referred to as TYPE 1 drought tolerance. The "Type 2" drought tolerant lines, such as Dan Ila and Kanannado, on the other hand, stayed green for long and continued modest trifoliate development under drought stress, with variety wilting and dying about four weeks after drought stress began. Cowpea drought tolerance processes include stomatal closure to prevent water loss by transpiration and growth cessation (for type 1 drought avoidance) and osmotic adjustment and continuing slow growth (for type 2 drought tolerance) (Umar, 2014). Mai- Kodomo. Cowpea is a dehydration avoider with very sensitive stomata and a slow development rate (Umar, 2014). This appears to be the mechanism behind Tvu 11986 and Tvu 11979's Type 1 drought response.

Dan Ila and Kanannado's type 2 reaction seem to be a blend of three mechanisms: stomata regulation (partial opening), osmotic control, and selective mobilization, displaying obvious variations in the desiccation of lower leaves versus upper leaves and developing tips (Mai-Kodomi *et al.*, 1999). The

type 2 drought tolerance mechanism appears to be more successful in prolonging the life of plants and improving their chances of recovery after the drought episode than the type 1 system.

2.9 Screening methods and approaches for drought tolerance in cowpea

Cowpea drought tolerance has not been bred for as successfully as many other features (Agbicodo, 2009; B. B. Singh *et al.*, 1997). This is partially caused by an absence of straightforward, affordable, and trustworthy screening techniques to choose plants and offspring resistant to drought from segregating populations. The degree of drought tolerance in plants has been measured using a number of different techniques. Two strategies have been put forth by researchers for screening and developing plants with drought resistance. The empirical approach, often known as the performance approach, which depends heavily on grain yield and its subcomponents is the first. The comprehensive statement of all characteristics relevant to productivity under stress is yield. The empirical approach primarily uses recombinant inbred lines (RIL) to permit the consistent evaluation of performance and understanding of genotype-by-environment interaction because the strength and incidence of naturally occurring drought stress are not completely predictable (Mustapha, 2017). Although different cowpea breeding materials, such as F₂, F₃, and backcross populations, have been used for drought tolerance studies in cowpea, individual lines having dispersed homozygous segments of a parental chromosome make up the recombinant inbred line (RIL) population, which was created through single seed descent of numerous selfed generations (Mustapha, 2017).

The second method uses an analytical or physiological technique to pinpoint a certain physiological or morphological characteristic that will greatly boost growth and yield when drought occurs. These include characteristics like root qualities (Watanabe, 1993; Matsui and Singh, 2003), leaf rolling (Mathews *et al.*, 1990) stomata behaviour and conductance

(Nkouannessi, 2005; Labuschagne *et al.*, 2008; (Agbicodo, 2009), osmotic adjustment (Laurie, 1999), leaf membrane stability (Labuschagne *et al.*, 2008); molecular markers (Agbicodo, 2009), and leaf wilting scales Watanabe *et al.*, 1997; Nkouannessi, 2005; Mai-kodomi *et al.*, 1999). However, because of the requirement to evaluate the yield of numerous lines across numerous locations and years, as well as the significant variance resulting from environmental influences and genotype-environment interactions, these empirical approaches are lengthy, tedious, and expensive. A straightforward screening method for drought resistance in cowpea was devised (Ishiyaku, 2009) based on seedling survival under water stress, and it evaluated the percentage of seedlings that wilted at the start of the drought treatment. This method identified heritable variations in the tested genotypes' responses to drought stress. The several traits used to evaluate for drought tolerance demonstrates the trait's complexity in both cowpeas and other crop species (Lawrent *et al.*, 2013). Since it simplifies the challenges of evaluating the effects of drought on crops, leaf wilting continues to be one of the best markers of drought stress in plants (Lawrent *et al.*, 2013). For evaluating cowpea's endurance to drought, many wilting scales have been employed including the International Board on Plant Genetic Resources devised scale of 1–9 (1 represents normal and 9 is dead under moisture stress), which has since been approved (Nkouannessi, 2005). An effective method for determining drought tolerance has been discovered to be the pot screening of genotypes at the seedling stage since it is simple to set up in a regulated environment and adaptable for screening a great quantity of genotypes (Nkouannessi, 2005). This was supported by Watanabe *et al.*, who came to the conclusion that the process that confers seedling drought resistance also appears throughout the flowering stage (1997). Different cowpea varieties tested in wooden boxes, in the field, and in pots revealed a significant correlation between drought tolerance

at the seedling stage and reproductive stage (Singh and Matsui, 2002). According to these authors, the wooden box method provided a quicker way of finding tolerant cultivars that could be kept and transplanted for additional offspring testing and selection.

2.9.1 Conventional Approach

The most practical and affordable method for boosting productivity during droughts continues to be the breeding of drought-tolerant crops, but because drought tolerance is a complicated physiological and genetic feature, conventional breeding initiatives to increase drought tolerance in crops have had very modest results. Farmers' preferred cultivars can be created by identifying genotypes with genetic variability for drought resistance through conventional breeding and adopting or introgressing those introduced into the locally adapted varieties. Because there are many decisions to be made and a significant capital investment is required, the conventional technique takes a long time (sequential evaluation). A number of undesirable genes have a high possibility of being introduced into the genotype that is agronomically beneficial. Unquestionably, being early is a key characteristic in cowpea production regions that are vulnerable to drought stress. The most preferred genotypes are those that reach maturity 50 to 60 days after planting (Ngalamu *et al.*, 2019). Additionally, as they contain the necessary genetic information, quantitative variables like the number of days to first bloom, 50% blossoming, first mature pod, and 95% maturity could be employed in selection for earliness (Owusu *et al.*, 2017).

2.9.2 Molecular breeding

The majority of crucial agronomic features are quantitatively inherited. The biggest benefit would come from improving these qualities using marker-assisted breeding because traditional plant breeding for quantitative traits is typically sluggish and challenging. The use of markers with high

heritabilities during marker assisted selection may help in the selection of features with low heritabilities (Chapman *et al.*, 2003). Other crop species have successfully had their genetics improved using contemporary techniques like marker-assisted selection (MAS) in conjunction with traditional breeding. The creation and application of molecular marker technologies and analytical methods based on biochemistry, such as restriction fragment length polymorphisms (RFLPs), random amplified polymorphic DNAs (RAPDs), amplified fragment length polymorphisms (AFLPs), and microsatellites or simple sequence repeats (SSRs), have greatly aided in the study of the structure of plant genomes and their evolution, including relationships among the Legumioseae (Timko *et al.*, 2007; Yang *et al.*, 2009; Huynh *et al.*, 2016). This has greatly aided our present understanding of the structure and evolution of the cowpea genome. In order to supplement traditional breeding in cowpea, it is obvious that current biotechnology technologies must be used (Alidu, 2019). The effectiveness of plant breeding systems may be impacted by the use of molecular markers in indirect selection of agronomically significant features. Using molecular markers can help with a number of elements of plant breeding, such as identifying and removing undesired individuals during the early phases of selection, identifying individuals prior to flowering who will be helpful in transferring genes governing the favorable expression of quantitative traits, expediting the development of new varieties, especially for traits that are challenging to score, and facilitating selection for multiple traits that are simulative (Bharadwaj *et al.*, 2011). In contrast to conventional breeding, where direct selection of traits is based on visual observation, molecular marker selection is based on molecular marker(s) strongly related to the trait of interest.

2.10 Genetics of drought tolerance

The foundation of any breeding program is knowledge of the genes influencing a particular trait of interest. It is important to determine and fully comprehend the genetic information relating to the gene effects and the degree of gene action controlling such qualities (Hinkossa *et al.*, 2013). Drought and yield are two traits that are polygenically influenced and controlled by external conditions that cannot be passed from parents to offspring. For the effectiveness of breeding program, it is crucial to identify the genetic influences on these qualities. Gene effects might be additive, dominance- or epistatic-based (Gamble, 1961). The non-additive portion is made up of dominance and epistatic. The dominance may be unidirectional or ambidirectional, with positive and negative dominance occurring at distinct gene loci (Kearsey and Pooni, 1998). Allele interactions at various loci are referred to as epistasis. When the additive-dominance model cannot account for variance alone, epistatic gene activity occurs (Derera, 2005). The narrow-sense heritability, which is represented in the additive gene effects, indicates how much descendants are expected to resemble their parents (Derera, 2005). In order to analyze and comprehend the genetic foundation underlying the inheritance pattern of the characteristic of interest, information on the GCA and SCA of the parents is helpful. It calculates a line's average performance in a series of hybrid combinations (GCA) and how much a line contributes to hybrid performance in a cross with a certain other line in comparison to how much a line contributes in crosses with a variety of other lines (SCA) (Ogunbodede *et al.*, 2000; Acquaah, 2012). The capacity to precisely identify parental pairings that will produce superior pure lines for farmers to adopt is extremely important to the breeding program's success in self-pollinating crops like cowpea. Constraints on time, space, money, and other biological factors, selecting acceptable parents and choosing good mating

designs are crucial for successful plant breeding schemes (Khan *et al.*, 2009; Acquah, 2012; Nduwumuremy *et al.*, 2013).



CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Experimental Site

The potted experiment was conducted between June, 2022 and November, 2022, at the research farm of the Department of Crop Science, University of Ghana. The experiment was conducted at a site located between latitudes 05°, 39.561° and 05°, 39.546°N and longitudes 000° 11.621° and 000° 11.641°W within the semi-arid coastal savanna zone of Ghana. This zone forms part of the sub-humid to semi-arid savanna zones., which are the biggest ecosystems of West Africa. Total annual rainfall was 800 mm with a temperature of about 27°C. The study site was nearly flat in topography.

3.2 Planting Material

Two F₂ cowpea populations (Tam X Hewale & Hewale X Tam) were obtained from a breeding program at the West Africa Centre for Crop Improvement (WACCI). Table 1 shows the characteristics of the two F₂ cowpea populations. The F₂ populations were advanced to F₄. At the F₄ stage, thirteen (13) top high yielding lines from both populations were selected along with the parental lines serving as checks totalling 30 lines.

Table 1: Characteristics of F₂ cowpea parental lines.

Parental Line	Days to Maturity	Growth Habit	Origin	Trait of Interest
Hewale	64-67	Erect	Ghana	High Yielding
Tam		Erect	Ghana	Drought tolerant

3.3 Soil Analysis

Soil samples were collected on the University of Ghana farm from 0 - 20 cm depth. The soil samples were thoroughly mixed, bulked, air dried, ground and passed through an 8 mm and 2 mm sieves for filling pots. The 2 mm samples were stored in a poly bag for analysis. Soil analysis was

carried out at the Department of Soil Science Laboratory of the University of Ghana, Legon. The soil (sandy clay loam) that was used was composed of 58.8% sand, 30.9% clay, 10.3% silt, 2.30 g/kg total nitrogen, 0.66 Cmol/kg of calcium, 0.56 Cmol/kg of potassium, 0.14 Cmol/kg of sodium and 0.58 Cmol/kg of magnesium. The soil has a pH of 4.6 and a bulk density of 1.43 g/cm³, organic carbon of 10.40 g/kg.

3.4 Planting

A rain-out shelter was used to screen for drought tolerance and high yielding progenies from F₄ population. Prior to planting F₄'s, pots each measuring 5,630 cm³, were filled with 5 kg of top soil and placed in the greenhouse. The pots were watered and left overnight for sowing to be done the next day. Sowing was done at a planting depth of 4 cm in pots perforated at the base. Three seeds were sown in each pot and later thinned to one seed per pot 14 days after sowing (DAS). Seeds were sown at a distance of 0.40m * 0.40m. Every treatment consisted of thirty (30) genotypes

3.5 Fertilizer Application

Fertilizer (NPK 20-20-20 + TE) was applied at optimum levels 2 weeks after the emergence of cowpea seedlings.

3.6 Weeding

Weeds were controlled manually in the greenhouse throughout the experiment. To ensure a clean pot, first hand weeding was done two weeks after sowing and subsequently when necessary.

3.7 Spraying

First spraying was done 14 days after sowing using the pesticides cyadim super (Dimethoate 400g/L and Cypermethrin 36g/L). Second spraying was done when flower initiation started, to control thrips (*Megalurothrips sjotedti*) and an early attack of Maruca (*Maruca vitrata*) pod borer.

3.8 Harvesting and Storage

Harvesting was done manually by hand picking when the pods were fully matured and dried. The harvesting was done at different days because the pods did not mature at the same time. The seeds were stored below 10% moisture content.

3.9 Drought Stress Treatment and Experimental design

A total of 30 lines were laid out in Split-plot in RCBD with three replicates, with the drought treatment as the main plot and the cowpea genotypes as the subplot. There were four treatments per replicate namely; Well-watered(control), Drought at vegetative stage (VEG), drought at pod filling stage (PF) and drought at both Vegetative and Pod -filling stage (VP) on the same plant. At the initial stage, five hundred milliliters of water were added to each pot every morning before sowing to reach its 100% field capacity. The soil moisture content was determined using soil meter. Watering was stopped for each plant after the emergence of flower buds. Drought stress treatment at 0% field capacity was imposed two times. First was for 18days at the vegetative stage and the second, at the Reproductive (pod filling) stage also for 18 days. After the elapse of drought stress induction, the stressed plants received water daily at 100% field capacity up to physiological maturity.

3.11 Data collection

Data was collected at the vegetative and reproductive stages on the agro-morphological traits of interest. Data were collected on the following growth parameters on individual plant basis by using the Cowpea Descriptor by IBPGR (1983) in line with the international plant genetic resources cowpea descriptors.

3.11.1 Qualitative and Quantitative traits

3.11.1.1 Qualitative traits

1. *Plant healthiness*

Overall plant healthiness was assessed on a 1 to 5 scale: 5 = green (100% health), 4 = green new trifoliolate with chlorotic unifoliolate and first trifoliolate (75% health), 3 = chlorotic new trifoliolate with necrotic unifoliolate and first trifoliolate (50% health), 2 = severe signs of necrotic on all leaves, with a green growing tip (25% health), 1 = dead plants (0% health).

The scoring was done at 9 and 18 days after imposing stress when some of the leaves had initiated senescing till end of the experiment. The scoring was done on drought cowpea plants.

2. *Stem greenness*

Stem greenness was scored using a scale of 1 to 5 as follows:

1 = completely yellow

2 = yellow

3 = intermediate

4 = green

5 = completely green

3. *Seed size*

Seed size was scored using a scale of 1 to 3 as follows:

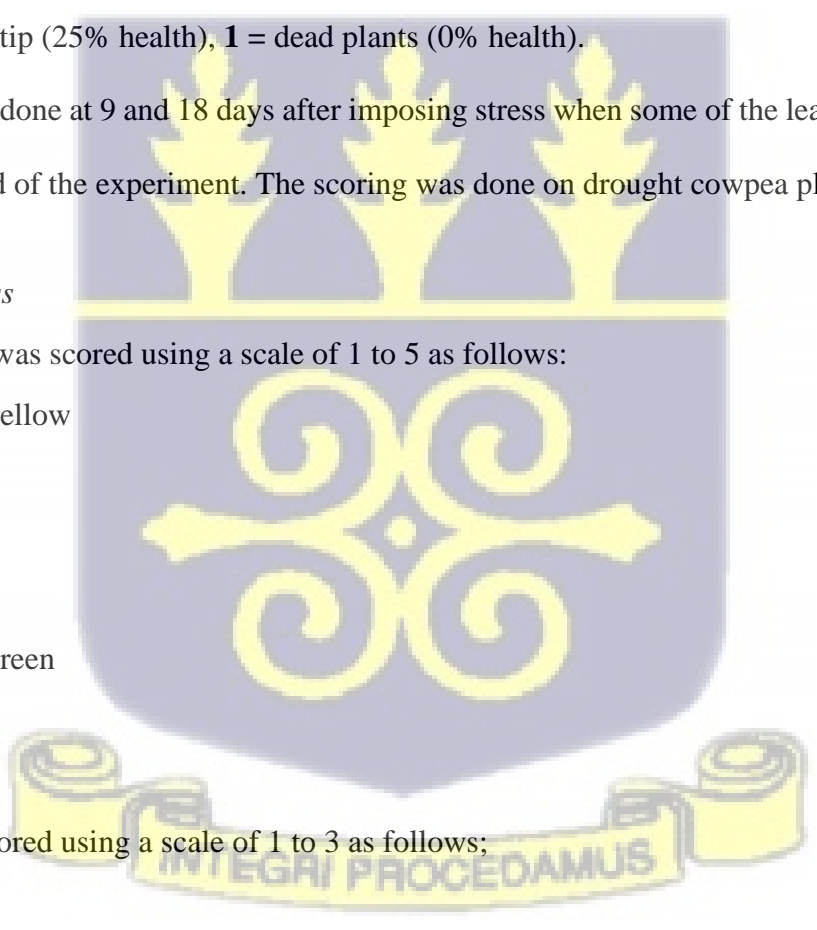
1 = small

2 = medium

3 = large

3.10.1.2 Quantitative traits

1. *Plant height (cm)*



Plant height was measured from the base of the plant to the last stem apex by using a metallic measuring tape.

2. Stem girth (mm)

Stem diameter of each genotype was measured with a digital caliper at 1.5 cm above soil surface to the nearest millimeter. The measurement was taken at the onset of drought stress imposition, 9 days and 18 days after drought stress.

3. Number of leaves per plant

The number of leaves were recorded for each genotype at the onset of drought stress imposition, 9 days and 18 days after drought stress.

4. Mean pod length (cm)

Mean length of all matured pods per plant was measured in centimeters with a rope and then placed on a rule to obtain the real measurement

5. Number of pods per plant
was counted and recorded.

6. Number of days to pod maturity

This was recorded as the number of days from sowing to complete yellowing of pods on each plant. At maturity, pods were harvested by hand picking, sun dried for one week and later shelled. The dry grain yield for each plant was weighed and recorded.

7. Number of days to 1st flower initiation

This was recorded as the number of days from sowing to the day each plant first flowered.

8. Estimation of chlorophyll content index (CII)

The chlorophyll content was taken at 0, 9 and 18 days after sowing at vegetative and pod filling stages in 3 leaves of each plant using chlorophyll meter SPAD.

9. Total Grain Weight

All seeds per plant were weighed on an electronic balance.

3.12 DATA ANALYSIS

The variance analysis was carried out using R statistical Package. Significant means were separated using Duncan's Multiple Range Test (DMRT) at 5% ($p= 0.05$) probability level-for the morphological, physiological and yield parameters. Association between the parameters studied was examined by calculating Pearson correlation coefficient (any cells with correlation values -1 , their cells were colored red, cells with values of 0 were colored white and those cells with values of $+1$ were colored blue. Because this was a color gradient, any values between these points had a shade that represented the correlation coefficient value). Drought tolerance of the cowpea genotypes was determined by computing the drought susceptibility index using chlorophyll content, plant healthiness and stem Greenness. During the experiment, the mean air temperature and relative humidity inside the greenhouse during the day were $35\text{ }^{\circ}\text{C}$ and 48% , respectively.

3.12.1. Chlorophyll Inflect index

By monitoring changes in chlorophyll content, each cowpea line's drought resistance was assessed using the Chlorophyll Inflect Index parameters (Gonzalez, 1996), which was estimated using the following formulas: Chlorophyll absolute decrease (CD) = $CC - CS$; Chlorophyll Inflect Index (CII) = $100\% * CD/(CC)$, where CC = chlorophyll content for control, and CS = chlorophyll content for drought stress.

3.12.2 Healthiness Inflect Index

"Healthiness" value was determined as follows: $100\% * (5 - \text{Overall Plant Health Score} - 1)/4$. The Healthiness Inflect Index (HII) parameter was employed using the following formulas to track

changes in healthiness. Healthiness absolute decline (HD) = HC - HS; healthiness index (HII) = $100\% * HD/(HC)$, where HC stands for control and HS for drought stress.



CHAPTER FOUR

4.0 RESULTS

4.1 Chlorophyll content for different stages of drought treatment.

Drought imposition lasted 18 days and differences in chlorophyll content started to show from the 9th day. Across all the 30 accessions, all three stages of drought imposition showed significant chlorophyll content drop during the last 9 days of drought stress (Fig 2). Overall, drought at (PF), (VP@PF) stages dropped more than at the vegetative stage over time; few lines managed to maintain their chlorophyll contents at high levels. After the 18 days of drought imposition, Danila (33.03), TH301(30.73) and TH252(29.8) recorded the highest chlorophyll content at VEG, with Danila (37.1) still scoring the highest at VP@VEG with 37.1, HT727(18.5), TH261(16.3) and HT419(15.2) scoring the highest at PF and HT727(21.2) scoring the highest at VP@PF stages respectively (Appendix 8).

CII indicated how much the chlorophyll content of that cowpea plant had changed (as a percentage) under drought stress compared with the same healthy genotype under a well-watered condition without drought stress. In comparison to the same healthy plant, the loss of chlorophyll content increases as the CII increases (i.e., the higher the CII, the more susceptible the line is). The CII value began to rise substantially after 9 days of drought imposition. At the end of the 18 days drought period, the CII value for drought at the VEG, PF, VP@VEG and VP@PF stages varied from 35.3 to 71.0, 38.8 to 100, 30.5 to 67.3 and 35.5 to 100 respectively (Appendix 9). Among the 30 lines TH71, HT402, HT540, TH252, TH301, TH54; HT141 and TA had the highest CII representing their incapacity, under drought stress, to maintain a steady chlorophyll concentration, indicating their susceptibility to drought stress conditions. On the other

hand, HT700, TH301; HT727, HT419; HT727, DANILA and TH192, HT120 recorded the lowest CII indicating that these eight lines were drought tolerant (Appendix 9). Some negative values recorded indicated a low chlorophyll content in the control as compared to the treatment genotypes. This is because at the time of drought imposition, the control genotype had completed or was almost completing its phenological cycle.

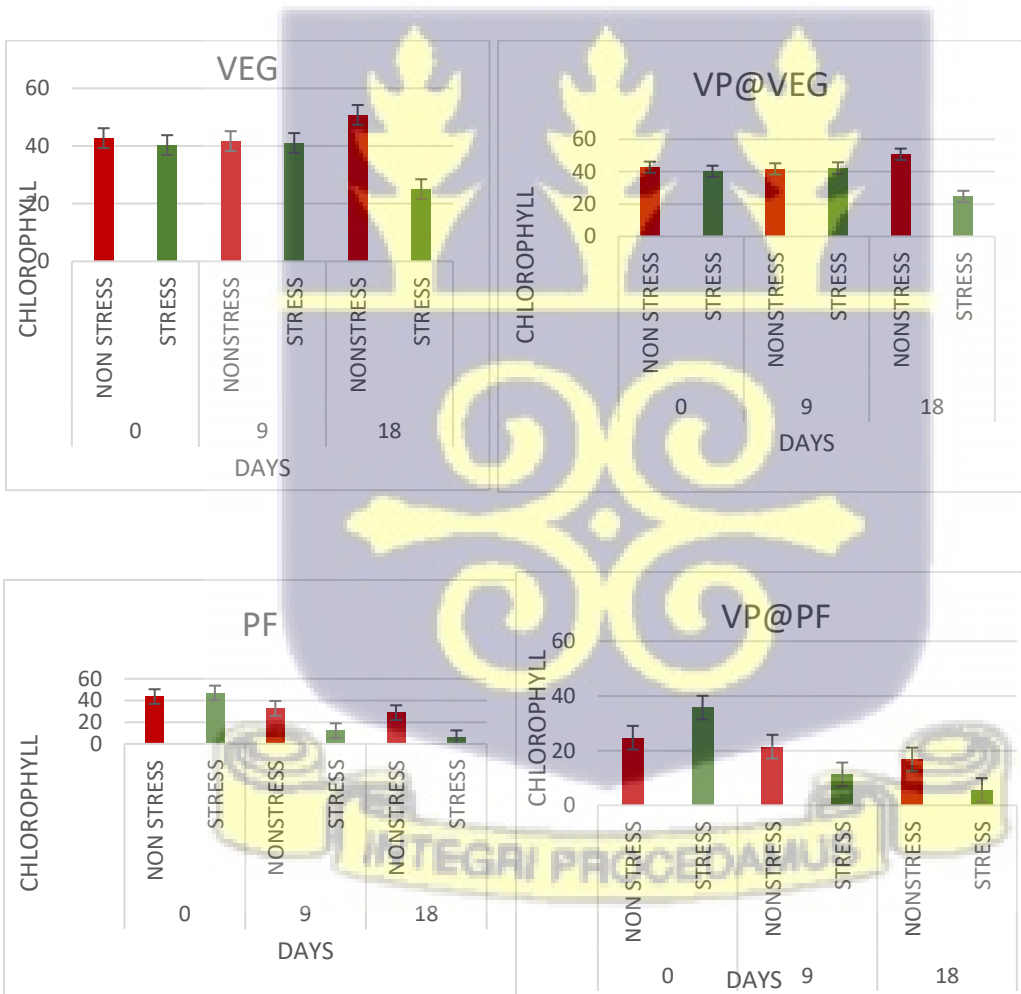


Fig 2. Chlorophyll content change of cowpea plant at vegetative (VEG), pod filling (PF), vegetative & pod filling at vegetative (VP@VEG) and vegetative & pod filling at pod filling (VP@PF) stages under nonstress (red) and stressed (green) in 18 days of drought imposition

4.2 Overall Plant Healthiness

Results for overall plant healthiness are presented in Fig. 3. The overall plant healthiness score was recorded in 18 days after the drought stress treatment. The non-stressed plants grew excellently whereas the healthiness of the stressed plants dropped rapidly in the final 9 days of drought stress imposition. For day 9, overall plant healthiness varied from 98.33 to 78.33 at the VEG, 93.67 to 36.67 at the PF, 96 to 80 at the VP at VEG and 63.33 to 10 at the VP at PF stage. For day 18, overall plant healthiness varied from 52.33 to 23.33; 41.67 to 9.0; 50 to 24 and 31.67 to 5.0 at VEG, PF, VP at VEG and VP at PF (Appendix 10). In Appendix 11, change in healthiness was obtained using the last 9 days of data. Higher value percentages indicated greater plant health under drought stress, indicating the cowpea line was drought tolerant. Various percentages of the healthiness changed from 75.6% to 45.9%, 86.8% to 23.8, 75.9% to 48.3% and 87.5% to 20.9% at the VEG, PF VP@VEG and VP@PF stages respectively. Based on the healthiness change, three cowpea lines, Danila, TH209 and HT120 across VEG, PF, VP@VEG and VP@PF respectively, had the least healthiness change implying their susceptibility to drought stress. TH54, TH80 at VEG; HT471, Hewale at PF, HT120 and HT475 for VP@VEG and TH72, HT154 for VP@PF had the most substantial healthiness variation, suggesting they are drought tolerant

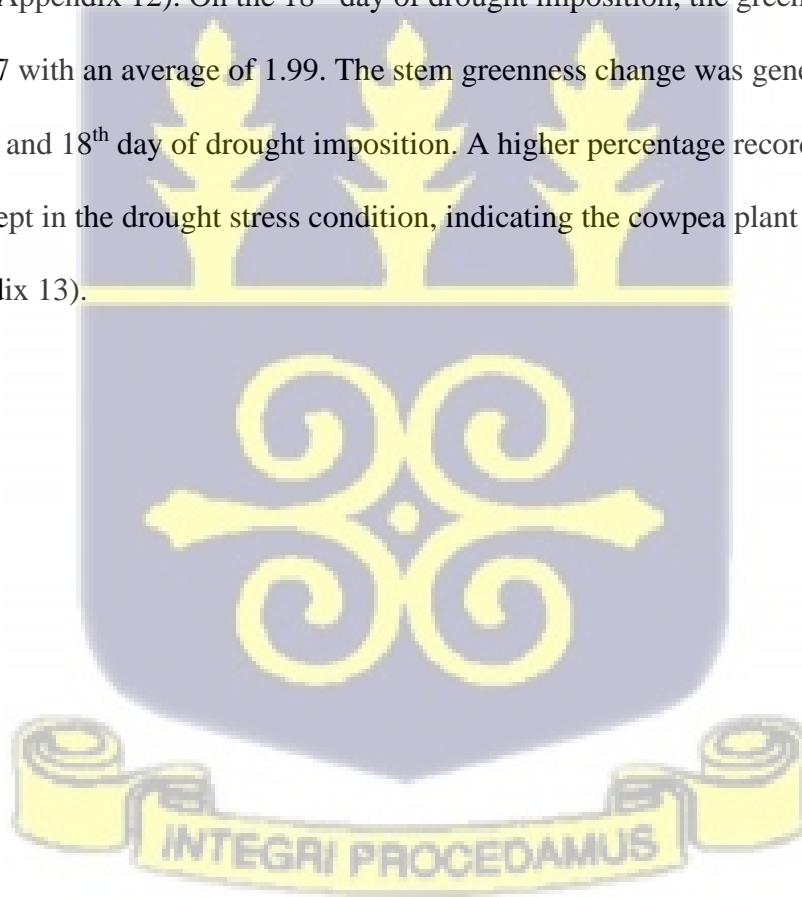




Fig 3. Healthiness changes of cowpea plant at vegetative (VEG), pod filling (PF), vegetative & pod filling at vegetative (VP@VEG) and vegetative & pod filling at pod filling (VP@PF) stages under nonstress (red) and stressed (green) in 18 days.

4.3 STEM GREENNESS

Results for stem greenness are presented in Fig. 4. Stem greenness scores were recorded on the 9th and 18th day after drought imposition. The plants serving as control(well-watered) had better growth condition as compared to the stressed pants whose stem greenness score dropped rapidly in the last 9 days. On the 9th day, the average plant healthiness score varied from 1 to 5 with an average of 4.50(Appendix 12). On the 18th day of drought imposition, the greenness score varied from 0.33 to 3.67 with an average of 1.99. The stem greenness change was generated using the data from the 9th and 18th day of drought imposition. A higher percentage recorded meant more greenness was kept in the drought stress condition, indicating the cowpea plant was drought tolerant (Appendix 13).



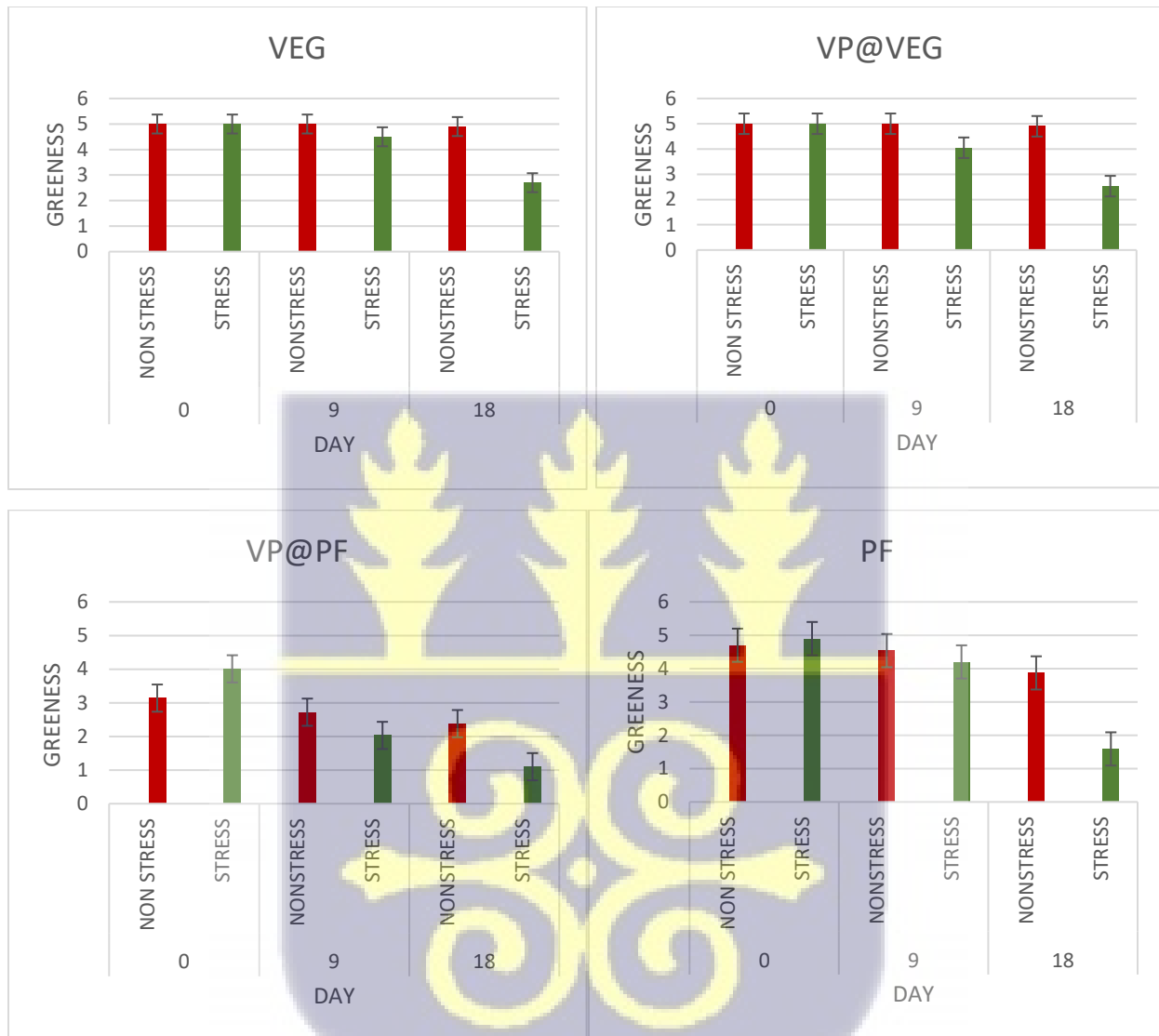


Fig 4. Greenness changes of cowpea plant at vegetative (VEG), pod filling (PF), vegetative & pod filling at vegetative (VP@VEG) and vegetative & pod filling at pod filling (VP@PF) stages under nonstress (red) and stressed (green) in 18 days.

4.4 CORRELATION ANALYSIS OF DROUGHT TOLERANCE TRAITS.

Results for correlation analysis of drought tolerance traits are presented in Table 3. The correlation analysis revealed that the drought tolerance parameters had positive correlation between each other (Appendix 11). The correlation between CVP@PF9 and HVP@PF18 ($r = 0.83$) had the strongest positive linear correlation. Likewise, a strong and positive linear correlation existed between CVPF@PF9 and SGVP@PF18 ($r = 0.82$). There was strong significant negative correlation between SGPF9 and HV18 ($r = -0.58$), SGPF9 and HVP@V18 ($r = -0.57$).

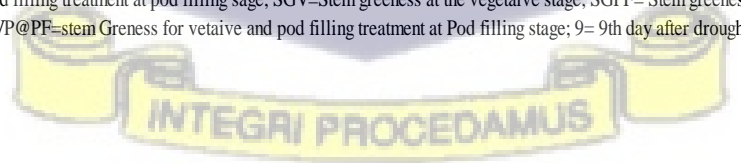
The results of the correlation also recorded some significant negative correlation between some parameters. HV18 and SGPF9 ($r = -0.58^*$), HVP@V9 and SGPF9 ($r = -0.57$), CVP@PF9 and HVP@V9 ($R = -0.48^*$)



Table 3. Correlation analysis of Chlorophyll decrease, stem lodging increase and healthiness change.

	CV9	CV18	CPF9	CPF18	CVP@V9	CVP@V18	CVP@PF9	CVP@PF18	HV9	HV18	HPF9	HPF18	HVP@V9	HVP@V18	HVP@PF9	HVP@PF18	SGV9	SGV18	SGPF9	SGPF18	SGVP@V9	SGVP@V18	SGVP@PF9	SGVP@PF18	
CV9	1.00																								
CV18	0.23	1.00																							
CPF9	-0.23	-0.30	1.00																						
CPF18	-0.03	0.02	0.78	1.00																					
CVP@V9	0.62	-0.08	-0.06	-0.01	1.00																				
CVP@V18	-0.14	0.05	0.18	0.24	-0.09	1.00																			
CVP@PF9	0.02	0.17	0.05	0.14	-0.21	0.02	1.00																		
CVP@PF18	-0.26	0.11	0.05	0.07	-0.34	0.31	0.64	1.00																	
HV9	0.10	-0.02	-0.38	0.12	-0.05	0.11	-0.06	-0.17	1.00																
HV18	-0.11	0.49	-0.22	-0.04	-0.23	0.48	-0.21	-0.08	0.22	1.00															
HPF9	0.21	-0.22	0.57	0.61	0.20	0.24	0.25	0.23	0.13	-0.27	1.00														
HPF18	0.09	-0.14	0.42	0.56	0.05	0.28	0.16	0.21	0.28	-0.07	0.79	1.00													
HVP@V9	0.05	-0.01	-0.12	-0.05	0.21	-0.19	-0.48	-0.26	0.26	0.01	0.07	0.14	1.00												
HVP@V18	-0.03	0.37	-0.02	0.23	-0.09	0.44	-0.14	-0.09	0.34	0.79	0.04	0.02	0.23	1.00											
HVP@PF9	0.03	0.08	0.17	0.39	0.09	0.04	0.61	0.56	-0.08	-0.07	0.15	0.32	-0.11	-0.15	1.00										
HVP@PF18	0.06	0.20	0.09	0.16	0.04	0.09	0.83	0.51	-0.18	-0.01	0.11	0.23	-0.43	-0.18	0.78	1.00									
SGV9	0.11	0.23	-0.23	0.16	-0.18	-0.05	-0.18	-0.20	0.27	0.23	-0.21	-0.19	0.08	0.25	0.04	-0.11	1.00								
SGV18	0.01	0.04	-0.06	0.13	-0.09	-0.20	-0.15	-0.12	0.13	0.14	-0.05	0.02	0.08	0.08	0.16	-0.01	0.70	1.00							
SGPF9	0.03	-0.37	0.27	-0.05	0.20	-0.08	0.17	0.09	-0.28	-0.58	0.39	0.27	-0.05	-0.57	0.05	0.17	-0.22	-0.07	1.00						
SGPF18	0.20	-0.13	0.26	0.29	0.19	0.20	0.05	0.22	0.11	-0.16	0.62	0.83	0.24	-0.17	0.34	0.16	-0.24	0.00	0.57	1.00					
SGVP@V9	0.00	0.11	-0.04	0.06	-0.12	0.22	-0.05	-0.01	0.09	0.26	0.00	0.06	-0.07	0.33	0.02	-0.04	0.47	0.44	-0.14	-0.03	1.00				
SGVP@V18	-0.04	-0.07	0.06	0.15	-0.13	-0.12	0.10	0.02	0.04	0.00	0.07	0.18	-0.10	0.07	0.08	0.02	0.53	0.74	0.10	0.04	0.64	1.00			
SGVP@PF9	0.22	0.11	0.17	0.42	0.05	-0.06	0.75	0.43	-0.07	-0.25	0.30	0.32	-0.32	-0.16	0.68	0.78	0.08	0.10	0.10	0.22	0.05	0.24	1.00		
SGVP@PF18	0.07	0.01	0.27	0.17	-0.10	0.11	0.83	0.60	-0.19	-0.25	0.36	0.27	-0.40	-0.22	0.57	0.78	-0.31	-0.15	0.35	0.24	-0.13	0.03	0.65	1.00	

*-P<0.05, ns= not significant; CV9= Chlorophyll content at vegetative stage; CPF= chlorophyll content at pod filling stage; CVP@V= chlorophyll content for vegetative and pod filling treatment at vegetative stage; CVP@PF= chlorophyll content for vegetative and pod filling stage treatment at Pod filling stage; HV= Plant healthiness at vegetative stage; HPF= Plant healthiness at Pod filling stage; HVP@V= Plant healthiness for vegetative and pod filling treatment at the vegetative stage; HVP@PF=Plant healthiness for vegetative and pod filling treatment at pod filling stage; SGV=Stem greenness at the vegetative stage; SGPF= Stem greenness at pod filling stage; SGVP@V= Stem greenness for vegetative and pod filling stage treatment at vegetative stage; SGVP@PF=stem Greenness for vegetative and pod filling treatment at Pod filling stage; 9= 9th day after drought imposition; 18= 18days after drought imposition.



4.5. Factor analysis of traits towards observed variability.

Results for the factor analysis are shown in Table 4. There were ten dimensions to explain the variability among the genotype of the F4 population. The first dimension (Dim1) had an eigenvalue of 5.02 and it accounted for 25.30% of the total variance. The variables associated with this dimension were PLV, PLPF, SWPF, SSPF and SSC. The second dimension (Dim 2) accounted for 17.80% of the total variance with an eigenvalue of 3.55. The second dimension was associated with SWC, SWPF, SSC, SSPF. The third dimension (Dim 3) accounted for 12.10% of the variability among the genotypes with an eigenvalue of 2.43. The major traits that contributed to Dim 3 were PPPV, SWC, SWV and SSV. The fourth dimension (Dim 4) showed an eigenvalue of 1.98 and it contributed 9.90% of the overall variances. The traits that contributed most to Dim 4 were PLC, SWC, SWPF and SSC. The fifth dimension (Dim 5) accounted for 7.08% of the total variances with an eigenvalue of 1.42. The Dim 5 was associated with SWC, PPPV, PLVP and SWVP. The sixth dimension (Dim 6) contributed 5.85% to the overall variances with an eigenvalue of 1.17. The Dim 6 was associated with SSVP, SSPF, PPPV and SPPVP. The eigenvalue of the seventh dimension (Dim 7) was 1.02 and it could explain 5.12% of the total variance. The variables SWPF, SPPVP, PLV, PLVP contributed most to Dim 7. The eighth dimension (Dim 8) accounted for 3.98% of the total variances with eigenvalue of 0.80 being associated with SPPPF, SPPVP, SWC and PPPVP. The ninth dimension (Dim 9) accounted for 4.45% of the total variances with eigenvalue of 0.69%. The main contributing variables to Dim 9 were SPPVP, PLC, PLV and PLPF. The tenth dimension (Dim 10) accounted for 2.36% of the total variance with eigenvalue of 0.47. The Dim 10 was associated PLV, SWC, SSVP and PPPV.

Table 4: Factor analysis based on yield and yield related attributes of cowpea F₄ population.

	Dim. 1	Dim. 2	Dim. 3	Dim. 4	Dim. 5	Dim. 6	Dim. 7	Dim. 8	Dim. 9	Dim.1 0
PPPC	0.41	0.21	0.50	-0.10	0.16	0.06	-0.39	-0.45	0.01	-0.08
PPPV	0.34	-0.38	0.46	0.17	0.39	0.46	-0.02	0.00	-0.01	0.12
PPPPF	-0.32	-0.92	0.01	0.09	-0.09	0.07	-0.03	0.00	0.03	0.06
PPPVP	0.27	-0.24	0.20	-0.63	0.26	-0.03	-0.43	0.36	0.08	-0.11
SPPC	-0.32	-0.91	0.06	0.13	-0.08	0.04	-0.07	0.03	0.06	0.02
SPPV	-0.26	-0.93	0.02	0.16	-0.06	0.09	-0.09	-0.05	0.04	-0.01
SPPPF	0.36	-0.43	-0.03	0.05	0.00	-0.71	0.01	0.24	-0.15	-0.10
SPPVP	0.60	-0.07	0.18	-0.06	0.15	0.16	0.49	0.33	0.28	0.06
PLC	0.48	-0.16	-0.39	0.57	0.15	-0.15	-0.12	-0.18	0.18	-0.29
PLV	0.68	-0.10	-0.19	-0.18	-0.22	-0.31	0.09	-0.24	0.08	0.43
PLPF	0.70	-0.27	-0.14	0.14	-0.07	0.01	-0.19	-0.09	0.32	0.16
PLVP	0.26	-0.50	-0.41	-0.12	0.42	0.02	0.38	-0.21	-0.23	-0.15
SWC	0.23	0.17	0.36	0.64	0.28	-0.15	-0.21	0.27	-0.24	0.20
SWV	0.62	-0.22	0.56	-0.17	-0.38	-0.03	0.11	-0.07	-0.16	-0.11
SWPF	0.67	0.18	0.22	0.32	0.42	-0.11	0.19	-0.08	0.03	-0.03
SWVP	0.36	-0.15	-0.39	-0.68	0.42	-0.08	-0.13	-0.05	-0.01	0.07
SSC	0.67	0.09	-0.43	0.24	-0.30	0.10	-0.28	0.18	0.07	-0.07
SSV	0.62	-0.22	0.56	-0.17	-0.38	-0.03	0.11	-0.07	-0.16	-0.11
SSPF	0.76	0.13	-0.28	-0.05	-0.25	0.35	0.07	0.15	0.06	-0.15
SSVP	0.49	-0.09	-0.52	0.06	-0.08	0.33	-0.14	0.05	-0.51	0.12
Eigen values	5.05	3.55	2.43	1.98	1.42	1.17	1.02	0.80	0.69	0.47
	25.3	17.8	12.1							
Variances (%)	0	0	0	9.90	7.08	5.85	5.12	3.98	3.45	2.36
Cumulative	25.2	43.0	55.1	65.0	72.1	77.9	83.1	87.0	90.5	
Variance (%)	5	3	7	7	4	9	1	8	3	92.90

PLC= pod length of the control; PLV= Pod Length for the Vegetative stage; PLPF= Pod length for pod filling stage; PLVP= Pod length for vegetative and pod filling stage treatment; SPPC= number of seeds per pod for control; SPPV= number of seeds per pod for vegetative stage; SPPPF= number of seeds per pod for pod filling stage; SPPVP= number of seeds per pod for vegetative and pod filling stage; PPC= number of pods per plant for control; PPPV= number of pods per plant for vegetative stage; PPPPF= number of pods per plant for pod filling stage; PPPVP= number of pods per plant for vegetative and pod filling stage; SWV= seed weight for the vegetative stage; SWPF= seed weight for the pod filling stage; SWVP= seed weight for the vegetative and pod filling stage

4.6 CORRELATION ANALYSIS OF YIELD AND YIELD RELATED TRAITS

Pearson correlations analysis of grain yield and yield related traits showed significant ($p < 0.01$) correlations among some of the quantitative traits: PPPPF and NSPPC were perfectly positively correlated ($r = 1.00$) with SPPV. Seed size at the vegetative stage was also perfectly positively correlated ($r = 1.00$) with seed weight at the VEG. Other positive and strong correlations were detected between SSPF and SSC ($r = 0.88$), SSC and PLPF ($r = 0.77$), SSPF and PLPF ($r = 0.73$) and PLPF and PLV ($r = 0.71$). On the other hand, Strong negative correlations were recorded between SWPF and SPPV ($r = -0.83^{**}$), PPPPF ($r = -0.86^{**}$), SPPC ($r = -0.84$), SSPF and SPPV ($r = -0.81^{**}$), PPPPF ($r = -0.82^{**}$), SPPC ($r = -0.83^{**}$) (Table 5).

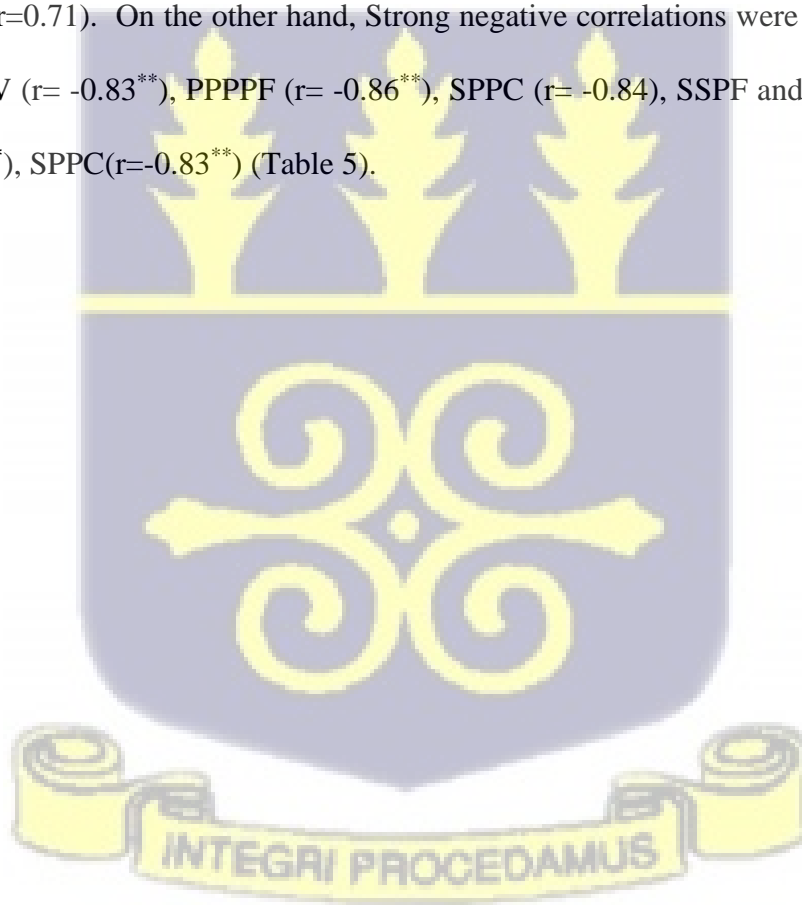


Table 5. Correlation analysis of yield and yield related parameters

	PLVP	SPPV	PPPPF	SPPC	SPPPF	PLC	PPPV	SWC	PPPVP	SWVP	SWV	SSV	SPPVP	SWPF	PLV	PLPF	SSC	SSPF
PLVP	1																	
SPPV	0.28	1																
PPPPF	0.29	1	1															
SPPC	0.24	1	1	1														
SPPPF	0.12	0.062	0.072	0.069	1													
PLC	0.13	-0.3	-0.35	-0.35	0.14	1												
PPPV	-0.15	0.16	0.14	0.16	-0.46	-0.3	1											
SWC	-0.59	-0.41	-0.44	-0.39	-0.029	0.31	0.33	1										
PPPVP	-0.045	-0.11	-0.074	-0.077	0.01	-0.64	0.034	-0.38	1									
SWVP	0.52	-0.31	-0.29	-0.32	0.059	0.093	-0.38	-0.58	0.63	1								
SWV	-0.44	-0.37	-0.36	-0.36	0.092	-0.29	0.24	0.11	0.21	-0.14	1							
SSV	-0.44	-0.37	-0.36	-0.36	0.092	-0.29	0.24	0.11	0.21	-0.14	1	1						
SPPVP	-0.12	-0.68	-0.66	-0.69	-0.1	0.049	0.26	0.19	0.086	0.14	0.54	0.54	1					
SWPF	-0.23	-0.83	-0.86	-0.84	-0.057	0.46	0.17	0.66	-0.21	-0.021	0.36	0.36	0.68	1				
PLV	0.019	-0.65	-0.64	-0.66	0.28	0.31	-0.46	-0.13	0.018	0.45	0.43	0.43	0.48	0.44	1			
PLPF	-0.096	-0.52	-0.56	-0.56	0.047	0.59	-0.18	0.084	-0.13	0.17	0.31	0.31	0.43	0.5	0.71	1		
PPC	-0.23	-0.7	-0.72	-0.73	-0.002	0.67	-0.43	0.18	-0.23	0.14	0.15	0.15	0.39	0.51	0.68	0.77	1	
SSPF	-0.15	-0.81	-0.82	-0.83	-0.19	0.4	-0.21	0.05	-0.015	0.29	0.41	0.41	0.66	0.6	0.73	0.73	0.88	1

*=P<0.05, ns= not significant; PLC=pod length of the control; PLV=Pod Length at the Vegetative stage; PLPF=Pod length at pod filling stage; PLVP=Pod length for vegetative and pod filling stage treatment; SPPC=number of seeds per pod for control; SPPV=number of seeds per pod at vegetative stage; SPPPF=number of seeds per pod at pod filling stage; SPPVP=number of seeds per pod at vegetative and pod filling stage; PPC= number of pods per plant control; PPPV= number of pods per plant at vegetative stage; PPPPF= number of pods per plant at pod filling stage; PPPVP= number of pods per plant at vegetative and pod filling stage; SWV= seed weight at the vegetative stage; SWPF= seed weight at the pod filling stage; SWVP= seed weight at the vegetative and pod filling stage;

4.7 GENETIC VARIABILITY OF YIELD AND YIELD RELATED ATTRIBUTES

Genetic variability results are shown in Table 6. For this F₄ population, all traits had low heritability (<30). Number of pods per plant had the highest heritability estimate (0.28) and seed size and seed weight recording the lowest of (0). The GCV ranged from 45.34% number of pods per plant at the vegetative stage to 1.49% for sees weight at vegetative stage and seed size at the vegetative stage. Genetic advance ranged from 0(seed weight at vegetative stage and seed size of control) to 1.94(pod length at the vegetative stage). Generally, values for PCV were high as well as those for ECV. GAM ranged from 0.06(SSV) to 49.76(PPPV).



Table 6: Genetic parameters of variability for cowpea F4 population,

	Range		Mean	σ_e^2	σ_g^2	σ_p^2	ECV%	GCV%	PCV%	$\%h_b^2$	GA	GAM
	Max	Min										
PPPC	10	0	4.36	3.38	0.16	3.54	42.23	9.25	43.24	0.05	0.18	4.08
PPPV	5	0	1.8	1.68	0.67	2.34	72.06	45.34	85.14	0.28	0.9	49.76
PPPPF	9	0	3.09	2.89	0.4	3.26	55.01	20.41	58.68	0.21	0.42	14.62
PPPVP	13	0	1.29	4.97	0.03	5	92.45	7.53	92.75	0	0.03	1.26
NSPPC	18	0	8.54	5.25	0.61	5.89	26.83	9.35	28.41	0.11	0.54	6.33
NSPPV	14	0	5.62	2.61	20.46	19.58	80.45	16.71	78.69	-0.05	-0.41	-7.31
NSPPPF	19	0	7.51	9.22	0.58	9.8	40.43	10.15	41.68	0.06	0.38	5.08
NSPPVP	11	0	5.04	12.35	1.91	14.25	69.67	27.37	74.86	0.13	1.04	20.62
PLC	23	0	14.42	9.71	0.74	10.45	21.61	5.94	22.41	0.07	0.47	3.25
PLV	19	0	8.86	38.58	6.31	44.9	70.15	28.37	75.67	0.14	1.94	21.92
PLPF	20.7	0	12.2	19.85	2.88	22.73	36.51	13.91	39.072	0.13	1.24	10.2
PLVP	19.5	0	10.37	36.31	5.36	41.68	58.09	22.33	62.23	0.13	1.71	16.5
SWC	16.22	0	7.64	5.12	0.58	5.7	29.63	9.99	31.27	0.1	0.5	6.58
SWV	7.28	0	3.08	6.32	0	6.32	81.63	1.49	81.65	0.0003	0	0.06
SWPF	11.51	0	6.07	4.8	-0.15	4.65	36.09	6.46	35.51	-0.03	-0.15	-2.42
SWVP	16.1	0	3.47	7.277	1.22	8.5	77.82	31.92	84.12	0.14	0.86	24.96
SSC	9.91	0	7.24	2.15	0.4	2.56	20.27	8.72	22.06	0.16	0.51	7.1
SSV	7.28	0	3.08	6.32	0	6.32	81.63	1.49	81.65	0.0003	0.0017	0.06
SSPF	10.13	0	6.92	5.28	-0.48	4.79	33.19	10.02	31.64	-0.1	-0.45	-6.54
SSVP	9.49	0	4.67	11.25	1.97	13.21	71.8	30.03	77.83	0.15	1.12	23.88

Min= minimum, Max= maximum, σ_g^2 =genotypic variance, σ_p^2 =phenotypic variance, PCV= phenotypic coefficient of variation, GCV= genotypic coefficient of variation, h^2 =broad sense heritability, GA= genetic advance, GAM= genetic advance of mean, σ_e^2 =environmental variance; PL=Pod Length; SPP=number of seeds per pod; PP= number of pods per plant; SW= seed weight; SS= seed size; C= control, V=vegetative stage, PF= Pod filling, VP=Vegetative and pod filling



4.8 EFFECT OF WATER STRESS ON THE DAYS TO FIRST FLOWERING

Days to first flowering was recorded for the first appearance of opened flowers on each genotype.

The well-watered treatment had a grand mean of 52days with TH80 having the earliest number of days to flowering at 41days and TH192 with the highest at 68days after planting. The vegetative stage drought saw a 70days overall mean with TA having the earliest flowering at 50days and HT419 with the terminal at 82days. 51days was recorded as the overall average number of days to first flowers for the pod filling stage drought treatment. HT 475 recorded the earliest days to first flowers at 39 days and TH160 with the terminal at 65days. For the Vegetative and Pod filling drought treatment, TA had the earliest flowering time at 51days and HT120 with the least at 81days after planting. The overall average number of days to first flowers for this treatment was 70days. There were significant differences amongst all the genotypes in all the treatments (Table 7).

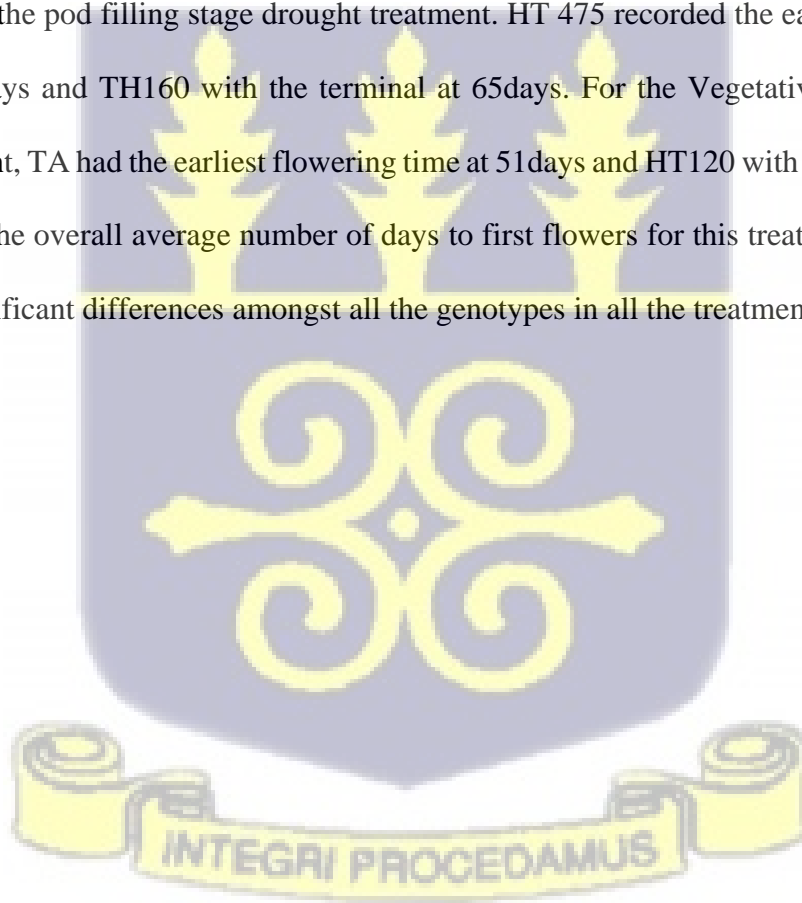


Table 7: Mean number of Days to first flowers for different genotypes under different stress conditions.

GENOTYPE	NO STRESS		STRESS					
	CONTROL		VEG		PF	VEGPF		
DANILA	54.67	abcdefgh	66.33	bcde	55.67	bcdef	71.18	abcdefg
HEWALE	46	abc	76.3	bcde	46	abcd	66.18	abcde
HT108	46.67	abcd	72	bcde	53.67	abcdef	69.33	abcdef
HT120	52.67	abcdefg	81	e	64.67	f	84	h
HT141	60	cdefgh	62.96	abcd	58.33	def	66.74	abcde
HT154	57.67	bcdefgh	75.67	bcde	63	ef	66	abcde
HT287	49.33	abcdef	69.74	bcde	45	abcd	66.09	abcde
HT372	49	abcdef	66.33	bcde	48.67	abcde	67.33	abcde
HT402	55	abcdefgh	70.8	bcde	46.67	abcd	63.83	abc
HT419	66	gh	80.96	e	62	ef	59.33	a
HT471	42.33	a	70	bcde	40.67	a	65.67	abcde
HT475	42.67	a	60.67	ab	39.33	a	60.67	ab
HT540	53	abcdefg	62.67	abc	58.33	def	68	abcde
HT700	62.33	fgh	79.33	de	45.33	abcd	71.67	bcdefg
HT727	46	abc	71.8	bcde	53.67	abcdef	69.59	abcdef
TA	55	abcdefgh	50.56	a	52.33	abcdef	80.79	fgh
TAM	61.33	efgh	73.3	bcde	64.33	f	82.59	gh
TH121	55.33	abcdefgh	80	e	53	abcdef	76.67	defgh
TH124	42.33	a	67.8	bcde	41.33	ab	68	abcde
TH131	42	a	67.33	bcde	42.33	abc	61.24	ab
TH160	55.33	abcdefgh	78	cde	64.67	f	65	abcd
TH192	67.67	h	73	bcde	56.33	cdef	72	bcdefgh
TH209	43.67	ab	68.53	bcde	44	abcd	68.74	abcdef
TH252	60.33	defgh	69.33	bcde	50.33	abcdef	74.67	cdefgh
TH261	48	abcde	67.67	bcde	46.33	abcd	77.8	efgh
TH301	51.33	abcdef	65	abcde	51.67	abcdef	61.67	ab
TH54	43.67	ab	62.46	abc	43.33	abc	70.33	abcdefg
TH72	45.67	ab	66.33	bcde	46.33	abcd	66.33	abcde
TH77	49.33	abcdef	74.67	bcde	46.33	abcd	76.67	defgh
TH80	41.33	a	62	abc	40	a	66.67	abcde
Grand mean		51.52		69.75		50.79		69.49
DMRT at 5%		11.56		13.43		12.01		12.26
ANOVA								
DROUGHT		NS		NS		NS		NS
GENOTYPE		*		*		*		*
D X G		NS		NS		NS		NS

Means with different letters in a column are significantly different from each other based on DMRT at $p=5\%$; VEG= vegetative stage drought, PF=Pod filling stage drought, VP=Vegetative and pod filling drought.

4.9 EFFECTS OF WATER STRESS ON NUMBER OF SEEDS PER POD

Results of the effects of water stress on number of seeds per pod are shown in Table 8. There were no significant differences amongst all genotypes across all the treatments (Appendix 14). For the well-watered treatment, HEWALE a high yielding parental line had the highest number of seeds per pod with 12 seeds and TH192 recorded the least number of seeds per pod with 5 seeds per pod. The numbers of seeds ranged from 5 to 12 but averagely the treatment had 9 seeds per pod. For the Vegetative stage drought treatment, the overall average number of seeds was 6 seed and ranged from 2 to 11 seeds. HT540 recorded the highest number 11 seeds per pod and HT727 the least with averagely 2 seeds per pod. Danila which was our positive control withered and was not able to make it to maturity. The pod filling stage treatment had an average of 8 seeds per pod. TH301 had 12 seeds per pod which is the highest compared to the lowest of 4 seeds per pod from TAM and TH131. TH254 recorded the least number of seeds per pod with 2 seeds and TH372 recorded the highest with 8 seeds per pod for the VEG/PF treatment. The grand mean for this treatment was 5 seeds per pod.

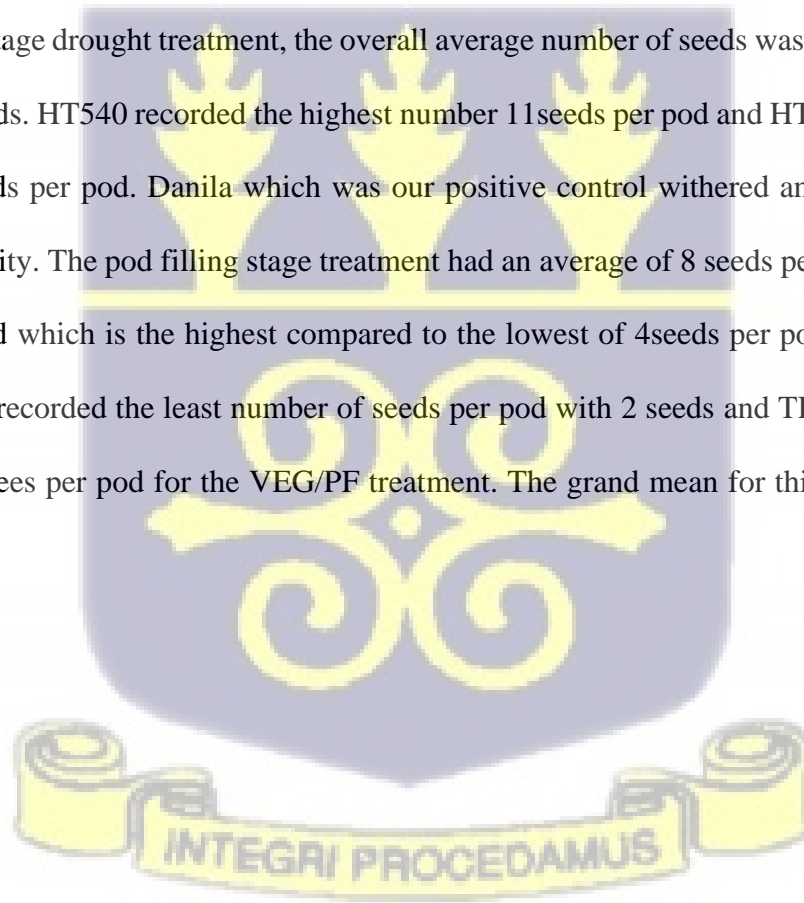


Table 8: Mean number of Seeds per pod for different genotypes under different stress conditions

GENOTYPE	NO STRESS		STRESS					
	CONTROL		VEG		PF		VEGPF	
DANILA	5.667	ab	0	a	6.333	abc	4	abc
HEWALE	11.667	c	7	ab	7	abc	5.333	abc
HT108	9.333	abc	5	ab	6.333	abc	4.333	abc
HT120	8	abc	8.667	ab	7.333	abc	6.667	abc
HT141	10.333	bc	6	ab	9.667	abc	5	abc
HT154	7	abc	8	ab	6.333	abc	4.333	abc
HT287	7	abc	4	ab	6	ab	4.667	abc
HT372	10.333	bc	7	ab	7	abc	10	c
HT402	7.667	abc	3	ab	8.667	abc	3	abc
HT419	7	abc	3.667	ab	4.667	ab	7.667	bc
HT471	8.667	abc	6	ab	8.667	abc	7	abc
HT475	7	abc	4.333	ab	6.333	abc	7.667	bc
HT540	9.333	abc	11.333	b	10	abc	5	abc
HT700	7.667	abc	5.333	ab	9	abc	7.333	bc
HT727	7.667	abc	1.667	a	4.333	ab	2.333	ab
TA	9.667	abc	4.667	ab	7	abc	0	a
TAM	10	abc	4.333	ab	4	a	0	a
TH121	10	abc	6	ab	10	abc	8.333	bc
TH124	10.333	bc	5.667	ab	6.667	abc	5.667	abc
TH131	9.333	abc	4.667	ab	4	a	5.333	abc
TH160	9	abc	5	ab	8.333	abc	8	bc
TH192	5.333	a	4	ab	8.667	abc	6	abc
TH209	7.333	abc	6.667	ab	7.667	abc	2.333	ab
TH252	11	c	7.667	ab	8	abc	5.333	abc
TH261	9.333	abc	4	ab	7	abc	3	abc
TH301	8.667	abc	8.667	ab	12.333	c	4.667	abc
TH54	7.667	abc	7	ab	10.333	bc	2	ab
TH72	7.667	abc	6.667	ab	8.333	abc	7	abc
TH77	9	abc	6.667	ab	8.667	abc	6.667	abc
TH80	7.667	abc	6	ab	6.667	abc	2.667	ab
Grand mean	9		7		8		5	
DMRT at 5%	3.8		7.7		4.9		5.9	
ANOVA								
DROUGHT	NS		NS		NS		NS	
GENOTYPE	NS		NS		NS		NS	
D XG	NS		NS		NS		NS	

Means with different letters in a column are significantly different from each other based on DMRT at $p=5\%$; VEG= vegetative stage drought, PF=Pod filling stage drought, VP=Vegetative and pod filling drought.

4.10 EFFECTS OF WATER STRESS ON POD LENGTH

Results of the effects of water stress on pod length are shown in Table 9. The lines were classified into those with short pod length (<11cm), medium (11-15cm), and long (>15cm). For the well-watered treatment, the pod length ranged from 11.3cm (TH131) to 18.47cm (TH80) (Table 9). 12 genotypes (40%) had long pods and the rest of the 18pods (60%) were of medium length. There was no short pod in this treatment. Pod length after the vegetative stage treatment ranged from 8.02cm (TAM) to 17.44cm (TH209). 7 genotypes (20%) had long pods, 19 genotypes (63.33%) had medium sized pods and 5 genotypes (16.67%) has short pods. For the pod filling stage treatment, pod length ranged from 9.2cm (TA) to 17.54cm (TH301). 11pods accounting for 36.67% were long, 18pods accounting for 60% were of medium length and 1 pod was small. For the vegetative and pod filling stage treatment, pod lengths ranged from 10.8cm (TH131) to 17.68cm (TH192). Genotypes with long pods were 7 accounting for 23.33%, 22 genotypes accounting for 73.33% were medium sized and 1 genotype was small sized. Aside the well-watered treatment which showed no significant differences amongst the genotypes, all other treatments showed significant differences amongst the cowpea genotypes.



Table 9: Mean number pod length for different genotypes under different stress conditions

GENOTYPE	NO STRESS		STRESS					
	CONTROL		VEG		PF	VEGPF		
DANILA	12.83	ab	13.34	cdefg	11.17	ab	11.68	abcd
HEWALE	15.43	ab	14.92	efg	14.87	defghi	13.48	abcdef
HT108	16.57	ab	10.65	abcde	14.13	bcdefgh	11.33	abc
HT120	14.17	ab	12.03	abcdef	14.63	cdefghi	11.83	abcde
HT141	16.37	ab	16.05	fg	15.33	efghi	13.33	abcdef
HT154	14.2	ab	13.47	cdefg	13.53	bcdefg	13.83	abcdefg
HT287	12.83	ab	15.9	fg	16.96	hi	15.75	fgh
HT372	16.23	ab	15.27	fg	16.43	fghi	17.2	gh
HT402	14.3	ab	14.4	defg	13.14	bcdef	14.68	bcdefgh
HT419	12.9	ab	15.65	fg	14.44	bcdefghi	14.37	abcdefgh
HT471	14.87	ab	13.4	cdefg	14.69	cdefghi	14.57	bcdefgh
HT475	16.23	ab	12.92	bcdefg	14.84	defghi	14.27	abcdefgh
HT540	15.3	ab	15.9	fg	15.53	efghi	14.43	abcdefgh
HT700	15.9	ab	13.8	cdefg	15.94	efghi	15.03	defgh
HT727	14.43	ab	12.47	abcdef	15.67	efghi	11.94	abcde
TA	12.93	ab	8.45	ab	9.2	a	14.15	abcdefgh
TAM	12	a	8.02	a	13.24	bcdef	14.15	abcdefgh
TH121	15.33	ab	9.91	abcd	14.1	bcdefgh	15.73	fgh
TH124	16	ab	12.67	bcdef	14.2	bcdefghi	14.8	cdefgh
TH131	11.13	a	9.8	abc	11.84	abcd	10.8	a
TH160	14.6	ab	14.65	efg	16.8	ghi	15	cdefgh
TH192	13.77	ab	14.72	efg	11.44	abc	17.68	h
TH209	16.87	ab	17.44	g	15.67	efghi	12.74	abcdef
TH252	13.57	ab	14.9	efg	12.54	bcde	15.5	efgh
TH261	13.1	ab	12.2	abcdef	12.97	bcde	14.13	abcdefgh
TH301	14.2	ab	15	efg	17.54	i	14.8	cdefgh
TH54	16.27	ab	14.4	defg	15.04	defghi	14.28	abcdefgh
TH72	14.6	ab	12.9	bcdefg	14.14	bcdefgh	14.67	bcdefgh
TH77	11.87	a	13.27	cdefg	13.43	bcdefg	11	ab
TH80	18.47	b	11.75	abcdef	15.8	efghi	17.23	gh
Grand mean	14.58		13.34		14.31		14.15	
DMRT at 5%	4.64		3.85		2.79		3.05	
ANOVA								
DROUGHT	NS		NS		NS		NS	
GENOTYPE	NS		*		*		*	
D X G	NS		NS		NS		NS	

Means with different letters in a column are significantly different from each other based on DMRT at $p=5\%$; VEG= vegetative stage drought, PF=Pod filling stage drought, VP=Vegetative and pod filling drought.

4.11 EFFECTS OF WATER STRESS ON SEED YIELD

For seed yield across all treatments, there was no significant differences amongst the genotypes (Table 10). The well-watered treatment recorded an average mean yield of 7.7g per plant. The yield ranged from 11.5g(HT108) to 5.0g(TH192). HT108(11.5g) and TH252(9.8g) performed better than Hewale the high yielding parental line. In the vegetative stage treatment, the seed yield ranged from 6.5g(HT419) to 3.0g(TA) with an average of 4.9g. For the Pod filling stage treatment, HT372 had the highest seed yield of 8.7g and TA with the least of 4.3g. On the average the treatment had a yield of 6.4g. The vegetative and pod filling stage treatment saw HT372 yielding the most with 8.5g and HT108 with the lowest of 3.7g and an average treatment yield of 5.2g(Table 10).

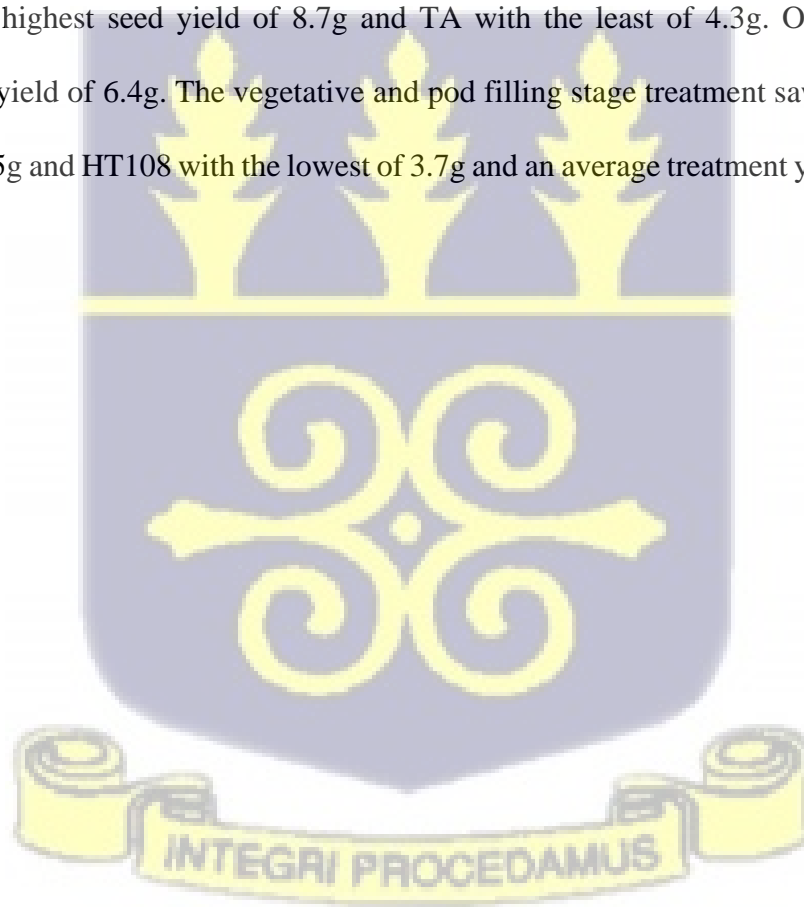


Table 10: Mean seed yield for different genotypes under different stress conditions.

GENOTYPE	NO STRESS		STRESS					
	CONTROL		VEG		PF		VEGPF	
DANILA	6.277	ab	4.848	abcd	6.163	abc	5.554	Ab
HEWALE	9.743	bc	3.591	ab	6.79	abc	4.149	A
HT108	11.487	c	4.618	abcd	8.457	bc	3.709	A
HT120	7.953	abc	5.117	abcd	6.877	abc	3.757	A
HT141	8.257	abc	5.207	bcd	7.297	abc	4.988	Ab
HT154	9.403	abc	5.713	bcd	6.183	abc	4.453	Ab
HT287	6.477	ab	5.397	bcd	6.957	abc	6.828	Ab
HT372	8.943	abc	4.743	abcd	8.656	c	8.51	B
HT402	6.35	ab	4.757	abcd	6.44	abc	6.55	Ab
HT419	5.81	ab	6.506	d	6.563	abc	5.537	Ab
HT471	8.18	abc	5.083	abcd	7.13	abc	4.517	Ab
HT475	7.09	ab	5.391	bcd	7.157	abc	4.23	A
HT540	8.803	abc	5.177	bcd	7.07	abc	6.319	Ab
HT700	5.827	ab	4.736	abcd	5.13	ab	7.853	Ab
HT727	6.797	ab	4.837	abcd	5.15	abc	3.927	A
TA	7.383	abc	2.987	a	4.333	a	5.153	Ab
TAM	6.367	ab	3.856	abc	4.374	a	5.153	Ab
TH121	8.57	abc	5.187	bcd	7.147	abc	3.787	A
TH124	8.4	abc	4.356	abcd	5.863	abc	4.403	Ab
TH131	8.18	abc	3.857	abc	5.84	abc	4.553	Ab
TH160	6.26	ab	4.293	abc	5.68	abc	4.973	Ab
TH192	5.005	a	4.211	abc	6.031	abc	6.389	Ab
TH209	6.927	ab	3.947	abc	5.463	abc	5.474	Ab
TH252	9.82	bc	5.573	bcd	6.383	abc	4.463	Ab
TH261	7.273	abc	4.342	abcd	6.753	abc	4.824	Ab
TH301	9.487	bc	5.95	cd	6.863	abc	6.178	Ab
TH54	7.493	abc	5.727	bcd	6.117	abc	4.674	Ab
TH72	7.107	ab	5.126	abcd	5.401	abc	4.943	Ab
TH77	7.723	abc	5.911	cd	5.323	abc	3.823	A
TH80	7.283	abc	4.392	abcd	6.94	abc	4.905	Ab
Grand mean	7.69		1.82		6.35		5.15	
DMRT at 5%	3.58		4.9		2.85		3.53	
ANOVA								
DROUGHT	NS		NS		NS		NS	
GENOTYPE	NS		NS		NS		NS	
D XG	NS		NS		NS		NS	

Means with different letters in a column are significantly different from each other based on DMRT at $p=5\%$; VEG= vegetative stage drought, PF=Pod filling stage drought, VP=Vegetative and pod filling drought.

4.12 EFFECTS OF WATER STRESS ON SEED SIZE

Seed size for the well-watered treatment ranged from 8.70mm (TH209) to 6.32mm (TA) with an average of 7.48mm. There were significant differences amongst the genotypes. The vegetative stage treatment had seed size ranging from 6.51mm (HT419) to 2.99mm (TA) with a treatment average of 4.85mm, with no significant difference among the genotypes. For the pod filling stage drought treatment, the seed size ranged from 6.1mm (HT419) to 2.99mm (TA) with an overall treatment average of 4.85mm with significant differences among the genotypes. The vegetative and pod filling stage treatment had a seed size range of 8.89mm (TH80) to 5.72mm (TH261) and a treatment average of 7.3mm, there were significant differences among the genotypes (Table 11).

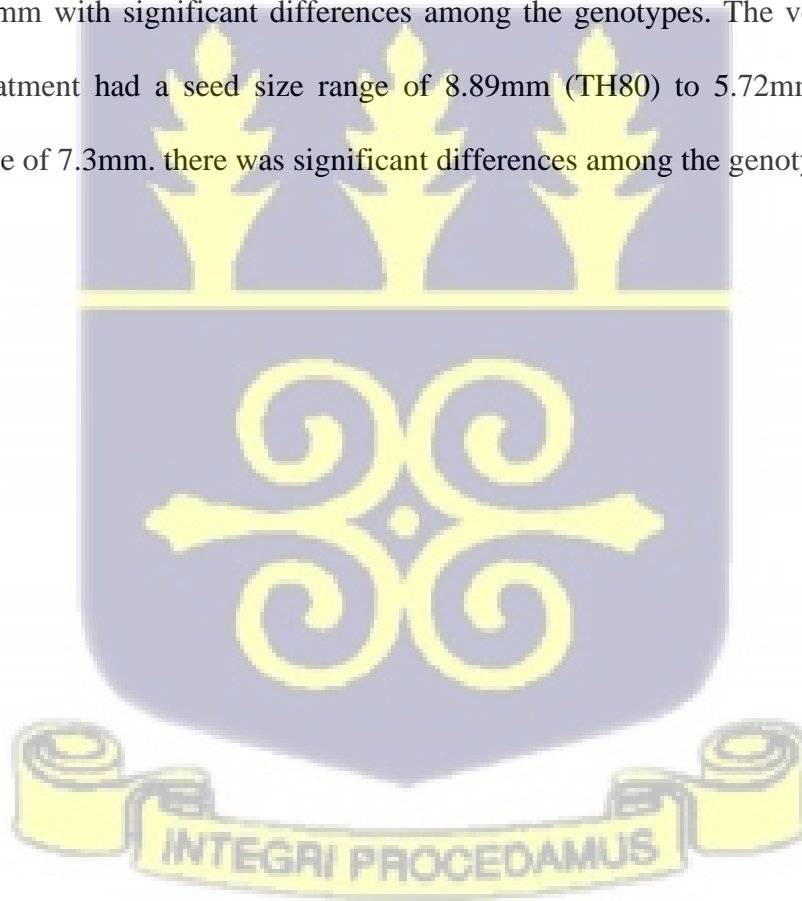


Table11: Mean seed size for different genotypes under different stress conditions.

GENOTYPE	NO STRESS		STRESS					
	CONTROL		VEG		PF		VEGPF	
DANILA	8.243	fghi	4.848	abcd	8.14	cdef	6.629	abcdef
HEWALE	8.357	ghi	3.591	ab	7.953	bcdef	8.634	fgh
HT108	7.723	defghi	4.618	abcd	7.46	bcdef	6.474	abcde
HT120	8.03	efghi	5.117	abcd	8.218	def	7.417	abcdefgh
HT141	7.473	abcdefghi	5.207	bcd	7.323	abcdef	7.793	bcdefgh
HT154	7.663	cdefghi	5.713	bcd	7.733	bcdef	7.583	abcdefgh
HT287	7.523	abcdefghi	5.397	bcd	7.92	bcdef	7.99	cdefgh
HT372	7.747	defghi	4.743	abcd	8.39	ef	7.961	cdefgh
HT402	7.047	abcdef	4.757	abcd	6.947	abcd	6.839	abcdefg
HT419	7.357	abcdefg	6.506	d	8.448	ef	8.434	efgh
HT471	8.287	fghi	5.083	abcd	8.491	ef	8.777	gh
HT475	7.177	abcdefg	5.391	bcd	7.273	abcdef	6.267	abcd
HT540	7.127	abcdefg	5.177	bcd	6.667	ab	6.919	abcdefgh
HT700	8.68	hi	4.736	abcd	8.667	f	8.43	efgh
HT727	7.392	abcdefg	4.837	abcd	7.48	bcdef	6.96	abcdefgh
TA	6.317	a	2.987	a	6.05	a	7.312	abcdefgh
TAM	6.383	ab	3.856	abc	6.781	abc	7.312	abcdefgh
TH121	7.077	abcdefg	5.187	bcd	7.117	abcde	6.913	abcdefgh
TH124	7.147	abcdefg	4.356	abcd	7.54	Bcdef	7.174	abcdefgh
TH131	6.37	ab	3.857	abc	6.558	ab	5.754	a
TH160	7.683	cdefghi	4.293	abc	7.356	abcdef	5.917	ab
TH192	6.422	abc	4.211	abc	7.23	abcde	7.094	abcdefgh
TH209	8.703	i	3.947	abc	7.643	bcdef	8.109	defgh
TH252	7.607	bcdefghi	5.573	bcd	7.37	abcdef	7.16	abcdefgh
TH261	6.503	abcd	4.342	abcd	7.22	abcde	5.72	a
TH301	7.867	efghi	5.95	cd	7.523	bcdef	8.324	efgh
TH54	7.403	abcdefgh	5.727	bcd	7.807	bcdef	6.01	abc
TH72	8.033	efghi	5.126	abcd	7.561	bcdef	7.937	cdefgh
TH77	6.797	abcde	5.911	cd	6.897	abcd	6.627	abcdef
TH80	8.347	ghi	4.392	abcd	7.74	bcdef	8.89	h
Grand mean		7.48		4.85		7.52		7.31
DMRT at 5%	1.05		1.82		1.16		1.68	
ANOVA								
DROUGHT	NS		NS		NS		NS	
GENOTYPE	*		NS		*		*	
D X G	NS		NS		NS		NS	

Means with different letters in a column are significantly different from each other based on DMRT at $p=5\%$; VEG= vegetative stage drought, PF=Pod filling stage drought, VP=Vegetative and pod filling drought.

4.13 EFFECTS OF WATER STRESS ON DAYS TO MATURITY

Singh *et al.*, (2007) and Dugie *et al.*, (2009) categorized cowpea varieties that mature in less than 60 DAP as extra –early, 60-70 DAP as early, 70-80 DAP as medium and more than 80 DAP as late. The well-watered control had 2 genotypes being extra early maturing, 14 genotypes as early maturing, 13 genotypes as medium and 1 genotype being late maturing. There were significant differences among the genotypes. For the vegetative stage treatment, there was no extra early or early maturing genotype. 4 genotypes made up medium maturing and the remaining 26 were late maturing. For the pod filling stage treatment, 5 genotypes were extra early maturing, 12 early maturing genotypes, 12 medium maturing and 1(Danila) late maturing genotype. The vegetative and pod filling treatment had 1 extra-early maturing genotype (HT700), 1 early maturing (TH301), 9 medium maturing and 19 late maturing varieties. Significant differences were observed amongst the genotypes for the well-watered treatment and the pod filling treatment (Table 12).



Table 12: Mean number of days to maturity of different genotypes under different stress conditions.

GENOTYPE	NO STRESS				STRESS			
	CONTROL		VEG		PF		VEGPF	
DANILA	79.67	cd	90.73	b	81	g	91.22	bc
HEWALE	66.33	abcd	90.31	b	62.67	abcd	79.77	abc
HT108	65	abcd	81.56	ab	72	cdefg	83	bc
HT120	72.33	abcd	90.86	b	77	fg	85.23	bc
HT141	77	bcd	83.13	ab	75.67	efg	79.36	abc
HT154	78.33	bcd	86.13	ab	80.33	g	80.33	abc
HT287	67.67	abcd	88.56	ab	64.33	abcde	77.3	abc
HT372	66.67	abcd	81.33	ab	68.33	abcdef	81.67	abc
HT402	78	bcd	79.13	ab	65.33	abcde	82.23	abc
HT419	70.16	abcd	88.4	ab	71	bcdefg	80.33	abc
HT471	62	abc	82.67	ab	59	a	80.67	abc
HT475	61	abc	78.33	a	61.67	abc	84.33	bc
HT540	74	abcd	82.33	ab	77	fg	83.33	bc
HT700	55	a	89.4	ab	64.67	abcde	57	a
HT727	64.67	abcd	84.81	ab	77.67	fg	85.37	bc
TA	77	bcd	89.86	ab	74	defg	96.22	c
TAM	81.67	d	83.86	ab	80.33	g	81.82	abc
TH121	74.67	bcd	85.31	ab	73.33	defg	84.86	bc
TH124	61.33	abc	86.81	ab	60.67	abc	80	abc
TH131	61.67	abc	83.67	ab	58.33	a	76.86	abc
TH160	73.33	abcd	85.31	ab	78.33	fg	79	abc
TH192	78.46	bcd	83.56	ab	77.75	fg	83	bc
TH209	61.33	abc	89.86	ab	60.33	abc	81.36	abc
TH252	77.33	bcd	85	ab	68.33	abcdef	84.67	bc
TH261	66.67	abcd	80.4	ab	62.67	abcd	90.22	bc
TH301	71.33	abcd	81.33	ab	70	abcdefg	70	ab
TH54	61.67	abc	81.63	ab	59.67	ab	83.33	bc
TH72	62.33	abcd	81.67	ab	67	abcdef	80.33	abc
TH77	75.33	bcd	84.69	ab	62.67	abcd	88.27	bc
TH80	59.67	ab	80	ab	59	a	83.67	bc
Grand mean	69.4		84.7		69		81.8	
DMRT at 5% ANOVA	15.74		9.87		9.69		21.39	
DROUGHT	NS		NS		NS		NS	
GENOTYPE	*		NS		*		NS	
D XG	NS		NS		NS		NS	

Means with different letters in a column are significantly different from each other based on DMRT at $p=5\%$; VEG= vegetative stage drought, PF=Pod filling stage drought, VP=Vegetative and pod filling drought.

CHAPTER 5

5.0 DISCUSSION

The research on drought tolerance is challenging because several factors interact to affect a crop's ability to withstand droughts, and each element may have a significant impact. Different habitats, distinct crop types, and various growth stages of the same variety have different mechanisms for a crop's ability to withstand drought (Cui et al., 2020). Consequently, the comprehensive index technique has received an increasing amount of attention. The comprehensive index technique, which employs many indications for a thorough assessment of agricultural drought tolerance, may address the drawbacks and limits of single-indicator drought tolerance evaluation and produces evaluation results that are more accurate (Cui et al., 2020).

5.1 Three drought-tolerance parameters.

In the chloroplasts of plants, photosynthesis takes place. Chloroplasts convert light energy into chemical energy as the initial stage of photosynthesis. Chlorophyll concentration has a direct impact on the rate of photosynthetic activity (Arjenaki *et al.*, 2012; Nikolaeva *et al.*, 2010). Reduced enzymatic activity necessary for the dark reaction, decreased chlorophyll content, ultrastructural damage to the chloroplast, and blocked transfer of photosynthates can all result in chloroplast damage from drought and water scarcity. These effects can build up in leaves and prevent them from moving to grains, creating a traffic jam in the leaves (Munne-Bosch *et al.*, 2001). By examining the information on chlorophyll content in 18 days of drought stress at vegetative, pod filling and vegetative and pod filling stages, it was observed that chlorophyll content at the pod filling and vegetative and pod filling stages dropped to a very low level (chlorophyll content lower than 10) at the end of the 18 days. The vegetative stage chlorophyll concentration decreased noticeably as well, though not to the same extent as the pod filling and

vegetative & pod filling stages. Additionally, it was discovered that some cowpea lines were able to maintain the vegetative chlorophyll content level. This resulted in the suggestion that the vegetative chlorophyll content and its associated parameters, such as the inflect index, may be a useful trait to measure for the evaluation of a plant's drought tolerance. This is consistent with findings of Kramer and Boyer (1995) who reported that the severity, duration, and developmental stage of the stress, as well as the plant's coping mechanism, all influence how drought affects a plant. Among the 30 cowpea lines, huge significant variations were observed both for the overall plant healthiness and stem greenness showing that both characteristics may significantly contribute to a cowpea line's overall level of drought tolerance. However, on the basis of the attributes we measured, various cowpea lines performed and scored in different ways. A plant's health can be determined by the relative water content of its leaves, which can also keep the entire plant's green color and habit (Dedio 1975). Strong drought-tolerant cultivars had leaves with a greater relative water content to prevent cell damage from water loss and to preserve the healthy morphology, structure, and function of the leaves (Siddique *et al.*, 2000). The degree of leaf curl is low in the drought-tolerant types' exterior morphology, and the waxy layer is thoroughly covered as was observed in this study. Numerous studies have demonstrated that cultivars with good drought resistance have more durable solitary leaves that can store water than variants with limited drought tolerance (Egilla *et al.*, 2005). Through the integration of the greenness, structure, curl, and growth of the leaves, we graded and evaluated the phenotypes of the cowpea leaves in this study to assess the whole plant's health under drought stress.

Cowpea stem greenness was discovered to be a crucial seedling feature linked to drought tolerance. In this study's findings, at the vegetative stage, seventeen (17) lines had a score of 3 in including

Danila, the control, three (3) lines also scored 3 at the pod filling stage but Danila scored 1 which indicates that with regard to stem greenness as tolerance parameter, Danila is only tolerant at the vegetative stage but susceptible at the pod filling stage. The vegetative and Pod filling treatments saw a highest score of 3 and a least score of 0.3 indicating a great loss of water which is directly correlated with stem greenness. Type 2 drought tolerance was present in lines that maintained high stem greenness. Even when the severity of the drought stress increased, type 2 members continued to grow slowly and remained green for a longer period of time. Similar findings were reported by Agbicodo *et al.*, (2009) and Muchero *et al.*, (2011). These findings of the current study also support those of the study of Mai-Kodomi *et al.* (1999b) on cowpea Type 1 and Type 2 drought tolerance. Three characteristics were measured in this experiment: a decrease in chlorophyll (CII), a change in health (HII), and an increase in stem lodging (LII) as the primary criteria for assessing drought tolerance. In order to rank each cowpea line for its drought tolerance, in the current study three qualities were used. These three values were added, assuming they were all of the same importance for overall drought tolerance. We added the values of the three features. Finally, an overall ranking score was given to each cowpea line based on the overall ranking score from the sum of the three features.

5.2 SEED SIZE

Seed size is an important plant fitness trait that can influence several steps between fruiting and the establishment of a plant's offspring (Singh *et al.*, 2023). All lines in the well-watered control had medium sized seeds ranging between 6.3 mm to 8.7 mm. For the vegetative stage treatment, 16 lines had small seed size and 14 lines were of medium size. The pod filling stage treatment had all 30 lines being medium sized seeds and same for the vegetative & pod filling stage treatment.

5.3 DAYS TO FIRST FLOWERS AND MATURITY

Days to first flowers increased significantly in the vegetative stage treatments. These treatments saw an 18days increase in the number of days to first flowers as compared to the control. Abayomi and Abidoeye (2009) reported that under extreme moisture stress, cowpea flowering dates and their onset were both significantly delayed. The number of days until anthesis was significantly influenced by cowpea variety and water stress. The number of days until anthesis was lengthened by water stress during the vegetative (Ndiso *et al.*,2015). According to Weiss (1971) and Adu-Dapaah *et al.*, (1988), a minor complex gene with a propensity for early flowering dominance may be responsible for the variability in the days until first flowering. This finding suggests that dominant genes at two or more loci may be partially responsible for the variability in days until first flowering. According to Ikram (2004), additive gene action had a greater impact on cowpea earliness than dominance effects. Environmental factors have also been observed to influence flowering. The variance in the number of days that the genotypes in this trial take to flower and mature reflects a genetic response of those genotypes to water stress or deficiency in the soil. Even though the cowpea plants were under drought stress throughout the reproductive stage, it nevertheless had an impact on their maturity and flowering (Dadson *et al.*,2005). The genotypes that responded to drought stress by shortening the time to physiological maturity while retaining high yields may have been affected by the cowpea plants' ability to withstand drought conditions (Agbicodo *et al.*, 2009). However, Patil and Navale (2006) discovered that dominant gene action regulates cowpea maturity. In addition, environmental factors like temperature, relative humidity, and soil moisture content have an impact on how crop plants grow and develop.

5.4 MEAN YIELD AND YIELD COMPONENTS OF THE COWPEA GENOTYPES

The number of seeds that will ultimately be produced by a cowpea plant depends on the quantity of pods and grains that will be produced on each plant, as well as how filled the grains are(Atakora

et al., 2023). Generally, there was a reduction in grain yield across all the stress treatments. For some types, water stress throughout the vegetative and blooming phases greatly increased the number of pods per plant, pod weight, grain yield, and harvest index. In the current study, the substantial decrease in all of these yield components was linked to the decreased seed yield under water stress. Numerous scholars (Turk and Hall, 1980b; Ziska and Hall, 1983; Ludlow and Muchow, 1990; Gwathmey *et al.*, 1992a) reported supporting evidences. They observed that fewer pods per plant, fewer seeds per pod, and smaller seeds all contributed to the decrease in seed output under water stress. Insufficient soil moisture at the most vulnerable stage of reproduction causes the plant to stop growing, abort reproductive structures like flowers and pods, lack grain filling, and even become more susceptible to diseases and pests (Mwale *et al.*, 2017), as was seen in the current study. Decline in cowpea yield varies depending on the severity and length of drought stress, the stage of crop growth, and the genotypes' genetic diversity (Nadeem *et al.*, 2019).

5.4.1 Number of pods per plant

The number of pods produced by stressed plants significantly decreased when drought stress was applied to the cowpea genotypes. The genotypes with and without drought stress were significantly different based on the interaction effect between watering regimes and the genotypes. When the cowpea plants were well watered, TH192, TAM and TH160 recorded the highest number of pods per plant as compared to HEWALE the high yielding parental line. Soil water deficit affected flowering and also increased the rate of flowering and pod abortion a Alves Bastos *et al.*, (2011), reported in a similar study that the greater loss of pods per plant under drought stress circumstances may be caused by floral abortion. Toudou *et al.*, (2018) observed a similar outcome, stating that when drought stress was present, cowpea genotypes produced more pods in non-limiting water

conditions than under stressed conditions. The number of pods per plant decreased with higher water deficit, regardless of the phenological stages., according to Carvalho *et al.*, (2012), who examined the impact of water deficit on the yield of several cowpea genotypes in the greenhouse. Abscission of reproductive structures (flowers and pods), the death of pollen grains, denaturation of physiological tissues, decrease in the allocation of dry matter to the reproductive sink, as well as seed formation factors, could all be contributing factors to the decrease in the quantity of pods per plant in this study (Alves Bastos *et al.*,2011; Ahmed *et al.*, 2010; Erman & Ceritoglu, 2020; Mwale *et al.*, 2017). According to Patil and Navale (2006), additive gene activity controls the total number of pods produced by a plant. In addition, the genotype's capacity for pod bearing, environmental responsiveness, and soil nutritional quality could all be factors in the variation in the number of pods per plant.

5.4.2 Number of Seeds Per Pod

The number of seeds per pod greatly varied among genotypes across the different stress treatments. According to Ozdemir (2002), cowpea typically has 3 to 15 seeds per pod. The observed averages across all treatments revealed that drought stress and its intensity greatly impacted the number of seeds per pod as cowpea yield is influenced by the number of pods per plant, the number of seeds per pod, and the degree of seed filling. In the well-watered treatment, HEWALE produced the highest number of seeds per pod averaging 12. The findings also indicated a substantial interaction between genotype and drought stress on the quantity of seeds produced per pod by the evaluated cowpea genotypes. The quantity of seeds per pod decreased as water stress increased in the research of Ahmed *et al.*, (2010), Alves Bastos *et al.*, (2011), Ezin *et al.*, (2021), Fatokun *et al.*, (2012), Kutama *et al.*, (2014), Olajide & Ilori (2017), Pushpavalli *et al.*, (2015), Saul *et al.*, (2017), Sousa *et al.*, (2015), and Toudou *et al.*, (2018). This agrees with the findings of this research. The

decrease in the quantity of seeds per pod was attributed to the abscission of reproductive structures and the restriction of dry matter partitioning to the reproductive sink (Abayomi & Abidoye, 2009; Agbicodo *et al.*, 2009; Alves Bastos *et al.*, 2011; Ghassemi-Golezani* & Lotfi, 2012; Mwale *et al.*, 2017; Pushpavalli *et al.*, 2015).

5.4.3 Average Pod Length

The current study's findings reveal a significant genotype-by-water regime interaction effect on the cowpea genotypes' pod lengths. Pod length was negatively impacted by the drought stress. As the amount of drought stress rose, the pod length reduced. This might be a result of the soil's limited ability to hold water for pod growth. According to Sousa *et al.*, (2015), there was significant genotypic heterogeneity among cowpea genotypes with regard to pod length in response to soil water deficiency.

5.5 Relationship Between Yield and Yield Components

From the current study, a significant positive correlation existed between pod length and seed size, number of pods per plant and number of seeds per pod., seed weight and pod length, seed weight and number of pods per plant, seed size and seed weight and seed size and number of seeds per pod.

The quantity of seeds per pod and grain yield also showed a substantial positive association, supporting De Almeida *et al.*, (2014) findings. An increase in the number of pods per plant could result in an increased number of seeds per pod per plant and yield. These outcomes are in agreement with those of Chiulele, (2010) who indicated that there was strong and positive correlation between grain yield and number of pods per plant and concluded that improvement could be achieved by using such germplasm with such attributes. Similarly, a positive and strong

correlation was observed between the number of seeds per pod and grain yield confirming de Almeida *et al.*, (2014). An increase in the number of pods per plant could result in an increased number of seeds per pod per plant and yield. These outcomes agree with those of Chiulele (2010) who reported that there were significant and positive relationships between grain yield and the number of pods per plant. In the current study, the genotypes that received moderate and severe drought stress treatments showed a drop in yield components, demonstrating the impact of drought stress. Supporting evidence were reported by many researchers including Ahmed *et al.*, (2010) who reported a drastic decrease in yield components after drought stress was imposed which eventually reduced the seed yield of the cowpea genotypes in their research.

The number of seeds per pod and the yield could both rise as the number of pods per plant increases. In other words, by selecting for a higher number of pods per plant, seed yield could be indirectly increased. For a successful breeding programme, higher grain yields and improved grain quality are the primary objectives (Timko and Singh, 2008). For grain yield, several physiological and morphological traits play a vital role. The efficiency of selection in genetic relationship between grain yield and its components can improve breeding programs. This confirms with the result of Turk *et al.*, (1980) who concluded that during water stress, there was a reduction in seed yield which is related to decrease in yield components such as number of seeds per pod, number of pods per plant. During flowering and pod filling, cowpea becomes sensitive to drought. Flower abortion, seed filling and pod dropping are caused by water stress. Therefore, in this study, the reduction in number of seeds per pod, number of pods per plant was credited to abscission of reproductive structures and restriction of dry matter partitioning to reproductive sink.

The factor analysis revealed 7 dimensions with eigen value greater than 1. These dimensions explained 83.11% of the variance among the genotypes of the population. It was observed that the traits: pod length at pod filling stage and seed size at the pod filling stage were the major contributing traits to the first dimension. The second dimension was associated with number of pods per plant for the control and seed weight at pod filling stage. These traits were the major contributors to the second dimension. Dimension 1 and 2 can be useful in selecting genotypes that gave higher yield since the traits in contributing to dimension 1 and dimension 2 are yield component traits. This result agrees with the findings of Sousa *et al.*, (2015) and Saidaiah *et al.*, (2021) who termed PC1 and PC2 as the reproductive axis. Vijayakumar *et al.*, (2020) reported that principal component 1 with pod length at pod filling stage and seed size at the pod filling stage as main contributing traits could be used in selection of genotypes for yield improvement. Sobda (2013) reported that principal component analysis could be used in establishing variability among genotypes and could serve as a means to select genotypes based on traits.

Generally, the phenotypic coefficient of variation (PCV) for all quantitative traits were higher than their corresponding genotypic coefficient of variation (GCV) in the population. This suggest that there was environmental influence on the expression of these traits. Traits such as number of pods per plant at the vegetative stage, number of seeds per pod at the vegetative stage, pod length at the vegetative stage, seed weight at the vegetative stage and seed size at the vegetative and pod filling stage had high GCV (>20%). Moreover, the GCV was moderate (10%-20%) for number of pods per plant at the pod filling stage, number of seeds per pod at the vegetative stage, pod length at pod filling stage and seed size at pod filling stage.

Low heritability (<30%) was observed across all the genotypes. Traits with such low heritability cannot be successfully passed on to other generations. The observed high PCV indicates more environmental influence on the trait than genetic. These results agree with those of Raja (2017) and Yeshiwas and Negash(2017).



CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Under drought stress circumstances, there were variations among the studied cowpea genotypes in terms of morphological and yield markers. In the current study, it was clear that the drought at the reproductive stage had a detrimental impact on the overall yield of cowpea since there was a decrease in total grain weight and other yield components compared to the control. The outcomes also supported the notion that cowpea genotypes display significant genetic differences in response to drought stress depending on the intensity of stress, despite its intrinsic and comparative tolerance to drought.

The following inferences could be derived from the outcome;

- i. Drought tolerant lines were identified for the different drought stress treatments. HT120, HT108, HT475, HT471, TH160, HT372 were tolerant to vegetative stage drought; HT540, TH54, HT120, HT727, TH209, TH160, HT419, HT287, HT154, TH131, TH261, HT372, TH192, TH301 and TA were tolerant to pod filling stage drought and TH124, TH80, TA, TH54, HT141, HT471, TH301, HT108, TH72, HT287, TH160 and TH252 were also tolerant after drought was imposed at both the vegetative and pod filling stages.
- ii. High yielding lines were identified as follows: HT419, TH301, TH77, TH54, HT154, TH252, HT287, HT475, HT141, TH121, HT 471 for the vegetative stage drought treatment; HT372, HT108, HT141, HT475, TH121, HT471, HT540, HT287, TH80, HT120 and TH301 for the pod filling stage treatment and HT372, HT700, HT287, HT402,

TH192, HT540, TH301, HT419, TH209, TA, TAM for the vegetative and pod filling stage treatment.

Overall, drought tolerant genotypes which were high yielding as well, were identified. For the vegetative stage treatment, the genotypes HT475, and HT 471; for the pod filling stage, genotypes HT540, HT120, HT287 and TH301 and for the vegetative and pod filling treatment, genotypes TA, TH301 and HT287 respectively.

6.2 Recommendations

- i. New drought tolerance cowpea genotypes; genotypes that performed better than Danila the drought tolerant control, should be tested in the field in order to evaluate their real performance.
- ii. Drought tolerant lines should be evaluated for their tolerance to heat stress in the field or under greenhouse conditions.
- iii. Genotypes exhibiting high and stable yields should be further evaluated in the farmer's fields to validate their performance for possible release.



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Appendices

Appendix 1. Analysis of Variance for Chlorophyll content, Plant Healthiness and Stem greenness.

TRAIT	STRESS	DESCRIPTION	TIME	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
CHLOROPHYLL	NON-STRESS		0	GENOTYPE	29	585.5	20.19	0.73	
				Residual	58	1593.81	27.48		0.816
				Total	89	2484.52			
		VEGETATIVE	9	GENOTYPE	29	759.55	26.19	1.35	0.166
				Residual	58	1128.25	19.45		
				Total	89	2323.99	26.11		
	18		GENOTYPE	29	909.3	31.36	1.58	0.069	
			Residual	58	1149.76	19.82			
			Total	89	2149.42	24.15			
	POD FILLING	0		GENOTYPE	29	4550.8	156.9	0.97	0.528
				Residual	58	9420.5	162.4		
				Total	89	14428.3	162.1		
		9		GENOTYPE	29	12442.8	429.1	2.09	0.008
				Residual	58	11882.7	204.9		
				Total	89	25783.9	289.7		
	VP @PF	18		GENOTYPE	29	23188.9	799.6	3.19	<.001
				Residual	58	14544.2	250.8		
				Total	89	38848.6	436.5		
		0		GENOTYPE	29	17454.1	601.9	1.61	0.063
				Residual	58	21738.2	374.8		
				Total	89	41427.5	465.5		
	9		GENOTYPE	29	19299.4	665.5	1.94	0.016	
			Residual	58	19889.6	342.9			
			Total	89	40839.6	458.9			
STRESS	18		GENOTYPE	29	21780.2	751	1.7	0.043	
			Residual	58	25655	442.3			
			Total	89	48029.5	539.7			
	0		GENOTYPE	29	972.15	33.52	1.02	0.459	
			Residual	58	1902.06	32.79			
			Total	89	3483.97	39.15			
VEGETATIVE	9		GENOTYPE	29	909.3	31.36	1.58	0.069	
			Residual	58	1149.76	19.82			
			Total	89	2149.42	24.15			
	18		GENOTYPE	29	1668.13	57.52	1.01	0.472	
			Residual	58	3300.12	56.9			
			Total	89	5328.06	59.87			

Appendix 1. (continued) Analysis of Variance for Chlorophyll content, Plant Healthiness and Stem greenness.

TRAIT	STRES S	DESCRIPTIO N	TIM E	Source of variation	d. f	s.s.	m.s.	v.r.	F pr.	
CHLOROPHYL L	STRES S		0	GENOTYPE	29	2172.18	74.9	1.48	0.103	
				Residual	58	2941.23	50.71			
				Total	89	5125.18	57.59			
				GENOTYPE	29	5120.5	176.6	1.29	0.202	
				Residual	58	7934.2	136.8			
				Total	89	13442.1	151			
	POD FILLING		9	18	GENOTYPE	29	3167.4	109.2	0.86	0.661
					Residual	58	7338.8	126.5		
					Total	89	10856.8	122		
					GENOTYPE	29	1675.54	57.78	2.11	0.008
					Residual	58	1589.9	27.41		
					Total	89	3482.64	39.13		
	VP@VEG		9	0	GENOTYPE	29	945.26	32.6	1.43	0.125
					Residual	58	1326.67	22.87		
					Total	89	2372.51	26.66		
					GENOTYPE	30	3650.29	121.68	1.97	0.014
					Residual	57	3524.48	61.83		
					Total	89	7418.5	83.35		
	VP@PF		9	18	GENOTYPE	29	13571	468	1.39	0.141
					Residual	58	19494.9	336.1		
					Total	89	33618.6	377.7		
					GENOTYPE	29	6732	232.1	1.03	0.45
					Residual	58	13077	225.5		
					Total	89	20230.3	227.3		
			18	GENOTYPE	29	2666.8	92	0.68	0.872	
				Residual	58	7869.6	135.7			
				Total	89	10845.6	121.9			

Appendix 1. (continued) Analysis of Variance for Chlorophyll content, Plant Healthiness and Stem greenness.

TRAIT	STRESS	DESCRIPTION	TIME	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
PLANT HEALTHINESS	NONSTRESS		0	GENOTYPE	29	275.556	9.502	1.24	0.243	
				Residual	58	445.844	7.687			
				Total	89	723.556	8.13			
			VEG	9	GENOTYPE	29	275.556	9.502	1.24	0.243
					Residual	58	445.844	7.687		
					Total	89	723.556	8.13		
	18		GENOTYPE	29	186.233	6.422	0.89	0.623		
			Residual	58	417.267	7.194				
			Total	89	608.9	6.842				
	PF		0	GENOTYPE	29	9624.5	331.9	1.16	0.313	
				Residual	58	16646.4	287			
				Total	89	26544.5	298.3			
			9	GENOTYPE	29	23011.6	793.5	1.34	0.173	
				Residual	58	34464.8	594.2			
				Total	89	59613.6	669.8			
	18		GENOTYPE	29	37780.3	1302.8	1.56	0.076		
			Residual	58	48558.9	837.2				
			Total	89	87894.3	987.6				
	VP@PF		0	GENOTYPE	29	55741	1922	1.75	0.036	
				Residual	58	63830	1101			
				Total	89	124530	1399			
			9	GENOTYPE	29	47282.2	1630.4	2.15	0.006	
				Residual	58	43892.8	756.8			
				Total	89	97332.2	1093.6			
18		GENOTYPE	29	34502.8	1189.8	3.48	<.001			
		Residual	118	40383.1	342.2					
		Total	179	105594.4	589.9					
STRESS		0	GENOTYPE	29	2153.16	74.25	1.76	0.033		
			Residual	58	2443.58	42.13				
			Total	89	4697.82	52.78				
		9	GENOTYPE	29	2153.16	74.25	1.76	0.033		
			Residual	58	2443.58	42.13				
			Total	89	4697.82	52.78				
18		GENOTYPE	29	2784.89	96.03	3.92	<.001			
		Residual	58	1420.58	24.49					
		Total	89	4493.56	50.49					

Appendix 1. (continued) Analysis of Variance for Chlorophyll content, Plant Healthiness and Stem greenness.

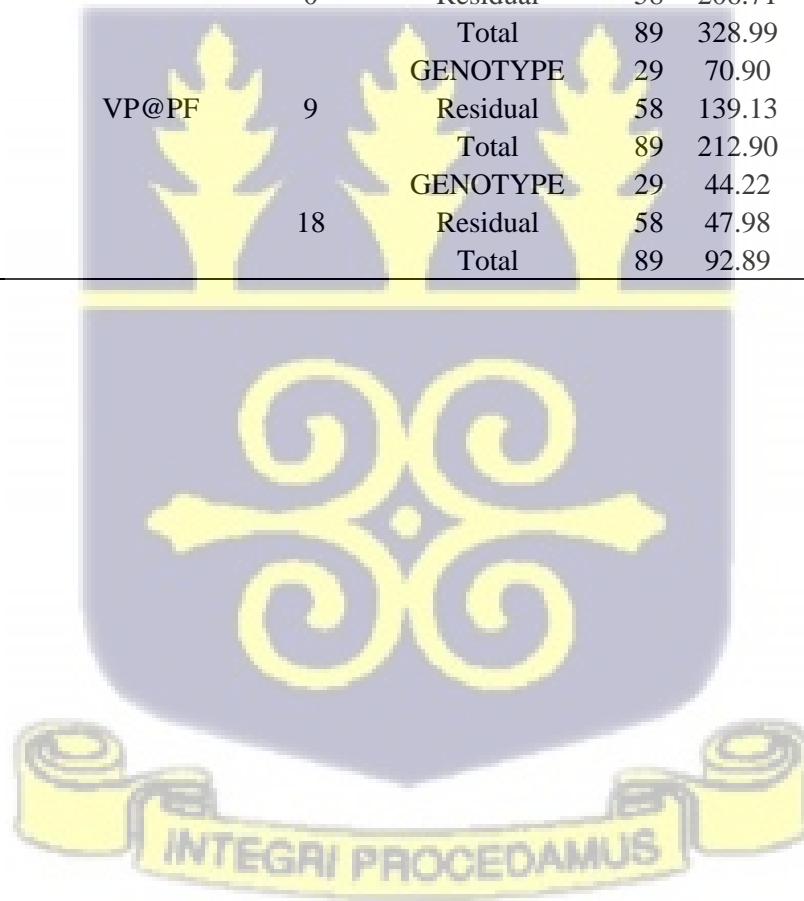
TRAIT	STRESS	DESCRIPTION	TIME	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.		
PLANT HEALTHINESS	STRESS		0	GENOTYPE	29	2931.7	101.1	0.97	0.524		
				Residual	58	6050.6	104.3				
				Total	89	9031	101.5				
			9	GENOTYPE	29	8308.1	286.5	1.41	0.131		
				Residual	58	11754.4	202.7				
				Total	89	23558.1	264.7				
			18	GENOTYPE	29	6293.4	217	1.42	0.128		
				Residual	58	8865	152.8				
				Total	89	16820.1	189				
			0	GENOTYPE	29	1393.12	48.04	1.82	0.026		
				Residual	58	1531.18	26.4				
				Total	89	3143.12	35.32				
			9	GENOTYPE	29	1393.12	48.04	1.82	0.026		
				Residual	58	1531.18	26.4				
				Total	89	3143.12	35.32				
			18	GENOTYPE	29	1839.73	63.44	5.03	<.001		
				Residual	58	731.4	12.61				
				Total	89	2574.4	28.93				
0	GENOTYPE	29	47072	1623	1.49	0.1					
	Residual	58	63384	1093							
	Total	89	112154	1260							
9	GENOTYPE	29	16243.3	560.1	1.65	0.052					
	Residual	58	19651.7	338.8							
	Total	89	36560	410.8							
18	GENOTYPE	29	6178.1	213	2.08	0.009					
	Residual	58	5942.8	102.5							
	Total	89	12194.7	137							
STEM GREENNESS	NON-STRESS		9	GENOTYPE	29	0	0	*	*		
				Residual	178	0	0				
				Total	269	0	0				
	VEG		18	GENOTYPE	29	2.26667	0.07816	1	0.486		
				Residual	58	4.53333	0.07816				
				Total	89	7.6	0.08539				

Appendix 1. (continued) Analysis of Variance for Chlorophyll content, Plant Healthiness and Stem greenness.

TRAIT	STRESS	DESCRIPTION	TIME	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.		
STEM GREE			0	GENOTYPE	29	14.89	0.51	0.77	0.78		
				Residual	58	38.64	0.67				
				Total	89	53.56	0.60				
			9	GENOTYPE	29	35.66	1.23	0.78			
				Residual	58	91.31	1.57		0.76		
				Total	89	128.32	1.44				
	18	GENOTYPE	29	99.73	3.44	1.41					
		Residual	58	141.00	2.43		0.13				
		Total	89	252.40	2.84						
	VP@PF			0	GENOTYPE	29	167.79	5.79	1.46	0.11	
					Residual	58	229.18	3.95			
					Total	89	421.12	4.73			
				9	GENOTYPE	29	164.72	5.68	1.63	0.06	
					Residual	58	202.38	3.49			
					Total	89	422.06	4.74			
	18	GENOTYPE	29	44.22	1.52	1.84	0.02				
		Residual	58	47.98	0.83						
		Total	89	92.89	1.04						
	STRESS	VEG		9	GENOTYPE	29	0.00	0.00	*	*	
					Residual	58	0.00	0.00			
					Total	89	0.00	0.00			
18				GENOTYPE	29	11.39	0.39	0.89	0.63		
				Residual	58	25.58	0.44				
				Total	89	38.06	0.43				
0		GENOTYPE	29	0.90	0.03	0.90	0.61				
		Residual	58	2.00	0.03						
		Total	89	2.90	0.03						
PF				9	GENOTYPE	29	70.99	2.45	2.23	0.01	
					Residual	58	63.58	1.10			
					Total	89	136.99	1.54			
18			9	GENOTYPE	29	47.79	1.65	1.32	0.18		
				Residual	58	72.24	1.25				
				Total	89	123.79	1.39				

Appendix 1. (*continued*) Analysis of Variance for Chlorophyll content, Plant Healthiness and Stem greenness

TRAIT	STRESS	DESCRIPTION	TIME	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
				GENOTYPE	29	0.00	*	*	
			9	Residual	58	0.00			
				Total	89	0.00			
		VP@VEG		GENOTYPE	29	33.73	1.16	1.84	0.02
			18	Residual	58	36.60	0.63		
				Total	89	72.40	0.81		
				GENOTYPE	29	116.32	4.01	1.13	0.34
			0	Residual	58	206.71	3.56		
				Total	89	328.99	3.70		
		VP@PF		GENOTYPE	29	70.90	2.45	1.02	0.46
			9	Residual	58	139.13	2.40		
				Total	89	212.90	2.39		
				GENOTYPE	29	44.22	1.52	1.84	0.02
			18	Residual	58	47.98	0.83		
				Total	89	92.89	1.04		



Appendix 2. Overall ranking of drought tolerance for 30 cowpea lines at Vegetative stage

GENOTYPE	CHLOROPHYLL	PLANT HEALTHINESS	STEM GREENNESS	TOLERANCE INDEX	RANK
HT120	26	16	29	71	1
HT108	24	26	14	64	2
HT475	19	9	29	57	3
HT471	20	21	14	55	4
TH160	25	15	14	54	5
HT372	15	19	14	48	6
DANILA	3	30	14	47	7
TH192	8	25	14	47	7
TH252	5	28	14	47	7
TH72	30	2	14	46	10
HT540	4	27	14	45	11
TH80	29	4	12	45	11
HT287	13	29	2	44	13
HT727	22	10	12	44	13
TH209	21	12	11	44	13
TH77	12	18	14	44	13
TA	16	24	1	41	17
TH261	11	20	10	41	17
HT402	6	17	14	37	19
HT700	1	22	14	37	19
HEWALE	28	6	2	36	21
TH121	17	5	14	36	21
TH131	27	7	2	36	21
HT154	10	11	14	35	24
TAM	9	23	2	34	25
TH301	2	14	14	30	26
TH124	14	13	2	29	27
TH54	23	1	2	26	28
HT419	18	3	2	23	29
HT141	7	8	2	17	30

Appendix 3. Overall ranking of drought tolerance for 30 cowpea lines at Pod filling stage

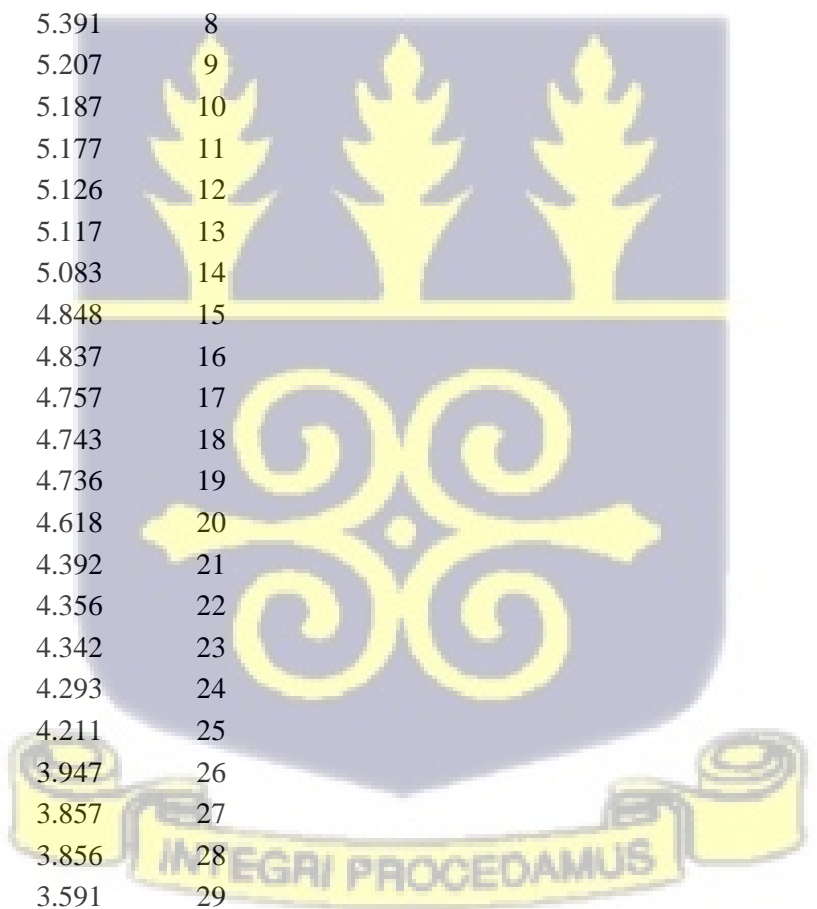
GENOTYPE	CHLOROPHYLL	PLANT HEALTHINESS	STEM GREENESS	TOLERANCE INDEX	RANK
HT540	26	24	18	68	1
TH54	26	20	18	64	2
HT120	12	23	27	62	3
HT727	5	28	29	62	4
TH209	2	30	30	62	5
TH160	9	26	24	59	6
HT419	6	27	25	58	7
HT287	16	25	14	55	8
HT154	15	18	21	54	9
TH131	17	22	15	54	10
TH261	8	19	27	54	11
HT372	1	29	23	53	12
TH192	7	21	25	53	13
TH301	26	8	17	51	14
TA	13	13	21	47	15
DANILA	19	16	6	41	16
HT402	26	9	6	41	17
TH72	18	14	9	41	18
TH252	26	10	4	40	19
TH124	21	7	11	39	20
TAM	20	5	13	38	21
HT475	2	17	18	37	22
HT700	10	6	16	32	23
TH121	11	12	9	32	24
HT141	14	11	6	31	25
HT471	24	1	5	30	26
HT108	25	3	1	29	27
TH77	23	4	1	28	28
TH80	2	15	11	28	29
HEWALE	22	2	1	25	30

Appendix 4. Overall ranking of drought tolerance for 30 cowpea lines at Vegetative& Pod filling stage.

GENOTYPE	CHLOROPHYLL	PLANT HEALTHINESS	STEM GREENESS	TOLERANCE IONDEX	RANK
TH124	18	20	27	65	1
TH80	22	16	19	57	2
TA	30	9	10	49	3
TH54	4	28	28	60	4
HT141	24	6	11	41	5
HT471	28	4	7	39	6
TH301	19	7	14	40	7
HT108	26	5	6	37	8
TH72	25	1	7	33	9
HT287	13	29	18	60	10
TH160	29	3	1	33	11
TH252	17	15	13	45	12
DANILA	27	11	2	40	13
HT120	12	19	17	48	14
HT700	14	17	15	46	15
TH121	5	25	19	49	16
HT419	16	13	12	41	17
HT540	3	27	19	49	18
TH192	11	18	16	45	19
HT727	2	14	19	35	20
HT154	20	2	5	27	21
TAM	1	21	19	41	22
TH77	23	8	2	33	23
HEWALE	15	12	9	36	24
TH131	21	10	2	33	25
HT372	6	21	19	46	26
HT402	6	21	19	46	27
HT475	6	30	19	55	28
TH209	6	21	19	46	29
TH261	6	25	19	50	30

Appendix 5. Overall ranking of seed yield for 30 cowpea lines at Vegetative stage.

GENOTYPE	VEG	RANK
HT419	6.506	1
TH301	5.95	2
TH77	5.911	3
TH54	5.727	4
HT154	5.713	5
TH252	5.573	6
HT287	5.397	7
HT475	5.391	8
HT141	5.207	9
TH121	5.187	10
HT540	5.177	11
TH72	5.126	12
HT120	5.117	13
HT471	5.083	14
DANILA	4.848	15
HT727	4.837	16
HT402	4.757	17
HT372	4.743	18
HT700	4.736	19
HT108	4.618	20
TH80	4.392	21
TH124	4.356	22
TH261	4.342	23
TH160	4.293	24
TH192	4.211	25
TH209	3.947	26
TH131	3.857	27
TAM	3.856	28
HEWALE	3.591	29
TA	2.987	30



Appendix 6. Overall ranking of seed yield for 30 cowpea lines at Pod filling stage.

GENOTYPE	PF	RANK
HT372	8.656	1
HT108	8.457	2
HT141	7.297	3
HT475	7.157	4
TH121	7.147	5
HT471	7.13	6
HT540	7.07	7
HT287	6.957	8
TH80	6.94	9
HT120	6.877	10
TH301	6.863	11
HEWALE	6.79	12
TH261	6.753	13
HT419	6.563	14
HT402	6.44	15
TH252	6.383	16
HT154	6.183	17
DANILA	6.163	18
TH54	6.117	19
TH192	6.031	20
TH124	5.863	21
TH131	5.84	22
TH160	5.68	23
TH209	5.463	24
TH72	5.401	25
TH77	5.323	26
HT727	5.15	27
HT700	5.13	28
TAM	4.374	29
TA	4.333	30

Appendix 7. Overall ranking of seed yield for 30 cowpea lines at Vegetative& Pod filling stage.

GENOTYPE	VP	RANK
HT372	8.51	1
HT700	7.853	2
HT287	6.828	3
HT402	6.55	4
TH192	6.389	5
HT540	6.319	6
TH301	6.178	7
DANILA	5.554	8
HT419	5.537	9
TH209	5.474	10
TA	5.153	11
TAM	5.153	11
HT141	4.988	13
TH160	4.973	14
TH72	4.943	15
TH80	4.905	16
TH261	4.824	17
TH54	4.674	18
TH131	4.553	19
HT471	4.517	20
TH252	4.463	21
HT154	4.453	22
TH124	4.403	23
HT475	4.23	24
HEWALE	4.149	25
HT727	3.927	26
TH77	3.823	27
TH121	3.787	28
HT120	3.757	29
HT108	3.709	30

Appendix 8. Chlorophyll content in 30 cowpea lines at different growth stages during 18days of drought.

CHLOROPHYLL CONTENT																					
GEN OTY PE	VEG						VP @ VEG			PF						VP @ PF					
	NONSTRES S			STRESS			STRESS			NONSTRES SS			STRESS			NONSTRES S			STRESS		
	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18
DANI LA	39	44	53	50	43	33	49	44	37	58	28	26	51	4.	2.	26	27.	28	29	1.2	0.
	.7	.4	.5	.1	.1	.0	.7	.3	.1	.7	.0	.3	.7	.57	.37	.1	.17	.6	.7	0	.77
	7	7	7	3	7	3	7	3	0	0	7	0	3			7		3	7		
HEW ALE	48	48	56	42	40	21	48	46	21	57	46	50	58	14	1.	36	28.	26	33	15.	11
	.4	.5	.5	.8	.2	.2	.1	.6	.4	.5	.0	.0	.0	.7	.83	.2	.87	.3	.0	30	.7
	7	0	7	7	0	7	0	3	7	0	3	3	0	0	0	7		3	0	0	0
HT10 8	41	44	56	41	40	23	42	44	36	46	40	45	48	11	0.	37	44.	26	38	5.3	1.
	.3	.9	.4	.2	.9	.0	.4	.6	.8	.7	.6	.3	.1	.5	.30	.3	.07	.4	.0	0	.47
	0	3	7	3	0	6	7	3	3	3	0	3	3	3	0	0		3	0		
HT12 0	42	46	45	44	45	18	34	45	18	43	42	51	42	19	14	43	41.	14	42	30.	7.
	.2	.3	.7	.1	.2	.0	.9	.4	.5	.0	.3	.1	.8	.0	.1	.6	.47	.6	.7	37	.03
	0	0	7	7	7	7	7	3	3	3	0	0	7	7	7	3		7	7		
HT14 1	39	35	49	39	42	27	41	42	16	37	26	22	43	4.	3.	17	14.	10	27	4.5	1.
	.7	.9	.4	.1	.0	.8	.8	.5	.1	.3	.4	.5	.2	.67	.80	.2	.70	.5	.1	0	.83
	0	7	3	0	3	7	0	3	7	3	7	0	7			0		7	7		
HT15 4	43	43	47	39	42	26	46	41	20	38	43	40	51	15	5.	41	27.	29	49	16.	7.
	.9	.4	.6	.3	.1	.3	.7	.9	.8	.0	.2	.3	.6	.6	.83	.4	.67	.3	.1	23	.97
	7	0	3	7	0	0	0	7	7	0	3	7	3	7		7		0	7		
HT28 7	43	39	48	40	40	26	38	40	28	39	28	34	47	14	4.	15	18.	19	30	23.	8.
	.3	.0	.4	.1	.0	.3	.6	.9	.8	.7	.6	.4	.6	.0	.33	.1	.07	.1	.1	00	.77
	3	0	7	3	7	3	3	0	7	7	0	0	3	0	0	3		0	7		
HT37 2	43	39	51	37	38	26	41	39	31	44	6.	1.	44	10	9.	0.	0.8	0.	46	0.9	0.
	.7	.8	.1	.4	.5	.7	.9	.6	.9	.8	.17	.30	.7	.8	.83	.80	0	.00	.3	3	.00
	7	0	0	3	7	3	7	7	3	7			0	7				7			
HT40 2	41	41	43	40	39	24	41	42	18	44	35	12	41	5.	0.	17	0.0	0.	31	7.1	0.
	.0	.8	.6	.7	.2	.6	.1	.3	.0	.0	.3	.9	.6	.57	.00	.5	0	.00	.1	3	.00
	3	3	0	3	3	0	0	0	3	0	3	0	0			3		0	3		
HT41 9	44	43	50	43	43	24	44	47	20	30	30	26	45	22	15	30	29.	33	44	15.	14
	.1	.8	.4	.2	.0	.2	.3	.5	.3	.2	.9	.9	.2	.1	.1	.2	.93	.6	.4	70	.0
	7	7	0	0	7	3	7	0	7	0	7	0	7	3	7	3		7	0		
HT47 1	42	45	58	35	44	25	43	44	22	48	40	40	48	1.	0.	46	41.	25	51	8.1	0.
	.1	.2	.1	.6	.7	.8	.5	.4	.3	.9	.4	.6	.6	.90	.50	.3	.07	.2	.4	7	.57
	3	3	3	0	7	0	7	3	7	3	0	3	3			7		7	3		
HT47 5	43	39	49	37	39	22	39	43	20	44	14	0.	50	6.	0.	0.	0.0	0.	42	4.8	3.
	.5	.9	.1	.2	.8	.9	.4	.4	.7	.1	.1	.00	.4	.79	.00	.00	0	.00	.2	3	.77
	3	0	0	0	0	3	3	7	0	7	7	0	7					3			
HT54 0	40	40	49	41	38	29	40	32	24	30	21	2.	46	0.	0.	3.	2.9	1.	40	3.6	7.
	.0	.7	.0	.8	.7	.7	.4	.1	.6	.2	.3	.53	.7	.70	.00	.93	.7	.77	.6	7	.53
	0	3	3	3	3	7	3	3	7	7	7		0					0			
HT70 0	38	41	45	35	40	29	37	40	14	46	48	46	48	16	14	40	36.	30	46	20.	13
	.7	.3	.1	.4	.4	.1	.7	.9	.8	.8	.8	.5	.1	.4	.0	.4	.13	.8	.1	.67	.8
	0	7	0	7	3	7	7	0	7	3	0	3	7	0	7	0		7	3		7
HT72 7	42	41	49	42	40	20	39	42	34	30	23	30	47	26	18	28	22.	4.	14	8.7	21
	.3	.9	.1	.9	.6	.8	.7	.2	.1	.8	.9	.2	.7	.5	.5	.5	.67	.40	.2	3	.2
	7	0	0	7	3	3	3	7	3	7	0	7	3	7	3	0		7			0

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.

Appendix 8. (Continued) Chlorophyll content in 30 cowpea lines at different growth stages during 19days of drought.

CHLOROPHYLL CONTENT																					
GEN OTY PE	VEG						VP @ VEG			PF						VP @ PF					
	NONSTRES S			STRESSS			STRESS			NONSTRES SS			STRESS			NONSTRES S			STRESS		
	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18
TA	40	43	49	43	42	25	37	39	31	43	42	42	45	28	9.	14	12	1.	2.	0.	0.
	.0	.7	.8	.7	.6	.9	.3	.9	.8	.3	.1	.3	.6	.7	30	.9	.2	97	40	00	00
	0	7	0	0	3	7	0	0	3	3	0	0	3	0	0	0	3				
TAM	42	37	45	38	32	25	33	36	27	44	44	29	31	12	2.	20	15	0.	24	25	6.
	.6	.6	.1	.1	.4	.2	.3	.4	.7	.9	.2	.3	.5	.6	50	.8	.3	77	.2	.5	20
	3	0	0	7	3	7	7	0	3	0	7	0	3	0	0	0	3		3	0	
TH12 1	46	40	51	38	43	26	29	42	19	46	46	16	37	9.	4.	29	2.	0.	25	3.	1.
	.3	.3	.9	.0	.3	.8	.4	.1	.9	.1	.1	.1	.8	90	77	.3	40	77	.7	97	77
	0	0	3	7	7	0	7	3	0	7	0	3	7			7			3		
TH12 4	41	40	55	35	44	29	37	45	27	50	28	20	50	4.	1.	27	21	14	42	17	4.
	.8	.0	.2	.9	.0	.7	.3	.2	.9	.5	.0	.6	.0	23	53	.5	.2	.4	.3	.9	90
	7	0	3	3	0	7	0	3	7	3	0	7	3			7	0	7	3	7	
TH13 1	41	35	45	37	32	17	33	37	23	46	42	40	47	16	4.	24	29	55	24	10	10
	.8	.1	.8	.7	.7	.6	.2	.5	.8	.8	.0	.1	.4	0	50	.6	.6	.4	.0	.4	.1
	0	0	0	3	7	7	3	0	7	7	0	7	7	3		3	0	3	7	0	7
TH16 0	46	45	51	38	43	20	43	43	20	42	40	42	53	19	14	41	41	41	49	0.	0.
	.8	.3	.6	.4	.4	.5	.6	.3	.3	.6	.9	.6	.4	.2	.3	.7	.1	.5	.4	93	90
	7	7	0	7	3	0	0	3	0	0	7	0	0	3	0	0	0	0	7		
TH19 2	41	39	49	46	41	28	38	41	26	37	34	33	50	15	13	30	30	14	48	14	9.
	.2	.0	.8	.6	.8	.0	.1	.4	.7	.3	.2	.3	.7	.5	.4	.4	.5	.7	.1	.8	50
	7	3	3	7	3	3	0	3	0	7	7	0	7	3	7	3	7	3	3	0	0
TH20 9	47	39	61	40	42	26	43	45	35	52	19	0.	52	4.	0.	0.	0.	0.	34	4.	0.
	.5	.9	.7	.1	.1	.7	.4	.1	.0	.1	.3	00	.2	03	50	00	00	00	.9	50	00
	3	7	7	7	3	7	0	7	7	7	3	7				7			7		
TH25 2	42	41	49	40	38	29	35	40	17	48	42	38	45	6.	0.	32	37	30	40	16	11
	.3	.6	.1	.6	.4	.8	.8	.4	.3	.8	.9	.1	.6	00	00	.4	.4	.0	.0	.9	.8
	3	3	3	7	0	0	7	0	0	3	7	0	0			7	3	7	3	3	0
TH26 1	39	37	48	39	37	26	42	41	22	41	32	44	45	28	16	0.	0.	0.	10	16	0.
	.3	.0	.2	.5	.0	.4	.1	.4	.8	.5	.9	.2	.6	.6	.3	00	00	00	.8	.1	40
	0	3	0	7	0	7	0	0	0	7	7	0	3	0	3				3	7	
TH30 1	41	38	49	39	41	30	39	38	18	42	45	47	46	13	0.	44	42	48	42	29	13
	.5	.6	.1	.5	.3	.7	.0	.9	.4	.2	.0	.1	.2	.3	00	.6	.0	.2	.0	.3	.1
	7	3	0	0	0	3	7	3	3	7	0	3	3	0		7	3	7	0	7	3
TH54	46	47	55	41	46	23	40	43	27	36	16	15	41	9.	0.	18	6.	0.	49	18	3.
	.9	.0	.3	.3	.4	.3	.5	.9	.1	.2	.4	.0	.5	80	00	.0	80	83	.9	.0	13
	7	3	7	7	7	0	3	7	0	7	7	7	3			7			0	7	
TH72	41	43	50	43	45	14	42	47	21	34	25	27	46	4.	2.	26	29	22	51	1.	2.
	.5	.0	.8	.3	.6	.7	.0	.4	.0	.8	.9	.9	.7	57	90	.3	.3	.8	.2	27	47
	3	7	0	3	7	3	0	3	7	7	3	3	3			7	0	3	0		
TH77	41	40	51	36	41	28	38	43	32	46	39	35	45	6.	0.	30	26	11	31	9.	2.
	.9	.8	.8	.0	.3	.3	.6	.2	.6	.8	.0	.9	.7	67	77	.7	.5	.7	.2	67	10
	3	3	3	7	3	3	7	0	3	0	3	7	3			3	0	3	7		
TH80	46	44	55	39	40	17	41	43	21	52	6.	0.	51	12	9.	15	14	9.	28	4.	1.
	.1	.9	.0	.2	.0	.4	.8	.5	.7	.8	63	00	.4	.0	03	.4	.1	27	.8	57	70
	7	0	0	7	0	3	0	7	0	7			3	3		7	0		3		

Appendix 9. Chlorophyll decreases at different growth stages in 30 cowpea lines during 19days of drought.

CHLOROPHYLL INFLECT INDEX (%)								
GENOTYP	VEG		PF		VP@VEG		VP@PF	
	9	18	9	18	9	18	9	18
E								
DANILA	2.92	38.34	83.72	91.00	0.31	30.74	95.58	97.32
HEWALE	17.11	62.40	68.06	96.34	3.86	62.05	47.00	55.56
HT108	8.97	59.16	71.60	99.34	0.67	34.78	87.97	94.45
HT120	2.22	60.52	54.92	72.28	1.88	59.51	26.77	52.06
HT141	-16.85	43.62	82.36	83.11	-18.24	67.29	69.39	82.66
HT154	3.00	44.78	63.75	85.55	3.29	56.18	41.34	72.81
HT287	-2.74	45.68	51.05	87.40	-4.87	40.44	-27.28	54.10
HT372	3.09	47.69	-76.18	-656.38	0.33	37.51	-16.25	0.00
HT402	6.22	43.58	84.23	100.00	-1.12	58.65	0.00	0.00
HT419	1.82	51.92	28.54	43.62	-8.27	59.58	47.54	58.42
HT471	1.02	55.62	95.30	98.77	1.77	61.52	80.11	97.76
HT475	0.25	53.30	52.08	0.00	-8.95	57.84	0.00	0.00
HT540	4.91	39.28	96.72	100.00	21.11	49.68	-23.57	-325.59
HT700	2.27	35.32	66.39	69.77	1.14	67.03	42.79	55.08
HT727	3.03	57.58	-11.17	38.77	-0.88	30.49	61.49	-381.82

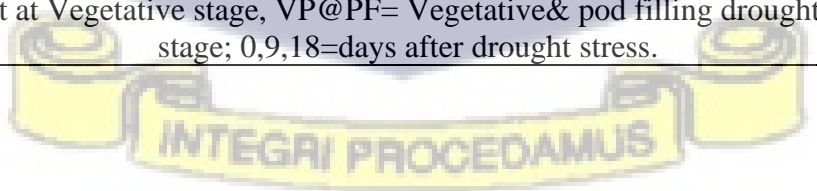
VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.



Appendix 9. (Continued) Chlorophyll decrease at different growth stages in 30 cowpea lines during 19days of drought.

CHLOROPHYLL INFLECT INDEX (%)								
GENOTYP	VEG		PF		VP@VEG		VP@PF	
	NONSTRESS & STRESS							
	9	18	9	18	9	18	9	18
E								
TA	2.60	47.85	31.83	78.01	8.84	36.08	100.00	100.00
TAM	13.75	43.97	71.54	91.47	3.19	38.51	-66.34	-705.19
TH121	-7.62	48.39	78.52	70.45	-4.54	61.68	-65.42	-129.48
TH124	-10.00	46.10	84.89	92.58	-13.08	49.36	15.24	66.14
TH131	6.64	61.42	61.83	88.80	-6.84	47.88	64.86	81.66
TH160	4.28	60.27	53.06	66.43	4.50	60.66	97.74	97.83
TH192	-7.17	43.75	54.57	59.66	-6.15	46.42	51.52	35.51
TH209	-5.40	56.66	79.15	0.00	-13.01	43.22	0.00	0.00
TH252	7.76	39.34	86.04	100.00	2.95	64.79	54.77	60.76
TH261	0.08	45.08	13.25	63.05	-11.80	52.70	0.00	0.00
TH301	-6.91	37.41	70.44	100.00	-0.78	62.46	30.12	72.79
TH54	1.19	57.92	40.50	100.00	6.51	51.06	-165.74	-277.47
TH72	-6.04	71.00	82.38	89.62	-10.12	58.52	95.67	89.19
TH77	-1.22	45.34	82.91	97.87	-5.80	37.04	63.51	82.10
TH80	10.91	68.31	-81.45	0.00	2.96	60.55	67.59	81.66

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.



Appendix 10. Overall plant healthiness of 30 cowpea lines at different growth stages during 19days of drought.

HEALTHINESS (%)																					
GEN OTY PE	VEG						VP A@VEG			PF						VP @ PF					
	NONSTRES S			STRESSS			STRESS			NONSTRES SS			STRESS			NONSTRES S			STRESS		
	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18
DANI LA	99	99	96	98	98	52	96	96	50	92	66	45	94	31	13	46	36	19	60	20	10
	.6	.6	.6	.3	.3	.3				.6	.6			.6	.3	.6	.6	.1			
	7	7	7	3	3	3				7	7			7	3	7	7	7			
HEW ALE	98	98	97	88	88	25	94	94	26	95	91	87	95	38	11	56	46	30	61	33	16
				.3	.3					.6	.6	.3	.3	.3	.6	.6	.6		.6	.33	.6
				3	3					7	7	3	3	3	7	7	7		7		7
HT10 8	98	98	97	92	92	33	88	88	29	91	76	70	91	28	10	80	68	30	80	30	11
	.6	.6			.6					.6		.3	.3		.6	.3	.8				.6
	7	7			7					7		3	3		7	3	3				7
HT12 0	97	97	98	93	93	28	86	86	24	75	63	51	81	43	23	81	68	35	89	63	28
	.3	.3		.3	.3	.6	.6	.6		.3	.6	.3	.3	.3	.3	.6	.3	.8	.3	.33	.3
	3	3		3	3	7	7	7		3	7	3	3	3	3	7	3	3	3	3	3
HT14 1	97	97	94	90	90	24	93	93	26	92	66	56	91	38	13	40	31	19	57	20	8
	.3	.3			.6	.3	.3	.3	.3	.6	.6	.6	.6	.3	.3	.6	.1	.6			.33
	3	3			7	3	3	3	3	7	7	7	7	3	3	7	7	7			
HT15 4	98	98	96	95	95	26	91	91	29	86	83	78	93	43	26	76	61	31	90	46	10
	.3	.3	.3	.3	.3	.6	.6	.6		.6	.3	.3	.3	.3	.6	.6	.6	.6		.67	
	3	3	3	3	3	7	7	7		7	3	3	3	3	7	7	7	7			
HT28 7	97	97	96	86	86	35	80	80	27	90	62	38	95	35	19	31	25	3	58	28	5
			.6	.3	.3	.3			.6	.6	.3	.6		.3		.6		.33	.3	.33	
			7	3	3	3			7	7	3	7		3		7					
HT37 2	99	99	98	93	93	29	89	89	34	96	41	35	94	46	26	10	6	3	91	23	3
				.3	.3				.6	.6	.6	.6	.6	.6	.6		.67	.33	.6	.33	.33
				3	3				7	7	7	7	7	7	7						
HT40 2	98	98	98	95	95	28	92	92	26	95	89	69	95	31	16	28	10	3	30	13	3
	.3	.3		.6	.6	.3	.3	.3		.3	.3	.3	.6		.3	.3		.33		.33	.33
	3	3		7	7	3	3	3		3	3	3	7		3	3					
HT41 9	98	98	96	94	94	23	92	92	28	67	56	45	86	48	28	63	58	40	93	31	23
	.6	.6	.6	.6	.6	.3	.3	.3	.3	.3	.6	.6	.3	.3	.3	.3	.3	.8	.3	.67	.3
	7	7	7	7	7	3	3	3	3	3	7	7	3	3	3	3	3	3	3	3	3
HT47 1	99	99	98	90	90	29	90	90	27	97	84	68	96	25	9	78	63	30	94	23	10
	.3	.3	.3	.6	.6	.6				.3	.6	.3	.3		.3	.3	.3			.33	
	3	3	3	7	7	7				3	7	3	3		3	3	3				
HT47 5	97	97	96	84	84	26	84	84	23	97	66	29	95	28	9	6	3	1	91	23	3
	.6	.6	.6		.6	.6	.3	.3	.3	.3	.6	.3	.3	.3	.33	.67	.33	.67		.33	.33
	7	7	7		7	7	3	3	3	3	3	3	3	3	3						
HT54 0	98	98	97	94	94	34	91	91	28	57	37	20	96	16	10	20	10	9	92	40	11
	.6	.6	.6	.3	.3		.3	.3	.3	.6	.6		.6				.17	.6		.6	.6
	7	7	7	3	3		3	3	3	7	7		7					.7			.7
HT70 0	98	98	96	82	82	29	91	91	26	98	93	88	93	43	18	83	78	50	90	40	31
			.3	.3	.3	.3	.6	.6	.3	.3	.3	.6	.3	.3	.3	.3	.3				.6
			3	3	3	3	7	7	3	3	3	7	3	3	3	3	3				.7
HT72 7	97	97	97	83	83	26	90	90	26	77	56	51	95	60	35	51	40	17	46	20	10
	.3	.3		.6	.6	.6			.6	.6	.6	.6	.3			.6		.5	.6		
	3	3		7	7	7			7	7	7	7	3			7					

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.

Appendix 10. (continued) Overall plant healthiness of 30 cowpea lines at different growth stages during 19days of drought.

GEN OTY PE	HEALTHINESS (%)																				
	VEG						VP @ VEG			PF						VP @ PF					
	NONSTRES S			STRESSS			STRESS			NONSTRES SS			STRESS			NONSTRES S			STRESS		
	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18
TA	96	96	96	85	85	31	83	83	27	95	83	66	96	35	16	23	16	6.	18	6.	3.
				.6	.6		.3	.3	.3	.3	.6					.3	.6	67	.3	67	33
				7	7		3	3	3	3	7					3	7		3		
TAM	98	98	97	85	85	29	85	85	28	87	80	73	79	31	15	40	26	6.	56	38	6.
				.6			.6			.3	.6	.6				.6	67	.6	.3	67	
				7			7			3	7	7	7			7			7	3	
TH12 1	99	99	97	90	90	24	86	86	28	91	70	41	71	45	10	31	10	4.	35	10	5
				.6	.3	.3	.6	.6		.3	.6	.6				.6		17			
				7	3	3	7	7	7	3	7	7	7			7					
TH12 4	97	97	97	86	86	27	86	86	27	96	70	58	97	40	13	53	46	29	88	51	28
	.6	.6		.6	.6		.3	.3	.6	.3	.3		.3	.3		.3	.6	.1	.3	.6	.3
	7	7		7	7		3	3	7	3	3		3	3		3	7	7	3	7	3
TH13 1	89	89	90	81	81	23	90	90	26	96	90	86	95	53	35	46	40	13	60	20	6.
	.3	.3	.3	.6	.6	.6	.6	.6	.6	.6	.6		.3	.3		.6		.3			67
	3	3	3	7	7	7	7	7	7	7	7		3	3		7		3			
TH16 0	98	98	96	91	91	27	89	89	26	90	78	73	94	56	41	86	58	30	95	30	10
				.3	.3	.3	.6	.6	.6	.3	.3	.6	.6	.6	.6	.6	.3	.8			
				3	3	3	7	7	7	3	3	7	7	7	7	7	3	3			
TH19 2	97	97	96	86	86	32	91	91	28	66	61	55	92	36	20	56	46	20	88	20	15
	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	.8	.6		
	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3	7		
TH20 9	97	97	96	94	94	26	94	94	25	96	36	11	95	26	10	6.	5	3.	64	18	3.
	.6	.6		.6	.3	.3	.6	.6	.6	.6	.6	.6	.3	.6		67		33	.3	.3	33
	7	7		7	3	3	7	7	7	7	7	3	7						3	3	
TH25 2	97	97	97	85	85	34	85	85	29	97	90	78	97	28	18	73	58	37	73	30	21
	.3	.3		.6	.6	.3	.3	.3		.6	.3		.3	.3		.3	.3	.5	.3		.6
	3	3		7	7	3	3	3		7	3		3	3		3	3		3		7
TH26 1	97	97	96	83	83	29	91	91	27	94	75	68	93	50	23	3.	3.	4.	25	16	5
	.6	.6	.6	.3	.3		.6	.6	.6	.6		.3	.6		.3	33	33	17		.6	
	7	7	7	3	3		7	7	7	7		3	7		3					7	
TH30 1	98	98	98	85	85	27	95	95	29	95	86	80	96	40	18	80	75	45	93	55	20
	.3	.3		.6	.6	.3			.6	.6		.6		.3							
	3	3		7	7	3			7	7		7		3							
TH54	98	98	97	90	90	22	83	83	26	96	53	36	96	41	13	33	23	18	91	48	23
	.6	.6		.6	.3	.3	.3	.3	.3	.6	.3	.6	.6	.3		.3	.3	.3	.6	.3	.3
	7	7		7	3	3	3	3	3	7	3	7	7	3		3	3	3	7	3	3
TH72	99	99	97	94	94	23	92	92	27	91	61	48	96	35	11	60	53	26	95	20	3.
	.3	.3		.6	.6	.3	.3	.3		.3	.6	.3		.6		.3	.6				33
	3	3		7	7	3	3	3		3	7	3		7		3	7				
TH77	97	97	97	88	88	28	84	84	27	97	93	90	97	38	13	55	50	27	58	23	13
	.3	.3	.3			.3			.6	.6		.6	.3	.3		.5			.3	.3	.3
	3	3	3			3			7	7		7	3	3					3	3	3
TH80	98	98	97	78	78	23	88	88	25	96	68	48	94	31	13	38	31	16	75	25	10
				.3	.3	.6			.3	.3	.3	.3	.6	.3		.3	.6	.6			
				3	3	7			3	3	3	3	7	3		3	7	7			

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.

Appendix 11. Overall healthiness changes at different growth stages in 30 cowpea lines during 19days of drought.

HEALTHINESS INFLECT (%)								
GENOTYP E	VEG		PF		VP@VEG		VP@PF	
	9	18	9	18	9	18	9	18
DANILA	1.34	45.87	52.50	70.38	3.68	48.28	45.46	47.84
HEWALE	9.87	74.23	58.19	86.64	4.08	73.20	28.58	44.43
HT108	6.76	65.29	63.05	85.71	10.81	70.10	56.10	62.15
HT120	4.11	71.43	31.58	54.85	10.95	75.51	7.32	20.93
HT141	7.53	73.76	42.51	76.48	4.11	71.99	36.85	56.55
HT154	3.05	72.31	48.00	65.95	6.77	69.90	24.32	68.42
HT287	11.00	63.45	44.15	49.57	17.53	71.38	-13.32	-50.15
HT372	5.73	70.41	-12.00	23.80	10.10	64.62	-249.78	0.00
HT402	2.71	71.09	64.42	76.92	6.10	73.47	-33.30	0.00
HT419	4.05	75.87	14.72	37.04	6.43	70.69	45.71	42.86
HT471	8.72	69.83	70.47	86.83	9.39	72.54	63.16	66.67
HT475	14.00	73.10	57.51	68.19	13.31	75.87	-600.60	-99.40
HT540	4.40	65.19	55.75	50.00	7.44	70.99	-300.00	-27.26
HT700	15.99	69.55	53.57	79.25	6.46	72.67	48.93	36.66
HT727	14.03	72.51	-5.88	32.26	7.53	72.51	50.00	42.86

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.



Appendix 11. (continued) Overall healthiness changes at different growth stages in 30 cowpea lines during 19 days of drought.

HEALTHINESS INFLECT (%)								
GENOTYP E	VEG		PF		VP@VEG		VP@PF	
	9	18	9	18	9	18	9	18
TA	10.76	67.71	58.00	76.00	13.20	71.53	59.99	50.07
TAM	13.27	69.41	60.41	79.54	13.27	70.44	-43.72	0.00
TH121	8.76	74.74	35.71	76.00	12.45	71.33	0.00	-19.90
TH124	11.26	72.16	42.86	77.15	11.61	71.47	-10.71	2.88
TH131	8.57	73.80	41.18	59.30	-0.75	70.47	50.00	49.96
TH160	6.81	71.53	27.65	43.17	8.50	72.22	48.57	67.56
TH192	11.95	66.20	40.54	63.64	6.14	70.34	57.15	27.99
TH209	3.76	72.22	27.27	14.31	3.42	73.96	-266.60	0.00
TH252	11.98	64.61	68.52	76.60	12.33	70.10	48.57	42.21
TH261	14.68	70.00	33.33	65.86	6.14	71.38	-400.60	-19.90
TH301	12.88	72.11	53.85	77.09	3.39	69.72	26.67	55.56
TH54	8.79	76.63	21.86	63.65	15.55	72.86	-107.16	-27.28
TH72	4.69	75.95	43.25	75.85	7.05	72.16	62.50	87.51
TH77	9.59	70.89	59.08	85.19	13.70	71.57	53.34	51.53
TH80	20.07	75.60	53.65	72.42	10.20	73.89	21.06	40.01

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.



Appendix 12. Overall Stem Greenness of 30 cowpea lines at different growth stages during 19days of drought.

STEM GREENNESS (%)																					
GENO TYPE	VEG						VP A@VEG			PF				VP @ PF							
	NONSTRES S			STRESSS			STRESS			NONSTRES SS		STRESS		NONSTRES S			STRESS				
	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18
DANIL A	5.0	5.0	5.0	5.0	5.0	3.0	5.0	5.0	2.0	5.0	3.0	3.0	5.0	1.0	0.0	3.0	3.0	3.0	3.0	1.0	0.0
HEWA LE	5.0	5.0	5.0	5.0	4.0	2.0	5.0	3.0	1.0	5.0	5.0	5.0	5.0	0.0	0.0	3.0	3.0	3.0	3.0	2.0	1.0
HT108	5.0	5.0	5.0	5.0	5.0	3.0	5.0	4.0	3.0	5.0	4.0	5.0	5.0	3.0	0.0	4.0	4.0	4.0	4.0	1.0	1.0
HT120	5.0	5.0	5.0	5.0	4.0	3.0	5.0	3.0	2.0	5.0	4.0	4.0	5.0	4.0	0.0	5.0	4.0	3.0	5.0	3.6	2.0
HT141	5.0	5.0	5.0	5.0	4.0	2.0	5.0	3.0	1.0	4.0	3.0	3.0	5.0	2.0	0.0	3.0	2.0	2.0	2.0	1.0	0.0
HT154	5.0	5.0	5.0	5.0	5.0	3.0	5.0	4.0	3.0	5.0	5.0	5.0	5.0	4.0	3.0	5.0	5.0	4.0	5.0	3.0	1.0
HT287	5.0	5.0	5.0	5.0	4.0	2.0	5.0	3.0	2.0	5.0	5.0	5.0	5.0	4.0	3.0	1.0	1.0	1.0	3.0	2.3	1.0
HT372	5.0	5.0	5.0	5.0	5.0	3.0	5.0	4.0	3.0	3.0	3.0	2.0	4.0	3.0	3.0	1.0	1.0	0.0	4.0	2.0	0.0
HT402	5.0	5.0	5.0	5.0	5.0	3.0	5.0	3.0	2.0	5.0	5.0	5.0	5.0	4.0	0.0	1.0	1.0	0.0	1.0	1.3	0.0
HT419	5.0	5.0	5.0	5.0	4.0	2.0	5.0	4.0	3.0	3.0	3.0	3.0	5.0	4.0	3.0	3.0	3.0	3.0	4.0	2.6	1.0
HT471	5.0	5.0	5.0	5.0	5.0	3.0	5.0	3.0	3.0	5.0	5.0	5.0	5.0	4.0	0.0	5.0	4.0	3.0	5.0	2.3	1.0
HT475	5.0	5.0	5.0	5.0	5.0	3.0	5.0	4.0	3.0	5.0	5.0	5.0	5.0	4.0	0.0	0.0	0.0	6.0	0.0	3.0	0.0
HT540	5.0	5.0	5.0	5.0	5.0	3.0	5.0	4.0	3.0	4.0	5.0	2.0	5.0	0.0	0.0	1.0	0.0	0.0	5.0	1.3	0.0
HT700	5.0	5.0	5.0	5.0	5.0	3.0	5.0	4.0	3.0	5.0	5.0	5.0	5.0	4.0	0.0	3.0	2.0	0.0	5.0	3.0	0.0
HT727	5.0	5.0	5.0	5.0	4.0	2.0	5.0	4.0	2.0	4.0	3.0	3.0	5.0	4.0	0.0	3.0	2.0	0.0	3.0	1.6	0.0

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.

Table 6. (continued) Overall Stem Greenness of 30 cowpea lines at different growth stages during 19days of drought.

STEM GREENNESS (%)																					
GENO TYPE	VEG						VP A@VEG			PF						VP @ PF					
	NONSTRES S			STRESSS			STRESS			NONSTRES SS			STRESS			NONSTRES S		STRESS			
	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18	0	9	18
TA	5.0	5.0	5.00	5.0	4.0	1.67	5.0	3.0	0.67	5.0	5.0	5.00	5.0	4.0	2.33	1.67	1.67	1.00	1.67	1.67	0.67
TAM	5.0	5.0	5.00	5.0	4.0	2.33	5.0	4.0	2.33	5.0	5.0	5.00	5.0	5.0	3.67	3.00	2.00	0.33	3.00	2.33	0.33
TH121	5.0	5.0	5.00	5.0	5.0	3.00	5.0	4.0	3.00	4.0	4.0	3.67	3.0	5.0	4.00	3.0	0.0	0.00	3.0	1.67	0.67
TH124	5.0	5.0	5.00	5.0	4.0	2.33	5.0	3.0	2.00	5.0	5.0	3.00	5.0	5.0	1.00	3.00	2.00	2.00	4.00	3.33	2.00
TH131	5.0	5.0	5.00	5.0	4.0	2.33	5.0	3.0	2.33	5.0	5.0	4.00	5.0	5.0	1.00	3.00	3.00	3.00	3.00	1.67	0.67
TH160	5.0	5.0	5.00	5.0	5.0	3.00	5.0	4.0	3.00	4.0	5.0	5.00	4.0	4.0	3.00	4.00	3.00	5.00	5.00	1.33	0.67
TH192	5.0	5.0	5.00	5.0	5.0	3.00	5.0	3.0	2.67	3.0	3.0	3.67	5.0	4.0	2.00	3.00	3.00	2.00	5.00	1.67	1.00
TH209	5.0	5.0	4.33	5.0	4.0	2.33	5.0	4.0	2.33	5.0	5.0	1.00	5.0	5.0	1.00	0.00	0.00	0.00	3.00	1.00	0.67
TH252	5.0	5.0	5.00	5.0	4.0	3.00	5.0	4.0	3.00	5.0	5.0	4.00	5.0	3.0	1.00	4.00	4.00	4.00	5.00	2.00	2.00
TH261	5.0	5.0	5.00	5.0	4.0	2.67	5.0	3.0	1.67	5.0	5.0	4.00	5.0	5.0	3.00	0.00	0.00	0.00	1.00	1.33	0.67
TH301	5.0	5.0	5.00	5.0	5.0	3.00	5.0	4.0	3.00	5.0	5.0	4.00	5.0	4.0	2.00	4.00	3.00	5.00	5.00	4.00	2.00
TH54	5.0	5.0	5.00	5.0	4.0	2.33	5.0	4.0	2.67	4.0	4.0	2.33	5.0	4.0	1.00	2.00	2.00	1.00	5.00	3.00	2.00
TH72	5.0	5.0	5.00	5.0	5.0	3.00	5.0	5.0	3.00	4.0	4.0	3.00	4.0	3.0	1.00	3.00	3.00	3.00	5.00	2.00	1.00
TH77	5.0	5.0	5.00	5.0	5.0	3.00	5.0	5.0	3.00	5.0	5.0	5.00	5.0	5.0	1.00	3.00	3.00	3.00	3.00	1.33	0.67
TH80	5.0	5.0	4.67	5.0	4.0	2.67	5.0	4.0	3.00	5.0	5.0	3.00	5.0	5.0	1.00	2.00	2.00	1.00	5.00	1.67	1.00

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.

Appendix 13. Greenness Increase at different growth stages in 30 cowpea lines during 19day of drought.

GREENNESS INFLECT (%)								
GENOTYP E	VEG		PF		VP@VEG		VP@PF	
	9	18	9	18	9	18	9	18
DANILA	0.00	40.00	54.54	72.73	0.00	46.66	70.00	79.99
HEWALE	20.00	53.34	0.00	80.00	37.60	73.34	39.99	70.00
HT108	0.00	40.00	21.43	80.00	11.20	40.00	78.57	76.92
HT120	20.00	35.72	7.16	35.72	20.80	50.01	15.37	36.38
HT141	20.00	53.34	36.38	72.73	39.60	73.34	50.00	66.65
HT154	0.00	40.00	20.00	53.34	20.00	40.00	40.00	78.57
HT287	20.00	53.34	6.66	63.65	22.40	53.34	-39.95	20.04
HT372	0.00	40.00	18.19	42.86	15.40	40.00	-100.00	0.00
HT402	0.00	40.00	0.00	72.73	30.60	60.00	20.04	0.00
HT419	20.00	53.34	-27.27	36.38	13.80	40.00	19.98	54.54
HT471	0.00	40.00	0.00	76.92	39.60	40.00	41.68	72.73
HT475	0.00	35.72	0.00	57.14	6.60	35.72	-99.85	0.00
HT540	0.00	40.00	22.23	57.14	12.20	40.00	-50.00	0.00
HT700	0.00	40.00	0.00	60.00	4.00	40.00	26.66	46.66
HT727	20.00	42.85	-27.27	18.19	20.00	50.01	37.50	0.00

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.



Appendix 13. (continued) Greenness Increase at different growth stages in 30 cowpea lines during 19day of drought.

GREENNESS INFLECT (%)								
GENOTYP E	VEG		PF		VP@VEG		VP@PF	
	NONSTRESS & STRESS							
	9	18	9	18	9	18	9	18
TA	20.00	66.66	20.00	53.34	27.00	86.66	59.99	66.70
TAM	20.00	53.34	26.66	66.66	20.00	53.34	-16.65	0.00
TH121	0.00	40.00	7.16	70.00	20.00	40.00	-149.93	0.00
TH124	20.00	53.34	0.00	66.67	29.40	60.00	-24.97	-33.35
TH131	20.00	53.34	0.00	61.53	20.60	53.34	49.98	79.99
TH160	0.00	40.00	13.34	40.00	20.00	40.00	55.57	86.66
TH192	0.00	40.00	-20.01	36.38	20.80	46.66	54.54	37.50
TH209	20.00	46.16	0.00	-33.30	20.00	46.16	-49.93	0.00
TH252	20.00	40.00	26.66	78.57	16.00	40.00	57.15	53.84
TH261	20.00	46.66	0.00	35.72	36.60	66.66	0.00	0.00
TH301	0.00	40.00	20.00	57.15	4.80	40.00	-20.01	53.34
TH54	20.00	53.34	-16.68	57.14	18.40	46.66	-28.59	-100.00
TH72	0.00	40.00	8.33	70.00	0.00	40.00	45.46	72.73
TH77	0.00	40.00	0.00	80.00	0.00	40.00	60.01	79.99
TH80	20.00	42.85	0.00	66.67	20.00	35.72	16.65	0.00

VEG= vegetative stage drought, PF=Pod filling stage drought, VP@VEG=Vegetative and pod filling drought at Vegetative stage, VP@PF= Vegetative& pod filling drought at pod filling stage; 0,9,18=days after drought stress.



Cowpea Genotypes



Hewale (High Yield)

Tam (Drought Tolerant)

