Pak. J. Bot., 57(1): DOI: http://dx.doi.org/10.30848/PJB2025-1(20)

DROUGHT STRESS IN WHEAT: MECHANISMS, EFFECTS AND MITIGATION THROUGH VERMICOMPOST

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Abstract

Climate change has increased the occurrence of biotic and abiotic stresses that steadily affected the crop growth and developmental processes. Drought is one of the worst abiotic stresses, affecting 40-70% of the global arable land. In recent years, a variety of genetic, molecular, and agronomic approaches have been developed to mitigate drought's negative effects. Among agronomic approaches, the use of vermicompost is reported to improve wheat growth and development while reducing the deleterious impact of drought stress. This review emphasizes the ramifications of drought stress on plant growth, water and nutrient interactions, photosynthesis, phenology, assimilate partitioning, and respiration. The physiological, morphological, and molecular mechanisms of drought tolerance in plants are described in detail. To combat drought stress tolerance, various management practices have been suggested. Drought stress decreases leaf area, stem elongation, and root multiplication, disrupts plant water relations and decreases water-use efficiency. Plants respond to prevalent drought stress in various biochemical and physiological ways; reduced water losses due to enhanced diffusive resistance, increased water absorption and efficient usage due to deep and extensive root systems, and smaller and succulent leaves to minimize transpirational losses are the major mechanism adapted by crop plants. Vermicompost, with a porous structure, encompasses high water storage potential, increase growth hormones such as auxins, cytokinins, and gibberlins, plant growth regulators, and contains high levels of macro and micro-nutrients and beneficial fungi, plays significant and positive impact on plant growth and development, particularly under environmental stresses.

Key words: Drought, Hormones, Mechanisms, Nutrients, Reactive oxygen species, Vermicompost, Wheat.

Introduction

Wheat (*Triticium aestivum* L.) is a major staple food crop that is extensively grown under diverse agro-climatic conditions (Braun *et al*., 2010). Wheat flour is processed commercially to bake chapatti, biscuits, French bread, Arabic bread, and pastry products and to produce gluten and starch. In order to provide for daily dietary requirements of the human population on a global and regional scale, wheat provides primarily 19 percent dietary calories and 21 percent proteins (Braun and Saulescu, 2002). Globally, China ranked first with a reported 134.3 million tons of wheat yield, followed by India, Russia, the United States, and France, with Pakistan ranked seventh among other developing nations (Anon., 2017). It covers an area of approximately 219.52 million hectares worldwide and touches production of almost 788.50 million metric tonnes (WAP, 2022-23). Wheat contributes almost 1.7% to the GDP of Pakistan also its value addition 8.7% in agriculture sector of country and wheat production was projected approximately 27 million tons on the total cultivated area of 9.2 million hectares (Anon., 2020).

Amongst the various factors that hamper the physiological, morphological and biochemical traits of plants drought is the major factor which is usually correlated with plant yield reduction rather than other constraint factors (Anjum *et al*., 2016; Anjum *et al*., 2017; Hussain *et al*., 2018). Drought stress arises when the water in the plant is limited and thus the plant reabsorbs the water from the rhizosphere, thus reducing its natural functioning under the impact of water scarcity. Plants susceptible to extreme drought stress severely interrupt their several morpho-physiological functions, such as leaf area, photosynthetic content, plant biomass, and plant development and growth. In plants, water shortage greatly represses the mechanism of photosynthesis associated with glucose formation. Photochemistry and photosynthetic metabolism are impaired and CO_2 accessibility is also decreased under restricted water conditions (Flexas *et al*., 2004; Hussain *et al*., 2018). In the field trial, the absorption of CO_2 by the plant subjected to water scare conditions normally decrease (Chaves, 1991; Chaves *et al*., 2002). Plants under limited water conditions significantly stimulate free radical mechanisms that impairs the plant's photosynthesis system, protein biosynthesis, and other metabolites. Plants have an innate mechanism to reduce drought stress injury by restricting their growth, such as shoot and leaves (Mitchell *et al*., 1998). According to reports, different wheat genotypes react differently to water shortages (Akram, 2011; Khakwani *et al*., 2011).

Drought stress impacts crop performance and productivity by altering different metabolic events, such as reduced carbon assimilation rates, higher oxidative damage, and decreased leaf gaseous exchange attributes (Hussain *et al*., 2018). It also retards various enzymatic processes, ions uptake, and leaf development due to which crop productivity severely hampers (Farooq *et al*., 2009; Anjum *et al*., 2017; Todaka *et al*., 2017). Drought stress being a serious problem influences several physiological events of crop growth and production. To eradicate such problem, however, it is highly recommended to incorporate organic amendments such as vermicompost and cultivation of drought-tolerant cultivars (Ji *et al*., 2010). We have a lot of farm waste in form of crop residues, tree residues and FYM, if this waste is managed and used wisely, it help to increase soil quality and nutrient levels, which help us meet the growing population's food demand. Farmers usually use agriculture wastes as fuel and heat due to a shortage of energy and coal, wasting an abundant supply of nutrient organic matter. Organic matter in the form of agricultural wastes is good source of food for insects and microorganism which can create a serious problem for sustainable agriculture. Different human activities, crop residues, and livestock add almost 38 billion per cubic meter organic matter in soil (Diacono *et al*., 2019). The enormous amounts of decomposable organic waste that are emitted every day in urban and agricultural zones are presenting environmental, gas production, community health, financial, and social challenges, especially in less developed countries such as Pakistan. This massive amount of organic waste could serve as a green cradle for agriculture industry. In Pakistan, there are about 72 million milk-producing animals (buffaloes and cows), approximately 81 million tonnes of crop residues per year, and approximately 785 million chickens. They collectively generate about 158.3 million tonnes of waste per year (Anon., 2013). Additionally, it is expected that roughly 18 million tonnes of weight from rice (straw and husk), cotton (sticks, waste and ginning), wheat, maize (autumn and spring), sugarcane (begass and tops) is surprisingly created yearly from different big cities of Punjab province. Some of components in rice straw like cellulose and silica are not digestible that's why farmers try to burn it out causing serious health and environmental hazards (Pimonsree *et al*., 2018). Paper waste produced by educational institutions and factories may be used as soil amendment. Through recycling these wastes, organic matter provided by these factories enhances soil quality, efficiency, and drought stress reduction. Since additional organic matter is limited in temperate areas, adding organic modifications is a significant component for enhancing soil properties and preserving soil productivity (Hijbeek *et al*., 2017). Vermicomposting technique can effectively be used to manage agriculture wastes like wheat straw, rice straw, cow dung and paper waste etc. (Sharma & Garg, 2018).

It is important to detect and recognize issues before they become serious. There are some solutions to this dilemma. One of them is vermicomposting. Previous research has shown that the amendment with vermicompost can mitigate drought stress due to its high ventilation, porosity, strong water preservation, and drainage capability (Hosseinzadeh *et al*., 2016). Indeed, beneficial microorganisms present in vermicompost enhance root water absorption. Vermicompost also enhances soil water preservation and increases fertilizer solution (Hosseinzadeh *et al*., 2018). Vermicompost contains soluble sugars, sorbitol, betaine, amino acids, and other organic acids, as well as ions of nitrogen, phosphorus, calcium, zinc, boron, magnesium, sulphur, and iron (Hosseinzadeh *et al*., 2016). Bio-fertilizers can also be produced by thermophilic composting, but the vermicomposting method is faster and more efficient in biofertilizer production (Atiyeh *et al*., 2000). Different types of organic products, such as sewage sludge, paper industry wastes, cow dung, rice straw, and pig wastes, were assessed as earthworm feed for remediation of heavy metals (Aira *et al*., 2011). Vermicompost is used to assess antifungal, microbial activity, and allelochemical detoxification for heavy metal removal and biological waste treatment (Bellitürk *et al*., 2015; Garg *et al*., 2012; Huang *et al*., 2014; Lieó *et al*., 2013; Pathma and Natarajan, 2012).Vermicompost is like peat with a fine structure, strong aeration, porosity, microbial activity, drainage, and a high water holding capability, as well as a high nutrient content that is ideal for improving plant and soil health and physicochemical properties (Pathma & Natarajan, 2012). The availability of enzymes and hormones is needed to improve plant health and eliminate pathogens. During the vermicomposting process these enzymes and hormones release from earth worm's gut (Gajalakshmi & Abbasi, 2004).

Vermicomposting is generally described as the aerobic deprivation and modification of solid organic remains by manipulation of the biological activity of earthworm and other mesophilic microflora (Garg & Gupta, 2009). The vermicompost produced by earthworm activity enriches predominantly with certain immobilized microflora, growth-regulating hormones, vitamins, macro/micronutrients and degrading enzymes *e.g.,* protease, chitinase, amylase and lipase. With the introduction of another antagonistic microflora, these enzymes have already been secreted by earthworm can degrade the organic substrate (Barik *et al*., 2011). Earth-worms are concerned with degradation and transformation of the physio-biological forms of organic residues by reducing its C:N ratio and revealing the surface area of splintered organic matter to micro-organisms and then further incorporating them with cellulolytic degrading microorganisms for utter organic residue degradation. Finally, the splinter of organic residues and bacterial excretions in the earthworm gut homogenizes the end product of organic matter and transforms into vermicompost. It is minutely fractionalized substance having resemblance with humus having high porosity and strong water retention and comprises of much of the plant's readily absorbed minerals (Dominguez & Edwars, 2004). A significant part of soil invertebrate biomass is specified by earthworms. Earthworms are undoubtedly important soil-dwelling organisms in many ecosystems for degradation of organic matter by altering microbial dynamics and soil micro-macro nutrients (Edwards, 2004). Numerous studies of cellulolytic activity in the intestines of different earthworm population, *Eisenia fetida*, *Pontoscolex corethurus*, *Polipheretima elongate* and *Millsonia anomala* primarily in epigeic earthworm species have been performed (Lattaud *et al*., 1997a, Lattaud *et al*., 1997b; Urbasek & Pizl, 1991; Zhang *et al*., 1993; Zhang *et al*., 2000). Earthworms contain fungi and bacteria in their gut which is helpful for digestion of their food material. In addition, activity of such microorganisms was also observed in the gut of earthworm populations *Lumbricus terrestris*, *Lumbricus rubellus* and *Aporrectodea caliginosa* (Ahmad *et al*., 2024). Several studies have been conducted on *Bacillus subtilis* living in the gut of *E fetida* earthworm, and above reported antagonistic bacteria strains conceal very beneficial and huge quantity of cellulolytic-degraded enzymes to disintegrate the organic matter's distinct cellular components (Ahmad *et al*., 2024).

Several researchers in cereal crops like maize and wheat have assessed the beneficial effects of vermicompost alone and combined with other organic-based nutrients under non-drought, moderate drought and severe drought stress conditions. These studies have produced controversial findings concerning the reduction of morpho-physiological and yield parameters, as well as the improvement of plant biochemical characteristics in extreme drought conditions (Hafez *et al*., 2020). Humic acid of vermicompost extracts has an advantageous effect on agronomic crops. The incorporation of vermi-fertilizer extracts into rice stabilizes the deleterious impacts of ROS produced in the plant under water limited and saline stress, by the activation of scavenger antioxidant, catalase (CAT) and superoxide dismutase (SOD) enzymes (García *et al*., 2012; Kiran, 2019). In legume crops (such as mungbean, chickpea, and lentil), oilseed crops, such as canola, as well as in other plant families, these affiliated studies were also confirmed (Mahmoudi *et al*., 2016; Akhzari and Pessarakli, 2017; Ahmadpour & Hosseinzadeh, 2017; Kiran, 2019).

Drought stress and it's management: A prolonged period of no rain is referred to as a drought in meteorology, and it has been intensified by the high emission rates of greenhouse gases leading to extreme climate change, consumption of fossil fuels and deforestation (Lockwood, 2009). Drought is described in agriculture as an insufficient supply of water, including precipitation. Water is becoming a limited resource as a result of population growth and aridity, a wreaking havoc on agriculture sector (Passioura, 2002). Drought is a typical characteristic of land areas with decrease and erratic rainfall patterns (Wang *et al*., 2005). Furthermore, it is demonstrated that drought decreases the productivity of major crop plants by 50% (Bayoumi *et al*., 2008). The most crucial component is water, that makes up 70-90% of the fresh mass of actively growing plants (Gardner & Gardner, 1983).

For optimum plant growth and crop production, water is essential (Fig. 1). About 90% of agriculture in most Asian countries is reliant on irrigation water, and water shortage has a negative consequence on crop productivity (Huaqi *et al*., 2002). Under the condition of limited water supply to crop roots and higher rates of transpiration, plants are said to be under water stress. Under arid and semi-arid climates, these two conditions have a considerable impact (Iqbal, 2009).

Water deficiency in plants can be treated using one of three approaches. First and foremost, proper soil conservation and water application are crucial. When there is a lack of water, it is important to conserve it. Appropriate management strategies increase the ability to hold water and minimize the rate of evaporation. The second approach is biological, which can be achieved in a variety of ways, including developing drought-tolerant cultivars through breeding or molecular genetics, or conducting screening programs to identify drought-tolerant crop cultivars. Vermicompost, which is spongy in nature and stores water, is the most recent and third strategy for reducing water stress. When the crop needs water, it slowly releases it in a stressful environment while still supplying vital nutrients to the plants. It has a high porous structure, water storage capacity strong aeration and drainage (Hosseinzadeh *et al*., 2016). Root water absorption is increased by microorganisms in the vermicompost, *e.g.* mycorrhizal fungi (Amiri *et al*., 2017). The vermicompost fertilizer aids in the water retention in the soil as well as an improvement in nutrient solution (Hosseinzadeh *et al*., 2016). High levels of compatible compounds are there in vermicompost which include soluble-carbohydrates, proline, organic acids, sorbitol, amino acids, betaine and nutrient ions including nitrogen, phosphorus, calcium, zinc, boron, magnesium, sulphur, and iron (Hosseinzadeh *et al*., 2016).

Drought stress impacts on wheat: Wheat is the most important and commonly grown cereal crop and requires water frequently at different stages. The deficiency of water at reproductive stages greatly influences crop productivity. Drought stress affects (Fig. 1) the crop productivity by altering various metabolic processes like a significant reduction in carbon assimilation, enhanced oxidative damage and reduced leaf gases exchange (Hussain *et al*., 2018). It also inhibits different enzymatic activities, ionic absorption, disruption of leaf development due to these problems crop productivity decreased (Farooq *et al*., 2009; Todaka *et al*., 2017).

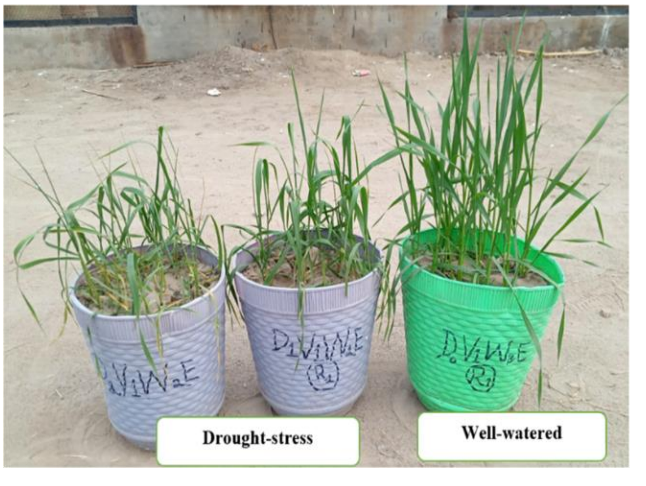

Fig. 1. Effect of drought stress on the vegetative growth of wheat cv. Faisalabad-08.

Drought stress is very dangerous for crop growth, development and overall productivity because it disrupts many physiological events (Fig. 2). To eliminate that problem use of organic amendments like vermicompost and improve drought tolerance cultivars that highly tolerant and productive under such condition because that is mandatory to increase productivity under water shortage conditions (Ji *et al*., 2010). ROS production increased under such conditions (Cechin *et al*., 2015) that damage several cellular components. In drought stress plants produced maximum reactive species that cause damage to lipid, protein, DNA and carbohydrates by their toxic action (Apel & Hirt, 2004).

Effect of drought stress on photosynthesis: Photosynthesis is an important component which takes significant role in CO_2 fixation and light harvesting in leaves which is significant for optimum growth and development of plants. Photosynthesis efficiency relay on genetic potential to light energy and conversion of it into carbohydrates, but it is also directly affected by drought (Andrianasolo *et al*., 2016). One advantage of drought stress is that it causes roots to store more dry matter, which improves plant water uptake (Leport *et al*., 2006). However many other factors lead to decrease productivity and growth rate of crops. Through stomatal and non-stomatal mechanism drought stress decreases CO_2 diffusion which directly reduces rate of photosynthesis. Under drought condition CO_2 diffusion causes the photosynthetic electron chain's excessive reduction, which is a major source of ROS production. In this situation rate of photosynthesis, leaf senescence, leaf expansion decreases and create reduction of food (Wahid & Rasul, 2005; Wahid, 2007). Anjum *et al.* (2003) also demonstrated that reduced activities of Calvin cycle under drought conditions ultimately decreases yield of crop. An important consequence of drought on photosynthesis is imbalance between antioxidant defense system and ROS production (Reddy *et al*., 2004) that ultimately enhances the generation of ROS and stress to cellular organelles, membrane lipids and protein.

Nutrients are very pivotal component for development and growth of plant. Plant requires these nutrients in dissolved form, for the dissolution of nutrients water is necessary. So here is a relationship between moisture and nutrient acquisition by plant is strong. Plants deficient in water are affected by various problems such as stomatal conductance, relative leaf water content, transpiration rate, below and above parts temperature. Under drought conditions, stomatal conductance is one of the most disturbed phenomena (Farooq *et al*., 2009). Water limited conditions result in reduced transpiration rates and leaf water status which increases the plant canopy thermal conditions (Ahmad *et al*., 2019). There are several components which affect plant water relationship such as leaves temperature, transpiration rates, stomatal conductance, and leaf water status. Leaves' relative water content and water potential are increased during the early developmental phases while decreased during the lateral phases as leaves get matured and attained higher biomass (Anwar *et al*., 2014). The ratio of the improvement in dry matter production per unit of consumption of water is known called plant water use efficiency (Umezawa *et al*., 2004). Furthermore, Abbate *et al*., (2004) concluded that during drought conditions increased WUE in wheat seedlings when compared with well-watered plants. He correlated water use efficiency increased with the closing of stomata due to reduction in rate of transpiration.

Drought stress decreases rate of nutrient uptake and increase their accumulation in plant tissues. The prime factor of water limitation is acquisition and transport of nutrients from roots. Decrease in rate of nutrient uptake also causes decrease in unloading mechanism and transpiration flow (Garg, 2003). Energy required for nutrient availability also decreases with drought stress. It inhibits the rate of photosynthesis which is an essential component for energy. Fertilizers application plays an important role to increase the crop productivity under water deficit conditions, as nutrient and moisture requirements are related in a close way. There is a significant relation between nutrient requirement and soil moisture contents. These findings show that by improving nutrient use efficiency under water stress condition increase crop yield upto maximum level (Garg, 2003).

Reactive oxygen species (ROS) as an oxidative stress agent: Different types of ROS such hydrogen peroxide (H_2O_2), superoxide anion radicals (O_2^-), singlet oxygen (O_2^1) and hydrogen peroxide are largely produced under drought stress (Munné-Bosch & Penuelas, 2003). Under stress, these species can react with protein, lipid, and deoxyribonucleic acid that decrease normal working of cells by oxidative damage (Farooq *et al*., 2009). There are several parts of cell involved for the generation of ROS, chloroplast is most important source for the productions of ROS while thylakoid interact with O_2 or O^1_2 to build up powerful oxidants (Reddy *et al*., 2004). Under normal as well as drought condition different apoplastic enzymes may play a significant role in the production of active species. These species are formed in the chloroplast during electron transport chain as its by product (Apel and Hirt, 2004). Some studies have also stated that this species formed in plasma membrane and mitochondria (Sairam *et al*., 2005). Mitochondria with redox reactive electrons carriers is the primary source for ROS production during electron transport chain.

Effect of drought stress on antioxidant defense: Under stress stimuli, various types of enzymatic and non-enzymatic components constitute a strong antioxidant defense system in plants. SOD, CAT, POD (Fig. 3), glutathione reductase, and APX are the commonly reported examples of these enzymes. Meanwhile, cysteine, ascorbic acid, and reduced glutathione are categorized as non-enzymatic antioxidants produced mainly under stress condition (Gong *et al*., 2005). Both defense system contents are important for tolerance against various biotic and abiotic stresses such as drought. Several lipids and water-soluble antioxidants enzyme take part a substantial role for the removal of ROS (Hasegawa *et al*., 2000). The positive role of antioxidant enzymes is efficient mechanism to eliminate ROS (Farooq *et al*., 2008). In addition to CAT, numerous peroxiredoxins and peroxidase, four enzymes including glutahthione reductase, monodehydroascorbate-reductase, dehydroascorbate-reductase and ascorbate peroxidase are involved for the scavenging of H_2O_2 and superoxide radical (Fazeli *et al*., 2007). In stomata of chloroplast, mitochondria, cytosol and peroxisome several enzymes are present (Jiménez *et al*., 1998).

Effect of drought stress on plant growth regulators: Different Plants' physiological events are significantly affected by the application of plant growth regulators exogenously and phytohormones at lower concentrations (Morgan, 1990). These phytohormones and regulators are interchangeable when referring to auxins, ABA, gibberellines, cytokinins and ethylene (Taiz & Zeiger, 2006). Nilsen & Orcutte, (1996) investigated that in drought condition inner levels of auxins, cytokinins and gibbrellins are reduced while those of ethylene and abscisic acid increase.

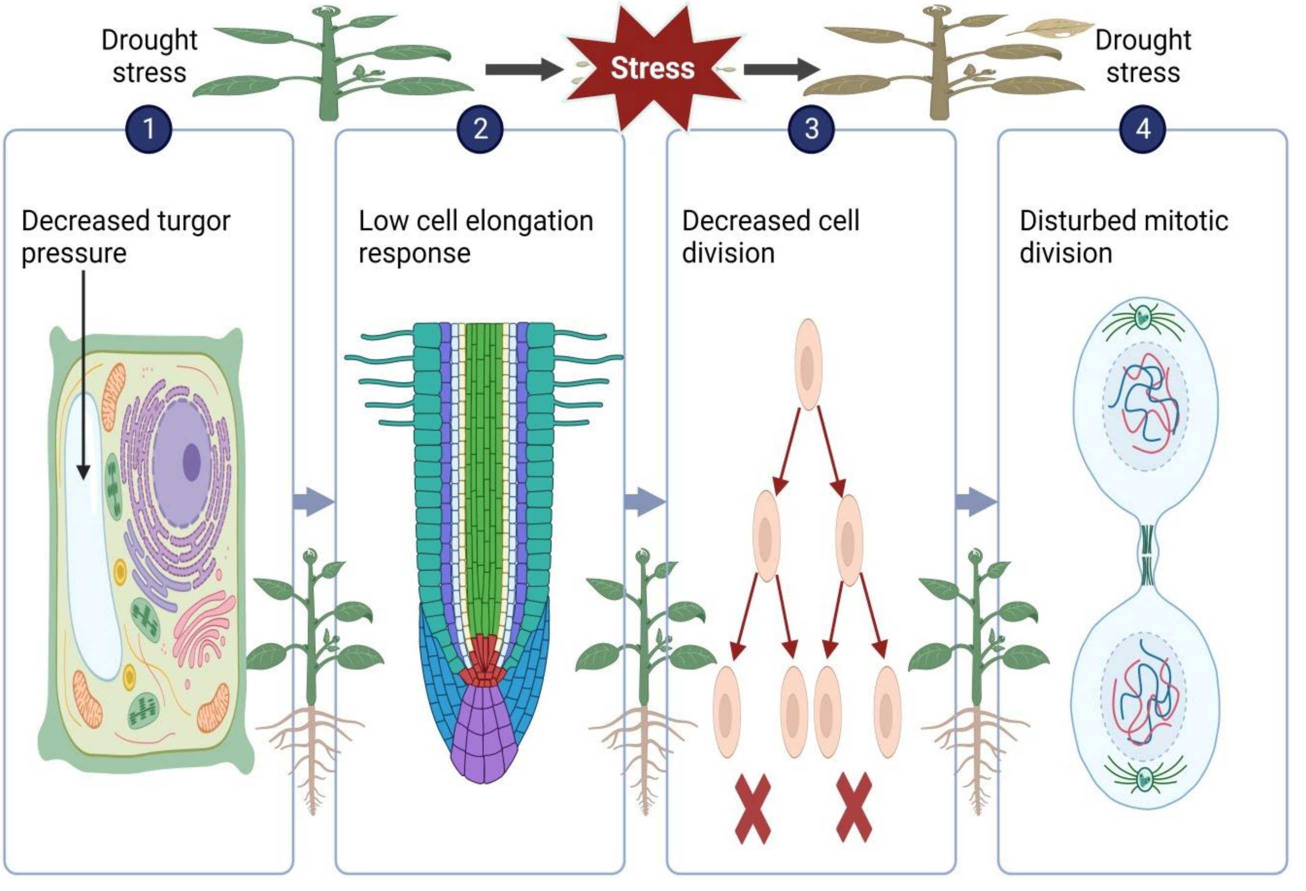

Fig. 2. Possible mechanisms of limited crop growth and development under water scare/drought stress conditions.

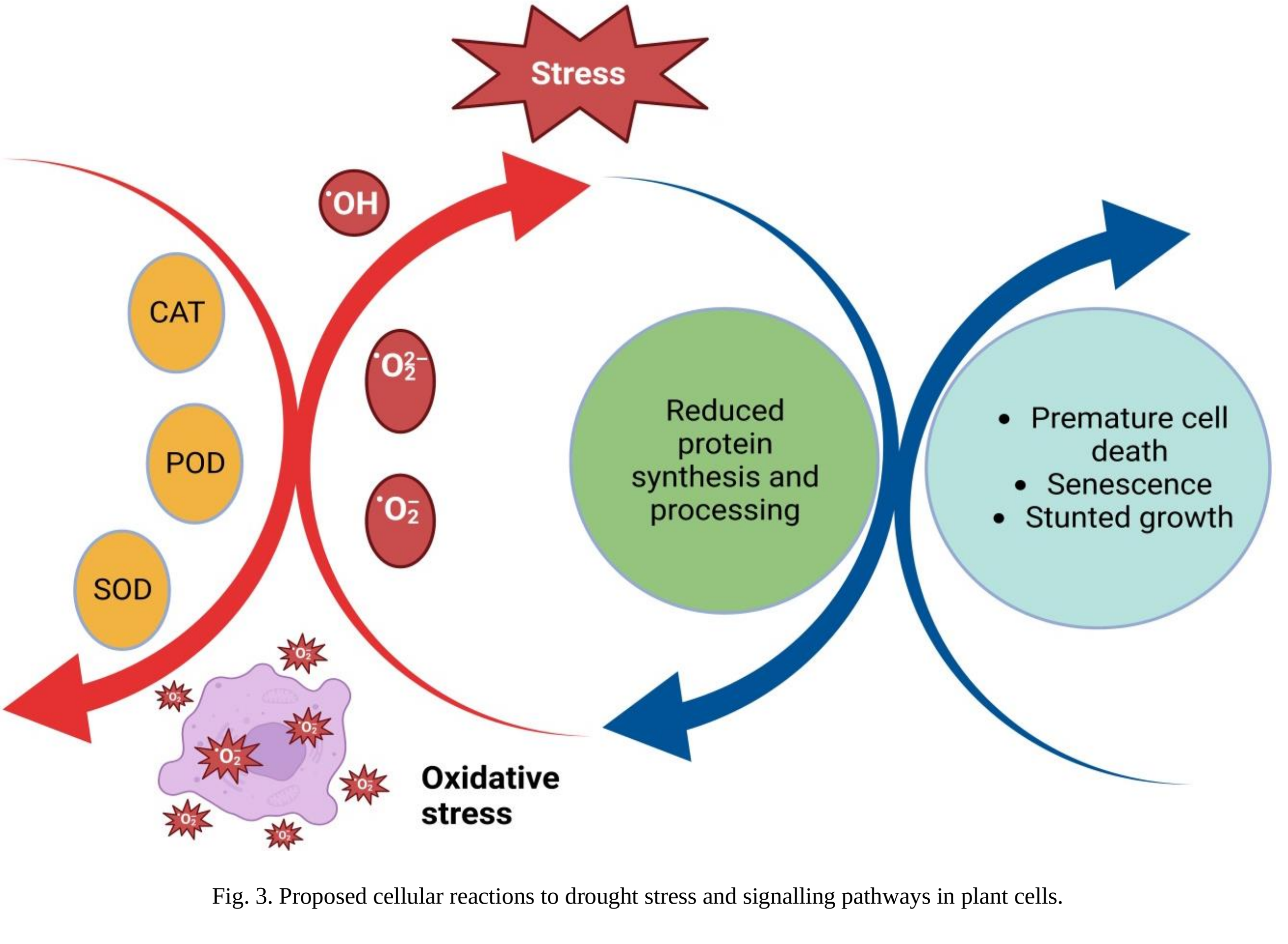

Fig. 3. Proposed cellular reactions to drought stress and signalling pathways in plant cells.

Compatible solutes and osmotic adjustment under drought stress: Plants have specific mechanisms for drought tolerance because every plant cannot tolerate stress. That is developed due to overproduction of various amicable organic solutes (reviewed by Serraj & Sinclair, 2002). These organic based solutes are highly soluble, having too low molecular weights and non-toxic at higher concentrations. These solutes through stabilization of protein, enzymes and membrane structure, detoxification of ROS and osmotic adjustment play a prominent role in plant protection from different stresses.

The water relation maintenance mechanism under osmotic stress is commonly known as osmotic adjustment. It plays most essential role in the storage of osmotically active ions/ molecules during less water availability and as a result of solute accumulation, so it helps to maintain the turgor of plants by lowering the osmatic potential of plant. Osmotic adjustments regulate the cytoplasmic and organelles activities which improve the plants' ability in terms of better photosynthesis, seedling growth and assimilate-partitioning for grain filling to grow well (Subbarao *et al*., 2000). It is concluded that in drought osmatic adjustment play a significant role to reduce its effects as compared to others (Morgan, 1990). Proline is an important cyto solute in a variety of organisms including bacteria, animals, algae and higher plants to decrease the water potential by accumulation (Wahid & Close, 2007; Ahmad *et al*., 2022). It is synthesized in plants leaves by combination of slow oxidation and increased biosynthesis in mitochondria at low water potential. An ammonium quaternary compound glycine betaine is extensively studied compatible solute in bacteria, animals, and plants (Wahid *et al*., 2007). Furthermore, it is also vital to improve the drought tolerance mechanism under abiotic stresses (Quan *et al*., 2004; Walter *et al*., 2011).

Different osmoprotectants build up in the vegetative tissues of crop plants to improve the ability to tolerate water stress, and they do so successfully (Farooq *et al*., 2009). These osmoprotectants enhance the ability of crop seedlings to growth well under water deficit conditions in succeeding years (Farooq *et al*., 2018). Consequently, the crop is compatible with stand against drought to an accumulation of stress protein in seed and compatible solute at grain development stages (Farooq *et al*., 2018). It is also a helpful mechanism to decrease the stress problem in the upcoming generation of plants (Farooq *et al*., 2018).

Under drought condition ubiquitous response in plants to survive in adverse effect of stressful conditions is through production of stress proteins. Through hydration of cellular components these water-soluble compounds play a significant role in increase stress tolerance mechanism in plant (Wahid *et al*., 2007). Stress proteins and transcription factors are exclusively used in studying the implications of drought (Taiz & Zeiger, 2006). Heat shock proteins are a subset of a large number of molecules known as chaperons. They significantly aid in keeping other protein structures stable. Environmental calamities like high temperatures encourage the production of heat shock proteins of low molecular weight (Wahid *et al*., 2007). Other types of environmental stimuli such as cold stress, drought and waterlogging also enhance the production of heat shock proteins-HSPs (Coca *et al*., 1994). It is also investigated that there is a great contribution of heat shock protein acting as molecular protein in unfolding of adenosine triphosphate and inhibiting denaturation of protein under abiotic stresses (Gorantla *et al*., 2006). Late embryogenesis abundant and membrane stabilizing proteins also significantly contribute to improving the tolerance mechanism of drought stress. These improve the ability to bind water through providing an environment for other structures and proteins known as dehydrin. During cellular dehydration ions sequestration also investigated as significant (Gorantla *et al*., 2006). Dehydrins, called a group of late embryogensis proteins due to minimum temperature and drought accumulated.

Impact of drought stress on crop growth and yield: Drought effect crop production by creating a hazard at different stages of crop plants. Plant population is most crucial element for crop production as compared to other yield components. Drought first and foremost effect is reduction of germination and poor crop stand establishment which cause low production (Kaya *et al*., 2006) while some other components of plant such as cell elongation, cell expansion, mitosis and seedling growth are severely affected under water limited conditions (Hussain *et al*., 2008). The biosynthesis of starch from the simple carbohydrates forms is taken place through involving four enzymes (Taiz & Zeiger, 2006). Under water scarce conditions, seedling growth and grain filling rates are decreased as a result of inactivation of various enzymes such as adenosine diphosphate-glucose-pyrophosphorylase and sucrose synthase; these are essential for the biosynthesis of starch under water-restricted circumstances (Reynolds *et al*., 2001).

Drought stress decrease the hypocotyl length, shoot dry weight, germination potential, vegetative and seedling growth (Fig. 3). It also impairs mitosis and minimizes cell elongation (Kaya *et al*., 2006; Hussain *et al*., 2008). Due to the turgor losses, the process of cell growth is constrained (Taiz & Zeiger, 2006).

Screening of drought tolerant wheat germplasm: In contrast to a non-water stressed environment, a plant's capability to grow well under limited moisture conditions with low level of organs water potentials with minimal yield loss is known as drought tolerance (Mitra, 2001; Lopez *et al*., 2002). Understanding plant physiological behavior under drought conditions could lead to the prediction of drought-tolerant crop varieties (Mian *et al*., 1993). Under drought conditions, several plant species showed changes in metabolic activities (Lawlor & Cornic, 2002), decreased plant vigor and reduced relative water content (Halder & Burrage, 2003). Wheat seedling response varies with growth rate in various soil field capacities and accumulates a wide range of complementary substances like proline and betaine, which is an adaptive mechanism for drought stress tolerance in crop seedlings (Farooq *et al*., 2009).

Various methods have been used to improve wheat drought resistance, including introducing drought resistance genes into modified genotypes, conducting large international germplasm collection screens, complete field experiments of specific genotypes, conventional and non-conventional crosses with wheat cultivars, and conducting screening programs to select drought tolerant crops (Fig. 4). Drought tolerance differences in wheat crop varieties have long been known and reported (Levitt, 1980).

Plant drought tolerance is a major research topic around the world, as well as in Pakistan. Plant breeders and researchers are focusing their efforts on achieving optimum yield under limited moisture conditions. Wheat yield losses in rainfed areas range from 40 to 70 percent (Li *et al*., 2009), which is a significant loss.

Earthworms and their role in plant nutrition: Earthworms belong to the phylum annelida and commonly have long, cylindrical and narrow segmented. These organisms have symmetrically bilateral soil-dwelling invertebrates with a gleaming brownish body coated in a smooth cuticular layer. There are 23 families, 700 genera, and 70,000 species of earthworms (Pechenik, 2009). Earthworms are reproductively hermaphrodite and weight between 1,400 and 1,500 mg after 1/2 month. Their bodies are made up of proteins, carbs, and fats. Depending on the ecological conditions, their life cycle will last anywhere from about 3-7 years. Their gut is a linear tube which initiates at the mouth and continues through pharyngeal, esophageal, and some other organs. The mucus in earthworms contains a sufficient number of amino acids, minerals, organic-material, polysaccharides, and protein in addition to symbiotic bacteria, protozoa and micro-fungi. Sustained levels of C:N and better moisture percentages in the earthworm gut provide ideal conditions for bacterial endospore production and the activation of dormant microorganisms. The earthworm food canal contains a large selection of digestive enzymes, including urease, chitinase, lipase, cellulase, and protease. The activities of vital enzymes namely mannose and cellulase were found to be regulated by gut microbes (Munnoli *et al*., 2010). The active vermicomposting stage is characterized by earthworms comminuting the substrate and thus raising the microbial degradation surface area. As this fractioned organic material is transported through the intestine, it interacts with digestive enzymes and intestinal-associated microbes, ultimately leaving the intestines in moderately digested produces "casts," during which the earthworms begin the phase of degradation (Lazcano *et al*., 2008).

Earthworms and microorganisms have a complicated relationship; different classes of microorganisms are being used as feed by the earthworms. Among these, protozoa and fungus species such as *F. oxysporum*, *A. solani*, and *D. calebi* are commonly reported. The earthworm groups such as *L. terrestris* and *E. fetida* digest *B. cereus* var mycoides, while *S. marcessens* and *E. coli*are totally excluded from passing through the earthworm intestine (Edwards & Fletcher, 1988).

Characteristics of *Eisenia fetida*: The commonly existed earthworm species, *E. fetida* (Savigny, 1826) is a member of the lumbericidae family and belong to phylum Annelida (classification is mentioned by Pavlíček & Csuzdi, 2012). These worms (Fig. 5) have a belly yellowish in color with segment lengths in the range from 23 to 130 mm and the number of segments is about 80-110. Adult earthworms having average weight of about 1.5 g and can reproduce after 50 to 55 days of emerging from the cocoon. On average, adult worms produce cocoons every three days. However, only one-third of newborns emerge from cocoons after 23 days, while the remaining do not survive (Fadaee, 2012).

Esienia fetida (Fig. 5) is a type of worm that is born on the surface, feeds on waste, and produces fertilizer. Bulk manures and lands with sufficient plant residues are all good places for its better growth. It can survive in all types of climatic conditions and is active throughout the year, acting as a suitable degrading agent in soil. These species of earthworms have a fantastic food ingestion and reproduction rate, as well as the ability to live, feed, and reproduce in environments rich in organic matter. They can therefore consume organic waste daily equal to half of their body mass (Tohidinejad *et al*., 2011).

Cellulase activity in *Eisenia fetida*: Cellulose, enriched with glucose units joined by –1, 4 glyosidic linkages, is by far the most abundant homopolymer in terrestrial environments (Sinsabaugh & Linkins, 1988). Because of this high complexity at molecular levels, cellulose degradation is a time-consuming practice that is hampered by many cellulase-related components such as enzyme's concentration, position, and flexibility. The production of cellulolysis is attributed to the collaborative action of fungi and some strains of bacteria with variable requirements of substrate that alter their weights depending on the substratum being metabolized (Aira *et al*., 2007). Fungi, bacteria, and actinomycetes predominate in aerobic environments, while mostly bacteria predominate in anaerobic conditions (Richmond, 1991). Earthworms contribute to substrate degradation in two ways: firstly, indirectly by manipulation of numerous microbial population structure and dynamics, and secondly directly by conducting cellulolytic activity in their gut. Other microbes that live in the ecosystem where cellulose is biodegraded fulfill carbon and energy requirements by using the products of cellulose hydrolysis, and this accessibility is at the center of many biological-interactions that induce the stimulation as well as the deactivation of microbial populations communities. It came as no surprise that cellulose-degrading microbial populations have evolved over the years in a wide range of forms. As the Latin word vermes means "worms", so term vermicomposting is fundamentally recognized with worms (Ghatnekar *et al*., 1998). It needs to be known if the earthworm's cellulose behavior is partly due to certain genes being transferred and integrated into its genome from microorganisms during evolution. Horizontal gene transfer (HGT) is the term for this form of genome transfer. Similarly, Kumar *et al*., (2010) observed a strong correlation between cellulase and earthworm gut microflora.

Comparison of vermicompost with simple compost: When compared with vermicompost, traditional compositing, (Table 1) increased the transformation of organic matter into stable compounds through interfering the beneficial microorganisms including bacteria and fungi at a temperature of 45-60°C and improved the sanitation of organic decay by eliminating harmful microbes (Zucconi & De Bertoldi, 1987). Simple compositing, is prepared in two phases where first stage called the thermophilic stage in which degradation of organic waste occurs mainly at high temperature of 45-65°C and the second stage called mesophilic stage in which degradation occurs at low temperature of 20-35°C. During the degradation process, length of decomposition process is largely omitted by the nature of organic decay, the aeration, and moisture content.

During the preparation of vermicompost (Fig. 6), organic waste products are oxidized by the mutual action of beneficial microbes and earthworms (Dominguez *et al*., 1997). Earthworms are known to change the chemical and physical composition of organic products, decrease the ratio of C:N and increase the surface area for microbes for enhancing their activities. According to Lores *et al*., (2006), there are two major phases of vermicomposting; the first phase earthworms increase surface area of organic materials for its breakdown and decomposition while in the next phase these organisms ingest the wastes and replace with fresh substances. Here the earthworm populations and species, used organic decay, and environmental conditions such as available humidity and ventilation directly influence the quality of produced compost (Edwards, 2004).

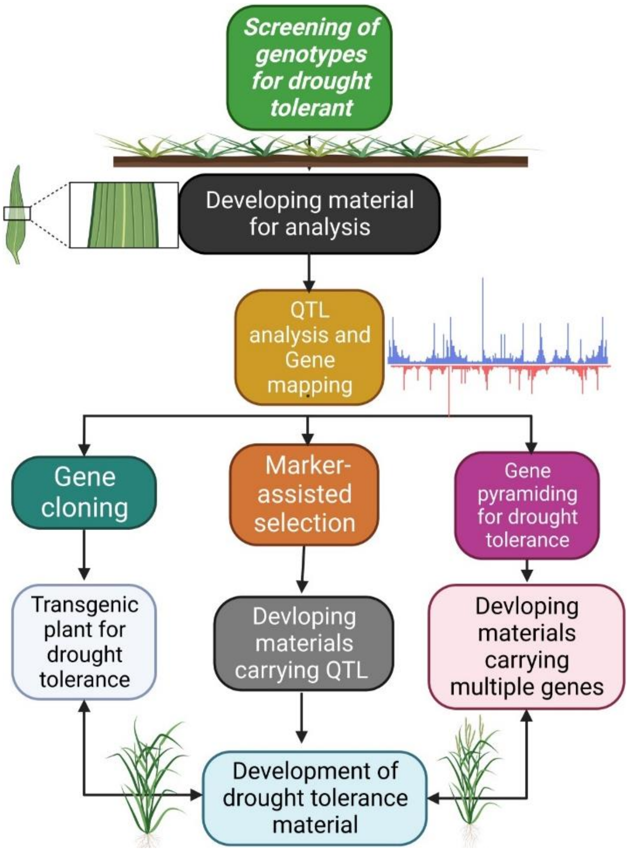

Fig. 4. Developing materials for drought tolerance.

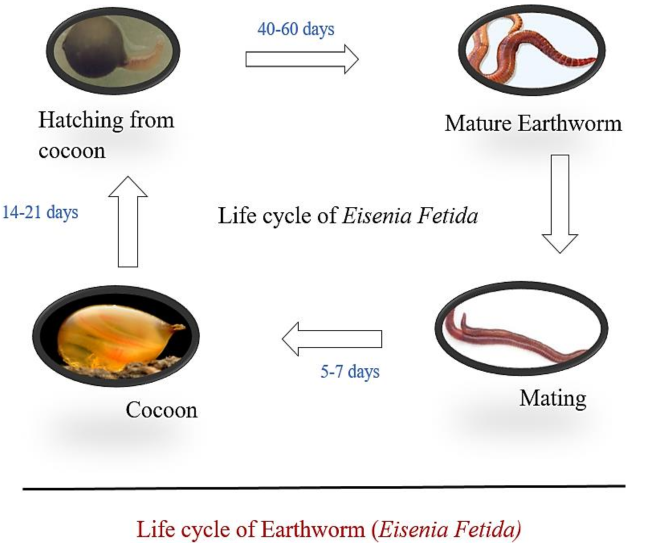

Fig. 5. *Eisenia fetida* life cycle.

Fig. 6. Vermicompost preparation procedure.

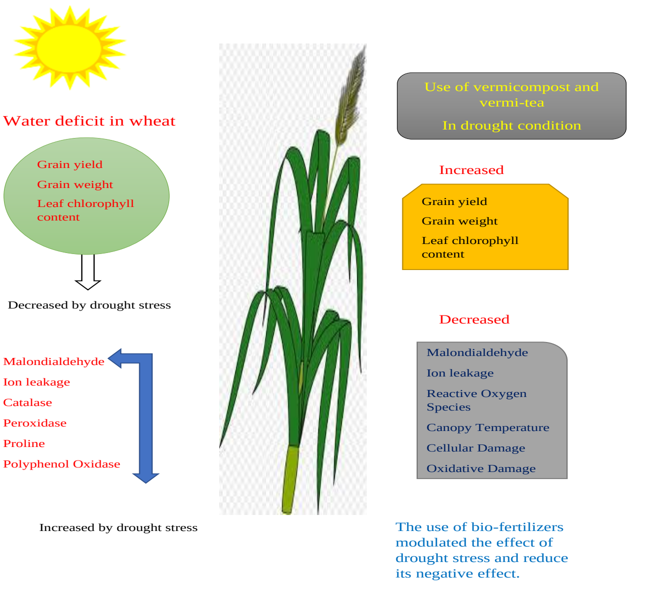

Fig. 7. Wheat drought stress and management through vermicompost.

Table 1. Vermicompost is superior to compost in light of a few key factors.

Sr #	Characteristics	Vermicompost	Compost	Important judgments	References
1.	Nitrogen (%)	2.20	1.09	Vermicompost contains high nitrogen contents than simple compost	Aslam *et al*., 2021
2.	Phosphorus (%)	1.80	1.15	More phosphorus contents in vermicompost than simple compost	Aslam *et al*., 2022
3.	Potassium (%)	0.83	0.17	The potassium contents are higher in vermicompost than compost	Ahmad *et al*., 2022
8.	EC (dS/m)	3.20	4.44	Less EC was noted in vermicompost as compared to simple compost.	Bellitürk *et al*., 2020
9.	pH	7.13	6.68	Vermicompost has high pH than traditional compost	Bellitürk *et al*., 2020
10.	C:N ratio	Less C:N ratio	More C:N ratio	Vermicast is more stable and mature than compost because it has a lower C: N ratio than compost, which may be linked to the earthworms' and bacteria' respiratory activity	Ravindran *et al*., 2015
11.	Plant growth hormones and microbial number	Green bean fruit output, root, and shoot weight are all more	Green bean fruit output, root, and shoot weight are all less	When utilized in similar volumes, vermicompost performed better than compost due to its increased levels of macronutrients and growth hormones	Soobhany *et al*., 2017
12.	Enzyme activities	enzyme activity faster	enzyme activity delays	In contrast to compost, where enzyme activity including urease, cellulose, protease, etc. reached their peak between the ages of 42 and 49, vermicompost reached its peak between the ages of 21 and 35	Devi *et al*., (2009)

Precious published clearly demonstrated that earthworm's species and organic waste products can influence the quality of vermicompost. Among the commonly used species, epigeic species are reported the first identified and the most effective in enhancing the soil organic matter and crop productivity (Oliver, 1937; Barrett, 1942). The term vermiculture was firstly used during late of the nineteenth century at that time some scientist used earthworms to degrade the garbage sludge (Graff, 1974; Bouche, 1977; Mitchell *et al*., 1977; Edward *et al*., 1985). However, during the early years of twentieth century, Reynolds and Wetzel (2004) identified about eighty-three hundred species of earthworms in the "Oligochaet Family" from which more than half are living in a terrestrial environment. The most abundant family, named as Lumbricidae, is commonly found in North America, Europe, and Western Asia. While, some other common families including *Eudrilidea,* and *Microchaetidae* are found in West Africa, Eastern Asia and Australia.

Dominguez & Edwards, (2011) defined earthworms as macroscopic "Oligochaete Dominguez" clitellates with symmetrical bilateral segmentations that are commonly found in wet soils. Based on feeding habits and burrowing patterns, earthworms can be classified into three classes *viz.*, anecic, epigeic, and endogeic (Bouche, 1977). Endogeic and anecic groups are commonly found in the subsoil layers and used both organic and inorganic minerals as feed. On the other hand, the epigeic group is largely found in upper surface layers and used surface litter as their feed to convert them into the organic matter.

Wheat straw, rice straw and farmyard manure as substrate for vermicomposting: Different types of organic wastes such as rice straw composite (RSC), rice straw (RS), and farmyard manure (FYM) are commonly used for vermicomposting. Previous studies have demonstrated that these substrates normally require 100-285 days for complete decomposition (Venkatesan *et al*., 2015). Furthermore, Reinecke *et al*., (1992) investigated the ability of three most used epigeic species (*P. excavatus*, *E. fetida* and *E. eugeniae*) for wheat and paddy straw composting and found that P. *excavates* was more effective in term of growth rates when compared with others. Similarly, *P. excavates* was reported to have better mineralization and growth than all other used species (Singh & Kulbaivab, 2009). Suthar (2007) studied the ability of the indigenous *Pertonyx excavatus* species and reported the highest average number of cocoons (692) when compared with other species. The authors further stated that the biological as well as chemical composition of the substrates played an important role during decomposition of decay and the production of earthworms. In another study, Swati & Reddy (2009) evaluated the effectiveness of two species viz., *E. eugeniae* and *P. excavates* for the preparation of rice straw vermicompost and reported that *E. eugeniae* produced about 48% more juveniles as compared with *P. excavates*, showing cost effective technique for the preparation of same.

Furthermore, Singh & Sharma, (2002) evaluated the performance of different species *i.e., Azotobacter chroococcum*, *Pleuroina sajor-caju*, *Aspergillus niger* and *Trichoderma harzianum* for different time periods while preparing the wheat-straw vermicompost and reported that vermicompost produce through the combined application of these species recorded higher nutrients quantities as compared with the sole application of these. Suthar (2008) compared pre-harvest residues of certain field crops with cow dung for vermicomposting through *E. eugeniae* specie. Authors reported that wheat vermicompost had a lower concentration of nitrogen and other essential nutrients as compared with cow-dung.

Role of vermicompost in alleviating drought stress: Vermicompost, as an ecological alternative, plays a significant role in enhancing drought tolerance (Fig. 7), through improving the synthesis of protein, and various enzymes in different plant organs (Muscolo *et al*., 2007; García *et al*., 2012). It has high ventilation, porosity, water storage and drainage capacity (Hosseinzadeh *et al*., 2016). Microorganisms present in the vermicompost, such as mycorrhizal fungi, increase the root water uptake (Amiri *et al*., 2017). Vermicompost also plays an important role in enhancing the uptake of nutrients and soil water (Hosseinzadeh *et al*., 2016). Due to the excess of humic substances, vermicompost releases minerals, hormones, vitamins and different enzymes (Prabha *et al*., 2007) for improving soil porosity, water and nutrient-holding capacity (Jashankar & Wahab, 2004; Atiyeh *et al*., 2001). In comparison with other chemical fertilizers, vermicompost application has been reported to increase nutrient availability, enzymes and hormones activities, and soil microbial populations for better growth and development (Jat & Ahlawat, 2004; Jat & Ahlawat, 2006).

Conclusion

In conclusion, organic fertilizer such as vermicompost improved plant physical, chemical, morphological and biological functions. As a sustainable soil amendment, vermicompost also improved soil health in terms of high porosity, water and nutrient retention capacity because it contains a diversity of beneficial microbes, and nutrients. Its application activated various mechanisms in plants for enhancing performance under stress conditions. Findings of this review-based study not only added the existing pool of knowledge but also suggested some ecologically safe approaches for imparting drought tolerance in crop plants. The imparted drought tolerance finally be reflected in terms of improved productivity. Farmers, especially those of drought hit areas, are ultimate beneficiary of the said project.

Authors' contributions

AA and ZA: Conceptualization and drafting of the manuscript; AA, ZA, SH, SB and SHu: Literature review and drafting of the manuscript. ZA, THA, SSy, KB and SS: Critical review and expert view; All authors contributed to the review article and approved the final version.

Acknowledgments

The current review paper is a part of Ph.D. studies of Dr. Ali Ahmad. The authors are grateful to HEC for funding this research through HEC project entitled "Vermicomposting: A resourceful organic fertilizer to improve agriculture production and soil health, NRPU-HEC project no. 7527/Punjab/NRPU/R&D/HEC/2017". The authors are also thankful to Punjab Agriculture Research Board that financially supported the project (Project# 18-550) entitled with "Developing agricultural waste management system to produce different kinds of organic fertilizers for sustainable agriculture".

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(Received for publication 26 June 2023)