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Waterlogging Stress in Vegetable Crops

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Waterlogging refers to the situation of soil with water or accumulation of excess water in the root zone of the plants. Absence of proper drainage leads to waterlogged conditions. During waterlogging the oxygen levels in the root zone gets reduced as water occupies the space which was previously filled with oxygen leading to inhibition of aerobic respiration. The inhibition of crop respiration have adverse effects on vegetative and reproductive growth of the plants which eventually leads to yield loss or even complete crop failure. Waterlogging condition, typically resulting from excessive rainfall, poor soil drainage or high ground water tables leads to saturated soil environments where oxygen availability to plant roots is severely restricted.

Effects of waterlogging on plants

- Oxygen starvation in tuber crops such as potato leads to cell death in tubers and storage roots. This appears as dark or discolored areas in the tubers or roots. In carrots and other root vegetables, the tap roots often die leading to the formation of unmarketable fibrous roots (Bahadur et al. 2023).
- Lack of root function and movement of water and calcium in the plant leads to calcium related disorders; most notably incidence of blossom end rot (BER) in tomato, pepper, watermelon, and several other susceptible crops.
- Leaching and denitrification losses of nitrogen and limited nitrogen uptake in flooded soils also lead to nitrogen deficiency in most vegetable crops.
- In bean crops, flooding or waterlogging has been shown to decrease flower production and increase flower and young fruit abscission or abortion.
- Ethylene buildup in saturated soil conditions can cause leaf drop, flower drop, fruit drop, or early plant decline in many vegetable crops.
- In tomato and other vegetables, flooding stress causes deleterious symptoms such as epinasty, leaf chlorosis, necrosis and reduced fruit yield.

Mechanisms of tolerance to waterlogging

1) **Morphological and Anatomical Adaptations:** Morphological and anatomical changes are mainly manifested as the formation of adventitious roots or other aeration tissues, rapid elongation of apical meristematic tissue, barriers to radial oxygen loss and the formation of air films in the upper cuticle.

Adaptations includes:

- **Adventitious roots:** these roots, which form during prolonged waterlogging helps in gas exchange, water absorption and nutrient uptake. Adventitious roots can replace damaged primary roots and support metabolic functions. They also contain more aerenchyma than primary roots, enhancing oxygen uptake and diffusion.
- **Aerenchyma formation:** under hypoxia, plant roots cortical cells undergo programmed cell death, create cavities that form aerenchyma. This tissue allows gas exchange,

transporting oxygen to roots and removing CO_2 and toxic substances, which supports the plants metabolic needs in waterlogged conditions.

- **Rapid oxygen loss barrier:** plants can form a barrier in the root to reduce oxygen loss into the rhizosphere, helping to maintain oxygen for root metabolism. This barrier is particularly important for plants like rice which form a lighter radial oxygen loss barrier under low oxygen conditions.
- **Rapid elongation of apical meristems:** this adaptation, known as low oxygen escape syndrome helps plants escape anoxic conditions by elongating stems and internodes to reach the air for respiration.

2) Photosynthetic Adaptations: Waterlogging also reduces the content of photosynthetic pigments, like chlorophyll A, B and carotenoids, which directly lowers photosynthetic capacity. Photosynthetic adaptation includes increased activity of enzyme **Sucrose Synthase** which allows normal transport of photosynthates during waterlogged conditions. It also includes the increased activity of the enzyme RuBisCo (Ribulose-1.5-bisphosphate carboxylase/oxygenase) which act as a catalyst in the carbon cycle and regulates the photosynthesis process.

3) Respiratory Adaptation: In waterlogged condition, the oxygen concentration is drastically reduced making the process ineffective. As a result plants rely on glycolysis and ethanol fermentation to produce ATP through these pathways much less ATP compared to the tricarboxylic acid cycle. During glycolysis, pyruvate accumulates and is converted into lactic acid or ethanol through fermentation. The enzyme Alcohol dehydrogenase (ADH) and Pyruvate decarboxylase (PDC) plays key roles in the process and their activity is crucial for waterlogging tolerance. Waterlogging tolerant plants regulate the expression of ADH and PDC to improve ethanol fermentation and temporarily provide energy. Lactate dehydrogenase also contributes to the response to waterlogging by facilitating lactic acid fermentation, which helps regenerate NAD^+ under hypoxic conditions (Manghwar et al. 2024).

4.) Antioxidant Enzymes: Under waterlogging stress, plants experience an increase in reactive oxygen species such as Superoxide radicles, hydroxyl radicles and hydrogen peroxides, due to insufficient oxygen. All the plants have the ability to detoxify the adverse effects of ROS by producing different types of antioxidants. These ROS can cause oxidative damage to membranes, proteins, DNA and organelles. Generally, antioxidants are categorized into enzymatic and non-enzymatic antioxidants. Enzymatic antioxidants include Ascorbate peroxidase (APX), Catalase (CAT), Superoxide dismutase (SOD) and Peroxidase (POD) and glutathione reductase (GR), whereas, ascorbic acid, glutathione tocopherols and carotenoids are non-enzymatic antioxidants. Waterlogging sensitive plants show a rapid decrease in antioxidant enzyme activities like SOD, POD, CAT, while waterlogging resistant plants maintain higher levels of these enzymes, helping them tolerate oxidative stress in the short term. For example, the enzyme Ascorbate peroxidate (APX) has been shown to play a critical role in waterlogging adaptation with eggplants displaying higher APX activity than tomatoes under waterlogging conditions.

Mitigation of waterlogging stress

1. Improved drainage systems: Efficient drainage systems are essential for minimizing the harmful effects of waterlogging in vegetable crops. By removing excess water from the root zone, these systems improve soil aeration and restore oxygen availability for healthy root growth. Subsurface drainage methods including tile drains and perforated pipes effectively lower the water table by channeling surplus water away from cultivated fields. The integration of controlled drainage with subirrigation not only enhances crop productivity but also improves nitrogen-use efficiency while reducing potential impacts on water quality (Kaur *et al.* 2020). Furthermore controlled drainage practices regulate the discharge of excess water, maintaining optimal soil moisture and ensuring efficient water management under variable environmental conditions (Ahmed *et al.* 2024).

2. Soil management practices: Adopting appropriate soil management practices is an effective approach to alleviating waterlogging stress by improving soil physical properties and drainage. Raised-bed cultivation elevates the planting surface allowing excess water to drain more rapidly and preventing prolonged root-zone saturation. Soil aeration enhances oxygen diffusion by creating pore spaces that facilitate gas exchange and support root respiration. In addition incorporating organic amendments such as compost and well-decomposed farmyard manure improves soil structure, increases porosity, enhances infiltration and promotes efficient drainage. Collectively, these practices create a healthier root environment, thereby reducing the adverse effects of waterlogging and improving crop growth, yield and overall productivity.

3. Crop rotation and intercropping: The crop Rotation and Intercropping practices bolster system resilience by diversifying plant species, optimizing resource utilization, and enhancing soil structure and nutrient cycling. This rotational approach facilitates soil health regeneration and diminishes the risk of waterlogging related crop failures. By integrating waterlogging-tolerant species into crop rotations and intercropping systems, farmers can elevate the overall resilience of their cropping systems.

4. Use of tolerant species and varieties: Introducing water logging-tolerant species and varieties to reduce losses in waterlogged conditions, considering genetic differences in tolerance among crops (Nadoda et al. 2023). Growing of vegetables that can tolerate short term waterlogging such as Kale, Spinach, Okra and certain legumes like Cowpea and Pea can mitigate waterlogging stress.

5. Nutrient application: Combating nutrient deficiencies caused by water logging using enhanced-efficiency fertilizers and organic sources. The use of enhanced-efficiency N fertilizers, Potassium fertilizer and exogenous application of various phosphorus (P) sources play an important role in improving plant growth and development under waterlogged conditions. Application of nutrients like Ca, K and seaweed extract helps in mitigating waterlogging stress. Ca helps in strengthening cell walls, reduces toxicity, enhances root recovery and improves soil structure. K helps in maintaining osmotic balance, enhances root functions, activates enzyme and improve disease resistance. Seaweed extract helps in enhancing root growth, improve stress tolerance, increases nutrient uptake and stimulate microbial activity.

6. Application of plant growth regulators: Application of PGRs such as auxins, cytokinins, paclobutrazol and tricyclazole helps to improve plant growth under flooding. Abscisic acid regulates stomatal closure to reduce waterloss and salicylic acid helps in aerenchyma formation. Jasmonic acid enhances antioxidant defence system which protects plants from oxidative stress. Cytokinin and auxin helps in maintaining normal growth under waterlogged conditions.

Conclusion

Waterlogging is a major abiotic stress that severely limits the growth, development and productivity of vegetable crops by reducing oxygen availability in the root zone. It disrupts normal physiological and biochemical processes resulting in poor nutrient uptake, oxidative damage and significant yield losses. However, vegetable plants possess several adaptive mechanisms including the formation of adventitious roots, aerenchyma tissues, enhanced anaerobic respiration and stronger antioxidant defense systems which help them survive under flooded conditions. Effective mitigation requires an integrated approach combining improved drainage, raised-bed cultivation, balanced nutrient management and the use of waterlogging-tolerant cultivars. Crop rotation, intercropping and soil improvement practices further enhance resilience against excess moisture. The application of suitable plant growth regulators also strengthens plant tolerance by regulating stress-responsive pathways. With increasing occurrences of extreme rainfall due to climate change adopting sustainable waterlogging management strategies has become essential. Overall, combining agronomic, physiological and genetic approaches can effectively minimize waterlogging damage and ensure sustainable vegetable production under changing environmental conditions.

References

1. Ahmed, A., Manibhushan, Prakash, V., Kumari, A., Upadhyaya, A. and Das, A. (2024). Recent Approaches for mitigation of waterlogging stress in Agriculture. Technical Innovation in Agriculture: Seeds of Progress, Deepika Book Agency, 148-167.
2. Bahadur, A., Kumar, R., Krishna, H. and Behera, T.K. (2023). Abiotic stress in vegetable crops: challenges and strategies. *Journal of Biotech Bioresources*, 5: 640-648.
3. Kaur, G., Singh, G., Motavalli, P.P., Nelson, K.A., Orlowski, J.M. and Golden, B.R. (2020). Impacts and management strategies for crop production in waterlogged or flooded soils. *Agronomy Journal*, 112: 1475-1501.
4. Manghwar, H., Hussain, A., Alam, I., Khoso, M.A., Ali, Q. and Liu, F. (2024). Waterlogging stress in plants: unrevealing the mechanisms and impacts on growth, development and productivity. *Environmental and Experimental Botany*, 224: 1-12.
5. Nadoda, N.A., Barot, D.C. and Chaudhari, V.M. (2023). Techniques of vegetable growing under water stress: Cutting-edge approaches and tips. *Vigyan Varta*, 4: 164-168.