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Light as a Key Abiotic Driver in Enhancing Germination and Phytochemicals of Chickpea Cultivars

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ABSTRACT

Light is crucial for plant growth, serving as both an energy source and a signaling agent. Different wavelengths regulate key physiological processes, influencing seed germination and phytochemical biosynthesis. This review examines how visible light enhances seed germination and phytochemical content in chickpea cultivars. Specific wavelengths, particularly blue, red, and UV light, activate metabolic enzymes like phenylalanine ammonia-lyase and chalcone synthase, significantly boosting the production of phenolic compounds, flavonoids, and anthocyanins. Light promotes seed germination by triggering photosynthesis, modulating gene expression, and regulating hormone synthesis and enzyme activity. It also influences pigment biosynthesis essential for seedling growth and environmental adaptation. Studies show that LED light treatments can enhance phytochemical concentrations, thereby improving plant nutrition and resilience. UV light increases phenolic and anthocyanin levels, while blue and red light enhance metabolic enzyme activity. These findings highlight the potential of using specific light treatments to optimize biochemical traits in chickpea cultivars, making them more resistant to environmental stress and increasing yields. Understanding light-driven biochemical processes offers innovative strategies for sustainable agriculture, enhancing crop quality, resilience, and nutritional value to promote food security and environmental sustainability.

Keywords Visible light, Germination, Phytochemical, Abiotic, Phenolic compounds, Flavonoids, Anthocyanins.

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INTRODUCTION

Importance of chickpeas in terms of nutrition and agriculture

Chickpea (*Cicer arietinum* L.) is a member of Leguminoseae family crops that is widely grown for its nutritious seeds. Chickpea is one of the important sources of low-cost high-quality protein. Indeed, chickpea is a complete food source, supplying both proteins and carbohydrates, as compared to other legumes. As a member of legumes, they have high level of nutritional content and are vital sources of protein, calcium, iron, phosphorus, and other minerals (Jukanti *et al.* 2012). Apart from this, chickpea seed contains several bioactive elements such as dietary fiber, polyphenols, flavonoids, phytosterols, starch, minerals, and vitamins (Bouchenak and Lamri-Senhadji 2013, Singh *et al.* 2017). Being nutriently dense food, it is used for human consumption as well as fodder for livestock/animals because of easily digestible quality. The grain is normally dehulled and split to make pulse (Channa dal) and then may be further processed to produce flour (besan)—a key ingredient used in a variety of snacks, dishes, sweets. For example, in southern Europe and Latin America, chickpeas are a common ingredient in soups, salads, and stews. In the Middle East, Chickpea is widely eaten as Hummus (a paste with lemon juice, olive oil, and tahini (sesame paste)) as a sauce and dip for bread (USDA 2014). It is eaten fresh as a green vegetable or parched, fried, roasted, boiled, or sprouted seeds added to salads in Indian subcontinent (MoEF&CC).

Chickpea as a significant legume crop globally

Based on seed coat color and geographic distribution, it is classified into two varieties: Desi (Brown Gram, also known as microsperma) and Kabuli (White Gram, also known as macrosperma).

Desi Chickpea, typically smaller in size, angular seeds having thick corticated (hard) coats with puckered and wrinkled surface and tan to black in color, are cultivated mostly in India and Bangladesh. On the other hand, Kabuli Chickpea, large size with thin coats and smooth seed surface, ram-head to rounded shape and ranging color from white to tan, are cultivated mostly in Africa, Europe, Afghanistan, Pakistan and Chille, the Mediterranean basin and Middle Eastern countries (Bampidis and Christodoulou 2011). In fact, the production of chickpea crops covers vast arid and semi-arid regions across the Globe such as Indian subcontinent countries like India, Pakistan, Myanmar, Bangladesh, and Nepal—collectively contributing almost 70% of the global production and another substantial production region includes countries like Turkey, Australia, Ethiopia, Iran, Mexico, Canada, and the USA (Jukanti *et al.* 2012) as shown in Fig. 1.

The varied climatic condition of these regions significantly affects the production processes from the beginning of germination of seed to plant growth and maturity of the crop. Apart from these, there are many biotic and abiotic constraints impose serious yield losses and weaken chickpea production (Nayyar *et al.* 2018).

Effect of biotic and abiotic factor on the growth of chickpea

Major abiotic stresses are drought, temperature, soil salinity, flooding, and light. These notable abiotic agents are profoundly affecting the life cycle of chickpea at different stages. Certainly, drought and tem-

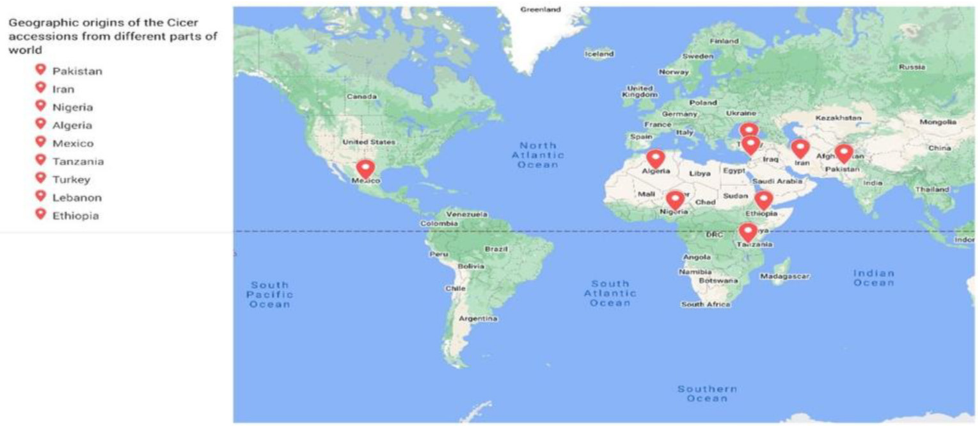

Fig. 1. Worldwide distribution of chickpea.

perature at different stages of growth are major yield limiting factors in arid and semiarid regions. Apart from it, the production of chickpea is also influenced by scarcity of nitrogen, phosphorus and the presence of heavy metals (Karalija *et al.* 2022). Lately, light has emerged as one of the abiotic signalling agents, regulating various physiological processes during the growth of plant.

Biotic factor is regarded as the most destructive factor which has been observed in almost all chickpea growing across the world, these causing significant production loss and seed quality degradation (Addisu *et al.* 2023). Pathogens such as fungi, bacteria, virous, nematodes, and insects can also develop numerous diseases and cause terrible harm to crops.

Ascochyta blight, fusarium wilt, botrytis gray-mold, dry root rot, collar rot, sclerotinia stem rot, rust, stunt disease, and phyllody have all been identified as emerging hazards to chickpea production in numerous producing regions (Choudhary *et al.* 2022). Ascochyta blight caused by *Ascochyta rabiei* (teleomorph: *Didymella rabiei*) is the most disastrous fungal disease of chickpea. As shown in Fig. 2.

Though to some extent plants synthesize and accumulate a variety of defence signalling weapons against pathogens attack. However, to control it at larger extent, the uses of insecticides as well as several chemicals during the reproductive phase are the most used practice by the farmers. With time, they have evolved resistance against the consistent use of chemicals (pesticides/insecticides) and are no more effective in killing them (Tudi *et al.* 2021). Further, excessive use of toxic agrochemicals disrupts the natural balance of the ecosystem and has (often irreversible) negative effect on the human health. Long term ecofriendly naturopathic treatment of such problems is buried in the biological variables itself.

The present article is aimed to briefly summarize effectiveness of supplemental wavelength exposure in activating biochemical compounds in seeds is significant.

Light as a factor to enhance the germination of seeds

The plant's life cycle begins with the germination of the seed which require ample moisture, adequate oxygen, and the right temperature (Khaeim *et al.* 2022). Under optimal atmospheric condition germination process of seed begins with imbibitions. This instigates numerous biochemical actions necessary for development of seedling. During this time, seed rehydrates and its protecting coat swells and softens due to absorption of water. Simultaneously activation of metabolic pathways in embryo (fertilized egg cells) started. This activity produces enzymes (proteins) that ramp up metabolic activity in the seed. Further this results in expansion of the embryonic cells—morphological and physiological alterations. Seed uses oxygen to break down its stored food supply during germination. In general, seeds have maximum germination rates at moderate (~25°–30°C) temperatures and often will not germinate at extreme temperatures (Sershen *et al*. 2014). Recent observations suggested that light also acts as additional signalling agent in ramping up the germination activities. It functions as signalling regulators and accelerates various chemical reactions.

Fig. 2. Ascochyta blight disease of chickpea.

Several light-absorbing components in seeds allow them to respond to changes in the natural light environment. Their production in developing seeds is heavily reliant on the light quality they perceive. Changes in light signal/quality (wavelength) influence a variety of physiological processes, including intra- and intercellular differentiation and seed germination (Wei *et al.* 2023). Among the environmental factors that are regulating various physiological processes, light has emerged as one of the signalling agents in the growth of plants. Light regulates early developmental events such as seed germination in plants too. Considering this, some of the investigation were conducted on the effect of different wavelength of light (natural, red, blue, yellow, and green) on seed germination, hypocotyl growth, biomass production, mobilization efficiency (ME), vigor index (VI) and photosynthetic pigments in Cowpea/ Lobia (*Vigna unguiculata* (L.) Walp). Further, it has been observed that light is one of the crucial factors in regulating the seed germination in numerous plant species (Jala 2011). In fact, phytochromes regulate light-dependent seed germination (Arana *et al.* 2014). Recently, it was shown that regulation of spectral wavelength of light affects photo morphogenesis and photosynthesis of plants significantly.

Burescu *et al*. (2015) investigated the influence of different wavelength LED lights on the growth of Spruce (*Picea abies* L.) plantlets and found higher production of chl a and chl b under blue and yellow light, respectively (Kaeser *et al.* 2023). Carotenoid production was also dramatically increased in yellow light-treated plantlets. Many researchers have examined the mechanisms involved in seed germination and how they are impacted by plant hormones in a variety of plant families, including the Brassicacea.

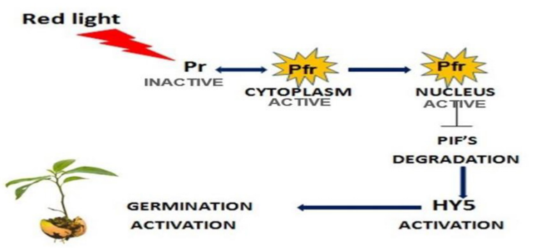

Fig. 3. Phytochrome mediated signaling pathway for seed germination by red light.

Photoreceptors in plants (e.g., phytochromes, cryptochromes) and their roles in detecting light

Responses of plant to light depend on the plant's ability to sense light. Sensing of light in plants is performed by special photoreceptors. Five distinct classes of photoreceptor proteins have been identified as triggers for plant responses to light. The phytochrome family constitutes the first class, which absorbs red (R) and far-red (FR) wavelengths. The second group includes three types of photoreceptors—cryptochromes, phototropins, and the ZTL/FKF1/LKP2 complex—that respond to blue (B) and ultraviolet-A (UV-A) wavelengths. Lastly, UVR8 serves as a receptor specifically sensitive to ultraviolet-B (UV-B) wavelengths (Wu *et al.* 2012). Phytochrome is a light sensitive pigment. This pigment is photo reversible i.e. change from one form to another by red and far-red light (Kong and Okajima 2016). It is made up of a protein linked to a light-absorbing element called a chromophore. The absorption of light, usually in the range of 320 to 760 nm, by the chromophore causes a instigate alteration in the shape of the protein, its activity and initiation of a signalling pathways. In fact, these photoreceptors convert the absorbed light into biochemical signals such as enzyme activations and protein-protein interactions (Shinomura *et al.*1994). These phytochromes are responsible for the promotion of the light-induced germination (Jones 2018).

PHYB mainly triggers red/far-red light reversible seed germination, while PHYA induces far-red light–mediated germination when the seeds experience a long period of imbibition in the dark as shown in Fig. 3 (Guo *et al.* 2012).

Therefore, applying selective wavelength of supplemental light at precise times and locations of organism or part of organs is treated as effective controlling tool in the field of agronomy (Le *et al.* 2022, Cioć *et al.* 2018).

Effect of different light wavelengths on physico-chemical compound

Phytochemicals (also known as bioactive compounds) have characteristic physico-chemical properties. Seed contains carbohydrates, lipids, proteins, and nucleic acids as major biochemical compounds. They act as elicitors and stimulate plant growth, protect plants against pathogens, and induce physiological changes (Azad *et al.* 2020). In general, plants have evolved sophisticated biochemical mechanisms to exert self-defence against some of the pathogen infections. Upon recognition of pathogens, plants respond by activating a battery of defence reactions. Such a wide array of defence responses is brought about by specific interactions between elicitor (s) originated from the pathogen and receptor (s) of the host cell (Manivannan *et al.* 2015).

Application of selective wavelengths (red, blue and UV) of light in seedling cultivation increases the concentration of bioactive compounds (Lee *et al.* 2014). For example, supplemental treatment with monochromatic (red/blue) light enhances appreciably the concentrations of phenolic compounds, flavonoids, and anthocyanins in *Rehmannia glutinosa* and perilla plants. In perilla, exposure to UV-A multiply increase the level of caffeic and rosmarinic acids. In sweet basil, short exposure to supplemental UV-B light increases the phenolic and anthocyanin content (Shiga *et al.* 2009). Such monochromatic light has significant influence on the chemical activation than the broad band light. Further it is reported that the activation efficiency using blue light is more than the red one. The degree of enhancement depends on the nature of species (Shoji *et al.* 2009).

Additionally, as antioxidant compounds available in human dietary are derived from phyto nutrients and it is believed that the biosynthesis of phyto nutrients are also affected by exposure under selective wavelengths such as red, blue, UV or their combinations. Thus, it is probable to enhance antioxidant quality in (herb) plants by the selective application of supplemental light spectral wavelengths. In this way it is now established that supplemental treatment with red, blue, and UV wavelengths of light not only activate the biochemical compounds but also enhances the sysnthesis of antioxidant properties in fresh herbs or herb supplements.

CONCLUSION

In conclusion, light plays a critical role in regulating plant growth and development through various signalling pathways. The application of specific light wavelengths significantly influences seed germination, physiological processes, and biochemical activation, enhancing phytochemical content. These findings provide valuable insights into how targeted light treatments can improve agricultural practices, particularly in seed germination and the enhancement of bioactive compounds. By integrating this knowledge, we can develop strategies to increase crop resilience to both biotic and abiotic stresses, while also enhancing nutritional value. This approach holds potential for more sustainable agricultural practices, contributing to food security and ecosystem health.

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