**The allelopathic potential, nutritional qualities and response of *Chenopodium quinoa* (willd.) to abiotic stresses conditions*-* a review**

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**Abstract**

*Chenopodium quinoa* (Quinoa) is one of the important cereal crops which isconsidered a new alternative crop due to its high nutritional value and economic importance. The seed of the crop are rich in such proteins (i.e. lysine, threonine and methionine) that are deficient in other cereals crops. It also contains essential fatty acids such as linoleic and alpha-linolenic acids and high quantities of vitamins e.g. Riboflavin (B2), -tocopherol (vitamin E), and other minerals. It contains carbohydrates, low glycemic, gluten-free, fiber, and high levels of antioxidants e.g. alpha and γ-tocopherol, which play an important role in stress tolerance against various environmental conditions. In many studies, Quinoa is reported to have allelopathic potential in plant growth and development. The aqueous extract from the root and leaves of Quinoa had various stimulatory effects on other plants. On the other side, the aqueous extract from inflorescences has inhibitory activities on other plants. Furthermore, due to its high-stress tolerance and adiposity characteristics, quinoa can be grown in different environments. The response of quinoa against abiotic stresses such as salinity, drought, temperature, heat and frost were report in the current review. Moreover, many approaches and constraints in connection to quinoa were explored, which should be addressed in the present and future in order to gain more and to assist them in prospering.

**Keywords:** *Chenopodium quinoa*; allopathic characteristics; nutritional value; stress tolerance

 **Introduction**

For almost 7,000 years, humans have grown and consumed Chenopodium quinoa (Quinoa). It is categorized as a pseudo cereal crop (Cusack, 1984; Koziol, 1993), along with domestic chenopods, amaranths, and buckwheat. Since 1980, quinoa cultivation has generated considerable attention in a number of countries due to its morpho-physiological properties (Galwey, 1992; Jacobsen, 1997). It is regarded as a multipurpose crop since it includes a wide range of essential components, including vitamins, protein, fatty acids, carbohydrates, and dietary fiber (Repo-Carrasco-Valencia, 2011). It also has the highest concentration of micronutrients, phenolic compounds, minerals, and antioxidant substances (FAO, 2013; Tang *et al.,* 2015; Nowak, 2016). However, Because of the ever-increasing global population and the severe effects of climate change, this crop is facing various challenges (Fahad *et al.,* 2017). Changes in ecosystems and human activities are generating numerous problems in the form of environmental stresses, which are causing severe concern (Wallington, 2004; Bajwa *et al.,* 2016). Different approaches, such as allelopathy are used to protect plants from a variety of environmental challenges as from the research quinoa is considered as one of the best plant with the greatest potential to use it on other plants, which could significantly affect the biological and physiological functions of plants (especially nearby plants) (Farooq *et al.,* 2013; Cheng & Cheng, 2015; Duke, 2015; Bajwa *et al.,* 2018). The purpose of this review is to represent an overview of current understanding about Quinoa's allelopathic potential. An overview of the existing research on the chemical composition and nutritional qualities of quinoa is also provided. Furthermore, the detailed description of the existing knowledge of quinoa’s tolerance to various abiotic stressors.

**Morphological characterization of Quinoa**

Quinoa exists in a range of colors and genotypes, including white, red, yellow, and black. The Quinoa’s cultivars differ enormously in tissue shape, phenology, and chemical composition (Bertero *et al.,* 2004). And it may also be cultivated up to 4500 meters above sea level (Tapia,1997). It may be grown in rows using mechanical agricultural techniques, with row spacing ranging from 40 to 80 cm (Valencia-Chamorro, 2003). Quinoa seeds are flattened and spherical, with diameters ranging from 1.5 to 4 mm; around 350 seeds weigh 1 gram and appear in a range of colors, including white, yellow, purple, and black (Ruales & Nair, 1993). Inside seeds, a core perisperm is surrounded by a peripheral embryo as shown in (Fig. 1). One to two cell layers thick endosperm protects the micropyle and the reserve stockpile is divided into many sections (Prego *et al.,* 1998). The reserve store is divided into many sections. The core perisperm stores starch, whereas embryonic tissues and endosperm store lipid and protein components (Bobreneva *et al.,*2018). The pericarp bonds to the seed and contains saponins, which contribute to quinoa's bitter taste. The cylindrical seed is surrounded by a thin layer of episperm. The embryo comprise for up to 60% of the seed's weight (Risic & Galwey, 1984). The cultivation period of Quinoa is from March-15- April-15, the germination percentage late spring e.g. May is very low and the ideal planting density is 25 plants/m2 or (10 kg per acre) (Iliades *et al.,* 1999). The root is lengthy up to 30 cm and grow deep. The stem is cylindrical, with a diameter of 3.5 cm, and may be straight or branching, with a range of colors (Jancurová *et al.,* 2009). The leaves are shaped like a goose foot and range in color from white to yellow to light brown to red, depending on the variety. The flowers are incomplete and lacking petals. Quinoa has both male and female flowers that develop at the distal and proximal edges of bunches (Valencia-Chamorro, 2003). Flowers may be grouped into clusters that are glomerulate or amaranthiforme (Jancurová *et al.,*2009).This structure develops many secondary branches from a central axis, conforming to compact, lax, or mixed inflorescences producing hermaphrodite or unisexual flowers. As a result, hermaphrodite flowers are found at the distal end of the inflorescence's primary, secondary, and tertiary branches (Abdelbar, 2018). Seed harvesting may occur 70–90 days after blossoming, with a total duration from seedling to maturity of 8 months (Valencia-Chamorro, 2003). It is likely to get yields ranging from 45 to 500 g/m2 depending on the species, area and method of cultivation.

**Biochemical and nutritional composition of Quinoa**

Grains are an essential part of the human diet since they provide half of a healthy diet and physical calorie and protein needs (Bobreneva *et al.,* 2018). Quinoa is a perfect example of a "health ingredients," since it may avoid possible a range of ailments (Vega-Gálvez *et al.,* 2010; Repo-Carrasco-Valencia & Serna, 2011). The functional properties may be linked to the availability of essential elements such as fiber, vitamins, fatty acids, antioxidants, and plant hormones, which are all necessary for human nutrition (Antonio, 2015). Quinoa was named one of 23 promising and recommended plants for study in "developing" countries by the National Academy of Sciences (NAS) in 1970, with the goal of improving nutrition and quality of life (Farro, 2008). After hundreds of years of cultivation, the ancient people discovered the crop's amazing nutritional potential, which they renamed "golden grain" and idolized as a holy delicacy, because it is one of the most nutrient-dense foods consumed by humans, the Food and Agriculture Organization (FAO) has identified it as one of the crops that will help ensure global food security in the twenty-first century (Repo-Carrasco-Valencia & Serna, 2011). According to Ogungbenle (2003) and Kupper (2005) quinoa contains less sugars, but it is a starchy raw material with a high carbohydrate content, which is mostly made up of starch. Quinoa is gluten-free and has a well-balanced mix of essential amino acids, making it an easy to digest and balanced meal (Abugoch *et al.,* 2009). It also contains more total protein, methionine, and lysine, as well as fatty acids equivalent to those found in soybean oil, it is a healthier alternative to traditional grains like rice, maize, barley, and wheat (Spehar *et al.,* 2007). Quinoa's biological value is comparable to that of milk protein. People with celiac disease may eat a larger variety of more healthy and acceptable meals since they are gluten-free (Calderelli *et al.,* 2016). It’s also has higher quantities of minerals including potassium, calcium, magnesium, phosphorus, and iron than most other cereals as listed in (Table 1). The panicles and leaves are abundant in protein, fiber, minerals, and vitamins, and may be used in soups, cereals, biscuits, and bread in the same way as rice seeds (Bhargava *et al.,* 2006; Spehar *et al.,* 2007). Furthermore, Quinoa sprouts and leaves are eaten in salads in the same way as spinach leaves are. Because of its great caloric and nutritional content, it is also fed to cattle, pigs, and chickens (Oelke *et al.,*1992; Schlick & Bubenheim, 1996). Some other importance alternative nutrients have been discussed in further detail in the following sections.

**Carbohydrates**

Quinoa has high carbohydrate content gives it the same glycemic index as grains. It is reported that it may now be utilized to generate products that are carbohydrate-based because the seed of quinoa have a perisperm that contains starch, which is different from the endosperm of cereal grains (Satheesh & Fanta, 2018). Based on analyses, starch accounts for 58.1–64.2 % of the dry weight of quinoa, with amylose contributing for around 11% (Repo-Carrasco *et al.,* 2003). Similarly, the seed of quinoa has 26% higher lignin content than other cereals crops even the size of quinoa’s seed is lower than maize and wheat (Qian & Kuhn, 1999; Valencia-Chamorro, 2003). Besides, monosaccharides, disaccharides, crude fiber, and pentosanes were found about 3%, 2%, 3% and 2.9% respectively (Valencia-Chamorro,2003). Some other carbohydrates including maltose (1.4 2.9 mg/100 gm), saccharide (2.9 mg/100 gm, D-galactose, D-ribose, fructose (0.2 mg/100 gm) and glucose (1.7 mg/100 gm) can be also found in quinoa’s seed (Abugoch *et al.,* 2009; Saturni *et al.,* 2010; Vega-Gálvez *et al.,* 2010). The starch of quinoa’s seed has higher viscosity compere to other cereals crops such as wheat and barley (Tang *et al.,* 2002). It is one of two key starches that are well-known across the world having average molar mass of 11.3, less dense than waxy maize starch and healthier (Praznik *et al.,*1999; Park *et al.,* 2007). Furthermore, it has a maximum polymerization degree of 161,000 glucose units and a weighted average polymerization degree of 70,000; it’s also depending on the plant origin(Yao & Shi, 2014). The length of the chain may range from 500 to 6,000 glucose units; however this is the most common range (Werner, 1999).

**Protein**

Proteins and amino acids serve as structural building blocks, catalysts, energy sources, and protein synthesis supplies in biological processes (Morrison & Laeger, 2015). The nutritional value of protein is determined by the quantity of essential amino acids it contains, which animals cannot create on their own and must get from diet (Morrison *et al.,* 2015; Lee *et al.,* 2015). Quinoa is a good source of protein for vegetarians and vegans alike, since it contains all essential amino acids and excludes casein, a protein found in milk (Repo-Carrasco*et al.,* 2003). Its protein content ranges from 12.9 to 16.5% p and it includes all necessary amino acids. The embryo of quinoa is the primary protein source (Saturni *et al.,* 2010; Meneguetti *et al.,* 2011). Also have a higher concentration of the first essential amino acid, lysine, than wheat or maize seeds, which improves amino acid balance (Vilche *et al.,* 2003). In a recent study, it was shown that Bolivian sweet and bitter quinoa provide 14.8% and 15.7 percent of the daily recommended protein intake, respectively (Wright *et al.,* 2002). Besides, quinoa contains isoleucine, lysine, methionine, cysteine, phenylalanine, tyrosine, tryptophan and valine which could be used in different purposes (Table 3).It has been discovered that a high-quality edible vegetable oil made from the lipids of quinoa seeds has an acid-fatty acid composition similar to soybean oil, meaning that the oil is of greater quality for cooking and other purposes than soybean oil (Comai *et al.,* 2007). Quinoa, being one of the most concentrated leaf protein sources available, has the potential to be used as a protein alternative in food and feed, medicine, and other applications ( Bhargava*et al.,* 2005). However, more discoveries are being made all the time, and more research is required to fully understand the protein and amino acid profiles of quinoa.

**Fats**

The essential fatty acids must be obtained from the diet since our systems are unable to produce all of the fatty acids we need. In this context, quinoa has been considered high quality and quantity of its lipid content in their seed oil. Lipid bodies are storage components found in endosperm and embryo tissue cells (Prego *et al.,* 1998).The oil content varies from 2.0% to 9.5% and it contains important fatty acids like linoleic acid, oleic acid, and alpha-linolenic acid, as well as high levels of antioxidants, such as α and γ-tocopherol (Maradini *et al.,* 2015).Tocopherols exist in four isomers, each with antioxidant properties. The obtained oils have a slightly higher concentration of γ-tocopherol than corn germ oil, which has 251 ppm of α-tocopherol and 558 ppm of γ-tocopherol. Thus, quinoa has a long shelf life due to its high oil content and the antioxidant properties of γ-tocopherol (Repo-Carrasco *et al.,* 2003). Quinoa oil also contains unsaponifiable matter (5.2%), lecithins (1.8%), and sterols (1.5%), and has a specific gravity of 0.8910 at 20°C, a refractive index of 1.4637 at 25°C, an acid number of 16.5, a saponification number of 190, and an iodine value (Wijs) of 129 (DeBruin, 1964). Quinoa seeds have the same fatty acid composition as maize and soy beans in terms of linoleicand alpha-linolenic fatty acids (Ando *et al.,* 2002). The oil also contains 85% unsaturated fats, making it comparable in terms of total fats. The most essential lipids are triglycerides found in quinoa seed around 50%, which is identified in significant amounts throughout the seed (Valencia-Chamorro, 2003). All of the fatty acids in quinoa are protected by vitamin E, which is a natural antioxidant (Gordillo-Bastidas *et al.,*2016).

**Minerals and vitamins**

Quinoa plant is rich in micronutrients, vitamins, and minerals, which make it a great source of food(Vega-Galvez *et al.,*2010; Nascimento *et al.,* 2014). It contains Calcium, magnesium, iron, and zinc are all in higher quantities in their grain (Jancurová *et al.,*2009).The embryo contains potassium and magnesium, while the pericarp cell wall contains calcium and phosphorus (Schoenlechner, 2017). Compered to maize, wheat and barley, Quinoa has higher calcium, magnesium, iron, and zinc levels in their grains (Ruales *et al.,* 1994; Ahamed *et al.,* 1998; Vega-Gálvez *et al.,* 2010). It is estimated that 100 g of Quinoa seed will provide adequate magnesium, copper, and iron for both neonates and adults to fulfill their daily needs. However, phosphorus and zinc levels are not ample for children but only meet 40–60% of adult daily needs (Jancurová *et al.,* 2009; González *et al.,* 2014; Nascimento *et al.,*2014). Furthermore, Quinoa has folic acid (78.1mg/100 gm), vitamin C (1.4mg/100 gm), vitamin B6 (0.20mg/100 gm) and pantothenic acid (0.61gm/100 gm)(Vega-Gálvez *et al.,* 2010). Quinoa contained vitamin B1,vitamin B2, vitamin E, α-carotene which are not available in other cereals crops (Kozioł, 1992; Li *et al.,* 2012). In addition, other vitamins such as vitamins A, B2, E, K2, γ, β-carotene, tocopherols, tocotrienols, and niacin can also be found in quinoa seed. Compared to other cereals quinoa has a higher concentration of niacin, riboflavin, vitamin B6, and total folate in their grains (Ranhotra *et al.*,1993; USDA, 2005).According to another study, the riboflavin, which is found in quinoa, can fulfil 85% of the children’s daily life requirements for the vitamin in a single 100 gm meal (National Academy of Sciences, 2004). Quinoa is also high in betaine and its metabolic precursor choline, which is a vitamin-like nutrient that helps the body produce phospholipids like phosphatidylcholine and sphingomyelin.

**Allelopathic potential of Quinoa**

Allelo-chemicals are produced naturally, which is responsible for the development of allelopathic reactions (Cheng & Cheng, 2015). These Allelo-chemicals are released into the environment through a variety of mechanisms as shown in (Fig. 2). Many of these chemical compounds may have an influence on the physiology and ecosystems of nearby plants and animals (Cheng & Cheng, 2015). Quinoa showed various effects (negative and positive) on other plants. Aqueous extracts from the inflorescences of quinoa were shown to suppress oat, bean, and duckweed plants, whereas extracts from the leaves and roots had less negative effecton mentioned plants (Bilalis *et al.,*2013). According to the assessment, due to its weed and crop suppressive properties, quinoa is an allelopathic crop that may be used to control weeds and crops without the use of pesticides (Bianchini *et al.,* 2019). The phyto-toxicity of quinoa plant extracts was assessed using three bioassay approaches. Exposure to the inflorescence caused a greater phytotoxic response than exposure to other quinoa tissue components i.e. leaves, stems, and roots (Bilalis *et al.,* 2013). Quinoa extract had a negative effect on wheat plantlet length, germination percentage, dry weight, and relative water content at low concentrations (5 and 25%), but it also improved it; however, at high concentrations, the extract had a negative effect on morphological traits, and the negative effects of leaf and inflorescence extracts were greater than those of stem and root extracts (Amraie *et al.,* 2021). According to another study, the Quinoa verity (KVL-SRA2; Regalona, Q-37 and Q-52), have positive allelopathic effect on the primary (sugar and carbohydrates) and secondary metabolites (flavonoids, hydroxicinnamic acids, phenolic acid) of Barley (*Hordeum vulgare*) and Onion (*Allium cepa*) (Valencia *et al.,* 2017). Secondary metabolites i.e. saponin component extracts from quinoa proven to have a minor influence on wheat growth as well as plant defense system (Oleszek, 1993). Phenolic composts and flavonoids were found in different varieties of Chenopodium quinoa seeds, which have allelopathic potential on some weeds and cultivated plants (Valencia *et al.,* 2017; Bianchini *et al.,* 2019). Furthermore, aqueous extracts from the quinoa have shown positive effect on the germination of fire plant (*Euphorbia heterophylla),* buckwheat*(Fagopyrum esculentum),* chicory*(Cichorium intbus)* and Bristle Oats*(Avena strigose)* (Bianchini *et al.,* 2019). The use of high concentrations of different quinoa organ extracts reduced germination percentage, germination rate, and the number of normal seedlings. The effects of inflorescence extract on wheat seeds were the most negative and low concentrations of shoot and root extract were found to have positive effects on some of the studied traits (Mansouri & Heshmat, 2020). Similarly, the extract of quinoa plant residue has been found to have a significant effect on the traits of wheat seedlings, such as high concentrations of different organ extracts, increased electrolyte leakage, and antioxidant content; after being exposed to the quinoa organ extract, chlorophyll a, b, and carotenoids decreased. The extracts in low concentrations had a positive effect on the leakage rate of electrolytes and chlorophyll a, whereas high concentrations had a negative effect (Mansouri & Heshmat, 2020). Quinoa is famaousfor antifungal properties against fungal pathogens (Ali *et al.,* 2017). Compounds such as 1-butanol, 3-methyl-; -sitosterol, and stigmasterol found in the n-butanol fraction of quinoa methanolic leaf extract have antifungal activity against *Macrophomina phaseolina* (Khan & Iqra, 2020). Furthermore, quinoa extracts of various parts inhibit mycelial growth and sporulation of a variety of phytopathogenic fungi, such as Sclerotinia sclerotiorum, Rhizoctonia solani, and Botrytis cinerea, and the antifungal effects are due to phenolics, flavonoids, and saponins (Miranda *et al.,* 2014; Glen-Karolczyk *et al.,*2016).

**Tolerance against abiotic stresses**

Abiotic stress is one of the most intractable problems that agriculture faces today. Abiotic stress causes morphological, physiological, biochemical, and molecular changes in plants that have a negative influence on their development and productivity (Wang *et al.,* 2001a). Abiotic stress, which reduces yields by more than 50% worldwide, is the main cause of crop losses. Quinoa can adapt to a variety of stresses due to its natural variability in traits such as inflorescence type, seed size, life-cycle duration, and nutritional value (Bertero *et al.,* 2004). Quinoa selected by the United Nations Food and Agriculture Organization (FAO) as the plant species that can ensure food security in the twenty-first century due to its nutritional properties and significant tolerance to abiotic stresses (Orsini *et al.,* 2011). Many stressors have been reported in the case of quinoa high tolerance response, including salt, drought, cold, frost, and heat, which are reviewed in the following sections.

**Salt stress**

Salt stress is one of the abiotic stress which strongly effect the crop quantity and productivity. The family ‘Chenopodiaceae’ comprises the most halophytic genera, accounting for 44% of all halophytic genera and 321 species (Flowers *et al.,*1986). Quinoa is the most commercially significant species in this family because it can tolerate against salt stress. According to research, it can survive salinities as high as 750 mM NaCl without losing nutritional value (Jacobsen & Mujica, 2001). However, even at 500 mM NaCl, some varieties can complete their life cycle (Adolf *et al.,* 2012). Quinoa may store salt ions inside its tissues to manage and maintain the water potential of its leaves in order to prevent dehydration and possibly death, plants may conserve cell turgor and reduce transpiration under salty circumstances by lowering the quantity of water they lose (Jacobsen *et al.,* 2000). Leaf area, biomass output, seed yield, and harvest index all increased when grown in moderately salty conditions (10–20 mS cm21), demonstrating that quinoa is an adaptive, variegated plant that thrives in saline situations (Jacobsen, 2003). Quinoa reduces salt toxicity in salt bladders by excluding salt from leaf tissues and compartmentalising Na+ into vacuoles (Jaikishun*et al.,* 2019). Epidermal bladder cells (EBCs) are modified epidermal hairs found in quinoa leaves, stems, and inflorescences that have a diameter about 10 times bigger than epidermal cells and can sequester 1000-fold more Na+ than regular leaf cell vacuoles (Hinojosa *et al.,* 2018). EBCs are thought to be storage cells for excess Na+, Cl, and K+ (Agarie *et al.,* 2007). Plant germination stages are sensitive to salinity; salt concentrations ranging from 100 to 250 mM NaCl have no effect on quinoa germination rates in most genotypes, whereas the optimum salinity for quinoa growth ranges from 100 to 200 mM NaCl (Hariadi *et al.,* 2011; Gul *et al.,* 2013; Sun *et al.,* 2017). However, NaCl concentrations ranging from 150 to 250 mM cause germination to be delayed (Orsini *et al.,*2011) and seed germination is inhibited above 400 mM NaCl (Hariadi *et al.,* 2011). The number of stomata per leaf area and density have been shown to be affected by salinity in different parts of the world. In young, middle, and old leaves, a saline concentration of 400 mg/NaCl was shown to have an effect on the stomatal area (Orsini *et al.,* 2011). The opposite effect was reported in "Achachino," with stomatal density increasing by 18% when the plants were grown at 250 mM NaCl; however, the salinity impact reduced stomatal size (Becker *et al.,* 2017). High salt concentrations in the soil cause hyperosmotic stress in the roots, reducing the plant's ability to absorb water efficiently and lowering photosynthetic efficiency (Flowers & Yeo, 1995). When quinoa plants were cultivated at a salt level of 500 mM NaCl, the net photosynthetic rate was reduced by 70%, while CO2 assimilation was reduced by 25% and 67%, respectively, when quinoa plants were grown at 400 mM NaCl (Dinneny, 2015; Eisa *et al.,* 2012). Other studies showed that halotolerant bacteria (Enterobacter sp. and Bacillus sp. sp.) reduced the negative effects of salinity when grown in 300 mM NaCl (Yang *et al.,* 2016). Due to their ability to manufacture phytohormones and dissolve mineral insoluble phosphate halotolerant rhizobacteria have also been used to reduce the damage caused by salt stress (Li *et al.,* 2017). In addition Paclobutrazol, a gibberellic acid synthesis inhibitor has been used to increase yield in quinoa under high salinity conditions 400 mM NaCl (Gómez *et al.,* 2011).

**Drought stress**

Drought is an extreme environmental condition that is increasing as a result of climate change and has a negative impact on agricultural yields globally (Barrera-Figueroa *et al.,* 2011). Quinoa is drought-tolerant, with the capacity to grow in water-stressed soil, resumes photosynthetic activity, and maintains leaf area after a period of drought (Jacobsen *et al.,* 2009). Quinoa contains drought escape, tolerance, and avoidance mechanisms; other preventive methods include tissue flexibility, low osmotic potential, decreased leaf area through dehiscence, the presence of vesicular calcium oxalate, and small and thin-walled cells (Garcia *et al.,* 2007; Abugoch *et al.,* 2009;). According to Siener (2006) and Alvarez-Flores (2012), quinoa's drought resistance is due to its branched and deep root system, which can reach 1.5 m in sandy soils, as well as the presence of calcium oxalate-containing leaf vesicles, which may reduce transpiration. Quinoa also avoids drought by shedding leaves, having small, thick-walled cells that maintain turgor even after severe water losses, and regulating its stomata (Jensen *et al.,* 2000). Quinoa has a high ability to quickly resume leaf formation after severe drought stress, and its wilting point is lower than other crops; the anatomical features that may confer drought tolerance are stomata deeply sunken in the leaf epidermis (Dizès, 1992). Quinoa resists drought for up to three months at the start of its growth cycle (González*et al.,* 2015). Jensen (2000) reported high net photosynthesis and specific leaf area in the early vegetative stage, and low osmotic potential and turgid/dry weight ratios in the later growth stage, during the desiccating soil effect on quinoa leaf conductance, photosynthetic rate, and water relations. Quinoa had higher levels of glucose and total soluble sugars under drought conditions, whereas other carbohydrates like fructose, sucrose, and starch differed slightly but not significantly (Gonzalez *et al.,* 2012). Mild soil drying increased xylem ABA, however ABA produced in the root influenced stomatal function, and soil drying promoted stomatal closure, which reduced photosynthesis (Jacobsen *et al.,* 2009). Stomata do not appear to respond to abscisic acid (ABA) unless they are exposed to extreme dryness, and quinoa plants may photosynthesize for a long period with low irrigation, even three days after stomata close (Jacobsen *et al.,* 2009). Quinoa plants' physiological responses to stress are shown in (Fig. 3). Other studies suggested that adding compost and acidified biochar to drought soils can enhance quinoa plant growth, yield, physiological and antioxidant activities, as well as the chemical and biochemical characteristics of quinoa seeds (Aziz *et al.,* 2018). Synthetic ascorbic acid and natural ascorbic acid (orange juice) increased plant growth, total carotenoids, free amino acids, and several antioxidant enzymes in drought-condition (Hinojosa *et al.,* 2018). Drought tolerance of quinoa was increased by using exogenous H2O2 as a seed primer and 15 mM as a foliar spray, resulting in higher photosynthetic rates, stomatal conductance, chlorophyll content indices, sugar contents, ABA regulation and proline levels (Iqbal *et al.,* 2018). Proline increased growth parameters, relative water content, yield components, and nutritional quality in drought conditions (Elewa *et al.,* 2017).

**Cold stress**

Quinoa is an important grain crop that is less damaged by cold than most other crop species, although little is known about its frost resistance mechanisms (Jacobsen *et al.,* 2005). Cold weather affects germination and other developmental stages such as leaf appearance, water relations, biochemical changes, biomass, and portioning (Bois *et al.,* 2006). The germination of quinoa is in a wide range of temperatures, from extremely cold (1.9 °C) to very hot (> 48.0°C) during the germination stage (Hinojosa *et al.,* 2018).The range of temperatures for germination is from 3 to 50°C. The base germination temperature is 3 ℃, the optimal germination temperature is 30 to 35 ℃, and the maximum germination temperature is 50 ℃ (González *et al.,* 2017). The base temperature is a variable threshold for quinoa development; e.g., Tb is 1°C for the flowering period and leaf appearance, whereas 6°C for leaf width (Bois *et al.,* 2006). Furthermore, it has also been shown to have super cooling properties, protecting it from damage caused by intense cold, andcan tolerate temperatures as low as-16 °C during the vegetative stage and grows well at temperatures as low as-5 °C (Jacobsen, 2003; Bois *et al.,* 2006). These strong antioxidant actvities allows it to tolerate ice formation in its cell walls without causing irreversible damage to the structure and components of the cell (Vera-Hernández *et al.,* 2018). Proline and soluble sugars, such as fructans, sucrose, and deshydrins in quinoa, are used to facilitate the avoidance of ice formation and could also be used as an indicator of frost resistance and lower the freezing and mean lethal temperatures (TL50) (Jacobsen, 2003; Jacobsen *et al.,* 2007). During anthesis, frost was more detrimental than during the vegetative stage, and frost later in the growing season is more detrimental to the crop than frost earlier in the season (Jacobsen *et al.,* 2005). The flowering stage is more susceptible to frost, with yield decreases of 56% in the research when plants were exposed to 4°C for 4 hours (Jacobsen *et al.,* 2005; Hinojosa*et al.,*  2018). A strong frost (-4.4°C) during flowering caused yield losses of more than 70% (Johnson, 1985). Temperatures below -2°C during flowering resulted in significant quinoa losses; however, frost tolerance developed once the seed reached the soft dough stage, and plants could tolerate temperatures as low as -7 °C (Oelke *et al.,* 1992). When plants in anthesis were exposed to -4°C, they reduced 66% of their yield, whereas seedlings at the two-leaf growth stage reduced only 9% (Jacobsen *et al.,* 2005). Quinoa can withstand freezing temperatures before flowerbud formation as well as temperatures as low as -8°C for up to 2 hours during flowering (Bhargava *et al.,* 2006; Jacobsen *et al.,* 2007).

**Heat stress**

Excessive high temperatures during plant growth are one of the most major abiotic stresses, and they are becoming more common as a result of current climate change. The average annual global air temperature is expected to rise by 0.3 to 0.7 ℃ per decade, with a maximum temperature rise of 4.8 ℃ predicted by the end of the century (IPCC *et al.,* 2014). Heat stress, defined as an increase in air temperature above the optimal growth temperature for a period of time long enough to harm plant growth and development, occurs often in tandem with drought in plants and causes severe agricultural losses all across the globe (Wahid *et al.,* 2007; Sehgal*et al.,* 2017). The response of plant to heat stress is different among different verities (Driedonks *et al.,*  2016). Heat stress direct effect plant system including Protein denaturation, increased membrane fluidity, photosynthesis, carbon metabolism enzyme activity. Also bring huge changes in phytohormones such as ABA, salicylic acid, and ethylene; and the induction of secondary metabolites (Wahid *et al.,* 2007). The stress responses of the quinoa plant are shown in (Fig. 4). Quinoa can effort a wide range of temperatures i.e. -8 to 35 °C, and relative humidity conditions i.e. 40-88%, depending on genetic characteristics and phonological stage (Jacobsen *et al.,* 2005). Heat-shock proteins (HSPs) play an important role in heat tolerance, and HSP70 and HSP90 are required to induce heat tolerance (Ohama *et al.,* 2017). The temperature above 35°C  during the flowering and seed fill stages reduces the yields by affecting inflorescences to become seedless or contain empty seeds, as well as the reabsorption of seed endosperm and inhibition of anther dehiscence in quinoa flowers (Bonifacio, 1995; Walters *et al.,* 2016). The high temperatures of 28 °C had no effect on plant dry mass or yield, but the plants had more and longer branches as a result of the high temperatures (Becker *et al.,* 2017). The increase in temperature from 25–6 °C to 40–25 °C during phonological development in quinoa had no effect on seed size, but there were differences in seed weights (Hinojosa *et al.,* 2019). When the temperature varies between 21°C and 28°C, the size of the seeds can change by up to 14% (Bertero *et al.,*1996). The seed production depends on quinoa varieties during high temperatures, e.g., the temperature from 20/14°C to 35/29°C decreased the seed yield of the variety "*Cherry Vanilla*", whereas the seed yield of the variety "Salcedo" increased by 70% (Bunce, 2017). Quinoa is a heat-tolerant plant that can maintain a high stomatal conductance at high temperatures, allowing for heat to be dissipated through transpiration (Kaushal *et al.,* 2016). When quinoa plants were exposed to high temperatures of 40–24°C, they improved maximum photosynthetic rate (A max), stomatal conductance (gs), as well as secondary axis elongation, and branching stimulation (Hinojosa *et al.,* 2019). Quinoa pollen viability decreased at high temperatures (40–24°C), however there was no effect on seed set and no morphological changes in the pollen surface (Hinojosa *et al.,* 2019). Thus, quinoa plants may maintain evaporative cooling under heat stress if there is enough water available (Becker *et al.,* 2017). Quinoa exposed to various water treatments and temperatures showed greater values of stomatal conductance, leaf photosynthetic rate, photosynthetic system efficiency (PSII), and water use efficiency under high temperature conditions (Yang *et al.,* 2016). By reducing the effects of heat stress, irrigation may be an important tool in quinoa cultivation. Under heat-stressed growth conditions, irrigation significantly increased yields (Walters *et al.,* 2016).

**Conclusion**

Quinoa is a significant cereal crop, in addition to having high nutritional value and a range of allopathic effects on other plants. Quinoa has a very significant allelopathic characteristic on herbs, shrubs and trees and increase the physiological and defense mechanism of many plants. It has the potential to be a beneficial crop for both humans and animals due to the high concentration of compounds in it. Quinoa is an easy-to-grow plant with a wide range of qualities that may be useful to people and the environment. It can tolerate salt, cold, and heat stress better than other plants. It includes the same growing conditions even under severe environmental stressors. Quinoa provides a significant portion of a human's nutritional needs, yet there has been relatively limited genetic research to improve the plant's growth, yield, and productivity. Furthermore, certain new varieties of quinoa that are better in flavor and quality are required to be introduced, so the usage of quinoa in meals may increase. Similarly, the allelopathic study is insufficient to fully comprehend the quinoa potential, necessitating more research.

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**Figures and tables**



 **Fig. 1:** Quinoa seed structure and parts.



**Fig. 2: The release of allelochemicals into the environment through possible mechanisms.**



 **Fig. 3:** The physiological responses of quinoa to drought, heat, and salinity.

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 **Fig. 4:** Stress responces in Quinoa plant.

**Table 1:** The nutritions availbale in quiona plant

|  |  |  |  |
| --- | --- | --- | --- |
| Component  | Amount  | Plant part | References |
| Proteina | 16.5 | Grain  | Valencia-Chamorro, 2003 |
| 15.6 | Grain  | DeBruin, 1963 |
| 16.5 | Grain  | Konziol *et al.,* 1992, Vega-Gálvez *et al.,* 2010 |
| 14.1 | Grain  | Hernández-Ledesma etal., 2019 |
| 14.4 | Grain  | Repo-Carrasco *et al.,* 2011, Kent, 1983 |
| 15.6 | Grain  | USDA, 2015 |
| 16.7 | Grain  | Wright *et al.,* 2002 |
| 12.5 | Grain  | Dini *et al.,* 1992 |
| 3.3 | Leaf  | Valencia-Chamorro, 2003 |
| Carbohydratesa | 69.0 | Grain  | Konziol *et al.,* 1992 |
| 61.6 | Grain  | USDA, 2015 |
| 69.0 | Grain  | Valencia-Chamorro, 2003 |
| 72.6 | Grain  | Repo-Carrasco *et al.,* 2011 |
| 69.7 | Grain  | DeBruin,1963 |
| 64.2 | Grain  | Hernández-Ledesma *et al.,* 2019 |
| 4.8 | Leaf  | Valencia-Chamorro, 2003 |
| 74.7 | Grain  | Wright *et al.,* 2002 |
| 60.0 | Grain  | Dini *et al.,* 1992 |
| Fatsa | 5.9 | Grain  | USDA, 2015 |
| 6.3 | Grain  | Konziol *et al.,* 1992 |
| 6.0 | Grain  | Repo-Carrasco *et al.,* 2011 |
| 1.8 | Leaf  | Valencia-Chamorro, 2003 |
| 7.4 | Grain  | DeBruin, 1963 |
| 6.1 | Grain  | Hernández-Ledesma *et al.,* 2019 |
| 6.3 | Grain  | Valencia-Chamorro, 2003 |
| 5.5 | Gain  | Wright *et al.,* 2002 |
| 8.5 | Grain  | Dini *et al.,* 1992 |
| Calcium (Ca)b | 1274 | Grain | Bhargava *et al.,* 2006 |
| 153 | Leaf  | Konziol *et al.,* 1992 |
| 1213 | Grain | Ando, 2002 |
| Potassium (K)b  | 9000 | Grain | Chauhan, 1992 |
| 8257 | Grain | Ando, 2002 |
| 357 | Leaf  | Konziol *et al.,* 1992 |
| Iron (Fe)b | 92 | Grain | Chauhan, 1992 |
| 168 | Grain | Repo-Carrasco *et al.,* 2011 |
| 20 | Grain | Bhargava *et al.,* 2006 |
| Zinc (Zn)b | 48 | Grain | Repo-Carrasco *et al.,* 2011 |
| 48 | Grain | Bhargava *et al.,* 2006 |
| Copper (Cu)b | 7 | Grain | Ando, 2002 |   |
| 9.5 | Grain | Chauhan, 1992 |
| 37 | Grain | Repo-Carrasco *et al.,* 2011 |
| Magnesium (Mg)b | 5000 | Grain | Chauhan, 1992 |
| 4526 | Grain | Ando, 2002 |
| Phosphorus (P)b | 3869 | Grain | Bhargava et al. 2006 |
| 3595 | Grain | Ando, 2002 |
| 42 | Leaf  | Konziol *et al.,* 1992 |
| 1400 | Grain | Repo-Carrasco *et al.,* 2011 |
| 3600 | Grain | Chauhan, 1992 |
| Ascorbic acid (C)c | 0.44 | Grain | Konziol *et al.,* 1992 |
| 16.40 | Grain | Antonio Manoel *et al.,* 2015 |
| Sodium (Na)b | 122 | Grain  | Konziol *et al.,* 1992 |
| 289 | Leaf  | Konziol *et al.,* 1992 |
| Chlorin (Cl)b | 1533 | Grain  | Konziol *et al.,* 1992 |
| Thiamin (B1 )c | 0.38 | Grain | Konziol *et al.,* 1992 |
| 0.36 | Grain | Usda, 2011 |
| Niacin (B3)c | 1.06 | Grain | Konziol *et al.,* 1992 |
| 1.52 | Grain | Usda, 2011 |
| Riboflavin (B2)c | 0.20 | Grain | Antonio Manoel *et al.,* 2015 |
| 0.39 | Grain | Konziol *et al.,* 1992 |
| α-Tocoferol (E)c | 5.37 | Grain | Konziol *et al.,* 1992 |
| β-Carotenec | 8.00 | Grain | Usda, 2011 |
| Linoleice | 53.1 | Grain | Konziol *et al.,* 1992 |
| 50.2 | Grain | Repo-Carrasco *et al.,* 2011 |
| Linolenice | 3.9 | Grain | Ruales, 1993 |
| 4.8 | Grain | Repo-Carrasco *et al.,* 2011 |
| Oleice | 23.3 | Grain | Konziol *et al.,* 1992 |
| 24.8 | Grain | Ruales *et al.,* 1993 |
| Histidined | 3.1 | Grain | Vega‐Gálvez *et al.,* 2010 |
| 3.2 | Grain | Jancurová *et al.,* 2009 |
| 2.4 | Leaf  | Konziol *et al.,* 1992 |
| Threonined | 3.4 | Grain | Repo-Carrasco *et al.,* 2011 |
| 3.8 | Grain | Konziol *et al.,* 1992 |
| Valined | 4.2 | Grain | Repo-Carrasco *et al.,* 2011 |
| 7.5 | Leaf  | Valencia-Chamorro, 2003 |
| 4.0 | Grain | Vega‐Gálvez *et al.,* 2010 |
| Lysined | 6.0 | Grain | Jancurová *et al.,* 2009 |
| 6.1 | Grain | Konziol *et al.,* 1992 |
| Tryptophand | 1.1 | Grain | Jancurová *et al.,* 2009 |
| 0.9 | Grain | Repo-Carrasco *et al.,* 2011 |
| Methionine+ cysteined | 2.0 | Grain | Vega‐Gálvez *et al.,* 2010 |
| 4.8 | Grain | Konziol *et al.,* 1992 |
| Phenylalanine+ tyrosined | 6.9 | Grain | Jancurová *et al.,* 2009 |
| 6.2 | Grain | Repo-Carrasco *et al.,* 2011 |
| Isoleucined | 4.4 | Grain | Konziol *et al.,* 1992 |
| 5.8 | Leaf  | Valencia-Chamorro *et al.,* 2003 |
| 3.3 | Grain | Vega‐Gálvez *et al.,* 2010 |
| Leucined | 6.6 | Grain | Jancurová *et al.,* 2009 |
| 5.8 | Grain | Vega‐Gálvez *et al.,* 2010 |
| 6.6 | Grain | Konziol *et al.,* 1992 |
| 6.9 | Leaf  | Konziol *et al.,* 1992 |
| 6.1 | Grain | Repo-Carrasco *et al.,* 2011 |

a(g/100g)

b(mg/kg DRY WT)

c (mg 100 g-1 )

d (g 100 g−1 protein)

e(g 100 g−1 of oil extract)

**Table 2:** Some other chemical availbale in quiona plant.

|  |  |  |  |
| --- | --- | --- | --- |
| Chemical name  | Extract parts | Function  | Refrences  |
| Caffeic acid | Seed | Activity against microbes | Tang *et al.,* 2016Tsou *et al.,* 2000 |
| Ferulic acid | Leaves, sprouts and seeds | Reduced inflammatory response | Pasko *et al.,* 2008Kwon *et al.,* 2010 |
| Rosmarinic acid | Seed  | Antiviral properties | Furtado *et al.,* 2008 |
| Kaempferol | Leaves and seed  | Anti-bacterial activity  | Cai, 1996 |
| Quercetin | Leaves and seed | Toxicity to the cells | Silva *et al.,* 2016Tang *et al.,* 2016 |
| Hesperidin | Seed  | Antifungal activity | Salas *et al.,* 2011 |
| Catechin | Seed  | Activity against mutagenesisAntifungal activityApoptosis-inducing activity | Tang *et al.,* 2016Geetha *et al.,* 2004Saeki *et al.,* 2000 |
| Daidzein | Seed  | Chemoprotective activity | Lepri *et al.,* 2013 |
| Oleanolic acid | Seed and bran  | Antifertility activity | Rajasekaran *et al.,* 1988 |
| β-Amyrin | Seed  | Growthregulating activities and Insecticidal activity | Kannan *et al.,* 2013 |
| β-Sitosterol | Seed  | Genotoxicity effectInducing apoptosis | Paniagua-Pérez *et al.,* 2005, Ahamed *et al.,* 1998 |
| Makisterone A | Seed  | Inhibitory activity on collagenase | Nsimba *et al.,* 2008 |
| Isovitexin | Sprout  | Inhibitory effect on α-glucosidase | Shibano *et al.,* 2008 |
| Vitexin | Sprout and seed  | Antioxidant activityAnti-viral effect Antimicrobial activity | Knipping *et al.,* 2012Pasko *et al.,* 2008 |
| Isorhamnetin | Leaves  | Chemopreventive activity | Saud *et al.,* 2013 |
| Genistein | Seed  | Induction of quinone reductase activity, Induces growth arrest and suppresses | Kim *et al.,* 1996Lutz *et al.,* 2013 |
| Methyl oleanate | Bran  | Anti-inflammatory activity | Lozano *et al.,* 2013 |
| Erythrodiol | Seed  | Antibacterial activity | Kemboi *et al.,* 2016 |

**Table 3:** Response of Quinoa towards abiotic stresses by different chimcal and antioxiandant enzymes

|  |  |  |  |
| --- | --- | --- | --- |
| Chemical  |  Function | Stress type | Refrences  |
| Saponin  | Reducing Na+ uptake and improving water relations | Salinity  | Yang *et al.,* 2018 |
| Polyethylene glycol l  | Improved germination in salinity conditions | Salinity | Moreno *et al.,* 2018 |
| Paclobutrazol  | Improved chlorophyll and carotenoid content, increased accumulation of osmoprotectants and antioxidants in leaf and root tissues | Salinity  | Waqas *et al.,* 2017 |
| Proline and phenolics  | Salt tolerance | Salinity  | Ruffino *et al.,* 2010, Ruiz-Carrasco *et al.,* 2011 |
| Choline  | Play an important role in the osmotic adjustment to salinity stress  | Salinity | Pottosin *et al.,* 2014 |
| Betalains | Salt stress tolerance due to their antioxidant activity | Salinity  | Jain *et al.,* 2015 |
| Gene CqCYP76AD1-1 | Involved in betalain biosynthesis during the hypocotyl pigmentation process in quinoa  | Salinity  | Imamura *et al.,* 2018 |
| Proline and Soluble sugar (Fructose, Sucrose ) | Used to facilitate the avoidance of ice formation and lower the freezing and mean lethal temperatures (TL50) | Cold  | Jacobsen *et al.,* 2007 |
| CO2/H2O gas | Key determinant for plant growth and biomass production | Salanity  | Gulzar *et al.,* 2003 |
| Heat-shock proteins (HSPs) | Play a central role in the heat stress response (HSR) when plants suffer from either an abrupt or gradual increase in temperature | Heat  | Wahid *et al.,* 2007 |
| Proteins (dehydrins) | Osmoprotective function | Salanity | Svensson, 2002 |
| Abscisic acid (ABA) | Induced a decreased turgor of stomata guard cells | Drought  | Jacobsen *et al.,* 2009 |
| Ammonium nitrate (NH4NO3) | Improve plant performance | Drought  | Alandia *et al.,* 2016 |
| Acidified biochar | Improve quinoa plant growth, yield, physiological, and antioxidant activit | Drought  | Aziz *et al.,* 2018 |
| Synthetic ascorbic acid and orange juice (natural ascorbic acid) | Increase Plant growth, total carotenoids, free amino acids, and several antioxidant enzymes | Drought  | Aziz *et al.,* 2018 |
| Heat shock protein HSP70s | Play an important role in response to stress | Drought  | Liu *et al.,* 2018 |
| Amino acids, Proline,Betain | Plants respond to stress by accumulating. | Drought  | Vartanian *et al.,* 1992Good, 1994Hanson, 1982 |