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Research Article

UNVEILING THE IMPACT OF ABIOTIC STRESSES ON ONION YIELD: A COMPREHENSIVE REVIEW

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Abstract

Onion (*Allium cepa* L.) is a globally significant spice and economic crop, valued for its substantial role in foreign exchange due to high export demand. Onion growth, production, and yield are influenced by different types of abiotic stresses, including salinity, waterlogging, heat, cold, and drought. Insufficient water availability leads to reduced productivity, making a consistent water supply essential for enhancing onion yield. Onions are vulnerable to salt stress particularly, which affects bulb height, the number of bulbs per unit area, and fresh weight, as well as the quality of the harvested bulbs. Waterlogging also significantly impacts bulb development and bulb yield at different growth stages, potentially hindering the movement of nutrients from the source to the sink, thereby decreasing yield. Additionally, the surrounding climate can influence the flavor and taste of onions. Temperature plays a key role in bulbing, with its effects varying among different onion varieties. As temperatures rise, the number of leaves per bulb typically decreases, while bulb weight, bulb diameter, and bulbing index (the ratio of bulb to neck diameter) generally increase. Onions are also affected by salinity, which significantly impacts both bulb yield and quality. This review offers a comprehensive overview of how abiotic stresses affect onion yield.

Keywords: *Onion yield, stress, drought stress, heat stress, waterlogging stress, salinity stress, bulb quality*.

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1. Introduction

Onions (*Allium cepa*) are one of the most widely cultivated and versatile vegetables globally. They belong to the Allium family, which also includes garlic, leeks, and chives. Onions are known for their distinct flavor and aroma, which come from sulfur compounds that also contribute to their potential health benefits. It is majorly consumed as a condiment in several cuisines across the world. Its significant export demand makes it a crucial economic crop, playing an essential role in international trade. It is grown over an area of 5,976,491 hectares globally, with approximately 110,616,269 tonnes world production in 2022 (FAO, 2022). Onion bulbs are raised on tropical as well as temperate area and are consumed year-round due to their unique sensory properties and beneficial nutritive elements (Mota *et al.*, 2010). Soils with a pH of 6-7 typically more suitable for onions as onions can thrive in most fertile soils. However, on organic soils, a lower pH is preferable. As a long-day plant, onions require longer daylight hours (> 12 hours). Yet, some varieties suited for tropical regions need only 11-12 hours of daylight. The crop cycle should experience minimal rainfall (less than 750 mm), and a relative humidity of under 70% is deemed acceptable (DAO, 2022). Central Asia is believed to have origin of Onions and the Mediterranean region being a secondary center for large-bulbed onions (M. Pitrat, 2012; M. A. Vaddoria and Ganesh Kulkarni, 2017). As the world's population growing rapidly, the need for onions is rising. Nevertheless, abiotic stresses such as salinity, heat, drought, waterlogging and cold negatively affect onion growth, development, and yield globally. Therefore, understanding the detrimental effects of environmental factors on onion production is crucial.

Effect of non-living (abiotic) environmental stresses:

Non-living environmental factors can significantly affect growth, development and yield through various mechanisms of crops including onions (Fig. 1). Stresses either biotic or abiotic are one of the primary obstacles to worldwide crop advancement. A significant segment of the population in developing nations, where farming for survival or basic farming is prevalent, is persistently endangered by these abiotic stressors and their interactions with biological stressors. Due to change in climatic conditions, the condition is expected to worsen. With the anticipated rise in world population and need of food, it will be essential to discover methods to enhance crop resilience to abiotic stresses to increase agricultural yields and issue of food security (P. P. Calance, 2017). This discussion covers the impacts of heat, cold, drought, waterlogging, and salinity stresses on onion cultivation.

Impact of Salinity stress:

Salinity, primarily caused by elevated NaCl levels, is a major non-living stressor that hampers crop yields and results in economic losses (Capiati *et al*., 2006). t is projected that by 2050, the agricultural land approximately 50% will be severely affected by salinization (W. Wang and B. Vinocur, 2003). Saline soils impact onion growth and the process of photosynthetic (Beinsan *et al*., 2015). Salinity stress negatively influences

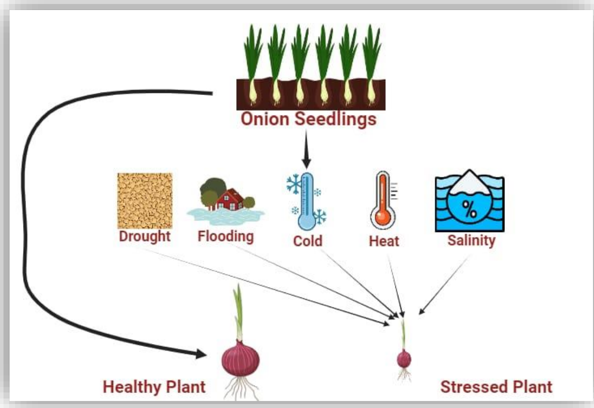


Fig. 1: Effect of non-living environmental stresses on onion

vegetative growth and bulb yield through various mechanisms, with osmotic stress and ionic toxicity being the primary effects. The osmotic pressure in the soil solution exceeds that within plant cells due to higher salt concentrations, restricting water and mineral uptake, such as K+ and Ca2+. This leads to secondary effects including reduced production of food assimilate, diminished cell expansion, lower cytosolic metabolism and function of membrane (Gull *et al*., 2019). High level of salts results in water deficits near the rhizosphere and elevated concentrations of Na+ and Cl- ions, which can be fatal to plants (Kunchge *et al*., 2012). Onions are particularly sensitive to salt and sulfate (Yamaguchi *et al*., 2005). Salinity in irrigation water significantly impacts bulb size, bulb weight and number of bulbs per unit area. It also affects bulb shape and the quality bulbs at harvested time (Sta-Baba *et al*., 2010). Additionally, salt stress applied at distinctive growth stages influences weight of fresh bulbs at the time of harvest. For commercial production of onion with saltish water, it is necessary to delay saltwater application until after the appearance of fourth leaf, with 1.41 dS/m electrical conductivity. However, this method is not cost-effective for bulk production due to a 50% reduction in yield but may be viable for small-scale operations. Research by Camilia *et al*., (Camilia *et al*., 2013) demonstrated that plant growth and production decreases with saline irrigating water in onions and less biomass production as compared to irrigation with tap water, with higher salt concentrations being more detrimental. Mineral content and flavor development of onion bulbs also adversely affects by saline water. Research findings on the variety 'Granex 33' revealed that increasing NaCl concentrations reduced bulb fresh weight, and plants lose their survival at 125 mM NaCl. High NaCl levels also decreased sulfur content and increased bulb pungency, although soluble solid content remained unaffected (Chang and Randle, 2004). Onions can tolerate upto to 100 mM concentrations of NaCl and can sustain growth under moderate salinity conditions. However, the impact of NaCl on flavor and growth at different developmental stages remains undetermined. Using H2O2 has been found to alleviate salinity stress in onions by enhancing photosynthetic efficiency (W. M. Semida, 2016).

Impact of Drought Stress:

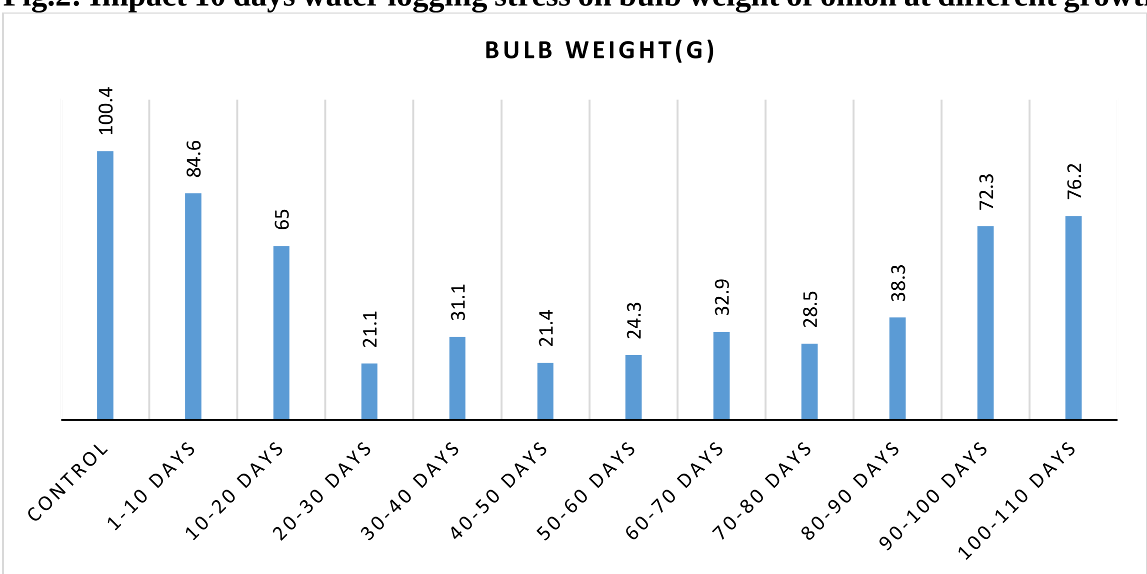
Onion is a globally important vegetable known for its economic value and culinary versatility. However, drought stress poses a significant challenge to onion production, impacting growth, yield, and quality. Onions requires a substantial amount of water for optimal production. Insufficient water availability leads to decreased productivity, as onions need high soil moisture to achieve a good yield (Kadayifci *et al*., 2005). Onions are classified as shallow-rooted, with most roots penetrating only up to 15 cm, and very few reaching 30 cm (Drinkwater and Janes, 1955). Consequently, they extract minimal water over 60 cm depth. Srinivasa Rao *et al*., (2016) observed that majority of the soil moisture is drawn out of above 30 cm, making it crucial to maintain adequate soil moisture for plant health. In experiments by Srinivasa Rao *et al*., (2009-10), applying drought stress for one, two, three, and four weeks to two onion varieties, Agrifound Dark Red (ADR) and Arka Kalyan, resulted in a gradual decrease in soil moisture from 22.0% on the first day to 5.5% after four weeks. This reduction led to significant declines in fresh bulb weight and dry weight, after three weeks of stress the bulb dry matter decreasing by 44.4–54.0%. Consistent water supply enhances onion yield, and drip irrigation is particularly effective in drought-prone areas. Bagali *et al*., (2012) observed that more frequent drip irrigation intervals significantly improved bulb yield, with the highest yield of 46.93 t/ha achieved with a daily irrigation schedule, compared to 42.80 t/ha and 46.47 t/ha for 3-day and 2-day intervals, respectively. A study by Ensico *et al*., (2009)] on subsurface drip irrigation indicated that soil moisture levels influenced both the yield and size of onions, though moisture levels and irrigation scheduling had minimal impact on pyruvic acid content, which affects pungency and soluble solids concentration. Maintaining soil moisture above 30 kPa at 20 cm depth resulted in higher yields and larger onions. Different growth stages affected by soil drought stress also significantly impact yield and bulb quality. Suppressing water application at various stages of growth-original, mid and late season showed that the maximum average yield of 15.30 Mg/fed for non-stressed onions, while lower yield 11.12 Mg/fed was produced by drought stress applied during later growth stage. Additionally, drought stress affects bulb weight and size, with non-stressed and early-stage water-stressed plants producing the highest average bulb weights of 102 g and 91 g, respectively, with significant differences noted at the 0.05 probability level (A. M. Zayton, 2007). Gocke Z. N. O *et al*., (2022) screened 32 turkish breeding lines against salinity and drought stress and observed the bulb weight significantly reduces with the onset of stresses.

Impact of Water logging:

Waterlogging is a significant non-living stress that impacts crops, resulting from abundant, erratic precipitation and inadequate soil drainage often due to soil compaction from heavy agricultural machinery (Hirabayashi *et al*., 2013). This stress impairs vegetative growth, production, and overall yield by minimizing oxygen availability to immersed tissues (Barickman *et al*., 2019). Onions, due to their shallow root systems, are particularly vulnerable to waterlogging stress (Drinkwater and Janes, 1955). The severity of damage from waterlogging varies depending on factors such as the climate, onion cultivar, soil properties, plant growth stage, and the period and magnitude of rainfall. These variables collectively influence bulb yield and plant survival.

Different onion genotypes respond differently to waterlogging stress. A pot experiment revealed that the W344 genotype had the highest bulb yield (8.38g/bulb) under waterlogging conditions, while the Acc.1630 genotype had the lowest yield (2.18 g/bulb) (Kuruwanshi, 2020). The movement of assimilates hindered by waterlogging stress from the source to the sink, thereby decreasing bulb yield (Parasanna and Rao, 2014). The impact of waterlogging varies at different growth stages; for instance, Ghodke *et al*., (2018) noted that waterlogging during initial stages of growth post-transplanting and bulb initiation decreases both quality and marketable size of bulb. Specifically, waterlogging stress after transplanting 1-10 days (DAT) resulted in larger bulbs (84.6 g), succeeded by a decrease in bulb weight from 10-20 DAT (65.0 g). Waterlogging at 20-90 days after transplanting caused a marked decrease in bulb weight, although waterlogging during the bulb formation and ripening stage (90-110 DAT) had a lesser negative effect on bulb size (Fig.2).

Fig.2: Impact 10 days water logging stress on bulb weight of onion at different growth stages



Additionally, Yiu *et al*., (2009) found that pretreating Welsh onions with spermidine or spermine mitigates the effects of waterlogging, likely by enhancing osmotic adjustment and maintaining membrane stability. They also reported that applying 2 ppm paclobutrazol (PBZ) protected onions out of waterlogging stress.

Impact of Cold Stress:

Cold and freezing stresses are prevalent environmental factors that negatively impact plant growth and production. In several parts of the world, crops are subjected to extremely low temperatures, which, when combined with chilling and drought conditions, can severely hinder plant growth and reduce productivity (Ruelland *et al*., 2009). Cold injury, specifically from chilling (around 20°C) and freezing (0°C) temperatures, can significantly affect onion bulb formation (Wang *et al*., 2016). Cold stress impedes plants out of reaching their full genetic potential by disrupting metabolic processes, and by inducing oxidative, osmatic, and several forms of stress (Wang *et al*., 2016 ; Tomassini *et al*., 2008).

Wickrama singhe *et al.,* (20000. observed that onions formed bigger bulbs with bold necks at the minimum tested temperatures (17–22°C), possibly due to structural changes in the bulbs induced by low temperatures. Cold stress can lead to minimum seed germination, discoloration, stunted growth of seedlings, poor leaf expansion, wilting, and even death of tissues. Additionally, cold stress badly impacts seed cycle development by causing significant membrane damage, primarily due to the severe dehydration linked with freezing temperatures (S. K. Yadav, 2010).

To protect themselves from cold stress (0-15°C) and lower temperatures, plants go through various biochemical and morpho-physiological adaptations. This process, known as "cold acclimation" (CA) enables some plants to endure cold and freezing conditions, though not all plants can adapt effectively (C. L. Guy, 1990). Su *et al*., (2007)found that the cultivars of Welsh onion exposed to low temperatures during winter experienced stress, but exposure to low temperatures for short period led to better bulb weight (mean) per plant (Khokhara *et al*., 2007).

Impact of Heat Stress:

Rising global temperatures are increasingly affecting plant growth and, more critically, crop productivity, making it a significant concern. Heat stress is characterized by its severity, period, and the rate at which temperatures increase. As temperatures exceed certain thresholds, the stress level escalates rapidly, leading to complex acclimation responses influenced by both temperature and other environmental conditions (Slafer and Rawson, 1995). Heat stress impairs seed germination rates, reduces photosynthetic efficiency, and affects plant performance. During the reproductive stage, excessively high temperatures can compromise pollen viability, fertilization, and the formation of grains or fruits (Hatfield *et al*., 2008 ; Hatfiled *et al*., 2011). Damage to reproductive tissues due to heat is a major factor in yield loss across global agriculture (Suzuki *et al*., 2013).

Temperature plays a crucial role in onion bulb formation and production. In high temperature stress, especially at reproductive phase, tapetal cells may lose functionality and turn into dysplastic (Gull *et al*., 2019). Optimal temperatures for various growth stages of onions are 20–25°C for seedling growth, 13–24°C for plant growth before bulb initiation, 15–21°C for bulb development, and again 20–25°C for overall growth (Mathur, 2011). Extremely low temperatures during bulb production favor bolting, causing early maturation and resulting in smaller bulbs. Increased temperatures are linked to reduced photosynthetic efficiency and lower crop yields. The impact of temperature on bulb development varies among onion varieties. Wickramasinghe *et al*., (2000) found that at lower temperatures (17–22°C), onions produced larger bulbs with thicker necks, likely because of structural modifications in the bulb. Bulbing also influenced by photoperiod, but temperature has a more significant impact on onion bulbing than photoperiod. This aligns with findings by Abdalla (1967), Robinson (1973), and Currah (1985), who observed that in tropical regions, onion bulbing is more affected by temperature than by day length. Lee and Suh (2009) reported that pyruvic acid content, bulb index, bulb diameter, and total sugar content are optimal among 20 and 25°C, with onions exhibiting superior sweet flavor grown at 25°C. Conversely, due to heat stress bulb weight decreases at 30°C.

Conclusion:

Salinity, drought, waterlogging, extreme cold, and heat stress are crucial challenges for onion cultivation. Onions are highly sensitive to both heat and water stress, which adversely affect bulb development and seed production. Soil moisture plays a crucial role in onion production, influencing physiological processes and bulb yield. Managing onion crops in conditions of insufficient irrigation, optimizing water use efficiency, and addressing excess moisture are complex tasks. Temperature fluctuations can impact bulb formation, with high temperatures posing a significant climatic threat by disrupting essential plant functions such as seed germination, vegetative growth, physiological metabolism, bulb formation, and yield across various agro-ecological zones. Onions are also affected by salinity, which significantly impacts both bulb yield and quality. To mitigate these abiotic stresses and improve yield, genetic modifications and chemical treatments designed to enhance resistance to heat, cold, water logging, drought, and salinity could be employed.

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Conflict of interest:

The author declares that there is no conflict of interest regarding the publication of this research. All financial support and resources utilized during the study were provided without any influence on the research outcomes.

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