Abiotic Stresses: Alteration of Composition and Grain Quality in Food Legumes

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Abstract: Abiotic stresses varyingly affect the grain composition and quality of food legumes. This paper is aimed at discussing the impact of abiotic stresses on the grain composition and quality of food legumes. As protein is the main grain constituent of food legumes for which it is being consumed by humans as a cheap protein source, abiotic stresses such as heat, cold, drought, salinity and heavy metals alter this grain protein content in different dimensions for different food legumes. Moreover, other valuable constituents such as starch, soluble sugar, oil, fatty acid and fiber content are affected differently by the abiotic stresses. The diverse impact of these abiotic stresses ultimately declines the grain quality and yield of food legumes. As food legumes play a vital role in the nutritional diet of millions of people in the world and are occasionally denoted as the meat of poor people, it is important to recognize that the sustainable production of food legumes, even under various environmental stresses, has the potential to ensure protein security for people globally. Therefore, it has become a necessity to improve the productivity and quality of food legumes under abiotic stresses through proper crop management and improved breeding strategies, thus enhancing food and economic security to the farmers, particularly in the developing countries of the world.

Keywords: abiotic stress; heat stress; drought; salinity; heavy metals; legume; food quality

1. Introduction

The increasing population along with global climate change are generating a great influence on the agroecosystem and creating various abiotic stresses that are major threats for global food security. Therefore, one of the major challenges of this era is to maintain a sustainable yield under these stresses and meet the global food demand with nutritional food. Food legumes are one of the major crops that may be included in the cropping system for attaining the nutritional and protein requirements of this growing population, as the protein gap is likely to increase with the increasing population [1].

Food legumes from the second most important plant family Fabaceae, are agriculturally important nourishing crops provided as a low-cost and rich source of protein to human beings. In terms of world production, food legumes rank third after cereals and oilseeds, having a strong impact on the agro-ecosystem and human nutrition [1]. Nearly 27% of global crop production is occupied with food legumes [2]. Food legumes are consumed mostly for edible proteins and oil; those are considered as the major grain quality components of food legumes. Food legumes are grown in variable climates and abiotic stresses
such as temperature, drought, salinity and heavy metals can affect the grain composition and quality of food legumes [3]. Grain starch, protein, oil, fatty acids, amino acids, sugars, dietary fibers, minerals and vitamin contents are considered as the major components of grain composition that help to determine the quality of food legumes [4]. Abiotic stresses disturb and distinctly change these grain components and the quality of food legumes. Heat stress has a damaging effect on the seed yield and the quality of food legumes as the process of entire seed setting such as the development of a male and female gametophyte, fertilization and the development of seed is sensitive to heat stress [5]. Cold stress is one of the limiting factors for the early sowing of food legumes, as it disrupts the membrane stability and whole-grain contents of food legumes [1]. Food legumes are commonly grown in rainfed production systems. As a result, food legumes are more susceptible to drought and the intensity and frequency of drought have been predicted to increase according to global climate models. Drought affects crop growth and becomes more devastating during reproduction and grain filling, thus decreasing grain yield [6]. The productivity of grain legumes is frequently affected by terminal drought.

Food legumes are highly sensitive to salinity stress, particularly at the seedling and developmental stages [7]. Salinity stress declines water potential due to abundance in Na⁺ and Cl⁻ ions in plant tissues resulting in stomatal closure, photosynthesis decline and inhibition of growth those ultimately affect the grain composition, yield and quality of food legumes [8]. Heavy metal is one of the major constraints in food legume production and the maintenance of grain quality. Heavy metals considerably diminish the grain protein content due to a lowered N uptake and supply to the emerging grains [9]. Ultra-structural and anatomical changes in plant cells take place due to the uptake and accumulation of heavy metals at higher concentrations as plant physiological activities such as nutrition distribution, nitrogen fixation, enzymatic activity, photosynthesis, function of pollen and the nutritional quality of seeds are adversely affected by heavy metal stress [10]. Research is needed on the impact of abiotic stresses on food legume grain composition and quality for developing programs to improve the grain quality as well as resistance to abiotic stresses to ensure the adequate global supply of food legumes as the most significant source of vegetable proteins.

### 2. Food Legumes

Mainly three types of legumes are used, namely forage legumes, food legumes and cover crops, whereas food legumes are mostly used as a rich source of protein [1]. Most of the legume crops are consumed as food in the mature and dry seed form [11]. Food legumes inhabit a minimum part of the cultivable land of the world, which is mostly conquered by major cereal crops (e.g., rice, wheat, maize) [12]. The protein demands of the growing population can be fulfilled by the insertion of food legumes into cropping systems. Food legumes play an important and diverse role as a nutritious staple of poor people around the world as an inexpensive source of protein, complex carbohydrates, vitamins and fiber [13]. Soybeans, peas, peanuts, lentils, different types of beans and chickpeas are commonly used food legumes (Table 1).

**Table 1. Different kind of food legumes and their uses in human nutrition.**

| Sl. No | Picture | Common Name | Scientific Name | Major Use | Sources of Images [Accessed on 22 May 2021] |
|-------|---------|-------------|----------------|-----------|------------------------------------------|
| 1.    | ![Soybean](https://zh-prod-1cc738ca-7d3b-4a72-b792-20bd8d8fa0e9.storage.googleapis.com/s3fs-public/styles/max_650\times650/public/2020-08/soybeans.jpg?itok=DuPlsOBn) | Soybean | Glycine max | Mainly used for soybean oil. Additionally used as food products such as soymilk, soy sauce, some beverages and whipped toppings, soy-fortified pastas, breakfast cereals and bars [14]. | [https://zh-prod-1cc738ca-7d3b-4a72-b792-20bd8d8fa0e9.storage.googleapis.com/s3fs-public/styles/max_650\times650/public/2020-08/soybeans.jpg?itok=DuPlsOBn](https://zh-prod-1cc738ca-7d3b-4a72-b792-20bd8d8fa0e9.storage.googleapis.com/s3fs-public/styles/max_650\times650/public/2020-08/soybeans.jpg?itok=DuPlsOBn) |
Table 1. Cont.

| Sl. No | Picture | Common Name | Scientific Name | Major Use | Sources of Images [Accessed on 22 May 2021] |
|--------|---------|-------------|-----------------|-----------|-------------------------------------------|
| 2.     | ![Chickpea](https://fgmh.tq.com/2jDB8mU_-S9vxjfebik4O763sg=-/696x/0/filters:no_upscale/1/06a30edc5f9b58b7d0d03627.jpg) | Chickpea | *Cicer arietinum* | Used as a dry pulse and also as a green vegetable [14,15]. | [https://agtfoods.co.za/wp-content/uploads/2018/06/Desi-Chickpea_600x600_1.jpg](https://agtfoods.co.za/wp-content/uploads/2018/06/Desi-Chickpea_600x600_1.jpg) (accessed on 22 May 2021) |
| 3.     | ![Pea](https://www.allergicleiving.com/wp-content/uploads/2019/09/Green-peas.jpg) | Pea | *Pisum sativum* | Used both fresh and dried. Peas are rich in protein, cholesterol-free and have good amounts of dietary fiber [14]. | [https://www.allergicleiving.com/wp-content/uploads/2019/09/Green-peas.jpg](https://www.allergicleiving.com/wp-content/uploads/2019/09/Green-peas.jpg) (accessed on 22 May 2021) |
| 4.     | ![Groundnut](https://www.nutstop.com/how-peanuts-grow/1.jpg) | Groundnut | *Arachis hypogaea* | Groundnuts contain high level of monounsaturated and polyunsaturated fatty acids that may keep the heart healthy by maintaining lower blood cholesterol levels [16]. | [https://www.nutstop.com/how-peanuts-grow/](https://www.nutstop.com/how-peanuts-grow/) (accessed on 22 May 2021) |
| 5.     | ![Red lentil](https://jiraphaserviceltd.com/wp-content/uploads/2020/10/7RLT1-1.jpg) | Red lentil | *Lens culinaris* | Red lentils contain plenty of protein and fiber; thus, it is called the meat of poor people. It is a healthier choice for the heart instead of processed meat [14]. | [https://jiraphaserviceltd.com/wp-content/uploads/2020/10/7RLT1-1.jpg](https://jiraphaserviceltd.com/wp-content/uploads/2020/10/7RLT1-1.jpg) (accessed on 22 May 2021) |
| 6.     | ![Green lentil](https://www.grainstar.com.au/wp-content/uploads/2018/05/richlea-lentils.jpg) | Green lentil | *Lens culinaris* | It is a rich source of protein and a good supplement for meat. It reduces the risk of heart diseases [17]. | [https://www.grainstar.com.au/wp-content/uploads/2018/05/richlea-lentils.jpg](https://www.grainstar.com.au/wp-content/uploads/2018/05/richlea-lentils.jpg) (accessed on 22 May 2021) |
| 7.     | ![Brown lentil](https://fthmb.tq.com/2jDB8mU_-S9vxjfebik4O763sg=-/696x/0/filters:no_upscale/1/06a30edc5f9b58b7d0d03627.jpg) | Brown lentil | *Lens culinaris* | Brown lentils are a good source of nutrients and its low calorie content and high fiber helps healthy digestion [16]. | [https://fthmb.tq.com/2jDB8mU_-S9vxjfebik4O763sg=-/696x/0/filters:no_upscale/1/170460595-56a30edc5f9b58b7d0d03627.jpg](https://fthmb.tq.com/2jDB8mU_-S9vxjfebik4O763sg=-/696x/0/filters:no_upscale/1/170460595-56a30edc5f9b58b7d0d03627.jpg) (accessed on 22 May 2021) |
| 8.     | ![Black lentil](https://agtfoods.co.za/wp-content/uploads/2018/06/Black-Lentils_3.jpg) | Black lentil | *Lens culinaris* | Black lentils are the most flavorful lentils and are quite different from other lentils, used in salads and soups [17]. | [https://agtfoods.co.za/wp-content/uploads/2018/06/Black-Lentils_3.jpg](https://agtfoods.co.za/wp-content/uploads/2018/06/Black-Lentils_3.jpg) (accessed on 22 May 2021) |
| 9.     | ![Mung bean](https://www.espacoagro.com/AFFAIRE/188567.jpg) | Mung bean | *Vigna radiata* | Contains essential amino acids and antioxidants that help to neutralize free radicals, thus working against chronic inflammation, heart disease, cancers and other diseases [14,18]. | [https://agtfoods.co.za/wp-content/uploads/2018/05/Black-Lentils_3.jpg](https://agtfoods.co.za/wp-content/uploads/2018/05/Black-Lentils_3.jpg) (accessed on 22 May 2021) |
| 10.    | ![Black eyed bean](https://agtfoods.co.za/wp-content/uploads/2018/06/Black-Eyed-Beans_600x600_1.jpg) | Black eyed bean | *Vigna unguiculata* | Improves digestion and its adequate iron content helps to prevent anemia. It is rich in potassium that helps to maintain lower blood pressure [14,19]. | [https://agtfoods.co.za/wp-content/uploads/2018/06/Black-Eyed-Beans_600x600_1.jpg](https://agtfoods.co.za/wp-content/uploads/2018/06/Black-Eyed-Beans_600x600_1.jpg) (accessed on 22 May 2021) |
### Table 1. Cont.

| Sl. No | Picture | Common Name               | Scientific Name          | Major Use                                                                 | Sources of Images                                                                 |
|--------|---------|---------------------------|--------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 11.    | ![Fayot bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252) | Fayot bean               | *Phaseolus vulgaris*        | It is a source of dietary fiber that helps to prevent cholesterol absorption and increase the fat elimination [14]. | [https://www.onlyfoods.net/different-types-of-beans.html](https://www.onlyfoods.net/different-types-of-beans.html) (accessed on 22 May 2021) |
| 12.    | ![Navy bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252)   | Navy bean                | *Phaseolus vulgaris*        | This bean has anticancer potential. It also helps to lower diabetes risk and greater gut health [14]. | [https://www.thedailymeal.com/sites/default/files/slideshows/1670994/2173040/21-navy_beans-ThinkstockPhotos-494876324.jpg](https://www.thedailymeal.com/sites/default/files/slideshows/1670994/2173040/21-navy_beans-ThinkstockPhotos-494876324.jpg) (accessed on 22 May 2021) |
| 13.    | ![Red bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252)       | Red bean                 | *Vigna umbellata*          | Protects the body from free radical damage that helps in controlling blood sugar levels [16]. | [http://productkg.com/sites/default/files/tomatnaya-fasoltalas_0.jpg](http://productkg.com/sites/default/files/tomatnaya-fasoltalas_0.jpg) (accessed on 22 May 2021) |
| 14.    | ![Red kidney bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252)  | Red kidney bean          | *Phaseolus vulgaris*        | Red kidney beans are full of folate (vitamin B9) and fiber, which helps to promote cardiovascular health [18]. | [https://www.foodsafetynews.com/files/2020/07/dreamstime_red-kidney-bean-lectins.jpg](https://www.foodsafetynews.com/files/2020/07/dreamstime_red-kidney-bean-lectins.jpg) (accessed on 22 May 2021) |
| 15.    | ![White kidney bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252) | White kidney bean        | *Phaseolus vulgaris*        | It helps in blocking the carbs from being absorbed and metabolized in the human body [18]. | [https://ixivixi.com/wp-content/uploads/2015/07/White-Kidney-Bean-Extract-for-Weight-Loss-1.jpg](https://ixivixi.com/wp-content/uploads/2015/07/White-Kidney-Bean-Extract-for-Weight-Loss-1.jpg) (accessed on 22 May 2021) |
| 16.    | ![Pinto bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252)        | Pinto bean               | *Phaseolus vulgaris*        | Contains a good amount of vitamin B1 that helps to convert food into energy. Additionally, it contains many antioxidants such as polyphenols and flavonoids [16,17]. | [https://cdn.shopify.com/s/files/1/1834/0943/products/bean-pinto_569fa89-d3d4-41b4-856d-3db099771330_80x.png?v=1505218437](https://cdn.shopify.com/s/files/1/1834/0943/products/bean-pinto_569fa89-d3d4-41b4-856d-3db099771330_80x.png?v=1505218437) (accessed on 22 May 2021) |
| 17.    | ![Cranberry bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252)      | Cranberry bean           | *Phaseolus vulgaris*        | It is good for the heart as it contains various powerful minerals and enzymes that help to lower bad cholesterol [18]. | [https://www.mexicanplease.com/wp-content/uploads/2017/03/cranberry-beans-spread-onto-cutting-with-solids.jpg](https://www.mexicanplease.com/wp-content/uploads/2017/03/cranberry-beans-spread-onto-cutting-with-solids.jpg) (accessed on 22 May 2021) |
| 18.    | ![Adzuki bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252)         | Adzuki bean              | *Vigna angularis*          | It helps to balance sugar level and reduces the risk of diabetes. Improves the strength of bones [20]. | [https://www.suttonshaytrading.com/wp-content/uploads/2013/06/adzuki-beans.jpg](https://www.suttonshaytrading.com/wp-content/uploads/2013/06/adzuki-beans.jpg) (accessed on 22 May 2021) |
| 19.    | ![Faba bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252)           | Faba bean (Broad bean)   | *Vicia faba*               | It helps to prevent birth defects as it is incredibly nutritious and an excellent source of soluble fiber, protein, manganese, copper folate and many other micronutrients [16]. | [http://storage.googleapis.com/powop-assets/kew_profiles/KPPCONT_085134_fullsize.jpg](http://storage.googleapis.com/powop-assets/kew_profiles/KPPCONT_085134_fullsize.jpg) (accessed on 22 May 2021) |
| 20.    | ![Lima bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_530x@2x.jpg?v=1578338252)           | Lima bean                | *Phaseolus lunatus*        | Helps to prevent chronic disease, diseases associated with digestion and stimulates blood circulation [14]. | [https://judiesblog.files.wordpress.com/2010/10/img_5993.jpg](https://judiesblog.files.wordpress.com/2010/10/img_5993.jpg) (accessed on 22 May 2021) |
Table 1. Cont.

| Sl. No | Picture | Common Name | Scientific Name | Major Use | Sources of Images [Accessed on 22 May 2021] |
|--------|---------|-------------|-----------------|-----------|------------------------------------------|
| 21.    | ![Grass pea](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_53bx62x.jpg?v=1578338252) | Grass pea | *Lathyrus sativus* | Grass pea seeds are used as a common staple food in many countries of Asia and Africa [21]. | [Link to image](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_53bx62x.jpg?v=1578338252) |
| 22.    | ![Lupin bean](https://i.pinimg.com/originals/21/29/fa/2129fa4b595f818e23046dd8aae4b290.png) | Lupin bean | *Lupinus albus* | It contains antioxidants that promote proper digestion and keep intestines healthy. Additionally, aids in weight loss, provides essential vitamins and minerals and reduces high blood pressure [18,22]. | [Link to image](https://www.firstforwomen.com/wp-content/uploads/sites/2/2019/01/what-are-lupin-beans-benefits.jpg?v=715) |
| 23.    | ![Common bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_53bx62x.jpg?v=1578338252) | Common bean | *Phaseolus vulgaris* | Beans are an excellent source of protein, lower in calories and saturated fat than some other protein sources such as meat [16,17]. | [Link to image](https://www.firstforwomen.com/wp-content/uploads/sites/2/2019/01/what-are-lupin-beans-benefits.jpg?v=715) |
| 24.    | ![Runner bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_53bx62x.jpg?v=1578338252) | Runner bean | *P. multiflorus* | The dried pods of runner bean have diuretic properties that help to cure urinary tract infections and reduce weight [18,23]. | [Link to image](https://www.firstforwomen.com/wp-content/uploads/sites/2/2019/01/what-are-lupin-beans-benefits.jpg?v=715) |
| 25.    | ![Hyacinthbean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_53bx62x.jpg?v=1578338252) | Hyacinthbean | *Lablab purpureus* | It contains complex carbohydrates and a good amount of zinc, which is useful to lose weight and prevent cancer, respectively, as Zn prevents cells mutating and assists cell division [16,22]. | [Link to image](https://www.firstforwomen.com/wp-content/uploads/sites/2/2019/01/what-are-lupin-beans-benefits.jpg?v=715) |
| 26.    | ![Rice bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_53bx62x.jpg?v=1578338252) | Rice bean | *V. umbellata* | It helps to cure diseases such as edema and increases digestibility [17,23]. | [Link to image](https://www.firstforwomen.com/wp-content/uploads/sites/2/2019/01/what-are-lupin-beans-benefits.jpg?v=715) |
| 27.    | ![Black gram](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_53bx62x.jpg?v=1578338252) | Black gram | *V. mungo* | It helps in boosting energy, protecting cardiovascular health, improving immunity, maintaining skin health, building strong bones, managing diabetes and strengthening the nervous system [16,18]. | [Link to image](https://www.firstforwomen.com/wp-content/uploads/sites/2/2019/01/what-are-lupin-beans-benefits.jpg?v=715) |
| 28.    | ![Pigeon pea](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_53bx62x.jpg?v=1578338252) | Pigeon pea | *Cajanus cajan* | It helps to manage blood pressure, boost heart health and prevent anemia, thus strengthening the immune system [18,20,22]. | [Link to image](https://www.firstforwomen.com/wp-content/uploads/sites/2/2019/01/what-are-lupin-beans-benefits.jpg?v=715) |
| 29.    | ![Velvet bean](https://cdn.shopify.com/s/files/1/2333/6781/products/grass_pea_photo_53bx62x.jpg?v=1578338252) | Velvet bean | *Mucuna pruriens* | Supplies L-Dopa that turns into dopamine, which helps to improve mood, mental clarity, sense of well-being, better sleep and brain function. Additionally, it helps to combat Parkinson’s disease and depression [18]. | [Link to image](https://www.firstforwomen.com/wp-content/uploads/sites/2/2019/01/what-are-lupin-beans-benefits.jpg?v=715) |
3. Economic Importance of Food Legumes

Food legumes are mainly essential to developing countries, as they offer a source of protein, trace nutrients and calories to people who are not able to afford more pricey nutritional sources [24]. These are perfect crops for accomplishing developmental goals such as improving the health and nutrition of humans, reducing poverty and enhancing the resilience of the ecosystem [25]. Due to the involvement of food legumes such as pulses in nutritional diversity that helps to eliminate hunger and malnutrition, the Food and Agriculture Organization (FAO) of the United Nations stated 2016 as the International Year of Pulses [11]. Food legumes can potentially manage sustainable agriculture through the enhancement of productivity as well as crop diversity and a reduction in the dependency on external inputs, as food legumes have the capabilities of nitrogen (N) fixation by biological means, efficient roles in nutrient and water retention, the ability to increase soil organic matter (SOM) and aid the recovery of soil health by improving soil properties [26]. As one of the most important food legume producing countries, India has started introducing cool-season food legumes that fit the rice-fallow ecology to change the rice-fallow system into a rice-food legume system that will help to not only uplift the socio-economic condition of smallholder rice farmers, ensuring their food and nutritional security, but also to break the pests and diseases cycle of rice and improve the soil’s structure and fertility through the augmentation of the overall sustainable productivity of the rice-fallow system [27].

4. Grain Composition of Food Legumes

The grain of a food legume is composed of protein, dietary fiber, starch or oil in the form of energy, macro and micronutrients, vitamins and several bioactive phytochemicals such as antioxidants [19]. The protein content of food legumes (Table 2) varies from 20–40% [28].

Table 1. Cont.

| Sl. No | Picture | Common Name | Scientific Name | Major Use |
|-------|---------|-------------|----------------|-----------|
| 30.   | ![Winged bean](https://i.pinimg.com/originals/21/29/fa/2129fa4b595f818e23046dd88ae4b290.png) | Winged bean | *Psophocarpus tetragonolobus* | This bean is rich in vitamin C and vitamin A, which help in strengthening the immune system and supporting the body against any possible infections and diseases [16,22,23]. |
| 31.   | ![Sword bean](https://i.etsystatic.com/7772783/r/il/442d44/1253663464/il_fullxfull.1253663464_bodq.jpg) | Sword bean | *Canavalia gladiata* | It enhances the function of the nervous system, prevents bone resorption and inhibits bone turn over [16–18]. |
| 32.   | ![Jack bean](https://i.etsystatic.com/15567684/r/il/ffddf/2833501891_8key.jpg) | Jack bean | *Canavalia ensiformis* | It is a fiber-rich bean that helps in removing toxins and waste products in the gut. Helps in preventing constipation and abdominal distention. The Vitamin C present in this bean helps in defending the body against disease-causing microorganisms such as bacteria and viruses [23]. |

Sources of Images

[Accessed on 22 May 2021]
Table 2. Percent protein, carbohydrate and lipid present in different food legumes.

| Food Legumes     | Protein % | Carbohydrate % | Lipid % |
|------------------|-----------|----------------|---------|
| Chickpea         | 21        | 62.95          | 6.04    |
| Groundnut        | 26        | 16.13          | 49.24   |
| Lentil           | 25        | 63.35          | 1.06    |
| Black gram       | 25        | 60             | 1.64    |
| Mung bean        | 24        | 62.62          | 1.15    |
| Soybean          | 40        | 6.4            | 21.3    |
| Pea              | 25        | 51.3           | 1.2     |
| Pigeon pea       | 22        | 62.78          | 1.49    |
| Cowpea           | 24        | 35.5           | 0.91    |
| Faba bean        | 29        | 44.7           | 1.4     |
| White lupin      | 38        | 0.0            | 10.0    |
| Adzuki bean      | 20        | 62.90          | 0.53    |
| Navy bean        | 22        | 60.75          | 1.50    |
| Lima bean        | 21        | 63.38          | 0.69    |

Source: Jukanti et al. [15,19], Kamboj and Nanda [17], Amarowicz [22], USDA [29], Ge [30].

It also contains oligosaccharides, phytoestrogens, phytohemagglutinins (lectins), saponins and phenolic compounds that play metabolic roles in humans who consume these foods frequently [22]. The primary phenolic compounds found in a legume seed and seed coats are phenolic acids, condensed tannins and flavonoids [19]. The phenolic compounds are varyingly distributed in different legume seeds (Table 3) and colored legumes are found with more phenolic compounds than uncolored legumes [19]. The total phenolic content (TPC) provides a wide variability in various food legumes and the antioxidant activity of these legumes is directly related to their TPC [31].

Table 3. Variable phenolic compounds present in food legumes.

| Legume          | Phenolic Compounds                        | Quantity (µg/g) | Found in | References |
|-----------------|-------------------------------------------|-----------------|----------|------------|
| Lentil          | Hydroxybenzoics                            | 5.69            | Seed     | [18,32,33] |
|                 | Dihydroxybenzoic acid                      | 3.68            |          |            |
|                 | p-hydroxybenzoic acid                      | 1.48            |          |            |
|                 | Protocatechluic acid                       | 0.36            |          |            |
|                 | Protocatechluic aldehyde                   | 0.13            |          |            |
|                 | 2,3,4-trihydroxybenzoic acid              | 16.9–29.2       |          |            |
|                 | Gallic acid                                | 90.9–136.8      |          |            |
|                 | Vanillic acid                              | 0.99–3.22       |          |            |
|                 | Hydroxycinnamianes                         | 3.76            |          |            |
|                 | Trans-p-coumaroyl malic acid               | 10.02           |          |            |
|                 | Trans-p-coumaroyl glycolic acid            | 2.88            |          |            |
|                 | Trans-p-coumaric acid                      | 5.74            |          |            |
|                 | Sinapic acid                               | 1099–2217       |          |            |
|                 | chlorogenic acid                           | 159–213         |          |            |
| Green lentil    | Trans-p-coumaric acid                     | 37.3            | Seed     | [18,32]    |
|                 | Trans-p-coumaric acid derivative           | 6.4             |          |            |
|                 | Trans-ferulic acid                         | 10.1            |          |            |
| Pinto bean      | Hydroxybenzoics,                           | 84.92           | Seed     | [18,32,33] |
|                 | Salicylic acid                             | 44.89           |          |            |
|                 | Vanillic acid                              | 17.01           |          |            |
|                 | P-hydroxybenzoic acid                     | 12.20           |          |            |
|                 | P-hydroxyphenyl acetic acid                | 8.42            |          |            |
|                 | Protocatechluic acid                       | 2.40            |          |            |
|                 | Hydroxycinnamianes                         | 36.31           |          |            |
|                 | Trans-ferulic acid                         | 11.80           |          |            |
### Table 3. Cont.

| Legume       | Phenolic Compounds                        | Quantity (µg/g) | Found in | References       |
|--------------|-------------------------------------------|-----------------|----------|------------------|
| Cannellini   | Hydroxybenzoic acids, Vanillic acid       | 21.66           | Seed     | [32,33]          |
| bean         | P-hydroxyphenyl acetic acid               | 10.71           |          |                  |
|              | P-hydroxybenzoic acid                     | 6.92            |          |                  |
|              | Hydroxycinnamic acids                     | 4.30            |          |                  |
|              | Trans-ferulic acid                        | 23.52           |          |                  |
|              |                                           | 8.95            |          |                  |
| Adzuki       | Protocatechuic acid                       | 67.6            | Crude    | [18,20,32]       |
| bean         | Protocatechuic aldehyde                   | 7.71            |          |                  |
|              | Trans-p-coumaric acid                     | 31.3            |          | [18,20,32,33]    |
|              | Trans-p-coumaroyl malic acid              | 4.57            |          |                  |
| Cowpea       | Gallic                                    | 27              | Seed coat| [32]             |
|              | Protocatechuic                            | 18.9            |          |                  |
|              | P-hydroxybenzoic                          | 5.81            |          |                  |
|              | Ferulic                                   | 26.25           |          |                  |
|              | Coumaric acid                             | 1.25            |          |                  |
| Cranberry    | Protocatechuic acid                       | 217             | Seed coat| [32,34]          |
| beans        | P-hydroxybenzoic acid                     | 239             |          |                  |
| Chickpea     | P-hydroxybenzoic acid                     | 19.2 to 60.5    | Seed     | [18,32,35]       |
|              | Syringic acid                             | 45.9            |          |                  |
|              | Gentisic acid                             | 8.1 to 26.0     |          |                  |
| Pea          | Protocatechuic acid                       | 12.1 to 163.5   | Seed     | [32,35]          |
|              | P-hydroxybenzoic acid                     | 45.4 to 101.7   |          |                  |
| soybean      | Benzoic acids                             | 57              | Seed     | [32,33]          |
|              | Protocatechuic acids                      | 44              |          |                  |
|              | Ferulic acid                              | 95              |          |                  |
| kidney       | P-hydroxybenzoic acid                     | 10.33           | Bean     |                  |
|              |                                           | 10              | Sprout   | [32]             |

5. Nutritional and Health Benefits

Food legumes are essential for the human diet as an important source of nutrients and amino acids, and it has been suggested by the Finnish National Nutrition Council and the Eatwell Guide in the UK to increase the consumption of vegetable protein predominantly from food legumes rather than the consumption of animal protein [35]. Replacing animal protein with vegetable protein has beneficial and significant positive effects on human health such as reducing cholesterol, useful in the diet of diabetics, controlling hypertension, maintaining a healthy weight, improving the health of the cardiovascular system and preventing some cancers [36,37]. The physiological effects of various food legumes differ significantly based on the variability of phytochemicals present in them, as the intake of these phytochemicals may provide various health benefits and protection against several diseases [16]. Food legumes have a comparatively high vitamins and minerals content (Table 4), mainly potassium, calcium, magnesium, zinc, iron and thiamin (vitamin B1) [23]. It has been suggested by several researchers to decrease animal protein consumption and replace it with proteins derived from plants because a positive correlation was found between a high intake of animal protein and a rise in cardiovascular disease, whereas a negative correlation was found between a high intake of plant protein and a reduction in cardiovascular diseases and overall mortality [38].
### Table 4. Vitamins and minerals constituent of different food legumes.

| Vitamins and Minerals | Soybean (Per 100 g Seed) | Chickpea (Per 100 g Seed) | Pea (Per 100 g Seed) | Grass Pea (Per 100 g Seed) | Cowpea (Per 100 g Seed) | Pigeon Pea (Per 100 g Seed) | Groundnut (Per 100 g Seed) | Lentil (Per 100 g Seed) | Mung Bean (Per 100 g Seed) | Faba Bean (Per 100 g Seed) | Lupin (Per 100 g Seed) |
|-----------------------|--------------------------|---------------------------|----------------------|-----------------------------|------------------------|-----------------------------|---------------------------|-----------------------|--------------------------|--------------------------|---------------------|
| α tocopherol          | 6.5 mg                   | 2.24 mg                   | 0.11 mg              | -                           | -                      | -                           | -                         | -                     | -                        | 0.08 mg                 | 1.1 mg               |
| γ tocopherol          | 23.0 mg                  | 10.68 mg                  | 5.0 mg               | -                           | -                      | -                           | -                         | -                     | -                        | -                       | 15.3 mg              |
| Vitamin B1            | 1.0 mg                   | 0.477 mg                  | 0.7 mg               | 0.37–0.54 mg                | 0.345 mg               | 0.643 mg                    | 0.64 mg                   | 0.87 mg               | 0.621 mg                 | 0.55 mg                 | 0.32 mg              |
| Vitamin B2            | 0.46 mg                  | 0.212 mg                  | 0.27 mg              | 0.18–0.27 mg                | 0.094 mg               | 0.187 mg                    | 0.135 mg                  | 0.21 mg               | 0.233 mg                 | 0.23 mg                 | 0.59 mg              |
| Vitamin B3            | -                        | 1.541 mg                  | -                    | 1.23–2.02 mg                | -                      | 2.96 mg                     | 12.06 mg                  | 2.6 mg                | 2.251 mg                 | -                       | -                   |
| Vitamin B5            | -                        | 1.588 mg                  | -                    | 1.44–2.24 mg                | 0.703 mg               | 1.26 mg                     | 1.76 mg                   | 2.14 mg               | -                       | -                       | -                   |
| Vitamin B6            | 1.1 mg                   | 0.55 mg                   | 0.12 mg              | 0.49–0.66 mg                | 0.171 mg               | 0.283 mg                    | 0.348 mg                  | 0.5 mg                | 0.382 mg                 | 0.37 mg                 | 0.4 mg               |
| β-Carotene            | -                        | 40.00 mg                  | -                    | 24.08–41.01 µg              | -                      | -                           | -                         | -                     | 68 µg                    | -                       | -                   |
| Vitamin K             | -                        | 9.00 mg                   | -                    | -                           | -                      | -                           | -                         | -                     | 5.0 µg                   | -                       | -                   |
| Calcium               | 0.21 g                   | 160 mg                    | 0.05 g               | 0.97–1.03 g                 | -                      | 130 mg                      | 92 mg                     | 35 mg                 | 132 mg                   | 0.14 g                  | 0.24 g              |
| Potassium             | 1.8 g                    | 875.0 mg                  | 1 g                  | 8.75–9.2 g                  | 475 mg                 | 1392 mg                     | 705 mg                    | 677 mg                | 1246 mg                  | 1.2 g                   | 1.1 g               |
| Magnesium             | 0.22 g                   | 138 mg                    | 0.12 g               | 1.14–1.24 g                 | 91 mg                  | 183 mg                      | 168 mg                    | 47 mg                 | 189 mg                   | 0.15 g                  | 0.13 g              |
| Phosphorus            | -                        | 366.0 mg                  | -                    | 4.68–5.13 mg                | 267 mg                 | -                           | 376 mg                    | 281 mg                | 367 mg                   | -                       | -                   |
| Iron                  | 8.0 mg                   | 5.0 mg                    | 5.2 mg               | 1.33–1.53 mg                | 4.29 mg                | 5.23 mg                     | 4.58 mg                    | 6.51 mg               | 6.74 mg                   | 6.7 mg                  | 5.4 mg              |
| Copper                | 1.2 g                    | 0.847 mg                  | 0.66 mg              | 6.98–7.95 g                 | 0.458 mg               | 1.057 mg                    | 1.144 mg                  | 0.75 mg               | 0.941 µg                  | 1.1 mg                  | 0.6 mg              |
| Zinc                  | 4.2 mg                   | 4.1 mg                    | 3.2 mg               | 4.35 mg                     | 2.21 mg                | 2.76 mg                     | 3.27 mg                    | 3.27 mg               | 2.68 mg                   | 4.1 mg                  | 5.1 mg              |
| Selenium              | 19 µg                    | -                         | 1.6 µg               | -                           | -                      | -                           | -                         | -                     | 0.1 µg                    | 8.2 µg                  | 2 µg                |

Source: Jukanti1 et al. [15], Arslan [19,21], Celmeli et al. [14], Mathobo et al. [31], Budhathoki et al. [39–46].
6. Abiotic Stresses

Although food legumes grow in diverse climates, different abiotic stresses such as temperature stress, drought, salinity and heavy metals may hamper the grain quality of food legumes [47]. Food legumes contain essential minerals and nutrients essential for human beings and a deficiency of these elements may lead to malnutrition or other health issues in the human body [48]. These essential elements of food legumes are affected and altered by variable abiotic stresses [49,50].

6.1. Temperature Stress

Food legumes can be alienated into two groups based on different growing seasons, specifically warm- or tropical-season and cool-season food legumes [51]. Common beans, black grams, cowpeas, pigeon peas, mung beans, peanuts and soybeans are mainly grown in hot and humid weather and are known as warm-season food legumes [52]. On the other hand, lentils, peas, chickpeas, grass peas, broad beans and dry beans are known as cool-season food legumes [53]. Food legumes exhibit variable levels of sensitivity to high and low-temperature stresses, which diminishes their performance at different growing stages [54]. Both high and low temperatures may act as abiotic stresses for food legumes if the temperature rises or falls beyond the required temperature level needed for the proper growth and development of the food legumes.

6.1.1. High Temperature

Mainly, cool-season food legumes are more sensitive to a high temperature than warm-season food legumes and if the temperature rises above the threshold temperature (Table 5), it turns into severe heat stress at particular growth stages [55].
### Table 5. Effect of heat stress on food legumes at different stages of growth.

| Food Legumes | Threshold Temp. | Growth Stage | Heat Stress (Day/Night) | Effects                                                                 | References |
|--------------|-----------------|--------------|-------------------------|-------------------------------------------------------------------------|------------|
| Lentil       | 15–30           | Reproductive stage | 38/23                  | Reduced electron flow during photosynthesis                              | [56–59]    |
| Peanut       | 30–35 25        | Vegetative development Anthesis Pod and grain yield | 38/22                  | Decreased pollen production, impaired photosystem II                     | [56,57]    |
| Pea          | 15–25           | Vegetative growth | 30/25                  | Reduced photosynthetic activity; impeded electron donation by OEC (Oxygen-Evolving Center) of PS II; reduced oxygen evolution and photochemical energy storage; shutting of PSI reaction center | [57,59,60] |
| Chickpea     | 15–30 25        | Growth Reproductive growth | 35/16                  | Impaired RuBisCO and sucrose metabolism in leaves; disrupted PSII; damaged structure and functioning of related enzymes and proteins; decreased stigma receptivity | [56,59]    |
| Pigeon pea   | 18–30           | Flowering     | 45/40                  | Damaged PSII                                                            | [56,59]    |
| Cowpea       | 18–28           | Flowering     | 36/27                  | Tapetal cells degeneration and anther indehiscence                       | [56,57,59] |
| Soybean      | 26 23 30.2 36.1 | Reproductive Post-anthesis Pollen germination Pollen tube growth | 38/30 35 35 38/30      | Abscission of flower, reduced reproductive development; pollen germination, pollen tube growth and yield; shrunk pollen; damaged PSII; reduced chlorophyll content and photosynthesis; decreased Fv/Fm | [56–61]    |
| Common bean  | 20–24           | Flowering     | 32/27                  | Carbon assimilation limited and NADPH supply reduced; reduced photosynthetic rate | [59,62]    |
| Mung bean    | 28–35           | Flowering Pod development | >40/25                 | Efficiency of photosynthesis impaired; reduced sucrose in leaves due to decreased sucrose synthesizing enzymes and RuBisCO activity | [57,59,63] |
| Broad bean   | 25–35           | Flowering     | 42                     | Reduced photosynthesis                                                  | [57,59,64] |
| Black gram   | 25–35           | Flowering     | 35                     | Reduced photosynthesis                                                  | [65]        |
| Lupin        | 20–30           | Flowering     | 38                     | Cytokinin level reduced in seed leading to diminished seed cell numbers and growth rates of seed, reduced seed growth and development processes | [57,59]    |
Seed filling is intimately associated with the whole-plant senescence process and early senescence takes place by heat stress during the seed filling process that enhances the remobilization of assimilating from the source to sink, thus reducing the seed filling duration [66]. The grain development of food legumes is affected by heat stress because the tapetum layer of the grain is disintegrated by heat stress, which decreases the nutrient supply to the microspores and such an impairment leads to anther dehiscence prematurely, impedes carbohydrate synthesis and distribution to the grain and develops fruited embryos and poor pods, which ultimately reduces the grain yield [59]. Heat stress significantly decreased the yield of lentils by 70% when it was exposed to a heat wave of 35°C for six days, as lentils are a cool seasoned food legume [66]. The grain composition and quality of food legumes is affected by heat stress in many ways, as heat stress mainly affects the reproductive phases (Figure 1).

Figure 1. Effect of heat stress on the reproductive stage of food legumes [64].

Heat stress hampers grain composing elements such as sugar, starch, protein, fatty acids and protein (Table 6). It also alters various components accumulating, primarily, in grain-like starch and proteins by preventing the enzymatic processes required for starch and protein synthesis [67]. The temperature of air and soil increases under heat stress, which adversely affect the grain protein content and quality of food legumes [68]. In most of the food legumes, the grain oil content was found to be increased under heat stress, whereas the protein content was found to be decreased [69,70]. The oil content in the grain was increased under heat stress by 20 and 37% in peanuts and soybeans, respectively [71]. However, in kidney beans, the oil content was found to be declined by 23% under heat stress [72]. The fatty acid composition in the grain of food legumes changes due to heat stress. Heat stress considerably enhanced the oleic acid content, whereas the linoleic acid content was found to be decreased in different food legumes [1]. The N and P content of the soybean grain declined when the temperature rose above 40/30 °C [73]. A decrease in total nonstructural carbohydrates was found with increasing temperatures and the ratio of soluble sugars to starch was also found to be decreased in various food legumes, particularly in soybeans [74]. Sucrose and oligosaccharides such as the raffinose content in grains increases with an increasing temperature and monosaccharides such as glucose and fructose decrease with an eminent temperature [75].
Table 6. Alteration in grain composition of food legumes under heat stress.

| Food Legumes | Temperature Control (Day/Night) | Heat Stress (Day/Night) | Grain Composition | Increase % (+) or Decrease % (−) over Control | References |
|--------------|---------------------------------|-------------------------|-------------------|---------------------------------------------|------------|
| Soybean      | 15/30 °C                        | 40/30 °C                | Oleic acid        | +104%                                       | [1,66]     |
|              | 18/13 °C                        | 33/28 °C                | Linolenic acid    | −48.6                                       |            |
|              | 18/13 °C                        | 33/28 °C                | Oil content       | +37%                                        |            |
|              |                                 |                         | Sucrose           | −56%                                        |            |
| Peanut       | 20/14 °C                        | 32/26 °C                | Total sugars      | −24.5%                                      | [1,66]     |
|              |                                 |                         | Starch            | −53%                                        |            |
|              |                                 |                         | Protein           | −19.6%                                      | [1,66]     |
|              |                                 |                         | Oil content       | +20%                                        |            |
|              |                                 |                         | Oleic acid        | +24%                                        |            |
| Chickpea     | 25 °C                           | 35/16 °C                | Soluble proteins  | +20%                                        | [1,66,68,76]|
| Kidney bean  | 28/18 °C                        | 34/24 °C                | Oil content       | −22.7%                                      | [1,66,71]  |

6.1.2. Low Temperature

Low-temperature stress or cold stress can be expressed as a temperature that causes injury or irreversible damage to a crop as it falls under the optimum temperature required for the proper growth and development of the crop. Cold stress not only hampers the vegetative stages of food legumes but also alters reproductive growth and grain compositions (Table 7). During the seed germination of food legumes, cold stress enhances the susceptibility to soil-borne diseases, leading to the poor establishment of crops and even the death of seedlings [54,77].

Table 7. Impact of low temperature on some highly important food legumes.

| Food Legumes | Cold Stress | Effects |
|--------------|-------------|---------|
| Soybean      | 1 °C for 4, 6 and 8 h | Early vegetative phase damage, impaired microsporogenesis and megasporogenesis, loss of pollen germination, inhibition of pollen tube growth, abnormal pod formation and seed filling [54] and alteration in starch, protein, fat and fiber composition [78] |
| Pea          | 3 °C        | Early vegetative phase damage, reduction in embryogenesis and poor seed quality [54] |
| Chickpea     | <10 °C; −10 °C for 15−30 min | Early vegetative phase damage, impaired microsporogenesis and megasporogenesis, pollen viability loss, loss of pollen germination, stigma receptivity loss, abnormal pod formation [79] and seed filling [54] and alteration in starch, protein, fat and fiber composition [78] |
| Broad bean   | 5 °C for 24 h | Early vegetative phase damage and poor seed quality [54] |

Food legumes grown in cool seasons are mainly sensitive to cold stress, mostly during the formation of a pod and seed filling [78,80]. Carbohydrate metabolism is impaired by cold stress that may lead to the energy deficiency of different reproductive organs such as style, tapetum and endosperm that ultimately causes the sterility of the gametophyte [81]. In various food legumes, it has been well recognized that phenology and grain filling were damaged by cold stress [82]. The grain filling duration and rate reduce under cold stress as grain filling depends on the source–sink relationship that declines under cold stress. The storage of amino acids, minerals and proteins in the grain of food legumes is inhibited by cold stress. In chickpeas, the sugar concentration in the grain increased, whereas storage amino acids, protein, starch, fat and crude fiber accumulation decreased under cold stress [83].
6.2. Drought

Drought is one of the major constraints that limits food legume production, mainly in the arid and semi-arid tropics and the occurrence of drought during the grain development stages is more critical as it causes a significant yield loss [84]. In food legumes, drought highly affects the composition and quality of the grain (Table 8). Abiotic stress, particularly drought, highly influences the grain protein, fat and carbohydrate contents of food legumes. Although, a mild water scarcity during flowering may prefer an increased grain protein content in some food legumes. However, in maximum food legumes, drought reduces the N, P, Fe and Zn content of the grain that ultimately decreases the total grain protein content [85]. The fatty acid composition of a soybean grain was altered by drought that finally altered the total oil composition, oil stability and oil level in the soybean, especially during grain filling [86].

Table 8. Influences of drought stress on growth stages and grain constituents of food legumes.

| Food Legumes   | Drought Stress at Growth Stages | Effects                                                      | References |
|---------------|---------------------------------|--------------------------------------------------------------|------------|
| Lentil        | Pod development and reproductive phase | Yield reduction by 70 and 24%, respectively                  | [87]       |
| Chickpea      | Reproductive phase, anthesis and late ripening | Yield loss by 49–54, 27–40 and 49–54%, respectively Grain protein, sodium, potassium and calcium content reduced by 41, 33, 25 and 7%, respectively | [88,89]    |
| Soybean       | Reproductive phase, pod set and Seed filling | Oil content of grain reduced by 3% and protein content increased by 5% | [90–92]    |
| Common bean   | Reproductive, flowering and Pod filling stage | Loss of grain yield by 46–71, 45–50 and 42%, respectively Sucrose and starch content reduced in grain by 29–47 and 18–20% | [93]       |
| Mung bean     | Reproductive and vegetative stage | Grain protein content increased by 8 and 3%, respectively Yield reduction by 26% | [94]       |
| Faba bean     | Grain filling                    | Carbohydrate, fat and protein content increased by 4, 5 and 3–9%, respectively Grain yield loss by 68% | [83]       |
| Spotted bean  | Reproductive stage                | Protein content of grain increased by 6%                    | [87]       |
| Black gram (Mash bean) | Flowering and reproductive         | Loss of grain yield by 31–57 and 26%, respectively          | [95]       |
| Cowpea        | Reproductive and pod filling      | Yield loss by 34–66 and 29%, respectively                   | [92]       |
| Pigeon pea    | Reproductive phase and flowering  | Grain yield loss by 40–55 and 42–57%                        | [83]       |
| Lupins        | 15 days after anthesis            | Reduction in soluble sugar, crude fiber and starch in grain by 18, 11 and 43%, respectively | [83]       |

The oil and oleic acid content in soybeans decrease simultaneously when the grain filling period faces drought [96–98]. The oil content of peanuts is influenced by drought, as drought decreases the digestible carbohydrates such as the sucrose, glucose and fructose concentration affecting the composition of fatty acids in the grain through decreasing the unloading of sugars from the stem to the developing seeds [99,100]. During pod filling, a free amino acid pool increased on cowpea grains but the incorporation of these amino acids into the protein chain was suppressed due to drought, which ultimately reduces the protein-amino acid fraction in the grain [76]. The soluble sugars and starch content decreased in the mature grain of the soybean and the common bean, respectively, under drought [100]. The oil contents of the lupin grain dropped by 50–55% under drought. Drought has a distinct effect on the mineral composition of grains of food legumes. In soybeans, the calcium (Ca), phosphorus (P), copper (Cu), manganese (Mn), molybdenum (Mo) and zinc (Zn) concentrations improved under drought, whereas, the sodium (Na), potassium (K) and calcium (Ca) content reduced but the proline content increased in
chickpeas under drought [1]. Under drought, \(\alpha\)-tocopherol increased in soybean grains by 2–3 fold, which is helpful for preventing the auto-oxidation of a lipid as the tocopherols found in vegetable oils are well-known antioxidants [6]. During the preliminary stage of seed expansion, the seed sink ability reduces due to drought, which results in a decreasing number of endosperm cells and amyloplasts [76]. Acid invertase is a vital enzyme for the seed development of food legumes and its activity decreases due to drought, thus inhibiting sucrose import. As a result, the scarcity of energy sources and prominent levels of abscisic acid (ABA) lead to a poor grain set under drought [101].

### 6.3. Salinity

Salt stress is one of the major concerns in arid and semi-arid regions, which comprise about 40% of the land area of the earth. It is a significant constraint for food legume production. Salinity stress interrupts grain composition and the quality of food legumes (Table 9) by affecting hormonal interactions, causing a nutritional imbalance, osmotic effects and ionic toxicity [102,103]. Salt stress disturbs the uptake, accumulation and transport of competitive nutrients in food legumes. The nutritional imbalance in legume plants takes place due to the profusion of the sodium (Na\(^+\)) and chloride (Cl\(^-\)) ion concentration at the rhizosphere region because these ions interfere with essential nutrients such as N, P, K, Ca, Zn, boron (B), Mg, Cu and iron (Fe) [104]. Salt stress causes an ionic imbalance mainly of K\(^+\) and Ca\(^{2+}\), creating harmful effects on plants [8]. Ca\(^{2+}\), K\(^+\) and Mg\(^{2+}\) play a vital role in plant photosynthetic activity, but their concentration decreases under higher salt contents due to a competitive uptake of Na\(^+\) and K\(^+\) ion flux, resulting in a deficiency of K\(^+\) and significant yield losses [105]. Salt stress highly affects the oil content and grain protein content because of disturbance in nitrate (NO\(_3^-\)) uptake and N metabolism of food legumes [106]. A reduction in stigma receptivity, pollen viability and photo assimilates supply during grain filling takes place due to salt stress that eventually reduces the grain yield of food legumes [107]. In mung beans, the total amount of amino acids, protein, carbohydrates and polysaccharides in the grain decreased with the increasing salt stress and the reduction in carbohydrate and polysaccharide contents headed to a reduced photosynthesis, a nutritional imbalance, ion toxicity and hyperosmotic stress [108,109], whereas N uptake was reduced due to the decline in the total amino acids in the grain of the mung bean under salt stress [109]. The K and P concentrations also declined in the grain of the mung bean with increasing salt stress; however, the concentrations of Na, Ca, Mg and chloride (Cl) increased [110].

Table 9. Effects of salinity stress on the grain composition and quality of food legumes.

| Food Legumes       | Concentration of Salt                                      | Impacts                                                                 |
|--------------------|------------------------------------------------------------|-------------------------------------------------------------------------|
| Soybean            | NaCl 3, 6 and 9 dS m\(^{-1}\) NaCl 9 dS m\(^{-1}\)         | Grain protein reduction by 29, 60 and 79%, respectively                 |
|                    | 7 dS m\(^{-1}\) in loam soil and 6.3 dS m\(^{-1}\) clay soil | Oil content of grain reduced by 77%                                     |
|                    |                                                            | Yield loss around 46%                                                  |
| Chickpea           | 3 and 3.8 dS m\(^{-1}\) 50 and 100 mM                     | Loss of grain yield by 50 and 69%, respectively                        |
|                    | 50 and 100 mM                                              | Sodium increased by 200 and 271%, respectively                         |
|                    | 2 and 9 dS m\(^{-1}\) NaCl 40 mM                           | Potassium decreased by 79.09 and 72.72%, respectively                 |
|                    |                                                            | Sodium increased by 79.80 and Potassium increased by 0.58%            |
|                    |                                                            | Increase in sodium, 51.03%; potassium, 40.31%; and chloride, 58.41%  |
| Lentil (cv. 6796)  | 3.1 and 2 dS m\(^{-1}\)                                    | Grain yield loss found to be 100 and 14%, respectively                 |
| Mung bean          | 4500 and 6000 ppm                                          | Reduction in grain protein content of 11 and 20%, respectively         |
|                    | 250 mM NaCl                                               | Reduction in total soluble sugars of 29 and 32%, respectively         |
|                    |                                                            | Reduction in total amino acids of 19 and 21%, respectively            |
|                    |                                                            | Nitrogen content in grain decreased by 37 and 24%, respectively       |
|                    |                                                            | Grain phosphorus content decreased by 30 and 20%, respectively        |
|                    |                                                            | Reduction in grain potassium content by 13 and 8%, respectively       |
|                    |                                                            | ≥80–100% yield loss                                                  |
Table 9. Cont.

| Food Legumes               | Concentration of Salt | Impacts                                                                 |
|----------------------------|-----------------------|-------------------------------------------------------------------------|
| Mungbean (cv. Pusavishal)  | 50 mM NaCl            | Yield loss by 41%                                                        |
| Faba bean                  | 6.6 dS m\(^{-1}\) in loam soil | Total yield loss around 50%                                                |
|                            | 5.6 dS m\(^{-1}\) in clay soil | Yield loss by 52%                                                        |
|                            | 50 and 100 mM         | Total carbohydrates of grain reduced by 9.97 and 33.40%, respectively  |
|                            |                       | Decrease in grain potassium content of 3.30 and 11.57%, respectively  |
|                            |                       | Increase in sodium content of around 12.5 and 62.5%, respectively       |
|                            |                       | Magnesium content reduction in grain by 28.57% in both salt concentration |
| Pinto bean (cv. Talash)    | 8 and 12 dS m\(^{-1}\) | Reduction in grain yield by 26 and 41%                                  |

Source: Farooq et al. [1], Torabian et al. [102], Zhou et al. [105], Ghassemi-Golezani et al. [108], Khan et al. [110], Narula et al. [111].

6.4. Heavy Metals

The accumulation of heavy metals such as mercury (Hg), lead (Pb), cadmium (Cd), chromium (Cr), Cu, Zn, arsenic (As) and nickel (Ni) in the soil is a serious constraint for the crops grown in that soil [112,113]. When these heavy metals are present above the optimum level in the rhizosphere zone, they limit the yield and quality of food legumes (Table 10) as well as cause human health concerns through accumulating in the grains of food legumes [114]. The predominant use of heavy metals leads to a decrease in the yield of food legumes and dangerously affects human health through entering into the food chain [9]. Heavy metal toxicity causes weak plant growth, chlorosis, a yield reduction supplemented by decreased nutrient uptake, plant metabolism disorders and a reduced molecular nitrogen-fixing ability [115]. The uptake of mineral nutrients is altered by heavy metals, which inhibits the opening of the stomata by cooperating with plant water balance, thus disturbing the enzymes of the Calvin cycle, carbohydrate metabolism, photosynthesis and, ultimately, reducing the productivity of food legumes [116]. Cd is a heavy metal highly toxic to plants, humans, animals and causes oxidative stress in plants.
Table 10. Impacts of different level of heavy metals on grain constituents of food legumes.

| Heavy Metals | Food Legumes | Level of Metals in Soil or Growth Media | Effects | References |
|--------------|--------------|-----------------------------------------|---------|------------|
| Cadmium (Cd) | Groundnut    | -                                       | Xerophytic anatomical features and reduction in grain quality | [1,9,10] |
|              | Common bean  | 5 µg mL⁻¹                               | Changes in lipid composition and alteration in the structural component of thylakoid membrane | [117,118] |
|              | Pea          | 50 µM CdCl₂                             | Chloroplast damage, reduction in grain filling rate | [119] |
|              | Chickpea     | 23 mg kg⁻¹                              | Decrease in starch content of seeds | [1,9,120] |
|              | Green gram   | 24 mg kg⁻¹                              | Decrease in grain protein by 22% | [1,9] |
|              | Soybean      | 0.1, 0.5 and 1.0 mM                   | Grain protein reduction by 8% | [1,9,97,117] |
|              | Pigeon pea   | 56 and 112 mg L⁻¹                      | Reduction in grain oil by 23, 28 and 33%, respectively | [1,9,97,117] |
|              |              |                                         | Reduced photosynthesis up to 50% | [1] |
| Lead (Pb)   | Grass pea    | 25, 50, 100, 200 and 300 ppm           | Chromosomal abnormalities | [1,120] |
|              | Chickpea     | 195 and 390 mg kg⁻¹                   | Grain proteins increase by 3 and 6%, respectively | [1,9] |
|              | Soybean      | -                                       | Inhibited growth | [98,117] |
| Chromium (Cr)| Common bean  | 500 ppm                                | Reduced seed germination up to 48% | [117] |
|              | Chickpea     | 67.5 and 135 mg kg⁻¹                  | Grain protein increased by 3% and decreased by 2%, respectively | [1,9,120] |
|              | Green gram   | 68 and 136 mg kg⁻¹                    | Increase in grain protein by 7 and 11%, respectively | [1,9] |
| Mercury (Hg)| Black gram   | 20 ppm                                 | Reduced 50% seed germination potential, contamination in the entire food chain | [1] |
|              | Mung bean    |                                         | | [117,120] |
|              | Pea          |                                         | | [1] |
|              | Lentil       |                                         | | [1,120] |
|              | Soybean      | 0.1, 0.5 and 1.0 mM                   | Grain oil reduction by 38, 58 and 68%, respectively | [1,9,117] |
| Copper (Cu) | Pea          | (50 and 75 µM)                          | Changes in the ultra-structure of chloroplasts, swelling of starch grains in the stroma | [1,117,120] |
|              | Chickpea     | 66.9 and 143.8 mg kg⁻¹                | Reduced grain protein of 9 and 18%, respectively | [1,116] |
|              | Cowpea       | 5 ppm                                  | Adversely affected the germination process | [1,116] |
|              | Green gram   | 334.5 and 669 mg kg⁻¹                 | Grain protein reduced by 4 and 5%, respectively | [1] |
| Nickel (Ni) | Chickpea     | 50, 100, 200 and 400 ppm              | Reduction in seed germination and seedling growth | [1,116] |
|              | Cowpea       | 290.1 and 580.2 mg kg⁻¹               | Reduced grain protein by 2 and 16%, respectively | [1] |
|              | Pigeon pea   | 5 ppm                                  | adversely influenced the germination process | [1,10] |
|              |              | 1.0 mM                                 | 32% reduction in net photosynthesis, decrease enzyme activity | [1,10] |
| Zinc (Zn)   | Cowpea       | 4890 and 9780 mg kg⁻¹                 | Adversely influenced the germination process | [1] |
|              | Chickpea     | 5 ppm                                  | Increased grain protein by 10 and 19%, respectively | [1,116,120] |
| Arsenic (As)| Peas         | 12.5–73.3 mg of sodium arsenate kg⁻¹   | Caused interference in mineral nutrient balance | [1,114,116] |
|              | Chickpea     | 5 mg kg⁻¹                              | Considerable inhibition in seed reserves accumulation such as starch, proteins, sugars and minerals, reduced the quality of seeds | [1,114,1121] |
An accumulation of Cd has potential health risks, and it mostly happens due to the consumption of soybeans grown in contaminated areas as soybeans have more potential in absorbing heavy metals compared to other food legumes [119]. However, the detrimental effects on soybean oil content were found to be greater for Hg than Cd. The grain oil content of soybeans was reduced when exposed to higher Cd and Hg concentrations and the oil content reduction rate was higher with an individual metal rather than a combined effort of metals, which emphasizes the antagonistic effect of heavy metals on the grain oil content [1,120]. Heavy metal changes major and minor fatty acids in food legumes; oleic and linoleic acid decreased significantly in soybeans under heavy metal stress, whereas palmitic, linolenic and stearic acid were markedly increased [120]. The starch content of pea seeds decreased when grown in 2.5 mM Cd [121]. Pb is another heavy metal, and its toxic effects mainly depend on how it reacts with functional groups such as carboxyl, sulfhydryl and amine, which results in a reduction in or loss of enzymatic activity vital for cell function. The total soluble sugars, soluble proteins and starch content of the common bean decreased with the increase in the Cd and Pb concentration when extended with different concentrations of Cd and Pb (1.5, 2.0, 2.5, 3.0 g kg\(^{-1}\) for Cd and 2, 4, 6, 8 g kg\(^{-1}\) for Pb) compared to control plants [118]. Pea grains store Fe and Zn, while lentils accumulate low levels of Pb. The grain protein content of maximum food legumes decreased with the increase in Cd, Cr, Ni, Zn, Pb and Cu, except for chickpeas and mung beans. A Zn application in chickpeas decreased the grain protein content [9]. The minerals’ uptake, accumulation and nutritional composition of legume seeds and shoots may be altered by As. The nutrient balance of Zn, Mn and Mg in peas was altered by As when exposed to 12.5 to 73.3 mg of sodium arsenate/kg dry weight of soil [117]. The accumulation of seed reserves such as starch, proteins, sugars and minerals was significantly inhibited in chickpeas when grown in As (5 mg/kg of dry soil) compared to the controls, indicating that As prominently reduced the grain quality of chickpeas [121].

7. Impacts of Abiotic Stresses on Nodulation and Nitrogen Fixation

Abiotic stresses affect the nodulation and nitrogen fixation of legumes. Most importantly, the drought stress because the formation, growth and functioning of nodules are being affected when there is a shortage of water in soil [122]. Under drought stress, different factors interfere with the nitrogenase enzymatic activity such as reducing the stock of ATP, reducing the respiration efficiency, altering the pH gradient across the bacteroid membrane and regulating nitrogenase by substrate or gene expression. A Considerable decrease in nitrogen fixation during soil dehydration has been found in many grain legumes such as chickpeas, peas, cowpeas, faba beans, etc. The stunted growth of a nodule and a partially developed root cortex-embedded organ was found when a nodule was subjected to dry conditions. Nitrogen fixation as well as nodule respiration degrades equivalently to the degree of water insufficiency under drought stress [123]. Nodule oxygen permeability reduces under drought stress. As a result, nodules face a limited ability to carry out oxidative phosphorylation, although maintaining relatively high photosynthesis [124].

On the other hand, salinity is one of the most limiting factors for leguminous nitrogen fixation. Nodule formation significantly decreases under soil salinity, simultaneously reducing the symbiotic nitrogen fixation. Salt stress reduces root hair formation, thus inhibiting infection threads and, ultimately, degrading the number of nodules. This happens because of the deleterious effect of salt stress on the colonization of the legume root, which restricts the Rhizobia bacterial growth [125].

Heavy metals are another constraint for nitrogen fixation by bacteria in a legume plant. Such metals firstly affect the soil microorganisms. The composition and activities of microbes are being changed dramatically by a high concentration of heavy metals in the soil [126]. The morphology, growth and many activities of multiple groups of microorganisms are found to be altered by the heavy metals such as Ni, Cu, Cd, As and Zn [127]. These metals have been found to enhance lipid peroxidation [128], thus creating oxidative stress for both rhizobia and host legumes. The induction of nodal genes was
found to be inhibited by a high concentration of heavy metals, which cause a loss of the N-fixing ability of rhizobia in association with some leguminous hosts [9].

8. Conclusions

The diverse climatic changes are significantly affecting the agroecosystem. Besides abiotic stresses, pandemic situations created by viruses such as COVID-19 have also hampered the economic and agricultural systems globally. Under such a situation, food legumes are the cheapest source of protein acquisition. The consumption of good quality legumes can be a replacement for animal protein. That is why there is considerable scope for exploring these safe protein sources in the cropping pattern. However, grain legumes’ production, grain composition and quality are hindered by several abiotic stresses, as stated in this review. A collection of stress tolerance diverse germplasms, the development of tolerant variety/varieties through plant breeding or advanced biotechnologies and the introduction of suitable agronomic management packages could be helpful to overcome the abiotic stress effects on legumes for their yield and nutritional quality improvement. This review not only provides an overview on the research that has been conducted, but also to identify the areas in which research on grain legumes is still needed in order to mitigate the abiotic stress effects on legumes.

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