DROUGHT MITIGATION IN OKRA (*Abelmoschus esculentus* L.) THROUGH CHEMICAL APPROACH

By

FATHIMATH SUHAILA

(2018-11-174)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled "**Drought mitigation in okra *(Abelmoschus esculentus* L.) through chemical approach.**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"DROUGHT MITIGATION IN OKRA (*Abelmoschus esculentus* L.) THROUGH CHEMICAL APPROACH"** is a record of research work done independently by Mrs. Fathimath Suhaila (2018-11-174) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Fathimath Suhaila

Dedicated to

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LIST OF ABBREVIATIONS AND SYMBOLS USED

Symbols	Abbreviations
%	Per cent
@	At the rate of
^{0}C	Degree Celsius
µg	Micro gram
µM	Micro molar
ANOVA	Analysis of Variance
AsA	Ascorbic acid
cm	Centimetre
DAP	Days after planting
DAS	Days after sowing
ds	Deci siemen
et al.	Co-workers/Co-authors
FC	Field Capacity
Fig.	Figure
FYM	Farm yard manure
G	Grams
ha	Hectare
i.e.,	That is
KAU	Kerala Agricultural University
kg	Kilograms
L	Litre
m	Metre
Mg	Milligrams
Ml	Milli litre
mM	Milli molar
Mm	Millimeters
MSL	Mean sea level
pH	Power of hydrogen ion

POP	Package of practices
ppm	Parts per million
RBD	Randomized block design
RGR	Relative growth Rate
RH	Relative humidity
RLWC	Relative leaf water content
SA	Salicylic acid
SLW	Specific leaf weight
t	Tonnes
TU	Thiourea
viz.,	Namely
WAP	Weeks after Planting
WAT	Weeks after transplanting

Introduction

1. INTRODUCTION

During the last 150 years, deforestation and excessive utilization of fossil fuels, shoot up the CO_2 concentration from 280 ppm to the current level of 410 ppm in the atmosphere. It is prognosticated that the concentration of CO_2 will raise two-fold, *i.e.*, upto 800 ppm at the end of this century. This steadily rising trace gas have its impact on global temperature. It is predicted that temperature would increase from 1.4 ^{0}C upto 6.4 ^{0}C by the year 2100. As there is continuous increase in temperature, climate undergoes severe alterations which results in uneven distribution of rainfall, changes of flood and drought is always in consideration. Agricultural crop production is being decided by the availability of soil water which in turn is related to global climate changes (Ciais *et al.* 2005).

Drought is undoubtedly harmful for plant growth. About two-third of the ground level is surrounded by water, however, shortage of water is a factor which limits the crop production in most areas of the world. Drought stress cause various morphological, physiological and biochemical variations in plants which is ultimately reflected on yield potential (Shintu and Jayaram, 2015).

Okra, or lady's finger, commonly known as 'Bhindi' (*Abelmoschus esculentus* L.) is an important summer vegetable crop belonging to the family Malvaceae, which is grown for its edible fruits. The crop is grown throughout the tropical and subtropical parts of the world and is acceptable in the market. Immature fruits are harvested and eaten as vegetable. The green fruits are rich sources of carbohydrates (6.4%), protein (1.9%), fat (0.2%), dietary fiber (1.2 g), vitamins, calcium (66 mg), potassium, and other minerals. The nutritional importance of okra aroused interest in bringing the crop into commercial production. Okra occupies an important position among vegetables grown in India and Kerala. In India, it covers over 0.5 million hectares area with annual production of 6.09 million tonnes. In Kerala it is cultivated in 1507 ha out of 46363 ha of total vegetable production.

Water requirement of vegetable crops are very high, in contrast to most of the field crops, hence, they are very sensitive towards drought stress. Drought stress affect the growth, yield and quality of vegetable crops. Even though okra is a drought tolerant crop, severe drought reduces its yield. Therefore, sufficient water supply and fairly moist soils are indispensable throughout the growing period for getting higher yields. When there is an unceasing water scarcity until the first picking, leads to greatest yield reduction. The period of flower initiation is most sensitive in okra to water scarcity and soil water depletion in the root zone during this period should not exceed 25 percentages.

The ground water level is insufficient for crop cultivation and this water-limited condition is a threatening problem all over the world. Improvement of drought tolerance in plants is possible in various ways such as application of plant growth regulators, antioxidants, bio-stimulants, plant breeding techniques etc. Utilization of growth regulating substances including salicylic acid, ascorbic acid acid and thiourea is easier and cheaper than the time consuming and costly methods of plant breeding.

Salicylic acid or ortho- hydroxy benzoic acid is an endogeneous plant growth regulator of phenolic nature that possess an aromatic ring with a hydroxyl group or its functional derivatives. In free state salicylic acid is found in a crystalline powder state having melting point of 157 – 159 ^{0}C and a pH of 2.4. Salicylic acid play various physiological role in plants which include seed germination, plant growth, thermogenesis, flower induction, nutrient uptake, ethylene biosynthesis, ion uptake and transport, membrane permeability, stomatal movement and photosynthesis. Salicylic acid mitigates drought effects in plants under stress by adjusting the activity of antioxidant enzymes. Exogenous application of salicylic acid during drought stress was found effective in major crops because, it can repair the damage caused by stress. SA treatment increased moisture absorption by plant roots and the amount of water loss by stomata was manipulated to decrease adverse effects of drought and it helped to regulate the availability of moisture in plant body (Keyvan, 2010).

Ascorbic acid (vitamin C) is a non-enzymatic water soluble antioxidant. It is a white or light yellow coloured soild with a melting point of 190 – 192 ^{0}C. It is one of the cheapest plant growth regulator having positive effects on plant growth and development under stress as well as non-stress conditions. Ascorbic acid is involved in many physico-chemical processes from seed germination to senescence (e.g. oxidative defence, the regeneration of vitamin E, flowering, fruit maturity, as a cofactor of enzymes, signalling, cell division and elongation, resisting pathogen attack, stress tolerance and increasing yields (Reihai and Farahbakhsh, 2013). Ascorbic acid is a main compound in plants and reduces the harmful effects of drought stress by reducing the amount of free radicals. Moreover, exogenously applied ascorbic acid is very effective in protecting proteins and lipids in plants exposed to water deficit (Naz *et al.*, 2016). By increasing the activities of catalase, superoxide dismutase, peroxidase enzymes and proline content, minimizing hydrogen peroxide production and elevating the levels of phenolics, ascorbic acid makes plant resistant to drought stress (Akram *et al.*, 2017).

Thiourea, chemically named as thiocarbamide (NH_2-CS-NH_2), is a nitrogen and sulfur containing compound which is sparingly soluble in water. It has three functional groups, amino, imino and thiol, each with important biological roles. Exogenous application of thiourea improves plant growth and productivity and stimulates defense mechanisms in plants under normal and stressful condition. Due to high water solubility and quick absorption in living tissues, thiourea imparts drought tolerance in plants. (Garg *et al.*, 2006).

Taking account of the importance of okra as a vegetable crop with respect to its nutritional value, area and production and alarming condition of drought occurrence in Kerala, a comprehensive study was carried out to assess the negative effects of drought stress on okra growth and productivity and also to mitigate these negative impact by foliar application of salicylic acid, ascorbic acid and thiourea. Hence, the study entitiled "Drought mitigation in okra *(Abelmoschus esculentus* L.) through chemical approach" was carried out with the following objectives:

- To investigate the influence of different chemicals namely, salicylic acid, ascorbic acid and thiourea on mitigation of drought.
- To evaluate the effect of chemicals on morphological, physiological and yield charcteristics of okra.

Review of literature

2. REVIEW OF LITERATURE

Okra, or lady's finger, widely known as 'Bhindi' (*Abelmoschus esculentus* L.) originated in Asia is one of the most favored summer vegetable crop grown extensively in Kerala for its edible green fruits. It is an annual vegetable crop, belonging to the family Malvaceae. Fruits are rich sources of vitamins, calcium, potassium, and other minerals, carbohydrates, protein, fat and dietary fiber.

Drought is a major yield limiting factor in agriculture and because of high water requirement of vegetables, they are very sensitive to drought stress when compared to majority of the field crops. Okra is moderately drought resistant (Singh *et al.*, 2014) because of its deep penetrating taproot, semi woody stem and hairy lobed leaves but drought can lower yield based on severity (Altaf *et al.*, 2015). The ground water level is insufficient for okra cultivation and this water-limited condition is a threatening problem all over the world.

Many investigators have explained the responses of plant under drought stressed condition, mechanism of drought tolerance and improvement of drought tolerance in plants through various physiological techniques, plant breeding techniques, application of plant growth regulators, antioxidants, bio stimulants etc.

In this chapter, review of relevant research work providing supportive information related to "Drought mitigation in okra (*Abelmoschus esculentus* L.) by salicylic acid, ascorbic acid and thiourea" has been compiled under the following headings.

2.1. EFFECT OF DROUGHT STRESS

Drought adversely affect various morphological, physiological and biochemical processes in plants which is ultimately reflected on yield potential. Sufficient water supply and fairly moist soils are indispensable throughout the growing period for getting higher yields. Drought is the most important limiting factor for crop production and it is becoming an increasingly severe problem in many regions of the world (Passioura, 2007).

2.1.1. Effect of drought stress on morphological parameters

Several workers had reported the effect of drought stress on morphological characteristics of okra. Mbagwu and Adesipe (1987) observed that the greatest reduction in plant height was found when moisture stress was imposed during the vegetative stage of okra. According to Sankar *et al.* (2007), when five varieties of okra were subjected to moisture stress by irrigating at 60 per cent of field capacity from 30 to 70 DAS, the shoot length was drastically reduced in all the varieties. In another study conducted by Hussein *et al.* (2011), severe water stress imposed by increasing irrigation interval of okra to 30 days reduced average plant height when compared to 12, 18 or 24 days interval. Kwajaffa *et al.* (2015) claimed that in okra there was a reduction in plant height when irrigation was given at 25 or 50 per cent field capacity compared to 75 or 100 per cent field capacity. Severe drought stress reduced the plant height by 24 per cent in tomato compared to the control (Sibomana *et al.*, 2013).

In sandy soils, biometric parameters such as plant height, number of branches plant^{-1} and number of leaves plant^{-1} were decreased in okra plants subjected to drought stress condition and highest number of leaves and branches plant^{-1} were obtained with shortest irrigation interval (El-Kader *et al.*, 2010). Ranawake *et al.* (2011) found that the number of leaves were significantly affected when 10 day water stress given at 8 WAP in mung bean. Irrigating every seven days significantly increased the plant height, branches plant^{-1} and leaves plant^{-1} in okra (Ghannad *et al.*, 2014). Altaf *et al.* (2015) found that okra could survive only low levels of drought (25%) and plant height and number of leaves were reduced under higher levels of drought (50%). A study conducted by Aliyu *et al.* (2016) reported that in okra the plant height, number of leaves plant^{-1} were decreased and took more days for 50 per cent flowering, when irrigation interval was increased from 5 or 8 days to 11 days.

Uddin *et al.* (2013) reported that in mung bean (*Vigna radiata* L.) plant height increased with the increase of number of irrigation and decreased in no irrigation condition. The highest number of leaves plant^{-1} and branches plant^{-1} were found when irrigated from pod setting to maturity and the lowest was observed when no irrigation was given (drought stress). In a recent study, Al-Ubayadi *et al.* (2017) observed that morphological characters of okra plants were decreased by widening irrigation intervals because crop faces drought. The irrigation given at every three days significantly gave the highest plant height (187.7 cm), number of branches plant^{-1} (12.33) and number of leaves plant^{-1} (40 leaf) as compared with 133.5 cm and 6.8 branches plant^{-1} and 32.0 leaves plant^{-1} in crop irrigated when needed, respectively.

Drought stress adversely affected root length and root volume of crops. In a study conducted by Hamidou *et al.* (2007) there was a decrease in root volume in various genotypes of cowpea when water stress was imposed at vegetative and flowering stage. The effect was more prominent at flowering than at vegetative stage. Sankar *et al.* (2007) reported that root length was reduced in okra varieties subjected to drought stress, (Irrigation given at 60 per cent field capacity) from 30 to 70 DAS.

2.1.2. Effect of drought stress on physiological parameters

The studies on the effect of drought on physiological parameters of some of the crops are reviewed below. Mbagwu and Adesipe (1987) observed greatest reduction in leaf area when moisture stress was imposed during the vegetative stage of okra. Ashraf *et al.* (2002) claimed that water deficit condition in okra had a significant detrimental effect on leaf area. Burman *et al.* (2004) confirmed that leaf area was reduced by 42.8 per cent at pre-flowering and 35.5 per cent at the post-flowering stage of cluster bean (*Cyamopsis tetragonoloba* Taub.) under drought. In another study conducted by Pagter *et al.* (2005) in *Phragmites australis* (common reed), drought reduced the leaf area and leaf biomass plant^{-1} because of decreased production of new leaves, increased leaf shedding and reduced average leaf size.

When five varieties of okra were subjected to moisture stress by irrigating at 60 per cent of field capacity from 30 to 70 DAS, the total leaf area was drastically reduced in all the varieties (Sankar *et al.*, 2007). According to Boutraa *et al.* (2010) severe water deficit decreased leaf area in wheat cultivars. The highest leaf area was found in the control plants of 80 per cent water regime, followed by the plants under 50 per cent water regime, while leaf area was lowest in plants of 30 per cent water regime. Kusvuran (2012) found that leaf area plant^{-1} was reduced in okra plants exposed to drought stress condition and lowest leaf area was obtained with longest irrigation interval.

Effect of drought stress on relative leaf water content of plants have been reported by many workers. Ashraf *et al.* (2002) reported that water deficit condition in okra had a significant detrimental effect on relative leaf water content (RLWC). Kirnak *et al.* (2002) observed in brinjal, drought resulted in significant reduction of relative leaf water content compared to well watered treatment. Burman *et al.* (2004) confirmed that drought stress significantly reduced RLWC at both pre-flowering and the post-flowering stage of cluster bean. Bhatt and Rao (2005) estimated RLWC in the irrigated plants of okra and it varied from 72 - 82 per cent, while in the stressed plants RLWC decreased to 66 - 75 per cent. Sibomana *et al.* (2013) reported that severe water stress (amount of water applied is 40 per cent of pot capacity) in tomato reduced relative leaf water content by 24.7 per cent. According to Pravisya and Jayaram (2015) relative leaf water content decreased in okra plants when stress was imposed by not irrigating for 3 days consecutively. Nahar and Ullah, (2018) claimed that with the increasing water stress, relative water content of tomato plants decreased significantly. The crop receiving the lowest water stress maintained higher RLWC. The maximum relative leaf water content was contributed at 100 per cent of field capacity. Okra plants subjected to water deficit of 10 days duration at vegetative and reproductive stages (25% FC) caused severe reduction in RLWC compared to the control (100% FC) (Adejumo *et al.*, 2019).

In a study conducted by Singh and Singh (2016), when moisture stress was imposed by giving irrigation at 9 days interval in okra, the dry matter accumulation plant^{-1} at 30, 60 and 90 DAP were reduced drastically compared to the unstressed condition with 5 day irrigation interval.

Dos Santos Farias *et al.* (2019) reported the significant effect of irrigation levels on okra plants for variable fluorescence (F_V), maximum efficiency of PS II (F_V/F_M), maximum efficiency of PS II photochemical process (F_V/F_0), basal quantum production of PS II (F_0/F_M) for non-photochemical processes. For F_V, (F_V/F_M), (F_V/F_0) and (F_0/F_M), the highest increase was found in irrigated plants at a well-irrigated level, with values 13.23 per cent, 10.52 per cent, 17.41 per cent, 20.22 per cent higher, respectively, in relation to low irrigated or drought stressed okra plants.

Boutraa *et al.* (2010) observed in wheat that root shoot ratio was increased under mild water deficit (50% field capacity), confirming that shoot dry weight was severely affected compared to the root dry weight. When water deficit was severe (30% field capacity) root shoot ratio did not change significantly because both shoot and root were affected equally. In a study conducted by Uddin *et al.* (2013) reported that in mung bean (*Vigna radiata* L.) water deficiency resulted in lowered relative growth rate and root shoot ratio. The highest relative growth rate (163.13 mg g^{-1} day $plant^{-1}$) and root shoot ratio (0.24) was found in irrigated plants and lowest in non-irrigated plants.

2.1.3. Effect of drought stress on biochemical parameters

Different scientists reported the effect of drought stress on chlorophyll content of okra. Altaf *et al.* (2015) claimed that drought reduced the photosynthetic pigments in okra and maximum reduction in photosynthetic pigment was found in higher level of drought (50% moisture depletion) than lower level. In their study, drought affected okra at early stage than the middle stage and drought up to 50 per cent depletion of available moisture was found to be fatal to the plants but plants can survive at low levels of drought. In another study, okra plants exposed to water deficit (25% FC) of 10 days duration at vegetative and reproductive phases caused severe reduction of chlorophyll content compared to the control (100% FC) (Adejumo *et al.*, 2019). Dos Santos Farias *et al.* (2019) found that in well irrigated okra plants, chlorophyll *a*, chlorophyll *b* and total chlorophyll showed an increase of 12.10 per cent, 64.2 per cent and 27.60 per cent over drought stressed plants, respectively.

Effect of drought stress on chlorophyll content of several other crops are reviewed below. Kirnak *et al.* (2002) reported that in brinjal, drought resulted in significant reduction in chlorophyll contents compared to well watered treatment. According to Pagter *et al.* (2005) in *Phragmites australis* the chlorophyll *a* content was remarkably reduced by severe water stress, while changes in the chlorophyll *b* content were insignificant, showing greater sensitivity of chlorophyll *a* to water stress. Talebi (2011) evaluated the effect of drought on chlorophyll content (SPAD reading) on twenty four genotypes of durum wheat under well-watered and moisture-stressed condition. He found that genotype with higher yield in well watered condition also had high chlorophyll content. Sibomana *et al.* (2013) reported that severe water stress in tomato reduced chlorophyll concentration by 32 per cent.

2.1.4. Effect of drought stress on yield and yield attributes

Several workers have reported the effect of irrigation interval and drought stress on yield and yield attributes of okra.

In an earlier study conducted by Mbagwu and Adesipe (1987) reported that irrigation withdrawn during the flowering or pod-filling stages of okra ended in reduction of more than 70 per cent fruit yields, while the lowest reduction in fruit yield remained with water stress during the vegetative stage. Similarly, Sam-Amoah *et al.* (2016) reported that water deficit during vegetative stage causes decline in yield in okra.

Studies have shown that okra fruit size was greatly affected when the quantity of water supplied is below that required for plants (Kumar *et al.*, 2007). Sankar *et al.* (2007) reported that when moisture stress was imposed in five varieties of okra, by irrigating at 60 per cent field capacity, decreased yield of the crop. According to Al-Harbi *et al.* (2008), when okra plants exposed to reduced water supply during its growth phase had an unfavorable effect on productivity. The flowering stage is the most sensitive stage of okra to water shortage, as it, causes early flowering and reduction in the number of fruits. Dos Santos Farias *et al.* (2019) reported that in well irrigated okra plants, fruit length (cm), fruit girth (cm) and productivity (t ha^{-1}) showed an increase of 29.16 per cent, 17.60 per cent and 338.70 per cent, respectively, when compared to drought stressed plants.

Water stress on okra plants directly impact the reduced fruit dry matter and yield of the plant (Bhatt and Rao, 2005; Sankar *et al.*, 2008; Bahadur *et al.*, 2009). Kwajaffa *et al.* (2015) reported that in okra the mean fresh fruit weight, fruit length and fruit dry weight were lower when irrigation was given at 25 or 50 per cent field capacity compared to 75 or 100 per cent field capacity, while the fruit diameter showed a quadratic response at a peak of 50 per cent soil moisture content. Pravisya and Jayaram (2015) observed that in okra the biomass and fruit yield were reduced under moisture stress condition. Sam-Amoah (2016) reported that the effects of water stress led to reduction in pod length and pod girth of okra.

The irrigation intervals significantly influence the flowering, fruit size and yield of okra. Hussein *et al.* (2011) claimed that fruit yield and fruit weight of okra was reduced with a wider irrigation interval of 30 days compared to 12 days interval. According to Ghannad *et al.* (2014), irrigation given to okra plants at 7 days intervals influenced the days to flowering initiation and gave the highest yield, fruits number plant^{-1} and seeds pod^{-1}. Aliyu *et al.* (2016) reported that the number of pods plant^{-1}, average pod weight, pod length and fruit yield of okra was reduced when irrigation interval was increased to 11 days from 5 days and 8 days which produced higher values. Similarly, Singh and Singh (2016) observed that when moisture stress induced by irrigating at 9 days interval in okra, led to lowest number of pickings (9), fruits plant^{-1} (15.33) and yield (7007 kg ha^{-1}) when compared to the unstressed condition with 5 days irrigation interval which produced the maximum number of pickings (11) and fruits plant^{-1} (17) and yield (9516 kg ha^{-1}). In another study conducted by Al-Ubaydi *et al.* (2017) plants irrigated at every 3 days initiated flowers much earlier when compared to plants which have been irrigated when needed. The highest fruit length (4.2 cm) was observed in plants irrigated every five days compared with plants irrigated when needed (2.5 cm). The highest diameter of the fruit (2.08 cm) was observed in plants irrigated at every 3 days, while the lowest fruit diameter (1.3 cm) in plants irrigated when needed.

Effect of drought stress and irrigation interval on yield and yield attributes of several other crops were reported. Nahar and Ullah (2011) found that the flower and fruit characteristics of tomato plants *i.e.*, flowers cluster^{-1}, fruits cluster^{-1}, clusters plant^{-1}, fruit stalk length, fruit length, fruit girth and fruit weight, were affected by soil moisture depletion and in their study, all the flower and fruit characters were significantly affected by water stress and the highest values were obtained at slight stress (70% field capacity) followed by severe stress (40% field capacity) and control (100% field capacity). Menon and Savithri (2015) claimed that drought stressed cowpea plants showed delay in flowering compared to normally irrigated plants. This is due to delay in attaining sufficient vegetative growth before flowering.

Bideshki and Arvin (2010) reported that, drought stress decreased yield of garlic (*Allium sativum*) crop. Kirnak *et al.* (2002) reported that in brinjal, the drought stress treatment receiving 80 per cent replenishment of open pan evaporation at 8 days interval and 70 per cent replenishment at 12 days interval reduced the marketable fruit yield and fruit size by 12 per cent and 28.6 per cent, respectively, when compared to well watered treatment. Sibomana *et al.* (2013) claimed that severe drought stress in tomato reduced the plant height by 24 per cent, chlorophyll concentration by 32 per cent and relative leaf water content by 24.7 per cent, fruit girth by 19 per cent and fruit yield by 69 per cent compared to the control. Uddin *et al.* (2013) reported in mung bean (*Vigna radiata* L.) moisture stress caused early flowering, pod formation and maturity of plant. The highest number of days (46.15 days) required to initiate flowering were found when irrigation given at emergence, flowering, pod setting and maturity stage and the lowest duration required to initiate flowering (38.65 days) in non-irrigated condition.

Ascorbic acid concentration was highly affected by drought stress. The concentration of ascorbic acid in fruits increased with increasing drought stress and the highest amount was seen at 40 per cent field capacity followed by 70 per cent and 100 per cent field capacity. An increase of 76 per cent of ascorbic acid concentration was observed at 40 per cent field capacity compared to 100 per cent field capacity (Amirjani and Mahdiyeh, 2013).

2.2. SALICYLIC ACID

Salicylic acid (SA) or ortho- hydroxy benzoic acid is an endogeneous plant growth regulator of phenolic nature that possess an aromatic ring with a hydroxyl group or its functional derivatives. In free state salicylic acid is found in a crystalline powder form having melting point of 157 – 159 ^{0}C and a pH of 2.4.

The biosynthetic pathway for synthesis of SA adopted by plants comprises two enzymatic pathways, *i.e.*, isochorismate synthase (ICS) and isochorismate pyruvate lyase (IPL), from a common precursor, chorismic acid. The PAL and ICS pathways act independently, and it is well known that the PAL pathway is mainly responsible for the synthesis of SA. SA is believed to be synthesized in the chloroplast and exported into the cytoplasm (Hasanuzzaman *et al.*, 2017).

Salicylic acid play a various physiological role in plants which include seed germination (Cutt and Klessig, 1992), plant growth (Khan *et al.* 2003), thermogenesis, flower induction, nutrient uptake, ethylene biosynthesis (Hayat and Ahmad 2007), ion uptake and transport (Harper and Balke, 1981), membrane permeability (Barkosky and Einhellig, 1993), stomatal movement (Larque-Saavedra 1979) and photosynthesis (Fariduddin *et al.* 2003). Salicylic acid adjusts the activity of antioxidant enzymes and enhances plant resistance to abiotic stresses (Hayat *et al.*, 2010).

Drought has been accounted as one of the most acute abiotic stresses presently affecting agriculture. Drought stress reduces photosynthesis and stomatal conductance, inhibit photosynthetic pigments synthesis and ultimately lead to reduction in growth of plants. Various results showed that salicylic acid alleviated the adverse effects of drought stress on the growth and development of okra and other crops. In general, salicylic acid have ability to enhance the tolerance of the plant under drought stress (Amin and Mahmood, 2011).

2.2.1. Effect of salicylic acid on morphological parameters

Many investigators have explained the effect of salicylic acid on morphological parameters of different crops, some of them are reviewed here. Munir *et al.* (2016) reported that salicylic acid foliar spray of 1 mM and 2 mM at all the growth stages of okra was found effective in improving morphological traits. SA foliar spray of 2 mM at all the three growth stages *i.e.*, two leaf stage, four leaf stage and flowering stage was found more effective in increasing plant height (68.62 cm) than untreated plants (40.55 cm).

Amin *et al.* (2008) reported that foliar spray of SA @ 100 and 200 mg L^{-1} promoted plant height of wheat plants in comparison with untreated plants. Salicylic acid @ 100 mg L^{-1} was the best treatment in increasing growth parameters of wheat plants, whereas, growth characters significantly decreased by increasing salicylic concentration up to 400 mg L^{-1}. Similar observation was made by Jayalakshmi *et al.* (2010) in groundnut, foliar application of salicylic acid @ 100 and 200 mg L^{-1} promoted plant height by 11 per cent and 21 per cent than untreated plants. Salicylic acid (200 mg L^{-1}) was most effective treatment in increasing growth parameters. Whereas, growth characters of groundnut plants significantly decreased by increasing salicylic acid concentration up to 400 mg L^{-1}. Abdelkader *et al.* (2012) observed that presoaking of wheat grains in 1 mM salicylic acid improved morphological traits such as plant height. According to Al- Razak *et al.* (2015), adverse effects of water stress on the growth of fenugreek can be mitigated by foliar spraying of salicylic acid at two concentrations (50 and 100 mg L^{-1}), particularly 100 mg L^{-1} salicylic acid concentration. Foliar sprays with 100 mg L^{-1} SA cause a significant increase in plant height by 37.13 per cent comparing to control plants.

Pradhan *et al.* (2016) claimed that exogenous application of salicylic acid @ 250 mg L^{-1} significantly increased plant height (71.08 cm) than untreated control (61.71 cm). Elhakem (2019) found that drought stress caused 25 per cent reduction in the plant height of peppermint (*Mentha arvensis*) plants when exposed to drought stress by withholding water twice at the vegetative stage for 30 days, when compared to the control plants. Seeds presoaked in SA (0.05 M) increased the plant height in both the control as well as drought stressed plants. In a study done by Edupuganti *et al.* (2019) reported that drought stress at reproductive stage of chickpea plants decreased the plant height by 17 per cent compared to control. SA application alleviated the drought stress effect on plant height in chickpea. SA (0.5 mM) applied to well-watered plants improved the plant height by 9 per cent compared to the unstressed control.

Senaratna *et al.* (2000) observed that the lower concentrations (0.1 mM) of salicylic acid, when exogenously applied to bean and tomato plants imparts tolerance against the damaging effects of drought, whereas, higher concentrations of salicylic acid (0.5 mM) did not show fruitful results. Noreen *et al.* (2009) showed that spraying salicylic acid (200 ppm) in sunflower caused the reduction of adverse effects of drought stress. The use of SA with concentrations of 1, 2 and 3 mM on peanut under drought stress conditions *i.e.*, at 50 per cent of field capacity significantly increased the performance of the crop (Karimian *et al.*, 2015).

Hayat *et al.* (2005) reported that number of leaf $plant^{-1}$ increased significantly in wheat seedlings raised from the grains soaked in lower concentration (10^{-5} M) of salicylic acid. Chavoushi *et al.* (2020) observed that in safflower number of leaf increased when treated with SA @ 250 µM under drought stress when compared to their controls, FC 25 per cent.

Foliar application of lower concentrations of salicylic acid significantly increased the root length of soybean, carrot, radish and beetroot (Hayat *et al.*, 2010). Munir *et al.* (2016) confirmed that salicylic acid spray of 1 mM and 2 mM at all the growth stages of okra was found effective in improving morphological traits. SA spray 2 mM at all the three growth stages *i.e.*, two leaf stage, four leaf stage and flowering stage was found more effective in increasing root length (41.15 cm) than untreated plants (25.1 cm).

Chavoushi *et al.* (2020) reported that in safflower dry weight of roots increased when treated with SA @ 250 µM under drought stress when compared to their controls (25% FC). Ornamental plant *Sinningia speciosa* flowered much earlier when they received an exogenous foliar spray of salicylic acid as compared to the untreated control (Martin-Mex *et al.*, 2005).

2.2.2. Effect of salicylic acid on physiological parameters

Several workers have reported the effect of salicylic acid on physiological parameters. Abdelkader *et al.* (2012) reported that presoaking of wheat grains in 1 mM salicylic acid improved leaf area. In safflower the leaf area was significantly increased compared to their controls (FC 25%), when sprayed with SA @ 250 µM under drought stress (Chavoushi *et al.*, 2020).

Munir *et al.* (2016) confirmed that minimum RLWC was in drought stressed plants (58.86%) and application of 2 mM SA spray at all three growth stages *i.e.,* two leaf stage, four leaf stage and flowering stage of okra significantly increased RLWC (89.92%) under drought stress.

There was a significant decline of relative leaf water contents in water stressed tomato plants. The treatment of these water stressed tomato plants with lower concentrations of salicylic acid (10^{-5}M) significantly enhanced the aforesaid parameter thereby improved tolerance of the plants to drought stress (Hayat *et al.*, 2008). According to Rao *et al.* (2012) foliar application of salicylic acid 100 ppm at 3 - 4 leaf stage of drought stressed maize (*Zea mays* L.) maintained the highest RLWC (79.37%) followed by 150 ppm SA (64.07%), when compared with check plants (52.27%). In another study conducted by Askari and Ehsanzadeh (2015) relative leaf water content of fennel (*Foeniculum vulgare*) decreased by 71.06 per cent due to drought and exogenous application of SA (0.5) mM alleviated drought induced harmful effects on RLWC. Abbas *et al.* (2019) stated that relative leaf water contents (RLWC) were significantly decreased when moisture stress was imposed to marigold plants. When foliar application of SA @ 100 mg L^{-1} was done at reproductive growth stage of marigold under normal irrigation and drought stress increased RWC. Foliar spray of salicylic acid @ 100 mg L^{-1} at vegetative stage of maize resulted in the maximum relative leaf water contents under control as well as water stress conditions. Priming and foliar spray with salicylic acid @ 100 mg L^{-1} gave second highest RLWC. Minimum relative leaf water contents were in conditions where priming or foliar spray were not given (Irfan *et al.*, 2019). Edupuganti *et al.* (2019) revealed 37.42 per cent decrease in RLWC in drought stressed chickpea plants compared to control. Exogenous application SA (0.5 mM) improved the RLWC by 55 per cent in well watered plants and 49.4 per cent in drought stressed plants over control.

Hussein (2015) reported that seed priming with salicylic acid concentration of 10, 25, 50, 75 and 100 mg L^{-1} increased relative growth rate in okra. Higher tolerance to drought stress was observed in the plants raised from the grains soaked in aqueous solution of SA and also improved dry matter accumulation (Hamada, 2002). According to Fariduddin *et al.* (2003), dry matter accumulation was enhanced in mustard when sprayed with lower concentrations (10^{-5} M) of salicylic acid but higher concentrations of salicylic acid (10^{-4} M or 10^{-3} M) had an inhibitory effect. Singh and Usha (2003) found that when wheat seedlings subjected to drought stress treated with salicylic acid exhibited higher dry matter accumulation compared to the untreated control. Abbas *et al.* (2019) reported that maximum dry weight per plant was obtained by foliar spray of SA @ 100 mg L^{-1} at reproductive growth stage of marigold plants during both normal moisture supply and drought stressed condition. The amount of plant dry weight was lowest with no salicylic acid application in water deficit condition. Irfan *et al.* (2019) claimed that foliar application of SA 100 mg L^{-1} at the vegetative growth stage of maize improved dry matter production $plant^{-1}$ by 26 per cent under moisture stress conditions. Foliar and priming with SA 100 mg L^{-1} gave second best results in the dry matter production $plant^{-1}$. Edupuganti *et al.* (2019) reported that total dry matter production was significantly declined (41.7%) in water-deficit chickpea plants at reproductive stage when compared to well-watered plants. SA (0.5 mM) application to drought stressed plants reversed the drought stress effect on dry mass accumulation and increased total dry mass by 50.6 per cent as compared to the stress control. Unstressed chickpea plants treated with exogenous SA (0.5 mM) accounted for 9.3 per cent increase in total dry matter over the unstressed control plants.

2.2.3. Effect of salicylic acid on biochemical parameters

Many workers have reported the effects of salicylic acid on chlorophyll content of leaf. Amin *et al.* (2009) reported that drought stress caused decreased chlorophyll *a*, chlorophyll *b* and total chlorophyll in okra plants when compared with control plants. The decrease of these pigments under drought stress conditions improved with application of salicylic acid and ascorbic acid @ 1 mM.

Fariduddin *et al.* (2003) reported that when mustard plants were sprayed with lower concentrations (10^{-5} M) of SA, chlorophyll content significantly enhanced, whereas, higher concentrations proved to be inhibitory. Singh and Usha (2003) confirmed that chlorophyll content in wheat plants increased with salicylic acid application under water stress as compared to the water stress control without salicylic acid. Chlorophyll contents at 1, 2 and 3 mM of SA respectively, were 38, 49.4 and 97.9 per cent higher than those of water stressed control.

According to Hayat *et al.* (2005) chlorophyll pigment was significantly enhanced in wheat seedlings, when raised from the grains pre-treated with lower concentration (10^{-5} M) of salicylic acid. There was a significant decline of photosynthetic parameters and chlorophyll content in water stressed tomato plants. The treatment of these stressed plants with lower concentrations of salicylic acid (10^{-5} M) significantly enhanced the aforesaid parameters thereby improved tolerance of the plants to drought stress (Hayat *et al.*, 2008). In a study conducted by Amin *et al.* (2008) in wheat, salicylic acid 100 mg L^{-1} increased chlorophyll *a*, chlorophyll *b* and carotenoids content. The content of chlorophyll pigments were reduced in higher concentration of salicylic acid (100 mg L^{-1} and 400 mg L^{-1}).

In another study, tomato plants receiving SA (10^{-5} M) possess the maximum value for SPAD chlorophyll meter readings (SCMR) and measured 27.5 per cent higher than that of the control. Application of water stress by withholding water for 10 days at 20 and 30 DAS decreased the value of SCMR. The SA foliar treatment @ 10^{-5} M overcame the negative effects generated by water stress (Hayat *et al.*, 2008). Idrees *et al*, (2010) reported that drought stress reduced the total chlorophyll and carotenoids content in lemon grass varieties and higher reduction was noted at 50 per cent FC. Higher total chlorophyll and carotenoids contents were found in stressed plant with SA (10^{-5} M) than without SA application.

Jayalakshmi *et al.* (2010) claimed that foliar application of salicylic acid (100, 200 and 300 mg L^{-1}) to 30 day old groundnut plants significantly increased chlorophyll *a*, chlorophyll *b* and carotenoids recording maximum values at 100 mg L^{-1}. The content of chlorophyll pigments were reduced when higher concentration of salicylic acid (400 mg L^{-1}) were applied. Rao *et al.* (2012) confirmed that foliar application 100 ppm of SA at 3-4 leaf stage significantly increased chlorophyll contents (63.62 µM) over control (26.98 µM) under drought stressed conditions in maize. Bidabadi *et al.* (2012) reported that banana shoot tip explants responded positively to the application of salicylic acid (1, 2 and 3 mM) by showing significant increase in chlorophyll contents under drought stress conditions.

Askari and Ehsanzadeh (2015) reported that chlorophyll *a*, chlorophyll *b* and total chlorophyll reduced under drought stress condition in fennel (*Foeniculum vulgare*) and exogenous application of SA @ 0.5 mM and 1 mM improved the chlorophyll content. According to Pradhan *et al.* (2016) exogenous application of SA @ 250 mg L^{-1} increased chlorophyll content of leaves (33.01 SPAD) than untreated control (26.77 SPAD). Spraying of SA three times had better efficacy than two times of spraying in terms of chlorophyll content of leaves. Elhakem (2019) reported that control peppermint (*Mentha arvensis*) plant leaves had higher chlorophyll *a*, chlorophyll *b* and total chlorophyll at all growth stages. Drought stress caused reduction in chlorophyll pigments and presoaking in SA (0.05 M) caused an increase in the photosynthetic pigment content in the stressed and the unstressed plants. In a study conducted by Chavoushi *et al.* (2020) in safflower, the contents of chlorophyll *a*, chlorophyll *b* and carotenoids were significantly decreased by the drought stress. The salicylic acid treatment @ 250 µM to the non-stressed plants (100% FC) reduced contents of chlorophyll *a* and carotenoids about 45 per cent and chlorophyll *b* had no significant effect. The SA treatment to the drought stressed plants increased chlorophyll *a*, but not changed the chlorophyll *b* and carotenoids compared to the drought stressed plants (FC 25%).

2.2.4. Effect of salicylic acid on yield and yield attributes

Many workers have reported the effects of salicylic acid on yield and yield attributes of crops. Munir *et al* (2016) reported that when 2 mM salicylic acid was sprayed at all three growth stages, two leaf stage, 4 leaf stage and flowering stage of okra crop grown under water stress, maximum fruits plant^{-1} (15.53), fruit weight (9.78 g), fruit yield (10.09 t ha^{-}) and seed yield (1695.8 kg ha^{-1}) was observed. On contrary, control plants showed minimum fruits plant^{-1} (5.93), fruit weight (4.52 g), fruit yield (1.6 t ha^{-1}) as well as seed yield (355.5 kg ha^{-1}).

The foliar application of salicylic acid to soybean enhanced the flowering and pod formation (Kumar *et al.*, 1999). Martin-Mex *et al.* (2005) reported that when plants of *Carica papaya* were treated with salicylic acid showed significantly higher fruit setting. Arfan *et al.* (2007) claimed that foliar application of salicylic acid (0.25 and 0.75 mM) increased grain yield and growth of spring wheat under water deficit conditions. Foliar spray of salicylic acid improved productivity of wheat due to an improvement in all growth characteristics such as plant height, number and area of leaves, stem diameter and total plant dry weight (Hussein *et al.*, 2007).

In cucumber and tomato, the fruit yield enhanced significantly when the plants were sprayed with lower concentrations of salicylic acid (Larque-Saavedra and Martin-Mex, 2007). Amin *et al* (2008) reported that foliar application of salicylic acid @ 100 mg L^{-1} resulted in the highest increase in yield and its components. Conversely, SA @ 400 mg L^{-1} recorded the lowest values of yield and yield components compared to their corresponding controls. In another study conducted by Jayalakshmi *et al.* (2010) reported that foliar application of salicylic acid 100 mg L^{-1} to 30 day old groundnut plants resulted in increased yield. However, SA 400 mg L^{-1} recorded the lowest values of yield and its components compared to controls. Pradhan *et al.* (2016) found that application of SA @ 250 mg L^{-1} at 30 DAS, 30 DAT and 45 or 60 DAT increased the total bulb yield (290.91 q ha^{-1}) and marketable bulb yield (180.91 to 183.10 q ha^{-1}) in onion variety Agrifound Light Red.

2.3. ASCORBIC ACID

Ascorbic acid (AsA) (vitamin C) is a non-enzymatic water soluble antioxidant. It is a white or light yellow coloured solid with a melting point of 190 – 192 ^{0}C. It is one of the cheapest plant growth regulators and had significant positive effects on plant growth and development under stress as well as non-stress conditions.

AsA is involved in many physico-chemical processes from seed germination to senescence (e.g. oxidative defence, the regeneration of vitamin E, flowering, fruit maturity, as a cofactor of enzymes, signalling, cell division and elongation, resisting pathogen attack, and increasing yields and stress tolerance (Reihai and Farahbakhsh, 2013). Ascorbic acid is one of the comprehensively studied antioxidant and had been figured in majority of plant species, organelles and apoplast. It is synthesized in the mitochondria and transported to the other cell components through a proton-electrochemical gradient or through facilitated diffusion. Generally, its concentration is higher in leaves as compared to other plant parts.

Ascorbic acid is a main compound in plants and reduces the harmful effects of drought stress by reducing the level of free radicals. It is well known to regulate stress tolerance in plants as reported in a number of studies, e.g., canola (Shafiq *et al.*, 2014), pea (Akram *et al.*, 2018), and maize (Dolatabadan *et al.*, 2010) etc. Literature supporting the effect of ascorbic acid under stressed and non-stressed condition is reviewed below.

2.3.1. Effect of ascorbic acid on morphological parameters

Several workers reported the effect of ascorbic acid on morphological parameters. Amin *et al.* (2008) reported that ascorbic acid @ 100, 200 and 400 mg L^{-1} was effective in increasing vegetative growth of wheat plants. The increment in growth characters (*i.e.*, plant height, number of tiller, number of spikes $plant^{-1}$, flag leaf area, and dry weight plant^{-1}) reached maximum values at 400 mg L^{-1} of ascorbic acid compared to control plants.

2.3.2. Effect of ascorbic acid on physiological parameters

Many workers reported the effect of ascorbic acid on physiological parameters, some of them are reviewed here. Darvishan *et al.* (2013) reported that irrigation withholding at 8-leaf stage, at silks appearance stage and at both 8-leaf stage and silks appearance stages of corn (*Zea mays* L) decreased RLWC. Foliar application of AsA 150 ppm concentration increased RLWC compared with control plants under irrigation withholding condition. According to Reiahi and Farahbakhsh, (2013) drought stress caused a significant reduction in RLWC (17.44%) in sorghum. AsA @ 1 mM led to an increase of 103 per cent in RLWC compared with control. Also priming with ascorbic acid concentration of 1 and 1.5 mM had the highest effect on RLWC under normal and stress condition.

Malik *et al.* (2015) found that AsA application as seed priming (1 mM), foliar spray (1 mM) and through rooting medium (0.5 mM), benefited the wheat seedlings under drought to overcome adverse effects of drought stress. Rooting medium treatment proved to be the most effective mode of application. Ascorbic acid application improved RLWC of wheat genotypes subjected to drought stress when compared to the control drought stressed genotypes. In another study Latif *et al.* (2016) found that water deficit conditions suppressed RLWC values in cauliflower cultivars and seed-soaking with ascorbic acid @ 75 or 150 mg L^{-1} improved RLWC values and increased tolerance to drought stress.

2.3.3. Effect of ascorbic acid on biochemical parameters

Amin *et al.* (2008) reported that in wheat, ascorbic acid concentration of 400 mg L^{-1} was effective in increasing the photosynthetic pigments, chlorophyll *a*, chlorophyll *b* and carotenoids over control.

According to Darvishan *et al.* (2013), irrigation withholding at 8-leaf stage, at silks appearance stage and at both 8-leaf stage and silks appearance stages of corn (*Zea* *mays* L) decreased total chlorophyll content. Foliar application of AsA @ 150 ppm increased total chlorophyll content when compared with untreated plants.

Farooq *et al.* (2020) claimed that chlorophyll *a* and chlorophyll *b* contents decreased significantly in all cultivars of safflower under water stress. Foliar application of ascorbic acid @ 100 mg L^{-1} and 150 mg L^{-1} caused marked improvement in chlorophyll *a* and chlorophyll *b* contents under both water regimes.

2.3.4. Effect of ascorbic acid on yield and yield attributes

Amin *et al.* (2008) reported that AsA significantly increased yield and yield components in wheat plants *i.e.*, plant height, tiller number, number of spikes $plants^{-1}$, spike length, spike weight $plant^{-1}$, grain index, grain and straw yield $plant^{-1}$ compared to the other treatments. The maximum values of yield and its components were obtained with foliar spray of ascorbic acid @ 400 mg L^{-1}. Latif *et al.* (2016) claimed that seed treatment with ascorbic acid @ 75 or 150 mg L^{-1} increased ascorbic acid concentrations in the leaves of cauliflower cultivars under drought stress. Significant increase was observed in AsA content in safflower cultivars due to foliar application of ascorbic acid (100 mg L^{-1} and 150 mg L^{-1}) under both well-watered and water deficit conditions (Farooq *et al.*, 2020).

2.4. THIOUREA

Thiourea (TU) is a sulphydral compound (NH_2-CS-NH_2) which is soluble in water. Exogenous application of TU (e.g. as seed priming, foliar spray, medium supplementation, soil application) improve productivity and stimulates defense mechanisms in plants under drought stress in arid and semi-arid regions (Sahu *et al.*, 1993; Srivastava *et al.*, 2017). It imparts drought tolerance because of its high water solubility and quick absorption in living tissues (Garg *et al.*, 2006). Literature supporting the effect of thiourea under stressed and non-stressed condition is reviewed below.

2.4.1. Effect of thiourea on morphological parameters

Several workers reported the effect of thiourea on morphological parameters of crops. Anitha *et al.* (2006) reported that in cowpea (*Vigna unguiculata* L.), seed soaking with 500 ppm thiourea combined with two foliar sprays @ 500 ppm at vegetative stage and flowering stages recorded the highest number of branches plant^{-1}. In a similar study conducted by Shanu *et al.* (2013) seed treatment with 1000 ppm thiourea followed by foliar spray with 1000 ppm of thiourea at vegetative and flowering stage of coriander under different irrigation levels resulted higher plant height and number of branches plant^{-1}. According to Burman *et al.* (2007), seed treatment with thiourea (500 mg kg^{-1}) followed by foliar spray of thiourea (1000 mg kg^{-1}) at vegetative and reproductive stage of cluster bean under rainfed conditions increased plant growth.

Amin *et al.* (2014) claimed that foliar spray of thiourea @ 1000 mg L^{-1} to faba bean plants during elongation stage increased plant height, number of leaves plant^{-1} and number of branches plant^{-1} compared to untreated control plants. Singh and Singh (2017) reported that maximum plant height and branches plant^{-1} were recorded with application of thiourea @ 500 ppm followed by thiourea @ 1000 ppm at pre flowering and pod initiation stages over water spray and control in lentil. In another study, Zain *et al.* (2017) reported that highest plant height (97.84 cm) in wheat was attained in plants treated with 300 mg L^{-1} of thiourea followed in plants sprayed with 600 mg L^{-1} of thiourea and reduced plant height (83.68 cm) was recorded in control plants. Shakoor *et al.* (2019) observed that exogenous application of thiourea @ 1000 mg L^{-1} and 500 mg L^{-1} at 20th, 30th and 40th days after germination of maize plants recorded maximum shoot length and minimum shoot length was in control. In a recent study conducted by Uddin *et al.*, (2020), foliar spray of thiourea in okra at three times found to be beneficial in case of plant height, number of leaves plant^{-1} and number of branches plant^{-1} (131.5 cm, 41.7 and 3.7, respectively) as compared to twice and single application over control or no application (109.5 cm, 12.6 mm, 29.7 and 1.3 respectively).

In gladiolus thiourea 1 % + salicylic acid 150 ppm recorded minimum days for 50 per cent sprouting of corms and maximum leaves plant^{-1} (Pawar *et al.*, 2018).

2.4.2. Effect of thiourea on physiological parameters

Many workers reported the effect of thiourea on physiological parameters. Ravat and Nirav (2015) found that in okra foliar spray of thiourea @ 500 ppm yielded the best for leaf area.

The role of thiourea in increasing leaf area has been reported for several crops (Sahu and Solanki, 1991; Garg *et al.*, 2006). Burman *et al.* (2004) reported that seed treatment with 500 µg g^{-1} thiourea and foliar spray with 1000 µg g^{-1} thiourea at 25 and 40 DAS in water stressed cluster bean (*Cyamopsis tetragonoloba* Taub.) increased leaf area of plants to the extent of 41.3 per cent and 38.8 per cent at pre flowering and post flowering stages, respectively.

Garg *et al.*, (2018) reported that drought stress significantly decreased relative leaf water content (RLWC) of leaf by 18.84 per cent as compared to control in garden pea (*Pisum sativum* L.). Application of thiourea 6.6 mM increased the RLWC in water stressed condition about 10.22 per cent.

2.4.3. Effect of thiourea on biochemical parameters

Many workers reported the effect of thiourea on chlorophyll content of leaves. Burman *et al.* (2004) reported that water stress decreased the chlorophyll content by 15.8 to 10.7 per cent at pre and post flowering stages, respectively, in cluster bean (*Cyamopsis tetragonoloba* Taub.) and seed treatment with 500 µg g^{-1} thiourea and foliar spray with 1000 µg g^{-1} thiourea at 25 and 40 DAS increased chlorophyll content by 6 - 7 per cent. Garg *et al.* (2006) reported a substantial increase in chlorophyll contents by the application of thiourea in cluster bean, under drought stress. Seed treatment with 1000 ppm thiourea followed by foliar spray with 1000 ppm of thiourea at vegetative and flowering stage of coriander under different irrigation levels resulted in higher chlorophyll content in leaves (Shanu *et al.*, 2013).

Foliar spray of thiourea at 250, 500 and1000 mg L^{-1} to faba bean plants during elongation stage increased photosynthetic pigments (chlorophyll *a*, chlorophyll *b* and carotenoids) compared to untreated plants (Amin *et al.*, 2014). According to Garg *et al.* (2018), drought stress decreased chlorophyll *a*, chlorophyll *b* and total chlorophyll content as compared to control garden pea (*Pisum sativum* L.). Thiourea treatments with and without drought increased chlorophyll *a* and total chlorophyll content. TU @ 6.6 mM increased chlorophyll *a* content by 164.7 per cent and chlorophyll *b* content by 133.3 per cent compared to untreated plants under drought.

2.4.4. Effect of thiourea on yield and yield attributes

The effect of thiourea on yield and yield attributes of several crops had been reported by many workers. Ravat and Nirav (2015) found that in okra foliar spray of thiourea @ 500 ppm yielded the best for yield characters *viz*., number of fruits $plant^{-1}$, fruit length, number of seeds $fruit^{-1}$, seed yield $plant^{-1}$ and seed yield $hectare^{-1}$.

Sahu and singh, (1995) reported that thiourea foliar spray at tillering stage, flowering stage and at both tillering and flowering stage of wheat increased grain yield by 15.2 percent, 6.6 percent and 23.9 per cent over control, respectively. Amin *et al.* (2014) claimed that foliar spray of thiourea at 1000 mg L^{-1} to faba bean plants during elongation stage increased number of pods $plant^{-1}$ compared to untreated control plants. In a study conducted by Anitha *et al.* (2006) thiourea application increased cowpea productivity under rainfed conditions. Soaking seeds in thiourea (500 ppm) solution followed by 2 sprays at both vegetative and flowering stages was most effective and increased seed yield by 26 per cent over control. This also resulted in the higher economic benefits over that of untreated control.

Siddiqui *et al.* (2014) observed that under rainfed condition application of thiourea 0.1per cent increased grain yield of pearl millet by 10.7 per cent over control. Also, foliar spray of thiourea at both tillering and flowering stages was found more effective than foliar spray at tillering or at flowering stage alone during rainy season. According to Sharma *et al.* (2015) foliar spray of thiourea 1000 ppm at heading stage of wheat enhanced the grain yield to the magnitude of 22.08 per cent over control and obtained additional returns and incremental B:C ratio of 3.33. Singh and Singh (2017) claimed that maximum pods $plant^{-1}$ and an increase of 20 per cent grain yield were obtained when foliar sprayed with thiourea @ 500ppm at pre flowering and pod initiation stage of lentil over water spray and control treatment under rainfed condition.

Yield contributing traits such as number of productive tillers, number of grains spike^{-1}, 1000 grain weight and grain yield were improved by the application of 300 mg L^{-1} of thiourea at tillering stage of late sown wheat (Zain *et al.,* 2017). Uddin *et al.* (2020) reported that application of thiourea resulted in significant increase in growth, yield and yield related attributes of okra. Foliar spray of thiourea at three times found to be more beneficial in case of number of fruits plant^{-1}, fruit length, fruit diameter, single fruit weight, fruit weight plant^{-1}, yield ha^{-1} (21.7, 15.7 cm, 15.5 mm, 17.5 g, 300.6 g, 15.3 t, respectively) as compared to twice and single application over control (14.3, 12.2 cm, 12.6 mm, 15.9 g, 227.9 g, 11.4 t, respectively).

Materials & Methods

3. MATERIALS AND METHODS

The research work entitled "Drought mitigation in okra (*Abelmoschus esculentus* L.) through chemical approach" was done at Regional Agricultural Research Station, Pilicode. The objective of the study was to investigate the influence of different chemicals namely, salicylic acid, ascorbic acid and thiourea on mitigation of drought and to evaluate their effect on morphological, physiological and yield characteristics of okra. The details of the materials used and methods adopted for the research work are detailed below.

3.1. GENERAL DETAILS

3.1.1. Experimental location

The experimental plot was located at Regional Agricultural Research Station, Pilicode, located at 13 ^{0}N latitude and 75 ^{0}E longitude at an elevation of 15 m above MSL.

3.1.2. Time of study

The crop was grown during the period December 2019 to March 2020.

3.1.3. Season and weather condition

The experimental plots comes under tropical humid region. Data on various weather parameters during crop period were collected from the Agromet Observatory of RARS, Pilicode and depicted graphically in Fig. 1 and summarized in Appendix I. The average weather parameters during the crop period at monthly average are given in Table 1.

Table 1. Average weather parameters during the crop period

Month	Max Temp (^{0}C)	Min Temp (^{0}C)	Rainfall (mm)	RH (%)	Evaporation (mm)	Total rainy days in the month
December 2019	31.7	22.8	91.0	77.0	110.9	3.0
January 2020	31.7	21.8	0.0	74.0	133.0	0.0
February 2020	32.0	22.5	45.8	75.0	126.9	1.0
March 2020	32.7	24.2	28.0	74.0	166.0	2.0

3.1.4. Soil

Soil samples were collected from the experimental plots prior to the crop sowing by making a 'V' shaped cut in the plot to a depth of 15 cm. Samples were then sieved through a 2 mm sieve and reduced sample to 500 g by quartering technique. Soil samples were then dried in shade for estimation of pH, EC, available N, P, K, S, Ca and Mg. Another set of samples were collected from 0 - 15 cm and 15 - 30 cm depth by using core sampler for determining the bulk density. The procedure followed for physico-chemical properties are given in Table 2.

Table 2. Physico - chemical properties of soil

Sl. No.	Particulars	Methods adopted	References
I	**Physical properties**		
1.	Bulk density (g cm^{-3})	Undisturbed core sampler	Black *et al.*, (1965)
2.	Wet bulk density (15 cm depth)		
3.	Dry bulk density (15 cm depth)		
4.	Wet bulk density (30 cm depth)		
5.	Dry bulk density (30 cm depth)		
II	**Mechanical composition**		
1.	Sand (%)	Robinson International pipette m	Piper (1966)
2.	Silt (%)		
3.	Clay (%)		
4.	Textural class		
III	**Chemical properties**		
1.	pH	1:2.5 soil water suspension pH meter	Jackson (1958)
2.	EC (dS m^{-1})	Conductivity meter	Jackson (1958)
3.	Organic carbon (%)	Walkley and Black method	Jackson (1958)
4.	Available N (kg ha^{-1})	Alkaline permanganate method	Subbiah and Asijablack (1956)
5.	Available P (kg ha^{-1})	Bray colorimetric method	Jackson (1973)
6.	Available K (kg ha^{-1})	Neutral normal ammonium acetate extractant flame photometry	Jackson (1958)
7.	Available Ca (mg kg^{-1})	Atomic absorption spectroscopy	Jackson (1958)

8.	Available Mg (mg kg^{-1})	Atomic absorption spectroscopy	Jackson (1958)
9.	Available S (mg kg^{-1})	Calcium chloride extraction and estimation using spectrophotometer	Massoumi and cornfield (1963)

3.1.5 Crop and variety

Okra var. Arka Anamika was used for the field experiment. It is a high yielding (20 t ha^{-1}) popular variety of 100 - 130 days duration and resistant to yellow vein mosaic virus (YVMV). It is developed by interspecific hybridization of *Abelmoschus esculentus* (IIHR20-31) X *Abelmoschus manihot* spp tetraphyllus followed by back cross method of breeding. It is tall and well branched variety having green stem with purple shade. Fruits lush green, tender and long and borne in two flushes. Fruits free from spines, having 5 - 6 ridges with delicate aroma. Purple pigment is present on both sides of the petal base. Fruits have good keeping and cooking qualities. Seeds were obtained from Indian Institute of Horticultural Research (ICAR-IIHR), Hesaraghatta, Bangalore.

3.2. EXPERIMENTAL STUDY

3.2.1. Experiment details

Variety	:	Arka Anamika
Season	:	Dec 2019 – Mar 2020
Spacing	:	60 cm × 30 cm
Size of the plot	:	3 m × 3 m
Design	:	RBD
Treatments	:	8
Replication	:	3
No of plants per plot	:	50

3.2.2. Treatments details

T_1 : Normal irrigation

T_2 : Drought stress (Stress was induced from 25 DAS, irrigation given at 50% field capacity)

T_3 : T_2 + Salicylic acid foliar spray @ 1 mM

T_4 : T_2 + Salicylic acid foliar spray @ 2 mM

T_5 : T_2 + Ascorbic acid foliar spray @ 1 mM

T_6 : T_2 + Ascorbic acid foliar spray @ 2 mM

T_7 : T_2 + Thiourea foliar spray @ 500 ppm

T_8 : T_2 + Thiourea foliar spray @ 1000 ppm

- Foliar spray was given at 10^{th}, 20^{th} and 30^{th} DAS.

3.2.3. Preparation of the chemical solutions

Salicylic acid : Salicylic acid having 99 per cent purity manufactured by Spectrum Reagents and Chemicals Pvt Ltd., Kochi was used for preparing solutions. Salicylic acid 138.12 mg and 276.24 mg dissolved in 1 L water to prepare 1 mM and 2 mM solutions of salicylic acid, respectively.

Ascorbic acid : Ascorbic acid having 99 per cent purity manufactured by Isochem Laboratories, Kochi was used for preparing solutions. 176.13 mg and 352.26 mg of ascorbic acid dissolved in 1 L water to prepare 1 mM and 2 mM solutions of ascorbic acid, respectively.

Thiourea : Thiourea having 99 per cent purity manufactured by Isochem Laboratories, Kochi was used for preparing solutions. 500 mg and 1000 mg of thiourea was dissolved in 1 L of water to prepare 500 ppm and 1000 ppm solutions, respectively.

3.2.4. Manures and fertilizers

Urea (46 per cent N), rajphos (20 per cent P_2O_5) and muriate of potash (60 per cent K_2O) were used as chemical sources of nitrogen, phosphorus and potassium, respectively.

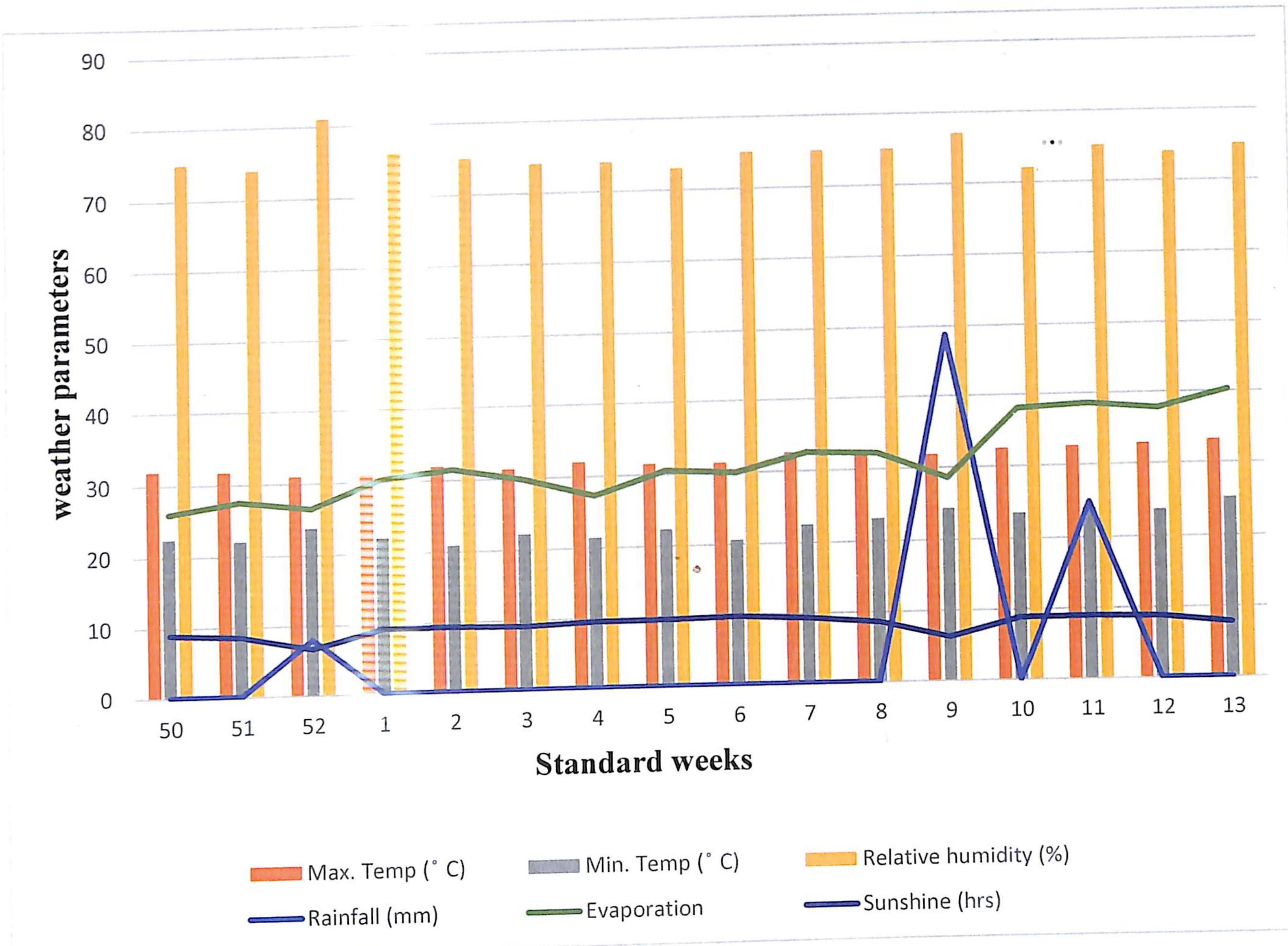

Figure 1: Weather parameters during the crop season in standard weeks

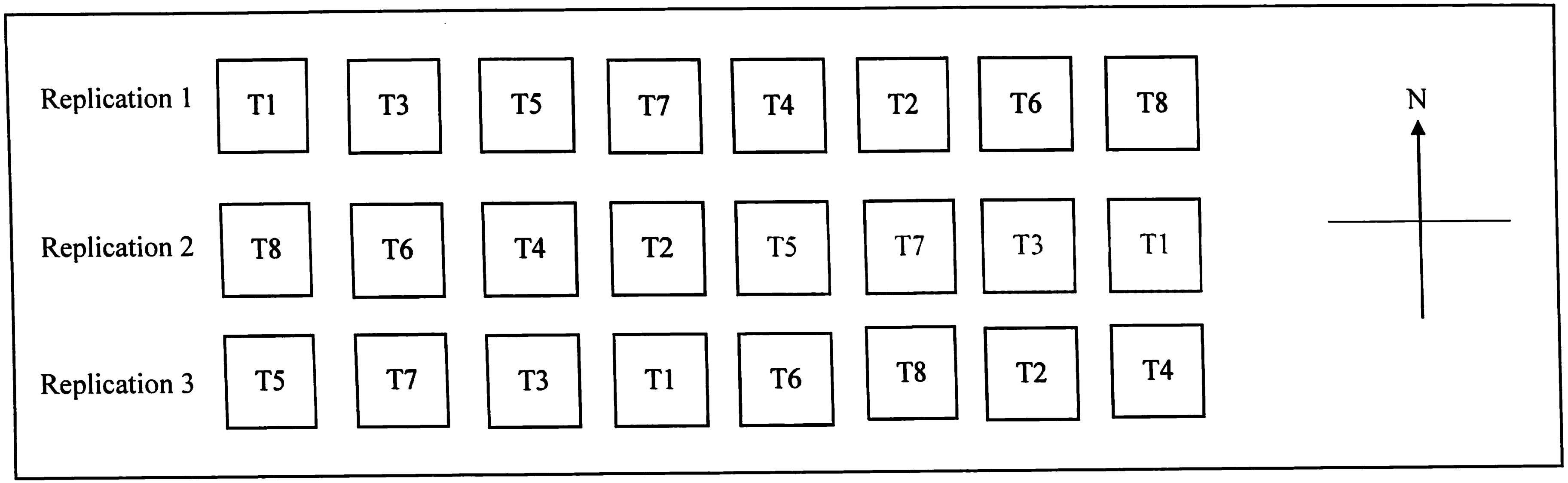

Figure 2. Layout of the experimental plot

Treatment details

- T_1 : Normal irrigation
- T_2 : Drought stress
- T_3 : T_2 + SA Foliar spray @ 1 mM
- T_4 : T_2 + SA Foliar spray @ 2 Mm
- T_5 : T_2 + As Foliar spray @ 1 Mm
- T_6 : T_2 + As Foliar spray @ 2 Mm
- T_7 : T_2 + Thiourea Foliar spray @ 500 ppm
- T_8 : T_2 + Thiourea Foliar spray @ 1000 ppm

- Design : RBD
- Plot size : 3 m x 3 m
- Spacing : 60cm x 30 cm
- SA – Salicylic acid
- As – Ascorbic acid
- Water stress- Stress induced from 25 DAS, irrigation given at 50% field capacity
- Foliar spray given at 10^{th}, 20^{th} and 30^{th} DAS

3.3. FIELD OPERATIONS

3.3.1. Land preparation, sowing and fertilizer application

The experimental field was cleared from weeds and soil samples were collected randomly from four to five spots at a depth of 0 -15 cm and 15 - 30 cm to determine the physico-chemical properties of the soil. Then the field was thoroughly ploughed using mould board plough and cross harrowing was done with tractor. The soil was brought to a fine tilth after removing stubbles and breaking clods and then the field was levelled. The experimental field was divided into 3 blocks and in each block, 8 raised beds of 3 m length, 3 m width and 45 cm height leaving 60 cm spacing between beds. Lime was applied in each bed and irrigated well. After one week, applied FYM @ 20 t ha^{-1} uniformly in all beds and thoroughly irrigated. Healthy seeds were soaked in water for 4 hours and kept in moist cloth overnight. Two seeds per hill were dibbled at a depth of 3 - 5 cm at a spacing of 60 cm between rows and 30 cm within the rows @ 7 kg ha^{-1}. The dibbling was followed by irrigation. Applied N, P_2O_5 and K_2O @ 110:35:70 kg ha^{-1} at the time of sowing as per Package of Practices Recommendations Crops (KAU, 2016). N was given in two spilt doses, another 55 kg N ha^{-1} was applied one month after sowing. Gap filling was done one week after seed sowing. Two weeks later thinning out to one seedling per hill was done. Foliar spray of chemicals namely, salicylic acid, ascorbic acid and thiourea was done at 10^{th}, 20^{th} and 30^{th} DAS.

3.3.2. Irrigation

3.3.2.1 Determination of field capacity and permanent wilting point

Field capacity and permanent wilting point of the soil samples were determined using pressure plate extractor set up. The apparatus consisted of an air tight metallic chamber in which a porous ceramic pressure plate was placed. The pressure plate and soil samples were saturated and were placed in the metallic chamber. The required pressure of 0.33 bar and 15 bar were applied through the compressor for determining the field capacity and permanent wilting point respectively. Required pressure was applied for a duration of 48 hours by keeping the compressor "on", so that the soil moisture content reaches in equilibrium against the applied pressure. After 48 hours, the soil samples were taken out of the apparatus and kept in an oven at 105 ^0C for 24 hours to determine the moisture content on weight basis. The moisture content on weight basis corresponding to field capacity and permanent wilting point were converted to moisture content on volume basis by multiplying with the bulk density. These moisture content values were used to find out the volume of water required to bring the soil of the experimental plot to field capacity.

3.3.2.2. Computation of irrigation requirement

Uniform daily irrigation was given to all the treatments for the first 25 days after sowing to bring the soil moisture content to field capacity. Irrigation was withheld 25 days after sowing in treatments T_2 to T_8 and re-irrigation was given at 50 per cent field capacity or when the plant showed temporary wilting symptoms.

3.3.2.3 Computation of irrigation interval and net depth of irrigation

The irrigation interval or frequency was calculated using the following relationship (FAO, 1977).

$$I = MAD / (ET_c - P_e - GW) + T_s$$

Where,

I - Irrigation interval (days)

MAD - Management allowed depletion (mm)

ET_c - Daily crop evapotranspiration (mm)

P_e - Mean daily effective precipitation (mm)

GW - Mean daily ground water contribution (mm)

T_s - Time (in days) required for soil to drain from saturation to field capacity after an irrigation, taken as 2 days in the case of red loam soil.

The Management allowed depletion (MAD) was obtained by:

$$MAD = P' \times AWC \times D$$

Where,

P' - Crop factor for soil moisture depletion

AWC - Available water holding capacity (mm/m depth of soil)

D - Effective rooting depth (m)

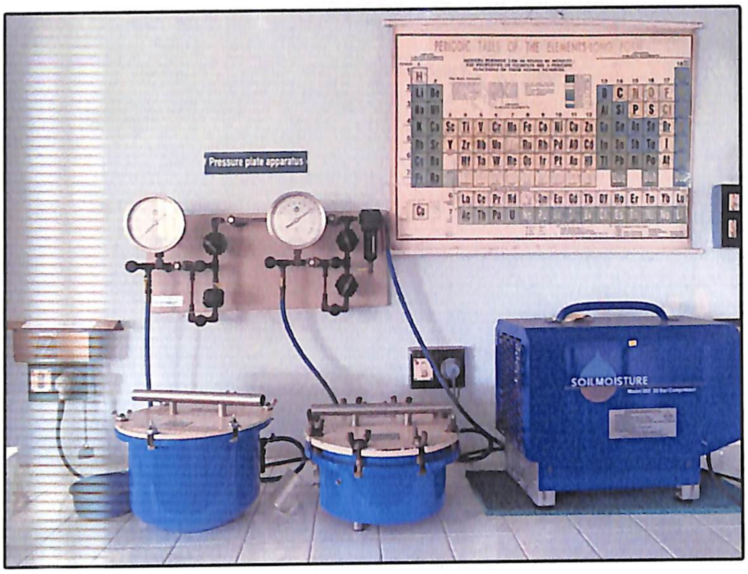

Plate 1. Pressure plate apparatus

Plate 2. Saturated pressure plate and soil samples

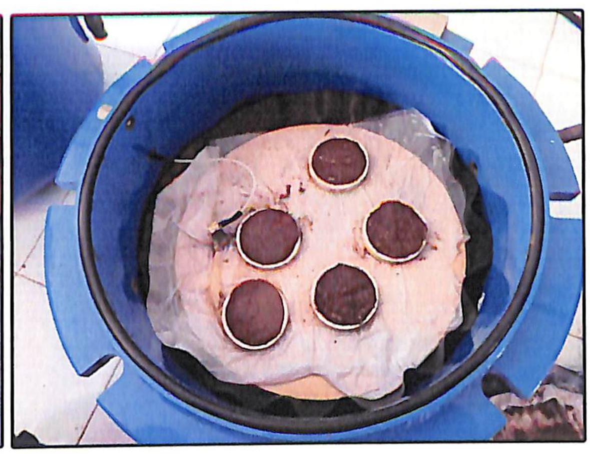

Plate 3. Saturated pressure plate and soil samples kept in metallic chamber

Plate 4. Soil samples taken out of apparatus after 48 hours

Plate 5. Ploughing

Plate 6. Layout

Plate 7. Bed preparation

Plate 8. Liming

Plate 9. FYM application

Plate 10. Irrigation

Plate 11. Seed sowing

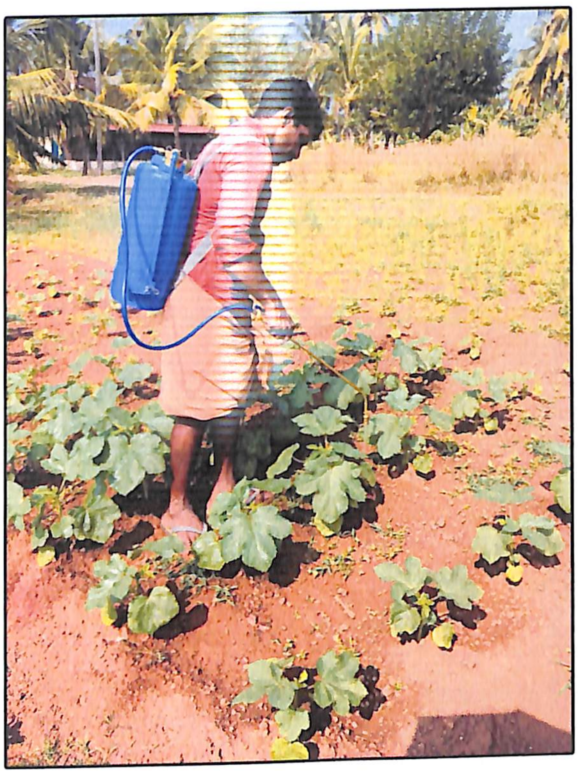

Plate 12. Foliar spray of chemicals

Plate 13. Harvesting of fruits

Plate 14. Taking observations

Available water holding capacity (AWC) = $\theta_{FC} - \theta_{PWP}$

Where, field capacity (FC) and permanent wilting point (PWP) were determined by using pressure plate apparatus.

Crop evapotranspiration was calculated by (FAO, 1977):

$$ET_c = K_c \times ET_0$$

Where,

ET_c - Crop evapotranspiration

K_c - Crop coefficient

ET_0 - Reference crop evapotranspiration

The net depth of irrigation required for a known irrigation interval and ET_c was computed based on the assumption that irrigation will be given to bring back the soil moisture content in effective root zone to field capacity every time, using the following equation (FAO, 1977).

$$d_n = I \times (ET_c - P_e - GW)$$

Where,

d_n - Net depth of irrigation (mm)

ETc - Average daily crop evapotranspiration over the period (mm)

P_e - Mean daily effective rainfall contribution (mm)

GW - Average daily ground water contribution (mm)

The ground water contribution for ET_c was assumed as NIL, since the groundwater table was considered to be below 3 m during the crop period (December to March).

Finally the volume of water to be applied in a treatment was calculated by multiplying the net depth of irrigation by the size of the plot.

3.3.2.4. Soil sample collection and determination of soil moisture content during drought period

Soil samples were collected from every treatment plot close to the rhizosphere zone of plants at a depth of 15 cm and 30 cm using soil auger. Sample from each plot was mixed separately and reduced the portion size by quartering technique. Soil samples were collected daily after the irrigation (when the soil moisture content reaches FC) and continued till the next irrigation (when the plant shows wilting symptoms). Soil samples were collected in moisture cans and wet weight of the samples were recorded. The soil samples were then dried in hot air oven at 105 ^{0}C for a duration of 24 hours and dry weight of the samples were recorded.

$$\text{Moisture content} = \frac{\text{Weight of wet sample} - \text{weight of dry sample}}{\text{Weight of dry sample}} \times 100$$

3.3.2.5. Indicator plant

A few sunflower plants (an indicator plant) were also grown in the field without any shading effect to the crop. Indicator plants shows wilting symptom (indication of drought stress) much before the crop.

3.3.3. After cultivation

First weeding and earthing up were carried out at 15 DAS. Second and third weeding was done at 30 and 60 DAS. Daily irrigation was given till 25 DAS in all the beds and later it was extended to once in two days in T_1 and in all other treatments irrigation was given at 50 per cent field capacity.

3.3.4. Plant protection

Timely plant protection measures were taken up as per Package of Practices Recommendations Crops (KAU 2016). The major pests noticed during the crop period were jassids, leaf roller and fruit and shoot borer. For controlling fruit and shoot borer, all drooping shoots and damaged fruits were removed regularly and quinalphos 2 ml 10 $L^{-1}$was sprayed. For controlling leaf roller, collected and burned all the leaf folding. Against jassids, sprayed thiomethoxam 2 g 10 L^{-1}on upper and lower surface of the leaf.

Plate 15. Two leaf stage

Plate 16. Three leaf stage

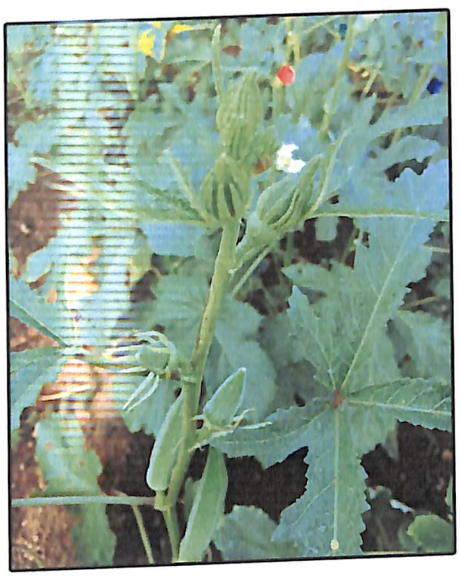

Plate 17. Bud stage

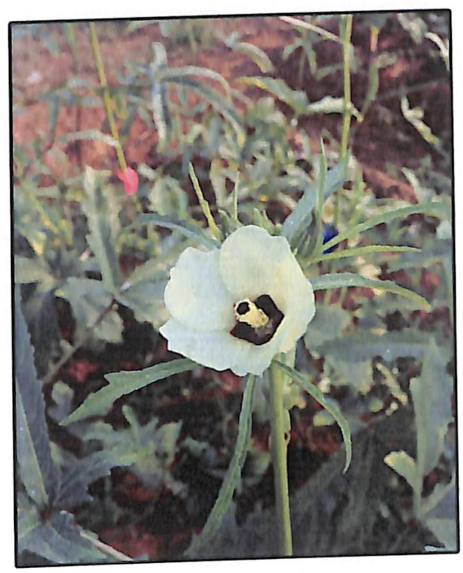

Plate 18. Flowering

Plate 19. Fruit set and fruit formation

Plate 20. General view of the field at 5 DAS

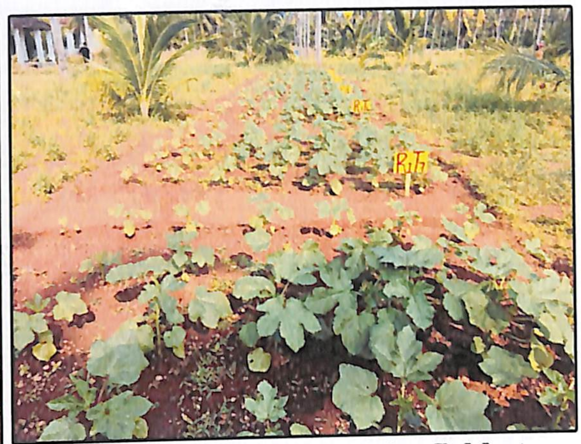

Plate 21. General view of the field at 20 DAS

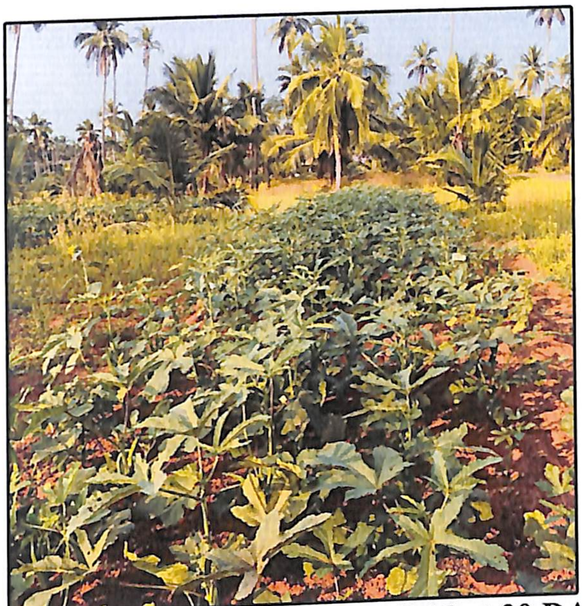

Plate 22. General view of the field at 30 DAS

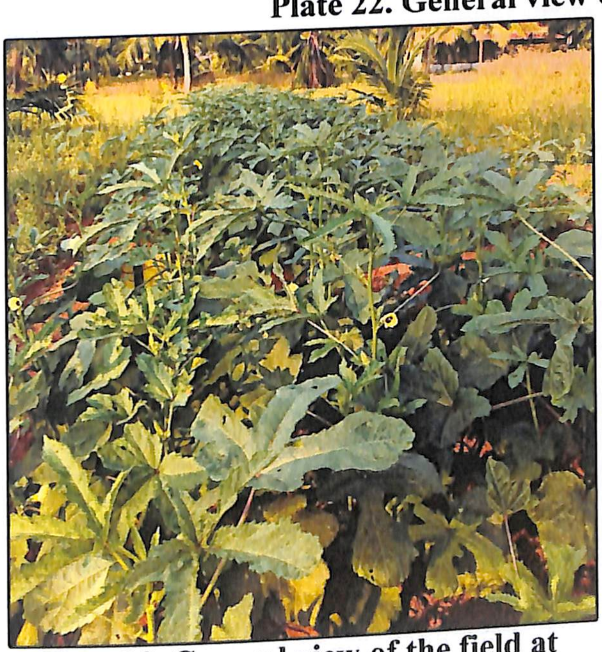

Plate 23. General view of the field at 40 DAS

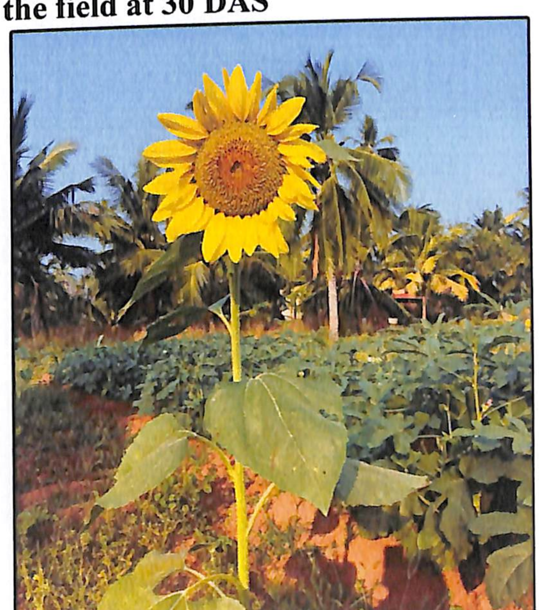

Plate 24. Indicator plant- Sunflower

3.3.5. Harvest

Fruits were plucked manually in the morning hours on every alternative days from 43 days after sowing when they are green, tender and of marketable size. The fruits become mature usually 7 days after flowering. Fruits were plucked separately from each treatments, weighed and subjected to other observations immediately after each harvest.

3.4. SAMPLE COLLECTION

Five uniformly sized healthy plants were randomly selected and permanently tagged in each treatments. Heterogeneous and border plants were avoided for tagging. The morphological, physiological, biochemical and yield and fruit quality observations were recorded on 25, 50 and 75 DAS from these tagged plants during the entire study period.

3.5. OBSERVATIONS

3.5.1. Morphological observations

Observations were taken at 25, 50 and 75 DAS.

3.5.1.1. Plant height

Plant height was measured from the base of the plant to the tip of the main shoot using a metre scale and average height of the tagged plant was worked out as mean plant height and expressed in cm.

3.5.1.2. Number of leaves per plant

Total number of fully opened leaves per plant of five tagged plants were counted and the mean number of leaves per plant was calculated.

3.5.1.3. Number of branches per plant

Total number of branches per plant was counted from the tagged plants and the mean was calculated.

3.5.1.4. Root volume

Root volume was measured by water displacement method. The measuring container with overflow spout was filled with water until it overflowed from the spout.

Then the fresh-washed roots of tagged plants which has been carefully dried with a soft cloth were immersed in the container and the overflow or rise in water level volume was measured in a graduated cylinder (Novoselov, 1960).

3.5.1.5. Days to 50 per cent flowering

The plant which produced first flower was tagged using a coloured ribbon and the tag was kept until 50 per cent of the plant population produced their first flower in a treatment. Then the number of days after sowing taken for 50 per cent of the crop population to flower in a treatment was noted.

3.5.1.6. Days to first harvest

Number of days taken for first harvest from the day of sowing was recorded.

3.5.1.7. Fruit length

The length from base to tip of five fruits from the selected plants of each treatment were measured in centimeters and their mean value was taken as fruit length.

3.5.1.8. Girth of fruit

After measuring the length, a thin wire is rolled around the broadest point of the same fruit and the length of the wire is measured, which gives the girth of the fruit in centimeters and the mean was computed.

3.5.1.9. Fruit weight

The same fruits after recording length and girth were weighed with the help of electronic balance and mean fresh weight was computed and expressed in grams.

3.5.1.10. Number of pickings

Number of times fruits harvested from each treatment during total crop period was recorded.

3.5.1.11. Duration of the crop

Number of days from sowing to final harvest is taken as the duration of the crop.

3.5.1.12. Pest and disease incidence

Incidence of pest and disease during the crop period were recorded treatment wise.

3.5.2. Physiological observations

Observations were taken at 25, 50 and 75 DAS.

3.5.2.1. Relative growth rate (RGR)

Expresses the dry weight increase in a time interval in relation to the initial weight. This can be determined by measuring plant dry weight periodically during growth (Blackman, 1919). The equation of RGR is,

$$RGR = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1} \quad (g\ g^{-1}\ day^{-1})$$

Where,

W_1 - Dry weight of plant at the time of T_1

W_2 - Dry weight of plant at the time of T_2

3.5.2.2. Specific leaf weight (SLW)

It is the ratio between leaf weight and leaf area. It signifies the thickness of leaf. SLW is considered a very important parameter showing positive correlation with photosynthesis and biomass production.

$$SLW = \frac{\text{Leaf weight}}{\text{Leaf area}} \quad (g\ cm^{-2})$$

3.5.2.3. Leaf area

Three plants from each treatment were uprooted for dry matter studies at 25, 50 and 75 DAS. The leaves of these plants were separated, washed, dried with a soft cloth and measured for its leaf area with an automatic leaf area meter (portable leaf area meter Model – LI – 3000A, LI - COR) and was expressed in cm^2.

3.5.2.4. Relative Leaf water content (RLWC)

Physiologically functional leaf samples were collected from tagged plants of different treatments separately and made them into uniform leaf bits. Fresh weight was recorded and then turgid weight was determined after floating leaf disc in water for 2 hours at room temperature and then dried at constant temperature of 80 ^{0}C for 18 hours to record the dry weight. Relative water content was calculated using the following formulae, (Barrs and Weatherley, 1962).

$$\text{Relative water content (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.5.2.5. Total dry matter production

Randomly selected 3 plants were uprooted from each treatment and their fresh weight was recorded. The uprooted plants were separated into different parts and first shade dried and then oven dried at 60 ^{0}C till constant weight was obtained. Similarly, the fresh and dry weight of fruit samples at each harvest of observational plant were also recorded. The mean total dry matter production of plant was calculated and expressed in g plant^{-1}.

3.5.2.6. Root shoot ratio

The root shoot ratio was analysed using the following formula:

$$\text{Root Shoot ratio} = \frac{\text{Dry weight of root}}{\text{Dry weight of shoot}}$$

3.5.2.7. SPAD chlorophyll meter readings (SCMR)

Direct measurement of chlorophyll was taken during morning hours using SPAD Chlorophyll Meter (model- Chlorophyll Meter SPAD - 502 Konica Minolta, Japan).

3.5.2.8. F_v/F_m, Y (II) and ETR

Chlorophyll fluorescence ratio or maximum quantum yield of PS II (F_v / F_m), light adapted quantum yield Y (II) and Electron Transport Rate (ETR) directly measured by using plant stress kit (ADC biosynthetic Ltd, Global house, Gedding Road) London.

Chlorophyll fluorescence parameter F_v/F_m, which is the ratio of variable to maximum fluorescence after dark-adaptation, represents maximum quantum yield of PS II. The parameter is being used for detecting stress in plants. Quantum yield Y (II), indicates the amount of energy used in photochemistry by photosystem II under steady-state photosynthetic lighting conditions. ETR, or electron transport rate, is also a light-adapted parameter that is directly related to Y (II).

3.5.3. Biochemical observations

Observation were taken at 25, 50 and 75 DAS.

3.5.3.1. Chlorophyll content

Chlorophyll pigments were extracted from leaf bits by using acetone (80%): DMSO (Dimethyl sulfoxide) (1:1 v /v) mixture. The leaf bits were incubated in acetone: DMSO solution in the dark, overnight. The coloured solution was decanted into measuring cylinder and made up to 10 mL. The absorbance was recorded at 663, 645, 510 and 480 nm using UV-visible spectrophotometer. The calculation was done by using the following formulae and expressed in mg g^{-1} of fresh leaf (Yoshida *et al.*, 1971).

Chlorophyll 'a' = [(12.7 x A 663) – (2.69 x A 645)] x V/1000 x W

Chlorophyll 'b'= [(22.9 x A 645) – (4.68 x A 663)] x V/1000 x W

Total chlorophyll = [(20.2 x A 645) + (8.02 x A 663)] x V/1000 x W

Where,

A = Absorption at given wavelength

V = Total volume of sample in extraction medium

W = Weight of sample

3.5.4. Yield and fruit quality observations

Observations were taken at 25, 50 and 75 DAS.

3.5.4.1. Average number of fruits per plant

The total number of fruits harvested in all the plucking from five tagged plants were counted and the average was calculated.

3.5.4.2. Average yield per plant per plot per hectare

Total weight (kg) of the fruits harvested from the five selected plants of each treatment at every harvest was recorded separately and mean were calculated. The fruit yield per plant was computed by addition of mean value thus obtained from each harvest. Also calculated average yield per plot (kg) and per hectare (tonnes)

3.5.4.3. Shelf life

From each plot five fruits were harvested randomly and kept in ambient conditions for checking the shelf life (days) of fruits. When the fruits started shriveling, observations were taken.

3.5.4.4. Crude fibre content of fruit

Two gram of ground, dried representative fruit sample was boiled with 200 mL H_2SO_4 for 30 min, washed and filtered through muslin cloth. It was then boiled with 200 mL NaOH for another 30 minutes, washed and filtered. The sample was dried out, weighed and ignited in muffle furnace at 600 ^{0}C. Loss in weight was considered as crude fibre content and expressed in per cent (A.O.A.C, 1975).

$$\text{Crude fibre (\%)} = \frac{W_2 - W_3 \times 100}{W_1}$$

Where,

W_1 = Initial weight of sample

W_2 = Weight of refluxed sample

W_3 = Weight of ignited sample

3.5.4.5. Ascorbic acid content of fruits

Ascorbic acid content of okra was determined by titrimetric method using 2, 6-dichlorophenol dye and expressed as mg 100 g $^{-1}$ on fresh weight basis (Sadasivam and Manickam, 1992). The ascorbic acid from okra fruits was extracted by homogenizing the fruit in 4 per cent oxalic acid and then volume was made up to 100 mL with oxalic acid and centrifuged. From that 10 mL supernatant was pipetted into a conical flask and 10 mL of 4 per cent oxalic acid was added to it and titrated against dichlorophenol dye. Appearance of pink colour, which persisted for few minutes, was considered as end point. The vitamin C content was calculated using the formula given below.

$$\text{Ascorbic acid} = \frac{\text{Titre value x 0.5 x 100 x 100}}{\text{Working standard titre value x 5 x Weight of the sample}}$$

3.5.5. Economics

3.5.5.1. Net returns

Economics of cultivation was worked out for the experiment by taking into account the cost of cultivation and prevailing market price of okra. Net returns was calculated as follows:

$$\text{Net income} = \text{Gross income - Total expenditure}$$

3.5.5.2 Benefit-cost ratio (BCR)

Benefit-cost ratio is the ratio of gross returns and cost of cultivation. It was calculated using the following formula.

$$\text{Benefit : Cost} = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.6. DATA ANALYSIS

The data obtained from the experiment were subjected to statistical analysis using Analysis of Variance technique (ANOVA) Randomized Block Design and the significance was tested using F test (Snedecor and Cochran, 1967). When F values were significant, critical differences were worked out at 5 per cent level. It was then used for comparison and interpretation of results. Statistical analysis was done using the statistical package WASP 2 and OPSTAT.

Results

4. RESULTS

The research work entitled "Drought mitigation in okra (*Abelmoschus esculentus* L.) through chemical approach" was done at Regional Agricultural Research Station, Pilicode. The objective of the study was to investigate the influence of different chemicals namely, salicylic acid, ascorbic acid and thiourea on mitigation of drought and to evaluate their effect on morphological, physiological and yield characteristics of okra. The observations recorded were subjected to statistical analysis and the results obtained are presented in this chapter.

Before starting the experiment, the soil of the experimental plot was analysed for its nutritional status and the data are presented in Table 3.

Table 3. Soil test details before the experiment

Sl. No.	Particulars	Content	Remarks
I	**Physical properties**		
1.	Bulk density (g cm^{-3})		
	Wet bulk density (15 cm depth)	1.453	
	Dry bulk density (15 cm depth)	1.365	
	Wet bulk density (30 cm depth)	1.830	
	Dry bulk density (30 cm depth)	1.735	
II	**Mechanical composition**		
	Sand (%)	52.76	
	Silt (%)	39.07	
	Clay (%)	8.17	
	Textural class	Red loam	
III	**Chemical properties**		
1	pH	4.12	Extremely Acidic
2	EC (dS m^{-1})	0.09	Normal
3	Organic carbon (%)	1.54	High
4	Available N (kg ha^{-1})	219.52	Low
5	Available P (kg ha^{-1})	18.06	Medium
6	Available K (kg ha^{-1})	75.6	Low
7	Available Ca (mg kg^{-1})	440	Sufficient
8	Available Mg (mg kg^{-1})	132	Sufficient
9	Available S (mg kg^{-1})	32.543	Sufficient

Soil was acidic in nature and the elements nitrogen and potassium were deficient in the experimental field. Lime was applied @ 250 kg acre^{-1} before sowing the seeds to overcome extremely acidic nature of the experimental plot. Sufficient nitrogen and potassium fertilizers were applied in the experimental plot.

4.1. MORPHOLOGICAL OBSERVATIONS

4.1.1. Plant height

The data on the effect of drought mitigating chemicals on mean plant height of okra at 25, 50 and 75 DAS are presented in Table 4.

Table 4. Effect of drought mitigating chemicals on mean plant height (cm) at various crop stages of okra

Treatments	Mean plant height (cm)		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	24.4^{abc}	81.0^{b}	152.8^{ab}
T_2 : Drought stress	23.9^{bc}	70.4^{e}	141.3^{d}
T_3 : T_2 + SA foliar spray @ 1 mM	25.8^{a}	85.5^{a}	153.5^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	23.3^{c}	70.6^{de}	144.4^{cd}
T_5 : T_2 + As foliar spray @ 1 mM	24.7^{abc}	76.6^{c}	146.3^{c}
T_6 : T_2 + As foliar spray @ 2 Mm	25.2^{ab}	79.1^{bc}	148.5^{bc}
T_7 : T_2 + TU foliar spray @ 500 ppm	23.3^{c}	77.7^{bc}	147.9^{c}
T_8 : T_2 + TU foliar spray @ 1000 ppm	23.3^{c}	74.9^{cd}	145^{cd}
SEM (±)	0.51	1.42	1.47
CD (0.05)	1.59	4.34	4.52

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

The plant height showed significant difference among treatments at all stages of crop, *i.e.*, 25, 50 and 75 DAS. At 25 DAS, maximum plant height was observed in the treatment T_3 (25.8 cm) which was on par with treatments T_6 (25.2 cm), T_5 (24.7 cm) and T_1 (24.4 cm).

At 50 DAS, maximum plant height (85.5 cm) was observed in the treatment T_3 *i.e.*, drought stress with SA foliar spray @ 1 mM, followed by T_1 (81 cm). T_1 was on par with T_6 (79.1 cm) and T_7 (77.7 cm). The lowest plant height was recorded for drought stressed plants T_2 (70.4 cm).

At 75 DAS, maximum plant height was observed in the treatment T_3 (153.5 cm) which was on par with control plants T_1 (152.8 cm) and the lowest plant height was recorded for drought stressed plants T_2 (141.3 cm). The highest and the lowest plant height were recorded in treatment T_3 and T_2, respectively, at all the crop growth stages.

4.1.2. Number of leaves per plant

The data on mean number of leaves per plant at 25, 50 and 75 DAS are presented in Table 5.

Table 5. Effect of drought mitigating chemicals on mean number of leaves per plant at various crop stages of okra

Treatments	Mean number of leaves per plant		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	10.46^{bcd}	25.85^{abc}	21.4^{bc}
T_2 : Drought stress	10.54^{bcd}	21.35^{d}	19.48^{c}
T_3 : T_2 + SA foliar spray @ 1 mM	11.99^{a}	28.16^{a}	24.6^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	11.39^{ab}	24.73^{abcd}	20.72^{bc}
T_5 : T_2 + As foliar spray @ 1 mM	11.1^{abc}	23.06^{cd}	20.35^{c}
T_6 : T_2 + As foliar spray @ 2 mM	11.55^{a}	26.93^{ab}	23.21^{ab}
T_7 : T_2 + TU foliar spray @ 500 ppm	10.2^{cd}	23.91^{bcd}	20.45^{c}
T_8 : T_2 + TU foliar spray @ 1000 ppm	10.0^{d}	22.32^{cd}	19.86^{c}
SEM (±)	0.31	1.26	0.84
CD (0.05)	0.96	3.88	2.57

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

At 25 DAS, SA foliar spray @ 1mM *i.e.*, T_3 (11.99) recorded maximum number of leaves per plant which was on par with T_6 (11.55), T_4 (11.39) and T_5 (11.1). The minimum number of leaves per plant was obtained in the T_8 (10.0).

At 50 DAS, the maximum number of leaves per plant was observed in the treatment T_3 (28.16) which was on par with treatments T_6 (11.55), T_1 (25.85) and T_4 (24.73) followed by T_7 (23.91). The lowest mean number of leaves per plant was observed in the treatment T_2 (21.35) *i.e.*, in drought stressed plants.

At 75 DAS, the maximum number of leaves (24.6) was observed in the treatment SA foliar spray @ 1mM under drought stress (T_3) which was on par with that of T_6 (23.21). The minimum number of leaves per plant (19.48) was obtained in drought stressed treatment (T_2) which was on par with that of T_8 (19.86), T_5 (20.35) and T_7 (20.45).

4.1.3. Number of branches per plant

The data on mean number of branches per plant for each treatment was recorded at 25, 50 and 75 DAS and are presented in Table 6.

The foliar spray of drought mitigating chemicals significantly influences the number of branches per plant at all crop growth stages when compared with drought stressed plants (T_2). The number of branches per plant increased from 25 DAS to 75 DAS.

At 25 DAS, the maximum number of branches (1.27) per plant was recorded with treatment T_3 (SA foliar spray @ 1mM), which was on par with T_5 (1.26), T_2 (1.25) and T_1 (1.24).

At 50 DAS, the maximum number of branches per plant was observed in treatment T_1 (2.34) which was on par with T_3 (2.33) and T_6 (2.30). The lowest number of branches per plant was observed in treatments T_2 (2.20) and T_8 (2.20).

AT 75 DAS, T_1 (3.14) and T_3 (3.13) recorded the maximum value for number of branches per plant followed by T_6 (3.00), T_4 (2.96), T_5 (2.89) and T_7 (2.87). T_2 (2.66) recorded the lowest number of branches per plant.

Table 6. Effect of drought mitigating chemicals on mean number of branches per plant at various crop stages of okra

Treatments	Mean number of branches per plant		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	1.24[a]	2.34[a]	3.14[a]
T_2 : Drought stress	1.25[a]	2.20[d]	2.66[c]
T_3 : T_2 + SA foliar spray @ 1 mM	1.27[a]	2.33[ab]	3.13[a]
T_4 : T_2 + SA foliar spray @ 2 mM	1.17[b]	2.24[bcd]	2.96[ab]
T_5 : T_2 + As foliar spray @ 1 mM	1.26[a]	2.22[cd]	2.89[abc]
T_6 : T_2 + As foliar spray @ 2 mM	1.16[b]	2.30[abc]	3.00[ab]
T_7 : T_2 + TU foliar spray @ 500 ppm	1.15[b]	2.21[cd]	2.87[abc]
T_8 : T_2 + TU foliar spray @ 1000 ppm	1.12[b]	2.20[d]	2.79[bc]
SEM (±)	0.01	0.02	0.09
CD (0.05)	0.05	0.08	0.28

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

4.1.4. Root volume

The data on mean root volume was recorded at 25, 50 and 75 DAS and are presented in Table 7.

At 25 DAS, the maximum root volume was observed in the SA foliar spray @ 1 mM treatment *i.e.*, T_3 (9.00 cm^3) and minimum root volume was recorded in T_5 (7.99 cm^3) and T_8 (7.95 cm^3).

At 50 DAS, the control plants (T_1) showed the higher root volume (21.66 cm^3) which was on par with T_3 (20.66 cm^3), T_6 (20.33 cm^3), T_7 (19.66 cm^3) and T_8 (18.66 cm^3). The lowest root volume (15.66 cm^3) was observed in drought stressed treatment (T_2).

Table 7. Effect of drought mitigating chemicals on mean root volume (cm^3) at various crop stages of okra

Treatments	Mean root Volume (cm^3)		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	8.98^a	21.66^a	26.08^a
T_2 : Drought stress	8.94^a	15.66^c	22.81^b
T_3 : T_2 + SA foliar spray @ 1 mM	9.00^a	20.66^{ab}	26.36^a
T_4 : T_2 + SA foliar spray @ 2 mM	8.47^{ab}	17.66^{bc}	22.12^b
T_5 : T_2 + As foliar spray @ 1 mM	7.99^b	18.33^{bc}	23.58^{ab}
T_6 : T_2 + As foliar spray @ 2 mM	8.67^a	20.33^{ab}	24.68^{ab}
T_7 : T_2 + TU foliar spray @ 500 ppm	8.68^a	19.66^{ab}	22.52^b
T_8 : T_2 + TU foliar spray @ 1000 ppm	7.95^b	18.66^{abc}	22.65^b
SEM (±)	0.20	1.07	0.99
CD (0.05)	0.61	3.30	3.03

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

At 75 DAS, maximum root volume was observed in treatment T_3 (26.36 cm^3) and T_1 (26.08 cm^3) which were on par with T_6 (24.68 cm^3) and T_5 (23.58 cm^3). The lowest root volume was observed in the treatment T_4 (22.12 cm^3).

4.1.5. Days to 50 per cent flowering and days to first harvest

The data on number of days taken for 50 per cent flowering and days to first harvest are presented in Table 8.

The days taken to 50 per cent flowering and days to first harvest showed no significant difference among the treatments. Although not significant, T_2 (37.9) took more days to complete 50 per cent flowering and treatment T_4 (36.2) took minimum days to complete 50 per cent flowering. The highest number of days to first harvest was recorded with treatment T_2 (42.1) and the least number of days to first harvest was recorded with treatment T_8 (37.8).

Table 8. Effect of drought mitigating chemicals on days to 50 per cent flowering and days to first harvest of okra

Treatments	Days to 50 per cent flowering	Days to first harvest
T_1 : Control (Normal irrigation)	35.7	41.7
T_2 : Drought stress	37.9	42.1
T_3 : T_2 + SA foliar spray @ 1 mM	37.0	41.2
T_4 : T_2 + SA foliar spray @ 2 mM	36.2	41.2
T_5 : T_2 + As foliar spray @ 1 mM	37.2	40.7
T_6 : T_2 + As foliar spray @ 2 mM	36.9	40.2
T_7 : T_2 + TU foliar spray @ 500 ppm	37.3	40.1
T_8 : T_2 + TU foliar spray @ 1000 ppm	37.6	37.8
SEM (±)	0.69	1.40
CD (0.05)	NS	NS

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

4.1.6. Fruit length

The data on fruit length was recorded and are presented in Table 9.

The maximum fruit length was recorded with the treatment T_4 (20.33 cm) which was statistically on par with treatments T_6 (19.61 cm) followed by T_7 (19.26 cm). The minimum fruit length was recorded with the treatment T_8 (16.46 cm) followed by T_2 (217.93 cm).

4.1.7. Fruit girth

The data on fruit girth was recorded and is presented in Table 9.

The highest fruit girth (7.86 cm) was exhibited by T_3 and the lowest by T_2 (5.43 cm).

4.1.8. Fruit weight

The data on fruit weight was recorded and are presented in Table 9.

A critical examination of the data in Table 9. revealed that the application of different drought mitigating chemicals significantly influenced the fresh weight of fruits. The highest fresh weight was recorded with the treatment T_3 (25.24 g) and the lowest was recorded with the treatment T_2 (19.35 g).

Table 9. Effect of drought mitigating chemicals on fruit length (cm), fruit girth (cm) and fruit weight (g) of okra

Treatments	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)
T_1 : Control (Normal irrigation)	18.73^{bcd}	6.66^{c}	23.46^{c}
T_2 : Drought stress	17.93^{d}	5.43^{h}	19.35^{g}
T_3 : T_2 + SA foliar spray @ 1 mM	18.54^{cd}	7.86^{a}	25.24^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	20.33^{a}	6.36^{d}	22.67^{d}
T_5 : T_2 + As foliar spray @ 1 mM	18.46^{cd}	5.96^{f}	22.39^{d}
T_6 : T_2 + As foliar spray @ 2 mM	19.61^{ab}	7.23^{b}	24.36^{b}
T_7 : T_2 + TU foliar spray @ 500 ppm	19.26^{bc}	6.20^{e}	21.57^{e}
T_8 : T_2 + TU foliar spray @ 1000 ppm	16.46^{e}	5.81^{g}	20.76^{f}
SEM (±)	0.31	0.01	0.01
CD (0.05)	0.96	0.03	0.58

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

4.1.9. Number of pickings

The data on total number of fruit pickings were recorded and are presented in Table 10.

The maximum number of pickings were recorded in treatment T_3 (17.66) and the minimum in T_2 (10.33). T_3 was on par with treatments T_1 (16.33), T_6 (16.00), T_5 (15.66) and T_4 (15.00).

4.1.10. Duration of the crop (days)

The data on the effect of drought mitigating chemicals on duration of the crop are presented in Table 10.

Plate 25. Okra fruit length under different treatments (7 days)

The duration of the crop was highest in treatment T_3 (107.66) which was on par with T_1 (106.66), T_6 (105.00), T_5 (103.66) and T_4 (103.00). The minimum duration of the crop was recorded in treatments T_2 (98.33) and T_7 (98.66).

Table 10. Effect of drought mitigating chemicals on number of pickings and duration of the crop of okra

Treatments	No. of pickings	Duration of the crop
T_1 : Control (Normal irrigation)	16.33^{ab}	106.66^{a}
T_2 : Drought stress	10.33^{d}	98.33^{c}
T_3 : T_2 + SA Foliar Spray @ 1mM	17.66^{a}	107.66^{a}
T_4 : T_2 + SA Foliar Spray @ 2mM	15.00^{abc}	103.00^{abc}
T_5 : T_2 + As Foliar Spray @ 1mM	15.66^{abc}	103.66^{abc}
T_6 : T_2 + As Foliar Spray @ 2mM	16.00^{ab}	105.00^{ab}
T_7 : T_2 + TU Foliar Spray @ 500 ppm	13.00^{cd}	98.66^{c}
T_8 : T_2 + TU Foliar Spray @ 1000 ppm	14.33^{bc}	100.33^{bc}
SEM (±)	0.96	1.90
CD (0.05)	2.94	5.82

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

4.1.11. Pest and disease incidence

The major pest observed in the field during the crop period were leaf folder (*Sylepta derrogata*), fruit borer (*Helicoverpa armigera*) and jassids (*Amrasca biguttula biguttula*). Both leaf folder and shoot borers attack were noticed during vegetative and reproductive stages of the crop, whereas jassid attack was noticed at the end of the crop period. The attacks were not severe and control measures were taken effectively.

4.2. PHYSIOLOGICAL OBSERVATIONS

4.2.1. Relative growth rate (RGR)

The data on effect of drought mitigating chemicals on relative growth rate (RGR) of okra at 25, 50 and 75 DAS were recorded and are presented in Table 11.

Table 11. Effect of drought mitigating chemicals on relative growth rate (RGR) (mg g^{-1} d^{-1}) at various crop stages of okra

Treatments	Relative growth rate (mg g^{-1} d^{-1})		
	1-25 DAS	26-50 DAS	51-75 DAS
T_1 : Control (Normal irrigation)	0.059^{ab}	0.035^{abc}	0.024^{b}
T_2 : Drought stress	0.058^{abc}	0.029^{c}	0.021^{b}
T_3 : T_2 + SA foliar spray @ 1 mM	0.065^{a}	0.040^{a}	0.025^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	0.052^{c}	0.031^{bc}	0.021^{b}
T_5 : T_2 + As foliar spray @ 1 mM	0.062^{ab}	0.032^{bc}	0.023^{b}
T_6 : T_2 + As foliar spray @ 2 mM	0.063^{ab}	0.036^{ab}	0.024^{b}
T_7 : T_2 + TU foliar spray @ 500 ppm	0.057^{bc}	0.031^{bc}	0.024^{b}
T_8 : T_2 + TU foliar spray @ 1000 ppm	0.058^{abc}	0.032^{bc}	0.022^{b}
Sem (±)	0.002	0.002	0.000
CD (0.05)	0.007	0.006	0.001

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

Up to 25 DAS, the maximum relative growth rate was recorded in T_3 (0.065 (mg g^{-1} d^{-1}), which was on par with T_6 (0.063 mg g^{-1} d^{-1}), T_5 (0.062 mg g^{-1} d^{-1}), T_1 (0.059 mg g^{-1} d^{-1}), T_2 (0.058 mg g^{-1} d^{-1}) and T_8 (0.058 mg g^{-1} d^{-1}). The lowest value was recorded in T_4 (0.052 mg g^{-1} d^{-1}).

During 26 to 50 DAS, the maximum relative growth rate was recorded in treatment T_3 (0.040 mg g^{-1} d^{-1}), which was on par with T_6 (0.036 mg g^{-1} d^{-1}) and T_1 (0.035 mg g^{-1} d^{-1}) and the lowest value (0.029 mg g^{-1} d^{-1}) was recorded in drought stressed treatment (T_2).

During 51 to 75 DAS, the maximum relative growth rate was recorded in T_3 (0.025 mg g^{-1} d^{-1}). Similar values of relative growth rate were recorded in treatments T_6, T_7 (0.024 mg g^{-1} d^{-1}) and T_2, T_4 (0.021 mg g^{-1} d^{-1}). All the treatments except T_3 were statistically on par.

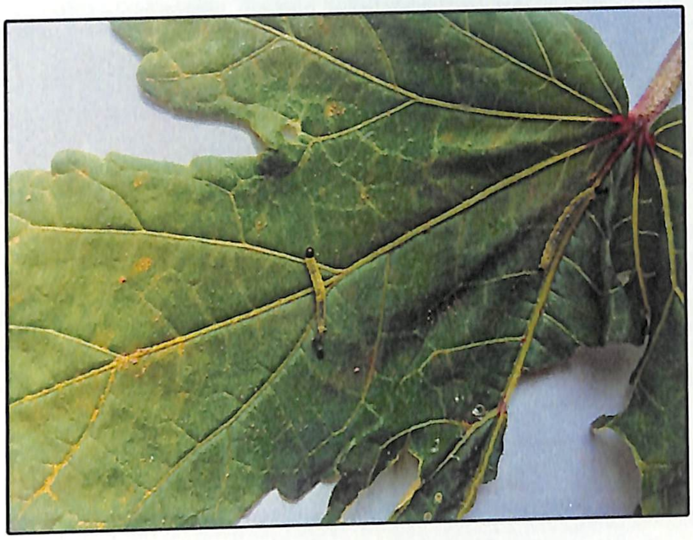

Plate 26. Leaf folder

Plate 27. Fruit and shoot borer

Plate 28. Hoppers

4.2.2. Specific Leaf weight (g cm^{-2})

The data on effect of drought mitigating chemicals on specific leaf weight (SLW) of okra at 25, 50 and 75 DAS were recorded and are presented in Table 12.

Table 12. Effect of drought mitigating chemicals on specific leaf weight (SLW) (g cm^{-2}) at various crop stages of okra

Treatments	Specific Leaf weight (g cm^{-2})		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	0.003^{bcd}	0.004^{bc}	0.005^{ab}
T_2 : Drought stress	0.003^{cde}	0.002^{e}	0.003^{d}
T_3 : T_2 + SA foliar spray @ 1 mM	0.004^{a}	0.006^{a}	0.005^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	0.004^{ab}	0.004^{bc}	0.005^{abc}
T_5 : T_2 + As foliar spray @ 1 mM	0.002^{ef}	0.003^{de}	0.004^{cd}
T_6 : T_2 + As foliar spray @ 2 mM	0.004^{abc}	0.005^{b}	0.005^{a}
T_7 : T_2 + TU foliar spray @ 500 ppm	0.002^{def}	0.004^{cd}	0.004^{bcd}
T_8 : T_2 + TU foliar spray @ 1000 ppm	0.001^{f}	0.003^{de}	0.004^{d}
SEM (±)	0.0003	0.001	0.001
CD (0.05)	0.001	0.003	0.003

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

At 25, 50 and 75 DAS, maximum specific leaf weight was recorded in T_3. At 25 DAS, T_3 (0.004 g cm^{-2}) was on par with T_4 and T_6. The lowest value for specific leaf weight was in treatment T_8 (0.001 g cm^{-2}).

At 50 and 75 DAS, lowest value for specific leaf weight was recorded in the treatment T_2. At 75 DAS, similar specific leaf weight were recorded in treatments T_3 and T_6 (0.005 g cm^{-2}), which were on par with T_1.

4.2.3. Leaf area

The effect of various treatments on mean leaf area of okra are presented in Table 13.

Table 13. Effect of drought mitigating chemicals on mean leaf area (cm^2) at various stages of okra

Treatments	Mean leaf area (cm^2)		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	679.42^{bcd}	1679.12^{abc}	1371.33^{bc}
T_2 : Drought stress	684.84^{bcd}	1386.86^{d}	1265.57^{c}
T_3 : T_2 + SA foliar spray @ 1 mM	779.25^{a}	1829.60^{a}	1598.14^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	740.28^{ab}	1606.59^{abcd}	1346.11^{c}
T_5 : T_2 + As foliar spray @ 1 mM	721.01^{abc}	1498.33^{cd}	1322.29^{c}
T_6 : T_2 + As foliar spray @ 2 mM	750.44^{a}	1749.49^{ab}	1508.07^{ab}
T_7 : T_2 + TU foliar spray @ 500 ppm	662.54^{cd}	1553.10^{bcd}	1328.57^{c}
T_8 : T_2 + TU foliar spray @ 1000 ppm	649.97^{d}	1450.04^{cd}	1290.25^{c}
SEM (±)	20.51	82.32	53.21
CD (0.05)	62.83	252.16	162.94

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

Leaf area was significantly influenced by treatments at all crop growth stages of okra. At 25, 50 and 75 DAS, highest leaf area was recorded in T_3 compared to all other treatments.

At 25 DAS, T_3 (779.25 cm^2) was on par with T_6 (750.44 cm^2), T_4 (740.28 cm^2) and T_5 (721.01 cm^2) and the lowest leaf area was recorded for T_8 (649.97 cm^2). At 50 DAS, T_3 (1829.60) was on par with T_6 (1749.49 cm^2), T_1 (1679.12 cm^2) and T_4 (1606.59 cm^2) and the lowest leaf area was recorded for T_2 (1386.86 cm^2). At 75 DAS, T_3 (1598.14 cm^2) was on par with T_6 (1508.07 cm^2).

4.2.4. Relative Leaf water content (RLWC)

The effect of treatments on relative leaf water content of okra was recorded at 25, 50 and 75 DAS and are presented in Table 14.

Table 14. Effect of drought mitigating chemicals on relative leaf water content (%) at various crop stages of okra

Treatments	Relative Leaf Water Content (RLWC) (%)		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	91.70^{ab}	86.60^{a}	83.47^{a}
T_2 : Drought stress	90.61^{abc}	78.15^{c}	68.10^{d}
T_3 : T_2 + SA foliar spray @ 1 mM	92.52^{a}	84.90^{ab}	77.24^{b}
T_4 : T_2 + SA foliar spray @ 2 mM	89.47^{cde}	83.92^{ab}	72.13^{cd}
T_5 : T_2 + As foliar spray @ 1 mM	88.34^{de}	82.77^{ab}	69.32^{d}
T_6 : T_2 + As foliar spray @ 2 mM	90.26^{bcd}	84.57^{ab}	74.00^{bc}
T_7 : T_2 + TU foliar spray @ 500 ppm	88.93^{cde}	83.52^{ab}	69.88^{d}
T_8 : T_2 + TU foliar spray @ 1000 ppm	87.65^{e}	82.51^{b}	68.64^{d}
SEM (±)	0.70	1.327	1.331
CD (0.05)	2.151	4.065	4.076

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

A critical examination of the data on relative leaf water content in Table 14. reveals that the application of drought mitigating chemicals significantly influenced the relative leaf water content of okra.

At 25 DAS, the highest relative leaf water content was recorded in treatment T_3 (92.52%), which was on par with T_1 (91.70%) and T_2 (90.61%) and the lowest in treatment T_8 (87.65%).

At 50 DAS, the maximum value for relative leaf water content was recorded in treatment T_1 (86.60%), which was on par with T_3 (84.90%), T_6 (84.57%), T_4 (83.92%), T_7 (83.52%) and T_5 (82.77%). Minimum relative leaf water content was recorded in treatment T_2 (78.15%).

At 75 DAS, relative leaf water content was recorded the highest in T_1 (83.47) and the lowest in T_2 (68.10). Treatments T_3 (77.24%), T_6 (74.00%) and T_4 (72.13%) maintained higher RLWC among all drought mitigating treatments.

4.2.5. Total dry matter production

The data on total dry matter production by the plant was recorded at 25, 50 and 75 are presented in Table 15.

Table 15. Effect of drought mitigating chemicals on total dry matter production of okra

Treatments	Total dry matter production (g)		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	31.43	55.56^{a}	106.70^{ab}
T_2 : Drought stress	31.57	46.80^{e}	88.60^{e}
T_3 : T_2 + SA foliar spray @ 1 mM	32.49	57.05^{a}	110.84^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	30.48	53.00^{bc}	99.45^{bcd}
T_5 : T_2 + As foliar spray @ 1 mM	28.89	51.27^{cd}	98.01^{cd}
T_6 : T_2 + As foliar spray @ 2 mM	31.66	54.60^{ab}	105.03^{abc}
T_7 : T_2 + TU foliar spray @ 500 ppm	28.67	50.96^{cd}	96.41^{de}
T_8 : T_2 + TU foliar spray @ 1000 ppm	29.04	48.86^{de}	93.28^{de}
SEM (±)	1.42	0.83	2.61
CD (0.05)	NS	2.55	8.00

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

The total dry matter production per plant increased from 25 to 75 DAS. Significant difference on total dry matter production were not observed among treatments at 25 DAS. At 25 DAS, T_3 (32.49 g) and T_6 (31.66 g) recorded higher dry matter production per plant than control plants (T_1).

The total dry matter produced showed significant influence with treatments at 50 and 75 DAS. The maximum dry matter was accumulated by T_3 (57.05 g, 110.84 g) which was on par with T_1 (55.56 g, 106.70 g) and T_6 (54.60 g, 105.03 g) at 50 DAS and 75 DAS respectively. However minimum dry matter produced recorded in drought stressed plants (T_2) at 50 DAS (46.80 g) and 75 DAS (88.60 g).

4.2.6. Root shoot ratio

The data on root shoot ratio at 25, 50 and 75 DAS are presented in Table 16.

Table 16. Effect of drought mitigating chemicals on mean root shoot ratio at various crop stages of okra

Treatments	Mean root shoot ratios		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	0.51^{ab}	0.60^{ab}	0.59^{cd}
T_2 : Drought stress	0.48^{bc}	0.40^{f}	0.53^{e}
T_3 : T_2 + SA foliar spray @ 1 mM	0.53^{a}	0.64^{a}	0.71^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	0.42^{e}	0.45^{ef}	0.61^{bc}
T_5 : T_2 + As foliar spray @ 1 mM	0.41^{ef}	0.52^{cd}	0.63^{b}
T_6 : T_2 + As foliar spray @ 2 mM	0.43^{de}	0.53^{cd}	0.65^{b}
T_7 : T_2 + TU foliar spray @ 500 ppm	0.46^{cd}	0.56^{bc}	0.55^{de}
T_8 : T_2 + TU foliar spray @ 1000 ppm	0.38^{f}	0.49^{de}	0.56^{de}
SEM (±)	0.011	0.020	0.014
CD (0.05)	0.032	0.061	0.043

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

Statistically, root shoot ratio showed significant difference among treatments at all stages of crop growth. T_3 showed higher value for root shoot ratio at 25, 50 and 75 DAS.

At 25 DAS, T_3 (0.53) was on par with T_1 (0.51) and the lowest value of 0.42 was exhibited by T_4. At 50 DAS, T_3 (0.64) was on par with T_1 (0.60) followed by T_7 (0.56). At 75 DAS, T_3 (0.71) recorded significantly higher root shoot ratio which was followed by T_6 (0.65) and T_5 (0.63). Minimum root shoot ratio was observed in T_2 at 25 DAS (0.40), 50 DAS (0.53) and 75 DAS (0.53).

4.2.7. SPAD chlorophyll meter readings (SCMR)

The data on SCMR at 25, 50 and 75 DAS were presented in Table 17.

Table 17. Effect of drought mitigating chemicals on mean SPAD chlorophyll meter readings (SCMR) at various crop stages of okra

Treatments	Mean SPAD chlorophyll meter readings		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	65.45^{b}	65.43^{b}	49.20^{a}
T_2 : Drought stress	64.94^{b}	57.76^{e}	36.22^{c}
T_3 : T_2 + SA foliar spray @ 1 Mm	68.99^{a}	69.01^{a}	48.94^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	62.47^{c}	62.05^{cd}	46.35^{a}
T_5 : T_2 + As foliar spray @ 1 mM	58.21^{d}	59.02^{de}	39.70^{bc}
T_6 : T_2 + As foliar spray @ 2 mM	58.92^{d}	64.59^{bc}	47.31^{a}
T_7 : T_2 + TU foliar spray @ 500 ppm	58.65^{d}	58.21^{e}	36.73^{c}
T_8 : T_2 + TU foliar spray @ 1000 ppm	61.27^{c}	60.50^{de}	43.30^{ab}
SEM (±)	0.68	1.09	1.96
CD (0.05)	2.08	3.33	6.00

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

At 25 and 50 DAS, the maximum SPAD chlorophyll meter readings (SCMR) was recorded in T_3. At 25 DAS, T3 (68.99) was followed by T_1 (65.45) and T_2 (64.94) and the minimum SCMR was recorded in T_5 (58.21), which was on par with T_7 (58.65) and T_6 (58.92).

At 50 DAS, T_3 was followed by T_1 (65.43) and the lower SCMR value was recorded in T_2 (57.76) and T_7 (58.21).

At 75 DAS, maximum SCMR value was recorded in T_1 (49.20) which was on par with T_3 (48.94), T_6 (47.31), T_4 (46.35) and T_8 (43.30) and the minimum value was recoded in T_2 (36.22) and T_7 (36.73).

4.2.8. F_v / F_m, Y (II) and ETR

4.2.8.1. F_v/F_m

The data on F_v/F_m at 25, 50 and 75 DAS under different treatments are presented in Table 18.

Table 18. Effect of drought mitigating chemicals on F_v/F_m at various crop stages of okra

Treatments	F_v/F_m		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	0.82[c]	0.79[a]	0.79[a]
T_2 : Drought stress	0.82[c]	0.72[e]	0.72[f]
T_3 : T_2 + SA foliar spray @ 1 mM	0.83[a]	0.78[ab]	0.78[b]
T_4 : T_2 + SA foliar spray @ 2 mM	0.82[d]	0.76[c]	0.76[d]
T_5 : T_2 + As foliar spray @ 1 mM	0.81[e]	0.74[d]	0.73[e]
T_6 : T_2 + As foliar spray @ 2 mM	0.83[b]	0.77[b]	0.77[c]
T_7 : T_2 + TU foliar spray @ 500 ppm	0.80[g]	0.74[de]	0.73[f]
T_8 : T_2 + TU foliar spray @ 1000 ppm	0.80[f]	0.75[cd]	0.75[d]
SEM (±)	0.001	0.005	0.002
CD (0.05)	0.002	0.014	0.006

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

At 25 DAS, maximum value of F_v/F_m ratio was recorded in treatment T_3 (0.83) and T_7 (0.80) recorded the minimum value of F_v/F_m ratio compared to all other treatments. At 50 DAS and 75 DAS, maximum F_v/F_m ratio was recorded in treatment T_1 (0.79) followed by T_3 (0.78) and T_6 (0.77) and the least F_v/F_m ratio was observed in treatment T_2 (0.72).

4.2.8.2. Effective quantum yield (Y (II))

The data on Y (II) at 25, 50 and 75 DAS under different treatments are presented in Table 19.

Table 19. Effect of drought mitigating chemicals on effective quantum yield (Y (II)) at various crop stages of okra

Treatments	Y (II)		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	0.77	0.73^{a}	0.68^{a}
T_2 : Drought stress	0.76	0.65^{c}	0.53^{h}
T_3 : T_2 + SA foliar spray @ 1 mM	0.77	0.73^{a}	0.67^{b}
T_4 : T_2 + SA foliar spray @ 2 mM	0.75	0.70^{ab}	0.63^{d}
T_5 : T_2 + As foliar spray @ 1 mM	0.74	0.69^{ab}	0.60^{f}
T_6 : T_2 + As foliar spray @ 2 mM	0.77	0.72^{a}	0.64^{c}
T_7 : T_2 + TU foliar spray @ 500 ppm	0.74	0.68^{bc}	0.57^{g}
T_8 : T_2 + TU foliar spray @ 1000 ppm	0.74	0.70^{ab}	0.67^{e}
SEM (±)	0.008	0.014	0.002
CD (0.05)	NS	0.044	0.005

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

At 25 DAS, all treatments were non significant on Y (II). At 50 DAS, the highest Y (II) value of 0.73 was recorded in treatments T_1 and T_3, which were on par with T_6 (0.72), T_4 (0.70), T_8 (0.70), T_5 (0.69) and T_7 (0.68). The lowest value of 0.65 was recorded in T_2. At 75 DAS, the highest Y (II) value was recorded in T_1 (0.68) followed by T_3 (0.67) and the lowest value was exhibited by T_2 (0.52).

4.2.8.3. Electron transport rate (ETR)

The data on ETR at 25, 50 and 75 DAS are presented in the Table 20.

Table 20. Effect of drought mitigating chemicals on Electron transport rate (ETR) of okra

Treatments	ETR		
	25 DAS	50 DAS	75 DAS
T_1 : Control (Normal irrigation)	115.73[ab]	129.25[a]	118.81[a]
T_2 : Drought stress	113.32[b]	99.86[e]	77.72[c]
T_3 : T_2 + SA foliar spray @ 1 mM	118.21[a]	128.58[a]	117.87[a]
T_4 : T_2 + SA foliar spray @ 2 mM	109.32[c]	115.84[c]	98.74[abc]
T_5 : T_2 + As foliar spray @ 1 mM	107.29[c]	105.50[de]	84.06[c]
T_6 : T_2 + As foliar spray @ 2 mM	115.96[ab]	122.03[b]	111.25[ab]
T_7 : T_2 + TU foliar spray @ 500 ppm	107.00[c]	102.07[de]	79.84[c]
T_8 : T_2 + TU foliar spray @ 1000 ppm	107.58[c]	106.76[d]	93.81[bc]
SEM (±)	1.206	1.937	7.942
CD (0.05)	3.694	5.933	24.322

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

At 25 DAS, maximum ETR was recorded in T_3 (118.21) which was on par with T_6 (115.96) and T_1 (115.73). The minimum was recorded in T_7 (107.00), which was on par with T_5 (107.29), T_4 (109.32) and T_8 (107.58).

At 50 DAS, maximum ETR was recorded in T_1 (129.25) and T_3 (128.58) and the minimum value was recorded in T_2 (99.86).

At 75 DAS, maximum values were recorded in T_1 (118.81) and T_3 (117.87), which were on par with T_6 (111.25) and T_4 (98.74). The minimum value was recorded in T_2 (77.72) which was on par with T_7 (79.84) and T_5 (84.06).

4.3. BIOCHEMICAL OBSERVATIONS

4.3.1. Chlorophyll content

The data on chlorophyll content of leaves at 25, 50 and 75 DAS are presented in Table 21.

Table 21. Effect of drought mitigating chemicals on chlorophyll content at various crop stages of okra

Treatments	Chlorophyll content (mg g^{-1} fresh wt.)								
	25 DAS			50 DAS			75 DAS		
	Chl. *a*	Chl. *b*	Total	Chl. *a*	Chl. *b*	Total	Chl. *a*	Chl. *B*	Total
T_1	2.48^{ab}	0.55	3.05^{ab}	1.63^{ab}	0.44	2.12^{ab}	0.12^{c}	0.04	0.37
T_2	2.45^{abc}	0.51	3.00^{ab}	1.19^{e}	0.42	1.63^{d}	0.15^{a}	0.05	0.21
T_3	2.52^{a}	0.53	3.08^{a}	1.73^{a}	0.41	2.16^{a}	0.15^{a}	0.09	0.24
T_4	2.10^{de}	0.55	2.86^{b}	1.53^{bc}	0.46	2.01^{b}	0.15^{a}	0.07	0.22
T_5	2.04^{e}	0.51	2.57^{d}	1.43^{cd}	0.37	1.82^{c}	0.13^{abc}	0.05	0.20
T_6	2.31^{bc}	0.52	2.87^{b}	1.59^{b}	0.47	2.11^{ab}	0.14^{ab}	0.08	0.23
T_7	2.04^{e}	0.50	2.64^{c}	1.40^{cd}	0.46	1.87^{c}	0.14^{ab}	0.06	0.21
T_8	2.27^{cd}	0.54	2.90^{ab}	1.34^{d}	0.37	1.76^{cd}	0.13^{bc}	0.05	0.18
SEM (±)	0.063	0.032	0.073	0.045	0.027	0.042	0.006	0.011	0.072
CD (0.05)	0.193	NS	0.224	0.137	NS	0.129	0.019	NS	NS

Chlorophyll *a* was found significantly different at 25, 50 and 75 DAS. Chlorophyll *b* was non significant at all the growth stages of okra. Total chlorophyll was significantly different at 25 and 50 DAS but was not significant at 75 DAS.

At 25 DAS, higher value for chlorophyll *a* content was recorded under treatment T_3 (2.52 mg g^{-1} fresh wt.) which was on par with T_1 (2.48 mg g^{-1} fresh wt.) and T_2 (2.45 mg g^{-1} fresh wt.) and the least value was recorded under the treatment T_7 and T_5 (2.04 mg g^{-1} fresh wt.). The maximum value for total chlorophyll was recorded with the treatment T_3 (3.08 mg g^{-1} fresh wt.), which was on par with T_1 (3.05 mg g^{-1} fresh wt.), T_2 (3.00 mg g^{-1} fresh wt.) and T_8 (2.90 mg g^{-1} fresh wt.).

At 50 DAS, the treatment T_3 (1.73 mg g^{-1} fresh wt.) recorded the maximum value for chlorophyll *a*, which was on par with T_1 (1.63 mg g^{-1} fresh wt.). The minimum value was recorded under the treatment T_2 (1.19 mg g^{-1} fresh wt.). The maximum value for total chlorophyll was recorded in the treatment T_3 (2.16 mg. g^{-1} fresh wt.), which was on par with T_1 (2.12 mg. g^{-1} fresh wt.) and T_6 (2.11 mg. g^{-1} fresh wt.) and the least value was recorded under the treatment T_2 (1.63 mg. g^{-1} fresh wt.).

At 75 DAS, highest chlorophyll *a* content were observed in treatments T_2, T_3 and T_4 which were on par with T_6 (0.14 mg g^{-1} fresh wt.), T_7 (0.14 mg g^{-1} fresh wt.) and T_5 (0.13 mg g^{-1} fresh wt.). The least chlorophyll a content was observed in treatment T_1 (0.12 mg g^{-1} fresh wt.).

4.4. YIELD AND FRUIT QUALITY OBSERVATIONS

4.4.1. Average number of fruits per plant

The average number of fruits per plant was recorded and are presented in Table 22.

Table 22. Effect of drought mitigating chemicals on average number of fruits per plant of okra

Treatments	Average number of fruits per plant
T_1 : Control (Normal irrigation)	37.66^a
T_2 : Drought stress	31.33^c
T_3 : T_2 + SA foliar spray @ 1 mM	38.95^a
T_4 : T_2 + SA foliar spray @ 2 mM	37.40^a
T_5 : T_2 + As foliar spray @ 1 mM	35.16^{ab}
T_6 : T_2 + As foliar spray @ 2 mM	38.04^a
T_7 : T_2 + TU foliar spray @ 500 ppm	36.32^{ab}
T_8 : T_2 + TU foliar spray @ 1000 ppm	33.11^{bc}
SEM (±)	1.25
CD (0.05)	3.83

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

A critical examination of the data in Table 22 revealed that the different treatments significantly influenced average number of fruits per plant. Maximum number of fruits per plant was recorded with the treatment T_3 (38.95), T_6 (38.04), T_1 (37.66) and T_4 (37.40) which were on par with T_7 (36.32) and T_5 (35.16). Minimum number of fruits per plant was recorded in the drought stressed treatment T_2 (31.33).

4.4.2. Average fruit yield per plant / plot / ha

The data on average fruit yield per plant / plot / ha was recorded and are presented in Table 23.

Table 23. Effect of drought mitigating chemicals on average yield per plant/plot/ha of okra

Treatments	Yield			Per cent increase over drought stress
	Per plant (kg)	Per plot (kg)	Per ha (t)	
T_1 : Control (Normal irrigation)	0.73^b	32.79^b	25.50^b	40.5
T_2 : Drought stress	0.52^g	23.34^g	18.15^g	-
T_3 : T_2 + SA foliar spray @ 1 mM	0.75^a	33.85^a	26.33^a	45.07
T_4 : T_2 + SA foliar spray @ 2 mM	0.65^c	29.29^c	22.79^c	25.56
T_5 : T_2 + As foliar spray @ 1 mM	0.62^e	27.66^e	21.51^e	18.15
T_6 : T_2 + As foliar spray @ 2 mM	0.73^b	32.98^b	25.65^b	41.32
T_7 : T_2 + TU foliar spray @ 500 ppm	0.63^d	28.48^d	22.15^d	22.04
T_8 : T_2 + TU foliar spray @ 1000 ppm	0.58^f	26.28^f	20.43^f	12.56
SEM (±)	0.005	0.243	0.190	-
CD (0.05)	0.017	0.744	0.580	-

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

The results revealed that total fruit yield was significantly influenced by treatments. Highest total fruit yield was recorded in T_3 (26.33 t ha^{-1}) followed by T_6 (25.65 t ha^{-1}) and lowest fruit yield was recorded in T_2 (18.15 t ha^{-1}) followed by T_8 (20.43 t ha^{-1}) and T_5 (21.51 t ha^{-1}). T_3 and T_6 recorded 45% and 41% higher yield over drought stressed treatment (T_2), respectively.

Plate 29. Harvested fruits

4.4.3. Shelf life

The data on shelf life of fruits are presented in Table 24.

Table 24. Effect of drought mitigating chemicals on shelf life of okra

Treatments	Shelf life of fruits (days)
T_1 : Control (Normal irrigation)	7.0^{a}
T_2 : Drought stress	6.0^{b}
T_3 : T_2 + SA foliar spray @ 1 mM	6.6^{ab}
T_4 : T_2 + SA foliar spray @ 2 mM	6.0^{b}
T_5 : T_2 + As foliar spray @ 1 mM	7.3^{a}
T_6 : T_2 + As foliar spray @ 2 mM	7.3^{a}
T_7 : T_2 + TU foliar spray @ 500 ppm	7.0^{a}
T_8 : T_2 + TU foliar spray @ 1000 ppm	6.0^{b}
SEM (±)	0.24
CD (0.05)	0.74

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

The results revealed that shelf life of the fruit was significantly influenced by treatments. The shelf life was highest in T_5 (7.3 days), T_6 (7.3 days), T_1 (7.0 days) and T_7 (7.0 days) and was on par with T_3 (6.6 days). In treatment T_2, T_4 and T_8 (6.0 days) similar shelf life of fruits was observed.

4.4.4. Crude fibre content of fruit

The data on crude fibre content of okra fruits are presented in Table 25.

Data collected on crude fibre content ranged between 6.66% (T_1) to 8.34% (T_3). Among the treatments the lowest crude fibre content (6.66%) was recorded with treatment T_3 and T_5 Significantly higher crude fibre content was recorded with treatment T_2 (8.34%) followed by T_8 (8.21%) and T_6 (7.32%).

4.4.5. Ascorbic acid content of fruits

The data on ascorbic acid content of fruits are recorded and are presented in the Table 25.

Significant differences were observed among treatments for ascorbic acid content in fruits (mg 100 g^{-1}). Ascorbic acid content of fruits ranged between 19.48 mg 100 g^{-1} to 13.07 mg 100 g^{-1}. Among the treatments, T_1 (19.48 mg 100 g^{-1}) was recorded maximum ascorbic acid content followed by T_6 (18.21 mg 100 g^{-1}) and T_5 (17.95 mg 100 g^{-1}). The lowest ascorbic acid content of fruit was observed in treatment T_8 (13.07 mg 100 g^{-1}) followed by T_4 (14.34 mg 100 g^{-1}) and T_2 (16.15 mg 100 g^{-1}).

Table 25. Effect of drought mitigating chemicals on crude fibre content and ascorbic acid content of okra

Treatments	Crude fibre content of fruits (%)	Ascorbic acid content of fruits (mg 100g^{-1})
T_1 : Control (Normal irrigation)	6.66^{f}	19.48^{a}
T_2 : Drought stress	8.34^{a}	16.15^{f}
T_3 : T_2 + SA foliar spray @ 1 mM	6.97^{e}	17.69^{d}
T_4 : T_2 + SA foliar spray @ 2 mM	7.15^{d}	14.34^{g}
T_5 : T_2 + As foliar spray @ 1 mM	7.03^{e}	17.95^{c}
T_6 : T_2 + As foliar spray @ 2 mM	7.32^{c}	18.21^{b}
T_7 : T_2 + TU foliar spray @ 500 ppm	7.06^{de}	17.44^{e}
T_8 : T_2 + TU foliar spray @ 1000 ppm	8.21^{b}	13.07^{h}
SEM (±)	0.033	0.006
CD (0.05)	0.101	0.018

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

4.5. NUMBER AND INTERVAL OF IRRIGATION

The data on number and interval of irrigation was recorded and are presented in Table 26.

The mean values of number and interval of irrigation with respect to different treatments are presented. The number of irrigation was highest in T_1 (41 times) followed by T_2 (18 times) and T_8 (17 times). The lowest number of irrigation were in T_3, T_6 and T_7 (15 times).

The irrigation interval was the highest in T_3, T_6 and T_7 (5 days). Irrigation interval was the lowest in normally irrigated plants, T_1 (2 days) and drought stressed plants, T_2 (3 days).

Table 26. Effect of drought mitigating chemicals on number of irrigation and irrigation interval (days) of okra

Treatments	**Number of irrigation**	**Irrigation interval (days)**
T_1 : Control (Normal irrigation)	41^a	2^d
T_2 : Drought stress	18^b	3^c
T_3 : T_2 + SA foliar spray @ 1 mM	15^e	5^a
T_4 : T_2 + SA foliar spray @ 2 mM	17^c	4^b
T_5 : T_2 + As foliar spray @ 1 mM	16^d	4^b
T_6 : T_2 + As foliar spray @ 2 mM	15^e	5^a
T_7 : T_2 + TU foliar spray @ 500 ppm	15^e	5^a
T_8 : T_2 + TU foliar spray @ 1000 ppm	17^c	4^b
SEM (±)	0.242	0.071
CD (0.05)	0.741	0.217

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

4.6. ECONOMICS

4.6.1. Net returns

The data on net returns (₹ ha^{-1}) are presented in Table 27. Net returns had significant influence with the treatments. The highest net returns (₹ 3.15 lakh ha^{-1}) was obtained in T_3 followed by T_6 (₹ 3.01 lakh ha^{-1}). The lowest net returns (₹ 1.55 lakh ha^{-1}) was in treatment T_2 followed by T_8 (₹ 1.97 lakh ha^{-1}).

4.6.2 Benefit - cost ratio (BCR)

The data on BCR are presented in Table 27. BCR had significant influence with the treatments. The highest BCR (2.49) was obtained in T_3 followed by T_6 (2.45) and T_1 (2.41). The lowest BCR (1.74) was in T_2 followed by T_8 (1.93) and T_5 (2.03).

Table 27. Effect of drought mitigating chemicals on net returns and benefit cost ratio of okra

Treatments	Net returns (₹ Lakh ha^{-1})	Benefit cost ratio
T_1 : Control (Normal irrigation)	3.02^{b}	2.41^{ab}
T_2 : Drought stress	1.55^{g}	1.74^{g}
T_3 : T_2 + SA foliar spray @ 1 mM	3.15^{a}	2.49^{a}
T_4 : T_2 + SA foliar spray @ 2 mM	2.44^{c}	2.15^{c}
T_5 : T_2 + As foliar spray @ 1 mM	2.19^{e}	2.03^{e}
T_6 : T_2 + As foliar spray @ 2 mM	3.01^{b}	2.45^{b}
T_7 : T_2 + TU foliar spray @ 500 ppm	2.32^{d}	2.09^{d}
T_8 : T_2 + TU foliar spray @ 1000 ppm	1.97^{f}	1.93^{f}
SEM (±)	0.038	0.018
CD (0.05)	0.117	0.056

SA: Salicylic acid, AS: Ascorbic acid, TU: Thiourea

Discussion

5. DISCUSSION

The research work entitled "Drought mitigation in okra (*Abelmoschus esculentus* L.) through chemical approach" was done at Regional Agricultural Research Station, Pilicode. This study was intended to investigate the influence of different chemicals namely, salicylic acid, ascorbic acid and thiourea on mitigation of drought and to evaluate their effect on morphological, physiological and yield characteristics of okra. The results obtained from the experiment were presented in the previous chapter are discussed and justified below based on the available literature.

5.1. INFLUENCE OF TREATMENTS ON MORPHOLOGICAL CHARACTERS

Plant height was reduced by 8.14 per cent in drought stressed okra compared with normally irrigated plants (control) (Figure 3.) This was in agreement with the observations made by Mbagwu and Adesipe (1987), Sankar *et al.* (2007), Hussein *et al.* (2011), El-Kader *et al.* (2010), Kusvuran (2012), Altaf *et al.* (2015), Kwajaffa *et al.* (2015), Aliyu *et al.* (2016) and Al-Ubayadi *et al.* (2017) in okra plants subjected to drought stress. Reduction in water content and turgidity potential and increase in cellular juice concentration in plant tissue cells cause decline in plant height. Drought stress results in the inhibition of cell division and decrease in mitosis and delay building of DNA due to more leaf senescence and low turgor pressure, leading to infiltration in the cellular walls, shrinking, and loss of cell elongation or differentiation which leads to a decline in plant height (Kusaka *et al.*, 2005; Manivannan *et al.*, 2007; Uddin *et al.*, 2013.).

The highest plant height was observed in T_3 (salicylic acid foliar spray @ 1mM under drought stress) followed by T_6 (ascorbic acid foliar spray @ 2 mM under drought stress). The plant height observed in T_3 was almost equal with that of normally irrigated plants but 8.63 per cent higher than that of drought stressed plants. Similar results of salicylic foliar spray enhancing plant height under drought stress were reported by Amin *et al.* (2008) in wheat, Jayalakshmi *et al.* (2010) in groundnut, Munir *et al.* (2016) in okra and Edupuganti *et al.* (2019) in chickpea. Salicylic acid increases the water content in the plant and raise the efficiency of photosynthesis and increase the concentration of hormones such as indole-acetic acid (IAA) and reduction of the concentration of abscisic acid (ABA) and ethylene which accelerate aging, and eventually results in increase in the plant height (Sakhabutdinova *et al.*, 2003; Yonova, 2010). Ascorbic acid foliar spray @ 2 mM (T_6) and thiourea foliar spray of 500 ppm (T_7) increased the plant height by 5.1 per cent and 4.67 per cent over drought stressed plants (Figure 3).

The maximum number of leaves plant^{-1} and branches plant^{-1} were recorded in plants treated with salicylic acid @ 1 mM under drought stress (T_3) followed by ascorbic acid foliar spray @ 2 mM (T_6) (Figure 4. and Figure 5.). All the three chemicals performed well when compared with drought stressed plants without foliar spray. Foliar spray of thiourea @ 500 ppm and 1000 ppm also increased plant height, leaves plant^{-1}and branches plant^{-1}, when compared to drought stressed plants. Many workers like Amin *et al.* (2014) in faba bean, Singh and Singh, (2017) in lentil, Zain *et al.* (2017) in wheat, Shakoor *et al.* (2019) in maize and Uddin *et al.* (2020) in okra reported the favourable influence of foliar spray of thiourea on plant height, leaves plant^{-1} and branches plant^{-1}. Thiourea delay leaf ageing and senescence, increased net photosynthetic rates, concentration of total chlorophyll and starch in leaves leading to increased plant height, number of leaves and branches plant^{-1} (Patel *et al.*, 2016; Singh and Singh, 2017).

Root volume at the final harvest was significantly influenced by spraying of chemicals and the highest root volume was observed with spraying of salicylic acid @ 1 mM (T_3) as shown in Figure 6. This is also in agreement with the findings of Hayat *et al.* (2010) in tomato, Munir *et al.* (2016) in okra and Chavoushi *et al.* (2020) in safflower, wherein there was an increase in root length and root dry matter by spraying of salicylic acid.

In this study, the days to 50 per cent flowering is non - significant. However, drought stressed plants without foliar spray (T_2) took more days to complete 50 per cent flowering and minimum number of days for 50 per cent flowering was recorded in the plants treated with salicylic acid @ 2 mM (T_4) (Figure 7). This might be due to the effect of salicylic acid in reducing the levels of ABA, the prime factor, imposing dormancy and thereby changing the endogenous hormonal balance in favour of promoters (Pawar *et al.*, 2018). The results were in conformity with the findings of

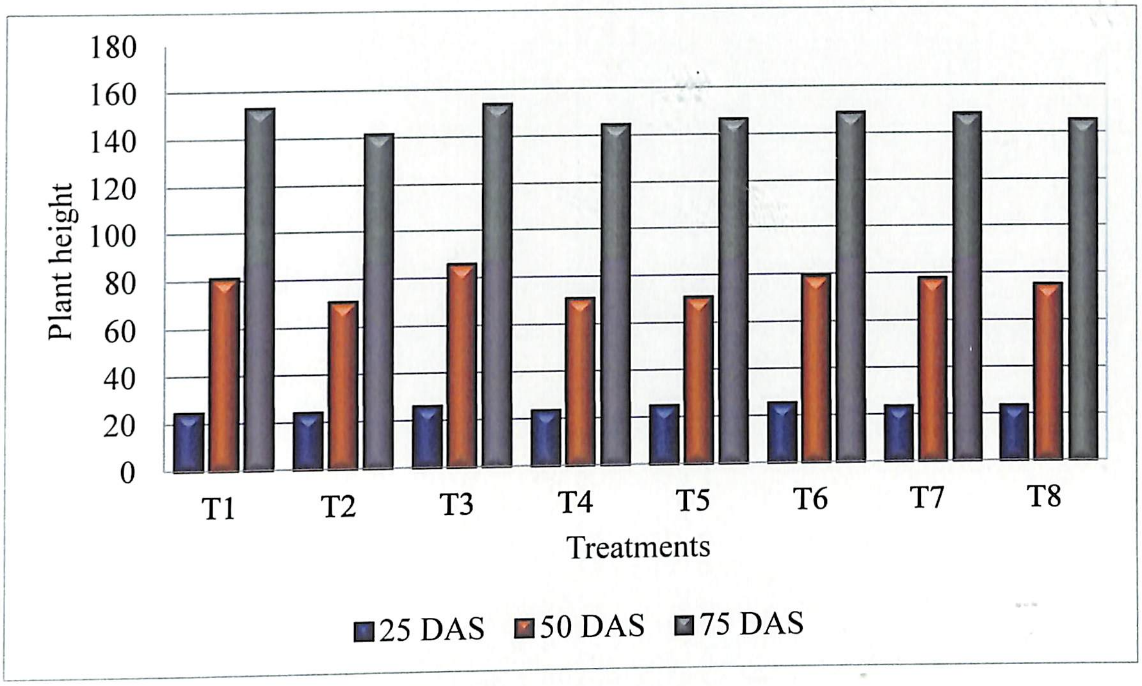

Figure 3: Effect of drought mitigating chemicals on mean plant height (cm) at various crop stages of okra

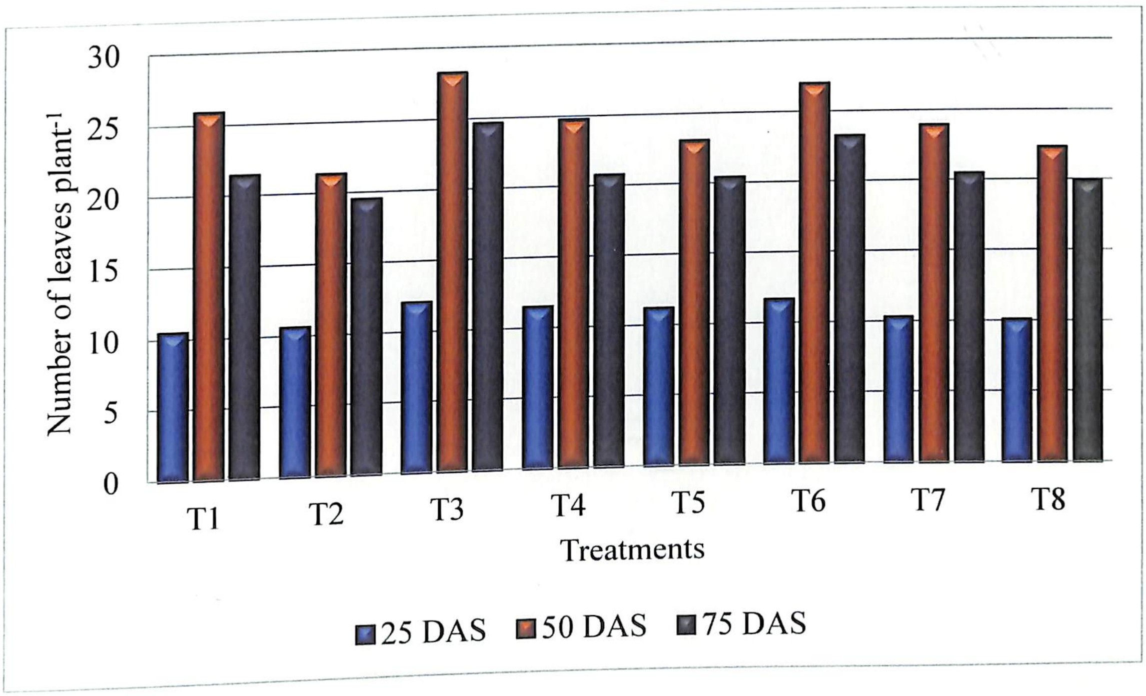

Figure 4: Effect of drought mitigating chemicals on mean number of leaves plant^{-1} at various crop stages of okra

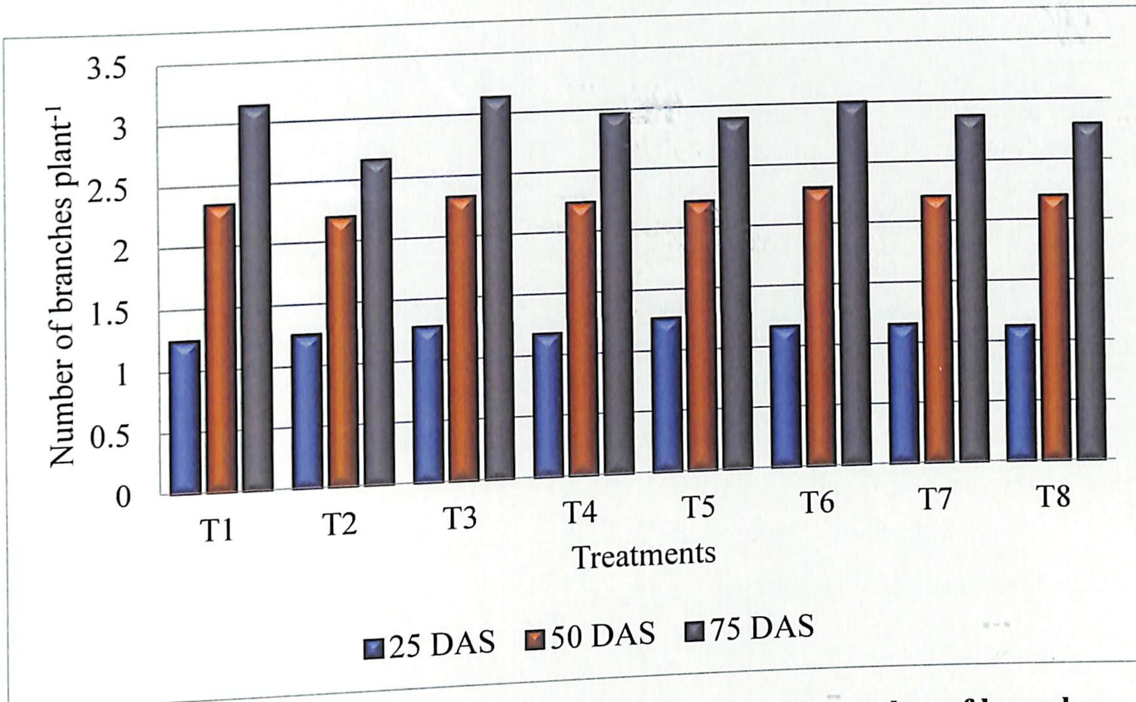

Figure 5: Effect of drought mitigating chemicals on mean number of branches plant^{-1} at various crop stages of okra

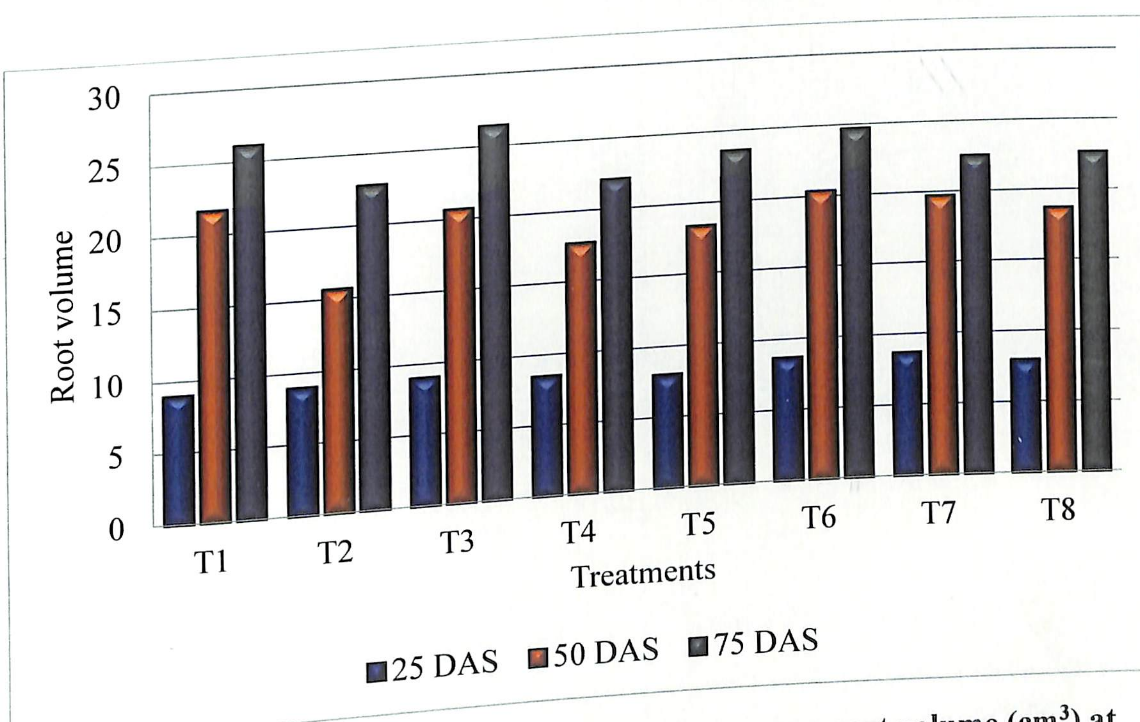

Figure 6: Effect of drought mitigating chemicals on mean root volume (cm^3) at various crop stages of okra

Padmalatha *et al.* (2014) in gladiolus and Martin-Mex *et al.* (2005) in *Sinningia speciosa*.

The treatments could not exert any significant effect on days to first harvest. However, the least number of days to first harvest was recorded with thiourea foliar spray of 1000 ppm (T_8) (37.8) and the highest number of days to first harvest was recorded with drought stressed plants without foliar spray (T_2) (42.1) (Figure 7).

The drought stress led to reduction in fruit length, fruit girth and fruit weight. The fruit length, fruit girth and fruit weight of drought stressed plants reduced @ 4.46 per cent, 22.65 per cent, 21.24 per cent, respectively, over normal irrigated plants (Figure 8). The decline in fruit length and girth as a result of drought is in line with work done by West *et al.* (2004) who reported that irrigation increases size and weight of fruit and that of Viets (1965) who found that poor carbohydrate utilization results in decreased fruit size (fruit length and girth). These result were also in agreement with that of Kumar *et al.* (2007), Hussein *et al.* (2011), Kwajaffa *et al.* (2015), Aliyu *et al.* (2016) Al-Ubaydi *et al.* (2017) and Dos Santos Farias *et al.* (2019) in okra.

The foliar spray of chemicals namely, salicylic acid, ascorbic acid and thiourea had a positive influence on yield characters like fruit length, girth and weight. Among these chemicals, T_4 (salicylic acid foliar spray @ 2 mM) recorded the highest fruit length though it did not statistically vary from T_6 (ascorbic acid foliar spray @ 2 mM). Morphological traits like plant height and leaf area had very strong positive correlation on okra fruit size (length, girth and weight) (Falusi *et al.*, 2012) and all these traits increased under foliar spray of salicylic acid, hence increasing the fruit size. Similar result of salicylic acid improving the fruit size was reported by Munir *et al* (2016) in okra.

The maximum number of pickings were recorded in T_3 (salicylic acid foliar spray @ 1 mM) and the minimum number of pickings were recorded in T_2 (drought stress) (Figure 9.). The highest duration of crop was recorded in T_3 (salicylic acid foliar spray of 1 mM) (108 days) and the minimum duration of crop was recorded in T_2 (drought stress) (98 days) (Figure 9).

5.2. INFLUENCE OF TREATMENTS ON PHYSIOLOGICAL CHARACTERS

All the treatments significantly influenced the physiological parameters of okra. Up to 75 DAS, the maximum relative growth rate was recorded in T_3 (salicylic acid foliar spray @ 1 mM) which does not differ much from T_6 (ascorbic acid foliar spray @ 2 mM) (Figure 10). Hussein (2015) reported that seed priming with salicylic acid concentration of 10, 25, 50, 75 and 100 mg L^{-1} increased relative growth rate in okra. But the drought stressed plants without foliar spray (T_2) cause severe reduction in the relative growth rate. There was a reduction of 14.29 per cent in drought stressed plant over control plants.

Specific leaf weight was recorded maximum in salicylic acid treated plants @ 1 mM (T_3) and minimum in drought stressed plants (T_2) at all the growth stages (Figure 11). Salicylic acid led to better absorption and translocation of nutrients which enhanced the specific leaf weight.

Leaf area was significantly influenced by treatments at all crop growth stages the highest leaf area was recorded in T_3 (salicylic acid foliar spray @ 1 mM) at all the growth stages (Figure 12). Salicylic acid increasing the leaf area of crops under drought stress had been reported by several workers, namely, Abdelkader *et al.* (2012) in wheat and Chavoushi *et al.* (2020) in safflower.

Leaf area was decreased @ 21.07 per cent and 8.36 per cent in drought stressed plants at 50 DAS and 75 DAS, respectively, over control plants. Decreasing of leaf area under drought stress is the result of decreasing cell division and expansion, which leads to the reduction of cell size and therefore the reduction of leaf area. The plant with decreasing leaf area alleviates water mortality and causes increasing resistance to drought (Liberman and Wang, 1982). The large decrease in total leaf area appeared as a result of reduced production of new leaves, increased leaf shedding and reduced average leaf size. Reduced leaf production and leaf expansion are frequently observed responses to water stress in many plants (Hsiao and Xu, 2000). Reduction in leaf area under drought stress was reported by many workers in okra, *viz.*, Mbagwu and Adesipe (1987), Ashraf *et al.* (2002), Sankar *et al.* (2007) and Kusvuran (2012).

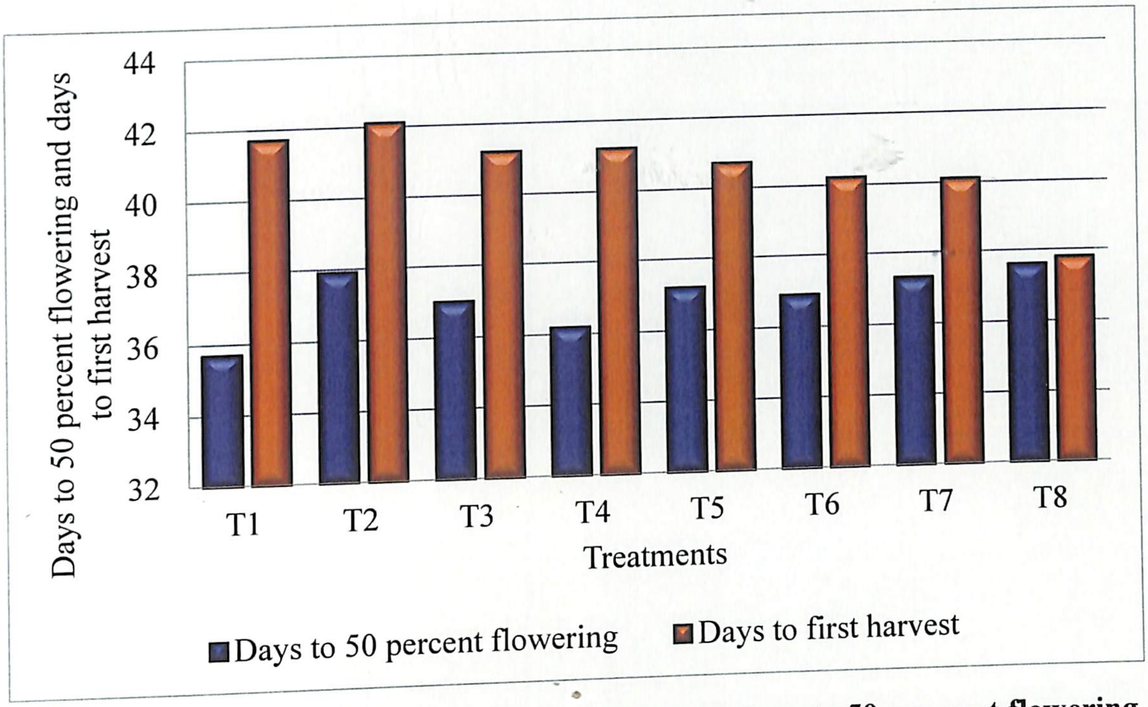

Figure 7: Effect of drought mitigating chemicals on days to 50 per cent flowering and days to first harvest of okra

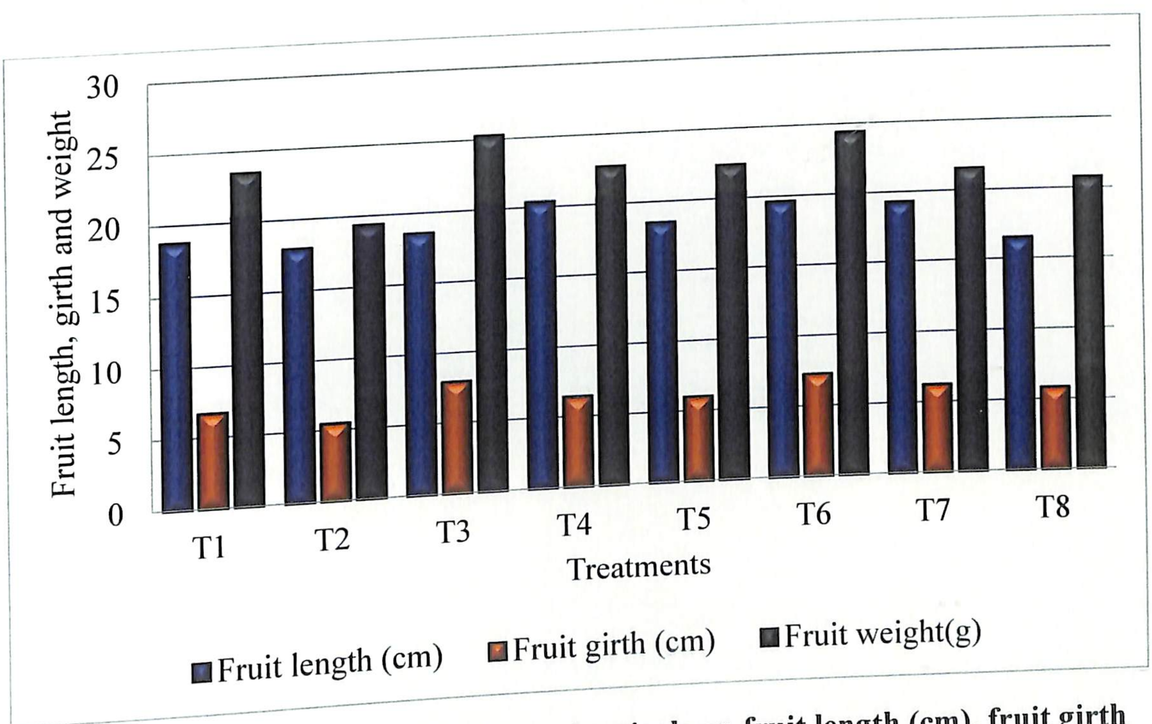

Figure 8: Effect of drought mitigating chemicals on fruit length (cm), fruit girth (cm) and fruit weight (g) of okra

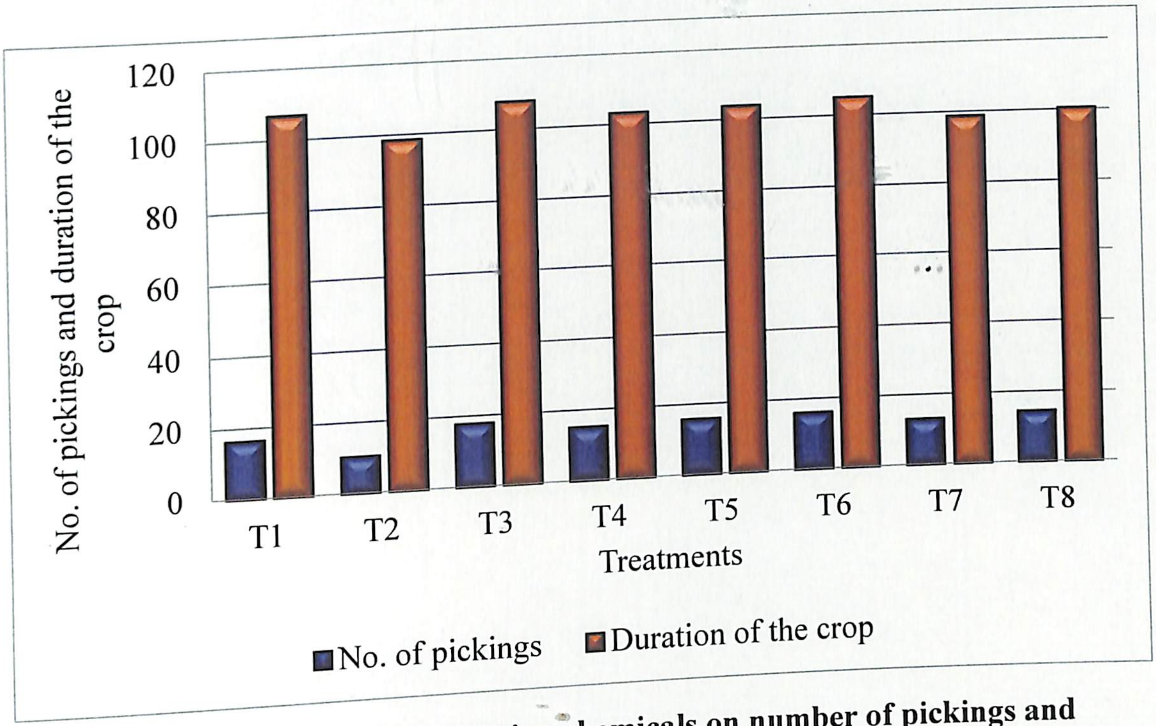

Figure 9: Effect of drought mitigating chemicals on number of pickings and duration of the crop of okra

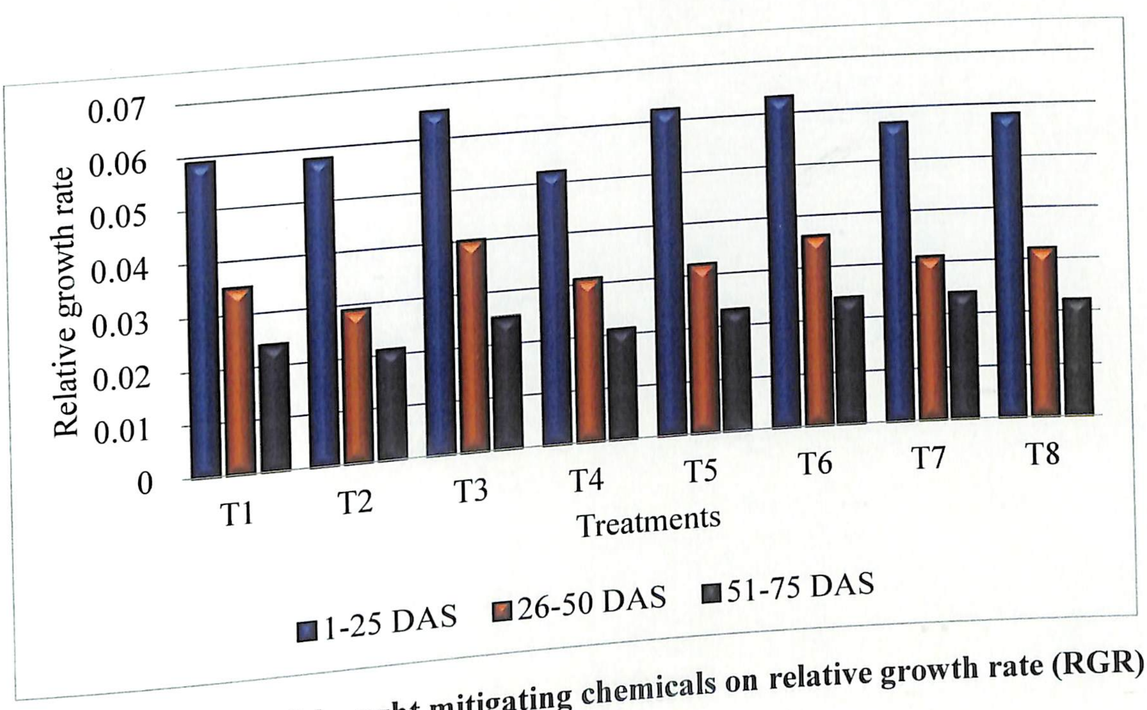

Figure 10: Effect of drought mitigating chemicals on relative growth rate (RGR) (mg g $^{-1}$ d^{-1}) at various crop stages of okra

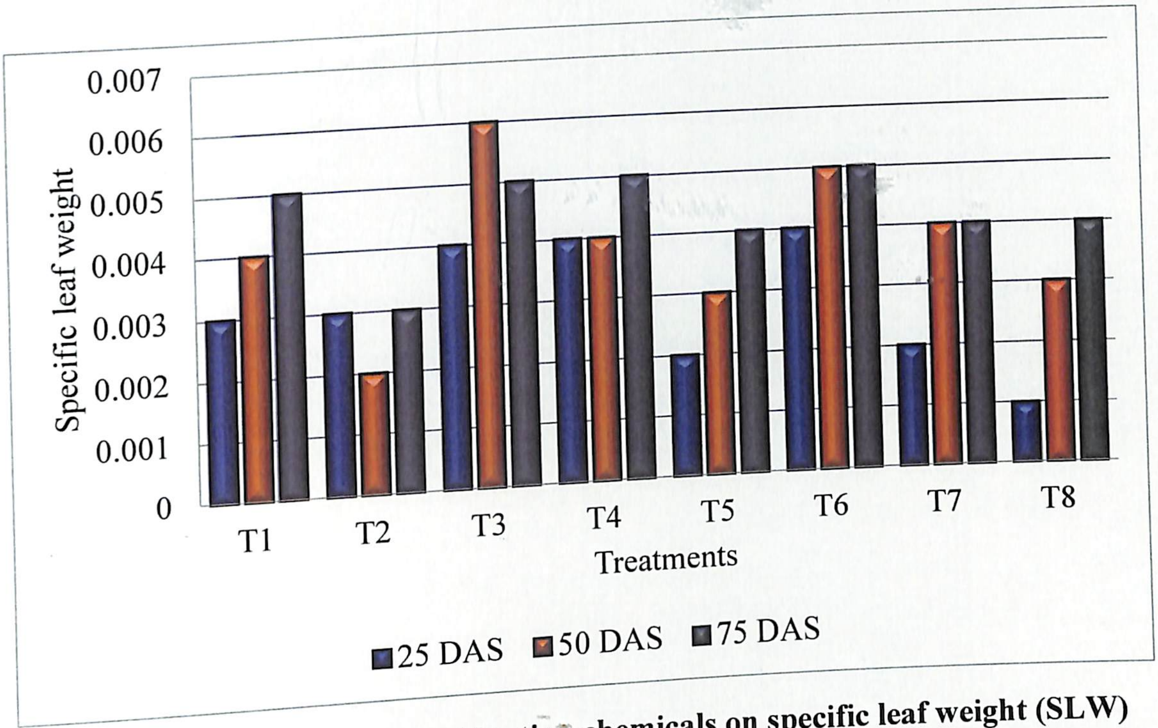

Figure 11: Effect of drought mitigating chemicals on specific leaf weight (SLW) ($g\ cm^{-2}$) at various crop stages of okra

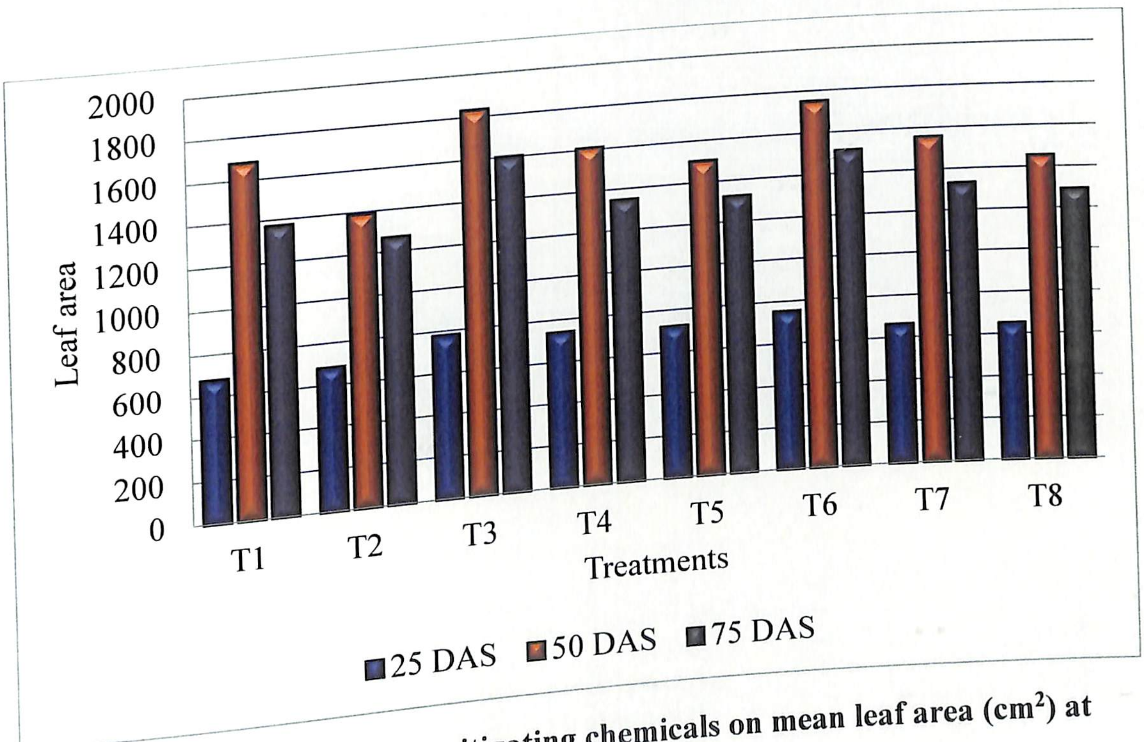

Figure 12: Effect of drought mitigating chemicals on mean leaf area (cm^2) at various stages of okra

Relative leaf water contents provide an excellent tool to determine water status in plants. It is the physical measure of water stress in plants. Under drought stress condition, relative leaf water content decreased @ 10.81 per cent and 22.57 per cent at 50 DAS and 75 DAS, respectively, over control (Figure 13.) due to decreasing soil water availability and increasing resistance to water flow in stems and leaves (Nahar and Ullah, 2018). This was in conformity with the work done by Ashraf *et al.* (2002) in okra, Kirnak *et al.* (2002) in brinjal, Burman *et al.* (2004) in cluster bean, Bhatt and Rao (2005) in okra, Sibomana *et al.* (2013) in tomato, Pravisya and Jayaram (2015) in okra, Nahar and Ullah (2018) in tomato and Adejumo *et al.* (2019) in okra. Salicylic acid foliar spray @ 1 mM (T_3) enhanced the relative leaf water content @ 8.64 per cent and 13.42 per cent at 50 and 75 DAS respectively over drought stressed plants (T_2). This was in agreement with that of Munir *et al.* (2016) in okra, Hayat *et al.* (2008) in tomato, Rao *et al.* (2012) in maize, Askari and Ehsanzadeh (2015) in fennel, Abbas *et al.* (2019) in marigold, Irfan *et al.* (2019) in maize and Edupuganti *et al.* (2019) in chickpea. He *et al.* (2005) and Sakhabutdinova *et al.* (2003) postulated that exogenous application of salicylic acid increased the production of photosynthetic apparatus that produced more photosynthates. This enhanced photosynthetic activity increased sap production in the leaf lamella and also decreased the transpiration losses, which resulted in maintenance of higher relative water content in leaf and better growth.

In all treatments, the dry matter production was increased from the initial growth stage to the final growth stage (Figure. 14). Salicylic acid foliar spray @ 1 mM (T_3) and ascorbic acid foliar spray @ 2 mM (T_6) significantly affected the total dry matter production compared to other treatments. Fariduddin *et al.* (2003) in mustard, Singh and Usha (2003) in wheat, Irfan *et al.* (2019) in maize and Edupuganti *et al.* (2019) in chickpea supported that salicylic acid influences the drymatter production. High chlorophyll content and photosynthetic rate along with high Rubisco activity in salicylic acid treated plants is responsible for the improved dry matter accumulation under drought condition (Singh and Usha, 2003).

Root shoot ratio gives estimates of the distribution of dry matter between the root and the shoot systems. Root shoot ratio was higher in plants of all treatments other than drought stressed plants (T_2) (Figure 15) showing that dry weight of shoots was extremely affected compared to the root system. Such increase in root shoot ratio indicates that the proportion of dry matter allocated to shoots was decreased compared to the roots (Boutraa *et al.*, 2010).

Chlorophyll fluorescence parameter F_v/F_m, which is the ratio of variable fluorescence to maximum fluorescence after dark-adaptation, represents maximum quantum yield of PS II. The parameter is being used for detecting stress in plants. Drought stress caused a reduction of 9.72 per cent F_v/F_m over control plants (Figure 16).

Quantum yield Y (II), indicates the amount of energy used in photochemistry by photosystem II under steady-state photosynthetic lighting conditions. The maximum Y (II) was recorded for T_3 (salicylic acid foliar spray @ 1 mM) and T_1 (control) at 50 and 75 DAS, whereas Y (II) value reduced about 12.31 per cent and 28.3 per cent at 50 and 75 DAS, respectively, in drought stressed plants over control plants (Figure 17).

ETR, or electron transport rate, is also a light-adapted parameter that is directly related to Y (II). The maximum ETR was recorded in salicylic acid foliar spray @ 1 mM (T_3) which was on par with control (T_1) and ascorbic acid foliar spray @ 2 mM (T_6). At 50 DAS and 75 DAS, maximum ETR was recorded in control and foliar spray of salicylic acid @ 1 mM. These treatments were on par with foliar spray of salicylic acid @ 2 mM and ascorbic acid @ 2 mM (Figure 18).

5.3. INFLUENCE OF TREATMENTS ON BIOCHEMICAL PARAMETERS

In this study, drought stress caused a large decline in the chlorophyll *a*, chlorophyll *b* and the total chlorophyll content. There were a reduction of 36.97 per cent of chlorophyll *a*, 30.06 per cent reduction of total chlorophyll at 50 DAS in drought stressed plants (T_2) over control plants (T_1). Chlorophyll *b* does not show any significant effect on treatments at all the growth stages. The decrease in chlorophyll under drought stress is mainly due to the damage to chloroplasts caused by reactive oxygen species (ROS). ROS lead to deterioration of thylakoids membranes, degradation in pigment composition and reduction in the enzyme activity which involves in chlorophyll synthesis, and substantial damage to photosynthetic pigments

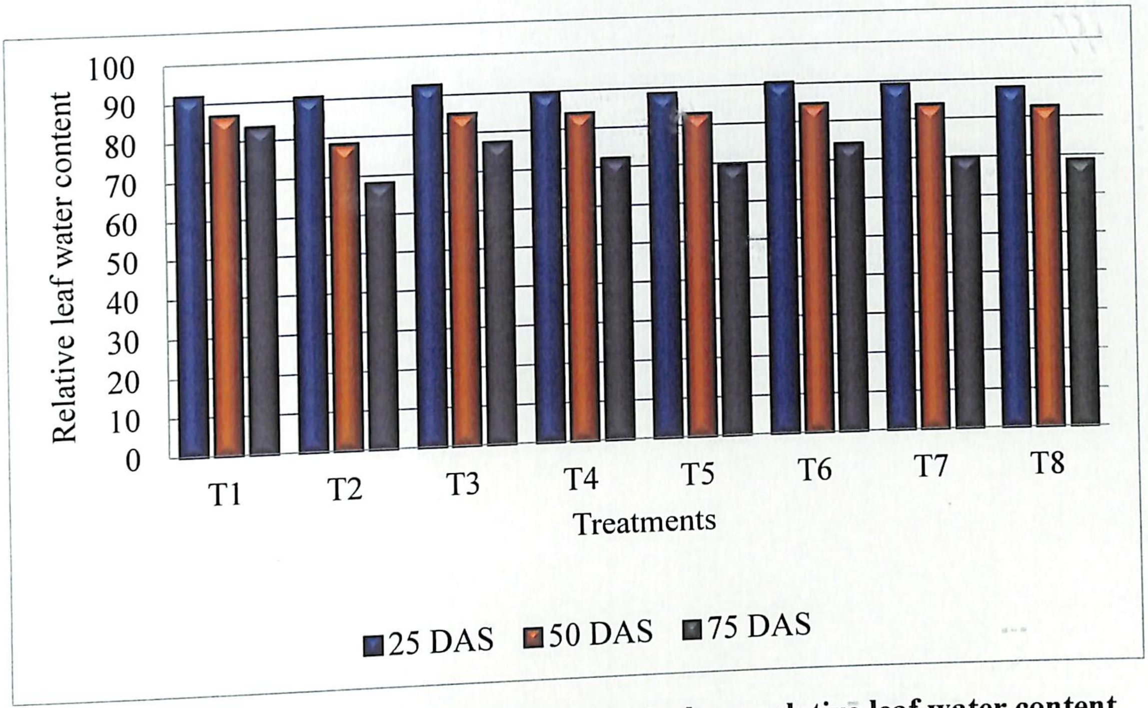

Figure 13: Effect of drought mitigating chemicals on relative leaf water content (%) at various crop stages of okra

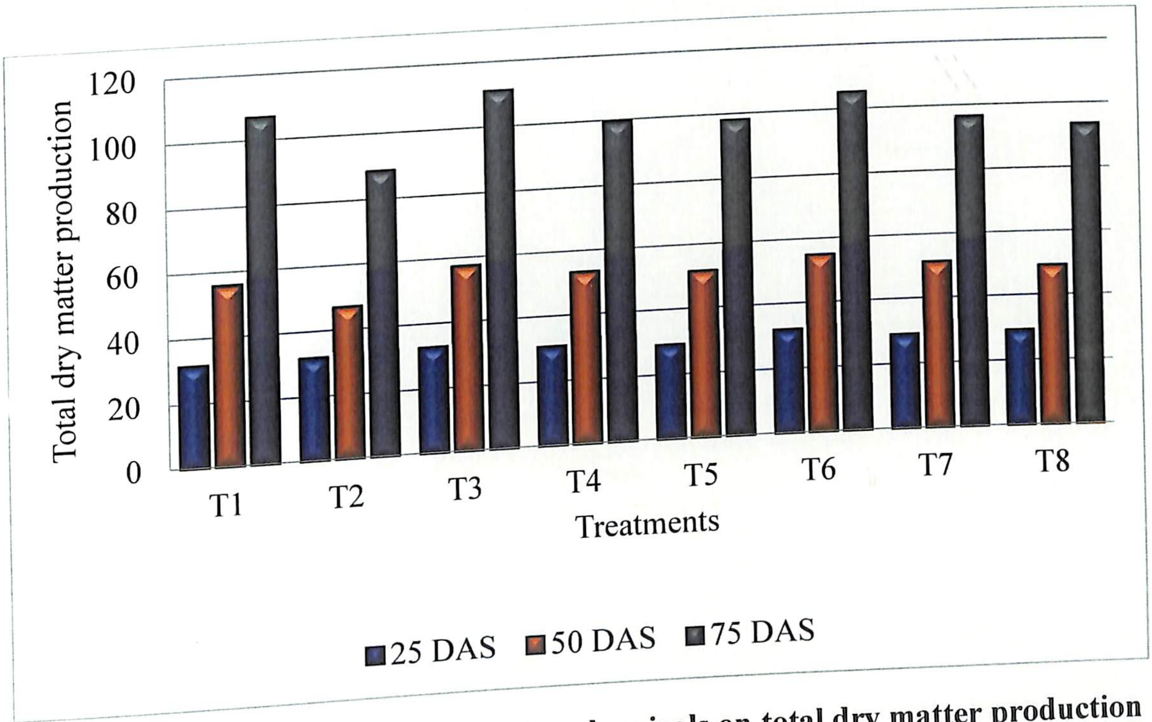

Figure 14: Effect of drought mitigating chemicals on total dry matter production (g) of okra

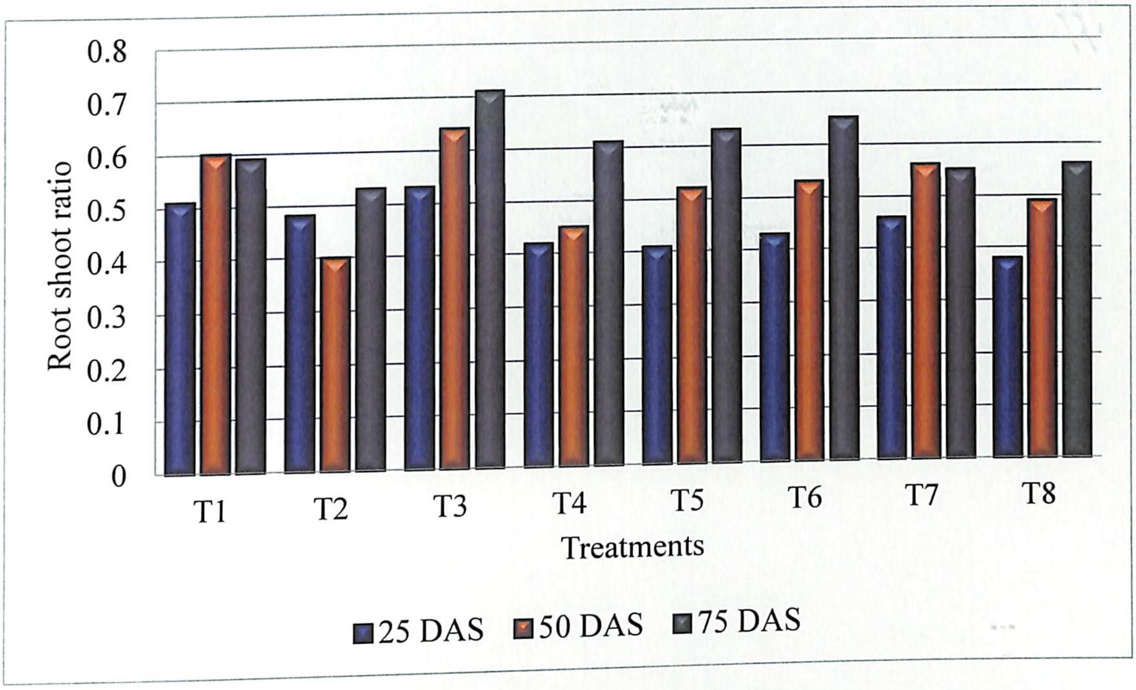

Figure 15: Effect of drought mitigating chemicals on mean root shoot ratio at various crop stages of okra

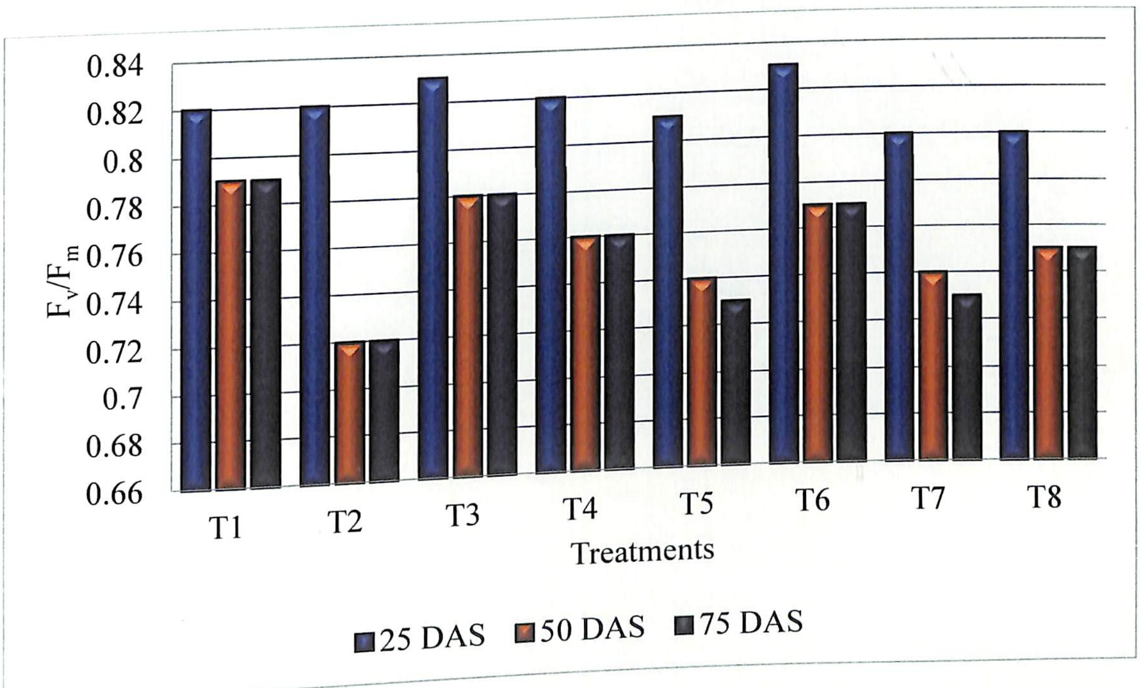

Figure 16: Effect of drought mitigating chemicals on F_v/F_m at various crop stages of okra

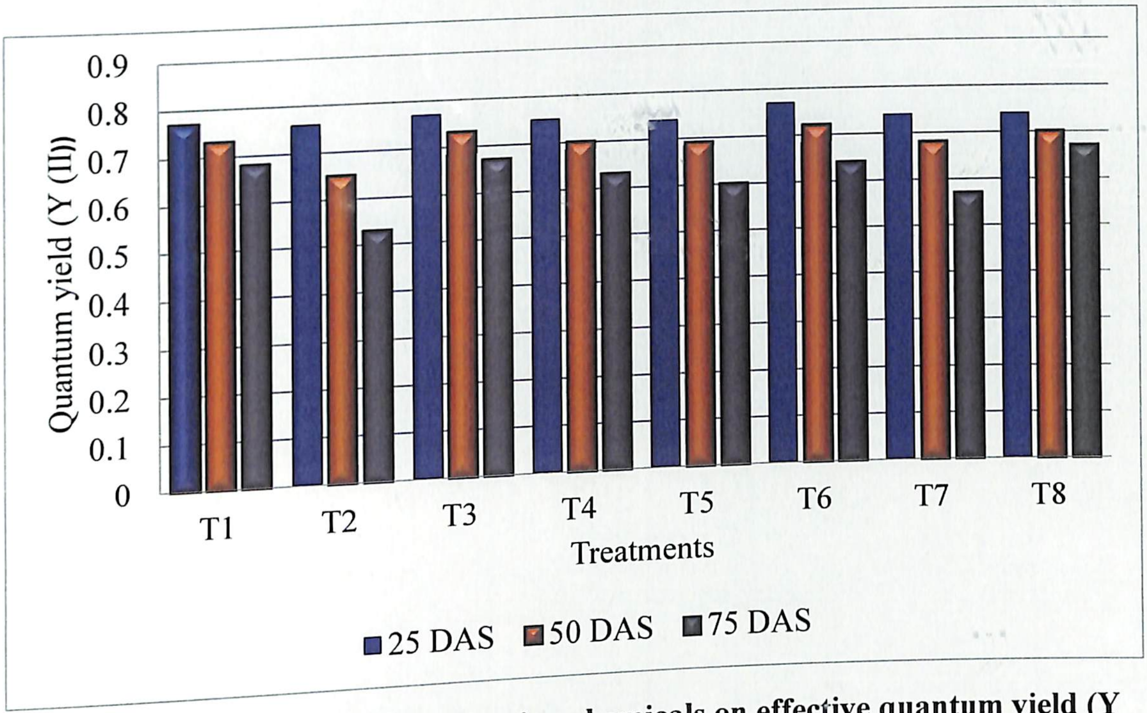

Figure 17: Effect of drought mitigating chemicals on effective quantum yield (Y (II)) at various crop stages of okra

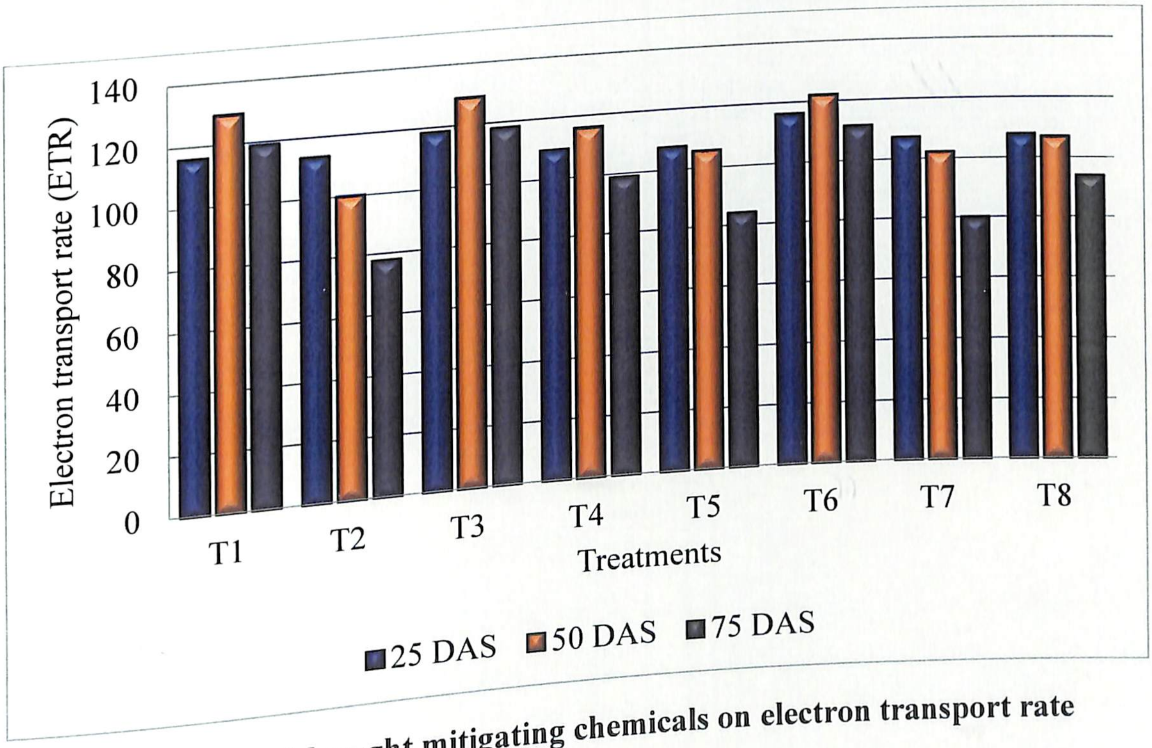

Figure 18: Effect of drought mitigating chemicals on electron transport rate (ETR) of okra

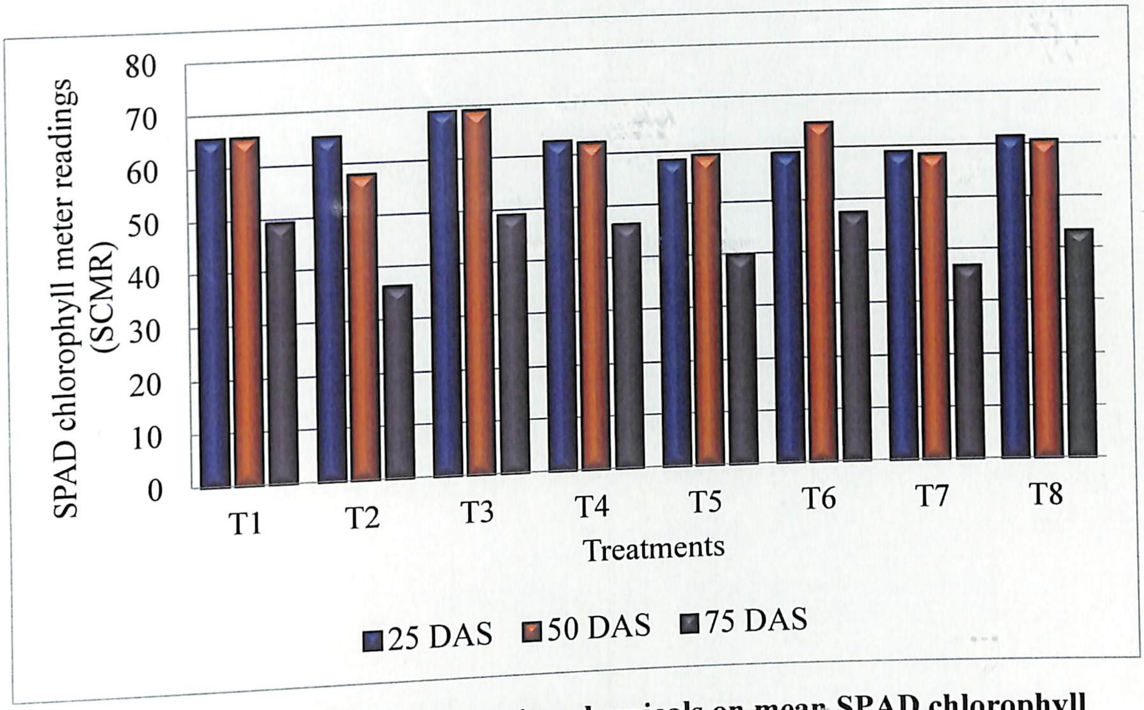

Figure 19: Effect of drought mitigating chemicals on mean SPAD chlorophyll meter readings (SCMR) at various crop stages of okra

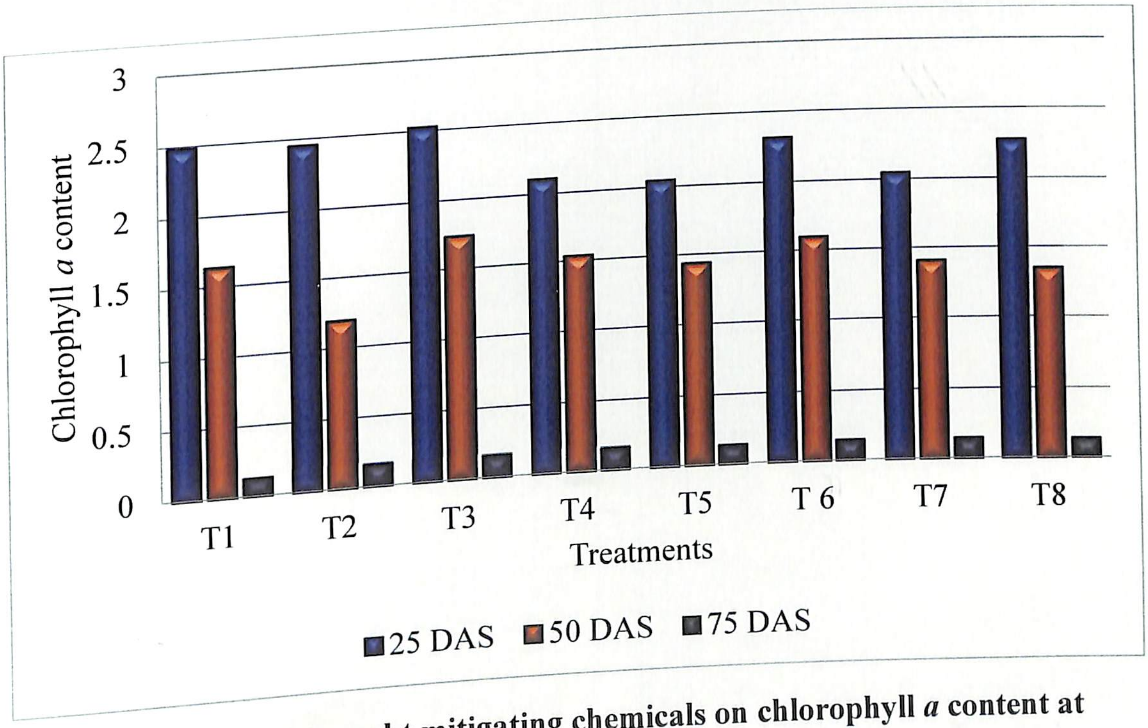

Figure 20: Effect of drought mitigating chemicals on chlorophyll *a* content at various crop stages of okra

which induce decrease in chlorophyll content (Ashraf and Karim, 1991; Huseynova *et al.*, 2009; Anjum *et al.*, 2011).

Foliar spray with salicylic acid 1 mM (T_3) recorded the maximum value for chlorophyll *a* and total chlorophyll under drought condition, which were almost equal with that of normally irrigated plants (Figure 20). The instability of protein complexes and destruction of chlorophyll by increased activity of chlorophyllase enzyme under drought stress condition ultimately results in decreased photosynthetic pigments. The enhancing effects of salicylic acid on photosynthetic pigment could be attributed to its stimulatory effects on Rubisco activity and photosynthesis. Salicylic acid induced synthesis of protein kinases, play an important role in regulating cell division, differentiation and morphogenesis (Zhang and Liu, 2001; El-Tayeb, 2005). SA plays an important role in the nitrate metabolism which is ultimately helpful for production of chlorophyll contents and energy production for almost all metabolic pathways going on in the plants for withstanding the adversities of drought.

5.4. INFLUENCE OF TREATMENTS ON YIELD AND FRUIT QUALITY CHARACTERS

Among the treatments, foliar spray with salicylic acid 1 mM (T_3) or foliar spray of ascorbic acid 2 mM (T_6) produced significantly higher fruit yield compared to other treatments (Figure 22). The control treatment however recorded significantly higher fruit yield (25.50 t ha^{-1}) compared to drought stressed plants.

Vegetative traits like plant height and leaf area had very strong positive correlation on okra yield traits like number of fruits $plant^{-1}$ and average fruit size (Falusi *et al.*, 2012). Reduction in leaf area by water stress is an important cause of reduced crop yield through reduction in photosynthesis (Kramer, 1983).

Salicylic acid foliar spray @ 1mM (T_3) increased the crop yield @ 45.07 per cent over drought stressed crops and 3.25 per cent over control crops. Salicylic acid foliar spray @ 2 mM (T_4) increased the crop yield @ 25.36 per cent over drought stressed crops. Foliar spray of salicylic acid cause higher marketable yield due to bettered assimilation of nutrient uptake, nutrient reduction and photosynthesis improved flow of assimilates and increased cell integrity which in turn reflected on the increased fruit yield (Pradhan *et al.*, 2016). This result was in confirmation with that of Arfan *et al.* (2007) in wheat, Amin *et al.* (2008) in wheat , Jayalakshmi *et al.* (2010) in groundnut, Munir *et al.* (2016) in okra and Pradhan *et al.* (2016) in onion.

Ascorbic acid foliar spray @ 1mM (T_5) and 2 mM (T_6) increased the fruit yield @ 18.15 per cent and 41.32 per cent, respectively, over drought stressed plants. Ascorbic acid increasing the crop yield under drought stress condition was supported by Amin *et al.* (2008) in wheat.

Thiourea foliar spray @ 500 ppm (T_7) and 1000 ppm (T_8) increased the crop yield @ 22.04 per cent and 12.56 per cent, respectively, over drought stressed okra crops (Figure 22). The increase in the yield recorded in this investigation by the application of thiourea could be a reflection of the effect of thiourea on growth and development. These results are conformity with Anitha *et al.* (2006) in horse gram, Ravat and Nirav (2015) in okra, Anitha *et al.* (2006) in cowpea, Sharma *et al.* (2015) in wheat and Singh and Singh (2017) in lentil. Thiourea increased yield by enhancing photosynthesis, efficient transport of photosynthates towards the sink and increased translocation and accumulation of certain metabolites in plant organs which ultimately leads to greater yield (Amin *et al.*, 2014; Singh and Singh, 2017).

The quality parameters such as the crude fibre and ascorbic acid content were significantly influenced by spraying of salicylic acid, ascorbic acid and thiourea. Among the different chemicals, spraying of salicylic acid @ 1 mM (T_3) recorded lowest crude fibre content (6.66%), which will increase the marketable fruit yield (Figure 25). Drought stressed plants (T_2) recorded the highest crude fibre content (8.34%) in fruits. As reported by Elangovan *et al.* (1983), the crude fibre content of okra fruits could be as high as 13.1 to 14.3 per cent in different genotypes and since the crude fibre content obtained with T_2 treatment is much below this reported range it could be still considered as a desirable trait without any effect on succulence and fruit quality.

In the present study, ascorbic acid content of fruits ranged between 19.48 mg 100 g^{-1} to 13.07 mg 100 g^{-1} (Figure 26). The highest ascorbic acid content of 19.48 mg 100 g^{-1} was recorded in control followed by spraying with ascorbic acid foliar spray @ 1mM (T_6) and 2 mM (T_5). Foliar applied AsA significantly increased the AsA content

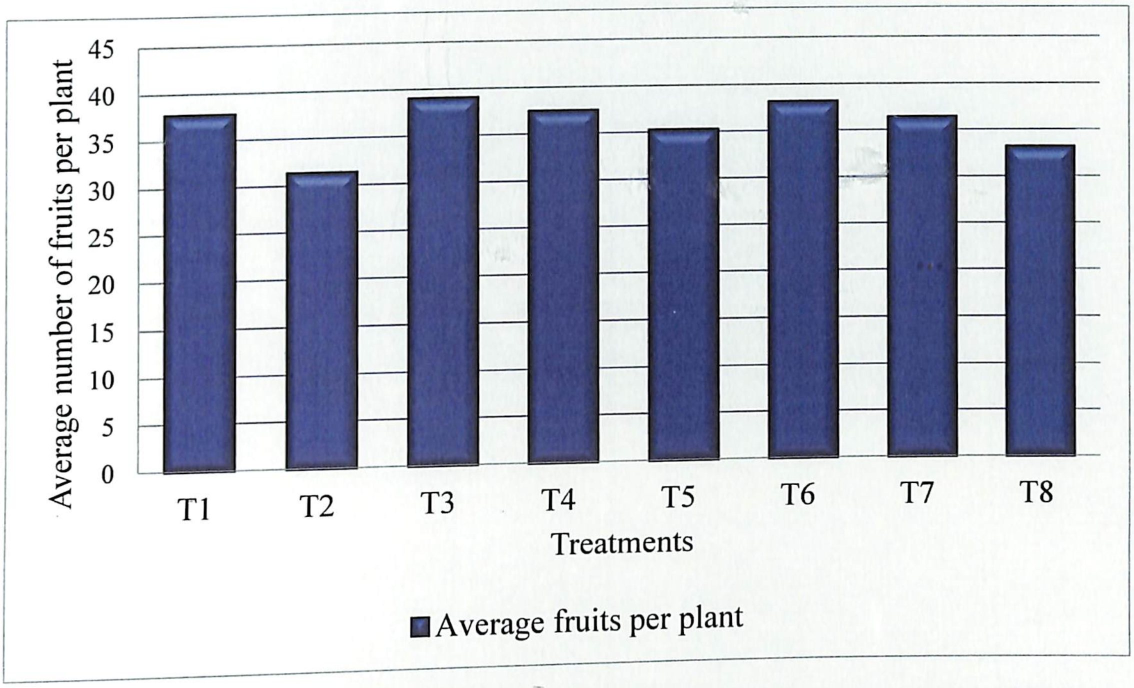

Figure 21: Effect of drought mitigating chemicals on average number of fruits per plant of okra

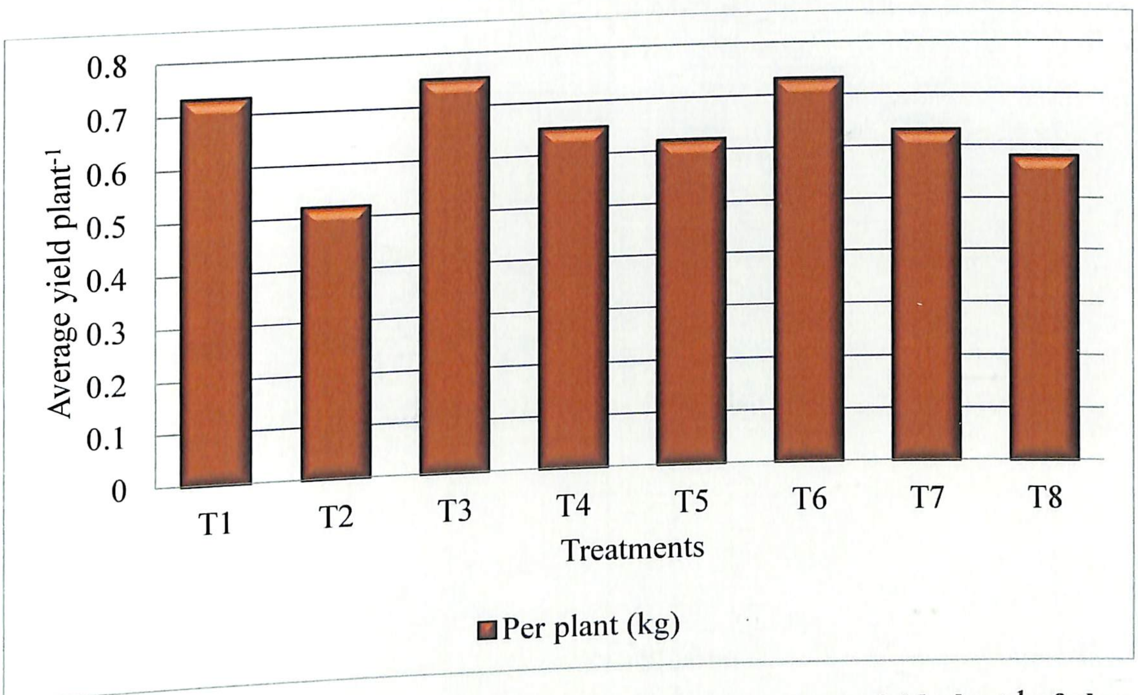

Figure 22: Effect of drought mitigating chemicals on average yield plant^{-1} of okra

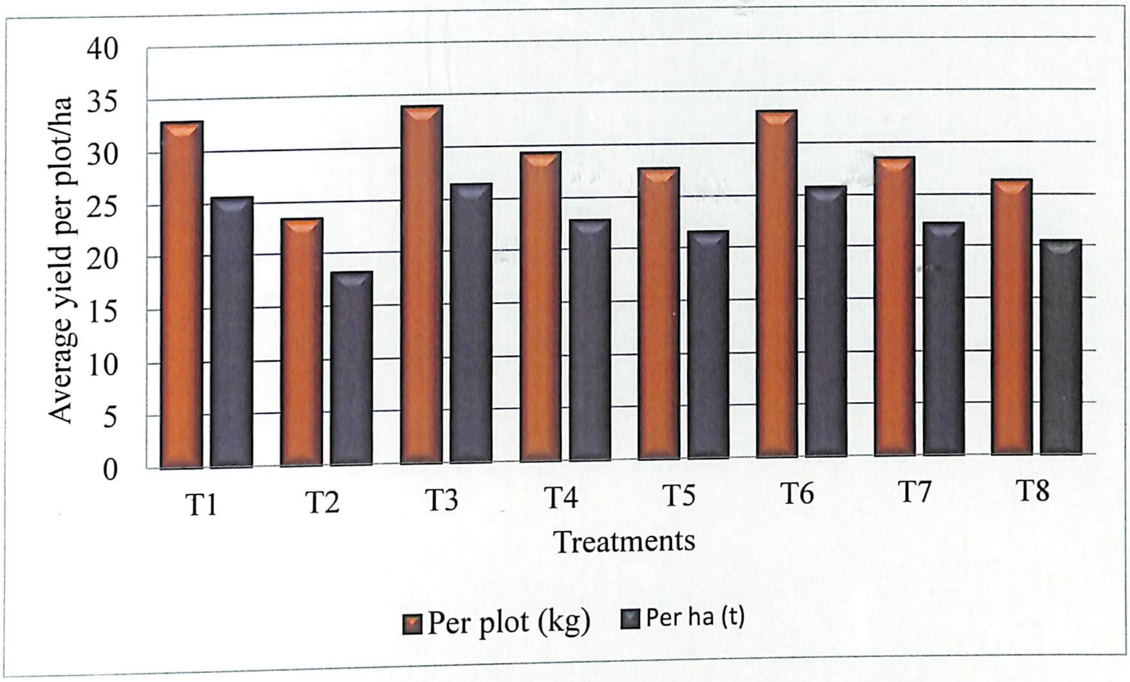

Figure 23: Effect of drought mitigating chemicals on average yield per plot/ha of okra

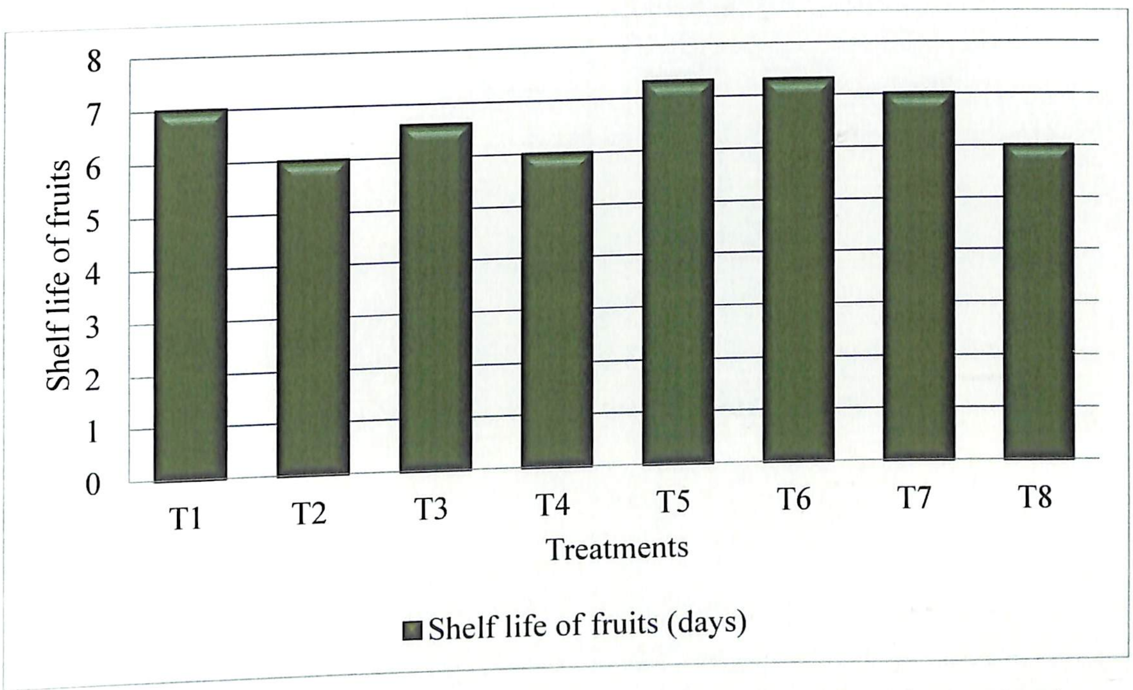

Figure 24: Effect of drought mitigating chemicals on shelf life of fruits (days)

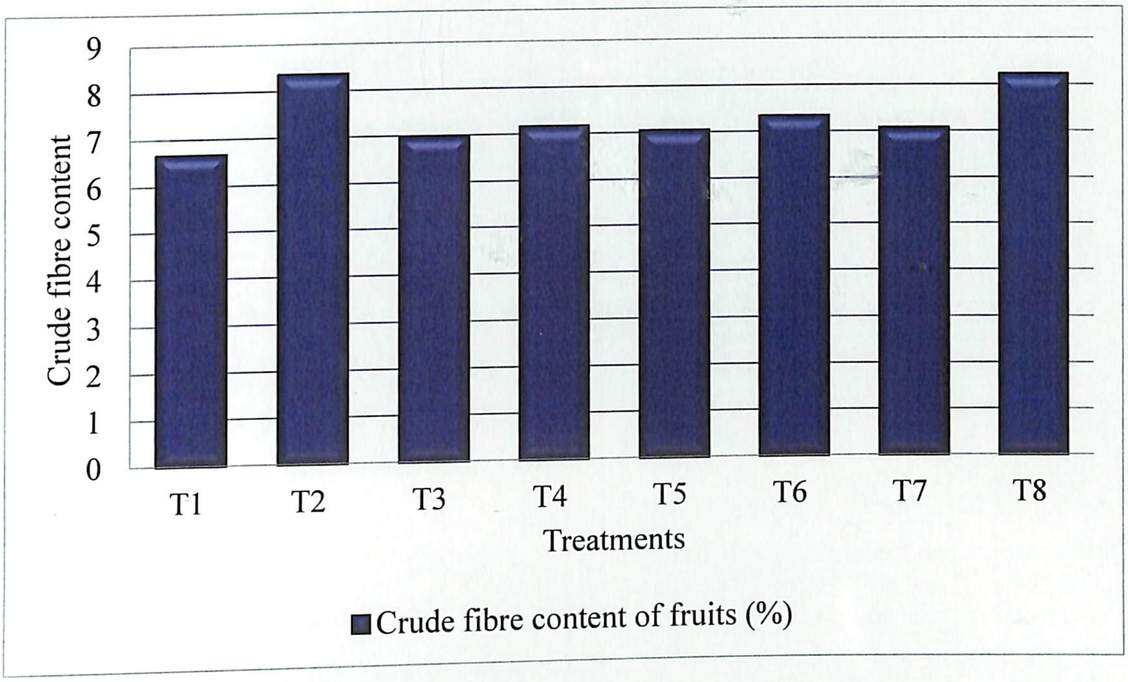

Figure 25: Effect of drought mitigating chemicals on crude fibre content (%) of okra

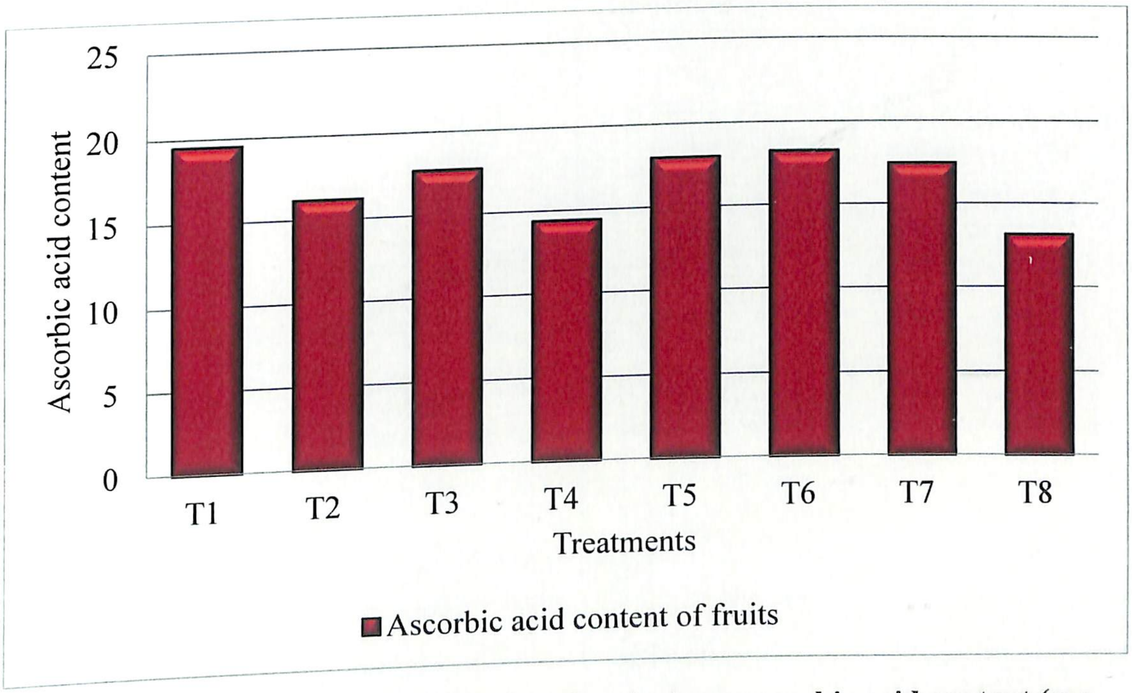

Figure 26: Effect of drought mitigating chemicals on ascorbic acid content (mg 100 g^{-1}) of okra

under water stress and non-stress conditions. Similarly, an increase in AsA content have already been observed in different crops, e.g., wheat (Smirnoff, 2018), tomato (Amirjani and Mahdiyeh, 2013), and canola (Shafiq *et al* 2014).

Foliar spray of ascorbic acid 1mM and 2 mM had maximum shelf life of about 7.3 days followed by control plants and thiourea foliar spray @ 500 ppm (Figure 24). The per cent increase in the shelf life of foliar treated fruits over the drought stressed ranged from 10 per cent to 21.67 per cent.

5.5. IRRIGATION

Frequency of irrigation was highest in control (41 times) followed by drought stress (T_2) (18 times). Irrigation interval was the highest with spraying of salicylic acid @ 1mM, ascorbic acid @ 2 mM and thiourea @ 500 ppm (Figure 27). The results indicated that foliar spray with salicylic acid, ascorbic acid and thiourea maintained turgidity for more duration, up to 5 days even on withdrawing irrigation, which signifies the usefulness of these chemicals. The lowest irrigation interval was noticed with control (2 days) which indicated that the plants wilted quickly on withholding irrigation.

5.5. ECONOMICS OF CULTIVATION

The economics of cultivation was worked out as net returns and benefit: cost ratio. It can be observed that the all the treatments significantly influenced the net returns and benefit: cost ratio.

Spraying of salicylic acid @ 1 mM (T_3) registered the highest net returns and benefit: cost ratio (Figure 28) which were significantly higher than all other treatments. It was observed that ascorbic acid foliar spray @ 2 mM (T_6) and control (T_1) were significantly superior in benefit:cost ratio and net returns. The improvement in net returns could be attributed to the enhanced yield realized in the above treatment. The increased net returns in these treatments are due to higher crop yield. The low net returns and BCR in drought stressed plants are due to low crop yield.

The discussions of the results obtained in this investigation indicated the usefulness of salicylic acid, ascorbic acid and thiourea in drought mitigation in field grown okra. Among different treatments, spraying of salicylic acid (1 mM) was found to be the best treatment for inducing stress tolerance, through reduction in irrigation requirement and it also produced higher yield, net returns and benefit:cost ratio followed by ascorbic acid foliar spray (2 mM). All the three chemicals at different concentration performed better than drought stress treatment (T_2) without foliar spray.

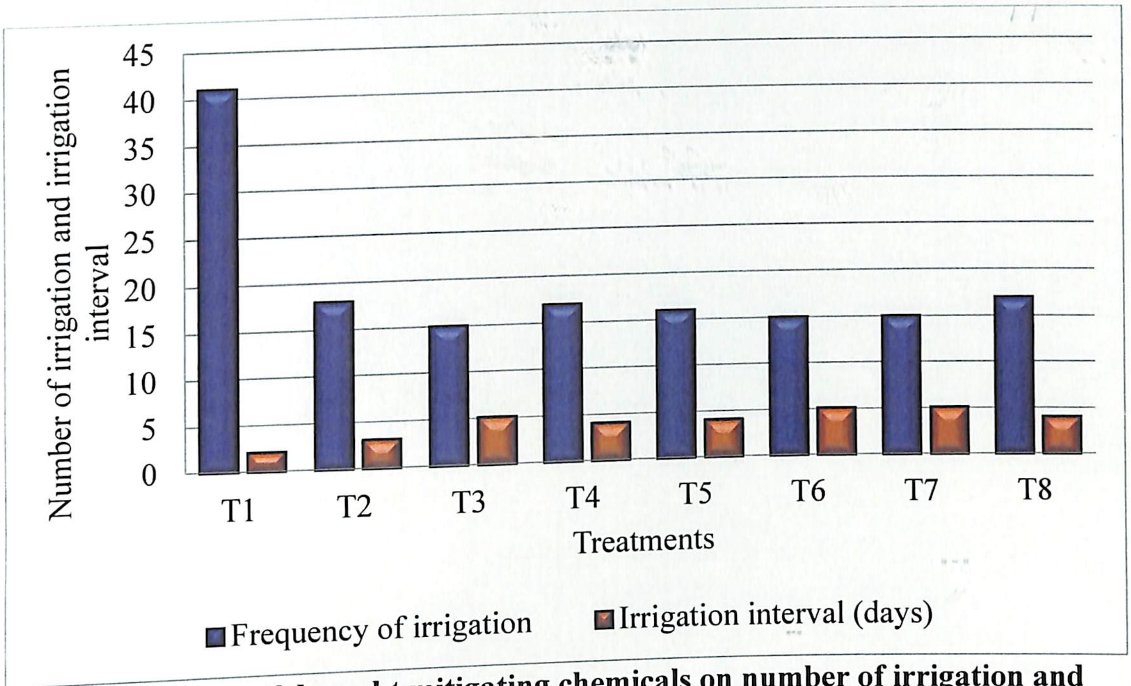

Figure 27: Effect of drought mitigating chemicals on number of irrigation and irrigation interval (days) of okra

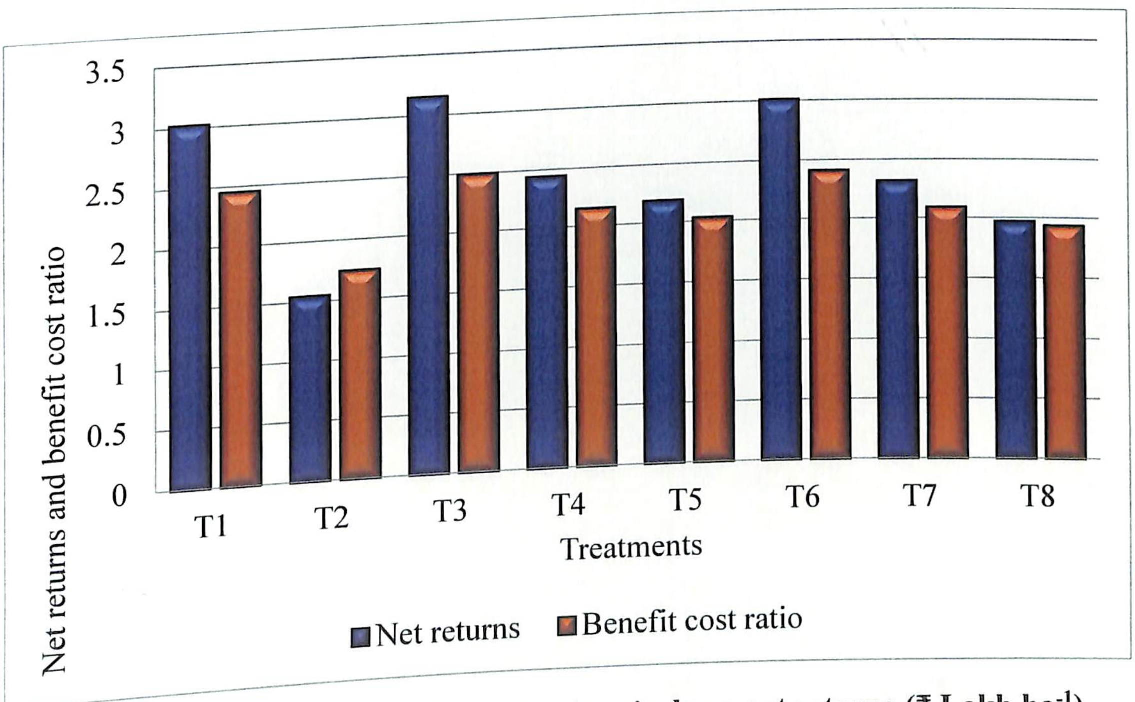

Figure 28: Effect of drought mitigating chemicals on net returns (₹ Lakh ha^{-1}) and benefit cost ratio of okra

Summary

6. SUMMARY

The research work entitled "Drought mitigation in okra (*Abelmoschus esculentus* L.) through chemical approach" was undertaken during December 2019 – March 2020 at Regional Agricultural Research Station, Pilicode. The objective of the study was to investigate the influence of different chemicals namely, salicylic acid, ascorbic acid and thiourea on mitigation of drought and to evaluate their effect on morphological, physiological and yield characteristics of okra.

The field experiment was carried out in randomized block design with eight treatments and three replications. Study was carried out with the okra variety Arka Anamika. The crop was raised as per Package of Practice recommendations of KAU and also under soil test nutrient management system. The experiment consisted of 8 treatments *viz*., normal irrigation (T_1) as control, drought stress (T_2), T_2 + salicylic acid foliar spray @ 1 mM (T_3), T_2 + salicylic acid foliar spray @ 2 mM (T_4), T_2 + ascorbic acid foliar spray @ 1mM (T_4), T_2 + ascorbic acid foliar spray @ 2 mM (T_5), T_2 + thiourea foliar spray @ 500 ppm (T_7) and T_2 + thiourea foliar spray @ 1000 ppm (T_8). Foliar application of chemicals was given at 10, 20 and 30 DAS. Uniform daily irrigation was given to all the treatments till 25 days after sowing to bring the soil moisture content to field capacity. Irrigation was withheld from 25 days after sowing in treatments T_2 to T_8 and re-irrigation was given at 50 per cent field capacity or when the plant showed temporary wilting symptoms. Irrigation was given on alternative days in control plot throughout the crop growth period. A few sunflower plants (an indicator plant) were also grown in the field without any shading effect to the crop. Indicator plants shows wilting symptom (indication of drought stress) much before the crop. The salient findings of the study are summarized below.

- The highest plant height was recorded in salicylic acid foliar spray of 1 mM at 25, 50 and 75 DAS. The treatment was on par with ascorbic acid foliar spray @ 1 mM and 2 mM and control at 25 DAS and with control at 75 DAS.
- Maximum number of leaves plant^{-1} were recorded in salicylic acid foliar spray @ 1 mM at 25, 50 and 75 DAS. The treatment was on par with ascorbic acid foliar spray @ 2 mM.

- Maximum number of branches plant^{-1} were recorded in salicylic acid foliar spray @ 1 mM at 25 DAS. At 50 and 75 DAS, maximum number of branches plant^{-1} were recorded in control plants, and this treatment was on par with salicylic acid foliar spray @ 1 mM.
- Higher root volume was observed in salicylic acid foliar spray @ 1 mM at 25 DAS. At 50, maximum root volume was recorded in control, and this treatment was on par with salicylic acid foliar spray @ 1 mM, ascorbic acid foliar spray @ 2 mM, thiourea foliar spray @ 500 ppm and 1000 ppm. At 75 DAS, higher root volume was observed in salicylic acid foliar spray @ 1 mM and control. These treatments were on par with ascorbic acid foliar spray @ 1 mM and 2 mM.
- Days to 50 per cent flowering and days to first harvest did not differ significantly with treatments. Although not significant, drought stressed plants took more days (37.9 days) to complete 50 per cent flowering and salicylic acid foliar spray @ 2 mM took minimum days (36.2 days) to complete 50 per cent flowering. The highest number of days (42.1 days) to first harvest was recorded with drought stressed plants and the least number of days to first harvest (37.8 days) was recorded with thiourea foliar spray @ 1000 ppm.
- Maximum fruit length (20.33 cm) was recorded in salicylic acid foliar spray @ 2 mM, this was on par with ascorbic acid foliar spray @ 2 mM. The highest fruit girth and fruit weight was exhibited by salicylic acid foliar spray @ 1 mM.
- Maximum number of pickings and highest duration of crop were recorded in foliar spray of salicylic acid @ 1 mM. This treatment was on par with all other treatment except drought stressed and foliar spray of thiourea treatments.
- The major pest observed in the field during the crop period were leaf folder (*Sylepta derrogata*), fruit borer (*Helicoverpa armigera*) and jassids (*Amrasca biguttula biguttula*).
- The frequency of irrigation given was highest in control (41 times) followed by drought stress (18 times) and thiourea foliar spray @ 1000 ppm (17 times). The lowest frequency of irrigation given were in foliar spray of salicylic acid @ 1 mM, ascorbic acid @ 2 mM and thiourea @ 500 ppm (15 times).

- The irrigation interval was more with foliar spray of salicylic acid @ 1 mM, ascorbic acid @ 2 mM and thiourea @ 500 ppm (5 days).
- Upto 75 DAS, maximum relative growth rate was observed when sprayed with salicylic acid @ 1 mM. All the treatments performed better than droughtstress treated crops.
- At all the growth stages, maximum specific leaf weight was exhibited when sprayed with salicylic acid @ 1 mM.
- Leaf area was significantly influenced by treatments at all crop growth stages of okra. At 25, 50 and 75 DAS, the highest leaf area was recorded in foliar spray of salicylic acid @ 1 mM. At 25 DAS, this treatment was on par with foliar spray of ascorbic acid @ 1 mM and 2 mM and salicylic acid @ 2 mM. At 50 DAS, it was on par with foliar spray of ascorbic acid @ 2 mM, salicylic acid @ 2 mM and control.
- At 25 DAS, the highest relative leaf water content (RLWC) was recorded in treatment foliar spray of salicylic acid @ 1 mM (92.52%), which was on par with control and drought stress treatment. At 50 DAS, the maximum relative leaf water content was recorded in control crops (86.60%), which was on par with foliar spray of salicylic acid and ascorbic acid (1 mM and 2 mM) and thiourea 500 ppm. At 75 DAS, relative leaf water content was recorded the highest in control followed by salicylic acid @ 1 mM and ascorbic acid @ 2 mM.
- Total dry matter production did not vary significantly with treatments at 25 DAS. At 50 and 75 DAS, maximum dry matter was accumulated by foliar spray of salicylic acid @ 1 mM. This treatment was on par with control at 50 DAS and foliar spray of ascorbic acid @ 2 mM at 75 DAS.
- Foliar spray of salicylic acid @ 1 mM showed higher value for root shoot ratio at 25, 50 and 75 DAS. At 25 DAS and 50 DAS, this treatment was on par with control.
- The maximum SPAD chlorophyll meter readings (SCMR) was recorded in salicylic acid foliar spray @ 1 mM at 25 and 50 DAS. At 75 DAS, maximum SCMR value was recorded in control, which was on par with foliar spray of

salicylic acid (1 mM and 2 mM), ascorbic acid @ 2 mM and thiourea @ 1000 ppm.

- Maximum F_v/F_m value at 25 DAS was recorded in salicylic acid foliar spray @ 1 mM followed by ascorbic acid @ 2 Mm. At 50 DAS and 75 DAS Maximum F_v/F_m value was in control followed by salicylic acid @ 1 mM and ascorbic acid @ 2 mM.
- Treatments did not have significant effects on Y (II) at 25 DAS. At 50 DAS, the highest Y (II) value was recorded in control and salicylic acid foliar spray @ 1 mM which were on par with all the treatment except drought stress. At 75 DAS, the highest Y (II) value was recorded in control followed by followed by salicylic acid @ 1 mM and ascorbic acid @ 2 mM.
- Maximum ETR was recorded in salicylic acid foliar spray @ 1 mM which was on par with control and ascorbic acid foliar spray @ 2 mM. At 50 DAS and 75 DAS, maximum ETR was recorded in control and foliar spray of salicylic acid @ 1 mM. These treatments were on par with foliar spray of salicylic acid @ 2 mM and ascorbic acid @ 2 mM.
- Chlorophyll *a* was found significantly different at all the three growth stages observed. At 25, 50 and 75 DAS, higher value for chlorophyll *a* content was recorded when sprayed with salicylic acid @ 1 mM. This treatment was on par with control and drought stress at 25 DAS and control and foliar spray of ascorbic acid @ 2 mM at 50 DAS. At 75 DAS, this treatment was on par with all others except control and thiourea spray @ 1000 ppm.
- Chlorophyll *b* was observed not varying significantly with treatments.
- Total chlorophyll was significantly different at 25 and 50 DAS but did not differ significantly with all the treatments at 75 DAS. The maximum value for total chlorophyll was recorded in salicylic acid foliar spray @ 1 mM at 25 and 50 DAS. This treatment was on par with control, drought stress and thiourea spray @ 1000 ppm at 25 DAS and control, ascorbic acid foliar spray @ 2 mM at 50 DAS.
- Maximum number of fruits per plant were recorded in control, foliar spray of salicylic acid @ 1 mM, 2 mM and ascorbic acid @ 2 mM. These treatments

were on par with foliar spray of ascorbic acid @ 1 mM and thiourea @500 ppm.

- The highest total fruit yield was recorded in foliar spray of salicylic acid @ 1 mM followed by ascorbic acid @ 2 mM. These treatments recorded 45 per cent and 41 per cent higher yield over drought stressed treatment respectively. Also salicylic acid @ 2 mM, ascorbic acid @ 1 mM, thiourea @ 500 ppm and thiourea @ 1000 ppm recorded 25.6 per cent, 18.5 per cent, 22.04 per cent and 12.56 per cent higher yield over drought stressed treatment respectively.
- The highest shelf life of fruits was recorded in foliar spray of ascorbic acid @ 1 mM (7.3 days), ascorbic acid @ 2 mM (7.3 days), control (7.0 days) and thiourea @ 500 ppm (7.0 days). These treatments were on par with salicylic acid foliar spray @ 1 mM (6.6 days).
- Data collected on crude fibre content ranged between 6.66 per cent to 8.34 per cent. Among the treatments the lowest crude fibre content was recorded in salicylic acid foliar spray @ 1 mM (6.66%) and ascorbic acid @ 1 mM (7.03%). The highest crude fibre content was recorded in drought stressed crops (8.34%).
- Ascorbic acid content of fruits ranged between 19.48 mg 100 g^{-1} to 13.07 mg 100 g^{-1}. Maximum ascorbic acid content was recorded in control followed by foliar spray of ascorbic acid 2 mM and 1 mM.
- The highest net returns (₹ 3.15 lakh ha^{-1}) and BCR (2.49) were obtained in salicylic acid foliar spray @ 1 mM followed by ascorbic acid foliar spray @ 2 mM.

Perusal of results revealed that foliar spray of salicylic acid @ 1 mM to field grown okra crops under both stressed and non-stressed condition was found to be the ideal treatment. This treatment induced stress tolerance, reduced the irrigation requirement, increased irrigation interval and produced higher yield, net returns and benefit:cost ratio than control and all other treatments. Ascorbic acid foliar spray @ 2 mM was found to be the next promising one. Hence the present study concluded that foliar spray of salicylic acid (1 mM) and ascorbic acid (2 mM) had mitigated the harmful effects of drought stress in okra.

FUTURE LINE OF WORK

- Testing the efficacy of chemicals in normal irrigated condition.
- Investigate the efficacy of chemicals under controlled (rain shelter) conditions.
- Identification of chemical constituents which induced the drought tolerance.
- Efficacy of chemicals on other abiotic stress mitigation can be looked into.
- Different concentrations and combinations of the chemicals can be tested.
- This same experiment can be done in other vegetable crops.

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Appendix

Appendix I. Weather parameters during the crop season in standard weeks

Standard weeks	Temperature (^0C)		Relative humidity (%)	Rainfall (mm)	Sunshine (hrs)
	Maximum	Minimum			
49 (Dec 3 – Dec 9)	31.7	22.4	75.8	7.3	7.6
50 (Dec 10 – Dec 16)	32.0	22.5	74.8	0	9.0
51 (Dec 17 – Dec 23)	31.8	27.1	73.7	0	8.6
52 (Dec 24 – Dec 31)	31.0	22.1	81.2	8	6.3
1 (Jan 1 – Jan 7)	31.1	22.3	76.3	0	9.3
2 (Jan 8 – Jan 14)	32.0	21.0	75.0	0	9.5
3 (Jan 15 – Jan 21)	31.3	21.5	74.1	0	9.1
4 (Jan 22 – Jan 28)	32.0	22.4	73.8	0	9.6
5 (Jan 29 – Feb 4)	31.5	22.4	72.8	45.8	9.6
6 (Feb 5 – Feb 11)	31.4	20.7	74.6	0	9.8
7 (Feb 12 – Feb 18)	32.6	22.6	75.0	0	9.5
8 (Feb 19 – Feb 25)	32.5	23.2	75.1	0	8.8
9 (Feb 26 – Mar 4)	31.9	24.4	77.4	0	6.6
10 (Mar 5 – Mar 11)	32.5	23.6	72.4	0	8.1
11 (Mar 12 – Mar 18)	32.7	24.1	74.5	0	9.0
12 (Mar 19 – Mar 25)	32.9	23.8	74.5	0	8.8
13 (Mar 26 – April 1)	33.2	25.3	75.8	0	7.6

DROUGHT MITIGATION IN OKRA (*Abelmoschus esculentus* L.) THROUGH CHEMICAL APPROACH

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Drought mitigation in okra (*Abelmoschus esculentus* L.) through chemical approach

Okra or Bhindi (*Abelmoschus esculentus* L.) is one of the most popular summer vegetable crop grown widely in Kerala for its edible green fruits. Drought is a major yield limiting factor in agriculture and vegetables are more sensitive to drought stress as compared to most of the field crops because of their high water requirement.

Hence, the study entitled "Drought mitigation in okra (*Abelmoschus esculentus* L.) through chemical approach" was carried out with the objective to investigate the influence of different chemicals namely, salicylic acid, ascorbic acid and thiourea on mitigation of drought and to evaluate their effect on morphological, physiological and yield charcteristics of okra.

The field experiment was laid out in randomized block design with 8 treatments and 3 replications at RARS, Pilicode during December 2019 to March 2020. The okra variety Arka Anamika was raised as per standard package of practices recommendations of Kerala Agricultural University and also under soil test based nutrient management system. The experiment consisted of 8 treatments *viz.*, normal irrigation (T_1) as control, drought stress (T_2), T_2 + salicylic acid foliar spray @ 1 mM (T_3), T_2 + salicylic acid foliar spray @ 2 mM (T_4), T_2 + ascorbic acid foliar spray @ 1 mM (T_4), T_2 + ascorbic acid foliar spray @ 2 mM (T_5), T_2 + thiourea foliar spray @ 500 ppm (T7), T_2 + thiourea foliar spray @ 1000 ppm (T8). Foliar application of chemicals were given at 10, 20 and 30 DAS and stress was induced by withholding irrigation from 25 days of sowing and re-irrigation was given at 50 per cent field capacity. Morphological, physiological and biochemical parameters were recorded at 25, 50 and 75 DAS and the yield and fruit quality characters were recorded at the time of harvest.

A perusal of morphological data showed that T_3 had maximum plant height, number of leaves plant^{-1}, number of pickings and highest duration of the crop followed

by T_6 when compared to all other treatments. The maximum number of branches per plant and the highest root volume were recorded in T_1 which was on par with T_3 followed by T_6. Foliar spray of chemicals did not significantly influence number of days for 50 per cent flowering and first harvest.

Up to 75 DAS, maximum relative growth rate was observed T_3. All the treatments performed better than drought stress treated crops. At all the growth stages, maximum specific leaf weight was exhibited T_3. Leaf area was observed maximum for T_3 and was on par with T_4, T_5, T_6 at 25 DAS and T_1, T_4 and T_6 at 50 DAS and T_6 at 75 DAS. The relative leaf water content was recorded the highest for T_3 at 25 DAS and for T_1 at 50 and 75 DAS. At 50 DAS, T_1 was on par with T_3, T_6 and T_7 and at 75 DAS T_1 was followed by T_3 and T_6. T_3 had maximum total dry matter production which was on par with T_1 and T_4.at 25 and 50 DAS, respectively. Root shoot ratio was recorded maximum in T_3 which was on par with T_1 at 25 and 50 DAS. SPAD chlorophyll meter reading (SCMR) was recorded maximum in T_3 at 25 and 50 DAS and in T_1 at 75 DAS. T_1 was on par with T_3, T_4 and T_6 at 75 DAS.

Considering the yield and fruit quality attributes, T_4 recorded maximum value for fruit length and was on par with T_1, T_7 and T_8. The highest average fruit girth and fruit weight were exhibited in T_3 and lowest was in drought stressed crop (T_2). The treatment T_1, T_3, T_4 and T_6 recorded maximum number of fruits plant^{-1} which were on par with T_5 and T_7. The highest total fruit yield was recorded in foliar spray of salicylic acid (1 mM) followed by ascorbic acid (2 mM). These treatments recorded 45 per cent and 41 per cent higher yield over drought stressed treatment, respectively. The crude fibre content was recorded highest for drought stressed crops (T_1) and the lowest was recorded in T_3. The ascorbic acid content was observed maximum in T_1 followed by T_5 and T_6.

The highest net returns and BCR was obtained in T_3 followed by T_6. The frequency of irrigation given was highest in T_1 followed by T_2 and T_8. The lowest frequency of irrigation given were in T_3, T_6 and T_7. The irrigation interval was more with T_3, T_6 and T_7 (5 days).

It can be concluded that morphological, physiological, biochemical and yield traits of okra were severely affected under drought stress. Among the three drought mitigating chemicals, salicylic acid (1 mM) recorded maximum values for morphological traits *viz.*, plant height, number of leaves plant^{-1}, root volume and duration of crop, followed by ascorbic acid (2 mM), which also significantly improved morphological traits of okra compared to all other treatments. Physiological traits such as total dry matter production, leaf area plant^{-1}, relative growth rate, specific leaf weight, root shoot ratio and SPAD chlorophyll meter reading increased over drought stress crop when sprayed with salicylic acid (1 mM) and ascorbic acid (2 mM). Salicylic acid (1 mM) and ascorbic acid (2 mM) is beneficial for getting higher fruit yield and maximum economic returns over drought stressed and normal irrigated crops. Therefore, application of salicylic acid (1 mM) and ascorbic acid (2 mM) significantly mitigated the harmful effect of drought stress in okra.

സംക്ഷിപ്തം

കേരളത്തിൽ വ്യാപകമായി കൃഷി ചെയ്തു വരുന്ന വേനൽക്കാല പച്ചക്കറി വിളകളിലൊന്നാണ് വെണ്ട. മറ്റു വിളകളെ താരതമ്യം ചെയ്യുമ്പോൾ പച്ചക്കറികൾക്ക് ജലത്തിന്റെ ആവശ്യകത കൂടുതലായതു കൊണ്ട് തന്നെ, വരൾച്ച വിളവിനെ കാര്യമായി ബാധിക്കുന്നു. ഇതിന്റെ അടിസ്ഥാനത്തിൽ രാസവസ്തുക്കളായ സാലിസിലിക് ആസിഡ്, അസ്കോർബിക് ആസിഡ്, തയോയൂറിയ എന്നിവയുടെ പ്രയോഗം വഴി വെണ്ടയിൽ വരൾച്ചയുടെ ആഘാതം കുറക്കുക, ഇവയുടെ സ്വാധീനം ചെടിയുടെ രൂപ സവിശേഷത, വിളവ്, സസ്യ ധർമങ്ങൾ എന്നിവയിൽ വരുന്ന മാറ്റങ്ങൾ വിലയിരുത്തുക എന്ന ഉദ്ദേശ്യ ലക്ഷ്യത്തോടെ, "രാസമാർഗങ്ങളിലൂടെ വെണ്ടയിൽ വരൾച്ചയുടെ ആഘാതം കുറക്കൽ" എന്ന തലക്കെട്ടിൽ പഠനം നടത്തുകയുണ്ടായി.

ഡിസംബർ 2019 മുതൽ ജനുവരി 2020 കാലയളവിൽ കാർഷിക കോളേജ് പടന്നക്കാട്, പിലിക്കോട് പ്രാദേശിക കാർഷിക ഗവേഷണ കേന്ദ്രം എന്നിവിടങ്ങളായി പരീക്ഷണം നടത്തി. അർക്കാ അനാമിക എന്ന വെണ്ട ഇനമാണ് പഠനത്തിനായി ഉപയോഗിച്ചത്. റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈനിൽ 8 പരിചരണമുറകൾ 3 അവർത്തനങ്ങളോടു കൂടിയാണ് പരീക്ഷണം കൃഷിയിടത്തിൽ ആവിഷ്കരിച്ചത്. കേരള കാർഷിക സർവകലാശാല ശുപാർശ പ്രകാരമുള്ള വിള പരിപാലന മുറയാണ് വെണ്ട കൃഷിയിൽ പിന്തുടർന്നത്. പഠനത്തിനായി ഉപയോഗിച്ച പരിചരണ മുറകളുടെ വിവരണങ്ങൾ: സാധാരണ ജലസേചനം (T_1), വരൾച്ചാ സമ്മർദ്ദം ചെലുത്തൽ (T_2), T_2+ സാലിസിലിക് ആസിഡ് @ 1 mM ഇലകളിൽ തളിക്കൽ (T_3), T_2 + സാലിസിലിക് ആസിഡ് @ 2 mM ഇലകളിൽ തളിക്കൽ (T_4), T_2 + അസ്കോർബിക് ആസിഡ് @ 1 mM (T_5) ഇലകളിൽ തളിക്കൽ, T_2 + അസ്കോർബിക് ആസിഡ് @ 2 mM ഇലകളിൽ തളിക്കൽ (T_6), T_2 + തയോയൂറിയ @ 500 ppm ഇലകളിൽ തളിക്കൽ (T_7), T_2 + തയോ യൂറിയ @ 1000 ppm ഇലകളിൽ തളിക്കൽ (T_8).

വിത്തു നട്ടതിനു ശേഷം, പത്താമത്തെയും, ഇരുപത്താമത്തെയും, മുപ്പതാമത്തെയും ദിവസങ്ങളിലാണ് രാസവസ്തുക്കൾ അടങ്ങിയ ലായനികൾ ഇലകളിൽ തളിച്ചു കൊടുത്തത്. നട്ടതിനു ശേഷം വരൾച്ചാ സമ്മർദ്ദം ചെലുത്തുന്നതിനായി ജലസേചനം പിൻവലിക്കുകയും തുടർന്ന് ഫീൽഡ് കപ്പാസിറ്റി 50 ശതമാനം ആവുമ്പോൾ വീണ്ടും ജലസേചനം നടത്തുകയും ചെയ്തു. വിത്തു നട്ടതിനു 25, 50, 75 ദിവസങ്ങൾക്കു ശേഷം ചെടിയുടെ രൂപ സവിശേഷതകൾ, സസ്യ ധർമ്മങ്ങൾ, ജൈവ രാസ ഗുണങ്ങൾ എന്നിവ നിരീക്ഷിച്ചു. വെണ്ടയിൽ നിന്നു ലഭ്യമായ വിളവും, ഫല ഗുണനിലവാരവും വിളവെടുപ്പു സമയത്തു തന്നെ രേഖപ്പെടുത്തുകയും ചെയ്തു.

ചെടിയുടെ ഉയരം, ഒരു ചെടിയിലെ ഇലകളുടെ എണ്ണം, വിളവെടുപ്പുകളുടെ എണ്ണം, വിള ദൈർഘ്യം എന്നിവയിൽ T_3 മുന്നിട്ടു നിന്നു. T_3 ക്കു പുറമെ മേൽപറഞ്ഞ സവിശേഷതകളിൽ T_6 ഉം മികച്ചതായി കാണപ്പെട്ടു. ശാഖകളുടെ എണ്ണത്തിലും, വേരുകളുടെ വ്യാപ്തിയിലും T_1 ഉം T_3 യും ഉയർന്ന അളവ് രേഖപ്പെടുത്തി.

നട്ടതിനു ശേഷം 75 ദിവസം വരെ ആപേക്ഷിക വളർച്ചാ നിരക്കിൽ T_3 മുന്നിട്ടു നിന്നു. നിരീക്ഷണത്തിന്റെ എല്ലാ ഘട്ടങ്ങളിലും നിർദിഷ്ട ഇലയുടെ ഭാരം T_3 യിൽ ഉയർന്ന മൂല്യം രേഖപ്പെടുത്തി. T_3 യിൽ പരമാവധി ഇലയുടെ വിസ്തീർണ്ണം നിരീക്ഷിച്ചു. ഇലകളിലെ ആപേക്ഷിക ജലത്തിന്റെ അളവിൽ നട്ടതിനു 25 ദിവസത്തിനു ശേഷം T_3 യിലും നട്ടതിനു 50 മത്തെയും 75 മത്തെയും ദിവസത്തിനു ശേഷം T_1 ലും ഏറ്റവും ഉയർന്ന അളവ് രേഖപ്പെടുത്തി. മൊത്തം ഉണങ്ങിയ വസ്തുക്കൾ T_3 യിൽ കൂടുതലായി കണ്ടെത്തി, ഇവ T_3 ക്കു പുറമെ നട്ടതിനു 25 ഉം, 50 ഉം ദിവസങ്ങൾക്കു ശേഷം, യഥാക്രമം T_1, T_4 എന്നിവ പ്രയോഗിച്ച ചെടികളിൽ തുല്യ നിലവാരം രേഖപ്പെടുത്തി. വേര് തണ്ട് അനുപാതം T_3 ഉം, T_1 ഉം, പരമാവധി രേഖപ്പെടുത്തി. SPAD ക്ലോറോഫിൽ മീറ്റർ റീഡിംഗ് (SCMR) പരമാവധി T_3 ൽ നട്ടതിനു 25 ഉം, 50 ഉം ദിവസങ്ങൾക്കു ശേഷവും T_1 ൽ നട്ടതിനു 75 ദിവസങ്ങൾക്കു ശേഷവും രേഖപ്പെടുത്തി.

വിളവും പഴത്തിന്റെ ഗുണനിലവാരവും കണക്കിലെടുക്കുമ്പോൾ, T_4 പഴത്തിന്റെ നീളത്തിന്റെ പരമാവധി മൂല്യം രേഖപ്പെടുത്തുകയും T_1, T_7, T_8 എന്നിവയ്ക്ക് തുല്യവുമായിരുന്നു. ഏറ്റവും ഉയർന്ന ശരാശരി ഫല വ്യാസം, പഴത്തിന്റെ ഭാരവും T_3 ൽ രേഖപ്പെടുത്തി, ഏറ്റവും കുറവ് രേഖപ്പെടുത്തിയത് വരൾച്ച സമ്മർദ്ദം ചെലുത്തിയ വിളകളിലാണ് (T_2). T_1, T_3, T_4, T_6 യിലാണ് വെണ്ടയുടെ എണ്ണം കൂടുതൽ രേഖപ്പെടുത്തിയത്. സാലിസിലിക് ആസിഡ് (1 mM) ഉം അസ്കോർബിക് ആസിഡ് (2 mM) ഉം ഇലയിൽ തളിച്ചപ്പോഴാണ് ഏറ്റവും കൂടുതൽ ഫലം നൽകിയത്. T_3, T_6 യഥാക്രമം 45%, 41% ഉയർന്ന വിളവ് രേഖപ്പെടുത്തി. വരൾച്ച സമ്മർദ്ദം നേരിട്ട വിളകളിലാണ് (T_1) ഏറ്റവും കൂടുതൽ ക്രൂഡ് ഫൈബർ അടങ്ങിയിട്ടുള്ളത്, ഏറ്റവും കുറഞ്ഞത് T_3 ലും. അസ്കോർബിക് ആസിഡിന്റെ അളവ് T_1, T_5, T_6 എന്നിവയിൽ കൂടുതലായി കാണപ്പെട്ടു.

ഏറ്റവും ഉയർന്ന അറ്റാദായവും, വരവ് ചെലവ് അനുപാതവും T_3 ലും T_6 ലും ആയിരുന്നു. നൽകിയ ജലസേചനത്തിന്റെ എണ്ണത്തിൽ T_1 ഉയർന്നു നിന്നു, തുടർന്ന് T_2, T_8 എന്നിവയിലാണ്. ജലസേചനത്തിന്റെ ഏറ്റവും കുറഞ്ഞ എണ്ണം T_3, T_6, T_7 എന്നിവയിലായിരുന്നു. ജലസേചന ഇടവേള T_3, T_6, T_7 (5 ദിവസം) എന്നിവയിലാർന്നു കൂടുതൽ.

വരൾച്ചാ സമ്മർദ്ദം വെണ്ടയുടെ രൂപ സവിശേഷത, സസ്യ ധർമങ്ങൾ, വിളവ് എന്നിവയെ കാര്യമായി തന്നെ ബാധിച്ചു. വരൾച്ച ലഘൂകരിക്കുന്ന മൂന്ന് രാസവസ്തുക്കളിൽ, സാലിസിലിക് ആസിഡ് (1mM) ചെടികളുടെ ഉയരം, ഒരു ചെടിയിലെ ഇലകളുടെ എണ്ണം, വേരിന്റെ വ്യാപ്തി, വിളയുടെ കാലാവധി എന്നിവയിൽ പരമാവധി മൂല്യങ്ങൾ രേഖപ്പെടുത്തി. ഇതിനു പുറകെ അസ്കോർബിക് ആസിഡ് (2mM) മികച്ച മൂല്യങ്ങൾ രേഖപ്പെടുത്തി.

മൊത്തം ഉണങ്ങിയ വസ്തുക്കളുടെ ഉത്പാദനം, ഒരു ചെടിയുടെ ഇല വിസ്തീർണ്ണം, ആപേക്ഷിക വളർച്ചാ നിരക്ക്, നിർദ്ദിഷ്ട ഇല ഭാരം, വേര് തണ്ട് അനുപാതം, സ്പാഡ്

ക്ലോറോഫിൽ മീറ്റർ റീഡിംഗ് എന്നിവയിൽ സാലിസിലിക് ആസിഡ് (1mM), അസ്കോർബിക് ആസിഡ് (2mM) എന്നിവ പ്രയോഗിച്ച ചെടികളിൽ വരൾച്ചാ സമ്മർദ്ദം ചെലുത്തിയ വിളകളേക്കാൾ കൂടുതലായിരുന്നു. ഉയർന്ന വിളവിലും ഫല ഗുണനിലവാര ഘടകങ്ങളിലും സാമ്പത്തിക വരുമാനത്തിലും സാലിസിലിക് ആസിഡും (1mM) (T_3) അസ്കോർബിക് ആസിഡും (2mM) (T_6) എന്നിവ ഗുണം ചെയ്തു. ചുരുക്കത്തിൽ മറ്റുള്ളവയെ താരതമ്യം ചെയ്യുമ്പോൾ സാലിസിലിക് ആസിഡിന്റെയും (1mM) അസ്കോർബിക് ആസിഡിന്റെയും (2mM) പ്രയോഗം വെണ്ടയിൽ വരൾച്ചയുടെ ആഘാതം കുറയ്ക്കുന്നതായി പരീക്ഷണത്തിലൂടെ കാണാൻ സാധിച്ചു.