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VEGETABLE GRAFTING: A SUSTAINABLE APPROACH FOR ENHANCING ABIOTIC STRESS TOLERANCE IN VEGETABLE CROPS

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ABSTRACT
Vegetable grafting is a way to help crops deal with problems like drought, salinity, waterlogging and extreme temperatures. This review looks at how grafting's used with big vegetable crops like tomato, brinjal, pepper, cucumber, watermelon and muskmelon.The technique is pretty simple: you join a scion with a rootstock, which means you combine the parts of both. The roots that can handle stress and the parts that grow the fruit and are high quality.Studies show that grafting helps plants grow better use water and nutrients efficiently and produce more fruit. It also helps the roots grow stronger balances the water and nutrients and keeps the plants healthy.When it is salty or too hot grafted plants do better because they can keep the balance of water and nutrients. They also do better when it is too hot because they have leaves are greener and can make more seeds. Grafting also helps prevent diseases that come from the soil and reduces the need for chemicals, which's good for the environment.Even though grafting has a lot of benefits it does not always work well because the rootstock and scion have to be compatible and the weather and how you take care of the plants matter. This review says it is important to choose the rootstocks for specific problems understand how plants handle stress and use grafting with other good farming practices. Overall vegetable grafting is a way to make crops stronger improve the quality of the fruit and help the environment. If we keep doing research on rootstocks how plants handle stress and use grafting more it can help make vegetable grafting even better and more resilient, to climate change.

KEYWORDS
Vegetable grafting, Abiotic stress, Rootstock, Scion, Flooding tolerance, Drought tolerance, Salinity tolerance, Thermal stress, Crop productivity, Sustainable agriculture

INTRODUCTION
Vegetable grafting is a help to people who grow vegetables. It makes the vegetables stronger so they can deal with things like not having water or too much salt in the soil. Vegetable grafting is also good for vegetables when the weather is really hot or really cold. Vegetable grafting is when you join two parts of a plant together to make one plant. You have the rootstock, which's the part of the plant that grows in the ground and the scion, which is the part of the plant that grows above the ground. These two parts of the plant grow together to make one plant that's healthy and strong.The rootstock is chosen because it is a part of the plant and can handle things that are in the soil. The scion is chosen because it produces the kind of vegetables that people want to eat and buy. Vegetable grafting is similar to what people do with fruit trees. When people graft a fruit tree they have to make sure that the rootstock and the scion work together. This is also true for vegetable grafting. If the rootstock and the scion are compatible the vegetable plant will grow well. Produce a lot of vegetables. Vegetable grafting is a technique, for people who grow vegetables (Lee et al., 2010; Schwarz et al., 2010).
The practice of vegetable grafting started in Asia in Japan, Korea and China. In these countries people would graft watermelon onto roots to stop diseases in the soil and make the plants stronger. On people began to use this technique on other vegetables like tomato, eggplant, pepper, cucumber and melons. When you graft peppers, eggplant and melons, onto roots that're strong and can handle stress vegetable grafting has shown that it can really help the plants

survive and produce more vegetables even when the weather is bad and it is hard to grow vegetables (King et al., 2010; Colla et al., 2010). Rootstocks that have good roots that go deep and spread out are very good at taking in water and nutrients. This makes the plant very healthy. These Rootstocks also help the plant deal with things like too much salt, not enough water and too much water. The Rootstocks are great at helping the plant survive when things get tough. The Rootstocks really help the plant to be strong and handle things, like drought and waterlogging and salinity (Savvas et al., 2010).

Vegetable crops do not grow well because of things like waterlogging and drought. When the soil is waterlogged the roots of the vegetable crops do not get oxygen. This means the vegetable crops cannot breathe properly. They also have a time taking in the nutrients that the vegetable crops need.On the hand when there is a drought the vegetable crops do not get enough water. This makes it difficult for the vegetable crops to make food through a process called photosynthesis. Then there is salinity stress, which's when the soil has too much salt in it. This causes problems for the vegetable crops because it messes up the balance of water and nutrients in the soil. The salt in the soil can also be toxic, to the vegetable crops, which can really hurt the vegetable crops and stop the vegetable crops from growing. The vegetable crops really struggle with these things, especially salinity stress and drought. The vegetable crops also have a lot of trouble with waterlogging (Munns and Tester, 2008). Grafting is a way to get around the problems that plants have. It does this by taking the things from different types of plants and putting them together. When you use a root system from one plant it helps the whole plant do better. This is because the roots are better at getting water and minerals from the ground. The plant is also better at keeping its hormones in balance. It can fight off damage from things like too much sun or not enough water. This means that the plant can deal with conditions outside like really hot or cold weather and still do okay. Grafting with stress- rootstocks is really helpful, for the plants (Schwarz et al., 2010; Kumar et al., 2017).

In years grafting vegetables has become very important. It is a way to help plants deal with stress from the environment. This method does not rely much on chemicals.Grafting helps plants grow better and produce more. It also makes fruits better. Helps plants handle changes in the weather.We need to know more about grafting and how it helps plants deal with stress. This knowledge will help us grow vegetables in a way that can handle climate change. This way we can keep farming productive and good for the environment.Grafting vegetables is key. It helps us make sure we can grow vegetables in a way. Vegetable grafting is important, for our farms (Lee et al., 2010; Rouphael et al., 2018).

History of Vegetable Grafting

People have been using vegetable grafting for a while now.It is a way to make vegetable plants stronger. Vegetable grafting helps vegetable plants grow better and deal with diseases and other issues that vegetable plants often have. Vegetable grafting makes vegetable plants more able to handle problems that vegetable plants face every day. Vegetable grafting began in Japan and Korea a time ago back in the 1920s.At that time people used vegetable grafting to help watermelon plants grow big and healthy. They would attach watermelon plants to the roots of plants like gourds.This helped to control diseases in the soil, such as Fusarium wilt, which is caused by a fungus called Fusarium oxysporum that can hurt vegetable plants. By using vegetable grafting people could keep their vegetable plants healthy and strong. Vegetable grafting was a solution, to the problems that people had with their vegetable plants. It helped vegetable plants grow well and stay healthy which is what people want for their vegetable plants (Lee et al., 2010). In the 1930s people in Japan started joining watermelon plants to the roots of bottle gourd and squash plants. They did this for a reason. It helped the watermelon plants to be stronger against Fusarium disease. It also helped the watermelon plants grow better in areas. The Japanese people did this with watermelon and bottle gourd and also with watermelon and squash plants. Watermelon plants grew stronger, with bottle gourd roots. Watermelon plants also grew well with squash roots (Oda, 1999; King et al., 2010).

In the 1950s, grafting technology expanded to solanaceous crops, particularly aubergine or brinjal (Solanum melongena), which was grafted onto scarlet eggplant (Solanum integrifolium) to improve tolerance to soil-borne pathogens and adverse environmental conditions (Lee et al., 2010). Subsequently, grafting of tomato (Solanum lycopersicum) began in the 1960s, driven by the increasing demand for disease-resistant planting materials and improved productivity in East Asian countries, which remain the largest market for grafted vegetable seedlings today (Schwarz et al., 2010). Over time, grafting techniques were further extended to crops such as pepper, cucumber, melon, and other cucurbits, demonstrating improved tolerance to salinity, drought, temperature stress, and soil-borne diseases (Colla et al., 2010).

In India, research on vegetable grafting was initiated by scientists to address major production constraints such as bacterial wilt, nematodes, and abiotic stresses. Early research was carried out by Dr. Bhatt and his team at the Indian Institute of Horticultural Research (IIHR), Bengaluru, focusing on brinjal grafting using Solanum nigrum as rootstock for resistance to bacterial wilt (Prasad et al., 2007). Studies at Tamil Nadu Agricultural University (TNAU), Coimbatore, have also demonstrated the effectiveness of grafting in improving tolerance to soil-borne pathogens and enhancing yield in solanaceous crops. Similarly, cucurbit grafting research conducted at the National Bureau of Plant

Genetic Resources (NBPGR) regional station, Thrissur, Kerala, reported high graft success rates using Momordica cochinchinensis as rootstock for improving vigor and stress tolerance (Pandey et al., 2012). Research at CSK Himachal Pradesh Krishi Vishvavidyalaya (CSKHPKV), Palampur, has identified several rootstocks in cucurbitaceous and solanaceous crops that provide resistance to bacterial wilt, nematodes, and environmental stresses (Kumar et al., 2017). In recent years, private seed companies such as VNR Seeds Private Limited and Takii Seed India Private Limited have expanded commercial vegetable grafting by supplying grafted seedlings with improved resistance to stresses and higher productivity. The increasing adoption of grafting technology reflects its importance as a sustainable and eco-friendly approach for improving vegetable production under changing climatic conditions.

Purpose of Vegetable Grafting

Vegetable production is greatly affected by various biotic stresses such as soil-borne pathogens (fungi, bacteria, nematodes) and abiotic stresses including drought, salinity, waterlogging, extreme temperatures, and nutrient imbalances. These stresses significantly reduce plant growth, yield, and quality, thereby limiting productivity and profitability in vegetable cultivation (Schwarz et al., 2010; Rouphael et al., 2018). Vegetable grafting is a way to get around some of the problems that vegetable plants have. It does this by taking the things from two different types of vegetable plants and putting them together. This way of growing vegetables is good, for the earth. It works really well. Vegetable grafting is a technique that helps vegetable plants by combining the things from two different kinds of vegetable plants.

Vegetable grafting is really good for the plants. It helps them grow stronger. When we use roots for the plants they can get water and food from the ground more easily. These strong roots are very good at getting what the plant needs. They help the plant make food from sunlight better.. When things get tough for the plant it can still grow well because of these strong roots. Vegetable grafting is, about using these strong roots to help the plants. Vegetable grafting makes the plants very healthy and strong (Lee et al., 2010). As a result grafted plants often show adaptability to bad environmental conditions like salty soil, lack of water and too much water.This is because grafting helps plants deal with stress from things like salt levels, not enough water and too much water. Grafted plants can handle these conditions better. They are more adaptable to environmental conditions such, as waterlogging stress, drought and salinity.

Vegetable grafting is really good for the plants. It helps them grow better and give vegetables. When you graft a vegetable plant it is more likely to survive and make fruit. The plant can also use the food it gets from the soil efficiently. Some roots are very strong.Can handle bad weather or other problems. This means the plant can keep growing and giving vegetables when things are tough. As a result you get vegetables from grafted plants than from plants that are not grafted. Vegetable grafting is a help, to the vegetable plants and the people who grow them (Colla et al., 2010). Grafting is also really important for making fruits better. It helps with things like how big the fruit's what shape it is, what color it is and how firm it is. Grafting also helps with the amount of things in the fruit like nutrients and how long the fruit lasts. So grafting is good for the quality of the fruit and the quantity of the fruit. Grafting helps with the soluble solids, in the fruit and the nutrient content of the fruit and the shelf life of the fruit (Kyriacou et al., 2017).

Due to increasing concerns regarding environmental safety and restrictions on the excessive use of chemical pesticides and fungicides, grafting has become an effective alternative strategy for managing soil-borne pathogens such as Fusarium, Verticillium, Ralstonia, and root-knot nematodes. Grafting susceptible scions onto resistant rootstocks provides natural resistance against these pathogens, thereby reducing dependence on chemical control measures (King et al., 2010). This approach is particularly important in intensive vegetable production systems where repeated cropping often leads to the build-up of soil-borne diseases.

So vegetable grafting is really good for sustainable farming. It helps to cut down on the use of chemicals to control diseases and pests. When we use rootstocks that can resist diseases it is better for the environment. This method reduces pollution makes the soil healthier and helps us grow vegetables in a way that's friendly, to the earth. Vegetable grafting is a way to do this because it supports organic and sustainable cultivation systems. Vegetable grafting helps to make sure that we have soil and clean air. Vegetable grafting is a part of growing vegetables in a sustainable way (Rouphael et al., 2018). Therefore, vegetable grafting is considered a promising tool for improving crop productivity, quality, and stress tolerance while ensuring environmental sustainability in modern vegetable production systems.

Prerequisites for Vegetable Grafting

Vegetable grafting is a process that needs some things to happen first. You have to make sure the rootstock and the scion are a match. You also need the tools and a place with the right temperature and light. When you get all these things right the rootstock and the scion will join together well. This helps the plant grow strong and healthy. Vegetable grafting is, about getting the rootstock and the scion to work together. If you choose the plants and use the right tools you will have a better chance of getting a healthy plant. Vegetable grafting depends on getting the rootstock and the scion to form a bond (Lee et al., 2010; Oda, 2007).

Choice of Rootstock and Scion

Selection of rootstock and scion is really important for successful grafting. The rootstock should have a root system be vigorous and able to handle tough conditions like salty soil, drought waterlogged soil and extreme temperatures. It should also be resistant to diseases that live in the soil. When choosing a scion we look for things like yield good fruit quality, great taste and what people want to buy. Rootstock and scion must be compatible so they can connect properly and help the plant grow well over time. This compatibility helps with the flow of water and nutrients. So rootstock and scion should work well together for a plant. The rootstock and scion both play a role, in how well the plant does (Hartmann et al., 2011; Schwarz et al., 2010).

Grafting tools

Grafting tools are really important to get the cutting right and to make sure the rootstock and the scion are attached properly. You will need things like blades or knives to cut the rootstock and the scion. Grafting clips and silicon tubes are also very useful. Some people use pins to hold everything in place.There are other materials that help keep the rootstock and the scion close together. When the vascular tissues of the rootstock and the scion are lined up correctly the rootstock and the scion will heal quickly. Form a strong bond between the rootstock and the scion. This is called a graft union, between the rootstock and the scion (Lee et al., 2010).

Screening House (Nursery Conditions)

Seedlings of rootstock and scion need to be healthy and uniform. They are usually grown in a place like a nursery or a special house called a screening house. This is before they are grafted together. The special house helps keep the environment right for the seedlings. It helps them grow strong and have the same size stem. This is very important for making sure the grafting is successful. The screening house also keeps the seedlings safe from things like pests and diseases. It protects them from changes in the environment when they are still growing and getting strong. This is an important time, for rootstock and scion seedlings (Kubota et al., 2008).

Healing Chamber

After the grafting process the seedlings are put in a room to help them heal and form a strong connection. This room has the conditions for the seedlings to recover, with a temperature of 25 to 30 degrees Celsius, a humidity level of 85 to 95 percent and very little light or even complete darkness, for the first one or two days. The high humidity stops the grafted seedlings from getting too dry. The controlled temperature helps the cells to divide and form a callus at the graft.As time goes by the seedlings are slowly introduced to light and the humidity is reduced over five to seven days, which helps them get used to their new surroundings and establish themselves successfully as grafted plants. The grafting process needs this care to ensure the seedlings become strong grafted plants (Lee et al., 2010; Rivard and Louws, 2008). Proper management of these prerequisites ensures success in grafting, improved plant growth and better tolerance, to pests and environmental stresses. This makes vegetable grafting a way to produce crops sustainably.

Steps in Vegetable Grafting

Vegetable grafting is a process that has steps. These steps are important to make sure the rootstock and the scion join together well. When they join together well the plant becomes stronger. Can handle stress better. It also helps the plant produce fruit regularly. To get all these benefits you have to do each step of the vegetable grafting process. This is how you get an union between the rootstock and the scion and this is how you help the grafted seedlings grow well. Vegetable grafting is, about making sure the rootstock and the scion work well together (Lee et al., 2010; Hartmann et al., 2011).

Selection of Rootstock and Scion Species

When it comes to vegetable grafting choosing the rootstock and scion species is the key. You want a rootstock that has a strong root system. It should also be able to fight off diseases that come from the soil.. It has to be okay with things like too much salt, not enough water and too much water.The scion is picked because it has fruit can produce a lot and people want to buy it. The rootstock and scion have to work together so they can connect properly. This way water and nutrients can get to where they need to go.. The plant will live for a long time. Vegetable grafting is about getting the rootstock and scion to work together. The rootstock and scion are important, for vegetable grafting (Schwarz et al., 2010; Kyriacou et al., 2017).

Creation of Graft Union

The graft union is made by joining the rootstock and the scion together using the grafting methods. These methods include splice grafting and cleft grafting and tongue grafting and approach grafting.To do this you make cuts on the rootstock and the scion using a very sharp and clean blade. This helps the tissues of the rootstock and the scion line up properly. When the rootstock and the scion are aligned right the graft union heals quickly and the rootstock and the scion can share water and nutrients. This happens because the cuts, on the rootstock and the scion help them form a callus and connect their tissues (Lee et al., 2010; Hartmann et al., 2011).

Healing of the Graft Union

After the grafting is done the seedlings are put in a room where the air and temperature are controlled. This helps the seedlings to heal and grow. The room is kept humid with a lot of moisture, in the air and the temperature is around 25 to 30 degrees. It is also kept a bit dark. The seedlings are kept in this room for a days. This is done so that the seedlings do not get too dry and the cells can grow. When the seedlings heal properly they can transport water and nutrients and other important things well. The grafting needs to be done right so that the seedlings can grow strong and healthy. The seedlings need to have connections so that they can get all the things they need to grow (Oda, 2007; Rivard and Louws, 2008).

Acclimatization of Grafted Plants

When the graft union has healed the grafted seedlings are slowly gotten used to the conditions outside by lowering the humidity and turning up the light. This helps the grafted seedlings get used to the world and stops them from getting transplant shock. If we do the acclimatization right it helps the grafted seedlings survive makes them strong and helps them do well when we plant them in the field. The acclimatization of grafted seedlings is important for the survival of grafted seedlings and the acclimatization of grafted seedlings to the world is key to a good start, for grafted seedlings (Kubota et al., 2008; Lee et al., 2010).

Grafting Methods Used in Vegetable Crops

People use ways to join plants together when they are growing vegetables. The way they do it depends on the type of vegetable how thick the stem's the weather and how good the person is at joining plants. You have to pick the way to join the plants so that they grow well heal quickly and do not die. There are a ways that people usually use to join plants. For plants like tomato, brinjal and pepper people often use splice grafting and tube grafting. For plants like cucumber, watermelon and melon people usually use hole insertion grafting. Vegetable growers use these methods to join plants and help them grow strong. The right method makes a difference, in how well the plants grow and how healthy they are (Lee et al., 2010; Hartmann et al., 2011). The different grafting methods used in crop-wise standardized grafting techniques are presented in Table 1**.**

1. Cleft Grafting

People have been using cleft grafting for a time. This is a method where you cut the stem of the rootstock up and down. Then you shape the scion into a wedge shape. After that you put the scion into the part of the rootstock. It is very important that the cambial tissues of the scion and the rootstock are lined up correctly. If they are the vascular connection will be good. The plant will heal. Cleft grafting is often used when the rootstock is a bit bigger than the scion. It works well for things, like vegetables. Cleft grafting is a way to join the rootstock and the scion together (Hartmann et al., 2011).

2. Tongue Approach / Approach Grafting

Grafting is a way to join two plants together. You take the part of the plant you want to graft, which is called the scion and the part that will support it which is called the rootstock. You keep them attached to their roots when you first join them. To do this you make cuts on both stems that are angled. Then you tie the cut parts together so they can heal. The scion and rootstock are tied together until they form a bond. After they have healed you remove the parts you do not need. You get rid of the shoot from the rootstock and the roots, from the scion. This way of grafting works well and is very useful when you need to make sure the graft survives (Oda, 2007).

3. Hole Insertion / Top Insertion Grafting

People often use a method called hole insertion grafting when growing cucurbit crops like watermelon and cucumber. To do this a hole is made in the stem of the rootstock. The scion is then put into this hole after the lower part is taken off. The part of the rootstock that helps it grow is removed so that the scion can grow well. Hole insertion grafting is very good for nurseries that want to grow a lot of plants because it works well and makes a connection, between the rootstock and the scion (Lee et al., 2010).

4. Slant / Splice Grafting

Splice grafting, which people also call grafting is a really popular way to join tomato and brinjal seedlings. To do this you cut the rootstock. The scion stems at an angle so they are similar. Then you use clips or tubes to hold them. This way of doing things is easy. It works really fast. It is also very good at getting results, which makes it perfect, for companies that do a lot of grafting (Kubota et al., 2008).

5. Tube Grafting

Tube grafting is a way to join two plants together. It is like splice grafting. You use a small tube made of plastic or silicon. You put this tube over the parts of the plants where you made cuts. The tube helps the plants heal and grow together properly. It makes sure the important parts of the plants line up correctly. People who grow plants, in greenhouses really like to use tube grafting because it's easy and usually works very well. Tube grafting is used a lot in these places because it is simple and the results are always the same. The success rate of tube grafting is very high (Lee et al., 2010).

6. Automated Grafting

Grafting machines are used for automated grafting. These machines. Align seedlings and then join them together very precisely. Using machines, like this means we need fewer people to do the work. It also makes the process of grafting go faster. Helps make sure all the seedlings are the same. Automated grafting is something that more and more people are using in countries that have a lot of technology for growing plants on a scale like automated grafting to make a lot of grafted seedlings (Kubota et al., 2008; Lee et al., 2010). Selection of a grafting method depends on the type of crop, weather conditions how skilled you are and what facilities are available. Using the right grafting techniques helps to get a success rate makes crops more resistant to stress and increases the yield of vegetables. The method you choose should match the crop you are working with. Grafting is useful, for vegetable crops. It gives results if you select the right method.

Grafting to Mitigate Abiotic Stress in Vegetable Crops

Vegetable crops over the world are really struggling with things like flooding, drought and too much salt in the soil. Also when it is extremely hot or cold this is very bad for them. These things are like problems that stop vegetable crops from growing well and being as good as they can be.They also affect how the plants work inside like how they make food and breathe.. They have a hard time getting the nutrients and water they need. Even the balance of water in the plant and the hormones that help it grow are affected. All of this means that vegetable crops do not produce much food as they could and that is a big problem for people who grow them because they lose money. Vegetable crops are very important and flooding and drought and other things like that are really bad, for them (Schwarz et al., 2010; Rouphael et al., 2018). Vegetable grafting is a way to help plants deal with environmental stresses. It is a way to make plants stronger without changing the things that make them good for selling. When we graft a plant we join a root system with a part of a plant that grows a lot of food. This way we get the things from both parts of the plant. The strong roots help the plant get water and nutrients from the soil better. They also help the plant stay healthy when the environment is not good. This means the plant can handle conditions like too much or too little water. Vegetable grafting is a way to make plants stronger and it is good, for the environment too (Lee et al., 2010).

Vegetable grafting is a way to help plants deal with too much water. It does this by getting air to the roots and keeping the plant alive when there is not enough oxygen.Vegetable grafting also helps plants deal with not water. It does this by making the roots better, at getting water and using it wisely. The Vegetable grafting plants can survive when they do not get enough water (Kumar et al., 2017). When plants have to deal with much salt, the roots that are good at handling salt help control how much bad stuff like sodium and chloride gets into the plant. This helps the plant get the nutrients it needs and stops the water from hurting the rest of the plant especially the scion tissues. The tolerant rootstocks are really good at keeping the balance of nutrients right. The plant does not get sick from too much salt. This is important because much salt can really hurt the plant but the tolerant rootstocks help reduce the damage, from the salt (Colla et al., 2010). Grafting is really helpful for plants. It helps plants deal with heat or cold stress. This is because grafting makes the roots of the plants work better. It also helps the plants make helpers that stop damage from things like heat.. It keeps the plants working properly even when it is really hot or really cold. Grafting helps the plants withstand stress by making the roots work better and by helping the plants make these special helpers. Grafting is good, for plants because it helps them survive when it is very hot or very cold (Rivero et al., 2003). Vegetable grafting is a help because it makes plants stronger against many kinds of bad things that can happen to them. This means vegetable grafting is a good way to deal with climate change and it helps plants grow well even when the weather is weird. So vegetable grafting is very important for growing vegetables in a way that's good for the earth. It helps plants get used to conditions and it reduces the bad effects of things like too much heat or cold. Vegetable grafting is really good at making sure we get a supply of vegetables that are healthy and taste good. Vegetable grafting plays a role, in this by making plants stronger and able to handle bad conditions (Rouphael et al., 2018).

Vegetable Grafting for Flooding Tolerance

When the soil gets too wet because of a lot of rain that comes and goes it can cause problems for vegetable crops. The water can get stuck in the soil. That is very bad for the plants.The roots of the plants need air to breathe. When the soil is flooded they do not get enough oxygen. This is really bad, for the plants because they need oxygen to grow and be healthy. The plants also need to be able to get nutrients and water from the soil. They need to be able to make food from sunlight.When the soil is too wet the plants have a hard time doing these things. If the soil stays too wet for long the roots of the plants start to get weak and they make bad things that can hurt the plant. This means the plants do not grow well and they do not produce many vegetables as they should. Vegetable crop productivity and vegetable crops are really affected by this (Else et al., 2009; Schwarz et al., 2010). Vegetable grafting is a way to deal with flooding. It works by joining plants that give a lot of vegetables with roots that can handle much water in the soil. These roots are really good, at dealing with much water. They have a structure and can bring more oxygen to the plant, which helps the plant survive when there is not a lot of oxygen. Vegetable grafting is helpful because it uses these roots. Vegetable grafting is a way to grow plants that can handle flooding. Various vegetable rootstocks with superior performance under flooding stress are summarized in Table 2, which highlights important rootstock–scion combinations and their key physiological characteristics contributing to improved tolerance.

The people who did this study used the tomato cultivar Arka Rakshak. They grafted it onto four eggplant rootstocks. These were BPLH-1, Neelkanth, Mattu Gulla and Arka Keshav. The study showed that grafting can help tomatoes deal with flooding. The results were pretty clear. Grafting had an effect, on how well the plants survived and how much they produced. This was true whether the plants were flooded or not.After five days of flooding some plants did not do well. The non-grafted and self-grafted plants struggled to survive.. The grafted plants did better. For example the Arka Rakshak grafted onto Arka Keshav and the Arka Rakshak grafted onto BPLH-1 were stronger. They survived better. Produced more tomatoes even when they were underwater.The reason the grafted plants did better was because their roots were more tolerant of not having oxygen. The grafted tomato cultivar Arka Rakshak also handled the stress of flooding. This was because the eggplant rootstocks helped the tomato plants adapt to the waterlogged conditions (Bhatt et al., 2015; Lee et al., 2010). So grafting is a way to help vegetables deal with flooding and keep them growing well when the soil is too wet. The information in Table 2 shows that choosing the rootstocks is important for helping plants do better when they are under stress from too much water. Grafting is a way to make vegetables more tolerant of flooding and it is good, for the environment. Vegetable production can keep going even when the soil has much water and that is because of grafting. The right rootstocks make a difference when it comes to dealing with waterlogged soil and keeping vegetable production going.

Vegetable Grafting for Thermal Stress Tolerance

Vegetable crops are really sensitive to temperature. They do not do well in temperatures that're too low or too high. This affects how the Vegetable crops grow how they flower and how fruit they produce.In places that're very hot, like tropical and subtropical regions Vegetable crops often get too hot during the growing season. This causes a lot of problems for the Vegetable crops as they do not make food from sunlight very well their cells get damaged they use up a lot of energy and they get hurt by things that can damage them. Vegetable crops are very sensitive to temperature conditions, high temperature stress, which can lead to big problems, for the Vegetable crops (Rivero et al., 2003; Wahid et al., 2007). Heat stress is a problem for plants like tomatoes. It hurts the pollen. That means the plants do not make as much fruit. It also affects the enzymes in the plants which's not good. This results in tomatoes and other vegetables not growing well as they should.Vegetable grafting is a way to help plants deal with heat stress. We can take a tomato plant that's not good, at handling heat and join it with a root system that is strong and can handle the heat. This helps the tomato plant grow better when it is hot outside (Schwarz et al., 2010). The performance of rootstock and scion combinations when it is very hot is shown in Table 3. This table has information about the rootstocks, for vegetables and how they are able to deal with high temperatures. The rootstock and scion combinations are very important for the vegetables to be strong when it is hot. Table 3 shows the rootstock and scion combinations that work well when the temperature is high.

The study on the heat- tomato cultivar 'UC 82-B' was really interesting. This tomato cultivar 'UC 82-B' was grafted onto the heat- tomato rootstock 'Summerset' and the eggplant rootstock 'Black Beauty'. The results of the study on the tomato cultivar 'UC 82-B' showed that grafting is good for the tomato cultivar 'UC 82-B' when it is really hot.The plants of the tomato cultivar 'UC 82-B' that were grafted onto the 'Black Beauty' rootstock did well. These plants of the tomato cultivar 'UC 82-B' had more chlorophyll fluorescence at the fruiting stage. The plants of the tomato cultivar 'UC 82-B' also had leaves and less electrolyte leakage compared to the plants of the tomato cultivar 'UC 82-B' that were not grafted.When the plants of the tomato cultivar 'UC 82-B' have electrolyte leakage it means they have better membrane stability. The plants of the tomato cultivar 'UC 82-B' that were grafted also had chlorophyll fluorescence, which means they were better, at making food from sunlight when it was hot.The reason the grafted plants of the tomato cultivar 'UC 82-B' did better was because they had roots could take up water better and their bodies could handle the heat stress better (Rivero et al., 2003; Lee et al., 2010). So grafting is a way to help plants deal with high temperatures and it is also good for the environment. This means we can have a supply of vegetables even when it is very hot. If we look at the information in Table 3 we can see that choosing the rootstock is very important for plants to do well when it is hot. Grafting is a technique for improving tolerance to thermal stress and ensuring stable vegetable production under high temperature conditions. The right rootstock can really make a difference, in how plants can handle thermal stress.

Vegetable Grafting for Drought Tolerance

Drought is a problem for people who grow vegetables. It really hurts the ability to keep growing vegetables in a way that's good, for the environment. When there is not water because it does not rain as much as it should or the rain comes at weird times and the air is really hot there is not enough water to use for irrigation. The soil also does not have much water in it as it should.Drought really affects how plants work. It makes it hard for plants to grow big and strong. It hurts the way they make food from sunlight release water into the air and get the nutrients they need. This means that plants do not grow well and they do not produce as many vegetables. The vegetables that do grow are also not as good. Drought stress affects vegetable production by reducing the growth of vegetables the amount of vegetables that are produced and the quality of the vegetables. Vegetable production is really hurt by drought (Farooq et al., 2009; Rouphael et al., 2018). Increased evaporation from plants under weather makes drought stress worse especially for vegetable crops. They are made up of 85-95% water. So keeping plants watered is crucial, for good harvests when water is scarce.The performance of vegetable rootstocks that can handle dry conditions better is shown in Table 4. It lists rootstock and scion combinations and their key features that help with drought tolerance.

Vegetable grafting is a way to help plants deal with drought. It does this by joining a root system that can handle drought with a part of the plant that produces a lot of vegetables. The roots of these plants are very good at getting water from the ground. They can also keep the water in the plant. Help it adapt when there is not enough water. This makes Vegetable grafting a technique, for Vegetable grafting. Vegetable grafting helps Vegetable grafting by using roots that're strong and go deep into the ground (Schwarz et al., 2010). Grafted plants are really good at controlling how they breathe and handle water. They do a job of this than plants that are not grafted. Grafted plants can also deal with stress better because they have antioxidants. This means grafted plants use water efficiently than non-grafted plants. Grafted plants are also good at making adjustments to handle changes in their environment. Overall grafted plants are a lot like -grafted plants but they have some extra benefits, like better water use efficiency and antioxidant enzyme activity (Kumar et al., 2017).

Watermelon, which is also known as Citrullus lanatus can be made stronger by joining it to the roots of a bottle gourd or Lagenaria siceraria or a special kind of squash that is made by combining Cucurbita maxima and Cucurbita moschata. This joining process is called grafting. When we do this it helps the watermelon plant deal with drought. The watermelon plant goes through some changes inside when it is grafted onto these roots. It starts to make some things that help it survive when it is not getting enough water. In fact than 40 tiny things called mRNAs that are inside the plant start to work differently. These tiny things are, like messengers that tell the plant what to do when it is stressed. All of these changes help the watermelon plant get water better. The roots of the plant can take in water easily and the plant is stronger when it does not have a lot of water. This means that the watermelon plant has a chance of surviving when it is dry. The watermelon plant is able to do this because of the changes that happen when it is grafted onto the roots of the bottle gourd or the special kind of squash (Sánchez-Rodríguez et al., 2013; Rouphael et al., 2018). Therefore grafting is a way to help vegetable crops deal with drought. It helps them work better when water is scarce. This method makes plants use water efficiently. It also keeps the plant healthy by maintaining its water level. As a result the crop yield stays steady when theres not enough water.The details in Table 4 show that choosing the rootstocks is key. It helps plants perform well when they're under drought stress. Grafting with rootstocks really matters for plant performance. Drought tolerance, in vegetable crops can be improved with the grafting strategy.

Vegetable Grafting for Salinity Stress Tolerance

Soil salinity is a problem for farming all over the world. It affects a lot of land. 7 Percent of the earth and around 20 percent of the land where we grow crops using irrigation. When there is much salt in the soil it hurts the plants. Soil salinity causes problems for plants because it makes it hard for them to get water and it also messes with the stuff they need to grow.Soil salinity has a lot of effects on plants. It makes it hard for plants to grow and develop. This happens because of the salt in the soil. The salt causes problems like stress and it also hurts the plants with too many bad ions. Soil salinity also causes problems with the nutrients that plants need to grow. When plants get much sodium and chloride it is very bad for them. The sodium and chloride ions build up in the plants. Cause a lot of problems. They mess with the way the plants make food. They also reduce photosynthesis. This means that plants do not grow well and it leads to big losses in the crops we grow to eat, like vegetable crops. Soil salinity is a problem, for vegetable crops (Munns and Tester, 2008; Colla et al., 2010). The performance of salt-tolerant vegetable roots and how they work is shown in Table 5.This table shows which root and plant combinations work well together to help plants grow in soil. Vegetable roots that can handle salt are very important for plant growth in soil conditions. Table 5 has information, about the combinations of vegetable roots and plants to use in salty soil.

Vegetable grafting is a way to help plants deal with salt. It is an earth friendly method. We use roots that can stop bad things like salt from getting into the plant. These special roots are good at keeping the balance of food for the plant. They can pick what they want like potassium. Not take in too much salt. This helps the plant stay healthy and work well even when the soil is salty. Vegetable grafting and the right roots can really make a difference. Vegetable grafting is a thing, for plants because it helps them handle salt (Schwarz et al., 2010). In watermelon (Citrullus lanatus), grafting onto bottle gourd (Lagenaria siceraria) rootstock has been reported to significantly improve salt tolerance by reducing sodium accumulation and enhancing plant growth performance under saline conditions. Similarly, in muskmelon (Cucumis melo), the use of interspecific squash rootstock (Cucurbita maxima × Cucurbita moschata Duch.) has been shown to increase plant biomass, leaf area, and overall tolerance to salinity stress compared to non-grafted plants (Colla et al., 2010; Rouphael et al., 2018).

The performance of grafted plants is really good when they are under a lot of stress from salt. This is because their roots work better they take in nutrients easily they have a good balance of sodium and potassium they deal with water and salt better and they make food from sunlight more efficiently. All these things help grafted plants to handle salt better and keep producing when the soil is salty. So grafting is a way to help vegetable plants deal with salt and make sure they keep producing even when the soil is not good.The information in Table 5 shows that choosing the roots for the plant is very important for it to do well when it is under stress from salt. Grafting helps plants to do well when they are under a lot of stress from salt. Salt tolerance is very important for vegetable crops and grafting can really help with that. Grafted plants can handle salt better. That is why grafting is a good idea, for vegetable crops that have to grow in salty soil (Munns and Tester, 2008; Schwarz et al., 2010).

CONCLUSION

Vegetable grafting is really important for growing plants these days. It helps plants deal with weather and other problems. When you combine roots with good parts of the plant it makes the plant grow better use water and food more efficiently and stay healthy. This means the plant grows more and the fruit is better. Vegetable grafting also helps stop things in the soil from hurting plants reduces the need for chemicals and makes growing plants better for the environment. There are still some problems with vegetable grafting. The roots and the rest of the plant need to work together and things like the weather and the way we graft plants are very important. We also do not fully understand how grafted plants deal with stress. We need to keep doing research to find better roots that can handle many problems understand how plants work and make grafting a normal part of growing plants. In the end vegetable grafting helps plants deal with problems now and also helps the environment in the long run. It is a way to grow plants that is good for the Earth and can be used by many people. Vegetable grafting helps make sure we have food makes the fruit better and keeps us safe from environmental problems. Vegetable grafting is a good way to grow plants and it helps a lot, with food security.

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Table 1. Standardized grafting techniques at Indian Institute of Horticulture Scion plant Rootstock Method

Scion Crop	**Rootstock**	**Grafting Method**	**Reference**
Tomato (Solanum lycopersicum)	Solanum habrochaites, Solanum pimpinellifolium	Slant / Splice grafting	Lee et al., 2010; Kubota et al., 2008
Brinjal (Solanum melongena)	Solanum torvum, Solanum nigrum	Cleft grafting	Rao et al., 2015; Lee et al., 2010
Chilli (Capsicum annuum)	Capsicum chinense, Capsicum frutescens	Splice grafting	Schwarz et al., 2010
Cucumber (Cucumis sativus)	Fig leaf gourd (Cucurbita ficifolia)	Hole insertion grafting	Oda, 2007
Watermelon (Citrullus lanatus)	Bottle gourd (Lagenaria siceraria)	Hole insertion grafting	Lee et al., 2010
Muskmelon (Cucumis melo)	Pumpkin (Cucurbita moschata)	Approach grafting	Colla et al., 2010
Bitter gourd (Momordica charantia)	Luffa cylindrica	Approach grafting	Kumar et al., 2017
Ridge gourd (Luffa acutangula)	Sponge gourd (Luffa cylindrica)	Approach grafting	Lee et al., 2010
Bottle gourd (Lagenaria siceraria)	Pumpkin (Cucurbita moschata)	Approach grafting	Oda, 2007

Table 2. Examples of different vegetable rootstocks and their characteristics performing best under flooding stress.

S. No.	Rootstock	Targeted Cultivar (Scion)	Key Physiological Characteristics under Flooding Stress	Reference
1	Lagenaria siceraria (Bottle gourd)	Citrullus lanatus (Watermelon cv. Crimson Tide)	Grafted watermelons showed greater tolerance to flooding compared with non-grafted; grafted plants had higher photosynthetic rate (CER), stomatal conductance and transpiration, and formed adventitious roots and aerenchyma, which helped maintain gas exchange under hypoxic conditions.	Yetişir et al. (2006)
2	Luffa cylindrica (Sponge gourd)	Momordica charantia (Bitter gourd cv. New Known You #3)	Grafting improved tolerance to waterlogging/flood stress in bitter melon; grafted plants retained higher CO_2 exchange, stomatal conductance, transpiration and RuBisCO activity compared with ungrafted plants under flooded conditions.	Liao & Lin (1996)
3	Solanum melongena (Eggplant, e.g., 'Arka Neelkanth', 'Mattu Gulla')	Solanum lycopersicum (Tomato cv. Arka Rakshak)	Grafting onto eggplant rootstock enhanced physiological resilience to flooding in tomato, including higher photosynthetic rate, stomatal conductance and chlorophyll fluorescence than ungrafted/self-grafted tomatoes under flood stress.	Bhatt et al. (2015)
4	Interspecific cross (Cucurbita maxima × Cucurbita moschata)	Cucumis sativus (Cucumber cv. Kaga-aonagafushinari)	Although direct flood studies are limited, Cucurbita hybrid rootstocks are widely used for physiological stress **a**melioration and show improved maintenance of chlorophyll content and gas exchange traits under harsh environments, suggesting potential for flood tolerance in cucurbits.	Rouphael et al. (2010)

Table 3. Examples of different vegetable rootstocks and their characteristics performing best under thermal stress

Sr. No.	Rootstock	Targeted Cultivar (Scion)	Major Characteristics under Heat Stress	References
1	Tomato (Summerset) and Brinjal (Black Beauty)	Tomato (UC 82-B)	Greater leaf area; increased leaf fresh and dry weight; higher pollen grains per flower.	Abdelmageed & Gruda, 2009
2	Solanum habrochaites (line LA1777)	Tomato (Moneymaker)	Enhanced root mass ratio; higher concentration of total leaf carbon.	Venema et al., 2008
3	Cucurbita ficifolia Bouche (Figleaf Gourd)	Cucumis sativus L. (Jinyan No. 4)	Carboxylation and RuBisCO activity less reduced, leading to higher CO_2 assimilation.	Zhou et al., 2007
4	Solanum lycopersicum (RX-335)	Tomato (Tinkitv2)	Enhanced PAL activity; decreased PPO and GPX activity.	Rivero et al., 2003
5	Solanum lycopersicum (LA 1778 accession)	Tomato	Reduced loss of dry weight; preservation of root hydraulic conductivity and stomatal conductance in grafted plants.	Bloom et al., 2004

Table 4. Examples of different vegetable rootstocks and their characteristics performing best under drought stress

Sr. No.	Rootstock	Targeted Cultivar (Scion)	Major Characteristics under Drought Stress	References
1	Tomato (Beaufort and Maxifort)	Tomato (Amelia)	Improved photosynthesis and stomatal conductance.	Chaudhary et al., 2017
2	Capsicum (Terrano, Atlante, Creonte)	Capsicum (Herminio)	Higher photosynthesis, LAI, and vegetative/reproductive preservation.	Lopez-Marin et al., 2017
3	Tomato (Unifort)	Tomato (Farida)	Improved yield, water-use efficiency (WUE), and growth.	Wahb-Allah, 2014
4	Tomato (Zarina)	Tomato (Josefina)	Improved utilization of micronutrients (Cu, N, P, K).	Sanchez-Rodriguez et al., 2014
5	Tomato (Beaufort)	Tomato (M28)	Higher photosynthesis rate and consistent LAI.	Almutu & Gul, 2012
6	Tomato (Ijak Klung)	Tomato (BHN 602)	Enhanced photosynthetic activity and aboveground growth.	Nilsen et al., 2014
7	PS 1313 hybrid	Watermelon	Increased uptake of Mg, N, and K, and enhanced CO_2 assimilation.	Rouphael et al., 2008
8	Sweet pepper (Verset)	PI-15225, ECU-973, and Atlante	Efficient lowering of osmotic potential and optimal photosynthesis.	Penella et al., 2014
9	Solanum lycopersicum (Faridah)	Tomato (Unifort)	Robust vegetative growth with enhanced Vitamin C and TSS.	Ibrahim et al., 2014

Table 5. Examples of different vegetable rootstocks and their characteristics performing best under salinity stress

Sr. No.	Rootstock	Targeted Cultivar (Scion)	Major Characteristics under Salinity Stress	References
1	Lagenaria siceraria Standl. (Numhems Zaden)	Watermelon	Increase in dry matter, total soluble solids, and sugar content.	Colla et al., 2006
2	Fig leaf gourd	Cucumber cv. Jinchun No. 2	Grafted plants showed higher scion dry weight, soluble sugar content, and micronutrient content.	Huang et al., 2010
3	Cucurbita hybrid rootstocks PS 1313	Cucumis sativus (Akito)	Higher nutritional value, net assimilation rate, and chlorophyll content (SPAD index).	Colla et al., 2012
4	Cucurbita hybrid (P360 and PS13132)	Cucurbita melo L. (Cyrano) / Cucumis sativus (Akito)	Reduced leaf area index reduction; salinity had smaller effect on net photosynthetic rate and stomatal conductance in grafted plants.	Rouphael et al., 2012
5	Interspecific cross (Solanum lycopersicum × S. habrochaites)	Tomato (Cuore di bue)	Increased juice content in fruits.	Di Gioia et al., 2013
6	Cucumber (Cucumis sativus L., Affyne)	Cucumis sativus L. (Ekron)	Increased photochemical activity.	Colla et al., 2013
7	Pumpkin	Cucumis sativus L. (Jinchun No. 2)	Less chlorophyll reduction (SPAD index); enhanced activities of peroxidase, glutathione reductase, ascorbate, and dehydroascorbate reductase in chloroplasts.	Zhen et al., 2011
8	Interspecific cross (C. maxima × C. moschata, RS841 improved)	Cucumis melo L.	Increased biomass and leaf area index (LAI); improved stomatal control under salt stress.	Orshua et al., 2013

9	Lagenaria siceraria Standl.	Citrullus lanatus cv. Xiuli	Overall rise in biomass.	Yang et al., 2013