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Contents

S. No.	Title	Page No.
1.	Introduction	1
2.	Growth and development	2
3.	Impact of water stress on cucurbit seedling	5
4.	Photosynthesis and associated parameters	8
	– Water status, photosynthetic activity and productivity in Ziziphus spp.	10
	– Impact of water stress on photosynthetic activity in kachari and muskmelon	14
	– Impact of water stress on photosynthesis and related parameters in musk melon and snapmelon	15
5.	Impact of water stress on soluble sugar and starch content	17
6.	Impact of water stress on metabolite accumulation	21
7.	Effect of water stress on enzyme activities	23
8.	Screening parameters for drought tolerance	28
9.	Way forward	29
10.	References	30

Preface

Among the various abiotic stresses which hamper the cultivation of arid and semi arid crops, drought has a major role since it drastically reduces the yield. The drought can affect crop either at the early stage (late monsoon) or after emergence (early withdrawl) or at the late stage (terminal drought). The need of the hour is to develop strategies to overcome the effect of these situations so that the farmers can get remunerative income.

In order to cope with this abiotic stress, the arid horticultural crops have developed and/or modified their organs to perform certain vital physiological functions such as strong deep root system (*ber, bael, aonla,* wood apple, *jamun,* etc.), synchronize their flowering and fruit development with the season of moisture availability (*ker, lasora, aonla, pilu*, etc.) and other xerophytic characters i.e. leaf shedding in summer (*ber*), scanty foliage (*ker*), spiny cladode (cactus pear), mucilaginous sap in plant part (*ker, gonda, pilu, bael*, etc.), sunken stomata and fur/ hairiness and waxy coating on the leaf surface (*phalsa, ber, lasoda*, fig, etc.) thorny nature, and selective or reduced absorption of cation (Na^+) and anions (Cl^-, $SO4^{--}$) for survival under adverse arid conditions. In addition to this, plants have also developed mechanisms for water conservation; reduce the evaporative and transpiration losses, carbon fixation, metabolite production and perpetuation of life.

During last 20 years, extensive studies on the physiological and biochemical mechanisms adopted by the arid and semi-horticultural crops were investigated and a fund of information was accumulated which can go a long way in developing strategies to overcome the effect of drought on plants or develop novel genotypes having desired traits. This technical bulletin presents the significant achievements made to assess the adaptive features developed by the plants to cope with the drought stress. The document will act as a ready reckoner for horticulturist, plant breeders and research students to plan way forward in growing crops under abiotic stress.

(Authors)

Place: Bikaner
Date: May, 2018

Introduction

Ever since the plants adopted terrestrial mode of life they are experiencing stress and strains in terms of environmental, edaphic and biological factors. Plants require certain physical, chemical and biological factors for their growth and development. Any deviation from these factors may cause aberrant metabolic changes as a result plant experience a tension, which is known as stress. Plants are sessile forms of life and as a consequence they don´t have the capacity to "escape" from unfavorable conditions. Therefore, plants often face the challenge to grow under stressful conditions such as water or light deficit or excess, low or high temperature, salinity, heavy metals, UV rays, insect and pests attack, etc. These stresses impose adverse effects on plant growth and development by inducing many metabolic changes, such as the occurrence of an oxidative stress. Abiotic stresses impact growth, development, and productivity, and significantly limit the global agricultural productivity mainly by impairing cellular physiology/biochemistry via elevating reactive oxygen species (ROS) generation.

Plant stresses are broadly classified into two categories i.e. abiotic and biotic stress. Abiotic stress includes physical (water deficit, flooding, temperature, radiation, mechanical, electrical and magnetic, etc.) and chemical (air pollution, allelochemicals, nutrients, pesticides, toxins, salts, pH of solution) factors while biotic factors are insect, pest, disease, microbes, competition between plants, allelopathy, lack of symbiosis and human activities. These factors cause imbalance in the natural status of environment that alter normal equilibrium leading to a succession of morphological, physiological, biochemical and molecular changes in plants, which unfavorably affect their growth, development and potential yield. On the other hand, plants also have developed instinctive adaptations to these stress conditions with a range of biochemical and physiological interventions that involves the function of many stress related genes.

Abiotic stress causes changes in the soil-plant-atmosphere continuum (SPAC) and can lead to reduced yields and decreased plant performance. These stresses are sensed in the plant and plants can either respond by increasing their tolerance or avoidance through morphological modification and/or physiological, biochemical and molecular mechanism. These strategies lead to physiological and developmental changes that affect the productivity and growth of the plants. In horticultural crops, unfavorable conditions of these abiotic and biotic factors adversely affects the plant growth, development and interfere with complete expression of genotype potential yield. It is estimated that only 9% area of world is conducive for crop production while 91% is under stress. Abiotic stresses cause 70% yield reduction and mostly crops are only reaching 20% of their genetic potential. The estimation of potential yield losses by individual abiotic stresses are 17% for drought, 20% for salinity, 40% for high temperature, 15% for low temperature and 8% for other factors (Ashraf and Harris 2005).

The most significant abiotic stress is water stress, both deficit stress (drought) and excess stress (flood). Plants experience water stress either when the water supply to their roots becomes limiting or when the transpiration exceeds absorption rate and plant experience a stress. It is situation that reduces plant water potential and wall pressure to the extent that plant faces difficulty in executing normal physiological activities. Water stress is mainly caused by the water deficit, i.e. drought or high salt concentrations. In case of salt concentrations, water logging and low soil temperature, water exists in soil solution but plants are unable to uptake it, this situation is

known as physiological drought. Drought occurs in many parts of the world every year, frequently experienced in the field grown plants under arid and semi-arid climates. Regions with adequate but uneven precipitation also experience water stress. Drought refers to lack of precipitation over prolonged period of time where any area receives annual rainfall less than average rainfall while water logging is a condition where water is present in excess amount than its optimum requirement which creates anaerobic condition around roots and plant is unable to absorb water.

Out of a total 142.1 million hectares of cultivated area in India, dry land accounts for 91.0 million hectares and irrigation is available for only 40% of the cultivated area and the remaining 60% is rainfed. About 12 % of India's total geographical area is hot arid zone and the extent of arid area is about 31.7 million hectares. Significantly, more than 61% of the area falls in Rajasthan and extends to Haryana and Punjab (9%), Gujarat (20%) and some pockets in Andhra Pradesh, Karnataka and Maharashtra (10%). The arid areas are characterized by low and erratic rainfall (100-420 mm/year), frequent droughts, high summer temperatures (45-50° C), high wind velocity (30-40 km/h), and high evapo-transpiration (1500-2000 mm/year).

This particular region has extremes in environmental factor due to long hot and dry spell in summer months (March to June) similarly chilled and dry spell in winter seasons (December to February). Therefore, plants in this particular region naturally sense all three type of stresses like drought and heat stress from March to June (Hot and dry spell temperature reach up to 50 ^{o}C), low temperature stress in December-January (temperature drops below 0 ^{o}C) and salinity stress. The sandy soils have poor fertility and low water retention. Water stress can be very critical for the yield response during particular phenological phases and is very important in scheduling irrigation in considerable water limiting areas. In perennial fruit crops, stress before or during the flowering and post-bloom periods have adverse effects on yields through decreased numbers of fruits and likely reductions in cell numbers of the remaining fruits. Later stresses will typically reduce final fruit size or quality more than total yield. As a result of this, the plants growing in this region has modified themselves morphologically, anatomically and physiologically so that adaptive characteristics have been developed which gives them opportunity to survive in such harsh conditions. Central Institute for Arid Horticulture has dedicated nearly two decades working on various adaptive features of the plants growing in this region. Some of the interesting findings are summarized here which provides as indications as to the adaptive nature of plants growing in arid and semi-arid regions.

Growth and development

Plant Morphometry

Land plants have been classified into various categories depending upon their ability to withstand the drought stress. As a result of drought stress, a marked reduction in growth and development of plants has been noticed in different crop species. This may be due to change at organ or cellular levels or assimilate partitioning which lead to reduction in plant growth. At the whole plant level, the effect of drought is usually perceived as decrease in growth. A comparative study conducted at Bikaner using mateera (drought tolerant) and water melon (drought susceptible) to study the effect of drought at whole plant level. In all 4 irrigation treatments were given viz. 1, 4, 6, and 9 in complete life cycle. Observations on plant morphometry, dry matter distribution and yield were recorded at periodic intervals viz. 45, 60, 75 and 85 days after sowing. The results

revealed that in both *mateera* cultivars viz. AHW 65 and AHW 19 various parameters such as plant height, number of leaves, number of branches, and inter nodal length do not get affected up to 4 irrigation levels throughout the life cycle of the plant. It is only at 1 irrigation level that the plant morphometeric characters start to decline. The trend in fruit number and average fruit weight also demonstrated that at 85 days after sowing, the number of marketable fruit were 3.88, 3.01, 3.0 and 1.83 at 9, 6, 4 and 1 irrigations respectively. Similarly the fruit weight at respective treatments was 2.84, 1.31, 1.75 and 1.2 kg in AHW 19. This illustrates that mateera has internal balance system to maintain water status as a result of which plant can grow and produce fruits even under drought condition. The pattern of growth and development in water melon (MHW 11) showed that plant height, nos. of leaves per plant, no. of fruits per plant were adversely affected after 60 days onward by withdrawing irrigation. The pattern of dry matter distribution in MHW-11 too reveals that treatments having less than 9 irrigation, maximum dry matter was accumulated in stem, leaves and root. However, by imposing water stress even to 6 irrigations reduced dry matter accumulation at 85 days in stem by 17.25%, 56.5% in leaves, 43.13% in roots.

Similar studies were also conducted using kachari and musk melon as the material under investigation. The plants were grown at normal spacing with drip irrigation. At 35 days after sowing, the water stress was imposed on the plants and maintained for long duration. The observations on the plant dry matter distribution was estimated at 60 days after sowing and the results are presented in Table 1.

Perusal of data in table 1 reveals that imposition of water stress in kachari had little effect on reducing the dry matter content of different plant parts. For instance, the stem dry matter decreased from 9.0g to 8.6 g under water stress. Similarly, the leaves dry matter decreased from 11.56 to 9.8g and that of root increased from 0.37 to 0.58g. This illustrates that under water stress the dry matter allocation to root is enhanced in Kachari.

Perusal of data for muskmelon reveals that there was drastic decrease in dry matter in all plant parts. For instance, the stem dry matter decreased from 14.48 to 3.42, leaves from 19.1 to 7.65 and root from 1.02 to 0.63g. The results demonstrate that under water stress kachari is able to maintain the growth and development but in musk melon the growth and development is highly hampered.

Table 1. Dry matter distribution in Kachari and musk melon under control and water stress at 60 DAS.

Species	Treatment	Dry matter (g)		
		Stem	Leaves	Root
Kachari	Control	9.0	11.56	0.37
	Stress	8.6	9.8	0.58
Musk melon	Control	14.48	19.1	1.02
	Stress	3.42	7.65	0.63

Dry matter allocation under water stress

The dry matter allocation pattern of plants also changes with the imposition of water stress. It has been demonstrated that in stress tolerant plants, mild water stress shift the dry matter allocation to root which increase the capacity to extract water from soil (Gorai et al., 2010). That

the soil water deficit reduces the plant growth and development has been demonstrated by several authors who have reported that dry matter reduction was associated with water deficiency.

In an experiment conducted to evaluate the effect of water stress on dry matter allocation, at periodic interval viz. 45, 60, 75 and 90 days after sowing, in mateera and water melon with 4 irrigation treatments viz. 2, 4, 6 and 8 irrigation in whole crop life, demonstrated that dry matter partitioning to root was more under 8 irrigations at 45 days after planting. This is illustrated by the fact that under 8 irritations the dry matter allocated to root was 20.07 and 21.76% respectively in AHW-65 and AHW-19. However, under other irrigation levels, the allocation to root was less at same day of harvesting. The characteristic feature encounter here is that under water stress (2 irrigation) more dry matter is allocated to root (6.01% in AHW-65 and 8.69% in AHW-19) (Fig. 1).

Similar comparison in water melon demonstrates that at full maturity (90 days) maximum share of dry matter is allocated towards leaves. It ranges between 54-67%. The root gets very less share (2-8%). The root dry matter remains fairly constant under different treatments.

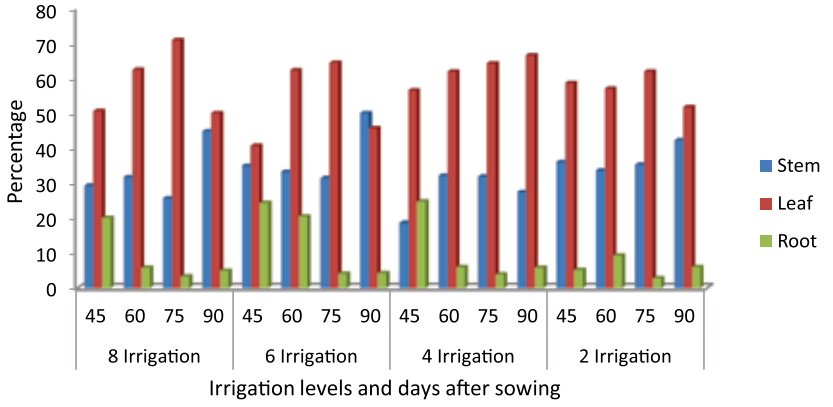

Fig. 1. Percentage dry matter partitioning in mateera under different level of irrigation

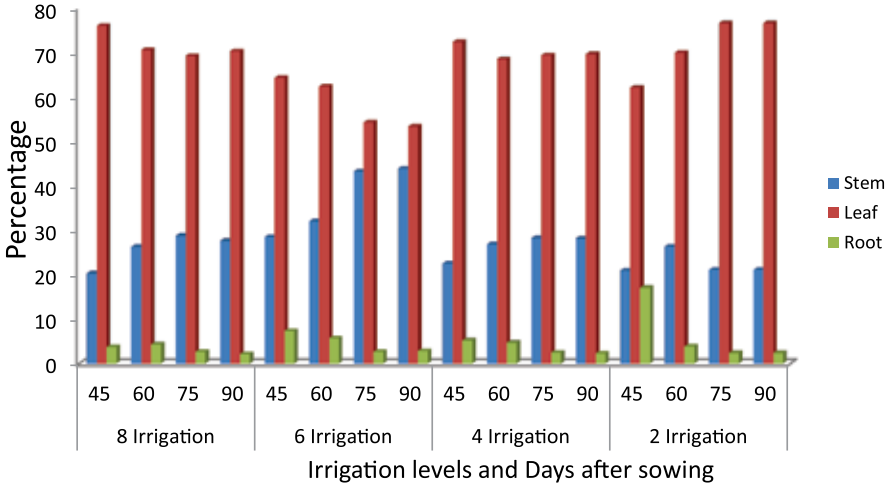

Fig. 2. Percentage dry matter partitioning in water melon under different level of irrigation

Critical stage for water stress

The critical stage of irrigation is the stage at which the plants are highly sensitive to water stress and if the irrigation is not given then the loss of economic yield is very high. In order to assess the critical stage of mateera, field experiment was laid out in RBD using two cultivars of *Mateera* (AHW 19 and AHW 65) and observations on growth, development and yield was recorded. The water stress was given at 3 stages viz. either at 30 days after planting, or 45 days after planting or 60 days after planting. In control plots all irrigations were given. It was observed that in cv. AHW 19 withdrawing the irrigation at 45 days after sowing adversely affected the vegetative growth of the plants. The plant height reduced to 133.8 cm as compared 141.8 cm in control; number of leaves reduced to 58.8 per plant as compared to 70.0 in control. Similarly, the dry matter distribution pattern demonstrate that lowest dry matter accumulation was in plants given viz. stress at 45 viz. days 11.09g in stem, 10.84g in leaves, 0.36g in root. Comparison of number of fruits and average weight of fruit reveals that withholding of irrigation at any stage has no effect on number of fruits/ plant. However, the average weight of fruit drastically reduced when water stress was imposed at 45 days after sowing. Similar results were found in other cultivar too. This illustrates that water stress imposed at 30-45 days after sowing has more detrimental effect on the growth, development and yield of *mateera* crop.

Impact of water stress on cucurbit seedling

Growth and dry matter allocation

It has been demonstrated that water stress at seed germination and seedling growth hampers the normal germination and seedling growth resulting into poor seedling stand and reduced leaf area for photosynthesis (Li et al., 2013). An attempt was made to study the effect of drought stress at seedling stage using Kachari, muskmelon and water melon as the test materials. The seeds were sown in pots and irrigated with the solution of 0.2 MPa and 0.5 MPa solutions of PEG 6000. The controls were irrigated with normal water. After one month the seedlings were harvested and their morphological observations were recorded. The results are presented in table 2. Perusal of table reveals that in Kachari the length of root was longest in control (15.41cm) followed by in 0.2 MPa (14.45 cm) and least in 0.5MPa (13.68 cm). Similar results were also obtained for Muskmelon where the longest root was recorded in control (10.43 cm) which slightly decreased at 0.2MPa (10.36 cm) and further decreased to 9.92cm at 0.5 MPa. Similar trend was also observed in water melon also. Thus the results showed that the length of root decreased with imposition of water stress.

The data on shoot length revealed that shoot length decreased with imposition of water stress in all plant species. The magnitude of reduction was highest in water melon which shows shoot length of 31.03 cm in control which dropped to 15.67 cm with irrigation of 0.5 MPa solution. Similar results were also shown by Muskmelon. However, the reduction of shoot length in Kachari was low as is illustrated by the fact that shoot length was 51.63 cm in control which dropped to 40.39 cm in plants irrigated with 0.5 MPa solution.

Table 2. Morphometeric parameters of seedling under water stress at one month after sowing

Plant species	Control	0.2 MPa	0.5MPa
Length (cm)			
Kachari (AHK 119) Root Shoot	 15.41± 7.44 51.63 ± 23.35	 14.45± 3.55 46.35 ± 6.65	 13.68 ± 5.15 40.39 ± 6.12
Muskmelon Root Shoot	 10.43 ± 4.43 48.40 ± 17.17	 10.36 ± 4.57 32.09 ± 8.16	 9.92 ± 4.83 29.01 ± 8.15
Water melon Root Shoot	 11.71 ± 5.96 31.03 ± 17.07	 9.35 ± 3.28 30.22 ± 12.52	 8.61 ± 4.75 15.67 ± 6.70
Fresh weight (g)			
Kachari	60.3	57.8	44.28
Muskmelon	93.34	53.98	44.7
Water melon	81.10	42.94	34.51

The biomass produced by the seedlings after one month of sowing shows that in control maximum weight was of muskmelon (93.34g) followed by water melon (81.10g) and least in kachari (60.30g). The percentage reduction in biomass production reveals that kachari showed minimum reduction as is illustrated by fact that only 4.14% and 26.56% reduction took place under 0.2 and 0.5 MPa solutions. However, in other materials the percentage reduction was to the tune of 42.16% and 52.11% with 0.2MPa and 0.5 MPa solutions, respectively in muskmelon and 47.05% and 57.44% with 0.2 MPa and 0.5MPa, respectively in water melon.

Water potential of seedling

Crop plants have developed many mechanisms to survive water deficit. Avoidance of stress includes rapid development of plant parts, increased stomatal and cuticular resistance, and change in phenology to cut water loss (Morgan, 1995; Jones and Corlett, 1992). Plants tolerate drought by maintaining sufficient cell turgor to allow metabolism to continue under increasing water deficit (Zlatko and Lidon, 2012). The studies conducted at Institute also attempted to stady the leaf water potential of seedling to assess the water status of plants under varying drought situations using Water potential meter. The results are presented in table 3. Perusal of data reveals that in kachari, the leaf water potential was -3.22 in controls which dropped to -4.41 in plants irrigated with 0.2 MPa solutions and further remained nearly constant in plants irrigated with at 0.5 MPa solutions. In musk melon, the magnitude of water potential was -2.88 in controls which dropped to -3.40 and -4.50 in plants irrigated with 0.2 MPa and 0.5 MPa solutions, respectively. Similar results were also obtained with water melon, showing thereby that in kachari the water potential is maintained under water stress whereas in other drought susceptible crops, it declined.

Table 3. Osmotic potential of seedlings grown under water stress.

Plant species	Control	0.2 MPa	0.5MPa
	Water potential (MPa)		
Kachari (AHK 119)	-3.22	-4.41	-4.46
Muskmelon	-2.88	-3.40	-4.50
Water melon	-1.36	-2.14	-2.30

Impact of water stress on relative water content of seedling

The relative water content of the leaves was estimated and data thus obtained is presented in table 4. Perusal of data reveals that relative water content in the leaves of kachari was 77.45% in control followed by 74.58% and 74.44% in 0.2Ma and 0.5MPa PEG solution. However, in water melon and musk melon, the magnitude of RWC decreased on imposition of water stress. This is illustrated by the fact that in muskmelon the RWC was 78.73%, 67.0% and 54.21% in control and plants irrigated with PEG 0.2MPa and 0.5MPa solution, respectively. Similar results were also obtained with water melon.

Table 4. Relative water content of seedling grown under water stress.

Plant species	Control	0.2 MPa	0.5MPa
	Relative water content		
Kachari (AHK 119)	77.45	74.58	74.44
Muskmelon	78.73	67.00	54.21
Water melon	84.94	67.41	52.72

Impact of water stress on membrane stability index of seedling

Membrane stability index is a stable parameter to assess the magnitude of drought resistance in plants. Accordingly, the membrane stability index was estimated and the results are presented in table 5. Perusal of data reveals that maximum values for membrane stability was recorded in kachari in all treatments. The value was 75.37 in control which slightly dropped to 69.43 at 0.2MPa and 62.75 at 0.5MPa. However, in other drought susceptible species, the membrane stability index dropped drastically under water stress condition. This is illustrated by the fact that in muskmelon, the MSI was 65.60, 61.14 and 52.14 in control, 0.2MPa and 0.5 MPa treated plants, respectively. Similarly, in water melon the values were 69.32, 59.44 and 52.36 at control, 0.2 MPa and 0.5 MPa, respectively.

Table 5. Membrane stability index of seedling grown under water stress.

Plant species	Control	0.2 MPa	0.5MPa
	Membrane stability index		
Kachari (AHK 119)	75.37	69.43	62.75
Muskmelon	65.60	61.14	52.14
Water melon	69.32	59.44	52.36

Photosynthesis and associated parameters

Photosynthesis

Plant physiological process such as photosynthesis, transpiration is dependent on the severity and duration of drought (Vadell and Medrano, 1992). It has been demonstrated that as soon as plants sense the drought stress, the stomata reduce the opening and hence restrict the transpiration rate (Flexas amd Medrano, 2002). Apart from this, it also reduce the internal CO_2 concentration in mesophyll cells which affects the rate of photosynthesis. In some plants drought also reduce the rate of photosynthesis by non–stomatal factors also such as decreased carboxylation efficiency(Ramanjula *et al.*, 1998; Rouhi *et al.*, 2007) regeneration of RuBP (Vu *et al.*, 1999) loss of RUBISCO activity (Parry *et al.*, 2002), etc.

The rate of photosynthesis, transpiration rate and water use efficiency was estimated using LICOR 6200 Infra Red Gas Analyzer under different levels of water stress in field. It was observed that at full irrigation level, the rate of photosynthesis is higher in water melon than in mateera. However, with the imposition of water stress, the magnitude of photosynthesis decline in both, but the decrease in rate of photosynthesis is much higher in water melon than that in mateera. This is illustrated by that fact that in water melon the rate of photosynthesis drops to 0.94 mg CO_2/m^2/s under 2 irrigation. Similarly, in mateera the rate of photosynthesis was 1.175 mg CO_2/m^2.sec under 8 irrigations which dropped to only 0.74 mg CO_2/m^2/s. Similar trends were observed in transpiration rates too (Table 6).

Table 6. Photosynthesis, transpiration and water use efficiency in mateera & water melon.

Irrigation	Mateera			Water melon		
	Pn	Tr.	WUE	Pn	Tr.	WUE
8	1.175	0.966	1.21	1.84	1.407	1.31
6	0.927	0.552	1.67	1.31	0.733	1.78
4	1.023	0.608	1.68	0.82	0.475	1.73
2	0.740	0.480	1.54	0.94	0.529	1.77

Pn= mg CO_2/m^2/s., Tr.= mg/m^2/s.

Transpiration and water use efficiency under water stress

The data on transpiration rate and water used efficiency under water stress was also calculated in above experiment. Perusal of table 7 reveals that in mateera the transpiration rate was highest (0.088 mol/m^2/s) at 8 irrigation which dropped to 0.0032 mol/m^2/s at 4 irrigations and to 0.0026 mol/m^2/s at 2 irrigation levels. Showing thereby that the transpiration rate is checked as the water stress is imposed in mateera (Table 7). The data in water melon reveal that the transpiration rates at 45 days after sowing is as high as 0.08 mol/m^2/s at 8 irrigation which drops only to 0.06 mol/m^2/s at 2 irrigation level. This illustrates that water melon is not able to check transpiration with imposition of water stress (Table 7).

Table 7. Transpiration in water melon and mateera with different irrigation levels at 45 and 60 days

Irrigation level	Transpiration (μ mol/m²/s)							
	45 Days				60 Days			
	AHW-65	AHW-19	Sugar Baby	Mahobobi	AHW-65	AHW-19	Sugar Baby	Mahobobi
2	0.0026	0.005	0.06	--	0.069	0.072	0.05	--
4	0.0032	0.0026	0.07	0.08	0.064	0.069	0.07	0.062
6	0.057	0.055	0.09	0.07	0.083	0.076	0.08	0.087
8	0.088	0.089	0.08	0.11	0.123	0.175	0.07	0.088

Carboxylation efficiency under water stress

The carboxylation efficiency (at 45 & 60 days after sowing) in mateera and water melon was estimated under different levels of irrigation. It was observed that in mateera, the carboxylation efficiency was to the tune of 0.087 at full irrigation which increased with the imposition of water stress (Table 8). On the contrary, in water melon, the carboxylation efficiency remains nearly constant. At 60 days after sowing too, the carboxylation efficiency was 0.107 in AHW 65 at 8 irrigation which increased to 0.132 at 2 irrigation level. On the contrary, in sugar baby, the carboxylation efficiency was 0.118 at 8 irrigations which dropped to 0.063 at 2 irrigations level (Table 8). Thus, the results reveal that mateera is able to maintain high carboxylation efficiency even at low moisture level.

Table 8. Carboxylation efficiency in water melon and mateera with different irrigation levels at 45 and 60 days

Irrigation level	Carboxylation Efficiency							
	45 Days				60 Days			
	AHW-65	AHW-19	Sugar Baby	Mahobobi	AHW-65	AHW-19	Sugar Baby	Mahobobi
2	0.132	0.202	0.067	--	0.132	0.104	0.063	--
4	0.174	0.265	0.066	0.073	0.083	0.120	0.100	0.069
6	0.087	0.096	0.081	0.070	0.108	0.089	0.118	0.079
8	0.087	0.079	0.063	0.079	0.107	0.170	0.118	0.120

Water status, photosynthetic activity and productivity in *Ziziphus* spp.

In terrestrial crops, the diurnal pattern of photosynthesis shows a depression in photosynthesis rate during mid noon. This is also known as mid day depression in photosynthesis. This is caused as a result of closure of stomata during afternoon. A total of 30 genotypes of ber were evaluated for diurnal variation in photosynthesis during fruiting period and it was recorded that ber cultivars vary with respect to pattern of diurnal variation in photosynthesis. The observations were recorded at 11 AM, 1PM and 3 PM and parameters studied were relative water content, stomatal conductance, transpiration, Internal CO_2 concentration, photosynthetic rate, carboxylation efficiency and physiological water use efficiency. Based on the values obtained on above parameters, the cultivars were classified variously. On the basis of photosynthetic activity, the cultivars can be divided into 2 groups viz. i) showing mid day depression and, ii) do not show mid day depression (Table 9). Perusal of table reveals that cvs. Kathali, Narma, Katha phal, Sanaur 5, Ladu, Seo, Khark 1, Badami *etc*. shows mid day depression whereas most of the commercial cultivars such as Gola, Umran, Seb, Banarsi pawandi, Banarsi karaka, Mundia, Kakrol Gola, Dandan, Alwar desi, Noki, *etc*. do not exhibit mid day depression.

Similarly, the cultivars under study were also classified on the basis of carboxylation efficiency into high and low groups. Based on this cultivars such as Seb, Banarsi pawandi, Banarsi karaka, Kaithali, Mundia, Dandan, *etc*. has high carboxylation efficiency. Whereas cv. Gola, Umran, Narma *etc*. had low efficiency (Table 10).

Similarly, on the basis of water use efficiency, the cultivars were divided into 3 groups viz. low, medium and high. Among the cultivars studied, Ladu, Alwar desi, Manuka, Govindgarh special, Kakrol gola, Noki *etc*. had high water use efficiency whereas Seo, Reshmi, Badami, *etc*. had low (Table 11).

The cultivars which rated best on the basis of above classification were further plotted on Venne diagram to select the cultivars which are best on the basis of all above parameters. It was observed that cvs. Seb, Banarsi pawandi, Banarsi karaka, Mundia, Dandan, Alwar desi, Govindgarh special, and Kala gola were best on the basis of above parameters. It is therefore suggested that these cultivars may prove to be ideal for arid ecosystem (Fig. 3).

Table 9. Classification of ber cultivars on the basis of photosynthetic activity

Showing mid day depression	Kethali, Narma, Katha Phal, Sanaur 5, Ladu,Manuki, Maharwali, Thornless, Khira, Gularvasi, Seo, Kharki 1, Badami
Do not show mid day depression	Gola, Umran, Seb, Banarsi Pawandi, Banarsi Karaka, Mundia, Kakrol Gola, Dandan, Alwar Desi, Govindgarh Special, Kala Gola, Gola Hisar, Noki, BS 75-1, B-51, Gola Gurgoan, Chonchal, Illaichi, Chhuhara, Bagwadi, Reshmi

Table 10. Classification of ber cultivars on the basis of Carboxylation efficiency

High (more than 0.1)	Seb, Banarsi Pawandi, Banarsi Karaka, Kaithali, Mundia, Katha Phal, Dandan, Sanaur 5, Ladu, Alwar Desi, Govindgarh Special, Kala Gola
Low (Less than 0.1)	Gola, Umran, Narma, Kakrol Gola, Manuki, Maharwali, Thornless, Khira, Gularvasi, Gola, Gola Hisar, Seo, Nonki, BS 75-1, B-51, Gola Gurgoan, Chonchal, Kharki No1, Badami, Illaichi, Chhuhara, Bagwadi, Reshmi

Table 11. Classification of ber cultivars on the basis of Water use efficiency

Low (less than 1.0)	Umran, Maharwali, Thornless, Khira, Gularvasi,Gola Hisar, Seo, Kharki No. 1, Badami,Chhuhara, Reshmi
Medium (1.0-2.0)	Gola, Seb, Banarsi Pawandi, B. Karaka, Kathali, Mundia, Narma, Kakrol Gola, Katha Phal, Dandan, Sanaur 5, Illaichi, Bagwadi
High (More 2)	Laddu, Alwar Desi, Manuki, Govindgarh Special, Kala Gola, Nonki, BS 75-1, B-51, Gola Gurgoan, Chonchal

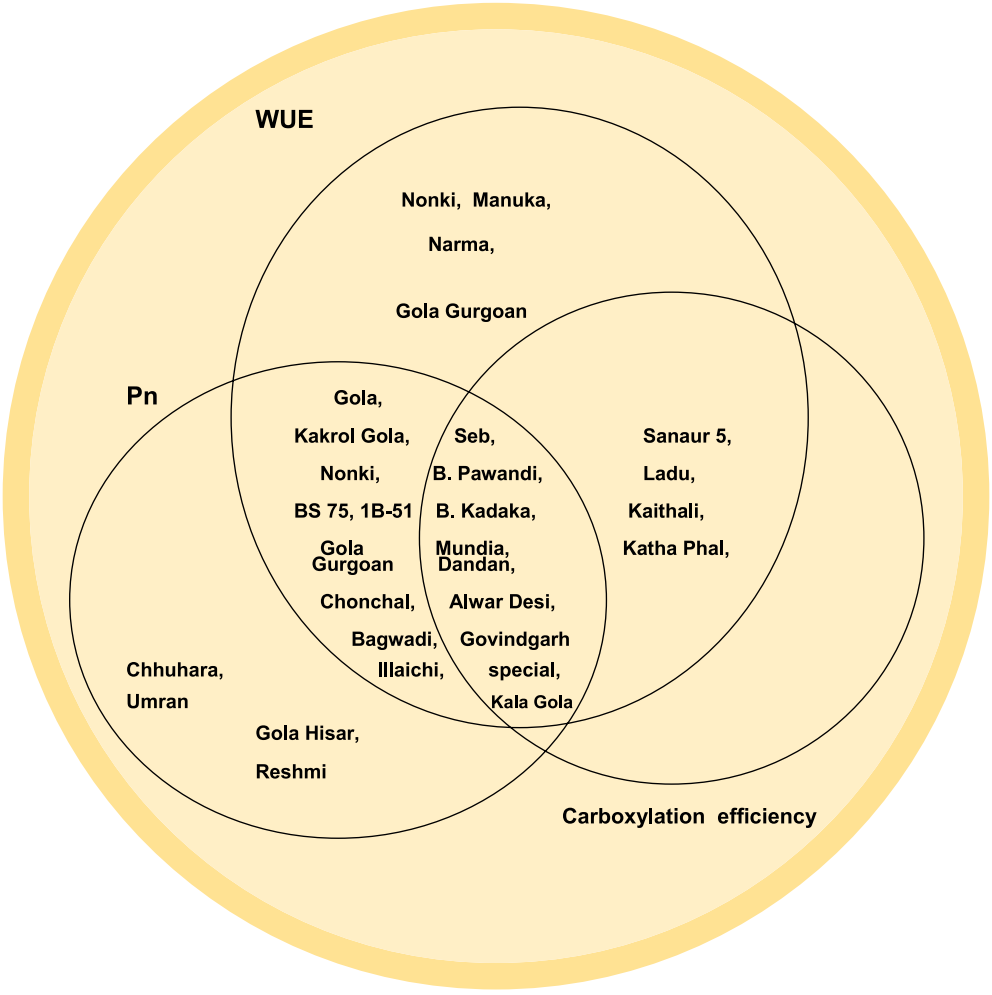

Fig. 3. Vienne diagramme showing classification of ber variety

In order to assess the impact of mid day depression or no mid day depression on productivity of ber cultivars were studied in 6 cultivars of ber. Of these 3 (Gola, Umran and Banarsi Pawandi) were not showing mid day depression whereas 3 (Kathaphal, Sanaur-5 and Kaithali) showed mid day depression. The attempt was to compare the growth and development of these two groups.

The data on morphometeric parameter is presented in Table 12. The perusal of data for plant height reveals that the plant height is not affected by the mid day depression in photosynthetic rate. This is illustrated by the fact that in both the groups, the plant height ranged from 2.5-4.0 m. Similar, results were also observed for plant spread where the variation was very less in both the groups.

Table 12. Morphometric parameters of ber cultivars.

Variety	Plant height (m)	Spread (m)		Cir. (cm)
		E-W	N-S	
Gola	3.25	3.20	4.00	51.00
Umran	2.50	4.38	4.05	26.00
Banarsi Pewandi	2.50	3.77	4.12	28.30
Katha Phal	3.00	4.00	5.00	44.76
Sanaur- 5	3.00	5.00	5.00	53.00
Kaithali	4.00	4.97	5.00	40.70

Perusal of data on tree volume (Table 13) reveals that the tree volume varied from 10.54 m^3 in Umran to 19.94 m^3 in Kaithali. However, in cultivars showing mid day depression it was 11.70 m^3 in Gola, 10.54 m^3 in Umran and 15.78 m^3 in Banarsi pewandi. Similarly, it was 13.50 in Katha phal, 15.0 in Sanaur-5 and 19.94 in Kaithali. The results reveal that none of the morphometeric parameters are affected by mid day depression.

Data on fruit yield reveals that the yield of fruits are higher in case of cultivars not showing mid day depression as compared to these showing mid day depression. This is illustrated by the fact that cultivars Gola, Umran and Banarsi pewandi gave 31.50, 25.00 and 29.00 kg/tree as compared to Katha phal, Sanaur-5 and Kathali which produced nil, 23.00 and 14.75 kg/tree respectively (Table 13).

The diurnal variation in RWC in leaves of ber cultivars was also recorded. It was observed that the leaves of Gola, Umran and Banarsi pawandi maintained the RWC as high as recorded in forenoon and evening but the cultivars Kathaphal, Sanaur-5 and Kaithali shows reduction in RWC during mid day. Thus, it illustrates that the group which do not show mid day depression makes osmotic adjustment to maintain turgidity of leaves (Table 14).

Table 13. Morphometric parameters of ber cultivars.

Variety	Crown area (Sq/m)	Tree volume (m3)	Yield (kg/tree)
Gola	3.24	11.70	31.50
Umran	4.44	10.54	25.00

Variety	Crown area (Sq/m)	Tree volume (m3)	Yield (kg/tree)
Banarsi Pawandi	3.89	15.78	29.00
Katha Phal	5.06	13.50	No fruiting
Sanaur- 5	5.300	15.00	23.00
Kaithali	5.00	19.94	14.75

Table 14. Relative water content of ber cultivars

Variety	RWC (%)		
	At 9 AM	At 12 Noon	At 4 PM
Gola	67.58	64.65	75.02
Umran	76.08	75.87	70.56
Banarasi pewandi	73.98	73.22	75.79
Katha Phal	71.26	61.76	69.45
Sanaur-5	72.06	66.57	68.20
Kaithali	78.73	68.73	73.26

Perusal of Table 15 reveals that the cultivars which do not show midday depression produced more pruned wood as compared to cultivars which show mid day depression. This is illustrated by the fact that cv. Gola produced 34.00 kg. pruned wood as compared to Katha Phal which produced only 12 kg.

Table 15. Morphometric Parameters of ber cultivars

Variety	Pruned wood weight (kg.)	Yield (kg/tree)
Gola	34.00	35.00
Umran	14.00	42.00
Katha Phal	12.00	28.00
Sanaur-5	14.00	13.50
Kaithali	24.00	22.00

The diurnal variation in RWC in leaves of ber cultivar was also recorded. It was observed that the leaves of Gola, Umran and Banarsi Pewandi maintained RWC as high as recorded in forenoon and evening, but cultivars Katha Phal, Sanaur-5 and Kaithali shows reduction in RWC during mid day. (Table 16).

Table 16. RWC Per Cent of Ber Cultivars

Variety	RWC (%)		
	At 9 AM	At 12 Noon	At 4 PM
Gola	67.58	64.65	75.02

Variety	RWC (%)		
	At 9 AM	At 12 Noon	At 4 PM
Umran	76.08	75.87	70.56
Banarasi Pewandi	73.98	73.22	75.79
Katha Phal	71.26	61.76	69.45
Sanaur-5	72.06	66.57	68.20
Kaithali	78.73	68.73	73.26

Impact of water stress on photosynthetic activity in kachari and muskmelon

An investigation was conducted in the field using kachari (drought tolerant) and musk melon (drought susceptible). The plants were grown at normal spacing with drip irrigation. At 35 days after sowing, the water stress was imposed on the plants and maintained for long duration. The observations on photosynthetic activity and carboxylation efficiency were measured at 45 and 60 days after sowing and the results are presented in Table 17.

Perusal of data in table 17 reveals that at 45 DAS the photosynthetic activity in kachari was to the tune of 22.06 $\mu molm^{-2}s^{-1}$ under irrigated condition which dropped slightly to 19.85 $\mu molm^{-2}s^{-1}$ under water stress. Similarly at 60 DAS the Pn was 25.30 $\mu molm^{-2}s^{-1}$ under irrigated condition which dropped to 21.25 $\mu molm^{-2}s^{-1}$ under stress condition. However, in musk melon the magnitude of Pn at 45 days was 19.99 $\mu molm^{-2}s^{-1}$ under irrigated condition which drastically dropped to 12.45 $\mu molm^{-2}s^{-1}$ and at 60 DAS the respective values were 20.45 $\mu molm^{-2}s^{-1}$ and 8.45 $\mu molm^{-2}s^{-1}$.

The data on carboxylation efficiency also reveals that it was maintained high in kachari under water stress condition being 0.132 and 0.083 μ mol m^{-2} $s^{-1}ppm^{-1}$ at 45DAS and 60 DAS, respectively. However, in musk melon, the magnitude was 0.056 and 0.063 μ mol m^{-2} $s^{-1}ppm^{-1}$ at 45 DAS and 60 DAS, respectively. This illustrates that the tolerant plants have mechanism to maintain carboxylation efficiency.

Table 17. Photosynthetic rate and carboxylation efficiency in kachari and musk melon under control and water stress

Species	Treatment	Pn ($\mu molm^{-2}s^{-1}$)		Carboxylation efficiency (μ mol m^{-2} $s^{-1}ppm^{-1}$)	
		45 DAS	60 DAS	45 DAS	60 DAS
Kachari	Control	22.06	25.30	0.087	0.107
	Stress	19.85	21.25	0.132	0.083
Musk melon	Control	19.99	20.45	0.078	0.118
	Stress	12.45	8.45	0.056	0.063

Impact of water stress on photosynthesis and related parameters in musk melon and snapmelon

The pattern of physiological process during recovery from stress has been studied by various workers. It has been demonstrated that quicker the recovery from stress environment more is adaptability of plants under drought condition (Bhargava et al., 2016). In order to assess this, the experiments were conducted to study the impact of water stress on photosynthetic activity and related parameters in musk melon and snap melon. The seeds were sown in the field in February and irrigated for normal growth and development. At 45 days after sowing, the plants were divided into two groups and one set was kept under normal irrigation (Control) and the irrigation was withheld in the second set for 10 days (Stressed). Thereafter, the plants were re-irrigated and recovery in the physiological parameters was recorded at 5 days interval. Table 18 presents the summary of the observations recorded.

Table 18. Photosynthetic rate and associated parameters in musk melon under water stress and recovery

Treatment (Days after imposing stress)	Water stress				Control				
	Pn (µ mol CO_2 m^{-2} s^{-1})	Transpiration (mmol H_2O m^{-2} s^{-1})	Leaf level WUE (µ mol CO_2 mmol H_2O^{-1})	Carboxylation efficiency (µ mol m^{-2} s^{-1}ppm^{-1})	Treatment (Days corresponding to stress treatment)	Pn (µ mol CO_2 m^{-2} s^{-1})	Transpirat-ion (mmol H_2O m^{-2} s^{-1})	Leaf level WUE (µ mol CO_2 mmol H_2O^{-1})	Carboxylation efficiency (µ mol m^{-2} s^{-1}ppm^{-1})
0	20.45	8.6	2.37	0.086	0	20.45	8.6	2.377	0.086
5	16.4	7.35	2.23	0.076	5	20.64	8.56	2.52	0.072
10	11.09	4.98	2.22	0.059	10	18.91	7.60	2.48	0.099
5 days recovery	16.1	8.25	1.95	0.084	15	19.01	8.22	2.31	0.114
10 days recovery	17.03	7.35	2.31	0.119	20	18.34	7.72	2.37	0.091
15 days recovery	17.52	7.46	2.34	0.08	25	17.85	7.65	2.32	0.864

Perusal of table 18 reveals that the Photosynthetic rate at time of imposition of stress was 20.45 µ mol CO_2 m^{-2} s^{-1} which dropped to 16.4 µ mol CO_2 m^{-2} s^{-1} and 10.09 µ mol CO_2 m^{-2} s^{-1} after 5 and 10 days of imposition of water stress. Subsequently, on re-irrigation, the photosynthesis rate recovered and it reached to 16.1, 17.03 and 17.52 µ mol CO_2 m^{-2} s^{-1} at 5, 10 and 15 days after recovery, respectively. However, in controls, the photosynthetic rate was 20.45, 20.64, 18.91, 19.01, 18.34 and 17.85 µ mol CO_2 m^{-2} s^{-1} at 0, 5, 10, 15, 20 and 25 days after the start of experiment. Similarly, the transpiration rate in controls was 8.6, 8.56, 7.60, 8.22, 7.72 and 7.65 mmol H_2O m^{-2}

s^{-1} at 0, 5, 10, 15, 20 and 25 days after start of experiment. In the treatments, the transpiration rate was 8.6 mmol H_2O m^{-2} s^{-1} at the start of experiment which dropped to 7.35 and 4.98 mmol H_2O m^{-2} s^{-1} at 5 and 10 days after imposition of stress. On recovery, the magnitude of transpiration rate goes to 8.25, 7.35 and 7.46 mmol H_2O m^{-2} s^{-1} at 5, 10 and 15 days after re-irrigation. Accordingly, the WUE of plants under treatment was 2.37, 2.23, 2.22 µ mol CO_2 mmol H_2O^{-1} at 0, 5 and 10 days after imposition of stress and was 1.95, 2.31 and 2.34 µ mol CO_2 mmol H_2O^{-1} at 5, 10 and 15 days after re-irrigation. In control plants the magnitude of WUE remained nearly same.

Table 19. Photosynthetic rate and associated parameters in snap melon under water stress and recovery

Treatment (Days after imposing stress)	Water stress				Control				
	Pn (µ mol CO_2 m^{-2} s^{-1})	Transpiration (mmol H_2O m^{-2} s^{-1})	Leaf level WUE (µ mol CO_2 mmol H_2O^{-2})	Carboxylation efficiency (µ mol m^{-2} s^{-1}ppm^{-1})	Treatment (Days corresponding to stress treatent)	Pn (µ mol CO_2 m^{-2} s^{-1})	Transpiration (mmol H_2O m^{-2} s^{-1})	Leaf level WUE (µ mol CO_2 mmol H_2O^{-2})	Carboxylation efficiency (µ mol m^{-2} s^{-1}ppm^{-1})
0	18.73	6.25	2.99	0.068	0	18.73	6.25	2.99	0.068
5	17.05	6.01	2.83	0.077	5	18.64	5.24	3.55	0.062
10	14.75	5.42	2.72	0.052	10	15.97	5.72	2.79	0.052
5 days recovery	19.88	7.87	2.52	0.080	5	15.92	6.83	2.33	0.059
10 days recovery	18.32	6.64	2.75	0.069	20	15.67	6.48	2.41	0.064
15 days recovery	18.64	7.09	2.62	0.070	25	14.97	6.01	2.49	0.064

Perusal of table 19 reveals that the Photosynthetic rate at time of imposition of stress was 18.73 µ mol CO_2 m^{-2} s^{-1} which dropped to 17.05 µ mol CO_2 m^{-2} s^{-1} and 14.75 µ mol CO_2 m^{-2} s^{-1} after 5 and 10 days of imposition of water stress. Subsequently, on re-irrigation, the photosynthesis rate recovered and it reached to 19.88, 18.32 and 18.64 µ mol CO_2 m^{-2} s^{-1} at 5, 10 and 15 days after recovery, respectively. However, in controls, the photosynthetic rate was 18.73, 18.64, 15.97, 15.92, 15.67 and 14.97 µ mol CO_2 m^{-2} s^{-1} at 0, 5, 10, 15, 20 and 25 days after the start of experiment. Similarly, the transpiration rate in controls was 6.25, 5.24, 5.72, 6.83, 6.48 and 6.018 mmol H_2O m^{-2} s^{-1} at 0, 5, 10, 15, 20 and 25 days after start of experiment. In the treatments, the transpiration rate was 6.25 mmol H_2O m^{-2} s^{-1} at the start of experiment which dropped to 6.01 and 5.42 mmol H_2O m^{-2} s^{-1} at 5 and 10 days after imposition of stress. On recovery, the magnitude of transpiration rate goes to 7.87, 6.64 and 7.09 mmol H_2O m^{-2} s^{-1} at 5, 10 and 15 days after re-irrigation. Accordingly, the WUE of plants under treatment was 2.99, 2.83 and 2.72 µ mol CO_2 mmol H_2O^{-1} at 0, 5 and 10 days

after imposition of stress and was 2.52, 2.75 and 2.62 µ mol CO_2 mmol H_2O^{-1} at 5, 10 and 15 days after re-irrigation. In control plants the magnitude of WUE remained nearly same.

The results of above experiments have shown that in musk melon, the photosynthetic rate parallels with transpiration rate hence it can be argued that in musk melon, the drought response is at the stomatal level as is also shown in other mesophytes (Reddy et al., 2004; Rouhi et al., 2007). The results also show that recovery in snap melon is very fast.

Impact of water stress on soluble sugar and starch content

Plants accumulate different types of organic and inorganic solutes to lower osmotic potential which leads to maintenance of cell Tourgour (Anjum et al., 2011). Plants also maintain leaf turgor by accumulation of solutes such as proline, soluble sugars, glycinebetaine, etc. The process of accumulation of such solutes is known as osmotic adjustment. In view of this, the Institute took up an investigation to study the carbohydrate profile in kachari and musk melon under stress and after recovery. The plants were grown at normal spacing with drip irrigation. At 35 days after sowing, the water stress was imposed on the plants and maintained for long duration. The observations on soluble sugar and starch content were estimated after giving water stress treatment for at least 20 days. The results are presented in table 20.

Perusal of data in table 20 reveals that the magnitude of soluble sugars accumulated in root are more in kachari as compared to that in musk melon. This is illustrated by the fact that the sugar levels were 65.04, 74.26 and 86.38 mgg^{-1} fr. wt. at 20, 23 and 26 days after imposition of stress whereas in musk melon the respective values were 38.11, 40.14 and 44.58 mgg^{-1}fr. wt. The data further reveals that in shoot the level of sugars were nearly same in both the materials.

Table 20. Effect of water stress on accumulation of soluble sugars and starch in kachari and musk melon

Source	Species	Days after imposition of stress		
		20	23	26
Soluble sugar (mg g^{-1} fr. wt.)				
Root	Kachari	65.04	74.26	86.38
	Musk melon	38.11	40.14	44.58
Shoot	Kachari	88.54	92.77	96.65
	Musk melon	87.25	96.48	104.06
Starch (mg g^{-1} fr. wt.)				
Root	Kachari	40.44	36.32	16.28
	Musk melon	44.32	40.57	25.60
Shoot	Kachari	62.78	56.24	32.72
	Musk melon	65.88	60.28	48.68

The data on starch content reveals that the magnitude of starch content in the roots of kachari was 40.44, 36.32 and 16.28 mg g^{-1} fr. wt. at 20, 23 and 26 days after imposition of stress. The values in musk melon at respective stage were 44.32, 40.57 and 25.60 mg g^{-1} fr. wt. The results revealed that there is no marked difference at starch content in roots of two species under water stress. Similar results were also observed in shoots.

Similar studies were also conducted using mateera and musk melon under different regimes of water stress. In this experiment, the seeds were germinated and then transferred in plastic pots. After 10 days of growth, the seedlings were given stress treatment by irrigating the seedling with the solution of PEG 6000 having the water potential of 0.2 MPa, 0.5 MPa and 1.0 MPa. The controls were irrigated regularly.

After 15 days of treatment, the seedlings were harvested and separated into root and shoot. Both were analyzed for total soluble sugars and starch content. Perusal of data revealed that in root tissue, the level of soluble sugar content in mateera increases with the magnitude of the water stress. This is illustrated by the fact that the soluble sugar content in root was 50 mg g^{-1} fr. wt. in control which gradually increased to 86 mgg^{-1} fr.wt. in plants treated with 1.0 MPa solution. Similar results were also obtained in the root tissue of musk melon, but the level of sugar accumulation was much lower than that recorded in the mateera (Fig. 4).

The data on soluble sugar content in shoot revealed that in the level of soluble sugar content in shoot is differs slightly with the imposition of water stress. This is illustrated by the fact that in control the level of soluble ugar was to the tune of 70 mgg^{-1} fr. wt. which increased slightly to 96 mgg^{-1} fr. wt. at 1.0 MPa treatment. Similar results were also obtained with respect to musk melon also (Fig. 5). The results highlights that accumulation of soluble sugars in root is the typical adaptive mechanism in drought tolerant plants. These reserve sugars not only increases the osmotic potential of the cell sap but also act as source of energy for growth and development as soon as the water is available to the plants.

The data on Starch content (Fig. 6-7) reveals that the starch content decreased with the imposition of the water stress. This is illustrated by the fact that in mateera the starch content was to the tune of 55 mg g^{-1} fr. wt. which declined to 36 mg g^{-1} fr. wt. at 0.5 MPa and to 16.0 mg g^{-1} fr. wt. at 1.0 MPa treatment. Similar results were also obtained in musk melon which also demonstrated decrease in the starch content in root.

Perusal of data on starch content in shoot revealed that starch content also declined with imposition of water stress. This is illustrated by the fact that in mateera shoot the starch content was 84 mg g^{-1} fr. wt. in control which dropped to 62.0, 56.0 and 32.0 mg g^{-1} fr. wt. at 0.2 MPa, 0.5 MPa and 1.0 MPa treatment, respectively.

The data was further analysed and it was found that the sugar/ starch ratio is also a typical parameter in adaptation to drought tolerance. The data on sugar/ starch ratio in root revealed that in mateera (drought tolerant) the ratio increased with increase in intensity of water stress. This is illustrated by the fact that the ratio was 0.91 at control which increased to 1.62, 2.05 and 5.37 at 0.2 MPa, 0.5 MPa and 1.0 MPa treatment. However, in musk melon the magnitude of increase in sugar/ starch ratio was very low (Fig. 8-9).

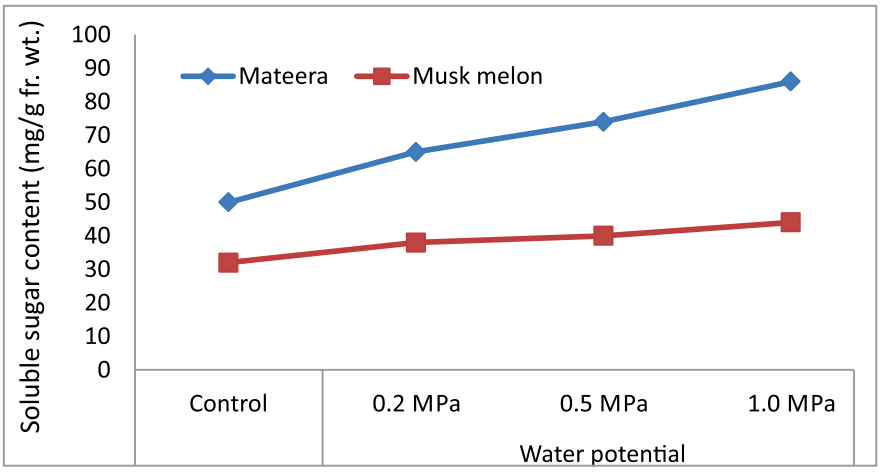

Fig. 4. Effect of water stress on soluble sugars in root

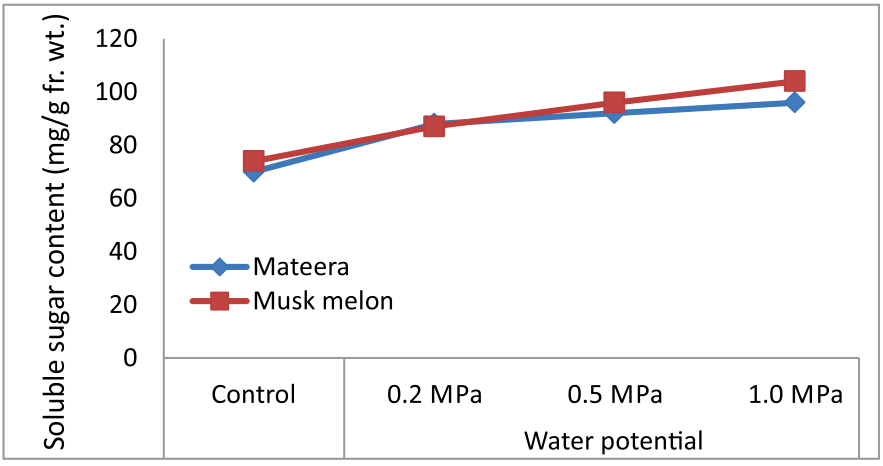

Fig. 5. Effect of water stress on soluble sugars in shoot

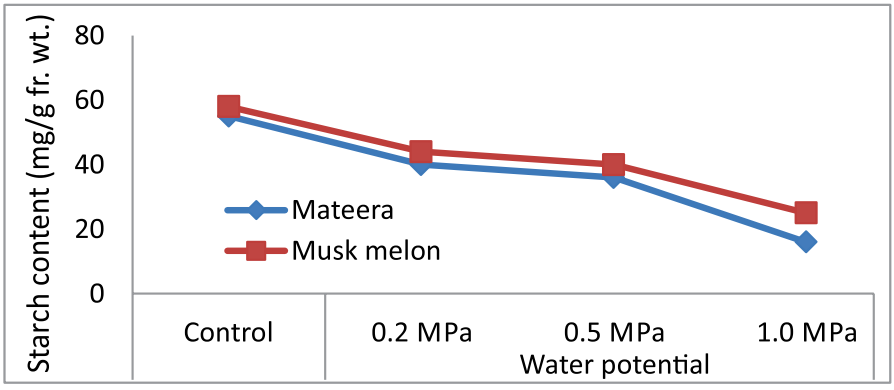

Fig. 6. Effect of water stress on starch content in root

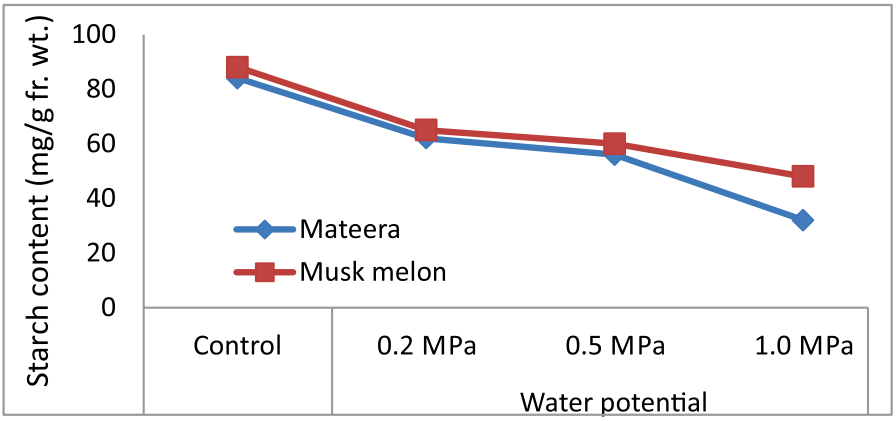

Fig. 7. Effect of water stress on starch content in shoot

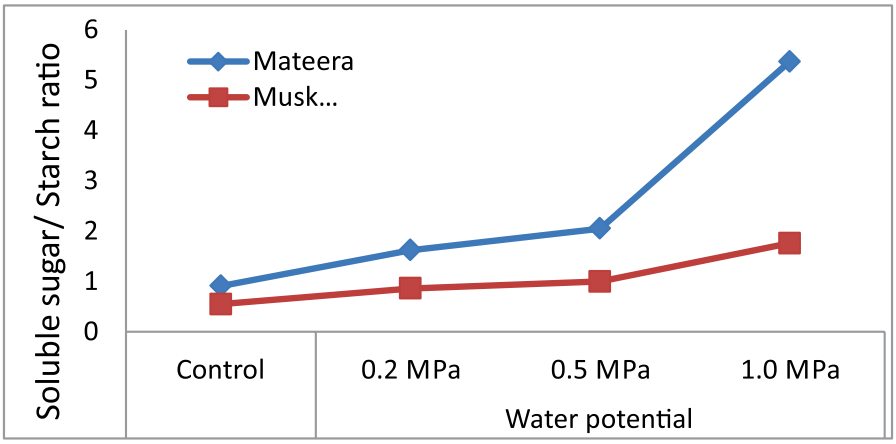

Fig. 8. Effect of water stress on soluble sugar/starch ratio in root

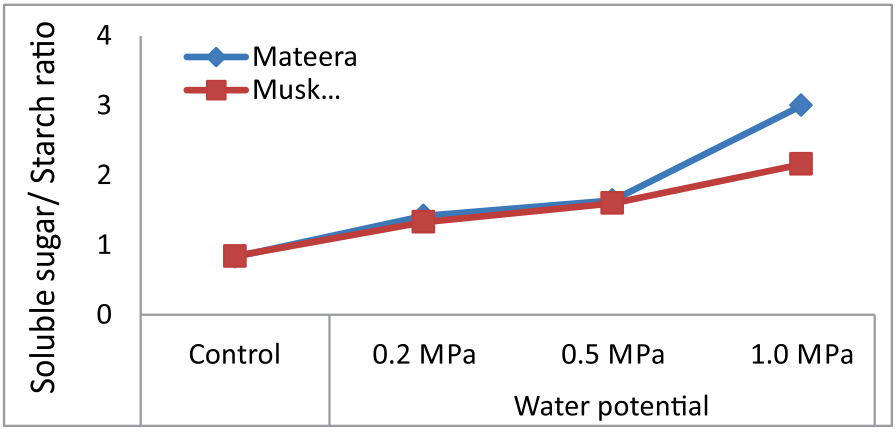

Fig. 9. Effect of water stress on soluble sugar/starch ratio in shoot

Impact of water stress on metabolite accumulation

Changes in metabolites in kachari and musk melon

Drought also creates oxidative stress in plants (Weidner *et al.*, 2009). This leads to production of excess of reactive oxygen species and free radicals which can be neutralized either by scavenging systems, such as superoxide dismutase, catalase and peroxidase or by involving small molecules such as glutathione, ascorbate, carotenoids, flavonoid, phenols, etc. Among various compounds present in plant tissue, phenolics and flavonoid have anti oxidative properties (Rosicka-Kaczmarek, 2004). The antioxidative effect produced by phenols mainly depends on ther hydroxyl groups present in its structure.

To assess the changes in metabolite composition in plants during water stress, an experiment was laid out in the field using kachari and musk melon as the material under investigation. The plants were grown at normal spacing with drip irrigation. At 35 days after sowing, the water stress was imposed on the plants and maintained for long duration. The observations on phenolics content was estimated after giving water stress treatment for at least 20 days. The results are presented in Table 21.

Perusal of data in table 21 reveals that in kachari root the magnitude of phenolic content at day of stress was 922.93 µg g^{-1} fr. wt. which remained upto 1152.10 µg g^{-1} fr. wt. under control condition, but the imposition of water stress drastically increased the phenolics and their magnitude went up to 2530.81 µg g^{-1} fr. wt. by 26 days after imposition of stress.

Similarly in shoot, in the control samples, the magnitude was 2455.90 µg g^{-1} fr. wt. at day of imposition of stress which remained nearly same at all stages in control but under water stress, it drastically increased and went up to 3482.97, 3863.00 and 3852.71 µg g^{-1} fr. wt. at 20, 23 and 26 days after imposition of stress.

Table 21 : Phenolic content (µg/ g fr. wt.) in plants under water stress

Treatments	Days after stress			
	Zero	20	23	26
Kachari (root)				
Control	922.93	1032.96	1152.10	1131.07
Stress		1540.25	2244.05	2530.81
Kachari (shoot)				
control	2455.90	2262.20	2695.29	2275.57
Stress		3482.97	3863.00	3852.71
Musk melon(root)				
Control	1418.30	1435.39	1609.06	1594.20
Stress		3135.99	2759.19	2722.15
Musk melon(shoot)				
control	1543.93	2191.55	2365.08	2099.80
Stress		3415.64	3854.25	3206.64

The results in musk melon also show an increase in phenolics content in the samples. This is illustrated by the fact that in root, the magnitude was 1418.30, 1435.39, 1609.06 and 1594.20 µg g^{-1} fr. wt. at day of imposition of stress, 20, 23 and 26 days after imposition of stress respectively under controls. However, under stress treatment, the magnitude was 3135.99, 2759.19 and 2722.15 µg g^{-1} fr. wt. at 20, 23 and 26 days after imposition of water stress. Similar results were also obtained for shoot also.

Metabolite composition in snap melon and musk melon under water stress

An experiment was conducted using snap melon and musk melon to assess the impact of water stress on metabolite composition in leaves. The experiment was laid out in the field and when the plants have attained age of 45 days they were divided into two groups. One set was maintained as control and other set was given water stress by withholding irrigation. Stress treatment was given for 10 days and after that the plants were irrigated and observations on metabolite composition were recorded during recovery.

Perusal of data in table 22 reveals the changes in total flavonoid content in musk melon and snap melon with imposition of water stress. In musk melon, the flavonoid content decrease with imposition of water stress but after re-irrigation, the magnitude increases. Similar trend was also observed in snap melon.

Table 22. Total flavonoid content in plants under different treatment

Treatment	Total Flavonoid (mgg^{-1} dry wt.)				
	Days after stress			Days after re-irrigation	
	5	10	05	10	15
CM	1.32±0.011	2.11±0.055	2.75±0.130	1.71±0.010	0.966±0.055
TM	1.34±0.015	0.81±0.062	2.80±0.045	2.37±0.202	0.76±0.036
CS	3.42±0.075	1.33±0.085	5.67±0.030	7.12±0.090	1.196±0.030
TS	1.44±0.087	6.55±0.133	5.186±0.106	4.36±0.096	1.46±0.140

Perusal of data in table 23 reveals that tannin content in musk melon increases with age in control. However, under water stress it decrease slightly but on re-irrigation the magnitude is maintained high. Similar trend was also observed in snap melon also.

Table 23. Tannin content in plants under different treatment

Treatment	Tannin (mgg^{-1} dry wt.)				
	Days after stress			Days after re-irrigation	
	5 day	10	05	10	15
CM	3.19±0.036	2.92±0.11	5.19±0.03	4.41±0.04	4.55±0.04
TM	2.34±0.061	3.30±0.04	5.11±0.21	5.033±0.045	4.05±0.015
CS	3.79±0.065	3.5±0.062	5.44±0.04	5.38±0.036	5.41±0.025
TS	3.49±0.19	3.91±0.088	5.016±0.032	5.153±0.035	4.9±0.097

Perusal of data with respect to alkaloid content shows that this metabolite increases with increase in age in control plants in musk melon. However, under water stress, it decreases nearly 50% but on re-irrigation its magnitude increases. Similar trend was also observed in snap melon (Table 24).

Table 24. Alkaloid content in plants under different treatment

Treatment	Alkaloid (%)				
	Days after stress			Days after re-irrigation	
	5day	10	5	10	15
CM	0.8±0.1	1.56±0.15	1.65**±0.05**	1±0.1	1.24±0.045
TM	1.46±0.11	0.78±0.07	1.27±0.07	1.46±0.06	2.71±0.206
CS	1.23±0.15	0.8±0.05	1.2±0.1	1.47±0.07	1.246±0.05
TS	2.28±0.10	0.8±0.1	1.43±0.057	1.2±0.05	1.48±0.076

Perusal of data with respect to total sugar demonstrate that the magnitude of total sugar remains nearly same in control plants of musk melon whereas in water stress plants there is a marked increase after 10 days of re-irrigation (Table 25).

Table 25. Total sugar content in plants under different treatment

Treatment	Total Sugar (mgg^{-1}dry wt.)				
	Days after stress			Days after re-irrigation	
	5 day	10	5	10	15
CM	26.12±0.13	39±1.89	32.29±0.51	43.52±1.37	37.69±1.95
TM	24.04±0.29	32.97±1.02	30.94±0.45	52.41±0.56	36.50±4.11
CS	29.26±0.14	41.49±3.82	26.71±0.23	33.91±3.42	29.86±0.22
TS	28.88±1.17	41.63±1.32	37.27±0.08	40.39±0.44	36.89±0.25

Effect of water stress on enzyme activities

Under optimal conditions leaves are rich in antioxidant enzymes and metabolites and can cope with reactive oxygen species. A fund of information is available on the deleterious effect of ROS produced under water stress (Blokhina et al., 2003, Foyer and Noctor, 2005). As a consequence, tolerant genotypes not only have maintenance of water in cytosol but also possess several tissue antioxidant enzymes such as Superoxide dismutase, ascorbate peroxidase, glycol peroxidase, glutathione reductase, Catalase, etc. (Zlatev and Lidon, 2012). These enzymes act as protectant and an increase in these enzymes may act as part of antioxidant system which leads to normal function of protein synthesis and gene expression. In view of this, the enzyme activity in drought tolerant and susceptible genotypes was assessed to understand the mechanism followed to protect plants from ill effects of drought.

Effect of water stress on enzyme activities in the embryo at different growth stages

The effect of water stress on enzyme activity in the embryo was assessed upto 98 days after treatment in cluster bean, mateera, muskmelon and water melon. The seeds were surface sterilized and germinated in different solutions i.e. 0.2 MPa and 0.5 MPa PEG (Water stress) and another set were kept as water control. Three enzymes were estimated viz. peroxidase, protease and amylase. Perusal of data revealed that in case of cluster bean, the level of enzyme was 2.5 units at 24 hrs under control which remained nearly constant at other treatments also. However, from 48 hrs onwards, the magnitude of peroxidase declined at 0.5 MPa solutions and dropped from 7.25 to

5.25 units. This difference further increased to 12.25 to 8.5 units by 96 hrs. The effect of water stress on peroxidase activity in muskmelon was very glaring. The imposition of water stress to the tune of 0.5 MPa declined the peroxidase enzyme activity from 4.5 units under control to 1.2 units. At different growth stages viz. 48, 72 and 96 hrs too, the magnitude of enzyme activity remained as low as 1.79 units at 0.5 MPa as compared to 10.5 units in control.

The data for protease activity also demonstrated that in mateera and cluster bean the imposition of water stress has minor effect on the magnitude of protease activity. This is illustrated by the fact that the protease activity in mateera was 0.05 units at 24 hrs which slightly dropped to 0.048 units. Similarly at 72 hrs it dropped from 0.69 to 0.054 units. The data in muskmelon revealed that the magnitude of enzyme activity was 0.03 units at 24 hrs in control which dropped significantly to 0.003 units by 24 hrs in 0.5 MPa PEG treatments. Similarly by 96 hrs the value dropped from 0.067 units in control to 0.008 units in 0.5 MPa PEG solutions. This illustrates that the drought tolerant plants have mechanism to protect the enzyme activity even under adverse conditions.

Effect of water stress on enzyme activities in the cotyledons at different growth stages

The effect of water stress on enzyme activity in the cotyledons was assessed upto 98 days after treatment in cluster bean, mateera, and muskmelon and water melon. The seeds were surface sterilized and germinated in different solutions i.e. 0.2 MPa and 0.5 MPa PEG (Water stress) and another set were kept as water control. Three enzymes were estimated viz. peroxidase, protease and amylase. Perusal of data revealed that in case of cluster bean, the level of peroxidase enzyme remained relatively high even under drought stress but declined slightly when the stress reached a magnitude of 0.5 MPa. However in drought susceptible species, the peroxidase activity remained low throughout.

The data for protease activity also demonstrated that in mateera and cluster bean the imposition of water stress has minor effect on the magnitude of protease activity. This is illustrated by the fact that the protease activity in mateera was 0.07 units at 24 hrs which slightly dropped to 0.058 units. The perusal of data in muskmelon revealed that the magnitude of enzyme activity was 0.04 units at 24 hrs in control which dropped significantly to 0.002 units by 24 hrs in 0.5 MPa PEG treatments.

Impact of water stress on enzyme activity in seedling

Catalase

The catalase activity in seedlings of three plant species was estimated after one month of sowing. The seedlings were harvested and separated into leaf, stem and root. After processing the catalase activity was estimated. The results revealed that in tolerant variety (Kachari) the catalase activity increased with the imposition of water stress. This is illustrated by the fact that in leaves the catalase activity was 0.12 unit, 0.16unit and 0.19 unit in control 0.2MPa and 0.5MPa treatments, respectively. The maximum activity was recorded in leaves followed by root. In tolerant cultivars, the catalase activity does not change much with the imposition of water stress.

Peroxidase

The peroxidase activity in seedlings of three plant species was estimated after one month of sowing. The seedlings were harvested and separated into leaf, stem and root. After processing the peroxidase activity was estimated. The data revealed that in tolerant variety (Kachari) the

peroxidase activity increased with the imposition of water stress. This is illustrated by the fact that in leaves the Catalase activity was 0.64 unit, 1.113 unit and 1.076 unit in control 0.2MPa and 0.5MPa treatments, respectively. The maximum activity was recorded in leaves followed by root. In root also the peroxidase activity was 0.22, 0.29 and 0.34 units in control, 0.2MPa and 0.5MPa treatments, respectively.

In tolerant plants, such as water melon, the peroxidase activity in leaves increased with imposition of water stress. It was 0.555, 0.72 and 0.84 units in control, 0.2MPa and 0.5 MPa treatments, respectively. Similarly, in roots the magnitude was 0.979, 1.324 and 1.28 units at control, 0.2 MPa and 0.5 MPa treatments, respectively.

Impact of water stress on enzyme activities at different growth intervals

In order to understand the mechanism of drought tolerance in arid horticultural crops, an experiment was conducted to assess the effect of water stress on the enzyme activities during the seedling growth stages. The experiment consisted of three treatments viz. Control, 0.2 MPa and 0.5 MPa solution of PEG. The seeds of two species viz. Cluster bean and muskmelon were germinated on distilled water and after emergence; they were transferred in the respective PEG solutions. The seeds of all above plant materials were sampled at 24, 48, 72 and 96 hours after transfer to PEG solution and fixed in respective buffer for estimation of enzyme activities. During the present study peroxidase, protease and amylase enzymes were estimated.

Impact of water stress on peroxidase activity in germinating seeds

The results obtained on the peroxidase activities under different water potential are presented in Fig 10. Perusal of figures reveals that in case of cluster bean the peroxidase activity was low at 24 hrs which increased gradually and reached to nearly 12.50 units in cluster bean under control condition. However when the seedlings were grown under water stress the enzyme activity was maintained as high as 9.75 units by 96 hrs under 0.2 MPa PEG solution and 8.5 units under 0.5 MPa

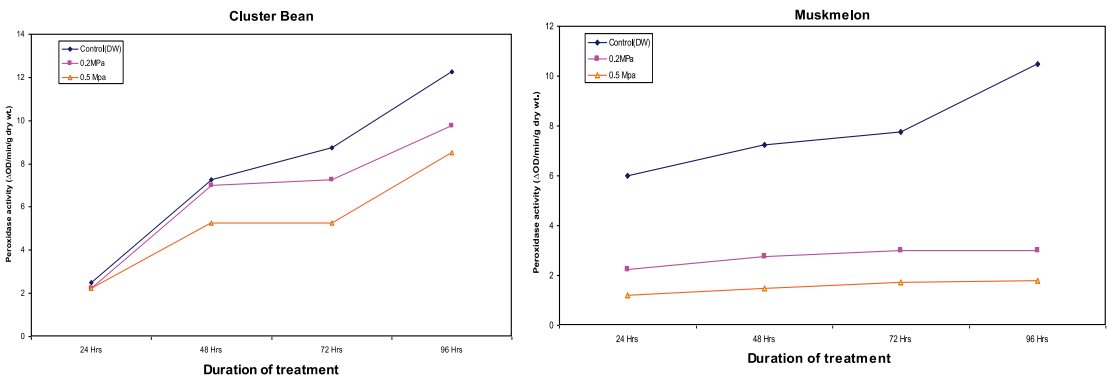

Fig. 10: Impact of water stress on peroxidase activity in germinating seeds

PEG solution.

The impact of water stress on the enzyme activity in drought susceptible species demonstrates that under control condition, the enzyme activity increased with the increase in duration of germination and reached a peak of 10.50 units in muskmelon However, when the seedlings were grown under drought

conditions, the enzyme activity remained very low. Showing thereby that drought susceptible species are not able to maintain the activity of this enzyme during germination which leads to failure of germination.

Impact of water stress on protease activity in seedling

Being an important enzyme necessary for hydrolysis of stored protein in the seeds which ultimately triggers synthesis of new proteins or increase in amino acid pool, the impact of water stress on changes in protease activity was studied in all the four plant species. The data thus generated are presented in Fig. 11.

Perusal of data in Fig. 11 reveals that in drought tolerant cultivars (Cluster bean) the protease activity (mg amino acid release/ min/ gram seed wt.) increased gradually and reached a peak of 0.07 mg amino acid release/ min/ gram seed wt. by 96 hrs under control condition. It was further demonstrated that in cluster bean the enzyme activity continued to increase even under drought condition and reached a peak of 0.08 mg amino acid release/ min/ gram dry seed wt. by 96 hrs after transfer under 0.2 MPa solution. Similar trend was also observed with 00.5 Mpa PEG solution in which the magnitude reached upto 0.064 units.

The enzyme activity in muskmelon showed a drastic reduction in the enzyme activity when they were grown under PEG solutions. Perusal of Fig. 11 demonstrates that in muskmelon grown in control condition, the activity was to the tune of 0.061 mg amino acid release/ min/ gram seed wt. by 96 hrs. However, when the seedlings were grown in PEG solutions, the activity dropped drastically The activity was 0.002 mg amino acid release/ min/ gram seed wt. at 24 hrs after

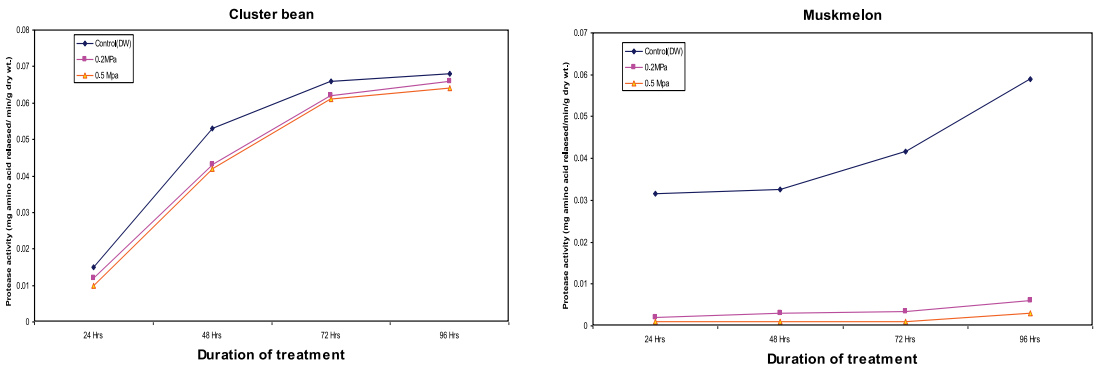

Fig. 11: Impact of water stress on protease activity during germination of seeds

sowing and 0.006 mg amino acid release/ min/ gram seed wt. by 96 hrs in 0.2 MPa solution. The activity further reduced when the seedlings were grown in 0.5MPa solution of PEG.

Impact of water stress on amylase activity in seedlings

The impact of water stress on amylase activity in germinating seeds of four plant species was estimated. It was observed that amylase activity also tracked the same patterns as other two enzymes described above. The data is presented in Fig. 12.

Perusal of Fig. 12 reveals that amylase activity (mg starch hydrolysed/hour/gram seed) was high in all plant species when grown under control condition. In cluster bean, the magnitude was as high as 18.10 mg starch hydrolysed/hour/gram seed at 24 hrs after germination which increased

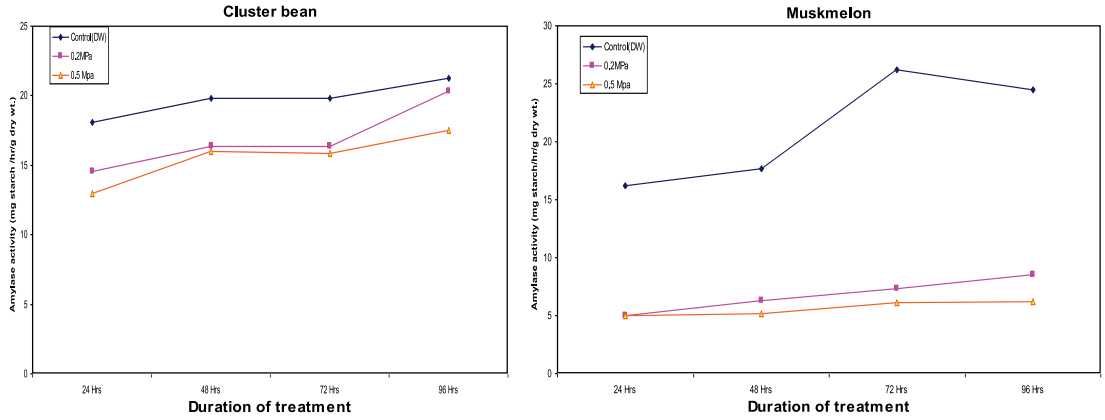

Fig. 12: Impact of water stress on amylase activity in germinating seeds

to 21.25 mg starch hydrolysed /hour/gram seed after 96 hrs of sowing. When the seedlings of cluster bean were transferred in PEG solution, there was marginal decrease in amylase activity.

Perusal of Fig. 12 shows that in muskmelon there was drastic decrease in the amylase activity when the seedlings were transferred in PEG solution. This is illustrated by the fact that under control condition, the amylase activity in muskmelon seedlings was as high as 16.24 mg starch hydrolysed/ hour/gram seed which reached a magnitude of 24.50 mg starch hydrolysed/hour/gram seed by 96 hrs. However, when the seedlings were grown under 0.2 MPa PEG solution, the activity remained as low as 5.0 mg starch hydrolysed/hour/gram seed which marginally increased to 8.50 mg starch hydrolysed/hour/gram seed by 96 hrs. Similarly when the seeds were grown under 0.5 MPa solution, the activity was low (4.99 mg starch hydrolysed/hour/gram seed) which marginally increased to 6.2 mg starch hydrolysed/hour/gram seed by 96 hrs. Thus, it was concluded that in drought susceptible species the activity of all the three enzymes gets drastically affected when the seedlings are exposed to stress condition, which leads to either failure to germinate or poor germination.

Impact of water stress on PGR levels in germinating seeds

In order to understand the mechanism of drought tolerance in arid horticultural crops, an experiment was conducted to assess the effect of water stress on the PGR levels during the germination of seeds. The experiment consisted of three treatments viz. Control, 0.2 MPa and 0.5 MPa solution of PEG. The seeds of watermelon and musk melon (drought susceptible) were germinated under the above three treatments and germination percentage was recorded. The seeds of all above plant materials were sampled at 24, 48, 72, 96, 120 and 144 hours after sowing and fixed in methanol for estimation of PGRs. During the present study ABA, GA and IAA were estimated.

Impact of water stress on ABA levels in germinating seeds

The impact of water stress on the ABA level in three plant species was assessed using HPLC. The samples were fixed at 24, 48, 72, 96, 120 and 144 hrs after sowing and analysed after purification on HPLC using methanol: water as solvent system. ABA levels were recorded to the tune of 4.0 µg/g dry seed at 24 hrs after sowing which dropped to 2.8 µg/g dry seed by 96 hrs and further to 2.34 µg/g dry seed by 144 hrs. However, when the seeds were exposed to water stress, the magnitude of ABA in the seeds increased. This is illustrated by the fact that it reached to 14.13 µg/g dry seed

by 72 hrs and after that dropped slightly at 0.2 MPa. Similar trend was observed at 0.5 MPa also where it peaked at 16.15 µg/g dry seed at 96 hrs and after that it dropped slightly.

In case of watermelon the trend observed was similar to that for muskmelon. In this case also the seeds germinated under control condition showed lower level of ABA which declined after germination (7.46 -4.0 µg/g dry seed). However when the seeds were exposed to water stress, there was a marked increase in ABA level. It can be seen that level of ABA increased to 40.41 µg/g dry seed by 48 hrs and remained more than 30 µg/g dry seed throughout the experimental period when seeds were exposed to 0.2 MPa solution. Similarly when the seeds were exposed to 0.5 MPa solution of PEG the value reached up to 42.77 µg/g dry seed by 72 hrs and remained high throughout.

Impact of water stress on GA levels in germinating seeds:

The GA level in two species viz. watermelon and musk melon was examined under control and water stress. Perusal of data revealed that in case of musk melon, the seeds sown under control condition showed high level of GA. This is illustrated by the fact that GA content was 23.62 µg/g dry seed at 24 hrs which increased further to 32.88 µg/g dry seed by 120 hrs. The level remained high throughout the germination period. However, when the seeds were exposed to 0.2 MPa solution of PEG, level initially increased but dropped subsequently.

The GA level in watermelon also shows the similar trend as depicted above. Under control condition, the GA levels remained high but when the seeds were germinated under stress condition, the GA content declined.

Screening parameters for drought tolerance

Plant Height Stress Index and Dry Matter Stress Index

An attempt was made to identity & develops screening parameters for drought resistance. Among large number of parameters available to screen the germplasms 2 viz. plant height stress index (PHSI) and dry matter stress index (DMSI) were tested. It was noted that both the parameters hold good in screening germplasm for drought resistances. For instance in drought resistant material (mateera, kachari and snap melon) the value of plant height stress index remained more than 70% whereas in water melon it was as low as 50%. Similarly, the values of dry matter stress index also reveals that the values are more than 60% in stress tolerant cultivars but was less than 50% in susceptible cultivars (Table 26).

An attempt was also made to evaluate the role of germination under water stress as a parameter for screening. In this case seeds of water stress tolerant (Snap melon, Kachari, Mateera) and susceptible (Musk melon) were germinated in control and 1 Mpa solution. It was observed that no reduction in germination percentage was observed during present study (Table 27).

Table 26. Stress index for screening drought tolerant lines

Genotype	Dry Matter	Plant Height
Water Melon		
Sugar Baby	34.10	71.63
Mahoboby	47.48	50.93
Kachari		

Genotype	Dry Matter	Plant Height
AHK 119	72.44	88.59
AHK 200	69.78	95.13
Snap melon		
AHS 82	91.11	80.95
AHS 10	88.70	72.32
Tinda	49.00	82.37
Mateera		
AHW 65	66.75	77.58

Table 27. Seed germination in selected plant species under control and stress conditions

Plant type	Control	Stress
Snap melon - AHS 10	91.65	93.30
Kachari - AHK 200	100.00	98.33
Mateera - AHW 65	41.65	41.65
Tinda	90.00	88.00
Musk melon	98.33	98.33

Degree of leaf rolling

The observations were recorded in field under irrigated and stressed plants. The data presented in Table 28 reveals that in tolerant cultivars such as kachari and mateera the leaf rolling was upto 45% under stressed condition whereas in susceptible cultivars the leaf rolling was more that 55% in both cultivars. Thus, this parameter can be employed to assess the nature of plant.

Table 28. Leaf rolling 20 days after withholding of irrigation.

Variety	Irrigated (%)	Stressed (%)
Kachari	-	42.25
Mateera	-	45.00
Muskmelon	-	58.82
Watermelon	2.45	60.00

Way forward

Although a comprehensive work on adaptation mechanism of drought tolerance in arid horticultural plants have been done, yet there is need to address the following issues in future:

1. Molecular approaches in drought tolerance mechanism needs special attention.
2. Functional genomics of abiotic stress in arid horticultural crops
3. Interaction between plant and soil microbes to mitigate drought
4. Marker assisted breeding for drought tolerance
5. Developing mitigation strategies for drought tolerance

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