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WATERLOGGING RESILIENCE IN VEGETABLE CROPS: PHYSIOLOGICAL AND MOLECULAR MECHANISMS, ADAPTIVE STRATEGIES AND SUSTAINABLE MANAGEMENT STRATEGIES

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ABSTRACT
Waterlogging is a problem that affects vegetable crops all over the world. It reduces growth, productivity and quality. When soil has much water it doesn't have enough oxygen, which hurts the roots. This makes it hard for plants to breathe take in nutrients and work properly.As a result waterlogging causes problems like photosynthesis bad chemicals building up and more stress from reactive oxygen species. Vegetable crops are especially vulnerable because their roots are close to the surface and they need a lot of oxygen.Plants try to deal with waterlogging by developing air-filled tissues growing new roots and changing how they make energy. Different plants and varieties respond differently which affects how well they can tolerate waterlogging. This review looks at how vegetable crops respond to waterlogging focusing on how they adapt and ways to mitigate the problem. Even though we've made progress we still don't fully understand how different varieties tolerate waterlogging how they perform in the term and how to manage them in changing climates.Future research should focus on creating vegetable crops that can tolerate waterlogging combining approaches to understand and breed better crops and optimizing management practices for specific areas. Understanding how plants respond to stress and how their roots work will be crucial for making vegetable production more sustainable in areas, to flooding and poor drainage.

KEYWORDS: Aerenchyma; Antioxidant enzymes; Crop tolerance; Drainage systems; Flooding stress management; Hypoxia; Reactive oxygen species; Raised beds; Vegetable crops; Waterlogging stress

INTRODUCTION
Waterlogging is a problem for the environment and it affects how we grow vegetable crops in many parts of the world. This happens when the soil gets much water for a long time and the air in the soil cannot move around. As a result the roots of the plants do not get oxygen and this causes a lot of problems. The plants need oxygen to breathe and to grow just like we do.When the soil is waterlogged it is like the roots are drowning. The plants cannot absorb the nutrients they need. They cannot grow properly. Waterlogging is different from flooding even though people often use these words to mean the thing. Waterlogging is when the roots are surrounded by water while flooding is when the whole plant is underwater.Both waterlogging and flooding are bad for plants because they cause much stress. This stress affects how the plants work and grow. The effects of waterlogging on crops are very bad. The roots do not work properly the plants wilt they do not grow well they do not produce flowers and fruits. The yield is reduced. You can see all these problems, in Figure 1. Vegetable crops experience a lot of problems because of waterlogging.

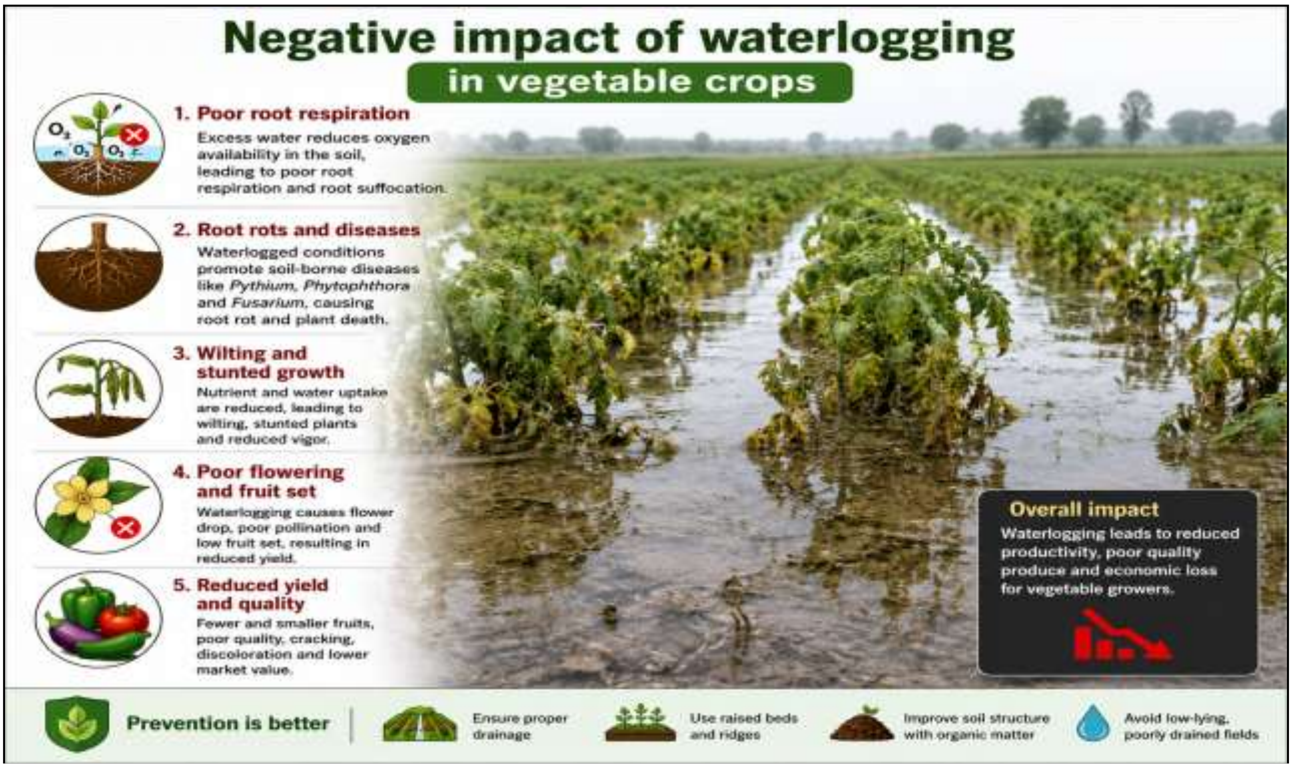

Fig. 1. Waterlogging-induced morphological and physiological damage in vegetable crops

Water does not drain properly. This causes flooding in many areas where people grow food. This is a problem because it hurts the crops and the quality of the food that is sold. The weather is. This is making it rain really hard more often. When it rains much the water does not drain and this is bad for the plants that people eat, like vegetables. Vegetable plants are more sensitive to much water than other plants like wheat. This is because their roots are not very deep and they need a lot of air. When the soil is too wet it is hard for the plants to breathe. They get sick easily.Much water stops the plants from making food from sunlight. It also hurts the roots so the plants cannot get the nutrients they need. The plants start to make things that can hurt them. The water also makes the plants produce things that can damage them. This makes the plants grow poorly and produce food. You can see pictures of farms that are flooded in parts of the world in Figure 2. Vegetable crops are really affected by waterlogging. This is a big problem, for the people who grow them.

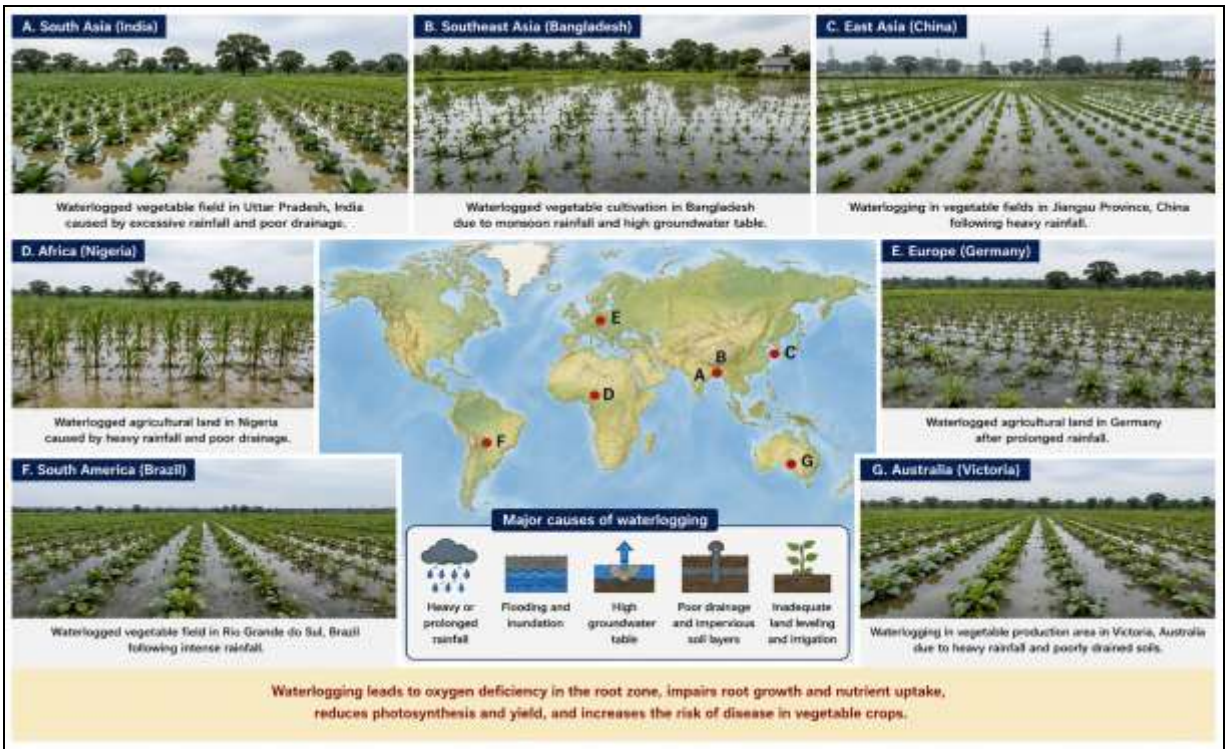

Fig. 2. Representative examples of waterlogged agricultural lands across different regions of the world

Plants have a lot of ways to deal with not having oxygen in the soil for a long time. They can make tissues to help get oxygen to the roots grow new roots that can get oxygen from the air control how much water they lose through their leaves change the way they use hormones and even make special defenses to protect themselves from damage. It is really important to understand how plants do all these things so we can find the vegetable crops that can handle much water and make them grow better. We also need to use farming practices like making sure the water can drain properly using raised beds covering the soil with mulch and choosing crops that can handle a lot of water. This review is, about how plants adapt to not having oxygen how they deal with the bad effects of too much water and what farmers can do to help vegetable crops handle waterlogging. Vegetable crops need to be able to handle waterlogging so they can keep growing and producing food. By understanding how plants adapt to waterlogging and using the farming practices we can help vegetable crops do better when there is too much water.

1.1. Global Impact of Waterlogging on Agricultural Production

Waterlogging is a problem that hurts the way plants grow and how well they do. It affects how food we can grow and the quality of that food. When the soil has much water it stops plants from growing like they should. This means we get food from our crops and it costs us money. Every year flooding happens on than 17 million km² of land around the world. It damages the crops we grow for food and the plants that grow naturally. Waterlogging is an issue that we have to deal with when it comes to growing plants. It is bad, for productivity and the quality of the food we produce (1). The worlds agricultural land is, in trouble. 10 To 12 percent of it has waterlogging or poor drainage. This is a problem. It means that farmers do not get much food from their land as they should. The waterlogging and poor drainage also make it harder for farmers to make money from their farms. Waterlogging and poor drainage are really hurting the land and the farmers who work on it(2,3).

Waterlogging is a problem for food security around the world. It hurts the crops. Makes it harder for people to grow food. Waterlogging reduces the amount of food that crops can produce. It also increases the risks for the people who are growing the food.Climate change is going to make waterlogging worse. This is because climate change will cause heavy rains to happen more often. These heavy rains will cause waterlogged conditions, in the fields where people grow food. Waterlogging will happen often in these fields (4). The amount of damage that waterlogging does to crops is different for each type of crop. Vegetable crops are usually more sensitive to waterlogging, than cereal crops. This means that vegetable crops will often have a lot of trouble growing and producing food when they are waterlogged. They just do not grow well and the food they produce is not as good when they are waterlogged. Waterlogging really hurts the growth and yield of vegetable crops and also the quality of the food they produce. Vegetable crops have a lot of trouble with waterlogging(5). Waterlogging is really bad for plants because it stops them from getting oxygen in the soil where their roots are. This means the roots have a hard time breathing and the plant has a time making food from sunlight, which is what photosynthesis is. The plant also has trouble taking in the nutrients and water it needs. If the soil is flooded for a time it can even make the plant sick by building up bad things like ethanol and lactic acid. This makes the plant more likely to get diseases that're in the soil. Waterlogging is a problem because it can cause all these issues with the roots and the plants overall health. The root zone is especially important, for waterlogging because that is where the roots are and the roots need oxygen to work properly (6). Plants react to much water in different ways. This is because different types of plants have ways of dealing with it. Some plants can handle it better than others because of the way their roots are made or because they can make special roots to help them breathe. They also have ways to protect themselves from damage caused by little oxygen in the water. Since plants are so different it is helpful to group them by how they can handle too much water. This helps us choose the plants to grow in areas that flood a lot. It also helps us figure out how to breed plants that can handle floods better and how to plan for climate change, in these areas (7–9) (Table 1).

Table 1: Classification of vegetable crops based on tolerance to waterlogging

Category	Crop	Scientific name (with author citation)	Level of tolerance	Key gene(s) associated with tolerance*	References
Highly susceptible	Onion	Allium cepa L.	Very sensitive to excess soil moisture; bulb rot occurs quickly	Limited information; ERF and ADH pathway genes induced under stress	(5,7)
	Garlic	Allium sativum L.	Sensitive to poor drainage and oxygen deficiency	ADH, PDC (anaerobic metabolism genes)	(7)
	Carrot	Daucus carota L.	Root growth severely affected by anaerobic conditions	DcERF family genes	(8)
	Tomato	Solanum lycopersicum L.	Yield reduction up to 40% under flooding stress	SlERF2, SlHB1, ADH2	(9)
	Cabbage	Brassica oleracea var. capitata L.	Poor tolerance due to shallow root system	BoERF genes	(7)
	Cauliflower	Brassica oleracea var. botrytis L.	Highly sensitive to water stagnation	ERF-VII family genes	(7)
	Brinjal	Solanum melongena L.	Can tolerate short-term waterlogging	SmERF, ADH genes	(8)

Moderately tolerant	Chilli	Capsicum annuum L.	Moderate tolerance depending on duration	CaERF and antioxidant-related genes	(8)
	Potato	Solanum tuberosum L.	Moderate tolerance; tuber growth affected	StERF94, ADH, PDC	(8)
	Pea	Pisum sativum L.	Sensitive at reproductive stage	PsADH1, ERF genes	(8)
	French bean	Phaseolus vulgaris L.	Moderately sensitive to soil saturation	PvERF, antioxidant enzyme genes	(7)
	Cucumber	Cucumis sativus L.	Shows variation among genotypes	CsARN6.1, CsERF31	(7)
Tolerant	Spinach	Spinacia oleracea L.	Performs relatively well under wet soil conditions	ERF-VII and antioxidant-related genes	(7)
	Amaranthus	Amaranthus spp.	Adapted to moist soil conditions	ERF and ROS-scavenging genes	(8)
	Taro	Colocasia esculenta (L.) Schott	Highly tolerant due to aerenchyma formation	ADH, PDC, ERF-related genes	(8)
	Coriander	Coriandrum sativum L.	Can tolerate temporary water stagnation	Antioxidant and ERF pathway genes	(7)
	Mint	Mentha spp.	Adapted to moist environments	Antioxidant defense-related genes	(8)
	Kang kong	Ipomoea aquatica Forssk.	Naturally adapted to flooded conditions	SUB1-like ERF, ADH, PDC genes	(7)

Waterlogging is bad for crops because it reduces the amount of food we get from them. It also makes the food not as good to eat. For example the fruit is not as firm. Does not taste as sweet. Waterlogging also reduces the amount of things in the food and it does not last as long after we pick it.Some vegetables like spinach and mint are better at dealing with much water in the soil. This is because they have features that help them survive. We need to understand how these vegetables can handle much water so we can grow other vegetables that are strong like them.To grow vegetables in a way that works when there is a lot of water we need to do a few things. We need to make sure the water can drain properly. We need to find vegetables that can handle a lot of water.. We need to use special helpers in the soil to reduce the bad effects of waterlogging on vegetable crops, like kang kong and coriander.

1.2. Reasons for Waterlogging

Waterlogging happens when the water that goes into the ground is more than the ground can handle. This means the water does not soak in move down or drain away and it also does not get used by plants. As a result the soil stays wet for a time. This usually happens because of the weather the type of soil the shape of the land and how people take care of the land. Waterlogging can occur because of things that happen naturally. Because of things that people do. The main reasons, for waterlogging are:

1.2.1. Climatological factors

When we have heavy rain or when it rains for a long time or when there are big storms and floods the fields where we grow food get too much water. This kind of rain fills up all the spaces in the soil with water instead of air and that makes it hard for the roots of the plants to get the oxygen they need. Also when it is cloudy the water in the fields does not evaporate quickly so the water just stays there for a long time, which is not good for the Extreme rainfall events and floods and the fields. The rain and the cyclones and the floods all lead to the accumulation of water, in the agricultural fields, which is a big problem (10).

1.2.2. Irrigation mismanagement

Watering much or at the wrong time often causes the soil to get too wet. This is especially true for soils that're very dense or have a lot of small particles. If you water at the time or use too much water it can lead to water collecting in certain areas of the field. This can happen if the field is not leveled properly. The water will stay in these areas for a time. This is a problem for the roots of the plants. Much water in the soil where the roots are can be very bad, for the plants. The roots need air to grow. If the soil is too wet they will not get enough air (11).

1.2.3. Poor drainage conditions

Soils that have a time letting water pass through like those with a lot of clay or that have been packed down do not let water move down very easily. When the water does not have a way to drain like when the drainage channels are not working right or the water table is too high the water just sits there for a long time and causes waterlogging. This is a problem for soils with permeability, high clay content or compacted layers because they restrict the downward movement of water. The absence of drainage channels and blocked drainage systems also lead to waterlogging conditions that last a long time especially when the water table is high and the soils, with low permeability, high clay content or compacted layers are present (12).

1.2.4. Soil characteristics

Soils that are clayey, like saline-sodic soils and soils that have pan layers do not let water in very easily. These types of soils like clayey soils and saline-sodic soils hold onto water for a time. This means that clayey soils saline-sodic soils and soils with pan layers can cause problems, for plant roots because they do not get enough oxygen (13).

1.2.5. Topographical conditions

Some places like areas and river floodplains and coastal areas where people grow food are likely to get flooded during certain times of the year. These low-relief landscapes and depressional areas and river floodplains and coastal agroecosystems get flooded because the water does not drain quickly. This is a problem, for low-relief landscapes and depressional areas and river floodplains and coastal agroecosystems because the water can stay for a time (14).

1.3. Physiological and Biochemical Adaptations to Waterlogging

Plants that get much water or are waterlogged do not get enough oxygen in the roots. This is a problem for the plant because it needs oxygen to do its normal things. When this happens plants do a things to try and stay alive. They change how they work on the inside to deal with the lack of oxygen. This helps the plant cells to stay in balance and the plant to keep growing. Plants have to do this to survive when they're, in these tough conditions. The plants roots need oxygen to work properly. When they do not get it the plant has to find other ways to keep going (Figure 3) (10,15). These changes that help plants deal with much water include the growth of special air spaces in the plant and the development of extra roots controlling the systems that help the plant fight off damage from things like too much water making changes to how the plant uses energy when it is not getting enough oxygen and turning on the genes that help the plant respond to stress. Understanding how plants adapt to water is really important for making vegetable plants that can handle being in waterlogged soil and, for making crops grow better in soil that does not drain well.

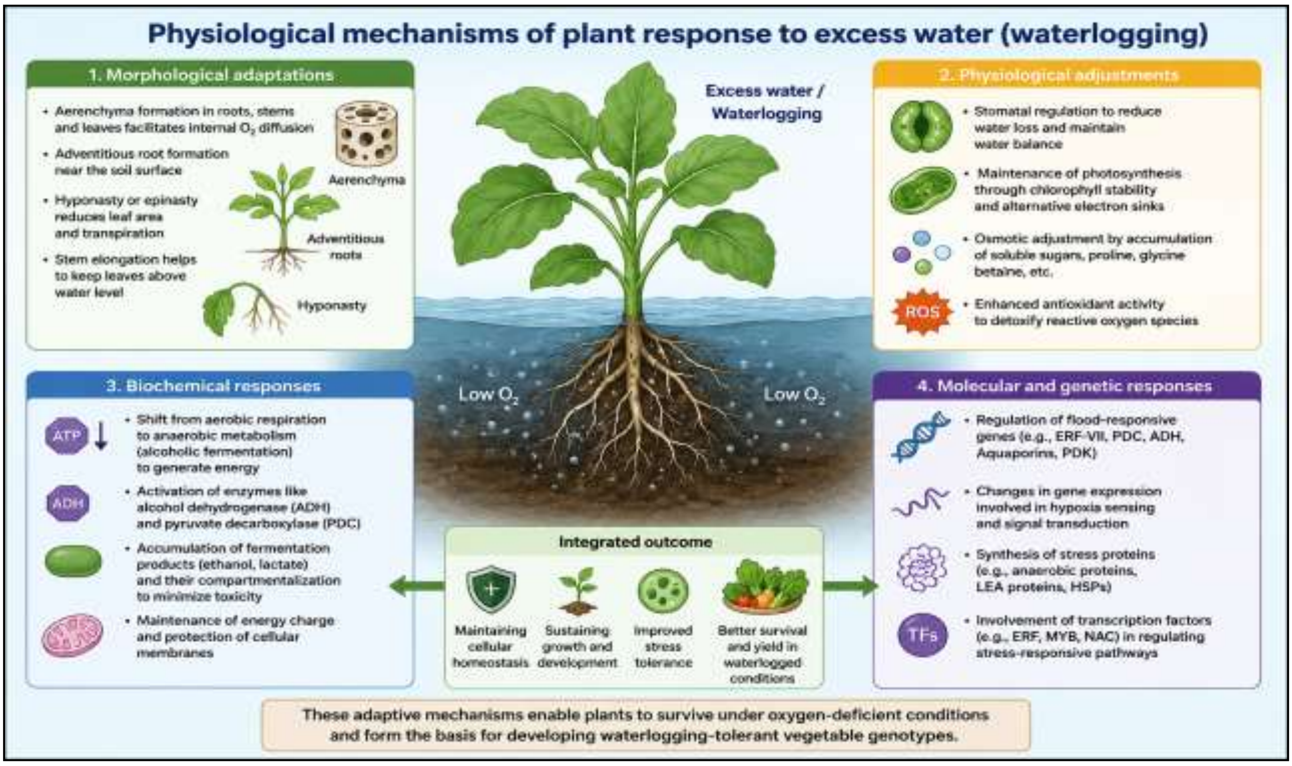

Figure 3. Integrated morphological, physiological, biochemical, and molecular responses of plants to waterlogging stress.

1.3.1. Reduced oxygen availability and shift to anaerobic respiration

When the ground is really wet oxygen moves through water 10,000 times slower than it does, in the air. This means that plant roots do not get oxygen. Because of this they cannot make much energy as they need to. Plant roots need oxygen to work properly. When they do not get oxygen they have to change the way they make energy. Of using oxygen plant roots start to make energy without oxygen. This process is called fermentation. The plant roots make ethanol and lactic acid when they ferment. They do this by breaking down things in a way. (16). However anaerobic respiration does not make much energy as aerobic respiration. This means that things do not grow well and you get a smaller yield. When there is not oxygen certain important enzymes like alcohol dehydrogenase and pyruvate decarboxylase get to work. These enzymes help make energy through a process called fermentation. Anaerobic respiration and fermentation are important because they help things make energy when there is not oxygen. Anaerobic respiration uses enzymes, like alcohol dehydrogenase and pyruvate decarboxylase to make energy (1).

1.3.2. Formation of aerenchyma tissue

Aerenchyma is a kind of tissue that has big spaces inside where air can move around. This helps aerenchyma get oxygen from the shoots to the roots. When the soil is too wet and plants are under stress they grow aerenchyma tissue, in the roots stems and leaves. This is called schizogenous aerenchyma tissue. It helps oxygen get to the plants. Keeps them alive when the soil does not have enough oxygen for the aerenchyma and the rest of the plant (17).The formation of aerenchyma is really helpful because it reduces resistance to gas diffusion. This means that the roots of plants like taro and spinach can still breathe easily. The aerenchyma helps maintain root respiration under oxygen- environments. This is a deal for plants like taro and spinach because they are often in flooding conditions with very little oxygen. The formation of aerenchyma is an adaptation in these crops. It is very useful for plants that have to deal with flooding conditions. The aerenchyma formation helps these plants to survive in environments with oxygen levels. Plants, like taro and spinach have this adaptation to stay alive when there is not oxygen.

1.3.3. Development of adventitious roots

Waterlogging stress often causes the formation of roots near the surface of the soil. This is a thing for the plant because these adventitious roots are able to get more oxygen. They are able to do this because they are closer to the surface where the oxygen levelsre higher than they are deeper in the soil. The adventitious roots also help the plant get nutrients and this increases the chance that the plant will survive when there is too much water. Adventitious roots are really important, for the plant when there is waterlogging stress (18). When vegetable crops are in water for a time they can do something really cool. They can grow roots and this is called adventitious rooting. Adventitious rooting is a help to these crops. These new roots usually grow near the top of the soil. That is where they can get oxygen. With oxygen the roots can breathe again and get the food they need. This is really good for the vegetable crops because it helps them survive when they are in water. Adventitious rooting is very important, for crops.

1.3.4. Stomatal regulation and reduced transpiration

Plants deal with much water by changing how much they open up. When plants are underwater for long they close up their leaves to save energy. This helps them get through the times.. When they do this they also take in less carbon dioxide from the air. This means they make food from sunlight and that hurts their growth. Plants need water but much water is bad for them so they have to find a balance. Plants, like water. They also need air to make food so they have to open up and close up at the right times (6). When plants do not lose much water it helps the plants to maintain the water they need.. If this keeps happening for a long time the plants may not grow as fast as they should. This is because reduced transpiration rate affects the plants and the plants do not grow at their growth rate under this kind of stress. The plants need to maintain their water balance and reduced transpiration rate helps the plants to do that.

1.3.5. Hormonal regulation

Plant hormones are really important for helping plants deal with much water (Figure 4).When the soil is waterlogged it is hard for gases to get in and out of the plant. This makes the plant produce ethylene. The plant hormones like ethylene help the plant make some changes to cope with the water. Ethylene helps the plant make air pockets, extra roots and it makes the stem grow longer Plant hormones, like ethylene are very important for the plant to survive when there is much water. (19). Abscisic acid helps plants close their stomata to prevent water loss. On the hand gibberellins help plants grow taller. This growth enables plants to stay in touch with the air when there is much water around.These two types of hormones work together. They help plants change shape and work better when there is much water. This helps plants survive and grow well. The abscisic acid and gibberellins are really important, for this. The abscisic acid and gibberellins make sure plants can deal with much water (20).

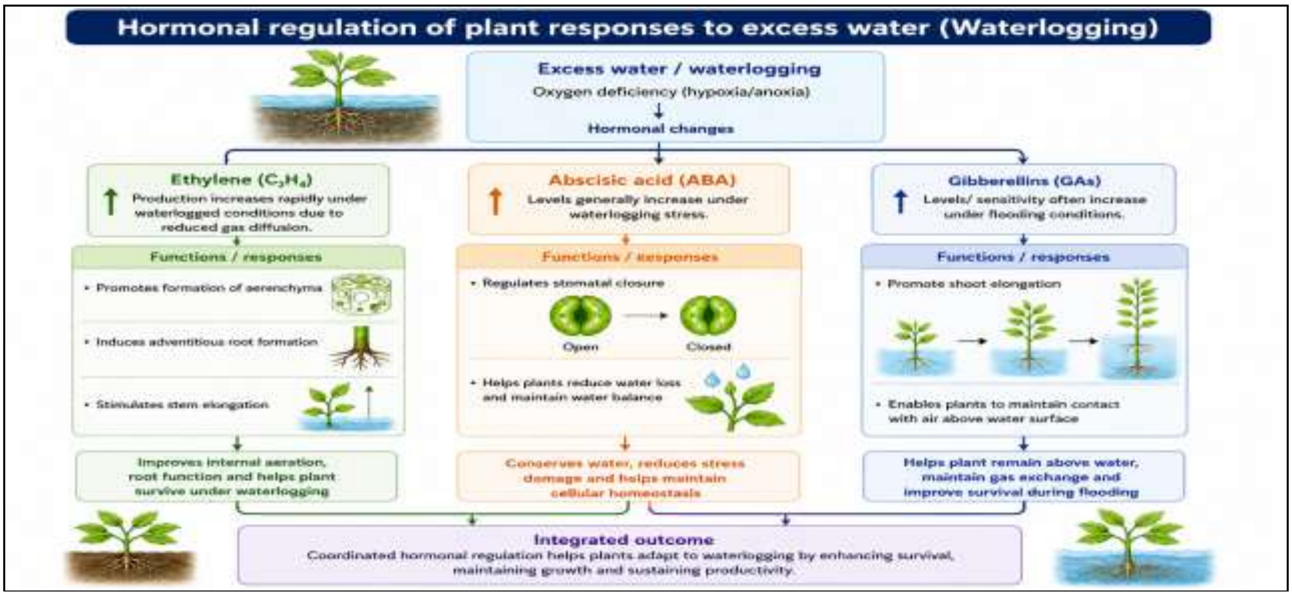

Figure 4. Hormonal regulation of plant adaptive responses to waterlogging stress

1.3.6. Accumulation of reactive oxygen species (ROS) and antioxidant defense system

Waterlogging is a problem for plants. It causes the roots to not get oxygen. This is called hypoxia or anoxia. When the roots do not get oxygen it messes up the way the cells work. The plant starts to make many bad things like superoxide radicals and hydrogen peroxide and hydroxyl radicals. Waterlogging stress is really bad for the roots. It makes the roots make much of these bad things. Waterlogging causes water to cover the roots and this leads to oxygen deficiency. The roots need oxygen to work properly. Without oxygen the roots get damaged. Waterlogging stress leads to the generation of these bad things like superoxide radicals and hydrogen peroxide and hydroxyl radicals, in the root zone (Figure 5). These reactive molecules are really bad for plants. They are not stable. Can hurt the tiny parts of a plant cell like the proteins, fats and genetic material. This can also damage the walls of the cells. When this happens it can stop the plant from working and make it grow more slowly. The plant will not be as healthy. Will not produce as much as it should. These reactive molecules can cause a lot of problems, for plant growth and productivity (15,21). When water covers the plants for a time this causes a big problem. The plants start to make a lot of things called ROS. These bad things damage the lipids in the plant cells, which's very bad for the plant. This damage causes the cell membranes to leak the enzymes to stop working and the chlorophyll to break down. All these things together make it harder for the plants to make food from sunlight, which's necessary for the plants to survive. The plants become weak. Their ability to do photosynthesis is reduced, which is bad, for plant survival. Photosynthetic efficiency is. Plant survival is reduced.

Plants have a way to protect themselves from damage caused by oxygen. They use a defense system that is made up of enzymes and other things that are not enzymes (Figure 5). This system has some enzymes, like superoxide dismutase, catalase and peroxidase. These enzymes do a job of cleaning up bad things that can hurt the plant. Superoxide dismutase takes the superoxide radicals and turns them into hydrogen peroxide. Then catalase and peroxidase take the hydrogen peroxide. Break it down into water and oxygen. This helps reduce the stress that oxygen can cause in plant cells (21, 22).The enzymes work together to keep everything in the cell running smoothly they keep the membranes stable. Help the plant deal with too much water. This is why people think that these enzymes are a way to figure out if a type of vegetable crop can handle too much water.

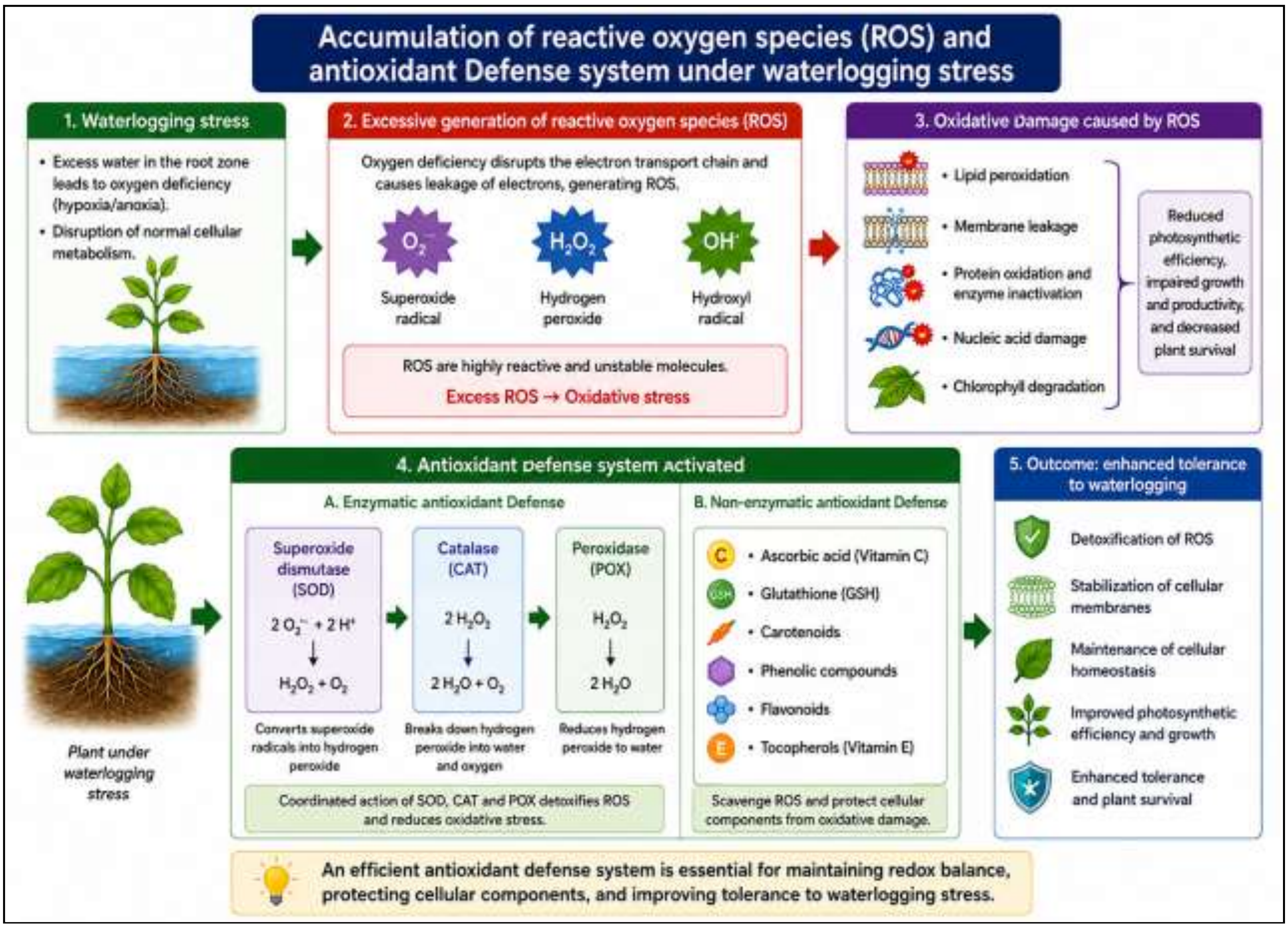

Figure 5. Accumulation of reactive oxygen species (ROS) and activation of the antioxidant defense system under waterlogging stress

1.3.7. Nutrient imbalance and reduced mineral uptake

Waterlogged soils are really bad for plants because the roots do not work properly and the soil is different. When there is not oxygen in the soil it is hard for plants to get the nutrients they need like nitrogen and phosphorus and potassium and calcium and magnesium. Waterlogged soils can also have much of some bad things like iron and manganese when there is no oxygen. If the soil is waterlogged for a time the plants can get sick and turn yellow and the leaves can fall off and the roots can get shorter. Waterlogged soils can cause all these problems because waterlogged soils are not good, for plant roots (13).

1.3.8. Reduced photosynthesis and chlorophyll degradation

When plants have much water it can be really bad for them. This excess water causes the plants to have trouble making food from sunlight. The plants have openings that they use to breathe and when they have too much water these openings get closed. This also hurts the parts of the plants that help them make food. The plants then have a time turning sunlight into energy. The green parts of the plants like chlorophyll get broken down. This means the plants can not use sunlight as well. This results, in the plants making food and growing more slowly. So when plants have much water it hurts their growth and the amount of food they can produce (23).

1.4. Practical Management Strategies for Mitigating Waterlogging Risks

To deal with waterlogged soil we need to use a combination of methods that help the water drain keep air in the soil and make the crops stronger when there is a lot of flooding. We have to do things to make sure the roots get enough oxygen and the crops do not die. If we use the farming methods take care of the soil and choose the right crops, Plant tolerance, to excess water stress will get better crops will be able to handle too much water and this will really help the crops when there is excess water stress (2,14). The following practical strategies are commonly recommended for mitigating waterlogging risks in vegetable production systems.

1.4.1. Drainage systems

Proper drainage is the way to deal with too much water in the soil where we grow crops. We can get rid of water from the surface with channels or ditches or by making the land slope. Proper drainage also helps get air into the soil by removing water from where the roots of the plants are. If we put in tile drainage or pipes with holes this helps keep the soil from getting too wet or too dry. This is good because it stops the soil from staying too wet for long which is not good, for the roots of the plants (11). Good drainage is really important for plants. It helps the roots breathe. It makes the tiny living things in the soil very active. This means the soil has a lot of nutrients that the crops can use to grow big and strong especially when it rains a lot. Good drainage systems make a difference in how well crops grow when there is a lot of rain. The crops can grow well because the drainage systems help the roots of the crops and the tiny living things, in the soil and they make sure the crops have the nutrients they need to grow big and strong under high rainfall conditions (12).

1.4.2. Drainage management

Surface and subsurface drainage systems are really important for stopping water from building up over a time. We need to make sure that drainage channels, field leveling, furrow systems and subsurface tile drainage are all designed correctly. This helps to get rid of water and prevents the soil from staying too wet for too long. Surface and subsurface drainage systems are especially crucial, in areas where we use a lot of water for irrigation and where it rains a lot. In these places if the drainage is not good it can really hurt how well the crops do. Surface and subsurface drainage systems help to make sure that crops can grow well (24-26).

1.4.3. Raised beds

Raised bed cultivation is a good way to help prevent water from building up in the soil and damaging vegetable crops. When you use raised beds water can drain away from the surface of the soil easily. This helps the soil to get air and it stops the soil from being too wet for too long. By raising the soil up the roots of the plants are above the water that might collect on the surface. This makes it easier for the water to soak into the soil. It makes the soil less dense. The soil is also less likely to get compacted which means it is easier for the roots of the plants to grow down into the soil and get the nutrients they need.In areas where the soil does not drain well using raised beds can really help the crops to survive and grow well. This is especially true when there is a lot of rain. Crops, like tomatoes, chilli, onions and cucumbers really benefit from being grown in raised beds. This is because the raised beds help to get oxygen to the roots of the plants and it reduces the chance of the roots rotting (27-29).

1.4.4. Crop selection

The best way to deal with waterlogging is to choose waterlogging- crops and genotypes. This is a way to save money and help the environment in areas that are prone to flooding. Some crops can adapt to flooding because they have features. These features include growing roots making their stems bigger creating air spaces in their stems and being able to breathe when there is not much oxygen.Vegetable crops like taro, spinach, amaranthus, mint and kang kong can tolerate waterlogging. On the hand crops like onion, garlic, cabbage and tomato are very sensitive to waterlogging. We need to breed crops that can handle stress and select the genotypes to make our farming systems stronger. This is especially important for farms that're vulnerable to flooding and other problems. Waterlogging-tolerant crops and genotypes are the key, to making our farms more resilient (8,15,30).

1.4.5. Adjusting planting dates

Changing when we plant or move crops is a help in dealing with the weather. This is because we can avoid planting at times when we know it will flood. If we time it just right we can make sure the crops are not too sensitive when the heavy rains come. This is especially important in places where it rains a lot during times of the year. If we get the timing of planting right we can really reduce the amount of crops that are lost and make the land more productive. We can do this when the weather is not always the same. Using tools that can predict the weather and tell us when it will rain can also help us figure out the best time to plant. This is really helpful, for people who grow vegetables in places that often flood (31,32).

1.4.6. Cover crops

Cover crops are really good for the soil. They help the soil get structure and they make it easier for water to get in and drain out. Some cover crops like grasses and legumes have roots. These roots make holes in the soil which helps to stop the soil getting too compacted. The soil also gets better at sticking together. It gets more organic matter in it.This makes it easier for water to move down into the soil. It also helps the soil get oxygen and it stops water from just running off the top. So cover crops are a way to help the soil deal with too much water.Cover crops also make the soil more fertile and sustainable in the term. Cover crops are good, for the soil. They help the soil to stay healthy (33). Cover crops are really good for the soil. They help the living things in the soil around the roots of plants to grow and get stronger. This makes the soil stick together better. It is easier for water to drain through. Cover crops also help the soil by making friends with kinds of fungus, like arbuscular mycorrhizal associations. This helps the soil to be healthier and work better. Cover crops make the soil structure better. They help the soil to drain water more easily (34).

1.4.7. Mulching

Mulching is really helpful in stopping water from building up in the soil. It does this by letting water soak in reducing the water that runs off stopping the soil from getting hard and keeping the soil in good shape. If we use things like straw, compost and leftover crop bits as mulch it makes the soil more open. Gets more tiny living things in it.On the hand plastic mulches keep the area around the roots from getting too much water. Mulching also helps keep the soil at a temperature and stops it from washing away which makes it easier for plants to grow in places that are tough for them. Mulching really supports the plants when they are first starting to grow in these environments. The mulching materials, like the synthetic ones are very important, for reducing waterlogging injury. These mulching materials, including synthetic mulching materials improve the soil and help the plants grow better (34-36). So there are these things called biological control agents. They are really helpful. For example Trichoderma spp and Bacillus spp. Are two kinds of biological control agents. These agents can stop root pathogens from doing harm. At the time they help roots that are stressed from too much water to get better. This is especially good for roots that are having a time because of waterlogging. Biological control agents like Trichoderma spp. And Bacillus spp. Are very good, at this.They can really help roots that are struggling with root pathogens and waterlogging (37).

1.4.8. Fertilizer management

Using a mix of nutrients helps plants grow strong and deal with flooding. Giving plants the amount of nitrogen, phosphorus, potassium and other nutrients helps them regrow roots keep their green color and fight off damage. If you give plants fertilizer in amounts especially nitrogen it helps stop nutrients from being washed away in flooded soil. So managing nutrients in a way helps plants recover and grow well after they have been flooded for a short time. This is because nutrient management helps plants like the nutrient application and the nutrient supply and the nutrient management is about the nutrient application. The plants need the balanced nutrient application to grow strong and to deal with the flooding stress and the nutrient management is important for the plants to recover after the flooding stress. The nutrient application is important for the plants. The nutrient management is, about the nutrient application and the balanced nutrient application is what helps the plants to grow strong and to deal with the flooding (37,38).

1.4.9. Disease management and fungicide use

Waterlogged soils are really bad for plants because they help bad things like Pythium, Phytophthora and Fusarium grow. To deal with these problems we need to use a combination of methods such as treating seeds with fungicides using liquids on the soil growing plants that can resist disease and using living things to control the bad things. This approach is necessary to stop roots from rotting plants from dying off and wilting when there is much water. Managing these things effectively makes a big difference in helping Waterlogged soils and plants grow in soils that do not drain well and it significantly improves crop survival, in Waterlogged soils (39).

1.4.10. Growth regulators and hormonal management

Plant growth regulators like salicylic acid and gibberellins can really help plants deal with much water. These Plant growth regulators also include things like ethylene inhibitors and abscisic acid modulators. We also have oxide and melatonin and polyamines and brassinosteroids. All these Plant growth regulators can help plants tolerate waterlogging. They do this by keeping the hormones in the plant balanced. They also help the plant defend against damage, from oxygen.

Plant growth regulators help the roots of the plant grow. They help the plant deal with stress. These compounds make the plant cells stronger. They reduce the damage caused by oxygen. Plant growth regulators help the plant recover after a flood (10,40).

1.4.11. Antioxidant defense enhancement

Waterlogging is a problem. It causes a lack of oxygen which's really bad for plants. This leads to the formation of things that damage the plants cells and the important parts inside the cells.To deal with this issue the plants defense system needs to be strong. This system has helpers like superoxide dismutase, catalase and peroxidase that clean up the bad things. When these helpers are working well the plant can handle waterlogging better.So if we want to help plants survive waterlogging we need to find ways to make their defense systems stronger. This can be done by using special management strategies that focus on making the plants antioxidant systems better. Waterlogging resilience can be improved a lot by doing this. Waterlogging is still an issue but with the right approach we can help plants become more resistant, to waterlogging (21,41).

CONCLUSION

Waterlogging is a problem for vegetable production. It happens in areas where the water does not drain well and where floods occur often. When the soil is too wet for a time it does not have enough oxygen for the roots of the vegetables. This means the vegetables do not get the nutrients they need they do not make food from sunlight well and their internal processes get messed up. The vegetables also start to make many bad things that can hurt them.Vegetables try to deal with much water in different ways. They can make energy without oxygen grow roots and make hormones to help them. They also have systems to fight off the things that can hurt them.. These things do not always work well enough to stop the bad effects of too much water. So when vegetables are in water, for long they do not grow very well they do not produce very much the quality of the produce is not good and the overall production of the crop is reduced. Waterlogging affects vegetable production in a way especially waterlogging.

To deal with waterlogging stress we need to do a lot of things. We have to make the soil and the crops better. We can grow crops that can handle waterlogging and use farming practices. This means we can use drainage systems and plant the crops in raised beds. We can also use plants that help the soil and add materials to the soil to keep it healthy. Giving the crops the amount of nutrients and using things that help the crops grow can also help. We need to be careful when we use these things so we do not hurt the crops.These things help the soil get air and the roots of the plants work better. This helps the plants grow even when there is much water. We should keep learning about how plants deal with stress and how we can breed plants that can handle waterlogging. We can also use helpers like fungi that live in the soil and help the plants.. We need to be smarter, about how we use water.We need to put all these things to make farming better. This way we can grow vegetables when there is a lot of water. Waterlogging is a problem because of climate change. So we need to find ways to make farming stronger and better so it can handle waterlogging. We need to keep working on waterlogging so we can have vegetable production systems that can handle the water. Waterlogging is an issue and we need to deal with waterlogging to have good crops.

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