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Determination of Optimum Harvesting Time for Okra (*Abelmoscus Esculentus* Var. Haritha) to Cope with Temperature and Water Stress Due to Global Warming

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Abstract

The aim of this study is to compare the physical and biochemical parameters of Okra when subjected to heat and water stress and to determine the optimum harvesting time as an adaptation to global warming. Experiments were conducted in three growing seasons in the low country wet zone as a replicated trial. The plants were grown in pots under temperature-controlled poly tunnels. Main plot included two different wetting applications (No water stress and 50% water stress from the field capacity) and sub plots contained 3 different temperature regimes (34 °C maximum temperature poly tunnel / 32 °C maximum temperature poly tunnel / ambient temperature). Individual water stress showed highly significant effect on growth, and yield parameters of Okra. High yield reduction has showed in the water stressed plants. Further temperature stress has especially affected the pod quality parameters such as fibre and pectin content. Therefore the optimum time of harvesting of Okra in days after full bloom under ambient temperature is 10 whereas in the temperature stress conditions it's varied. Accordingly the optimum harvesting time in 32°C and 34°C will be 7-8 days and 5-6 days after full bloom when plants are not subjected to water stress. Results also showed that Okra has 27% higher yield than ambient temperature, when it is grown under high temperature environment with no water stress. Therefore by maintaining irrigation at field capacity level even at high temperature stress conditions, it is possible to achieve a good yield by harvesting Okra pods 5 to 7 days after full blooming.

Key words: Global warming, temperature stress, water stress, Okra, harvesting time.

Introduction

One of the most fundamental questions facing humanity today is global warming and how the humanity will face it with respect to increased food production. Up to now model-based research on climate impact on regions dominated by agriculture mostly deals with yield development. landscape water balance, nutrient dynamics and nutrient loads or endangerment of habitats separately. Higher temperature in next decades implies higher evaporation and therefore higher water demand for the crops will expect. The phenological development rates of the crops will increase due to the higher temperature and an increase of temperature as well as water stress can be expected.

Studies in Sri Lanka based on HadCM3 general circulation model has revealed that the temperature will increase in coming years and in 2050s the highest temperature increase by 2^0C in predicted in Anuradhapura compared to the baseline temperature of 1961-1990. Further the rainfall during northeast monsoon is predicted to decrease in selected areas of the dry zone. Therefore the decreased rainfall and increased in temperature will increase the evapotranspiration and soil moisture deficits. Agricultural activities in the dry zone may be affected by predicted climate change in Sri Lanka (De Silva et. al., 2007). Therefore this research aimed to determine the effect of high temperature and water stress on growth, yield and quality parameters (Physical and Biochemical) of Okra variety (*Abelmoscus esculentus* var. Haritha) Haritha.

In this study Okra (*Abelmoschus esculentus* L.) was selected with a special reason as it is a common vegetable grown and for several other reasons explained below. Okra belonging to the family Malvaceae and it is an oligo purpose crop, but it is usually consumed for its green tender fruits as a vegetable in a variety of ways. These fruits are rich in vitamins, calcium, potassium and other mineral matters (Camciuc et al., 1981). Okra is one of the Sri Lankan traditional vegetable crop rich in nutrition (Rajapaksha, 1999). The immature pods use for curry preparation. Four varieties; VT, MI-5, MI-7 and Haritha are cultivated in Sri Lanka for above purposes. The variety Haritha was introduced as a resistant variety to yellow mosaic virus (Chandrani et. al., 1993).

Okra pods should be picked while they are tender and immature. During maturation pods become tough due to thickening of fiber bundles present in the pericarp region (Salunkhe et al., 1984). Tough pods have less market value since they are not suitable for curry and soup preparation. Therefore, controlling of fiber thickening is the major objective in the post harvest handling of Okra pods. Blanching and freezing methods are used to control toughening of okra pods for certain extent. But if the pods were not in correct maturity level these treatments will not be effective.

Okra plant require warm temperatures and unable to tolerate low temperature for long time or tolerate any threat of frosts. The optimum temperatures are in the range of 21°C - 30°C, with minimum temperatures of 18°C and maximum of 35°C. Okra has a high crop water use despite having considerable drought resistance. Drought and temperature stresses are considered most important factors that limiters plant production in arid and semi-arid zone. (Ehdaie, 1995), where such areas are subjected to a wide range of climate variation as well as climate changes. Under such conditions lower yield and lower water use efficiency take place specialty under the instability of water amounts from year to year. (Owies et al., 2000).

Bhatt and Srinivasa (2005) were indicated that the pod influences the plant responses to water stress as indicated by the differences in leaf area production, plant height and carbon exchange characteristics in podded and depodded plants during water stress. When we consider individual temperature stress for okra Heitholt et al., (1992) described higher yields of okra shows due to leaf isolines for a given amount of intercepted radiation Which indicating that the okra-leaf types utilized more efficiently the intercepted radiation than the normal-leaf types.

Materials & Methods

The study was conducted at the Open University of Sri Lanka, Nawala, Nugegoda (Low country wet zone) from September 2009 to April 2011 for three consecutive seasons. Recommended Okra cultivar Haritha was used in this study. All the plants were planted in pots filled with reddish brown soil (Figure 1).

Simulated environmental conditions

Two temperature regulated poly tunnels were constructed in order to maintain the stipulated temperature conditions by means of a thermostat and air circulation fans (Figure 2). One of the poly tunnels was maintained at 32°C (maximum) while the other one was maintained at 34°C. When the temperature increases above the respective maximum temperature (set point), the fans automatically starts to operate and keep on operating until the temperature comes down to the set point of that particular poly tunnel.

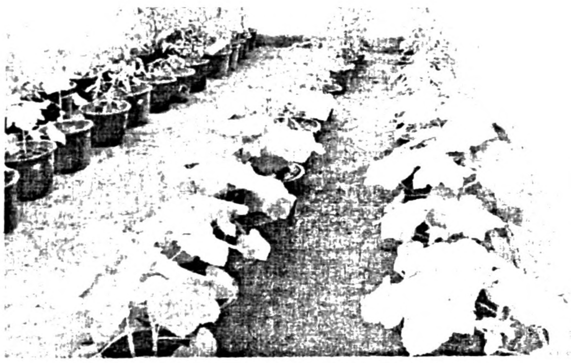

Figure 1: pots arrangement

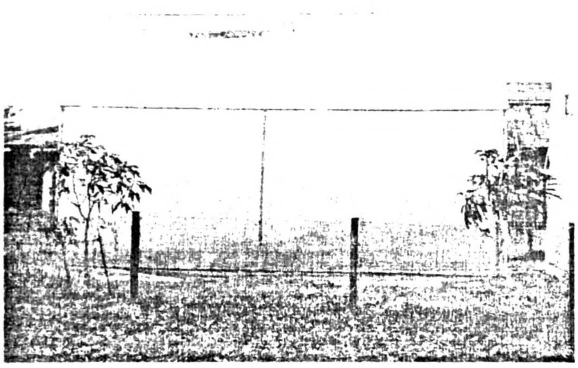

Figure 2: poly tunnels

Experimental Design

The experiment was laid out as a split plot experiment based on Complete Randomized Design (CRD) with ten replicates for the main plot treatment. Main plot included two different soil moisture conditions such as field capacity of reddish brown earth soil (no water stress) and 50% of the field capacity level (with imposed water stress) and sub plots contained 3 different temperature regimes such as 34°C maximum temperature, 32°C maximum temperature and ambient temperature (around 30°C). Soil moisture regimes were maintained using tension meters. Plant growth parameters were investigated weekly during the vegetative and reproductive periods.

Half of Okra plants in each temperature block were subjected to water stress until they reached relative soil water content (RWC) of 50%. In the open space (ambient temperature) general crop management with water stress and without water stress were practiced as a control.

As crop management, cultural practices recommended for fertilizing, weeding etc. were adopted except water management. Three to five seeds were sown at each pot and seedling were thinned to two per pot stand at 18– 23 days after sowing.

In Sri Lanka fresh tender green pods of Okra consumed as vegetable. Therefore data were recorded for fresh green pod yield. To obtain sample of pods of uniform maturity, blossoms were tagged with coloured wool at the beginning of full bloom between 07.00 am and 9.00 am. Plant heights and number of flowers were determined by nondestructive sampling at a weekly basis during vegetative and flowering period.

Fruit yield per plant (g), Number of pods per plant were also recorded. All pods were harvested on single plant basis and put into a paper kraft bag. These pods were then used to determine the pod weight, pod length, pod diameter and seed yield per plant. Chemical parameters such as soluble solid (by hand refractro meter). calcium pectate (Ranganna. 1978) and fibre (Gould.1977) were analyzed in the laboratory.

Statistical Analysis

All extraction runs and analyses were carried out at least in duplicate and in randomized order with the mean values being reported. Analysis of variance (ANOVA) of the results was performed using General Linear Model procedure of SPSS (Software Version 19). Multiple comparison of the various means were analyzed by LSD (Least Significant Difference) test at $P = 0.05$ and $p = 0.01$

Results and Discussion

Temperature control in the poly-tunnels

Figure 3 shows the variation of temperature inside the poly tunnel and the outside ambient temperature over a period of 24 hours. Even though the sensors and exhaust fans used to maintain temperature inside the poly tunnels the temperature during the night falls below the maximum temperature set for that particular poly tunnel. However the temperature maintained inside the poly tunnels was always higher than the ambient temperature: assuring some sort of temperature stress was on the plants throughout the day.

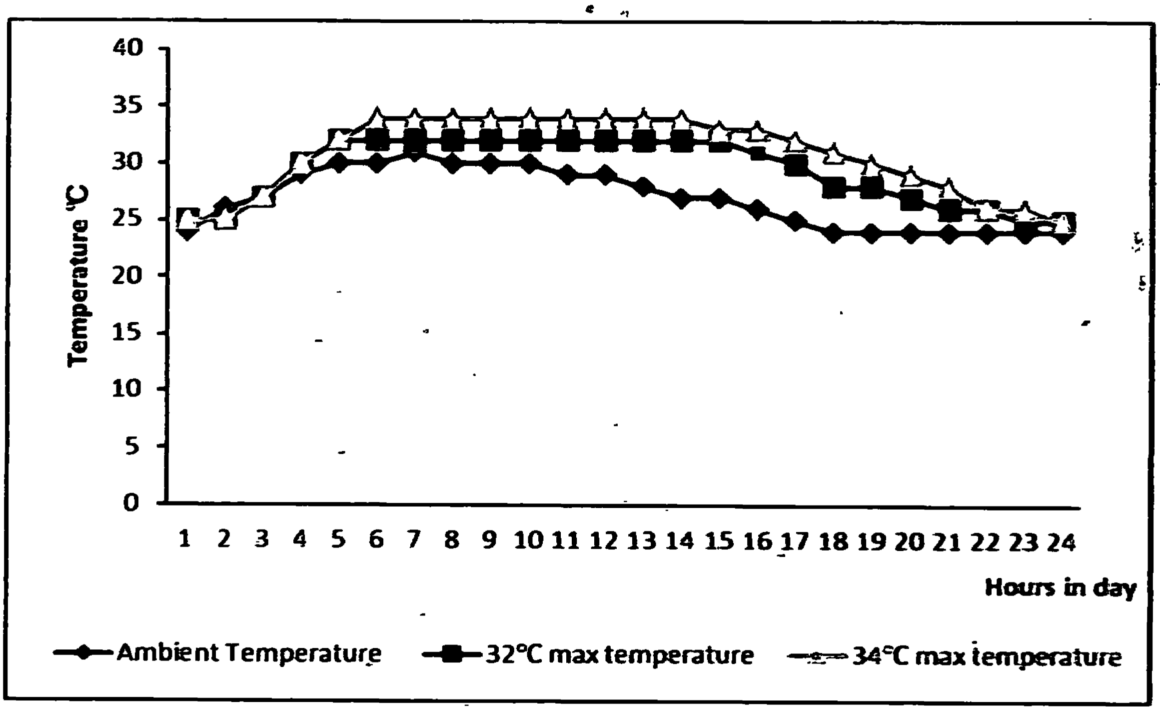

Figure 3: Average Temperature variations inside and outside the poly tunnels within a day

Temperature and water stress on physiological parameters of Okra

Germination of Okra seeds is statistically significant ($p < 0.01$) for the availability of water irrespective of the temperature (Table 1a and 1b). Seedling emerging rate was significantly reduced by water stress in all temperature regimes at two weeks after seeding. In addition, temperature stress has a significant effect on the germination (at $P = 0.05$). However, an interaction effect of temperature and water stress for seed germination was not statically significant. Individual effects of both water and temperature stress had significantly adverse effects ($p < 0.01$) on plant height together with a combination (at $p = 0.05$). Higher temperature leads to increase in plant height due to elongation of internodes. Therefore tallest plants were found in the higher temperature treatments.

Table 1a: Variations of plant growth parameters of Okra under stress condition

Treatments	Germination %	Flowers/plant	Plant height (cm)
Ambient tem.no water stress	82	6.6	65.75
Ambient tem.50% water stress	55	4.65	42
32°C max.tem no water stress	89	6.5	68.25
32°C max.tem 50% water stress	76	4.8	42.4
34°C max.tem no water stress	92	8.45	136.6
34°C max.tem 50% water stress	53	5.3	102.2
MS of main plot trt (WS)	2403.55**	23.12**	3536.405**
MS of Sub plot trt (TS)	246.22**	3.06**	8388.27**
MS of interaction (WS*TS)	53.55	0.9	48.69*

Table 1b: Variation of plant yield parameters of Okra under stress condition

Treatments	Pods/plant	Fruit Diameter (mm)	Fresh pod weight (g)	Pod length (cm)
Ambient tem.no water stress	6.3	14.38	20.34	17.02
Ambient tem.50% water stress	3.55	13.8	15.89	13.93
32°C max.tem no water stress	6.2	18.75	22.13	17.75
32°C max.tem 50% water stress	3.35	13.74	12.23	11.72
34°C max.tem no water stress	6.75	19.65	25.32	18.72
34°C max.tem 50% water stress	5.2	16.62	18.47	14.46
MS of main plot trt (WS)	35.56**	22.15**	224.55**	89.6**
MS of Sub plot trt (TS)	2.56**	38.46**	37.4*	5.23**
MS of interaction (WS*TS)	0.78**	5.11**	11.18**	3.26**

The Okra variety Haritha started to flower 34 days after sowing. The number of flowers /plant was counted up to 3 weeks from the first flowering. The highest number of flowers was observed at 34 ^{0}C temperature without water stress condition. There was no significant treatment interaction with respect to number of flowers. But the individual effect on both water and temperature stress has significant influence on flowering. It is interesting to note that water stress has negative influence on flowering where temperature stress has positive influence on flowering.

The diameter of the pods rapidly increased until nine days after full blooming (Figure 4). Then the rate of increase gradually decreased before coming to a stability at last. When plants were exposed to 34 °C maximum temperature and no water stress the diameter of the pods have rapid growth and reached to the maximum (Figure 4). Pod length too followed the same pattern as pod diameter (Figure 5).

Both individual stress as well as interactive stress have highly significant influence ($p<0.01$) on the pod diameter. The treatments are highly significant on the ($p<0.01$) fresh weight of Okra pods under water stressed as well as in the interactive stressed condition. In case of dry matter of the fruit the maximum weight was observed at the 34°C temperature with no water stress condition. Combined effect of high temperature and water stress had a substantial effect on the fruit weight of Okra compared to the other treatments. Water stress in combination with temperature stress had less negative effects on growth parameters as compared to the water stress treatments. Even at high temperature stress (34 °C maximum temperature) when the plants are maintained without any water stress (Field capacity soil water condition) it significantly enhanced the weight of the pod.

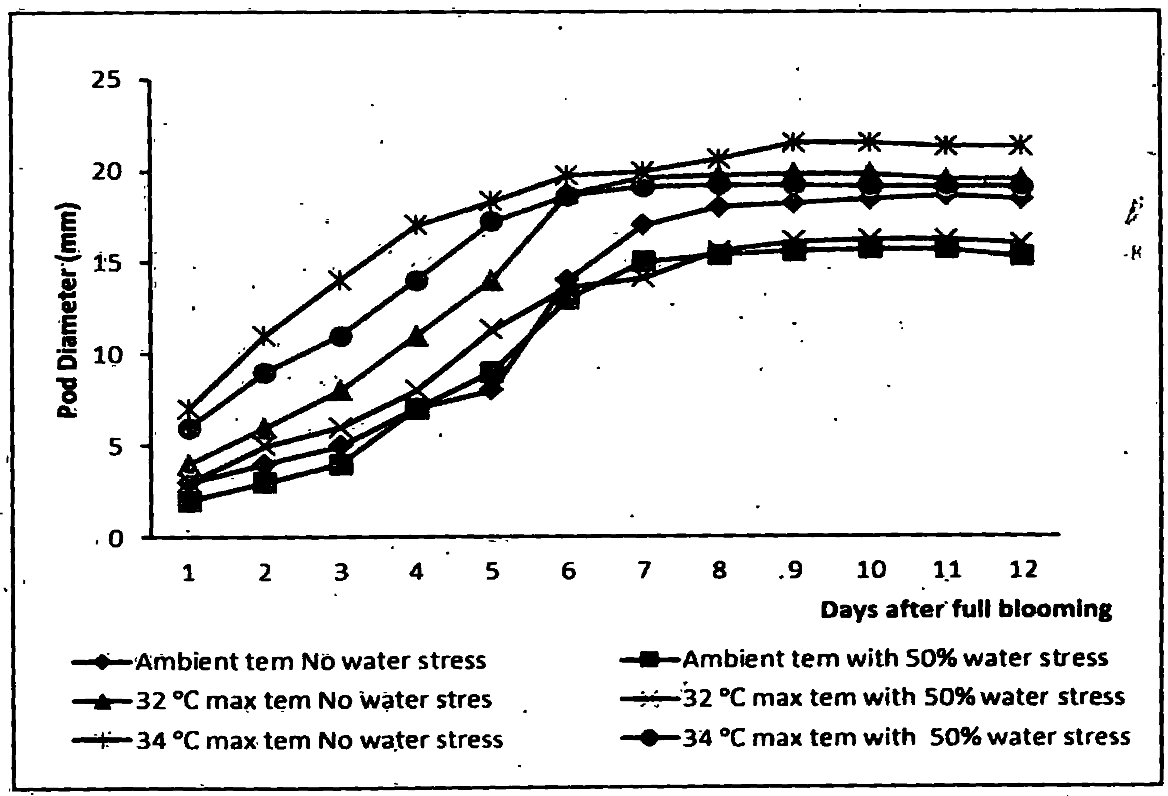

Figure 4: Effect of treatments on temporal variation of pod diameter.

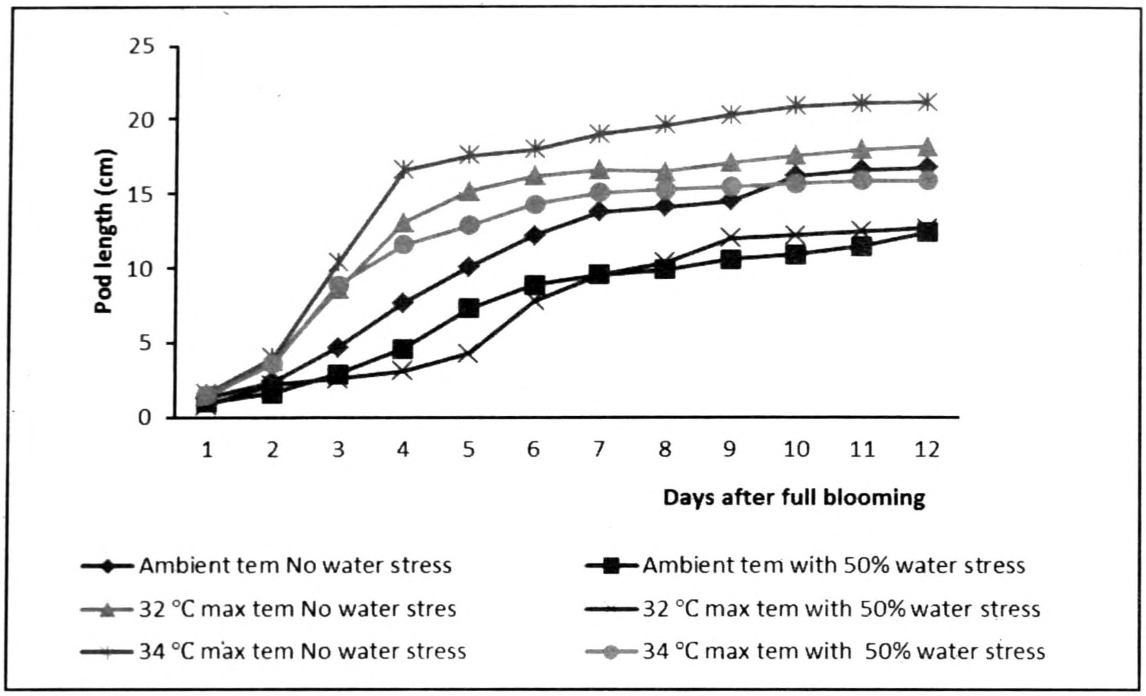

Figure 5: Effect of treatments on temporal variation of pod length

Temporal variation of fresh weight represents a very simple sigmoid shaped curve (Figure 6). Rapid growth was shown in early days after full bloom and the maximum growth rate was achieved in 34 ^{0}C temperature with no water stress and the lowest weight of pod weight was found water stressed treatments at 32^{0}C temperature. The plants grown in 34 ^{0}C with water stress condition also showed higher pod weight compared to other treatments. Rapid rate of pod weight was achieved in the Okra plants grown in the highest temperature condition.

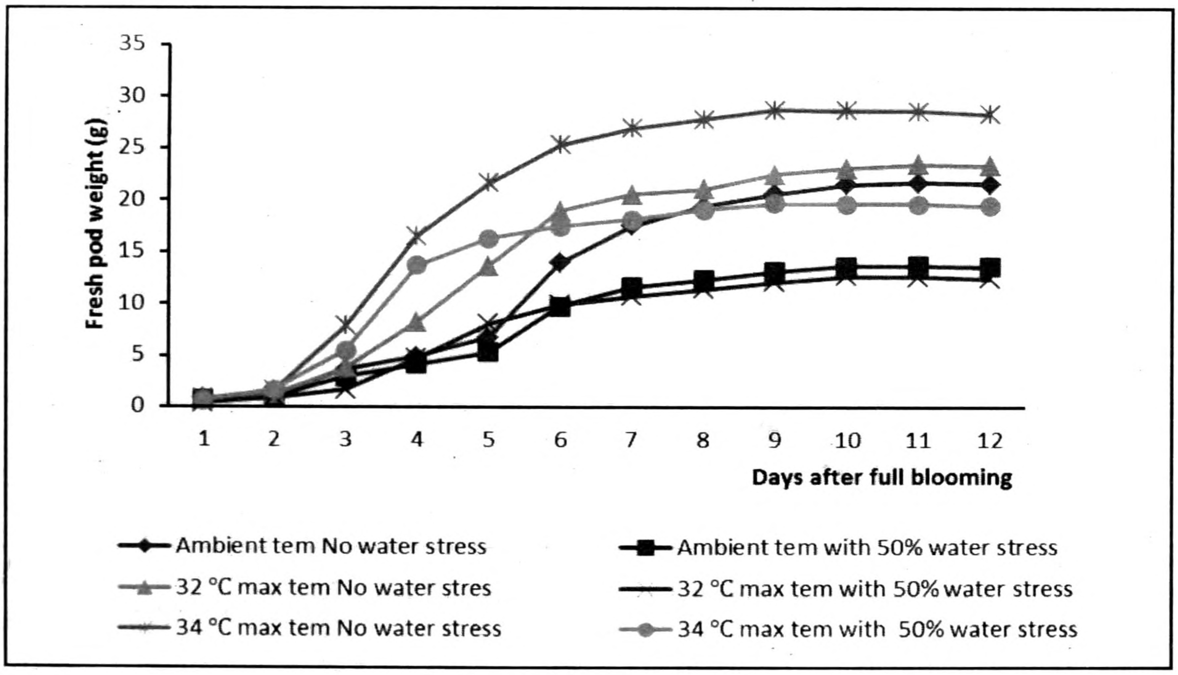

Figure 6: Effect of treatments on temporal variation of fresh pod weight.

According to Table 1 water stress conditions had significantly ($p<0.01$) affected for the number of fruits per plant. Further the highest temperature stress with no soil moisture stress condition has significantly ($p<0.01$) increased the number of fruits per plant compared to other treatments. Highest number of fruit per plant was found in high temperature (34°C) without water stress condition and followed by 32°C temperature without water stress condition. At all water stressed conditions number of fruit per plant was the lowest. However it is interesting to note that even the highest temperature and water stress has higher number of fruits per plant (5.2) compared to other water stressed treatments. It shows that the combination effect of temperature (34°C) and water stress have less negative effects on number of fruits per plant in Okra when compared to the ambient and 32°C temperature water stressed treatments.

Temperature and Water stress on Biochemical parameters of Okra

Soluble solids of the Okra pericarp slowly increased and reached to maximum on the seventh day under 32°C temperature treatment and of the sixth day under 34°C temperature treatment irrespective of water stress (Figure 7). But in the ambient temperature soluble solids reached the maximum on the eighth day of pod development and after that it decreased steadily.

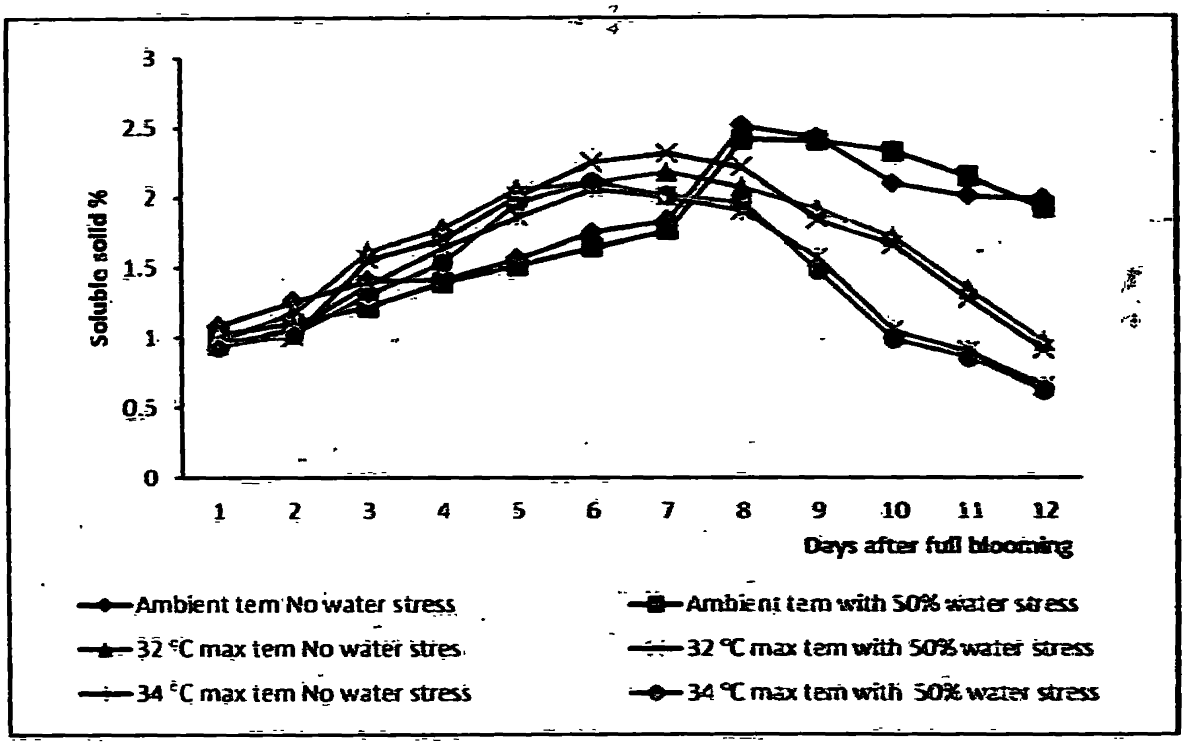

Figure 7: Effect of treatments on temporal variation of soluble solid concentration

It shows that the temperature stress enhance the Okra pods to reach the maximum soluble solids level quicker than that treatment in the ambient temperature conditions. The slow increase of soluble solids in the pericarp during the early development may be due to the presence of chlorophyll in the pericarp which would therefore have a capacity for photosynthesis. (Crafta and Crisp,1971; Singh and Pandey, 1980). Fibre content of the pericarp has steadily increased during the fruit development after full bloom (Figure 8). Similarly Ketsa and Chutichudet (1994) showed that fibre content of the pericarp steadily increased during development of the pod. Higher temperature treatments have enhanced higher fibre content in the pericarp compared to the ambient temperature treatment. The toughness of the Okra pod is caused by the development of fibre in the pericarp and it has steadily increased days after full bloom.

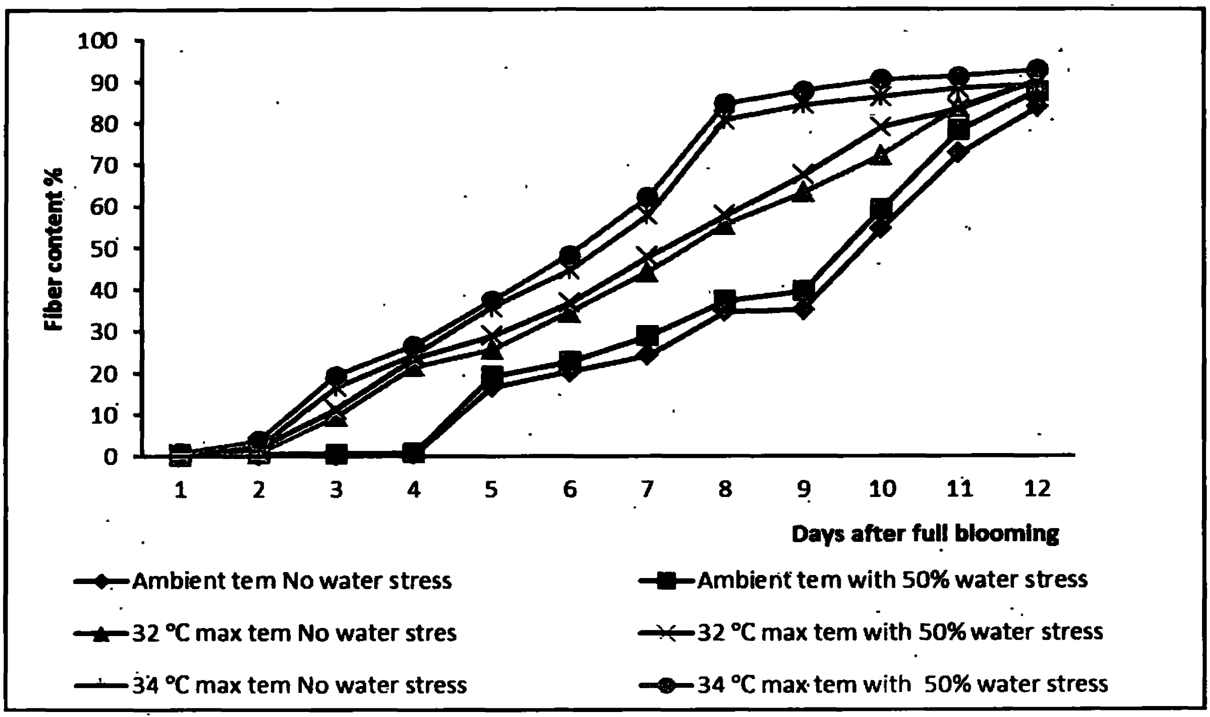

Figure 8: Temporal variation of fibre content of the pod days after full blooming

Figure 9 shows the temporal variation of calcium pectate content of the Okra pericarp under different temperature stress treatments without any water stress. It was very high at early stage of the pod development and rapidly decreases with increasing days after full bloom. This showed a continuous decreasing of calcium pectate in the pericarp may be due to the loss of calcium pectate from cell walls by pectinesterase (Leopold, 1964). The activity of pectinesterase has reported to be a greater influenced as they gradually mature (Lodh and Pantastico, 1975). However the decrease in calcium pectate varies with different temperature treatments. Accordingly the decreasing rate is slower in higher temperature stress treatment than the ambient temperature treatments. This might have been caused by higher temperature as it retards the activity of enzyme pectinesterase.

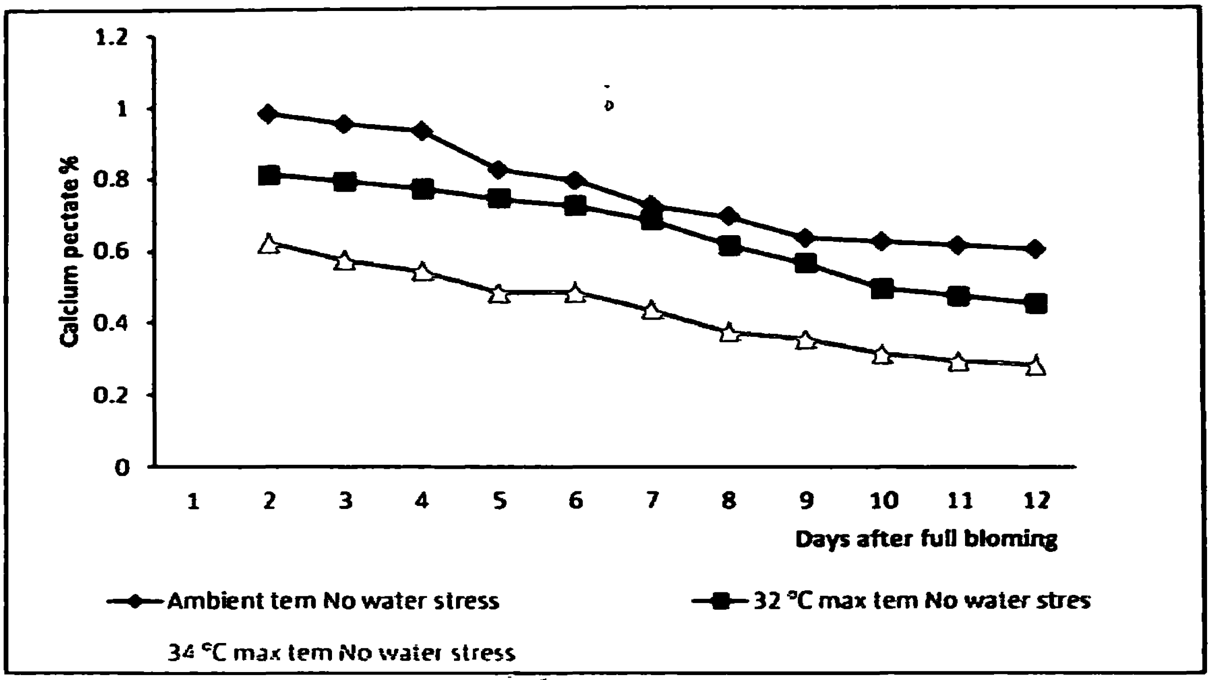

Figure 9: Temporal variation of calcium pectate content in Okra pericarp Days after full bloom (DAF).

Determination of optimum harvesting time

According to the fibres content, calcium pectate and weight gaining, it is possible to establish the optimum harvesting time for Okra pods. The decrease in the calcium pectate and increase in fibre in the pericarp with the pod maturity resulting in less crispness of the pod. Therefore in this study the optimum harvesting time in days after full bloom (DAF) is established when the calcium pectate curve cuts the fibre content curve in Figure 10. As a usual practise the dry zone farmers harvest around 8-10 day after full bloom. Culpepper and Moon (1941) observed that the edible quality of Okra increased up to sixth day after pollination and then declined so that 10 days old pods were unsuitable for consumption. Singh et al., (1974) in India has recommended that the harvesting the best time for Okra pods is 6 days after pod set so as to ensure good quality. Therefore different countries adapt different days after flowering according to their preference for cooking.

The results of the this study indicates that the optimum time for harvesting Okra pods can be determined by fiber and pectin contents as shown in Figure 10. Accordingly under ambient temperature, Okra pods could be harvested 10 days after full blooming. Whereas when there is temperature stress such as 32^{0}C and 34^{0}C, Okra pods could be harvested at 7 days (10 cm) and 5 days (15 cm) after full bloom, respectively provided plants are grown under no water stress conditions. Further the yield was 27% higher in temperature stressed treatments than the plants grown under ambient temperature conditions. This may due to the fact that vigorous growth and development in the higher temperature conditions were lead to higher production.

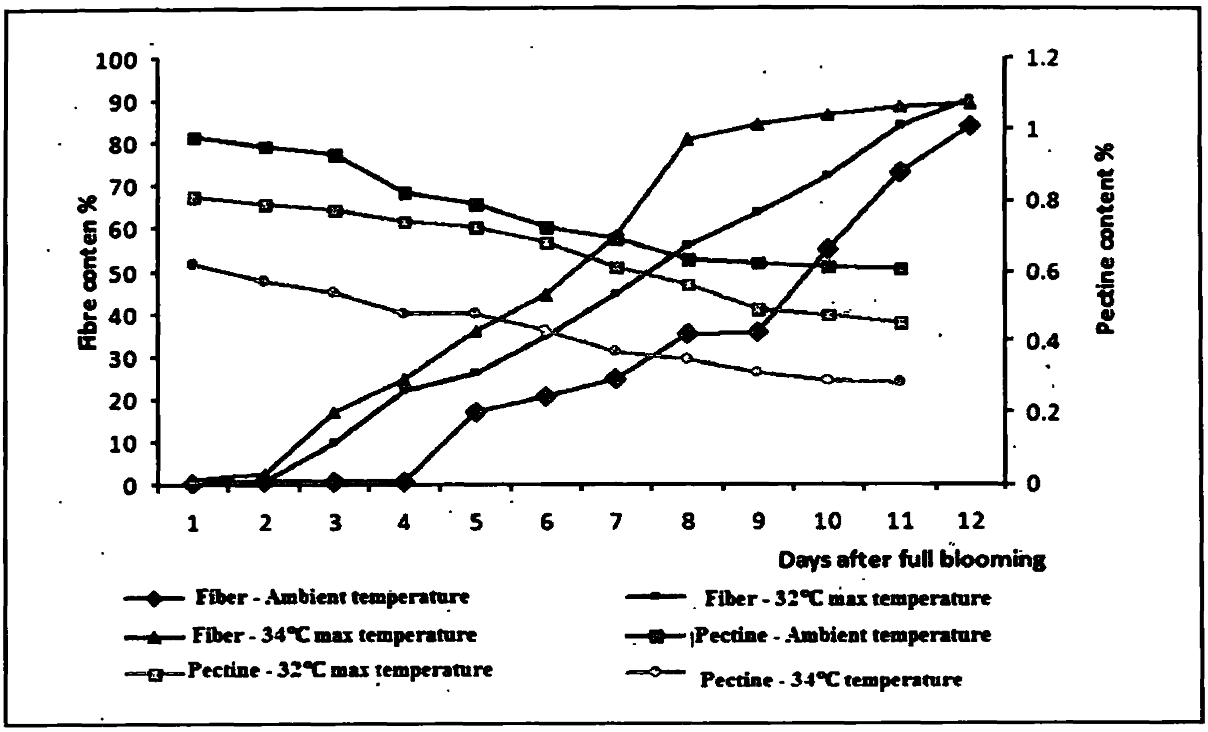

Figure 10: Temporal variation of fibre and calcium pectate content in Okra pericarp days after full blooming (no water stress condition)

As the global warming may not be mitigated but adaptation to it by careful planning of Okra cultivation with adequate water supply (at field capacity) will increase the yield irrespective of stress due to high temperature. Further, the Okra pods will be in 10-15 cm in size at the stage of harvesting which could be suitable to avoid postharvest losses on transport. This study reveals a valuable adaptation measure for cultivating Okra under global warming situations by advancing the harvesting time than the usual practice of farmers in the dry zone.

Conclusion

According to the results, there is a significant effect of individual stress of water and temperature and the combination affect for the physical parameters such as plant height, fresh weight, pod diameter, etc of Okra . Water stress in had negative effects on yield parameters such as number of pods per plant compared to the temperature stress with no water stress treatments. Further the high temperature stress in combination with no water stress situation can increase the Okra yield significantly compared to other treatments. Therefore it can be concluded that in high temperature situations if plants can be maintained without water stress pods can be harvested earlier such as on 5th day after full bloom in 34 °C temperature stress and 7th day after full bloom in 32 °C when pods are 15 cm and 10 cm long respectively to get good quality and higher yield. Therefore the finding of this study can be used as an adaptation to global warming in Okra cultivation.

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