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Abiotic Stress Management in Vegetable Crops

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ABSTRACT **-** Vegetables are highly sensitive in nature thus affected by various biotic and abiotic stress. Any adverse effect of non-living elements on living things in a particular habitat is known as abiotic stress. The production and productivity of vegetable crops got highly effected by the extreme event of climate change i.e, heat stress, water stress, drought, heavy rainfall, salinity etc. Vegetables are full of various nutrients which help in lowering the risk of various diseases such as cancer, heart disease, blood pressure, diabetes etc. Most of the vegetables contain more than 90% of water thus highly sensitive to climate change. Sudden change in climatic factors like in temperature affects all stages of plant growth, pollination, flowering and fruiting which directly reduces the yields and quality of major vegetables. Vegetable crops like beans or tomatoes may lose some of their blossoms at such high temperatures, especially in dry or windy conditions, which will lead to a poor fruit set. High temperatures may harm sweet corn pollination and result in inadequately filled ears of corn. Few fruits are produced because cucurbits (the family that includes pumpkins and squash) typically develop mostly male flowers when temperatures are high.

Keywords: Abiotic stress, vegetables, effect

I. Introduction

Abiotic stress occurs when non-living components negatively affect living organisms in a certain ecosystem (Imran et al., 2021). Non-living variable have major negative impact on population performance or individual physiology of the organism, it must alter the environment in a ways that go beyond its usual range of fluctuation. Abiotic stress factors, commonly referred to as stressors, are intangible, naturally occurring forces like strong winds or sunshine that may harm the plants and animals in the impacted region, as opposed to biotic stress factors, which would include things like living disturbances as fungi or harmful insects. Abiotic stress cannot really be prevented. Animals are also affected by abiotic stress, while plants are more restricted because of their heightened reliance on environmental conditions. The most detrimental element affecting the development and yield of crops globally is abiotic stress. Furthermore, studies have indicated that combinations of abiotic stress variables are when abiotic stressors are most detrimental. Abiotic stressors have a connection to the natural world and come in different sizes in terms of time and space. Humanity faces significant obstacles as a result of climate change, which also puts enormous strain on the horticultural sector's capacity to survive. It is crucial to develop methods to accommodate expanding populations and rising demand for fruits, vegetables, and other horticultural goods. No matter what steps are done now, according to climate models, there will be warming over the next decades. Producing horticultural crops that can withstand abiotic stress will be the single most important step we can take to adapt to the challenges we face both now and in the future.

II. Climate change effects on horticulture:

Increasing temperature and changing rainfall patterns are two key indicators of climate change that have significant impact on horticulture and agriculture in general (both in terms of quantity and intensity). These factors make it necessary to step up study on abiotic stress.

A handful of various effects that the changing climate will have on horticulture are listed below.

1) A significant amount of prospective appropriate zones will have moved if the temperature rises by more than 1°C.
2) The production schedule will alter. Crops will grow sooner and develop more quickly as a result of the

temperature increase. Citrus, grapes, melons, and other produce, for instance, mature around 15 days early.

3) Photoperiods might not vary significantly when the temperature rises. Onions, a photosensitive plant, will grow more quickly, resulting in smaller bulbs. Strawberry runners will increase at the expense of fruit runners.
4) In temperate regions, the winter regime and length will be shorter, which will affect the crops farmed there.
5) The produce will require shorter storage time in trees and plants because of the accelerated maturation and increased temperature-induced ripening. They'll turn too ripe.
6) Due to the increased warmth, pollination would suffer. There will be floral abortions.
7) The planting season will advance since the soil temperature will rise significantly earlier in the spring. If there are late frosts, this may be disastrous.
8) The need for yearly irrigation will rise, not as a result of increased evaporation, but rather as a result of the trees growing more quickly over the course of a year. The necessary Heat Units will be produced in a lot less time.
9) Increased temperatures will result in a slower commencement of potato tubers, worse tomato quality, and poor pollination of numerous crops. It may cause bolting in crucifers crops and in apples and capsicum, it influence anthocyanin production. Because of the more specific cooling needs of pome and stone fruits, dormancy breaking will occur sooner. In tomatoes, tip burn and blossom end rot will frequently occur.
10) As projected increases in acidity, alkalinity, and salinity, soil conditions may become problematic. Sea water will likely percolate into inland water tables considerably more quickly in coastal places, increasing salt.

III. Research priorities

Research efforts should be stepped up to identify potential threats to the crop and create a strategy for dealing with them in light of the examples of abiotic stress mentioned above. For some crops, an increase in temperature and CO2 may be beneficial. The crops will be able to grow in newer places. These need to be considered.

However, historical experience has demonstrated that horticulture scientists have successfully addressed a number of these issues. For instance, it has been successful to transform grapes, a typical temperate crop, into a tropical or subtropical one. Typical temperate vegetables like cauliflower and cabbage may be effectively cultivated in tropical climates. There are tomatoes that can withstand heat. It takes a long time to develop a new variety, and the capacity to do so is hampered by the quick decline in biodiversity of horticultural crops, that hastens by climate change. Additionally, according to estimates, more than 20% of all farmed areas worldwide have salt concentrations high enough to harm agricultural plants, a problem made worse by global warming. Through horticultural crop development, it is urgently necessary to reduce these abiotic pressures. It will take a lot of work from many different disciplines to complete this big and challenging undertaking. Research on stress physiology explores the processes behind stress tolerance and offers strategies, techniques, and characteristics for identifying genotypes that are resistant to stress. Through the use of molecular markers and high-throughput genotyping techniques, molecular biology and genomic studies improve our knowledge of the structural and functional characteristics. By adding new sources of stress-tolerant characteristics or transgenes, one can increase the gene pool, enable gene-based selection, and increase genetic variation for stress-related traits. By utilizing all the instruments at their disposal, including germplasm screening, transformation of plants using markers, and traditional techniques of breeding, plant breeders translate these discoveries into crop varieties that are stress-tolerant.

IV. Ongoing research programmes on abiotic stress

The quick scientific advancements made by 10 central institutes around the nation in plant protection, storage and processing, biotechnology, agro-techniques, varietal development, etc. The following are a few of the ongoing vegetable and spice programmes being run by several ICAR institutes.

Table 1. Soil and climatic requirement of vegetables and spices in terms of soil and climate.

Sl No	Crop	Soil pH	Temperature(°C)		Rainfall(mm)/ water requirement(mm/ha)
			Min	Max	
1	*Solanum lycopersicum*	5.5 to 7	15	24	330 mm/ha
2	*Solanum melongena*	5.5 to 6.6	21	27	486 mm/ha
3	*Capsicum annuum*	6.5	20	35	640 mm/ha
4	*Cucumis melo*	6 to 7	30	35	450 mm/ha
5	*Pisum sativum*	5.5 to 6.0	10	18	240 mm/ha

6	*Phaseolus vulgaris*	5.5 to 6.0	15	25	300-350 mm/ha
7	*Allium cepa*	5.5 to 6.6	20	25	500 mm/ha
8	*Piper nigrum*	5to 6	10	40	1500 to 3000mm
9	*Elettaria cardamomum*	4.2 to 6.8	10	35	1500 to 5000mm
10	*Zingiber officinale*	5 to 7	19	28	15000 to 3000mm
11	*Curcuma longa*	4.3 to 7.5	18	30	640 to 4000mm

A. Abiotic stressors that affect vegetable crops include:

a. Drought – Capsicum annuum, Cucumis melo, Solanum lycopersicum, Allium cepa

b. Heat – Pisum sativum, Solanum lycopersicum, beans, Capsicum

c. Salinity – Cucumis melo, Pisum sativum, Allium cepa

d. Flooding/ excess moisture – Solanum lycopersicum, Allium cepa , Capsicum annuum

Present status of research with respect to varieties/ technology:

Varieties Released:

a) Drought/ Rainfed –Tomato - Arka Vikas

Onion - Arka Kalyan

Chilli - Arka Lohit

b) Photo insensitive – Dolichos – Arka Jay, Arka Vijay, Arka Sambram, Arka Amogh, Arka Soumya

Cowpea - Arka Garima, Arka Suman, Arka Samrudhi

Advanced lines identified:

a) Drought – Chilli - IIHR – Sel. 132

Tomato - RF – 4A

Onion - MST 42 & MST 46

b) High temperature – Capsicum - IIHR Sel 3

French bean - IIHR – 19-1

Peas - IIHR – 1 & 8

Cauliflower - IIHR 316-1, IIHR – 371- 1

c) Photo-insensitive – Dolichos - IIHR – 16- 2.

Classification of certain vegetable crops based on how well they tolerate temperature changes in the field.

A. COOL-SEASON CROPS		
1. Hardy (can withstand moderate frosts)		
Asparagus	Garlic	Radish
Broad bean	Horseradish	Rhubarb
Broccoli	Kohlrabi	Spinach
Brussels sprouts	Mustard	Turnip
Cabbage	Parsley	
Chive	Pea (flowers & pods are more sensitive to frost)	
2. Half-hardy (can withstand light frosts)		
Beetroot	Chinese cabbage	Potato
Carrot	Globe artichoke	Swiss chard
Cauliflower	Lettuce	
Celery	Parsnip	
B. WARM-SEASON CROPS		
1. Tender (sensitive to frost and low temperatures)		
New Zealand spinach	Sweet corn	Tomato
Green bean		
2. Very Tender (very sensitive to low temperatures)		
Chili	Okra	Sweet pepper
Cucumber	Pumpkin	Sweet potato
Eggplant	Squash	Vegetable marrow
Lima bean	Sweet melon	Watermelon

The approximate temperatures for best growth and quality of some vegetable crops:

Mean Monthly Temperatures (°C)			
Optimum	**Minimum**	**Maximum**	**Vegetables**
Cool Season Crops			
12 - 24	7	29	*Allium schoenoprasum, Allium sativum, Allium porrum, Allium cepa.*
15 - 18	5	24	*Beta vulgaris, Vicia faba, Brassica oleracea* var. *italica, Brassica oleracea* var. *gongylodes, Brassica oleracea* var. *capitata, Pastinaca sativa, Raphanus sativus, Spinacea oleracea, Brassica rapa*
15 - 18	7	24	*Cynara carduncullus* var. *scolymus, Daucua carota, Brassica oleracea* var. *botrytis, Apium graveolens var. rapaceum, Apium graveolens, Brassica rapa subsp. pekinensis, Lactuca sativa, Petroselinum*

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			crispum, Pisum sativum, Solanum tuberosum
Warm Season Crops			
15 - 21	10	27	*Phaseolus lunatus, Phaseolus vulgaris*
15 - 24	10	35	*Zea mays, Tetragonia tetragoinoides*
18 - 24	10	32	*Cucurbita moschata, Cucurbit asp.*
18 - 24	15	32	*Cucumis sativus, Cucumis melo, Cucumis melo var. cantalupensis*
21 - 24	18	27	*Capsicum annuum, Solanum lycopersicum*
21 - 29	18	35	*Capsicum annuum, Solanum melongena, Abelmoschus esculentus, Ipomea batatus, Citrullus lanatus*

Note: At temperatures below 7°C, many biennial plants, such as Beta vulgaris, Brassica oleracea var italica, Brassica oleracea var. capitata,, Daucua carota, Brassica oleracea var. botrytis, Apium graveolens, Petroselinum crispum, Pastinaca sativa, Spinacea oleracea and Brassica rapa, may be encouraged to produce seed early. Depending on how long and how cold a period was, bolting was induced to varying degrees. Each vegetable's cultivars respond in a unique way. On the other side, when temperatures rise beyond 30°C, a crop like lettuce can be forced to produce seed. Vegetable crops like beans or tomatoes may lose some of their blossoms at such high temperatures, especially in dry or windy conditions, which will lead to a poor fruit set. High temperatures may harm sweet corn pollination and result in inadequately filled ears of corn. Few fruits are produced because cucurbits (the family that includes pumpkins and squash) typically develop mostly male flowers when temperatures are high.

Classification of vegetables based on soil reaction:

Slightly tolerant **pH 6.8 – 6.0**	**Moderately tolerant** **pH 6.8 – 5.5**	**Highly tolerant** **pH 6.8 – 5.0**
Asparagus	Bean	Chicory
Beet	Carrot	Potato
Cabbage	Pumpkin	Rhubarb
Okra	Squash	Sweet potato
Cauliflower	Cucumber	Watermelon
Celery	Tomato	
Spinach	Brinjal	
Palak	Garlic	
Onion	Turnip	
Leek	Parsley	
Lettuce	Pea	
Muskmelon	Pepper	

Classification of vegetables based on salt tolerance:

Sensitive	**Medium tolerant**		**High tolerant**	
0.25	**0.50**	**0.75**	**1.00**	**1.25**
Tomato	Chilli	Amaranths	French bean	Bitter gourd
Snake gourd	Okra	Cauliflower	Ridge gourd	Ash gourd
	Cabbage	Onion		
	Sweet potato	Radish		
		Bottle gourd		

Days needed for different vegetable crops to sprout from seeds sowed 12 mm deep and at varying soil temperatures.

Vegetable Crop	**Soil Temperature (°C)**						
	5	**10**	**15**	**20**	**25**	**30**	**35**
Celery	41	16	12	7	N	N	N
Lettuce	15	7	4	3	2	3	N
Spinach, true	23	12	7	6	5	6	N
Radish	29	11	6	4	4	3	-
Pea	36	14	9	6	6	6	-
Parsnip	57	27	19	14	15	32	N
Cabbage	-	15	9	6	5	4	-
Cauliflower	-	20	10	6	5	5	-
Parsley	-	29	17	14	13	12	-
Beetroot	42	17	10	6	5	5	5
Carrot	51	17	10	7	6	6	9
Onion	31	13	7	5	4	4	13
Asparagus	N	53	24	15	10	12	20
Sweet corn	N	22	12	7	4	4	3
Tomato	N	43	14	8	6	6	9
Turnip	N	5	3	2	1	1	1
Bean, green	N	N	16	11	8	6	6
Cucumber	N	N	13	6	4	3	3
Muskmelon	N	N	-	8	4	3	-
Watermelon	N	N	-	12	5	4	3
Bean, lima	N	N	31	18	7	7	N
Pepper, sweet	N	N	25	13	8	8	9
Okra	N	N	27	17	13	7	6

N = No germination likely - = Not tested

The table demonstrates that warm-season crop seeds lose their ability to germinate at temperatures of 10°C or lower, whereas temperatures of 35°C (celery 25°C) is not good for germination of cool season crops. The bulk of vegetable crops appear to encourage the fastest emergence at a mean soil temperature of 20°C to 30°C.

Vegetable crops listed with some abiotic stressors:

Sl. No.	Tolerant	Vegetables

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1	Tolerant to drought	*Capsicum annuum , melons, Solanum lycopersicum, Allium cepa*
2	Tolerant to high temperature	*Pisum sativum, Solanum lycopersicum, beans, Capsicum annuum*
3	Tolerant to salt	*melons, Pisum sativum, Allium cepa*
4	Tolerant to extra wetness or flooding	*Solanum lycopersicum,, Allium cepa, Capsicum annuum*

List of some advanced varieties and lines that can withstand abiotic stress.

Sl. No.	Tolerant	Crop	Variety	Advanced Line
1	Drought/rainfed	*Solanum lycopersicum*	Arka Vikas	RF-4A
		Allium cepa	Arka Kalyan	MST-42 and MST-46
		Capsicum annuum	Arka Lohit	IIHR Sel.-132
2	Photo insensitive	*Dolichos*	Arka Jay, Arka Vijay, arka Sambram, Arka	IIHR-16-2
			Amogh, Arka Soumya	
		Vigna unguiculata	Arka garima, Arka Suman, Arka Samrudhi	
3	Heat tolerant	*Capsicum annuum*		IIHR Sel.-3
		Phaseolus vulgaris		IIHR-19-1
		Beans		
		Pisum sativum		IIHR-1 & IIHR-8
		Brassica oleracea var. botrytis		IIHR (316-1 &371-1)

V. Impact on Vegetables

A. POTATO

In the near future, India's production and productivity of the heat-sensitive potato crop would be significantly impacted by global warming (Albiski et al., 2012). The major GHG, CO2, is now present in the atmosphere at 369 ppm, which is 35.4 percent more than pre-industrial levels. In the years 2020, 2050, and 2080, the expected CO2 levels are 393, 543, and 789 ppm, respectively. The proportional increase in temperature would be between 1, 3 and 5OC during India's primary winter potato-growing season. The primary abiotic stress brought on by climate change is stress from high temperatures throughout the growth season. In order to investigate the effects of climate change on potato crop yield in India's primary potato-growing regions and the potential for agronomic adaptation, CPRI is conducting research.

1. *Preliminary results*

Severe minimum and/or maximum temperatures both have the potential to produce high temperature stress. As a result, potatoes are produced in India in a thermally appropriate window when the likelihood of both high temperature stress situations occurring is low. Climate change and global warming are likely to have a substantial influence on India's capacity to have a suitable planting season. The Indo-Gangetic plains account for around 80% of the overall area under the heat-sensitive potato crop because of climatic limitations. Here, the shorter growing season would result from the greater temperature at the beginning of the growing season. The effects of the warmer winters brought on by climate change were investigated through. This makes sense because these are the areas where the growing season is now short due to the frequency of frost, and since the winters may become less chilly as a consequence, a full growing season may be attained, improving productivity. In other states and regions of the Indo-Gangetic plains as well as the neighbouring states, such as Bihar, West Bengal, Gujarat, etc., where winters are already milder, productivity is likely to decline by 2 to 19 percent in 2020 and by 9 to 55 percent in 2050, respectively. This is because higher winter temperatures would have a negative effect on productivity. Karnataka, Maharashtra, as well as the plateau regions of Madhya Pradesh, Jharkhand, and Orissa all often cultivate the Kharif crop is another example of potato farming in India. Here, the essential temperature for tuber start and adequate bulking is being threatened chiefly by high nighttime temperatures that are already nearing that range. Preliminary simulation studies predict that the climate change scenario would significantly harm output in these areas, and productivity reductions ranging from 6 to 18 percent in the different states are predicted even by 2020 if no adaptation plan is implemented. According to studies, the main adaptation strategy for the potato-growing regions of West Bengal and Kharif should be the development of heat-tolerant varieties. In most states of the Indo Gangetic plains, however, delaying the date of planting can be an adaptation strategy to reduce yield reductions. These findings are currently being confirmed by more thorough research.

B. TUBER CROPS

Cassava is planted in Kerala under rainfed circumstances in April or May as the first pre-monsoon showers arrive, and it is harvested ten months later. When perennial plants are planted here in highland environments, plant experiences dryness for the last three to four months. Cassava is planted in East region of Andhra Pradesh, Godhavari. District in June as the SW monsoon begins, and it is harvested seven to eight months later. Varieties which are short-lived (H-165 & Shree Prakash) faces seasonal dryness in its final three to four months of growth (between December-May). Cassava is sown in Tamil Nadu's plains during the winter months of November and December and harvested ten months later under rainfed circumstances. Plants of the H-165 and H-226 types are present here. During the crop's first growing cycle, the crop may experience drought for up to six months. Cassava planting must be postponed under rainfed conditions if summer fails, there are no pre-monsoon showers, or the monsoon arrives later than expected (as in hilly area of Tamil Nadu). This shortens the crop's growing season and eventually lowers the output of tubers and starch. Reduced tuber yields are caused by contingent drought (absence of rain during the typical monsoon season) in both Tamil Nadu and Andhra Pradesh. The starch content of cassava tubers is also likely to decrease under extended drought (> 2 months) and hot temperatures (>33–40oC) because of the possibility that these stressful circumstances will cause starch to turn into lignin. Despite the fact that sweet potatoes and cassava are regarded as drought-resistant, considerable tuber production and starch content reductions do occur, and responses to water deficiency stress and high temperature stress conditions vary among cultivars. A slight water deficiency stress (WDS) is beneficial for the growth of tubers. Cassava needs sufficient soil moisture throughout the first month of growth in order to establish itself. When the soil is sufficiently moist, tuber (modified storage root) initiation in cassava occurs within a month of planting and tuber bulking begins two to three months later. During this time of growth, drought inhibits both tuber start and tuber bulking. When WDS lasts for a long time (WDS > 20 days), the plant sheds around 80% of its leaves, turns dormant, and stops both vegetative growth and tuber bulking. When conditions are favourable, the plant recovers, resumes growth, develops a canopy, ingests a significant amount of starch from the tubers, and the tuber continues to enlarge (enough soil moisture).A decrease in rate of photosynthesis, overall production of dry matter, or yield of tuber under water deficiency stress circumstances was found in studies of CTRI in which they studied on the reaction of cassava to drought in field conditions. In the final four months of crop growth, it was discovered that drought conditions had lowered tuber yield by between 28 and 42%. Cassava, on the other hand, was discovered to sustain photosynthetic rate by 50% under drought circumstances, making it a superior crop choice in the event of future climate change. Cassava genotypes exhibit tolerance (survival) under drought circumstances, however genotypes significantly reduced tuber production, and a large variation in tuber yield was discovered across 62 genotypes. The drought tolerance of 62 genotypes and 109 land races of cassava was assessed by CTCRI using data on total dry matter (DM) production, DM partitioning, LAI, light interception, photosynthetic rate, stomata conductance/resistance, transpiration rate, PEG stress, percent of yield reduction, tuber yield, and starch content. A total of 9 land races (129, 7, 16, TP White, Narukku-3, Ci-4, Ci-60, Ci-17, Ci-80) and 5 genotypes (CE-54 & 534, CI-260 & 308, and CI-848) were shown to be drought tolerant in this study. Retention of leaves during drought is linked to high drought tolerance and productivity (El-Sharkawy et al. 1993). Based on the total amount of dry matter (DM) produced, the DM partitioning, the LAI, the light interception, the rate of photosynthetic activity, the conductance/resistance of the stomata, the rate of transpiration, the PEG stress, the percentage of yield reduction, the tuber yield, and the starch content, CTCRI evaluated the drought tolerance of 62 genotypes and 109 land races of cassava. A total of 9 land races (129, 7, 16, TP White, Narukku-3, Ci-4, Ci-60, Ci-17, Ci-80) and 5 genotypes CE-54 & 534, CI-260 & 308, and CI-848) were shown to be drought tolerant in this study. Retention of leaves during drought is linked to high drought tolerance and productivity. Sweet potatoes produce their highest yields when they are irrigated at a soil moisture level of 25%; soil moisture levels above 50% have no effect on storage yield. For a 16–20 week growth period, the crop needs 500mm of water under typical production conditions. However, the quantity, timing, and distribution of water all have an impact on tuber yields. Under water deficiency stress (WDS), tuber yield declines, especially when the available soil moisture falls below 20%. It has also been noted that irrigation less than 50% of the total pan evaporation rate reduces tuber production. Due to WDS's impact on tuber number, the tuber initiation period is the most vulnerable. WDS during the tuber start phase causes tuber lignification and inhibits tuber development. Compared to cultivars with high sink capacities, lignification and tuber yield decrease are more evident in cultivars with low sink capacities. Three (VLS6, IGSP 10, IGSP 14) of the 91 sweet potato land races that were examined for several physiological characteristics in the field were found to be drought tolerant. The sweet potato variety "Sree Bhadra" was made available by CTCRI after it was discovered to be drought-tolerant (Laurie et al., 2015).

1. *Response of high temperature on tropical tuber crops*

In Kerala, during its final three months of growth, from mid-January to mid-April, the cassava crop experiences considerable temperature stress (33°C and above). The crop in

Andhra Pradesh has considerable temperature stress during its final three to four months of growth, from February to May. In Tamil Nadu, during the early 2nd to 5th month growing period between February and May, the crop experiences considerable temperature stress. In Kerala, during its final three months of growth, from mid-January to mid-April, the cassava crop experiences considerable temperature stress (33°C and above). The crop in Andhra Pradesh has considerable temperature stress during its final three to four months of growth, from February to May. In Tamil Nadu, during the early 2nd to 5th month growing period between February and May, the crop experiences considerable temperature stress. Compared to plants cultivated at 24/19oC (12.0 mg CO2 dm-2h-1), A higher photosynthetic rate was seen in the leaves of cassava plants cultivated under a 29/24oC day/night temperature regime (19.0 mg CO2 dm-2h-1). This indicates that photosynthesis increases by 1.4 mg CO2 dm-2h-1 for every 1oC increase in temperature. PN increased by 0.2 to 0.6 mol CO2 m-2s-1 for every 1oC increase in temperature between 25 and 35oC in cassava plants cultivated at a 20–22–12–15oC day–night temperature regime (measuring temperature). The synthesis of starch in the tubers and export from the leaves would be hindered at temperatures above 30°C, even though cassava can maintain vegetative growth and biomass at high temperatures (33-40°C) with enough soil moisture. Different cassava cultivars responded to a rise in temperature in different ways. Between 20oC and 24oC, the 4 types examined in their studies exhibited a discernible increase in tuber yield. Between 24oC and 28oC, tuber yield did not, however, considerably increase. According to research on the effects of annual mean temperature on Cassava at Salem, tuber output over a 20-year period from 1986 to 2005, the tuber yield grew from 29.3 t ha-1 (the average yield from 1986 to 1991) to 36.8 t ha-1 (average of 1991 – 2005 yield). Salem's yearly average temperature is the region of Tamil Nadu where cassava is grown, ranged from 27.7 to 28.9oC over a 20-year period, with a mean of 28.3oC. However, throughout a period of 20 years, the annual mean temperature stayed below 30oC, and future warming may reduce tuber output. On a fresh weight basis, the starch content of cassava tubers ranges from 20 to 41 percent, of which 20 to 33 percent can be extracted. At growing circumstances temperatures of around 24oC, it has a dry weight content of more than 80% starch.

Tamil Nadu farmers enhance the starch content of their cassava crops by keeping them in the field during the winter at a temperature of 27 to 18°C both day and night. High elevations in cassava result in tuber starch contents that are over 5% greater (1000 m msl) than it is at lower altitudes (warmer plains). Therefore, it appears that temperature has a significant role in how elevated CO2 affects cassava yield enhancement. Increased temperatures and drought can also cause photosynthetic to be diverted to lignification, a metabolic change that requires careful study because it significantly lowers starch yield. Cassava/sweet potato tuber yield and starch content can thus be dramatically decreased by high temperatures (over 33oC) and extended drought (> 30 days). Sweet potatoes are grown either during the winter (rabi) season under irrigation or during the rainy season (kharif), with rabi offering higher tuber yields. It is planned to move sweet potato cultivation from the kharif to the rabi seasons when temperatures rise to at least 33 degrees Celsius. In sweet potato leaves, an enzyme involved in photosynthesis called rubisco activase and electron transport are sensitive to high temperatures (over 35 °C).

It has been well investigated how high CO2 and high temperatures affect sweet potato photosynthesis. Rubisco activase, an enzyme involved in photosynthesis, and sweet potato leaves is susceptible to high temperatures (above 35°C) in terms of electron transport. Ipomea batatas leaves' photosynthetic rate increased as temperature rose to 34°C and CO2 concentration rose to 560 ppm. The rate of photosynthetic growth was unaffected by an increase in CO2 at temperatures above 34°C. Due to a larger transfer of sugar from the shoot to roots at night, the air temperature appears to be the most important element for tuber development. The bulking rate of tubers is greatly increased by two or three additional irrigations during the fifth to thirteenth week of the growth phase and cooler night air temperatures (11.3-26.4oC). When the night air temperature ranges between 14 and 22 °C, sweet potato varieties produce higher yield. When nighttime air temperatures above 25°C, tuber development is suppressed while shoot growth is encouraged. At air temperatures over 30°C, increases in gibberellic acid (GA) stimulate shoot development, but increases in IAA oxidase activity inhibit tuber formation and growth. Photosynthesis partitioning is shifted away from tuberous roots and toward fibrous roots at higher temperatures (>28oC). At a cool soil temperature (20oC), sucrose concentration in the stem and root was lower than at a high temperature (30oC). The starch content was opposite of the sucrose content. This shows that at cooler soil temperatures, tubers convert sugar to starch more quickly. The SPOTCOMS model was used in CTCRI to simulate how the yield of sweet potatoes changes as temperature rises. This model predicts that a 1oC rise in mean temperature between 19.24 and 20.24oC would increase tuber yield by 1.26 t ha-1, while a 1oC rise in mean temperature between 28.24 and 29.24oC would decrease yield by 0.12 t ha-1. The spermidine synthase gene (FSPD 1) was inserted into the sweet potato plants to create transgenic versions of them. The sweet potato plants that are FSPD1 transgenic developed more mass and quantity of storage roots as well as increased tolerance to heat stress, salt, and drought.

C. Studies on response of sweet potatoes and cassava react to high CO2

Up to 500 ppm CO_2, it indicated an increase in net photosynthetic rate, but after that, the increase in PN rate was minimal. In comparison to control plants that grew at 350 ppm CO_2, high CO_2 (700 ppm) and high temperature (33/26oC) boosted the tuber production (plant-1 or ha-1) in cassava. High CO_2 (700 ppm) and high temperature (33/26oC) significantly accelerated shoot growth compared to tuber growth in cassava. By doubling CO_2, the shoot to root ratio was decreased, however the decline was less pronounced at high temperatures due to increased shot activity (Imai et al. 1984). Their study found that the plants of cassava at high temperatures (33/26°C) and high CO_2 (700 ppm), accumulated high dry matter whereas, cassava tubers that grow at 350 ppm CO_2 gave 8 times high dry weight of tubers as compare to control. When CO_2 levels were high, the water use efficiency of cassava plants increased to 10.5 to 17.1 mgCO2/gH2O compared to control plants (3.3-4.5 mg CO2/g H2O).The interaction between increased CO_2, high temperatures, and dryness on starch output remains unknown in their investigations, though. At 560 / 710 ppm CO_2, there is no increase in plant growth and photosynthetic rate. Since cassava is a C3 plant, its leaves have a special, incomplete Krantz anatomical characteristic. It possesses between 15 and 25 percent more PEP case (phosphoenol pyruvate corboxylase) activity than sorghum and maize. Cassava's PEP case activity is higher than that of normal C3 plants and comparable to that of C3-C4 intermediates. The PEP case activity of cassava increased by 13% whereas the RUBP case activity decreased by 42% under water deficiency stress. As a result, cassava has a better ability to react to high CO_2 levels. In other crops, elevated CO_2 has also been shown to shift and partition more dry matter toward the root system, which could be advantageous for cassava and sweet potatoes. Despite this, due to their susceptibility to heat stress and water stress, cassava and sweet potatoes are unable to benefit from the growing atmospheric CO_2. For cassava to produce the most tubers, sink capacity is crucial. The source-sink relationship has been found to be altered by elevated CO_2, which can either divert

more dry substance to subsurface organs, or to create feedback effects by an accumulation of carbohydrates. Consequently, sink strength is a crucial consideration because it must be able to hold the extra carbohydrate that results from CO_2 enrichment. Therefore, it is essential to find and develop novel genotypes with high sink potential. Under conditions of elevated CO_2, sweet potato Pn rate, SLW, biomass, and tuber yield rose (666 ppm). With an increase in the root: shoot ratio, high CO_2 lessened the impact of the drought. Glucose, starch, and carotenoid content in tubers increased when CO_2 levels were high (675 ppm).

VI. References

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