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Impact of Drought Stress on Yield and Nutritional Quality of Groundnut (*Arachis hypogaea* L.)

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Abstract

Changes in the global climate pose a danger to plant growth and production and have a significant direct and indirect impact on the quantity and quality of plant nutrients. Combined with the rise in abiotic stresses, notably drought, developing nations are in urgent need of solutions that will maintain the production and nutritive value of their food crops. An essential food and oil crop for the world, groundnut supports agriculturally based livelihood methods that ensure food, nutrition, and financial security. Groundnut is an energy-dense food item and it contains a substantial amount of fat, proteins, and carbohydrates both fat soluble and water soluble vitamins, fibers, polyphenols, antioxidants, vitamins, and minerals. Due to the high nutrient contents of peanuts, they have been used to combat malnutrition in most developing countries.India is the second largest producer of groundnuts in the world, and the crop's primary usage is for its oil. Peanuts are consumed in many forms such as boiled peanuts, peanut oil, peanut butter, roasted peanuts, and added peanut meal in snack food, energy bars, and candies.Drought causes substantial yield losses to groundnut production and adversely impacts nutritional quality. Increased aflatoxin levels in groundnuts during field production are caused, in part, by drought stress, which limits the use of peanuts as healthy food and has a negative influence on the peanut trade.Therefore, maintaining groundnut nutritional quality under drought stress may present a great opportunity to supply enough human food and animal feed. This article focuses on the impact of drought stress on the nutritional value of groundnuts and provides an overview of the nutritional chemistry of groundnut components in relation to health benefits.

Keywords: Groundnut; Drought stress; Seed chemistry; Oil content; Nutritionalquality; Yield

1. Introduction

There is a shred of major evidence that the environment on our planet is changing as a result of human activity at a rate that endangers human health by disrupting the functioning of global systems. Increased incidences of abiotic and biotic stresses are expected to become even

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more prevalent in the future decades, causing fundamental reductions in the growth and quality of crop plants. According to predictions made by the Intergovernmental Panel on Climate Change, the average global temperature might rise by 1.4 to 5.8°C by the year 2100 (IPC, 2001). This exceptional rise in temperature is linked to negative effects on the global water cycle, which have an impact on the dynamics of ecosystems, sea level, food output, and other related processes, consequently putting a wretch on global food supply systems and nutrition of human population (Gurditta and Singh, 2016).Contrarily, the demand for food has grown tremendously in the past decades and is expected to further escalate as the population reaches 9.7 billion in 2050 (DeSA, 2015) from the present 7.6 billion. Therefore, one of the largest problems the current and future generations are confronted with is the need to meet the food demands quantitatively and qualitatively. Despite efforts to increase global food availability, a key requirement for food and nutrition security, the global burden of malnutrition and micronutrient deficiencies remain alarming and closely linked to climate change, particularly in low-income communities. Previous attempts to alleviate food and nutrition insecurity were biased towards grains and tubers, which unintentionally resulted in protein and other micronutrient shortages among the population in the world's arid and semi-arid tropics (Chibarabada*et al*., 2017).In order to improve the diets of rural households with limited resources, it is necessary to include inexpensive, nutrient-dense foods. In the diets of humans, legumes such as groundnut are significant sources of nutrients and are associated with positive health benefits.

Groundnut (*Arachis hypogaea* L.) also known as peanut from the family of legumes, is one of the principal economic crops of the world ranking 13th among the food crops and 4th most important oil seed crop of the world.They are believed to have originated in the Central American region from where they spread to other parts of the world. The species of this genus are diverse in habitat, including grasslands, open patches of forest, and temporarily flooded areas. Based on its morphology and sexual compatibilities, the genus has been subdivided into 80 species and 9 infrageneric taxonomic sections. There are many different peanut cultivars available, however, four major types (Runner, Virginia, Spanish and Valencia) have been accepted by the market due to flavor, oil content, size, shape, and disease resistance. Global peanut production is nearly 45 million tonnes from the 27.7 million ha of agricultural lands with China leads in the production of peanuts, having a share of about 45 % of overall world production, whereas India has a (16 %) share and the United States of America has (5 %) (Rachaputi*et al*., 2021).

Groundnut is widely grown under energy-starved conditions across continents in semi-arid tropics, where frequent drought is one of the limiting factors adversely affecting its productivity and deterioration in peanut quality worldwideWhile India has the largest area under groundnut (6.36 million ha) in the world, its production (6.5 million tons) and productivity (1,022 kgha^{-1}) have remained low; the latter being well below the world average (Birthal*et al*. 2010), because 80% of the crop is grown under rainfed conditions. The yield of groundnut is influenced by the availability of soil moisture during vegetative and reproductive stages and crop experiencing drought during the reproductive phase shows significant yield reductions (Singh, 2011). Drought stress has an adverse influence on water relations, biochemical and physiological processes, growth and yield of groundnut (Reddy *et al.*, 2003;2015a Madhusudhan and Sudhakar, 2002, 2014a, 2014c,2015a, 2022). Drought has adverse effects on the seed chemistry leading to a loss of nutritional quality (Chakraborty *et al*., 2013). Drought impairs the defense mechanism of the plant and favors the production of aflatoxin by the fungus which poses a serious threat to human health (Jeyaramraja*et al*., 2018).Although there are only a few papers on the influence of drought stress on the yield and kernel quality of groundnut (Diwedi*et al*., 1996; Kandoliya*et al*., 2015; Chakraborty *et al*., 2016), there is a lack of sufficient information on its impact on the effect of water deficit on seed nutritional chemistry. Hence, this review highlights the nutritional chemistry of groundnuts with a special focus on the impact of drought stress on nutritional quality in relation to health benefits.

2. NutritionalProfile of groundnut

Groundnut is a rich source of dietary protein with the ability to meet up to 46% of the recommended daily allowance; essential vitamins especially E, energy from its oils and fats, and dietary fiber. It is also a rich source of minerals such as K, Na, Ca, Mn, Fe, and Zn among others and a rich source of biologically active compounds (arginine, resveratrol, phytosterols, and flavonoids). The WHO encourages the consumption of groundnut-based "ready-to-use therapeutic foods" (RUTF) for community-based treatment of severe malnutrition. Apart from oil, peanuts are widely used for the production of peanut butter, confections, roasted peanuts, snack products, extenders in meat product formulation, soups and desserts. Groundnut

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consumption is reported to be associated with several health benefits for human beingsand its oil cake can be used as organic manure or animal feed.

2.1 Proximate compositionof groundnut

Groundnuts are a rich source of nutrients and are consumed all over the world in a wide variety of forms,most of which are traditional cuisine. The nutritional values associated with peanuts can vary among peanut varieties and processing techniques. The proximate composition of groundnut seeds (raw, sundried and roasted) was reported to contain moisture content of 7.40%, 3.40%, 1.07%; ash content of 1.48%,1.38%, 1.41%; Crude protein of 24.70%, 21.80%, 18.40%; Crude fat of 46.10%, 43.80%, 40.60%; Crude fiber of 2.83%, 2.43%, 2.41%; Carbohydrate of 17.41%,27.19%, 36.11%; respectively (Ayoola*et al*., 2012). The recently reported proximate composition of different varieties of Indian raw groundnut in the range of extracted oil, moisture, crude protein, total ash, crude fat, crude fiber, carbohydrate and calories per 100gmswas 39.45-41.48 %, 1.68-2.48 %, 28.75-30.63 %, 1.39-2.02 %, 28.68-30.15 %, 1.69-2.32 %, 33.77-36.29% and 520.8-526.43 respectively (Shashikant, 2019).The presence of high-fatcontent makes it a suitable source of nutrients that can improve the energy density of man and animals. The protein in groundnut seeds contributes to the growth and repair of worn-out tissues,and will also improve the nutrition of humans and animals. The low moisture content of groundnut is beneficial with respect to storability and shelf life. The crude fibre is not high enough but can aid digestibility in humans (Ayoola*et al*., 2012).

2.2. Oil and fatty acid compositionof groundnut

The chemical and physical properties of fats and oils are mainly determined by the fatty acid profile of the oil and their position within the triacylglycerol molecule. Peanut oil is a non-drying oil, which does not harden when exposed to air and solidifies from 0 to 3^0C. In peanut seed oil, two unsaturated fatty acids (UFA), oleic acid (C18:1, Δ9), a mono UFA (MUFA) and linoleic acid (C18:2, Δ9, Δ12), a poly UFA (PUFA) contribute around 80% of the total oil composition. Further, a saturated fatty acid (SFA), palmitic acid contributing to about 10%, whereas, rest 10% is constituted of up to 9 other fatty acids (Janila*et al*., 2016).Thus, the flavor, shelf-life, and nutritional quality of peanut seeds and its products are reliant on the proportion of three main fatty acids viz., oleic, linoleic and palmitic acid present in its oil (Derbyshire, 2014). Normally Steric (C18:0), Arachidic (C20:0), Eicosenoic (C20:1), Behenic (C22:0), and Lignoceric (C24:0) acids occur in minor proportions, while trace levels of linolenic (C18:3) can

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also be present (Carrin and Carelli, 2010). The fatty acid composition of groundnut oil varies depending on the genotype, seed maturity, climatic conditions, growth location, and interactions between these factors (Andersen and Gorbet, 2002). In groundnut as seeds progressed from intermediate through nearly mature to mature stages, palmitic and linoleic acid decreased while oleic acid increased (Casini*et al*., 2003). Most of the fatty acids present in peanut oil are present as triacylglycerols (TAG) at approximately 93.3 to 95.8% of weightand are dependent upon seed maturation and increase incrementally until full maturation(Toomer, 2018). The palmitic acid is reported to increase the risk for multiple life-threatening diseases such as cardio-vascular diseases (CVD) and atrial-fibrillation (Wang *et al*., 2015).Oleic acid reduces systolic blood pressure, which decreases the risk of cardiovascular disease (Teres *et al*., 2008) An oleic acid-rich diet also helps reduce the level of blood glucose and increases the high-density lipoprotein (HDL) to low-density lipoprotein (LDL) ratio, which also has health benefits (Vassiliou*et al*., 2009). As a result, peanut seeds with a higher level of oleic acid are more popular with consumers; the development of new varieties that contain high levels of oleic acid is therefore important (Li *et al*., 2022). Regular consumption of peanuts can provide sufficient poly unsaturated fatty acids (PUFA) and mono unsaturated fatty acids (MUFA) to protect against CVD, some types of cancer and age-related cognitive decline (Bonku and You 2020).

2.3.Protein and amino acid composition of groundnut

Like other grain legumes, the nutritive value of peanut proteins is also a function of its protein content, amino acid composition, and protein digestibility. As reported above, the protein content of peanuts ranges between 24 to 30 % showing a large variation that is greatly influenced by genotypes and environments. The peanut seed contains 32 different proteins comprised of albumins and globulins. The seed storage proteins are mainly composed of arachin (legumin), conarachin (vicilin). To date, 17 peanut proteins (Ara h 1 through Ara h 17) have been identified as peanut allergens responsible for peanut allergy by the World Health Organization and the International Union of Immunological Societies (WHO/IUIS, 2017). Although the amino acid composition of peanuts varies greatly with variety and plant location, peanuts contain all 20 amino acids in variable proportions and is the richest source of “arginine”(Young, 1980, Batal., 2005). The common limiting amino acids of peanuts are sulfur-containing amino acids such as methionine and cysteine (Young, 1980). However, these can be complemented by consuming peanut products together with cereal grains because the proteins in cereal grains are rich in

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methionine and cysteine.According to the Protein Digestibility Corrected Amino Acid Score (PDCAAS) peanut proteins and other legume proteins such as soy proteins are nutritionally equivalent to meat and eggs for human growth and health (FAO 2002). The peanut proteins have been found to have good emulsifying activity, emulsifying stability, foaming capacity, excellent water retention and high solubility, and can also provide a new high protein food ingredient product formulation and protein formulation in the food industry (Wu *et al*. 2009). Although groundnut proteins are often recognized as incomplete proteins (i.e., do not contain all essential amino acids) when compared to animal proteins, their consumption is strongly associated with cardiovascular health (Hertzler*et al*., 2020). Moreover, large quantities of arginine in all groundnut nuts have positive effects on immune response, inflammation, and cardiovascular function, including its key role in reducing the risk of cardiovascular disease and reproductive performance (Arya *et al*., 2016).

2.4.Carbohydrate composition of groundnut

The major carbohydrate present in peanuts is starch which is a homopolysaccharide made up of α-D glucose residues joined together by glycosidic bonds. However, peanut research has demonstrated that peanut carbohydrate content is dependent upon cultivar, maturation, and geographic location (Pattee and Young, 1982) and may contain the following carbohydrates in varying quantities (major to minor): sucrose, fructose, glucose, inositol, raffinose, stachyose. Defatted peanut flour has been shown to contain approximately 38% total carbohydrates of which account for oligosaccharides 18%, starch, 12.5%, hemicellulose A 0.5%, hemicellulose B 3.5%, and cellulose (fiber) 4.5% and of the oligosaccharide fraction, approximately 13.90% sucrose, 0.89% raffinose, 1.56% stachyose, and 0.41% verbascose in unprocessed peanut flour (Tharanathan*et al*., 1975). Pattee*et al*. (1995) found that groundnut varieties with high sweet taste intensities had high free sugar content compared to those varieties with lower intensities and free soluble sugars have also been associated with the flavor of groundnut.

2.5.Micronutrientcomposition of groundnut

Peanuts have a broad range of vitamins and minerals in detectable quantities. When considering recommended daily nutritional values, minerals such as copper, manganese, calcium, phosphorus, magnesium, zinc, and iron as well as vitamins such as vitamin E, thiamin, niacin, and folate highlight the role of peanuts in a well-balanced diet. Additionally, some of the highest proportions of manganese (a cofactor for enzymes), folate (which helps maintain and produce

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cells), and niacin (which assists the digestive system, skin, and nerves) are found in peanuts. Other compounds identified in peanuts include arginine, phytosterols, flavonoids, and resveratrol (American Peanut Council, 2010). Resveratrol, found in the skin and cotyledon of peanuts, is touted as a "life-extending" compound (Jang *et al.*, 1997) that can protect against many prominent cardiovascular and neurodegenerative diseases (Das & Das, 2007).

3. Impact ofdroughtstress on yield and yield attributes of groundnut

Groundnut is an important crop of the semi-arid tropics where potential yields are frequently reduced by water stress. Several stages in the groundnut's life cycle have been reported to result in reduced pod yields; intense flowering; full pegging and pod development; pod formation; early vegetative and late pod setting stageand peak flowering to early fruiting (Reddy *et al.*, 2003; Singh *et al.*, 2014). During these stages, if stress is given and later on water supply is resumed only the vegetative growth is benefited not the reproductive growth of the crop. Thus, the period of maximum sensitivity to drought occurs between 50-80 DAS, the period of maximum flowering and vegetative growth (Singh *et al.*, 2013; Rachaputi*et al.*, 2021). Moisture deficit stress reduces pod yield primarily by shortening the pod development stage (Singh 2011). Pod and seed development in groundnut are progressively inhibited by drought due to insufficient water availability inside the plant tissues and hindered supply of assimilates and these stages are delayed by lack of sufficient soil moisture in the pod zone (Boote and Ketring 1990). Reduction in seed yield was associated with reduction in seed size and number of seeds per plant under moisture deficit stress in groundnut (Vorasoot*et al.*, 2003). Meisner and Karnok (1992) reported 30 % reduction in pod yield due to moisture deficit at pod development stage. The number of pods per plant can be low due to increases in soil resistance caused by prolonged drought (Sharma and Sivakumar 1991), and reduces pod yield primarily by decreasing the duration of the pod development phase (Stirling and Black, 1991).Water stress at the pod filling stage reduced kernel yield and nitrogen partitioning to reproductive parts.The decrease in pod and fodder yieldswas attributed to limited moisture availability during the entire growth phases of the plant which resulted in poor total biological yield (Chakraborty *et al.*, 2013). In spanish groundnut cultivars subjected to soil moisture stress at different crop growth stages, moisture stress during the early vegetative phase resulted in an increase of 100-seed weight and seedling vigour index but stress at the pod initiation/ development stage reduced germinability, vigour, seed membrane integrity and embryo RNA content (Singh *et al.*, 2013). Stress during pod development was most detrimental to all physiological and biochemical processes studied (Nautiyal*et al*. 1991). Among the different habit groups Virginia Runner (CSMG 84-1 and GG 11) showed the highest reduction, followed by Spanish Bunch (JL 286 and TPG 41) and the least reduction in cultivars of Virginia Bunch (HNG 10 and GG 20) group due to moisture deficit stress (Chakraborty *et al*., 2013).The majority of reports reveal that the pod development stage is the most sensitive to moisture stress during which the demand of photosynthetic products for active sinks (pods) is higher (Vakharia*etal*.,1997).

4. Impact of drought stress on the nutritionalprofileof groundnut

The chemical composition of groundnut seed is influenced by availability of soil moisture during growth stages and also duration of crop growth period as all these are inter-related with one way or other (Sanders, 1980). Nutritional quality of the groundnut seed is strongly influenced by production location, cultivar and season, particularly soil moisture and temperature during crop growth and seed maturation (Dwivedi *et al*., 1993).

4.1. Impact of drought stress on oil and fatty acid composition of groundnut

Over 60% of global groundnut production is crushed for extraction of oil for edible and industrial uses, while 40% is consumed in food uses and as seed for sowing the next season crop (Baldani et al., 2000; Birthal*et al*., 2010). Total oil content was not affected by early-season drought (Yao *et al*.,1982; Conkerton*et al*., 1989; Bhalani and Parameswaran, 1992), but declined (by up to 3%) under mid-season (50-80 DAS) drought (Conkerton*et al*., 1989). For late-season drought (110-140 DAS), different studies have reported no effect (Conkerton*et al*., 1989; Musingo*et al*., 1989) and a decline (Yao *et al*., 1982; Bhalani and Parameswaran, 1992) in total oil content. The results from the experiments conducted by Rasve*et al* (1983) revealed that the application of 540mm water with a 10 days irrigation interval proved most beneficial in increasing the oil % (to 50.39) when groundnut crop was grown in summer season.Sarma (1983) observed that the imposition of early moisture stress on peanut (moisture stress imposed from emergence to peg initiation) increased the seed quality in terms of oil and protein content and also observed that when moisture stress was imposed from flowering to the end of pod set this resulted in decreased oil but improved protein content. A high O/L ratio and low iodine value (IV) value generally indicate good stability and long shelf-life. The composition of saturated (palmitic and stearic) and unsaturated (oleic and linoleic) fatty acidswas altered significantly in groundnut cultivars due to moisture deficit stress (Chakraborty *et al*., 2013). 'Florunner' stressed

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for 30 days at seed maturation (80 DAS) had a higher percentage of palmitic and linoleic acids, lower percentage of stearic, oleic and eicosenoic acids, higher IV and alpha-tocopherol and lower O/L ratio than nonstressedFlorunner (Singh *et al*., 2014). A similar 30-day stress during the pre-flowering (20 DAS) and pod formation (50 DAS) increased behenic and lignoceric acids and decreased IV and gamma-tocopherol (Diwedi*et al*., 1996). While pre-flowering stress increased O/L ratio, stress at pod formation increased alpha-tocopherol compared to the stress at seed maturation. Regardless of the timing of drought, with increasing seed grades, arachidic acid, behenic acid, lignoceric acid, eicosenoic acid, O/L ratio and alpha-tocopherol decreased significantly (Hashim *et al*., 1993). However, Bhalani and Parameswaran (1992) did not find any major changes in the fatty acid composition, except for oleic acid which increased due to differential irrigation regimes in a summer irrigated crop. Mid-season drought had no significant effect on the content of oil, protein and fatty acids other than eicosenoic fatty acid. End-of-season drought significantly reduced total oil, and linoleic and behenic fatty acid content, and significantly increased total protein and stearic and oleic fatty acid content (Diwedi*et al*., 1996). Misra and Nautiyal (2005) studied fatty acid composition as influenced by the soil moisture-deficit stress imposed during different phenophases, in the summer season in four Spanish cultivars of groundnut, AK 12-24, J 11, GAUG 1 and GG 2 and observed increase in stearic acid due to stress during pod development in all cultivars except GG 2, increase in palmitic acid only in GAUG 1 and oleic acid in AK 12-24. Seghal*et al*. (2018) have indicated that under drought conditions the decrease in oil content is due to reduction in concentration of digestible carbohydrates and unloading of sugars from stem to developing seeds.The composition of saturated (palmitic and stearic) and unsaturated (oleic and linoleic) fatty acid were also altered significantly due to moisture deficit stress (Chakraborty *et al*., 2013). An increase in oleic acid content in groundnut due to moisture deficit stress has been reported by Chaiyadee*et al*. (2013). On imposing drought, the total lipid percentage decreased though the treatment differences were found statistically nonsignificant (Kandoliya*et al*., 2015). Under drought stress, due to shortening of pod development and seed filling period alteration of oil/protein ratio in legume seeds were reported, which was mainly because of the fact that during seed filling accumulation of carbohydrate and protein were much faster than that of oil (Kambiranda*et al*., 2011). There is a shift of oleic to linoleic acid in seeds of groundnut under water deficit stress resulting in reduced O/L ratio and oil stability (Chakraborty *et al*., 2016)

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4.2.Impact of drought stress on protein and amino acid composition of groundnut

Peanuts are an excellent source of plant-based protein, offering 25.8 g per 100 g of peanuts, or around half of a person's daily protein needs. No consistent effect on protein content have been documented due to drought stress at any particular growth period; nor was protein content in any specific genotype always reduced or increased by drought stress (Conkerton*et al*., 1989). However, Musingo*et al*. (1989) and reported that late-season (50 days before harvest) drought caused little change in the total protein content of groundnut.Yao *et al.,* (1982) reported that drought at flowering increased the number of shriveled kernels with reduced protein content but during the seed development phaseincreased the protein content.Mid-season drought had no significant effect on the content ofprotein and end-of-season drought significantly increased total protein. (Diwedi*et al*., 1996). During water deficit conditions, oil has a negative correlation with protein content thus decrease in oil content may eventually result in increased protein content (Chakraborty *et al*., 2016).Moisture deficit stress significantly reduced the total soluble protein content in the seeds of all the groundnut cultivars(Chakraborty *et al*., 1993). Akkasaeng*et al*. (2007) found up-regulation of several proteins including a homologue of serine-threonine protein kinase under moisture deficit stress. Besides this, other proteins like chaperon protein DNAJ, auxin-responsive protein IAA 29, peroxidase 43, etc. were down regulated in groundnut (Chakraborty *et al*., 1993). Reddy *et al*. (2003) observed the application of the different irrigation levels had different responses on the protein content of the seeds of groundnut; while the plants with adequate irrigation water not only gave more kernels but also produced higher levels of total protein contents. Continued expression methionine rich proteins (MRPs) and arachin proteins seems to enhance drought tolerance, reduce aflatoxin levels and enhance the nutritional value of peanuts(Basha *et al*., 2007). Drought exhibited no definite trend of increase or decrease for total free amino acid and sugar in mature as well as premature seeds(Jharna *et al*., 2015). In peanut seedlings, drought stress increased the amount of total amino acids during drought periods and the amount decreased within 3 days after stress was relieved (Saini and Srivastava, 1981). The increase of arginine in kernel under drought stress is likely because it is a precursor of proline synthesis (Aninbon*et al*., 2017), and proline is an important amino acid for osmotic adjustment in plants under drought stress (Madhusudhanand Sudhakar 2014b).In a study of 40 peanut genotypes by Jharna *et al*. (2013), drought stress increased total amino acid content in 21 genotypes but reduced it in 19 genotypes. In 2007, Basha and his co-workers revealed that seed polypeptide composition of drought-tolerant peanut genotypes (Vemana and K-1375) was least affected while that of drought-susceptible genotypes (M-13 and JL-220) significantly altered due to water stress.Theincrease in free amino acid content might possibly be due to an increase in kernel protein content as well as stress-induced breakdown of it (Chakraborty*et al*., 2016).

4.3.Impact of drought stress on carbohydrate composition of groundnut

Sugars in plants, derived from photosynthesis, act as substrates for energy metabolism and the biosynthesis of complex carbohydrates, providing sink tissues with the necessary resources. Sucrose and glucose either act as the substrates for cellular respiration or as the osmolytes to maintain cellular osmotic potential (Gupta*et al*., 2005). Madhusudhan and Sudhakar, (2015b) concluded that osmotic adjustment occurs in groundnut at mild water stress resulting in the maintenance of turgor, there by the carbohydrate status and finally the dry matter production, where asmoderate and severe stress inhibited the levels of the end products of carbohydrate resulting decrease in dry matter production.The production and partitioning of metabolically important non-structural carbohydrates (starch and sugar alcohols) have been reported to accumulate during drought (Keller and Ludlow, 1993).Soluble and total carbohydrate increased in Jumbo showing the highest increase under drought and temperature stress. (Musingo*et al*., 1989). As the maturity approaches from premilchto mature stages, percent concentration of moisture, total carbohydrates, soluble sugars and reducing sugars decreases, while that of total lipid and nonpolar lipid increased in general. Drought treatment increases total soluble sugars and reducing sugars concentration in pod where as total lipid fraction adversely affected as compared to the control (Kandoliya*et al*., 2015).Basha*et al*.,(2007) also reported that the stored, non structural carbohydrates serves as a source of energy for synthesis of lipids and proteins.Among the stress treatments, however the differences were nonsignificant, pod contains higher concentration of total carbohydrate at dough and mature stage as compared to control may be due to drought effect as reported by Musingo*et al*., (1989).According to Chakraborty *et al*., (2016), the content of sugar alcohols increased along with an increase in stress induced oligosaccharide (Raffinose and Stachyose) content, but the level of monosaccharide and disaccharides did not show significant alteration in the kernel tissue. Further, reduction in simple sugars under stress in the leaf with subsequent translocation to kernel tissue suggests a drought escape mechanism in groundnut. The expression of enzymes related to the biosynthesis of galactinol and raffinose family oligosaccharides (RFOs), such as raffinose, stachyose and

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verbascose, their intracellular accumulation in plant cells are closely associated with the responses to environmental stresses (Peters *et al*., 2007)

4.4.Impact of drought stress on micronutrients composition of groundnut

Like other agricultural crops, peanut requires essential nutrients during its life cycle. However, most nutrients are taken up into the plant in forms of soluble inorganic fertilizers by the root system; therefore, water stress reduces nutrient absorbability and nutrient uptake of the plant (Fageria*et al*., 2002). The reductions in nutrient uptake caused by drought during the flowering (Kulkarni *et al*., 1988), pegging, pod formation (Kolay, 2008), and pod-filling stages (Kulkarni *et al*., 1988) were also reported.Drought can positively affect nutrient uptake if it occurs at vegetative growth stages, but droughts between reproductive stages and harvest negatively affect nutrient uptakes. Reduction in nutrient uptake as caused by drought can severely reduce plant growth and yield. Nutrition balance is a key factor in diminishing environmental risks and promoting healthy plants with sustainable growth, yield, and quality (Magen, 2008). Improvement of nutrient uptake, therefore, is necessary to maintain acceptable growth and yield under drought. Enrichment of tissue with Ca in groundnut and cowpea (Chari *et al*., 1986) with improved drought toleration ability. Similarly, K supplementation proved helpful in mitigating the adverse effects of water stress in peanut and sorghum (Umar, 2006). However, differential responses among species and genotypes for nutrient uptake under drought stress were observed (Garg, 2003).The results of Dinh*et al*., (2014) showed that midseason drought significantly reduced the uptake of all nutrient elements. Peanut genotypes with higher levels of drought tolerance took up more nutrients than those with lower levels. The uptake of all nutrient elements contributed to biomass production, pod yield, and the number of pods per plant. Early or late in the growing season had little or no effect on mineral contents, but stress during mid-season growth affected mineral nutrition (Conkerton*et al*. 1989).Drought and heat stress alter compositional changes in seed chemistry, including adverse effects on minerals (Dwivedi *et al*., 2013). Regarding the preferred water regime, Xia *et al*. (2020) demonstrated that a moderate irrigation scheme has better impacts on yield compared to severe or full schemes, especially when combined with the application of 150 kg ha−1 of nitrogen.

4.5.Impact of drought stress on aflatoxin contaminationof groundnut

Drought stress has a strong effect on biocompetitive (phytoalexins, antifungal proteins) or protective compounds (phenols), which influence the growth of *Aspergillusflavus*and aflatoxin synthesis, as well as the proper maturation of peanut seeds. Aflatoxin contamination threat increases with increasing seed maturity. Pre-harvest aflatoxin contamination is a common occurrence in groundnuts that are grown under non-irrigated conditions. Under drought conditions, phytoalexin production is inhibited and the low moisture favored *A. flavus* growth (Dorner *et al*., 1989). Thus, drought is a predisposing factor for aflatoxin production in groundnut (Waliyar*et al*., 2003). However, aflatoxin production depends on many other factors besides *A. flavus*infection (Hamidou *et al*., 2014).The aflatoxin contamination is often related to the intensity of drought stress, the stage when drought stress occurs, and the soil and/or air temperature (Cole et al., 1989). Drought and temperature stress increase the accumulation and/or synthesis of carbohydrates and certain polypeptides may enhance *Aspergillus* invasion and aflatoxin production (Musingo*et al*., 1989). Terminal drought effect on aflatoxin contamination is well documented (Sudhakar *et al.,* 2007). Drought tolerant genotypes may possess some degree of tolerance to aflatoxin contamination (Girdthai*et al*., 2010). On the contrary, there is no association between drought tolerance ofgroundnutand their aflatoxin contamination (Hamidou *et al*., 2014).Wu *et al.,* (2013) showed that consumption of large amounts of groundnuts contaminated with aflatoxins even at low levels is detrimental to health.

5. Conclusion

Peanuts are a well-balanced nutritional food legume and a great source of protein, lipids, carbohydrates, minerals, and vitamins. They are also considerably more inexpensive than other nuts. With climate change, heat, and drought stresses have become more frequent and intense in groundnut growing areas with a strong influence on phenology, yield, and nutritional quality. There are three major aspects of drought, duration, intensity and timing which vary with groundnut phenophases. Numerous studies have differed in identifying the most sensitive growth stage to water stress and the optimal intensity of water regimes for achieving the best groundnut yield. Generally, the highest yield under water stress conditions is obtained during the vegetative stage, followed by the flowering stage, and finally the pod-filling stage. Drought stress is one of the most important abiotic stresses that adversely affect the nutritional quality of groundnut crops across the globe. In order to cope with this drought stress complexity and improve groundnut nutritional quality and yield in light of challenging environmental factors, it is essential to explore more options and strategies.

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