Assessment Of Drought Responses of Chilli (*Capsicum annum* L.) Genotypes By Using Modern Plant Phenomics Tools

BY

Babar Rohit Rajiv
B. Sc. (Hort.)

THESIS

Submitted to the
Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani
in partial fulfillment of the
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MASTER OF SCIENCE

(HORTICULTURE)

IN

VEGETABLE SCIENCE

DEPARTMENT OF HORTICULTURE,
COLLEGE OF AGRICULTURE,
VASANTRAO NAIK MARATHWADA KRISHI VIDYAPEETH,
PARBHANI - 431402 (M.S.), INDIA
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PARBHANI - 431402 (M.S.), INDIA
2019

CANDIDATE'S DECLARATION

I, hereby declare that, the entire work

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has not been previously submitted

by me for a degree of

any University or

Institution.

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CERTIFICATE - I

This is to certify that **Mr. BABAR ROHIT RAJIV** has satisfactorily prosecuted his course credits and research for a period of not less than two years and the thesis entitled **"ASSESSMENT OF DROUGHT RESPONSES OF CHILLI (*Capsicum annum* L.) GENOTYPES BY USING MODERN PLANT PHENOMICS TOOLS "** submitted by him is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination for the award of the degree of **MASTER OF SCIENCE (Horticulture)** in the subject of **VEGETABLE SCIENCE**.

I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any University or institution.

Place: PARBHANI **Dr. G. M. WAGHMARE**
Date: / /2019 **Research Guide**

CERTIFICATE-II

This is to certify that the thesis entitled **"ASSESSMENT OF DROUGHT RESPONSES OF CHILLI (*Capsicum annum* L.) GENOTYPES BY USING MODERN PLANT PHENOMICS TOOLS "**submitted by **Mr. BABAR ROHIT RAJIV** (Reg.No.2017HT/10M) to the Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE (Horticulture)** in the subject of **VEGETABLE SCIENCE** has been approved by the student's advisory committee after oral examination in collaboration with the external examiner.

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Do what you can, with what you have…Where you are!

-Theodore Roosevelt.

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ABBREVIATIONS

@	-	at the rate
%	-	per cent
/	-	per
^{0}C	-	Degree Celsius
CD	-	Critical difference
cm	-	ccentimetre
DAT	-	Days after transplanting
e.g.	-	Exampli gratia (for example)
et al.	-	Et alia (and associates)
etc.	-	Et cetera
Fig.	-	Figure
g	-	Grams
ha	-	Hectare
i.e.	-	That is
kg	-	Kilogram (s)
m	-	Meter
mm	-	Millimeter
MSS	-	Mean sum of squares
No.	-	Number
NS	-	Non significant
Q. Y.	-	Quantum yield
SE $\pm$	-	Standard error
Sig.	-	Significant
t	-	tons
Viz.	-	Videlicet (namely)
wt/wt	-	weight by weight basis

THESIS ABSTRACT

ABSTRACT

Assessment of Drought Responses of Chilli (*Capsicum annum* L.) Genotypes By Using Modern Plant Phenomics Tools

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A candidate for the degree of

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2019

Research Guide	**:**	**Dr. G. M. Waghmare**
Department	**:**	**Horticulture**

Although the Global temperature has increased, it is expected to increase further in the next century. The annual daily maximum temperatures are projected to increase at the rate of 3^0C by mid-21st century and about 5^0C by the late 21st century. This would result in a more recurrent and extreme drought events in many parts of the world. To face this problem, there is a great need to identify the different genotypes which can withstand drought stress and yield sustainably (Annex, I, 2012; Sherwood *et al*., 2013). Hence the present investigation was undertaken to study the performance of different chilli genotypes under depleting soil moisture conditions which occurs during drought. Above experiment was set in pots and the evaluation of genotypes was done by adopting conventional as well as modern image based approaches. Eight genotypes *viz*., *Parbhani Tejas, Parbhani Mirchi, Phule Jyoti, Jayanti, Hirkani, Arka Lohit, Arka Suphal* and *Local Genotype* were sown in a pots with three stress treatments *viz*., non-stress (control), stress at flowering and stress at fruit development, with two replications. In addition to this, same genotypes were used to study the influence of

depleting soil moisture level on shoot traits. Present investigation was conducted at National Institute of Abiotic Stress Management (18° 09’ 30.62’’N; 74° 30’ 03.08’’E; MSL 570m), Malegaon (Baramati), Dist.- Pune during Rabi season of 2018.

Observations were recorded on growth, leaf, physiological, phenological, fruit, yield and quality parameters. Along with all these parameters, plants responses also captured through different imaging systems by employing plant phenomics facility. Results showed that drought stress imposed at flowering and fruit development stage; adversely affected growth and physiological processes of plants of all genotypes which resulted in decreased commercial yield. Drought stress imposed at flowering stage was found to be the most effective on restricting the growth and inducing major flower drop, which was ultimately resulted into decreased yield as compared to yield under non-stress condition. However, plants which were subjected to drought stress at stage of fruit development produced fruits of shortest length and having less fruit weight with more pungency while these fruits had low ascorbic acid content. Physiological parameters were significantly affected by stress imposed at both growth stages. Physiological traits like RWC, chlorophyll content, chlorophyll fluorescence, stomatal conductance, NDVI, SPAD index were sustainably less under stress conditions; however, canopy temperature and proline content were relatively high as compared those under non stress conditions. This negative impact on physiological parameters can be used as an indicator of magnitude of stress and as predictor of yield potential of genotypes under stressed conditions. From the recorded observations, it is evident that the genotype – *Parbhani Mirchi* was less influenced under drought stress as compared to other genotypes. *Parbhani Mirchi* was found to be the tallest genotype and could maintain physiological status even under stress conditions.

Image based parameters also revealed that *Parbhani Mirchi* was less affected under depleted soil moisture conditions. Shoot architecture of plants were studied by visible images however tissue water level of genotypes were interpreted from NIR images. Shoot architecture of plants were studied by interpreting the data generated from parameters like area, caliper length and digital volume. Image based data revealed that *Parbhani Mirchi* was more efficient in maintaining its shoot architecture even under stressed conditions as compared to other genotypes. *Parabhni Mirchi* also preserved its tissue water level under stressed condition.

Parbhani Mirchi showed higher shoot dry weight and biomass under both control and stressed conditions as revealed by conventional and phenomics

methods. Hence, it may be concluded that, *Parbhani Mirchi* was the most promising among selected eight genotypes.

Overall, from the present study it is evident that *Parbhani Mirchi* has outstanding performance among all the eight genotypes tested. Therefore the genotype can be considered suitable for sustainable cultivation of chilli crop in water stress-prone areas of the country. This experiment was carried out for only one time hence to make any standard recommendations, same trial should be repeated. Additionally the genotype also appears suitable as parent in breeding experiments that are targeted towards stress tolerance and yield improvement in chilli.

INTRODUCTION

CHAPTER - I

INTRODUCTION

Vegetables play a key role in food nutrition and economic security of our country and crop diversification. India ranks second in the total vegetable production after China. In India, vegetables are grown on commercial scale in an area of 10.29 million ha with production of 175 million MT with productivity 17.01MT/ha (Anonymous, 2017).

Chilli (*Capsicum annum* L.) is an important cash crop grown for national and international market. It is native of new world tropics, which was brought to India by Portuguese prior to year 1785. Centre of origin of chilli is Mexico while Guatemala is secondary center of origin (Salvador, 2002). Diploid chromosome number of chilli is 2n=24. Genus Capsicum belongs to family Solanaceae and comprises about twenty species (Gadaginmath, 1992).

India is the largest producer, consumer and exporter of chilli, which contributes about 40 per cent of total world production. In India, chilli occupies an area of 0.287 million ha with annual production of 3.406 million MT and its productivity is 13.4 MT/ha. Maharashtra contributes 1.60 lakh hectare areas with annual production of 18.68 lakh MT/ha its productivity is of 11.68 MT/ha (Anonymous, 2017). In India, Andhra Pradesh is the largest producer of chilli contributing to about 44 percent to the total production, followed by Karnataka (12%), West Bengal (8%), Madhya Pradesh (7%), Maharashtra (4%) and Tamil Nadu (2%) (Anonymous,2017). The major chilli growing districts in Maharashtra are Nagpur, Chandrapur, Dhule, Nanded, Pune, Kolhapur, Amravati, Jalgaon, Beed, Aurangabad, Nashik, Palghar and Yawatmal, all of which are featured by scarcity of water.

Chilli is an indispensable vegetable cum spice crop in every home of the tropical countries. It is used for its pungency, colour and taste. Green chillies are rich in vitamin A, E and C and seed contains traces of starch (Hosmani, 1993). The fruits of chilli also contain a fixed oil, red coloring matter which is non pungent and yields 20 to 25% alcoholic extract. Red chilli fruit contains dry matter 22.02%, Ascorbic acid 131.06 mg/100g (fresh weight), oleoresin 66.53 ASTA units, coloring matter 67.38 ASTA units, capsaicin 0.34% (dry weight), crude fiber 26.75% and total ash 6.69%.

Hundred gram of green chilli contains 85.70g moisture, 2.90g protein, fat 0.60g, minerals 1g, fibre 6.80g, carbohydrates 3g, calcium 30mg, magnesium 24mg, riboflavin 0.39mg, oxalic acid 67mg, nicotinic acid 0.90mg, phosphorous 80mg, iron 1.20mg, sodium 6.50mg, copper 1.55mg, chlorine 15mg, thiamine 0.19mg, vitamin A 292I.U. and vitamin C 111mg, (Bose *et al*. 2002).

Chillies are major ingredients of curry powder in the culinary preparations. Extracts of chillies are used in the production of ginger beer and beverages. Chillies are also rich in 'rutin' which is of immerse pharmaceutical needs. Chilli is specially used for its pungency, spicy taste, besides the appealing color it adds to the food. It is used in pickles, sauces, ketchup, essences, oleoresins and it is an inevitable ingredient in Indian dishes. Capsaicin, derived from chilli, has significant physiological action and hence it is used in many pharmaceutical preparations like ointments for cold, throat infection, chest congestion etc. It is also used in cosmetics like prickly heat powders and skin ointments. Capsanthin, which is coloring principle in chilli, is used as coloring agent for preparation of jams and sauces. Due to its wide utility, demand of chilli is increasing day by day (Janaki, 2016).

Although the Global temperature has increased moderately, it is expected to increase further in the next century. The annual daily maximum temperatures are projected to increase at the rate of 3°C by mid of 21st century and about 5°C by the late 21st century. This would result in a more recurrent and extreme drought events in many parts of the world Annex I, 2012; Sherwood *et al*., 2013). On a global basis, the occurrence of climate change on precipitation and temperature patterns will result into about one-third of prospective arable land experience inadequate water supply (Liu *et al*., 2015). In addition, the physiological basis for yields response of much of the remainder would be intermittently altered by drought. Drought conditions decrease plant growth by stressing several physiological and biochemical processes such as leaf respiration, leaf chlorophyll content, gas exchange, leaf water content, plant relative growth rate, among others. This situation can lead to significant reduction in total yield of crops (Farooq *et al*., 2012; Lei *et al*., 2006). Plants' responses to drought are rather complex; they utilize different mechanisms to contest the adverse effects of drought stress at varying stages of growth and development. During severe drought stress, plants either accumulate compatible osmolytes, adjusts osmotic potential, complete life cycle within a very short period (Bartels and Sunkar, 2005; Chaves *et al*., 2003), or

keep stomata open to allow CO_2 assimilation through cell enlargement (Hare *et al*., 1998). These mechanisms may work synergistically to prompt effective but varying tolerance levels during the periods of depleting soil moisture stress.

Most of the cultivars of chilli commercially grown have been developed based on their yield potential under optimal soil moisture condition. In the many of the regions of Maharashtra, which is known for water scarcity, the yield performance of these varieties are far than below their actual potential due to suboptimal access to irrigation. Therefore, it is necessary to identify the stable and drought tolerant cultivars of chilli as the best adaptation options under drought situation. Cultivars thus identified can also serve as donor lines for developing drought tolerant genotypes.

Several attempts have been made to assess germplasms of cultivated plants through traditional approaches involving invasive methods. However, recently noninvasive tools have been developed and available for assessing response of plants to drought with greater precision. These tools have become integral part of plant phenomics. These tools, which have not been used so far to identify promising lines in horticultural crops like chilli; for drought prone areas. Hence, the studies were conducted with the following objectives.

Objectives:

1. To study the morpho-physiological changes in chilli genotypes under depleting soil moisture stress conditions

2. To identify the promising chilli genotypes for moisture stress tolerance by employing plant phenomics tools

REVIEW OF LITERATURE

CHAPTER - II

REVIEW OF LITERATURE

Chilli is an important vegetable crop. Now days, world facing major problem of climate change. Due to this climate change, ecological balance has been broken down, which ultimately leads to abrupt climatic conditions. And because of such undesirable changes in climate, production of agricultural produce is greatly hampered. These effects are nothing but the results of drought, flood, global warming and so on. To find the solution on this many resesrchers are trying.

The present investigation entitled "Assessment of drought responses of Chilli (*Capsicum annum* L.) genotypes using modern Plant Phenomics tools" was conducted during *Rabi* season 2018 at ICAR – National Institute of Abiotic Stress Management, Malegaon (Baramati). However, there is a need to select high yielding drought stress tolerant lines suitable for drought prone or rainfed conditions.

The literatures available on effect of different genotypes and drought stress along with their interactions on various parameters of chilli is presented under subheadings as listed *viz*; growth , leaf , physiological, phenotyping, flowering, fruiting , fruit , yield and quality parameters.

2.1 Soil parameters:

2.1.1 Soil moisture content (%)

Nahar *et al*. (2011), conducted pot culture experiment on two cultivars of tomato with three treatments of water stress to investigate effects of water stress on moisture content in soil at different depth and revealed that moisture content distribution was higher at the surface and decreased with increasing stress at all growth stages which have direct impact on growth and yield of plant.

Wakchaure G. C. *et al*. (2018), conducted experiment on onion with different deficit irrigation regimes and revealed that soil moisture percent goes on decreasing with increase in soil moisture stress.

2.2 Growth parameters:

2.2.1 Plant height (cm)

Abou-Hussein *et al*. (1984), reported that the increase in field capacity percentage (9 to 90) significantly increased plant height.

Ramesh (1986), observed that higher levels of irrigation recorded more or less same plant height compared to plants under deficit irrigation.

Showemimo F. A. *et al.* (2007), conducted experiment on sweet pepper with four regimes of irrigation intervals such as control, three, seven nd fourteen days and found that significant reduction in plant height as interval goes on increasing.

Kirnak *et al*. (2001), conducted experiment on egg plant cv. Teorem F1 with four treatments and revealed that there was reduction in plant height under stressed conditions as compared to normal irrigation.

Techawongstien *et al.* (1992), conducted dexperiment on fifteen cultivars of chilli under water stress treatment and revealed that plant height was significantly decreased under stress treatment as compared to control.

Suh *et al*. (1987), conducted experiment on two chilli cultivars with irrigation regimes and revealed plan height was decreased due to stress regime.

Gunawardena *et al*. (2014), conducted experiment on chilli cv. MI2 with treatments of temperature and water stress, in combination and observed least plant height under water stress at temperature of 34^0C.

Khan *et al*. (2008), conducted experiment on two chilli cultivars *viz*, C-0277 and C-0272 with six water treatments *viz*, W1= watering once everyday, W2= watering twice everyday, W3= watering at 4 days interval, W4= watering at 8 days interval, W5= watering at 16 days interval and W6= no watering (control) which were imposed at three different growth stages *viz*, vegetative stage, flowering stage and fruiting stage and revealed that plants subjected to water stress at vegetative stage showed least height as compared control and plants subjected to stress at flowering and fruiting stage. In addition to this, longer the irrigation interval also negatively affects the plant height.

Akinbile *et al.* (2011), conducted experiment on chilli pepper with four irrigation treatments and three replications observed that plants irrigated at 50% ET attained maximum plant height while plants at 100% ET showed least height

Khan *et al*. (2012), conducted experiment on ten chilli accessions with four watering treatments in three replications and observed that accession C0271 attained maximum plant height, treatment of no watering shown least height.

Phimchan *et al*. (2012), conducted experiment on nine cultivars of chilli and reported that plants subjected to drought stress shown decreased plant height.

Gobu et *al*. (2017), conducted experiment on sixty five genotypes of brinjal under water stress and non stress condition to identify the drought tolerant cultivars of brinjals and revealed that plant height in water stressed pots was reduced by 30.86 % compared to non-stressed plants.

2.2.2 Stem girth (mm)

Kirnak *et al*., (2001), conducted experiment on *Solanum melongena* plants and revealed that at 40 percent of water stress, the stem diameter was reduced by 51 percent compared to control.

De Koning *et al*. (1983), reported that under drought stresss conditions, tomato plants were attributed with lower stem diameter

Phimchan *et al*. (2012), conducted experiment on nine cultivars of chilli and reported that plants subjected to drought stress shown decreased stem girth.

Byari (1995), conducted experiment on four eggplant cultivars *viz*., Black Beauty, Long Purple, Florida Market, Egyptian White, with four irrigation levels : daily, every four days, every eight days and every twelve days interval. And reported that plants irrigated at 12 days of interval, attained significantly thin stem diameter as compard to regular irrigating plants.

Buriro *et al*. (2015), conducted experiment on sunflower with four irrigation regimes : T1 = 2 irrigations (30 and 45 DAS), T2 = 3 irrigations (30, 45 and 60 DAS), T3 = 4 irrigations (30, 45, 60 and 75 DAS), T4 = 5 irrigations (30, 45, 60, 75 and 90 DAS) and observed that plants irrigated at 30, 45, 60, 75 and 90 DAS (T4), attained thickest stem diameter whereas plants irrigated twice : 30 and 45 DAS (T1), shown thinner diameter as compared to other treatments.

2.3 Leaf parameters:

2.2.1 Leaf area (cm^2)

Schaefer *et al*. (1978), reported that withholding water from 32nd day old pepper plants cv. Yolo Wonder had a marked influence on reducing leaf area.

Wolfe *et al*. (1982), revealed that reduction in dry matter production in potato plants under stress conditions was attributed to the reduction in leaf area .

Beese *et al*. (1982), reported that under moisture stress condition, the leaf area was lower in chile pepper when compared to control treatments.

Aloni *et al*. (1984), reported that, there was a positive correlation between water potential and leaf area, as water potential deplets, leaf are also gets reduced.

Thakur *et al*. (1993), revealed that water stress for seven days reduced leaf area in five tomato cultivars when stress was intensified for another three days, leaf area was reduced upto 71 per cent compared with unstressed controls.

Khan *et al*. (2008), conducted experiment on two chilli cultivars *viz*, C-0277 and C-0272 and observed that drought stress significantly reduces leaf area.

Khan *et al*. (2012), conducted experiment on ten chilli accessions with four watering treatments in three replications and observed lowest leaf area when plants were subjected to drought stress at vegetative stage whereas plants`response to drought stress in concern to leaf area was non significant at other stages.

Phimchan *et al*. (2012), conducted experiment on nine cultivars of chilli and reported that plants subjected to drought stress shown decreased leaf area.

2.4. Physiological parameters

2.4.1 Relative Water Content (%)

Dar *et al*. (1981), reported that reduction in RWC was associated with decreased leaf water potential.

Kuhad *et al*. (1986) found that water deficits decreased the RWC in leaves of all cultivars of cluster beans resulting in reduction in photosynthesis

Vijayakumar (1989), reported a highly significant RWC as the intensity of stress increased of the six chilli cultivars Byadagi maintained maximum RWC as well as diffusive resistance indicating its unique drought avoidance mechanism.

Thakur *et al*. (1993), reported that when the stress was given up to 10 days, it significantly reduces the RWC with increasing stress duration in all tomato cultivars.

Phimchan *et al*. (2012), conducted experiment on nine cultivars of chilli and reported that plants subjected to drought stress shown decreased relative water content.

Sivakumar *et al*. (2014), conducted experiment on 18 genotypes of tomato with two treatments *viz.*, 100% F.C and 50% F.C and reported that plants subjected to stress treatment *i.e.*, showed lower percent of RWC as compared to control.

Olarewaju *et al*. (2017), conducted experiment on three different species of genus- *Capsicum* with four drought stress treatments such as control, light, moderate and severe drought stress by withholding the water to 80–85%, 55–60%, 40–45% and 30–35% water holding capacity (WHC) respectively and observed that moderate and severe drought induced significant reduction in leaf relative water content (LRWC).

Gobu *et al*. (2017), conducted experiment on sixty five genotypes of brinjal under water stress and non stress condition to identify the drought tolerant cultivars of brinjals and revealed that RWC in moisture stressed plants shown 46.85% decrease when compared to non-moisture stressed plants.

2.4.2 Chlorophyll fluorescence (*Fv/Fm*)

Arani et *al*. (2017), conducted experiment on fenugreek under five irrigation regimes (unstress control, irrigation at 60% available soil water (ASW); mild stress, irrigation at 40% ASW during the vegetative and reproductive stages; severe stress, irrigation at 20% ASW during the vegetative and reproductive stages) and revealed that water deficit stress decreased maximum Chl fluorescence (*Fm*), variable Chl fluorescence (*Fv*), the photochemical efficiency of PSII (*Fv/Fm*).

Paknejad *et al*. (2007), conducted experiment on three wheat varieties with seven irrigation treatments and revealed that there was declined trend in chlorophyll fluorescence under stressed irrigation condition and shown positive correlation between *Fv/Fm* and grain yield.

Zewdie *et al.* (2007), conducted experiment on enset clones with treatments of drought and normal irrigation, and reported negative impact of drought stress on photosynthetic efficiency (*Fv/Fm*) as that of controlled condition.

Geetha *et al*. (2017), conducted experiment on twelve sunflower genotypes with two stress treatments such as irrigation withheld from 40 DAS to 60 DAS and revealed that severe stress significantly reduces *Fv/Fm*.

Shahenshah(2010), conducted experiment on five cultivars of cotton and six cultivars of peanut were grown in pots under two water levels; the control and water stress condition, where irrigation water equal to 100% and 50% of the daily transpiration, respectively and revealed that peanut genotypes canopy showed reduced Chlorophyll fluorescence than that of cotton genotypes under water stress condition.

2.4.3 Chlorophyll content (mg g^{-1})

Kirnak *et al*. (2001), conducted experiment on egg plant cv. Teorem F1 with four treatments and revealed that there was reduction in total chlorophyll content under stressed conditions as compared to normal irrigation.

Arani *et al*. (2017), conducted experiment on fenugreek under five irrigation regimes (unstress control, irrigation at 60% available soil water (ASW); mild stress, irrigation at 40% ASW during the vegetative and reproductive stages; severe stress, irrigation at 20% ASW during the vegetative and reproductive stages) and revealed

that water deficit stress decreased total chlorophyll content which has direct on photosynthesis ability of plant.

Olarewaju *et al*. (2017), conducted experiment on three different species of genus- *Capsicum* with four drought stress treatments such as control, light, moderate and severe drought stress by withholding the water to 80–85%, 55–60%, 40–45% and 30–35% water holding capacity (WHC) respectively and observed that moderate and severe drought induced significant reduction in total chlorophyll contetnt of plants.

Shahenshah (2010), conducted experiment on five cultivars of cotton and six cultivars of peanut were grown in pots under two water levels; the control and water stress condition, where irrigation water equal to 100% and 50% of the daily transpiration, respectively and revealed that peanut genotypes canopy showed decreased chlorophyll content than that of cotton genotypes under water stress condition.

2.4.4 Canopy temperature (^{0}c)

Jackson *et al.* (1981), conducted an experiment on wheat and revealed that water stress increases canopy temperature; therefore, it can be used as an indicator of water stress

Ndiso *et al*. (2016), conducted experiment on eleven cultivars of cowpea with three stress treatments *viz.* control, stress at vegetative stage and stress at flowering stage and revealed that plants which were subjected to stress at both growth stage have been found with increased canopy temperature.

Rezaei *et al*. (2014), conducted experiment on eleven hybrids of pea under treatments *viz.*, well watered and water stressed, and revealed that plants under stress treatment showed higher canopy temperature.

Paknejad *et al.* (2007), conducted experiment on three wheat varieties with seven irrigation treatments and revealed that there was higher canopy tempearure under stressed irrigation condition.

Shahenshah (2010), conducted experiment on five cultivars of cotton and six cultivars of peanut were grown in pots under two water levels; the control and water stress condition, where irrigation water equal to 100% and 50% of the daily transpiration, respectively and revealed that peanut genotypes canopy showed higher canopy temperature than that of cotton genotypes under water stress condition

Stark *et al.* (1991), conducted experiment on fourteen potato genotypes under control (100% of potential ET) and stressed irrigation treatments (40% to 50% of

potential ET) and reported that genotypes subjected to water stress shown elevated canopy temperature as compared to genotypes under control.

Çolak *et al.* (2015), conducted experiment on eggplant with two irrigation systems (surface drip and subsurface drip systems), two irrigation intervals (IF3: 3-day; IF6: 6-day) and four irrigation levels in sub-sub plots (Full irrigation, FI; deficit irrigation, DI-50; deficit irrigation, DI-75; and Partial Root-zone drying PRD-50% of full irrigation treatments) were tested in split-split plot design with four replications. And revealed that more the interval between irrigation imposed stress and deficit irrigation might creat drought conditions, and hence concluded that plants under these factors would show more Crop Water Stress Index (CWSI) which was indicated by increased canopy temperature of plants.

Kirnak *et al*. (2001), conducted experiment on the eggplant (*Solanum melongena* L. cv., Teorem F1) with four irrigation treatments 100%, 80%, 60% and 40% of pot capacity. And reported that plants receiving less water (60% and 40%) were having higher canopy temperature, almost 3.6^0C than the plants under 100% and 80% of pot capacity.

2.4.5 Chlorophyll Index (SPAD value)

Sivakumar *et al.* (2016), conducted experiment on ten tomato cultivars under two stress treatments and revealed that SPAD value (chlorophyll index) was reduced due to stress.

Gobu *et al*. (2017), conducted experiment on sixty five genotypes of brinjal under water stress and non stress condition to identify the drought tolerant cultivars of brinjals and revealed that chlorophyll index was significantly reduced under stressed conditions.

Shahenshah(2010), conducted experiment on five cultivars of cotton and six cultivars of peanut were grown in pots under two water levels; the control and water stress condition, where irrigation water equal to 100% and 50% of the daily transpiration, respectively and revealed that peanut genotypes canopy showed reduced SPAD value than that of cotton genotypes under water stress condition

Naderikharaji *et al*. (2008), conducted experiment on four rapeseed cultivars with four levels of moisture: control, 75%FC, 50%FC, 25%FC and revealed that chlorophyll index (SPAD value) was significantly decreased as moisture stress increases

Nemeskéri *et al*. (2019), conducted experiment on three super-sweet corn hybrids (*Zea mays* L. convar. saccharata) under in three water supplies (regularly irrigated, deficit-irrigated, and unirrigated) and observed that unirrigated conditions significantly reduces chlorophyll index (SPAD value).

2.4.6 Normalized Difference Vegetation Index (NDVI)

Silva *et al*. (2015), conducted experiment on cluster bean and observed that higher NDVI value in normally irrigated plants as compared to stressed plants.

Bayoumi *et al*. (2015), conducted experiment on two bread wheat genotypes along with their F1`s under different levels of water stress and shown that, NDVI gets significantly reduced because of water stress condition as stress directly impacts on chlorophyll formation in leaves.

Nemeskéri *et al*. (2019), conducted experiment on three super-sweet corn hybrids (*Zea mays* L. convar. saccharata) under in three water supplies (regularly irrigated, deficit-irrigated, and unirrigated) and observed that unirrigated conditions significantly reduces NDVI.

Ihouma *et al* (2017), reported that as leaf water potential deplets, NDVI also gets reduced which can be treated as stress indicator.

2.4.7 Stomatal conductance (mmol $m^{-2}s^{-1}$)

Ihouma *et al.* (2017), reported that as leaf water potential deplets, stomatal conductance also gets reduced which can be treated as stress indicator.

Bayoumi *et al*. (2015), conducted experiment on two bread wheat genotypes along with their F1`s under different levels of water stress and shown that, stomatal conductance gets significantly reduced due to water stress condition as stress directly impacts on stomatal behavior in leaves.

Naderikharaji *et al*. (2008), conducted experiment on four rapeseed cultivars with four levels of moisture: control, 75%FC, 50%FC, 25%FC and revealed that stomatal conductance was significantly decreased as moisture stress increases during both stages *viz*., vegetative and flowering.

Delfine *et al*. (2002), conducted experiment on field-grown sweet pepper under irrigated and rainfed (stress) conditions and revealed that water stress significantly reduces stomatal conductance as compared to control.

Bhatt *et al*. (2014), conducted experiment on eight brinjal genotypes and under different water stress conditions and reported that there was significant decline in stomatal conductance under drought stress.

Riaz *et al*. (2013), conducted experiment on two marigold varieties *viz*., Super giant and Inca F1 with four drought levels at 100% (control), 80%, 70% and 60% field capacity and revealed that stomatal onductance significantly reduced at 60% FC as compared to control and 80% FC.

2.4.8 Proline content (mg g^{-1} f w)

Ghai *et al*. (2016), conducted experiment on fourteen genotypes of hot pepper and revealed that proline accumulation increases under stressed condition as compared to control.

Ichwan *et al*. (2017), conducted experiment on eight red chilli cultivars under three stress treatments such as 100%, 75%, 50% of field capacity and observed that plants subjected to higher stress 50% FC shown more accumulation of proline content, which can be treated as stress indicator.

Khan *et al*. (2015), conducted experiment on tomato in greenhouse under two different conditions of water availability *i.e*. controlled and drought. Results showed that drought stress significantly increases proline content in leaves of plants.

Lakshmi *et al*. (2015), conducted experiment on eleven different cultivars of chilli under three different stress treatments: control, mild stress (withholding of water for 10 days) and sever stress (withholding of water for 20 days), and reported that variety S-10 and No-5 showed higherproline content when stress imposed at vegetative stage similarly, during reproductive above two varieties shown higher accumulation of proline than that of other varieties.

Ghaffari *et al*. (2012), conducted experiment on Sunflower inbred lines with different levels of moisture stress and revealed that proline accumulation was increased as stress proceed.

Sivakumar *et al*. (2014), conducted experiment on eighteen brinjal genotypes under two moisture stress levels : 100% FC and 50% FC and revealed that proline accumulation was increased in plants subjected for 50% FC as compared to 100% FC.

Khan *et al*. (2015), conducted experiment on tomato cv. B Bombino with two treatments of irrigation : control and stress; and found more proline content in plants subjected to stress.

2.5 Flowering parameters

2.5.1 Days to initiate first flower

Phimchan and Techawongstien (2012), conducted experiment on nine cultivars of chilli and reported that flowering was iniated after 45 – 50 days of transplanting.

Dorji *et.al* (2004), conducted experiment on chilli cv. Ancho St. Luis three irrigation treatments : full irrigation on both sides of the rootzone similar to commercial irrigation (CI) considered as control, irrigation with half the volume of CI on both sides of rootzone considered as DI, and half of irrigation volume in CI applied to one side of rootzone at each irrigation time designated as PRD and reported early flower emergence in stressed plants than that of control.

Showemimo F. A. et al. (2007), conducted experiment on sweet pepper with four regimes of irrigation intervals such as control, three, seven nd fourteen days and found that stressed plants showed ealy flowering than that of control plants.

Sivakumar, S. Srividhya (2016), conducted experiment on ten genotypes of tomato with two irrigation regimes : 1.0 IW/CPE and 0.5 IW/CPE field capacity. And reported early flower emergence in plants subjected to 0.5IW/CPE of field capacity.

2.5.2 Flower drop (%)

Vijay *et al*, (1979) reported that peak production of flowers in chilli was very much dependent on soil moisture levels. Chilli plants grown in a moisture stress condition of 10 per cent of field capacity caused 71.2 per cent flower drop compared to the 20 and 30 per cent of field capacity, which caused 55.6 and 57.4 per cent flower drop respectively.

Haynes and Herring (1981), reported that the· percentage of flower retention was highest with irrigation at 560 mb with viaflo.

Wein *et al*. (1990) demonstrated that low soil moisture status increased the percentage of flower drop in hot pepper compared to more adequate levels.

Rao and Padma (1991) reported that moisture stress at the flowering stage resulted in high percentage flower drop which lead to low fruit set in all the five varieties of tomato.

Rao and Bhatt (1992), conducted experiment on tomato and reported that water stress accompanied by temperature above 28@C during fruiting resulted in 30-45 per cent flower drop.

Sivakumar *et al*. (2014), conducted experiment on eighteen brinjal genotypes under two moisture stress levels : 100% FC and 50% FC and revealed that flower drop

percentage was increased in plants subjected for 50% FC as compared to 100% FC which was resulted into lower yield.

Sivakumar and Srividhya (2016), conducted experiment on ten genotypes of tomato with two irrigation regimes : 1.0 IW/CPE and 0.5 IW/CPE field capacity. And reported that as the stress increased from 100% field capacity to 50% field capacity, flower drop was more as compared to control.

Phimchan and Techawongstien (2012), conducted experiment on nine cultivars of chilli and reported that plants subjected to drought stress, dropped more number of flowers per plant as compared to regular watered plants.

Dorji *et.al* (2004), conducted experiment on chilli cv. Ancho St. Luis three irrigation treatments : full irrigation on both sides of the rootzone similar to commercial irrigation (CI) considered as control, irrigation with half the volume of CI on both sides of rootzone considered as DI, and half of irrigation volume in CI applied to one side of rootzone at each irrigation time designated as PRD and recorded more than 50% of flower drop in deficit irrigation as compared to commercial irrigation.

Kirnak *et al.* (2001), conducted experiment on egg plant cv. Teorem F1 with four treatments of moisture stress and revealed that there was more than 40% flower abcission under stressed conditions as compared to normal irrigation.

Delfine *et al*. (2002), conducted experiment on field-grown sweet pepper under irrigated and rainfed (stress) conditions and revealed that water stress significantly increases flower drop percentage as compared to control which ultimately turned into lowering of yield.

Ferrara *et al.* (2011), conducted experiment on capsicum cv. Peppone under green house conditions with 3 water regimes (control, stress at vegetative stage and stress at reproductive stage) and revealed that stress at vegetative stage significantly reduced number of flowers.

2.6 Fruiting parameters

2.6.1 Number of days required to initiate first fruit

Rao and Padma (1991), that moisture stress at the flowering stage delayed fruit development in all the five varieties of tomato.

Sivakumar, S. Srividhya (2016), conducted experiment on ten genotypes of tomato with two irrigation regimes: 1.0 IW/CPE and 0.5 IW/CPE field capacity. And

reported early fruit development in plants subjected to 0.5IW/CPE of field capacity at late vegetative stage.

Showemimo F. A. *et al.* (2007), conducted experiment on sweet pepper with four regimes of irrigation intervals such as control, irrigation at three, seven and fourteen days interval and found that longer the interval, produce early fruiting in plants.

2.6.2 Number of fruits per plant

Vijay *et al*, (1979) reported that peak production of flowers in chilli was very much dependent on soil moisture levels. Chilli plants grown in a moisture stress condition of 10 per cent of field capacity retained only 29.8 per cent of fruits compared to the 20 and 30 per cent of field capacity, which retained 45.4 and 43.6 per cent fruits respectively.

Rao and Padma (1991), reported that moisture stress at the flowering stage resulted in low fruit set in all the five varieties of tomato.

Wein *et al*.(1990), demonstrated that low soil moisture status reduced the retaintaion of fruits in hot pepper as compared to controlled conditions.

Nuruddin *et al.* (2003), conducted experiment on tomato cv. Sunstart under green house conditions with two available soil water deficit thresholds (65% and 80%) and five irrigation timing patterns (1. no water stress; 2. stress throughout the entire growing season; 3. stress during first cluster flowering and fruit set 4. stress during first cluster fruit growth; and 5. stress during first cluster fruit ripening) and reported that water stress during first clusterof flowering significantly reduced number of fruits per plant.

Ferrara *et al.* (2011), conducted experiment on capsicum cv. Peppone under green house conditions with 3 water regimes (control, stress at vegetative stage and stress at reproductive stage) and revealed that stress at reproductive stage (flowering stage) significantly reduced number of fruits per plant.

Sivakumar *et al*. (2014), conducted experiment on tomato with 18 genotypes by adopting CRD with three replications and two treatments viz, 100 and 50 % field capacity and observed more fruits per plant in 100% FC as compared to 50% FC.

Lakshmi *et al*. (2015), conducted experiment on 11 varieties of chilli with treatments : control (Regular irrigation); mild moisture and severe moisture stress and reported that severe moisture stress, which was imposed at both vegetative and

reproductive phases by withholding water for 10 and 20 days resulted into lowering the number of fruits per plant.

Khan *et al*. (2015), conducted experiment on tomato cv. B Bombino with two treatments of irrigation : control and stress; and found less numbers of fruits in plants subjected to stress.

Kirnak *et. al* (2002), conducted experiment on eggplant cv. Pala with four irrigation treatments : well-watered treatment receiving 100% replenishment of a pan evaporation on a daily basis (C); water-stressed treatment receiving 90% replenishment of a pan evaporation at 4-day intervals (WS1); water-stressed treatment receiving 80% replenishment of a pan evaporation at 8-day intervals (WS2); and water-stressed treatment receiving 70% replenishment of a pan evaporation at 12-day intervals (WS3) and revealed that WS3 significantly reduced 28% of total number of fruits as compared to control.

Showemimo F. A. et al. (2007), conducted experiment on sweet pepper cv. L5962-2 with four regimes of irrigation intervals such as control, irrigation at three, seven and fourteen days interval and found that only 11.56% of fruits retained per plant which was irrigated at fourteen days interval as compared to control.

Khan *et al*. (2008), conducted experiment on two cultivars of chilli *viz*., C-0277 and C-0272 with six water treatments—W1= watering once everyday, W2= watering twice everyday, W3= watering at 4 days interval, W4= watering at 8 days interval, W5= watering at 16 days interval and W0= no watering (control), which were imposed at different growth stages *viz*., vegetative stage, S1 = 28-43 days, flowering stage, S2 = 44-59 days and fruiting
stage, S3 = 60-76 days and revealed that no watering throughout crop growth period gives significantly less number of fruits per plant as compared to other treatments.

Nahar *et al*. (2011), conducted pot culture experiment on two cultivars of tomato : BR-4, BR-5 with three treatments of water stress to investigate effects of water stress on number of fruits per plant that fruits from plants under control condition (70% FC) showed more number of fruits per plant than that of fruits from stressed condition (40% FC).

Gunawardena *et al*. (2014), conducted experiment on chilli cv. MI2 with six treatments of temperature and water stress in combination : no water stress at ambient temperature, 50% water stress at ambient temperature, no water stress at 32^0C maximum temperature, 50% water stress at 32^0C maximum temperature, no water

stress at 34^0C maximum temperature, 50% water stress at 34^0C maximum temperature and observed that 50% water stress at temperature of 34^0C significantly reduces number of fruits per plant as compared to control (no stress at ambient temperature).

2.7. Yield parameters

2.7.1 Number of pickings

Kirnak *et. al* (2002), conducted experiment on eggplant cv. Pala with four irrigation treatments : well-watered treatment receiving 100% replenishment of a pan evaporation on a daily basis (C); water-stressed treatment receiving 90% replenishment of a pan evaporation at 4-day intervals (WS1); water-stressed treatment receiving 80% replenishment of a pan evaporation at 8-day intervals (WS2); and water-stressed treatment receiving 70% replenishment of a pan evaporation at 12-day intervals (WS3) and revealed that WS3 significantly reduced number of harvestings of fruits as compared to control.

Dorji *et.al* (2004), conducted experiment on chilli cv. Ancho St. Luis three irrigation treatments : full irrigation on both sides of the rootzone similar to commercial irrigation (CI) considered as control, irrigation with half the volume of CI on both sides of rootzone considered as DI, and half of irrigation volume in CI applied to one side of rootzone at each irrigation time designated as PRD and reported that there was a fall in number of harvestings due deficit irrigation which was an indicator of lowering the yield.),

Lakshmi *et al*. (2015), conducted experiment on eleven varieties of chilli with treatments : control (Regular irrigation); mild moisture and severe moisture stress and reported that severe moisture stress, which was imposed at both vegetative and reproductive phases by withholding water for 10 and 20 days resulted into lowering the number harvestings of fruits per plant in all varities.

Rao and Padma (1991), reported that moisture stress at the flowering stage resulted into less fruit production which ultimately leads to less number of pickings all five varieties of tomato.

Vijay *et al*. (1979), conducted experiment on chilli with different treatments of field capacity and revealed that plants exposed to higher water stress shown less number of pickings throughout the growth period.

2.7.2 Fruit yield per plant (g)

Rezaei *et al*. (2014), conducted experiment on ten pea hybrid lines at two different places : irrigated and rainfed (stress) and revealed that all ten hybrid lines shown reduced pod yield under rainfed condition.

Ichwan *et al*. (2017), conducted experiment on eight red chilli cultivars under three stress treatments such as 100%, 75%, 50% of field capacity and observed that plants subjected to higher stress *i.e*, 50% FC shown reduced fruit yield per plant.

Kirnak et al., (2001) conducted experiment on egg plant cv. Teorem F1 with four treatments and revealed that there was reduction in fruit yield under stressed conditions as compared to normal irrigation.

Nahar *et al*. (2011), conducted pot culture experiment on two cultivars of tomato : BR-4, BR-5 with three treatments of water stress to investigate effects of water stress on number of fruits per plant that fruits from plants under control condition (70% FC) showed significantly more fruit yield per plant than that of fruits from stressed condition (40% FC).

Khan *et al*. (2008), conducted experiment on two cultivars of chilli *viz.*, C-0277 and C-0272 with six water treatments—W1= watering once everyday, W2= watering twice everyday, W3= watering at 4 days interval, W4= watering at 8 days interval, W5= watering at 16 days interval and W0= no watering (control), which were imposed at different growth stages *viz.*, vegetative stage, S1 = 28-43 days, flowering stage, S2 = 44-59 days and fruiting stage, S3 = 60-76 days and revealed that no watering during flowering stage significantly reduced fruit yield per plant per plant as compared to other treatments.

Sivakumar *et al*. (2014), conducted experiment on 18 genotypes of tomato with two treatments *viz.*, 100% F.C and 50% F.C and reported that plants subjected to stress treatment showed lsignificantly lower fruit yield as compared to control.

Sivakumar, S. Srividhya (2016), conducted experiment on ten genotypes of tomato with two irrigation regimes: 1.0 IW/CPE and 0.5 IW/CPE field capacity. And reported significantly less fruit yield in plants subjected to 0.5IW/CPE of field capacity as compared to fruit yield in 1.0 IW/CPE.

Delfine *et al*. (2000), conducted experiment on field-grown sweet pepper cv. Peppone and revealed that water stress significantly reduces fuit yield as compared to others.

Gunawardena *et al*. (2014), conducted experiment on chilli cv. MI2 with six treatments of temperature and water stress in combination : no water stress at ambient temperature, 50% water stress at ambient temperature, no water stress at 32^0C maximum temperature, 50% water stress at 32^0C maximum temperature, no water stress at 34^0C maximum temperature, 50% water stress at 34^0C maximum temperature and observed that 50% water stress at temperature of 34^0C significantly reduces fruit yield per plant as compared to control (no stress at ambient temperature).

2.7.3 Yield per ha (t ha^{-1})

Khan *et al*. (2008), conducted experiment on two cultivars of chilli *viz.*, C-0277 and C-0272 with six water treatments—W1= watering once everyday, W2= watering twice everyday, W3= watering at 4 days interval, W4= watering at 8 days interval, W5= watering at 16 days interval and W0= no watering (control), which were imposed at different growth stages *viz*., vegetative stage, S1 = 28-43 days, flowering stage, S2 = 44-59 days and fruiting
stage, S3 = 60-76 days and revealed that no watering during flowering stage and fruiting significantly reduced total yield per hectre as compared to regular irrigating treatment.

Vijay *et al*. (1979), conducted experiment on chilli with different treatments of field capacity and revealed that plants exposed to higher water stress shown significant reduction in total marketable yield in hectre as compared to regular watering.

Dorji *et.al* (2004), conducted experiment on chilli cv. Ancho St. Luis three irrigation treatments : full irrigation on both sides of the rootzone similar to commercial irrigation (CI) considered as control, irrigation with half the volume of CI on both sides of rootzone considered as DI, and half of irrigation volume in CI applied to one side of rootzone at each irrigation time designated as PRD and reported that there was a great fall in total yield per hectre due deficit irrigation.

Showemimo F. A. et al. (2007), conducted experiment on sweet pepper cv. L5962-2 with four regimes of irrigation intervals such as control, irrigation at three, seven and fourteen days interval and reported that plants irrigated at fourteen days interval gave lowest total yield (per ha) as compared to control.

2.7.4 Percent reduction in yield due to drought stress (%)

Nahar *et al*. (2011), conducted pot culture experiment on two cultivars of tomato : BR-4, BR-5 with three treatments of water stress to investigate effects of

water stress on number of fruits per plant that fruits from plants under control condition (70% FC) showed more than 50% reduction in yield due to stress.

Kirnak *et al*. (2001), conducted experiment on egg plant cv. Teorem F1 with four treatments and revealed that fruit yield was reduced by up to 68% in the water stressed plants (WS2 and WS3) compared with unstressed (C) plants.

2.8. Fruit parameters

2.8.1 Fruit weight (g)

Ferrara *et al.* (2011), conducted experiment on capsicum cv. Peppone under green house conditions with 3 water regimes (control, stress at vegetative stage and stress at reproductive stage) and revealed that water stress at reproductive stage significantly reduced significantly reduced fruit weight per plant.

Kirnak *et. al* (2002), conducted experiment on eggplant cv. Pala with four irrigation treatments : well-watered treatment receiving 100% replenishment of a pan evaporation on a daily basis (C); water-stressed treatment receiving 90% replenishment of a pan evaporation at 4-day intervals (WS1); water-stressed treatment receiving 80% replenishment of a pan evaporation at 8-day intervals (WS2); and water-stressed treatment receiving 70% replenishment of a pan evaporation at 12-day intervals (WS3) and observed maximum fruit weight in control treatment (C) whereas fruits under water stress treatment (WS3) attributed with least fruit weigth.

Nuruddin *et al.* (2003), conducted experiment on tomato cv. Sunstart under green house conditions with two available soil water deficit thresholds (65% and 80%) and five irrigation timing patterns (1. no water stress; 2. stress throughout the entire growing season; 3. stress during first cluster flowering and fruit set 4. stress during first cluster fruit growth; and 5. stress during first cluster fruit ripening) and reported that water stress during fruit growth significantly reduced weight of individual fruit.

Gunawardena *et al*. (2014), conducted experiment on chilli cv. MI2 with six treatments of temperature and water stress in combination : no water stress at ambient temperature, 50% water stress at ambient temperature, no water stress at 32^0C maximum temperature, 50% water stress at 32^0C maximum temperature, no water stress at 34^0C maximum temperature, 50% water stress at 34^0C maximum temperature and observed that 50% water stress at temperature of 34^0C significantly reduces weight of individual fruit per plant as compared to control (no stress at ambient temperature).

2.8.2 Fruit length (cm)

Kirnak *et al*. (2001), conducted experiment on egg plant cv. Teorem F1 with four treatments : 100% (control), 80%, 60% and 40% of water needed to reach pot capacity (PC) in the soil and revealed that there was reduction in fruit length under stressed conditions (60% and 40% of pot capacity) as compared to control.

Kirnak *et. al* (2002), conducted experiment on eggplant cv. Pala with four irrigation treatments : well-watered treatment receiving 100% replenishment of a pan evaporation on a daily basis (C); water-stressed treatment receiving 90% replenishment of a pan evaporation at 4-day intervals (WS1); water-stressed treatment receiving 80% replenishment of a pan evaporation at 8-day intervals (WS2); and water-stressed treatment receiving 70% replenishment of a pan evaporation at 12-day intervals (WS3) and observed that fruits in control treatment (C) attained highest fruit length whereas fruits under water stress treatment (WS3) shown least fruit length.

Gunawardena *et al*. (2014), conducted experiment on chilli cv. MI2 with six treatments of temperature and water stress in combination : no water stress at ambient temperature, 50% water stress at ambient temperature, no water stress at 32^0C maximum temperature, 50% water stress at 32^0C maximum temperature, no water stress at 34^0C maximum temperature, 50% water stress at 34^0C maximum temperature and observed that 50% water stress at temperature of 34^0C significantly reduces length of individual fruit per plant as compared to control (no stress at ambient temperature).

Nahar *et al*. (2011), conducted pot culture experiment on two cultivars of tomato viz., BR-4 and BR-5 with three treatments of water stress : 40% FC; 70% FC and 100% FC (control) to investigate effects of water stress on fruit length and revealed that fruits from plants under control condition (70% FC) showed more fruit length than that of fruits from stressed condition (40% FC)

2.8.3 Fruit diameter (mm)

Nuruddin *et al.* (2003), conducted experiment on tomato cv. Sunstart under green house conditions with two available soil water deficit thresholds (65% and 80%) and five irrigation timing patterns (1. no water stress; 2. stress throughout the entire growing season; 3. stress during first cluster flowering and fruit set 4. stress during first cluster fruit growth; and 5. stress during first cluster fruit ripening) and reported that water stress during fruit growth significantly reduced fruit diameter as compared to fruits in other treatments.

Kirnak *et al*. (2001), conducted experiment on egg plant cv. Teorem F1 with four treatments : 100% (control), 80%, 60% and 40% of water needed to reach pot capacity (PC) in the soil and revealed that water stress (60% and 40% of pot capacity)significantly reduces fruit diameter as compared to control.

Kirnak *et. al* (2002), conducted experiment on eggplant cv. Pala with four irrigation treatments : well-watered treatment receiving 100% replenishment of a pan evaporation on a daily basis (C); water-stressed treatment receiving 90% replenishment of a pan evaporation at 4-day intervals (WS1); water-stressed treatment receiving 80% replenishment of a pan evaporation at 8-day intervals (WS2); and water-stressed treatment receiving 70% replenishment of a pan evaporation at 12-day intervals (WS3) and reported that fruits in control treatment (C) have longer fruit diameter than that of fruits under water stress treatment (WS3).

Gunawardena *et al*. (2014), conducted experiment on chilli cv. MI2 with six treatments of temperature and water stress in combination : no water stress at ambient temperature, 50% water stress at ambient temperature, no water stress at 32^0C maximum temperature, 50% water stress at 32^0C maximum temperature, no water stress at 34^0C maximum temperature, 50% water stress at 34^0C maximum temperature. And observed that 50% water stress at temperature of 34^0C significantly reduces diameter of individual fruit per plant as compared to control (no stress at ambient temperature).

Nahar *et al*. (2011), conducted pot culture experiment on two cultivars of tomato viz., BR-4 and BR-5 with three treatments of water stress : 40% FC; 70% FC and 100% FC (control) to investigate effects of water stress on fruit diameter and revealed that fruits from plants under control condition (70% FC) showed more fruit diameter than that of fruits from stressed condition (40% FC).

2.9 Quality parameters

2.9.1 Capsaicin content (%)

Phimchan and Techawongstien (2012), conducted experiment on nine cultivars of chilli with water stress treatments : 25%, 50%, and 75% of water applications by volume at 10, 20, and 30 days after flowering (DAF) and reported that plants subjected to 25% of water application at 30 days after flowering shown increased level of capsaicin.

Jeeatid *et al*. (2018), conducted experiment on four cultivars of hot pepper (*Capsicum chinense* Jacq.) with four water regimes after anthesis: daily irrigation (control; S1), every 2□ days (S2), every 3□ days (S3) and every 4□ days (S4) and reported that Akanee Pirote with the S2 treatment gave the highest capsaicin content and concluded that appropriate water stress could increase capsaicin content in some, but not all hot pepper cultivars.

Sung *et al*. (2005), conducted experiment on three cultivars of hot pepper (*Capsicum annuum* L. var. annuum) *viz*., Hungariana, Beauty Zest and Home Flavor with ample water and deficit water treatment imposed after flowering and revealed that fruits from deficit irrigation condition shown increased capsaicin content as compared to normal irrigating plants.

Olarewaju *et al*. (2017), conducted experiment on three different species of genus- *Capsicum* with four drought stress treatments such as control, light, moderate and severe drought stress by withholding the water to 80–85%, 55–60%, 40–45% and 30–35% water holding capacity (WHC) respectively and observed that moderate and severe drought stress significantly increases capsaicin content when stress imposed at fruiting stage.

2.9.2 Ascorbic acid content (mg $^{-100g}$)

Mahendran *et al*. (2000), conducted experiment on chilli cv. Arunalu with six water treatments : T1 = Control-Regular watering at 5 days interval at field capacity, T2 - 15 days stress at late vegetative and podding stages, T3 = 15 days stress at flowering and pod maturing stages, T4 = 15 days stress at pod setting and pod maturing stages, T5 = 15 days stress at podding and fruit ripening stages, T6 = 15 days stress at pod maturing and fruit ripening stage and observed lowered ascorbic acid content when water stress was imposed at podding and fruit ripening stages.

Lerma *et al*. (2011), conducted experiment on chilli cv. C-40 with three treatments were applied: i) control (usual drip fertigation in Valencia), ii) saline stress (TS: control fertigation with salinity increased at 5 dS/m) and iii) hydric deficit stress (TH: control fertigation reduced to 40%) and observed decreased ascorbic acid content under deficit irrigation treatment imposed at fruit ripening stage.

Ahmed *et al*. (2014), conducted experiment on chilli cv. Battle with four treatments of WHC : 100% (control), 85%, 70%, and 55% and srevealed that water stress at fruit ripening stage reduces ascorbic acid content and concluded that Battle' hot pepper is sensitive to deficit irrigation.

Vijitha *et al*. (2010), conducted experiment on tomato cv. KC-1 with five moisture stress treatments *viz*., T1 = Control- Regular watering to Field Capacity; T2 = Moisture stress for 4 days during the vegetative stage; T3 = Moisture stress for 4 days during the flowering stage; T4 = Moisture stress for 4 days during the early fruiting stage; T5 = Moisture stress for 4 days during the fruit ripening stage. And reported that moisture stress reduced ascorbic acid content; especially it would be more severe, when it was imposed at fruit ripening stage.

2.10 Dry weight (g)

Khan *et al*. (2012), conducted experiment on ten chilli accessions with four watering treatments : W1= watering once a day, W2= watering at 4 days interval, W3 =watering at 8 days interval and Wo= no watering (control) which was imposed in 4 stages of vegetative growth each having 7 days of span (S1= 25-31 days (after seed sowing), S2 = 32-38 days, S3 = 39-45 days and S4 = 46-52 days) in three replications and observed dry weight significantly decreased when stress was imposed at early vegetative stage by withholding water for 46-52 days after sowing.

Ichwan *et al*. (2017), conducted experiment on eight red chilli cultivars under three stress treatments such as 100%, 75%, 50% of field capacity and observed that plants subjected to higher stress *i.e*, 50% FC shown significantly reduced shoot dry weight (42.94% of control).

Dorji *et.al* (2004), conducted experiment on chilli cv. Ancho St. Luis with three irrigation treatments : full irrigation on both sides of the rootzone similar to commercial irrigation (CI) considered as control, irrigation with half the volume of CI on both sides of rootzone considered as DI, and half of irrigation volume in CI applied to one side of rootzone at each irrigation time designated as PRD and reported that plants under deficit irrigation significantly produce less dry weight as compared to commercial irrigation.

Byari *et al*. (1995), conducted experiment on four eggplant cultivars *viz*., Black Beauty, Long Purple, Florida Market, Egyptian White, with four irrigation levels : daily, every four days, every eight days and every twelve days interval. And reported that plants irrigated at 12 days of interval, gained significantly less leaf as well as stem dry weight as compard to regular irrigating plants.

Techawongstien *et al*. (1992), conducted experiment on four cultivars of chilli pepper : Deshi Morich, Huay Siithon, Khonkaen University Cluster and Yatsubusa

with treatments grouped under two classes; a.) in a plastic greenhouse, the stress treatment was applied at the seedling and mature stages by withholding water supply, b.) Mature stages were divided into three 10-day intervals, namely pre-anthesis, anthesis and post-anthesis stages. And reported gradual decrease in dry weight in all cultivars due to water stress imposed at any growth stage; however only "Khonkaen University Cluster" shown significant response for reduction in shoot dry weight as compared to control irrigation throughout the life cycle ogf plant.

Khan *et al*. (2008), conducted experiment on two chilli cultivars *viz*, C-0277 and C-0272 with six water treatments *viz*, W1= watering once everyday, W2= watering twice everyday, W3= watering at 4 days interval, W4= watering at 8 days interval, W5= watering at 16 days interval and W6= no watering (control) which were imposed at three different growth stages *viz*, vegetative stage, flowering stage and fruiting stage and revealed that plants subjected to water stress at vegetative stage showed least dry weight as compared control and plants subjected to stress at flowering and fruiting stage and concluded that longer the irrigation interval, less the dry weight of shoot.

2.11 Phenotyping (Image based) parameters

2.11.1 Tissue water content (kilo pixels)

Neilson *et al*. (2015), conducted experiment to study the phenotypic responses of a single hybrid (Hy A) in comparison with a variety of grain sorghum [*Sorghum bicolor* (L.) Moench (Sb)] grown under well-watered and water-limited conditions and revealed that count of NIR pixels significantly increased under limited water condition than that of well-watered condition which concludes tissue water content in plants under limited water condition reduced as compared to plants under well watered condition.

2.11.2 Area (kilo pixels)

Neilson *et al*. (2015), conducted experiment to study the phenotypic responses of a single hybrid (Hy A) in comparison with a variety of grain sorghum [*Sorghum bicolor* (L.) Moench (Sb)] grown under well-watered and water-limited conditions and observed significant rerduction in area due to less water supply.

2.11.3 Caliper length (kilo pixels)

Neilson *et al*. (2015), conducted experiment to study the phenotypic responses of a single hybrid (Hy A) in comparison with a variety of grain sorghum [*Sorghum*

bicolor (L.) Moench (Sb)] grown under well-watered and water-limited conditions and observed decreased caliper length under water stress condition.

Honsdorf *et al*. (2014), conducted dexperiment on fourty eight genotypes of wild barley under well watered and water stressed treatments and revealed caliper length goes on decreasing as water stress exceed.

2.11.4 Digital Volume (mega pixels)

2.11.5 Biomass (g)

Techawongstien *et al*. (1992), conducted experiment on four cultivars of chilli pepper : Deshi Morich, Huay Siithon, Khonkaen University Cluster and Yatsubusa with treatments grouped under two classes; a.) in a plastic greenhouse, the stress treatment was applied at the seedling and mature stages by withholding water supply, b.) Mature stages were divided into three 10-day intervals, namely pre-anthesis, anthesis and post-anthesis stages. And reported gradual decrease in dry weight which was ultimately resulted into reduction of biomass across all cultivars due to water stress imposed at any growth stage; however only "Khonkaen University Cluster" shown significant response for reduction in shoot dry weight as compared to control irrigation throughout the life cycle ogf plant.

Ichwan *et al*. (2017), conducted experiment on eight red chilli cultivars under three stress treatments such as 100%, 75%, 50% of field capacity and observed that plants subjected to higher stress *i.e*, 50% FC shown significantly reduced shoot dry weight which finally led to decreased biomass of plant (42.94% of control).

Khan *et al*. (2008), conducted experiment on two chilli cultivars *viz*, C-0277 and C-0272 with six water treatments *viz*, W1= watering once everyday, W2= watering twice everyday, W3= watering at 4 days interval, W4= watering at 8 days interval, W5= watering at 16 days interval and W6= no watering (control) which were imposed at three different growth stages *viz*, vegetative stage, flowering stage and fruiting stage and revealed that plants subjected to water stress at vegetative stage showed restricted plant growth, undeveloped branches and less number of leaves as compared to plants subjected to stress at reproductive stages (*i.e*., flowering and fruiting stages respectively). And hence, it is concluded that longer the irrigation interval at vegetative stage resulted into lowered biomass.

MATERIAL AND METHODS

CHAPTER - III

MATERIALAND METHODS

The pot experiment entitled "Assessment of drought responses of chilli (*Capsicum annum* L.) genotypes using modern plant phenomics tools" was carried out during *Rabi* season, 2018 at ICAR – National Institute of Abiotic Stress Management, Malegaon, Baramati - 413115. The details of the materials used and technologies adopted during the course of the present study are described in this chapter under appropriate headings and sub headings.

3.1 General

3.1.1 Location

The present investigation was conducted at ICAR – National Institute of Abiotic Stress Management, Malegaon. Geographically, Instituteis situated at 18° 09' 30.62''N; 74° 30' 03.08''E; MSL 570 m at Malegaon khurd, Baramati in Pune district of Maharashtra state.

3.1.2 Climate conditions

The area falls under the agro- ecological region Deccan Plateau, hot and semi-arid climate (AER-6) and agro-climatic zone AZ-95 i.e. scarcity zone of Maharashtra. The long-term average annual rainfall is 560mm, and this is restricted to south-west and retreating monsoon. Because of low rainfall, the soils in the area are shallow and poorly developed. Major agricultural area is rainfed except for about one-third of Baramati area along the Nira canal that is irrigated and mainly supports sugarcane. Agricultural drought is a common phenomenon in the area.

Long-term analysis of weather data of Baramati (1986-2011) reveals that mean monthly temperature varies between 22°C (Dec) and 31.4°C (May). Daily maximum temperature becomes highest in the month of May (39.1°C) and lowest during December (29.8°C). Similarly, in case of daily minimum temperature too, May and December are the months when the highest (23.7°C) and lowest (14.2°C) values occur respectively. Morning time relative humidity measured at standard prescribed hour of 0700 Local Mean Time (LMT) varies between 81% (July and September) and 55% (April) and the annual average is 73 percent.

3.2 Materials

3.2.1. Experimental site

The land used for experimental layout was fairly uniform with gentle slope. The soil of experimental plot was well drained, medium black having depth of 1.5 meters. Representative soil samples were collected and processed for physico-chemical properties. The findings of same are given in Table 1.

Table 1. Physico-Chemical properties of experimental soil

Sr. No.	Particulars	Values	Method of analysis
A	**Physical properties**		
1	Sand	12.25%	International Pipette Method (Piper, 1966)
2	Silt	21.10%	International Pipette Method (Piper, 1966)
3	Clay	66.65%	International Pipette Method (Piper, 1966)
B	**Chemical Properties**		
1	pH	8.4	pH meter (Jackson, 1967)
2	Electrical Conductivity (EC)	0.24 dSm^{-1}	ConductivityBridge (Jackson, 1967)
3	Organic Carbon	6.3g kg^{-1}	Walkley and Black Method (Piper, 1966)
4	Available Nitrogen	176 kg ha^{-1}	Alkaline Permagnate (Subbiah and Asija, 1956)
5	Available Phosphorus	25 kg ha^{-1}	Olsens Method (Olsens*et al*. 1954)
6	Available Potassium	148 kg ha^{-1}	Flame Photometer (Jackson, 1967)

3.2.2 Experiment details

1. Crop : Chilli (*Capsicum annum* L.)
2. Family : Solanaceae
3. Experimental design : Factorial Randomized Block Design (F.R.B.D)
4. Number of treatments : Factor A – Different Genotypes – 8
Factor B – Drought stress at different growth stages - 3
5. Number of treatment combinations : 24
6. Number of replications : 2
7. Number of plants per treatment : 6
8. Number of plants required : 240
9. Season : *Rabi*2018
10. Date of transplanting : 02/11/2018

3.2.3 Treatment details

Table 2. Details of experimental treatments

Factor A - Genotypes

Genotypes
G_1 : Parbhani Tejas (V.N.M.K.V, Parbhani)
G_2 : Parbhani Mirchi (V.N.M.K.V, Parbhani)
G_3 : Phule Jyoti(M.P.K.V, Rahuri)
G_4 : Jayanti (Dr. P.D.K.V, Akola)
G_5 : Hirkani (Dr. P.D.K.V, Akola)
G_6 : Arka Lohit (I.I.H.R, Bangalore)
G_7 : Arka Supahl (I.I.H.R, Bangalore)
G_8 : Local genotype

Factor B – Stress stages

Drought stress at different growth stages
S_0 - Control
S_1 - Stress at flowering
S_2 - Stress at fruit development

The experiment was conducted in Factorial Randomized Block Design with twofactors and two replications, Factor A – Genotypes (G) and Factor B- Drought stress at different growth stages(S). There were eight genotypes selected and for each of them drought stress was imposed at 2 stages *viz*;stress at flowering and stress at fruit development along with one control, where regular irrigation was applied.Details of the treatment and design are depicted in table 2.

The total treatment combinations were twenty four which are given in Table 3.

Table 3. Treatment combinations

T_1 - G_1S_0	T_5 - G_2S_1	T_9 - G_3S_2	T_{13} - G_5S_0	T_{17} - G_6S_1	T_{21} - G_7S_2
T_2 - G_1S_1	T_6 - G_2S_2	T_{10} - G_4S_0	T_{14} - G_5S_1	T_{18} - G_6S_2	T_{22} - G_8S_0
T_3 - G_1S_2	T_7 - G_3S_0	T_{11} - G_4S_1	T_{15} - G_5S_2	T_{19} - G_7S_0	T_{23} - G_8S_1
T_4 - G_2S_0	T_8 - G_3S_1	T_{12} - G_4S_2	T_{16} - G_6S_0	T_{20} - G_7S_1	T_{24} - G_8S_2

3.2.4 Seed

The Seeds of different chilli genotypes were collected from different sources. The seed was stored and cleaned properly at room temperature prior to its use for actual experimentation.

R I	G_1S_0	G_2S_0	G_3S_0	G_4S_0	G_5S_0	G_6S_0	G_7S_0	G_8S_0
	G_1S_1	G_2S_1	G_3S_1	G_4S_1	G_5S_1	G_6S_1	G_7S_1	G_8S_1
	G_1S_2	G_2S_2	G_3S_2	G_4S_2	G_5S_2	G_6S_2	G_7S_2	G_8S_2
R II	G_1S_0	G_2S_0	G_3S_0	G_4S_0	G_5S_0	G_6S_0	G_7S_0	G_8S_0
	G_1S_1	G_2S_1	G_3S_1	G_4S_1	G_5S_1	G_6S_1	G_7S_1	G_8S_1
	G_1S_2	G_2S_2	G_3S_2	G_4S_2	G_5S_2	G_6S_2	G_7S_2	G_8S_2

Fig. 1 Plan of layout of experimental setup

Plate 1. General view of experimental setup

3.3 Methods

3.3.1 Cultural practices

3.3.1.1 Nursery sowing

Seeds of each genotype were sown in separate trays of 104 cells on 25th October, 2018 and in cocopeat, water was sprinkled regularly. The seeds germinated within a week after sowing and the seedlings were transplanted to pots 35 days after sowing.

3.3.1.2 Pot filling and shifting

240 pots were filled up with fine black native soil. Each pot with 12.00 kg of soil. While filling soil, 1.00 kg of well rotten FYM was added to mixture. Filled pots were transferred to shade-net house.

3.3.1.3 Layout

Pots were arranged as per the experimental layout. The plan of layout for experiment is given in Fig.1. The layout consisted of 48 experimental units with 2 replications.

3.3.1.4 Transplanting

The transplanting of seedlings was done on 2ndNovember, 2018 as per the plan at the middle portion of pot.

3.3.1.5 Irrigation

The first irrigation was applied immediately after sowing while subsequent irrigations were given as and when required depending upon soil moisture and weather conditions.

3.3.2 Intercultural operations

3.3.2.1 Weeding

In order to keep the plants healthy, weeds were removed from pots during the entire crop period. Weeding was done at weekly interval.

3.3.2.2 Plant protection

After transplanting, to prevent the incidence of pests and diseases, recommended preventive measures were adopted.

3.3.2.3 Harvesting

The crop was first harvested 90 days after transplanting when the fruits gained good size with tenderness. Harvesting was done attwo daysinterval from first picking onwards. In all total 7 pickings were taken during the cropping period.

3.3 Imposition of drought stress

Drought stress was imposed at two growth stages of plant *viz.* flowering and fruit-development. Stress at flowering was imposed when more than fifty percent flowering was observed in plants. Stress was imposed by withholding the water for three weeks. Similarly, stress at fruit development was imposed when fruit development started. Stress was imposed by withholding the water for three weeks *i.e.* up to harvesting. For comparison, control plants also there. In control treatment, watering was given at regular interval.

3.4 Observations recorded

Four plants were selected from each of treatment and labeled. The following observations were recorded on the different characters which are given as follows.

3.4.1 Soil parameters

3.4.1.1 Soil moisture content (%)

Soil moisture content was measured by gravimetric method on fresh weight basis. Soil moisture content was recorded periodically at 30, 60, 90 DAT. Soil was taken out from pots by using augers at particular depth and fresh weight of that sample was recorded. Then those samples were subjected for oven drying in hot air oven for complete removal of moisture from soil at 60^0C for 24 hours. After this again those dried samples were weighed and by this soil moisture content was measured on fresh weight basis.

$$\text{Soil Moisture content (\%)} = \frac{\text{Fresh weight of soil sample (g)} - \text{Oven dried weight of soil sample (g)}}{\text{Fresh weight of soil sample (g)}} \times 100$$

3.4.2 Growth parameters

The observations in respect of growth parameters were recorded at an interval of 30 days, starting from 30DAT up to 90 DAT.

3.4.2.1 Plant height (cm)

Plant height from the base of the plant to tip of the main stem was measured with scale. Plant heightswere measured at 30, 60 and 90 DAT respectively and mean values were expressed in centimeter.

3.4.2.2 Stem girth (mm)

The data on the stem girth was measured in each four selected plants were counted and was recorded. The girth of stem was measured by using digital Vernier caliper. The mean value of four plants was taken for statistical analysis.

3.4.3 Leaf parameters

3.4.3.1 Leaf area (cm^2)

Leaf area per plant was calculated by using digital leaf area meter and expressed in centimeter square (cm^2) at 30, 60, 90 DAT.

3.4.4 Physiological parameters

3.4.4.1 Canopy temperature (^0C)

Canopy temperature of plants was recorded periodically at 30, 60, and 90 DAT. Canopy temperature was recorded with the help of InfraRed Thermometer (*Everest Interscrience INC. – AGRI THERM III*).Mean values calculated and used for statistical analysis.

3.4.4.2 Chlorophyll content (mg/g)

Chlorophyll content from leaves was recorded at 30, 60, and 90 DAT by using Dimethyl sulphoxide (DMSO). 25mg of leaf sample soaked in 5ml DMSO overnight and then absorbance was recorded at 663 and 645 nm wavelength and running DMSO as blank.

$$\text{Chlorophyll - a} = \frac{12.21(A_{663}) - 2.81(A_{646})}{1000}$$

$$\text{Chlorophyll - b} = \frac{20.13(A_{646}) - 5.03(A_{663})}{1000}$$

$$\text{Total chlorophyll} = \frac{7.93(A_{663}) + 19.53\,(A_{646})}{1000}$$

3.4.4.3 Proline content (mg/g f w)

Free proline was determined by using the method of Bates *et al*., (1973) at 30, 60, 90 DAT. Briefly, proline from the leaf samples was extracted using 3% sulfosalicylic acid. After filtration, filtrate was treated with acid ninhydrin, boiled for 1 hr. Chromophore is extracted using Toulene and absorbance read at 520 nm. Amount of proline is calculated using the formula.

$$\text{Proline } (\mu\text{mg/g f w}) = \frac{\mu\text{ g proline per ml} \times \text{toluene (ml)} \times 5}{115.5 \times \text{sample taken for estimation (g)}}$$

3.4.4.4 Relative Water Content (%)

RWC was estimated by employing a method developed by Barrs and Weatherley (1962) at 30, 60, 90 DAT. Fresh leaves were plucked and fresh weight of leaves were recorded and then these leaves were soaked under water for 12 hours. After soaking, turgid weight of leaves was recorded and then these samples were subjected for oven drying at 60^0C for 12 hours.

$$\text{Relative Water Content (\%)} = \frac{\text{Fresh weight of leaf (g)} - \text{Dry weight of leaf (g)}}{\text{Turgid weight of leaf (g)} - \text{Dry weight of leaf (g)}} \times 100$$

3.4.4.5 Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index of plants was recorded periodically at 30, 60, and 90 DAT.Normalized Difference Vegetation Index was measure with *Green Seeker (Handheld Crop Sensor).*

Mathematically NDVI, can be expressed as follow which was given by Rouse *et al.* in 1974.

$$NDVI = \frac{(NIR - IR)}{(NIR + IR)}$$

3.4.4.6 SPAD value (Chlorophyll Index)

Chlorophyll Index of plants was recorded periodically at 30, 60, and 90 DAT. Chlorophyll Index was measure with *SPAD 502 Plus Chlorophyll meter.*

3.4.4.7 Chlorophyll fluorescence (*Fv/Fm*)

Chlorophyll fluorescence is the image based phenotyping tool. It describes photosynthetic health of plants. It is used to study the PSII of plant, which ultimately describes efficiency of plant to produce food for it. Chlorophyll fluorescence was recorded periodically at 30, 60 and 90 DAT. Chlorophyll fluorescence was measured with *Handy FluorCam*. It is also described in form of quantum yield or *Fv/Fm*. Mathematically it can be expressed as follows

$$Q.Y(\text{Quantum Yield}) = \frac{Fm - F_0}{Fm} = \frac{Fv}{Fm}$$

Where,
Fm – Fluorescence maximum
F_0– Fluorescence at initial
Fv – Fluorescence variable

3.4.4.8 Stomatal Conductance (mmol $m^{-2}s^{-1}$)

Stomatal conductance was measured by employing steady state porometer on 3 leaves of each plant and average was expressed in mmol $m^{-2}s^{-1}$.
The mean values were taken for statistical analysis.

3.4.5 Flowering parameters

3.4.5.1 Days to initiate first flower

The number of days required from transplanting to the appearance of first flower on theplants was recorded as days to first flowering and mean was worked out.

3.4.5.2 Flower drop (%)

Flower drop was calculated by counting total numbers of fallen flowers with respect to total number flowers emerged per plant.

$$\text{Flower drop} = \frac{\text{Fallen / Aborted flowers from plant due to stress}}{\text{Total numbers of flowers appeared on plants}} \times 100$$

3.4.6 Fruiting parameters

3.4.6.1 Number of days required to initiate first fruit set

Number of days taken from the date of transplanting to the day on which first fruit was observed.

3.4.6.2 Number of fruits per plant

The number of tender fruits harvested from observational plants in each treatment was counted from different pickings and average was worked out and expressed as number of fruits per plant.

3.4.6 Yield parameters

3.4.6.1 Number of harvestings

The number of days was counted on which, harvesting had done for each treatment.

3.4.6.2 Fruit yield per plant (g)

Fruit yield per plant of observational plants was computed by adding the fruit weight of all the pickings and by averaging, and was expressed in grams per plant.

3.4.6.3 Total yield per ha (t ha^{-1})

The total yield per hectare was calculated based on spacing and yield per plant and expressed in ton per ha.

3.4.6.4 Percent reduction in yield due to drought stress (%)

Percent reduction was calculated by considering the yield from control treatment of each genotype, as 100%. From that value, reduced value was calculated for treatments *viz;* stress at flowering and stress at fruit development.

$$\text{Reduced yield (\%)} = \frac{\text{Yield under control treatment} - \text{Yield under stress treatment}}{\text{Yield under control treatment}} \times 100$$

3.4.7 Fruit parameters

3.4.7.1 Fruit weight (g)

Average fruit weight was calculated by adding the weight of the fruits and by dividing with the total number of fruits average fruit weight was calculated and expressed in grams per fruit.

3.4.7.2 Fruit length (cm)

The length of each selected fruit was measured from the base to tip with the help of scale and average of 5 fruits was computed and expressed in centimeters.

3.4.7.3 Fruit diameter (mm)

The diameter of the selected fruits was measured at the center of fruit by using digital Vernier caliper and average of 5 fruits was computed and expressed in millimeters.

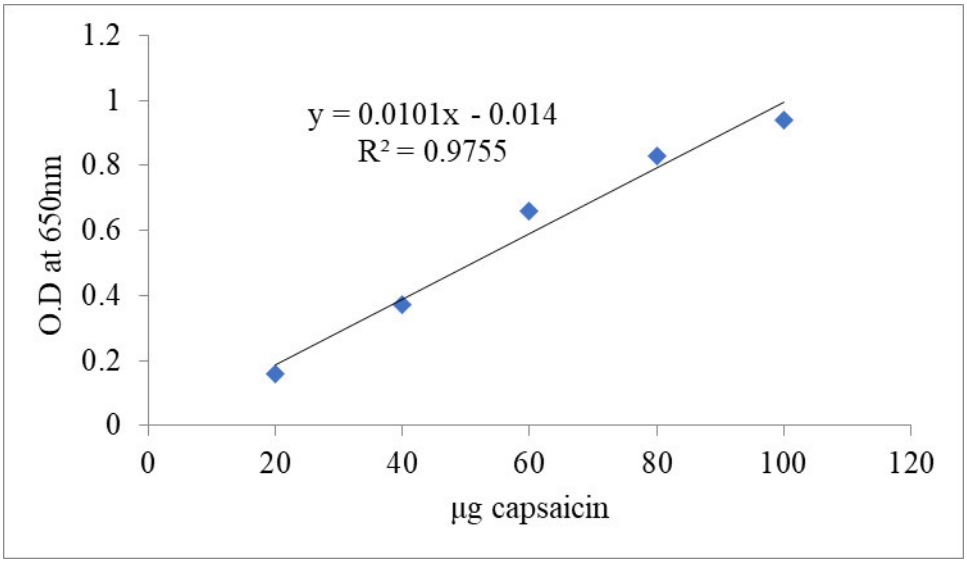
3.4.8 Quality parameters

3.4.8.1 Capsaicin content (%)

The capsaicin content of fruits was estimated by colorimetricmethod described by S. R. Thimmaiah in the book entitled "Standard Methods of Biochemical Analysis" (1999).

0.5g dry chilli powder was weighed into glass-Stoppard test tube; 10ml dry acetone was added into the test tube and kept overnight for extraction. Next day samples were centrifuged at 10000 RPM for 10min to get clear supernatant. One ml of the supernatant was taken into a test tube and evaporated to dryness in a hot water bath. Then, the residue was dissolved in 5ml of 0.4% of NaOH solution and 3ml of 3% phosphomolybdic acid was added. The contents were shaken and left undisturbed for 1hr. After 1hr, the solution was quickly filtered into centrifuge tubes to remove any floating debris, and then centrifuged at 5000 RPM for 15min. The clear blue colored solution was directly transferred into the cuvette and absorbance was read at 650nm along with a reagent blank.

A standard calibration curve was prepared using 0-100µg pure capsaicin. Simultaneously 0.2, 0.4, 0.6, 0.8 and 1ml of working standard solution were taken into new test tubes and proceeded as mentioned above.



3.4.8.2 Ascorbic acid content (mg^{-100g})

The ascorbic acid content of fruits was estimated by volumetricmethod described by S. R. Thimmaiah in book entitled "Standard Methods of Biochemical Analysis" (1999).

The green fruits were cut in to small pieces and 2.5 g sample was blended with 0.4 per cent oxalic acid and filtered through muslin cloth. To an aliquot of the extract (5ml) of sample, 3 ml acid mixture was added and titrated against the standard dye till the end point appears of pink color (V_2). Similar procedure was followed against standard solution made in 0.4 per cent oxalic acid to get standard titer value (V_1).

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Titer} \times \text{Dye factor} \times \text{Volume made up} \times 100}{\text{Aliquot of extract taken for estimation} \times \text{Volume of sample taken for estimation}}$$

3.4.9 Dry weight (g)

Average dry weight of plants was measured in grams. Plants were uprooted from pots and aerial part of plant was subject for oven drying at 60^0C till constant weight. After, complete drying plants were weighed on digital balance.

3.5 Phenotyping (Image based) parameters and Biomass

To study the effect of depleting soil moisture stress on phenotyping traits of chilli plants, same genotypes were sown in pots (Nisarga 302) which were filled with 12 kg of clay loam soil. Plants were grown initially under natural conditions and

maintained as per recommended cultural practice. These pots were transferred to greenhouse of plant phenomics facility at flowering stage. Inside the greenhouse, temperatures were maintained at 32^0C/24^0C day/night, 50-65% relative humidity, and 450-750µmol $m^{-2}s^{-1}$ PAR. Three pots each for well-watered and water-stressed treatment was maintained for each genotype throughout the experiments.

Soil Field Capacity Determination and Watering

The soil was air-dried and ground to pass through a 5 mm sieve at room temperature to determine field capacity. Water holding capacity was assessed by using a gravimetric method with five replicates as the amount of moisture (percentage) (Canavar *et al*., 2014). Five pots were randomly selected from 48 pots filled with 12 kg of soil mixture. Each of the five pots was kept overnight in tray containing water and the soil was allowed to absorb water through holes at the bottom of the pots by capillary action. The wet surface on the top layer of the soil was considered as indicator of completion of capillary action and hence absorption of soil moisture up to the field capacity. Then excess water was allowed to drain by moving the pots carefully to empty trays without water until there was no sign of water drop dripping from the pots. The field capacity was calculated based on initial dry weight and final weight of the pots (Canavar *et al*., 2014). This was used to compute estimates of the gravimetric water content and the amount of water needed to be added to establish specific field capacities. The pots were weighed every day and the reduction of pot weight was used to calculate relative water losses. Nearly 80% and 50% of water at field capacity were maintained in well-watered and water-stressed treatments respectively.

Image Acquisition and Analysis

In the automated conveyer for plant transport and imaging systems (the ICAR-NIASM LemnaTec Scanalyzer system for large plants), top and side view images were taken of the VIS range of the light spectrum (VIS). These images were captured by using piA2400-17gc CCD cameras (Basler, Ahrensburg, Germany) with top and side illumination of plants through incandescent bulbs (FQ 24W 865 HO or FH 28W 865 HE, respectively, Osram GmbH, München, Germany). The Lemna Grid, Integrated Analysis software for high-throughput plant image analyses was used for image-based plant feature extraction. Image processing is divided into two major parts: image segmentation, and feature extraction. A color image from a VIS camera

is transformed from RGB to LAB color space. Thresholding is applied individually on both greyscale images from the output channels *A* and *B*. The result are two binary images which are combined and refined using logical set operation (OR) and general morphological operations (erosion, dilation, fill). The final image mask is used to measure the size of the projected area of a plant by counting the number of image pixels. Chilli imaging data was extracted by using Grid – "Chilli IAC5". Following traits were studied by using plant phenomics facility,

i. Area
ii. Caliper length
iii. Digital volume
iv. Tissue water content

To validate same traits, fresh and dry biomass of plants was also recorded.Plants were harvested after 30 days of shifting inside the greenhouse. The leaf and the stem fresh weights (g) were determined per pot and also on a single-plant basis by harvesting the shoot directly above ground using a medium-scale balance (Model Ohaus R21PE30). The sum of leaf and stem fresh weight was considered as total shoot (fresh) biomass. Dry weight was measured after placing the plant material in a hot air oven at 65°C till constant tissue weights were obtained. BM/WU refers to ratio of total dry weight (stem+leaf) to the mean of water used per day.

3.6 Statistical analysis

All the data were subjected to statistical analysis for proper interpretation. The statistical analysis of the data in respect of growth, yield, quality components and phenotyping parameters of chilli was done according to the standard procedure given for factorial randomized block design by Panse and Sukhatme (1985).

RESULT AND DISCUSSION

CHAPTER - IV

RESULTS AND DISCUSSION

The present investigation entitled "Assessment of drought responses of chilli (*Capsicum annum* L.) genotypes using modern plant phenomics tools" was undertaken at ICAR – National Institute of Abiotic Stress Management, Malegaon Kh. (Baramati) - 413115, District Pune in *Rabi* season 2018.

The results of the present investigations on growth, yield and quality parameters along with the statistical tests and their scientific interpretations are presented in this chapter under appropriate headings.

4.1 Soil parameters

4.1.1 Soil moisture content (%)

Soil moisture content was measured periodically at 30, 60 and 90 DAT. Data on soil moisture content for different chilli genotypes under the influence of drought stress which was imposed at different growth stages *viz*., flowering and fruit development, is presented in Table 4 and graphically depicted in Fig.2.

4.1.1.1 Genotypes

The effect of genotypes on soil moisture content found non – significant during all growth stages *viz*., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively. This indicated that the trend of soil moisture depletion was nearly same for all the genotypes. This also reveals that in the present experiment different genotypes of chilli were exposed to same level of soil moisture during the experiment.

4.1.1.2 Effect of drought stress

The data in Table 4 showed there was significant effect of treatment imposed to create drought like conditions as revealed by significant differences in soil moisture levels of control and treated pots at both flowering and fruit development stage which coincided with 60 and 90 DAT respectively.

In control condition, soil moisture content was 35% (wt/wt), however, the same was 19% in plants subjected to soil moisture stress indicating that the control

Table 4. Effect of drought stress imposed at different growth stages on soil moisture content (%) of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor A : Genotypes (G)				
G_1	Parbhani Tejas	32.98 (19.59)	29.18 (17.25)	29.90 (17.70)
G_2	Parbhani Mirchi	32.10 (19.05)	30.13 (17.83)	31.82 (18.87)
G_3	Phule Jyoti	33.85 (20.12)	27.75 (16.39)	29.40 (17.40)
G_4	Jayanti	33.60 (19.97)	29.23 (17.72)	30.11 (17.83)
G_5	Hirkani	34.10 (20.28)	30.27 (17.92)	29.85 (17.67)
G_6	Arka Lohit	34.78 (20.71)	29.78 (17.62)	28.80 (17.03)
G_7	Arka Suphal	32.57 (19.33)	30.20 (17.88)	29.98 (17.75)
G_8	Local Genotype	34.83 (20.74)	30.35 (17.97)	29.22 (17.29)
S.E ±		0.42	0.50	0.52
C.D at 1%		NS	NS	NS
Factor B : Stress Stages (S)				
S1	No stress	33.66 (20.01)	35.01 (20.84)	36.73 (21.93)
S2	Stress at Flowering	33.17 (19.71)	19.38 (11.37)	34.18 (20.34)
S3	Stress at Fruit development	33.98 (20.20)	34.44 (20.50)	18.75 (10.99)
S.E ±		0.158	0.19	0.19
C.D at 1%		NS	0.52	0.55
Interaction Effect (G X S)				
T01	G_1S_1	33.8 (19.76)	33.8 (19.76)	35.85 (21.01)
T02	G_1S_2	32.35 (18.87)	20.95 (12.09)	33.9 (19.82)
T03	G_1S_3	32.8 (19.15)	32.8 (19.15)	19.95 (11.51)
T04	G_2S_1	29.9 (17.40)	34.45 (20.15)	39.65 (23.36)
T05	G_2S_2	32.1 (18.72)	21.65 (12.50)	34.25 (20.03)
T06	G_2S_3	34.3 (20.06)	34.3 (20.06)	21.55 (12.44)
T07	G_3S_1	35.35 (20.70)	31.7 (18.48)	35.26 (20.65)
T08	G_3S_2	33.2 (19.39)	19 (10.95)	34.09 (19.93)
T09	G_3S_3	33 (19.27)	32.55 (19.00)	18.85 (10.87)
T10	G_4S_1	34.6 (20.24)	34.6 (20.24)	37.26 (21.88)
T11	G_4S_2	32.6 (19.03)	19.5 (11.24)	34.69 (20.30)
T12	G_4S_3	33.6 (19.63)	33.6 (19.63)	18.39 (10.60)
T13	G_5S_1	35.1 (20.55)	36.7 (21.53)	36.45 (21.38)
T14	G_5S_2	31.65 (18.45)	18.55 (10.69)	34.87 (20.41)
T15	G_5S_3	35.55 (20.82)	35.55 (20.82)	18.24 (10.51)
T16	G_6S_1	33.13 (19.35)	35.33 (20.69)	35.45 (20.76)
T17	G_6S_2	34.55 (20.21)	18.5 (10.66)	33 (19.27)
T18	G_6S_3	36.65 (21.50)	35.5 (20.79)	17.95 (10.34)
T19	G_7S_1	31.05 (18.09)	37.15 (21.81)	38.65 (22.74)
T20	G_7S_2	35.15 (20.58)	18.06 (10.40)	35.25 (20.64)
T21	G_7S_3	31.5 (18.36)	35.4 (20.73)	16.05 (9.24)
T22	G_8S_1	36.35 (21.32)	36.35 (21.32)	35.25 (20.64)
T23	G_8S_2	33.75 (19.72)	18.85 (10.87)	33.4 (19.51)
T24	G_8S_3	34.4 (20.12)	35.85 (21.01)	19 (10.95)
S.E ±		1.26	1.49	1.56
C.D at 1%		NS	NS	NS

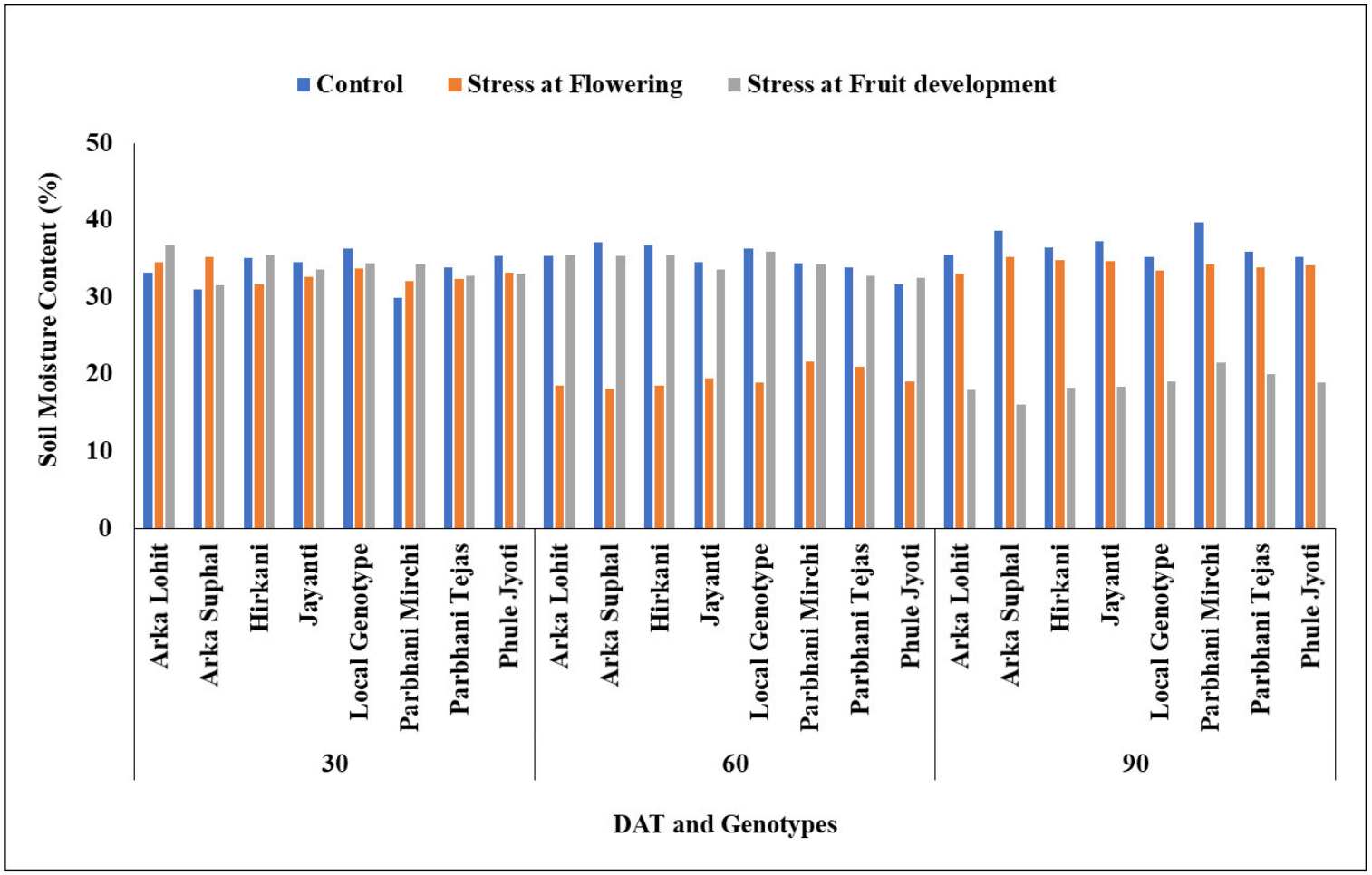


Fig. 2 Effect of drought stress imposed at different growth stages on soil moisture content (%) of different chilli genotypes

plant had access to nearly two folds soil moisture as compared to stressed plants (55% of control).

Similarly, stress imposed at fruit development stage, significantly lowered soil moisture content to 19%; however in control it was 37%. Thus, stress imposed resulted in depletion of soil moisture to a level equivalent to almost 51.04% of control.

In the present experiment, the depletion of soil moisture could be attributed losses caused by both evaporation and transpiration. As plants keep absorbing desired amount of moisture from soil to keep their canopy cool, soil water level gets depleted if not replenished through irrigation. Similar results have been reported by Wakchaure *et al*. (2018) in onion and Nahar *et al*. (2011) in tomato.

4.1.1.3 Interaction Effect

Interaction effect of various chilli genotypes and drought stress imposed at different growth stages found non-significant throughout the life cycle which further provides an explanation that the there was no differences levels of soil moisture stress imposed across the genotypes.

4.2 Growth parameters

4.2.1 Plant height (cm)

Data on plant height for different chilli genotypes under the influence of drought stress which was imposed at different growth stages *viz*., flowering and fruit development, is presented in Table 5 and graphically depicted in Fig.3.

4.2.1.1 Genotypes

Plant height was recorded at 30, 60 and 90 DAT. Plant height differed significantly amongst selected eight genotypes during all the growth stages. At 30 DAT, Parbhani Mirchi (20.34cm) attained maximum height amongst all; which was followed by Parbhani Tejas (19.28cm) and Local genotype (18.91cm); whereas Phule Jyoti, Jayanti and Arka Suphal found at par with each other.

At 60 DAT, Parbhani Mirchi (42.50cm) was the tallest amongst all; which was followed by Parbhani Tejas (39.33cm) and Local genotype (37.79cm); whereas Phule Jyoti, Jayanti and Arka Suphal were found to be at par with each other.

Similar trend was observed at 90 DAT with marginal increase in height of Parbhani Mirchi (45.04cm), followed by Parbhani Tejas (41.62cm) and Local

genotype (40.11cm); However, Hirkani (35.13cm) was found to be most dwarf genotype amongst all.

It is interpreted that the variation in plant height at any stages of growth in the experiment was mainly because of genetic variation. Similar observations were recorded in drought experiments conducted by Techawongstien *et al*. (1992), Khan *et al.* (2008) and Phimchan *et al*. (2012) who studied in chilli crop.

4.2.1.2 Effect of drought stress

Drought stress significantly affects the plant height, when imposed at flowering and fruit development; which was recorded at 60 and 90 days after transplanting. When stress imposed at flowering stage, plant height was significantly reduced to 30.06cm as that of plant height in control treatments attained 40.13cm. Similarly, when drought stress was imposed at fruit development, restrict height but the difference was not that much. During fruit development, plants in control showed height of 43.36cm and stressed plants showed 40.79cm.

Growth parameter like plant height was observed to study the influence of drought stress, imposed at different stages: flowering and fruit development, measured at 60 and 90 DAT. Plant height was reduced in stressed condition as compared to controlled condition. Amongst the selected stages, flowering stage found to be more sensitive than fruit development stage.

The reduced plant height was due to the reduced cell size that occurs when plant develops under water stress which often leads to drought like conditions resulting into the cessation of growth rate. Decreased cell growth must be the most sensitive response of the plant to water stress. Since cell growth is quantitatively related to cell turgor and cell turgor decreases with any dehydration induced by decrease in cell water potential. Further, cell enlargement acts as water sink using large quantities of water (Boyer, 1970). Cell enlargement is more sensitive than cell division under moisture stress (Hsiao, 1973). Respiration rate is sometimes enhanced under drought like conditions created due to water stress, causing reduction in the growth rate (Kramer, 1962). Above results found in agreement with Khan *et al*. (2008), Akinbile *et al*. (2011), Phimchan *et al*. (2012), Gobu *et al*. (2017) reported in chilli.

Table 5. Effect of drought stress imposed at different growth stages on plant height (cm)on different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor A : Genotypes (G)				
G_1	Parbhani Tejas	19.28	39.33	41.62
G_2	Parbhani Mirchi	20.34	42.50	45.04
G_3	Phule Jyoti	18.42	35.79	38.46
G_4	Jayanti	18.53	35.13	37.25
G_5	Hirkani	17.65	33.42	35.13
G_6	Arka Lohit	17.58	34.50	36.61
G_7	Arka Suphal	18.53	32.67	34.84
G_8	Local Genotype	18.91	37.79	40.11
S.E ±		0.10	0.41	0.44
C.D at 1%		0.29	1.21	1.24
Factor B : Stress Stages (S)				
S1	No stress	18.63	40.13	43.36
S2	Stress at Flowering	18.70	30.06	31.75
S3	Stress at Fruit development	18.64	38.98	40.79
S.E ±		0.037	0.15	0.16
C.D at 1%		NS	0.46	0.47
Interaction Effect (G X S)				
T01	G_1S_1	19.34	43.25	46.20
T02	G_1S_2	19.34	32.63	34.38
T03	G_1S_3	19.18	42.13	44.28
T04	G_2S_1	20.63	47.75	50.87
T05	G_2S_2	20.18	33.63	35.63
T06	G_2S_3	20.21	46.13	48.63
T07	G_3S_1	18.11	38.50	42.86
T08	G_3S_2	18.53	30.63	32.18
T09	G_3S_3	18.61	38.25	40.35
T10	G_4S_1	18.73	38.75	41.55
T11	G_4S_2	18.60	29.38	30.83
T12	G_4S_3	18.26	37.25	39.37
T13	G_5S_1	17.74	37.25	40.10
T14	G_5S_2	17.58	27.50	28.88
T15	G_5S_3	17.63	35.50	36.43
T16	G_6S_1	17.65	38.38	42.13
T17	G_6S_2	17.58	28.00	29.86
T18	G_6S_3	17.53	37.13	37.85
T19	G_7S_1	18.34	36.00	39.21
T20	G_7S_2	18.91	27.00	28.85
T21	G_7S_3	18.33	35.00	36.46
T22	G_8S_1	18.50	41.13	43.98
T23	G_8S_2	18.86	31.75	33.40
T24	G_8S_3	19.36	40.50	42.95
S.E ±		0.30	1.23	1.27
C.D at 1%		NS	NS	NS

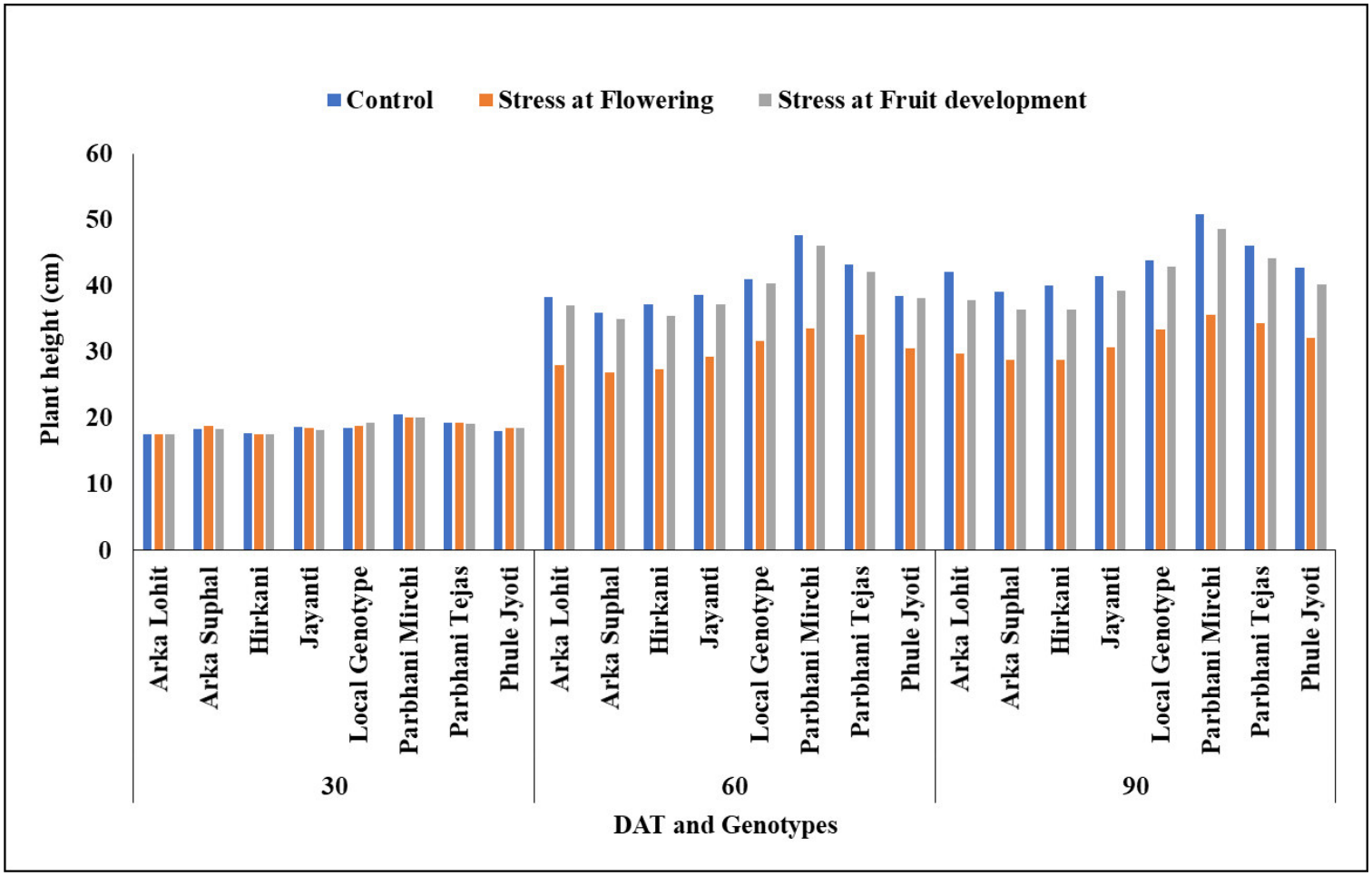


Fig. 3 Effect of drought stress imposed at different growth stages on plant height (cm) of different chilli genotypes

4.2.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress imposed at different growth stages found non-significant on plant height throughout the life cycle.

4.2.2 Stem girth (mm)

Data on stem girth for different chilli genotypes under the influence of drought stress which was imposed at different growth stages *viz*., flowering and fruit development, is presented in Table 6 and graphically depicted in Fig.4.

4.2.1.1 Genotypes

The effect of genotypes on stem girth found non – significant during all growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively.

4.2.1.2 Effect of drought stress

Drought stress significantly affect the stem girth, when imposed at flowering and fruit development; which was recorded at 60 and 90 days after transplanting. When stress imposed at flowering stage, stem girth was significantly reduced to 8.62mm as that of stem girth in control treatments attained 13.54mm. Similarly, when drought stress was imposed at fruit development, restrict the expansion of girth but the difference was not that much. During fruit development, plants in control showed girth of 19.69mm whereas stressed plants showed 16.04mm.

Stem girth was observed to study the impact of drought stress, imposed at different stages : flowering and fruit development, which was measured at 60 and 90 DAT. Stem girth was reduced in stressed condition as compared to controlled condition. Amongst the selected stages, flowering stage found to be more sensitive than fruit development stage.

The stem girth was decreased with high magnitude of drought stress at flowering and fruit development stage. The decreased stem girth induced by drought stress in plants could be due to the reduction in plant water status which reduces stem expansion that ultimately results into under development of plant. Extreme water stress also hampers the ability of plant to utilize soil nutrients and which adversely affect the metabolic processes in plant. Due to this, stem girth of plants grown under stressed condition remain under developed as compared to stem girth of plants in control condition. Similar results were found by Byari *et al.* (1995), Kirnak *et al.*

Table 6. Effect of drought stress imposed at different growth stages on stem girth (mm) of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor A : Genotypes (G)				
G_1	Parbhani Tejas	6.38	11.81	15.81
G_2	Parbhani Mirchi	6.74	12.20	16.23
G_3	Phule Jyoti	6.51	11.96	15.97
G_4	Jayanti	6.39	11.82	15.83
G_5	Hirkani	6.22	11.63	15.62
G_6	Arka Lohit	6.51	11.96	15.97
G_7	Arka Suphal	6.12	11.53	15.51
G_8	Local Genotype	6.46	11.90	15.90
S.E ±		0.063	0.069	0.073
C.D at 1%		NS	NS	NS
Factor B : Stress Stages (S)				
S1	No stress	6.44	13.54	19.69
S2	Stress at Flowering	6.32	8.62	11.80
S3	Stress at Fruit development	6.48	13.40	16.07
S.E ±		0.023	0.026	0.219
C.D at 1%		NS	0.076	0.65
Interaction Effect (G X S)				
T01	G_1S_1	6.48	13.58	19.73
T02	G_1S_2	6.37	8.67	11.85
T03	G_1S_3	6.29	13.18	15.84
T04	G_2S_1	6.91	14.06	20.24
T05	G_2S_2	6.57	8.89	12.09
T06	G_2S_3	6.73	13.67	16.36
T07	G_3S_1	6.36	13.45	19.60
T08	G_3S_2	6.51	8.82	12.02
T09	G_3S_3	6.67	13.60	16.28
T10	G_4S_1	6.19	13.26	19.40
T11	G_4S_2	6.35	8.65	11.83
T12	G_4S_3	6.63	13.56	16.25
T13	G_5S_1	6.22	13.30	19.43
T14	G_5S_2	6.06	8.33	11.49
T15	G_5S_3	6.37	13.27	15.94
T16	G_6S_1	6.72	13.84	20.01
T17	G_6S_2	6.42	8.72	11.91
T18	G_6S_3	6.41	13.31	15.98
T19	G_7S_1	6.18	13.25	19.39
T20	G_7S_2	6.13	8.41	11.58
T21	G_7S_3	6.05	12.91	15.56
T22	G_8S_1	6.46	13.56	19.71
T23	G_8S_2	6.20	8.49	11.66
T24	G_8S_3	6.72	13.65	16.34
S.E ±		0.19	0.21	0.22
C.D at 1%		NS	NS	NS

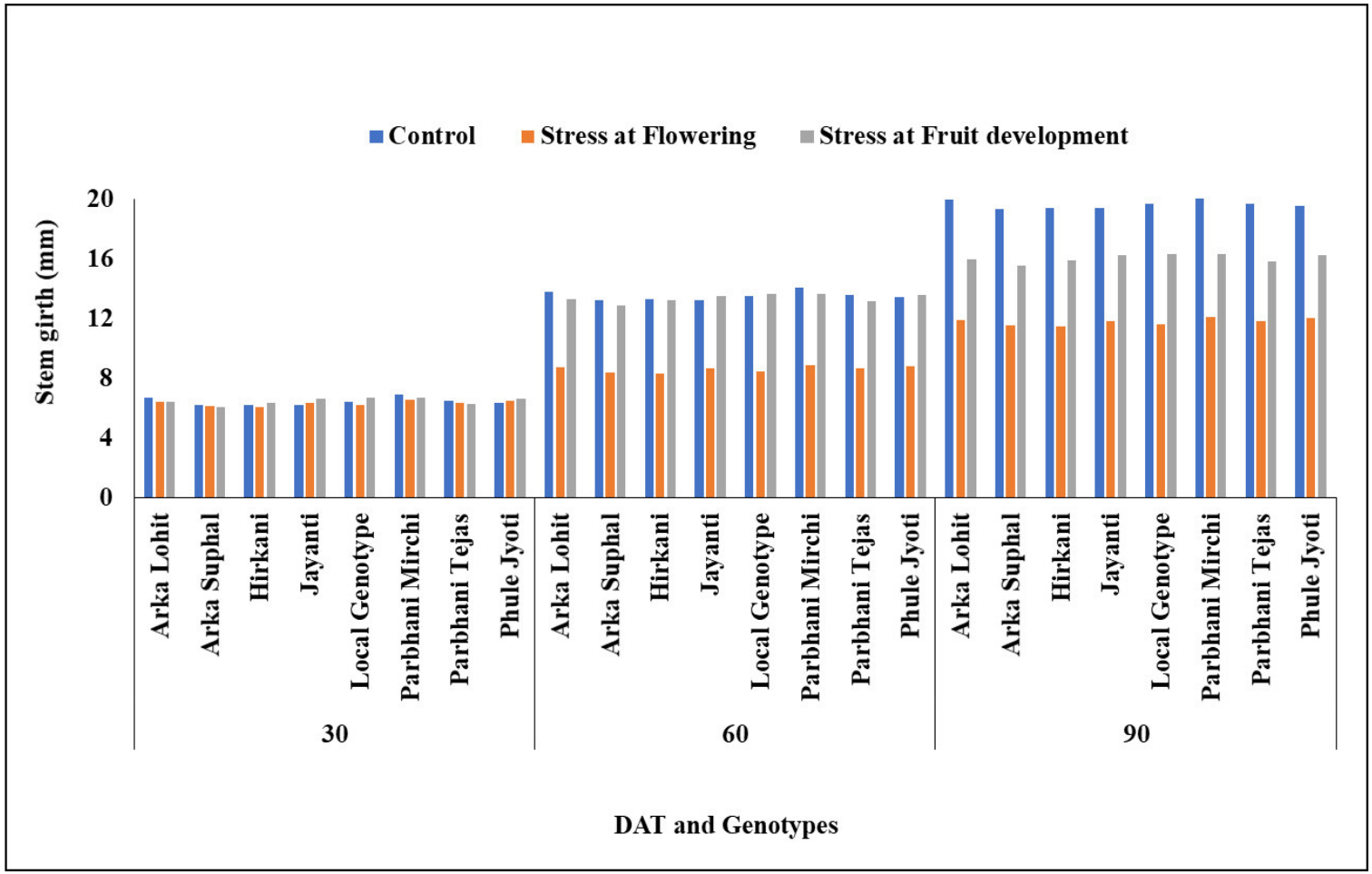


Fig. 4 Effect of drought stress imposed at different growth stages on stem girth (mm) of different chilli genotypes

(2001) who reported that stem girth was reduced for brinjal grown under drought stress conditions and Phimchan *et al*. (2012) for chilli.

4.2.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress imposed at different growth stages found non-significant on stem girth throughout the crop period.

4.3 Leaf parameters

4.3.1 Leaf area (cm^2)

Data on leaf area for different chilli genotypes under the influence of drought stress which was imposed at different growth stages *viz*., flowering and fruit development, is presented in Table 7 and graphically depicted in Fig.5.

4.3.1.1 Genotypes

The effect of genotypes on leaf area found non – significant during all growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively.

4.3.1.2 Effect of drought stress

Drought stress significantly affects the leaf area, when imposed at flowering and fruit development; which was recorded at 60 and 90 days after transplanting. When stress imposed at flowering stage, leaf area was significantly reduced to 16.37 cm^2 as that of leaf area in control treatments attained 18.29 cm^2. Similarly, when drought stress was imposed at fruit development, reduced the expansion of leaf. During fruit development, plants in control showed area of 18.37 cm^2 whereas stressed plants showed 16.16 cm^2.

Leaf area was observed to study the impact of drought stress, imposed at different stages : flowering and fruit development, which was measured at 60 and 90 DAT. Leaf area was reduced in stressed condition as compared to controlled condition.

The reduced leaf area under depleting soil moisture condition might be the resultant effect of the reduction in cell turgidity which would result in inhibition of cell division and cell expansion. Reduction in cell turgidity was attributed to the reduction in cell water potential, caused due to the dehydration.

Table 7. Effect of drought stress imposed at different growth stages on leaf area (cm^2) on different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor A : Genotypes (G)				
G_1	Parbhani Tejas	16.88	18.05	17.52
G_2	Parbhani Mirchi	17.41	18.61	17.87
G_3	Phule Jyoti	16.44	17.76	17.22
G_4	Jayanti	16.59	17.63	17.20
G_5	Hirkani	16.27	17.32	17.09
G_6	Arka Lohit	16.08	17.12	17.06
G_7	Arka Suphal	15.02	16.06	16.26
G_8	Local Genotype	16.80	17.85	17.43
S.E ±		0.206	0.224	0.210
C.D at 1%		NS	NS	NS
Factor B : Stress Stages (S)				
S1	No stress	16.67	18.29	18.37
S2	Stress at Flowering	16.25	16.37	17.09
S3	Stress at Fruit development	16.39	17.99	16.16
S.E ±		0.077	0.084	0.079
C.D at 1%		NS	0.247	0.232
Interaction Effect (G X S)				
T01	G_1S_1	17.22	18.49	18.60
T02	G_1S_2	16.78	17.50	17.71
T03	G_1S_3	16.65	18.16	16.24
T04	G_2S_1	17.42	19.22	19.02
T05	G_2S_2	17.25	17.30	17.51
T06	G_2S_3	17.56	19.30	17.09
T07	G_3S_1	17.07	18.99	18.99
T08	G_3S_2	16.25	16.29	17.01
T09	G_3S_3	16.00	18.00	15.67
T10	G_4S_1	16.96	18.55	18.55
T11	G_4S_2	16.22	16.26	16.95
T12	G_4S_3	16.59	18.09	16.11
T13	G_5S_1	16.49	18.08	18.08
T14	G_5S_2	16.10	16.14	17.22
T15	G_5S_3	16.24	17.74	15.97
T16	G_6S_1	16.10	17.69	17.69
T17	G_6S_2	16.15	16.19	16.40
T18	G_6S_3	15.99	17.49	17.08
T19	G_7S_1	15.24	16.82	17.54
T20	G_7S_2	14.47	14.49	16.21
T21	G_7S_3	15.36	16.86	15.03
T22	G_8S_1	16.91	18.50	18.50
T23	G_8S_2	16.77	16.81	17.72
T24	G_8S_3	16.74	18.24	16.07
S.E ±		0.62	0.67	0.63
C.D at 1%		NS	NS	NS

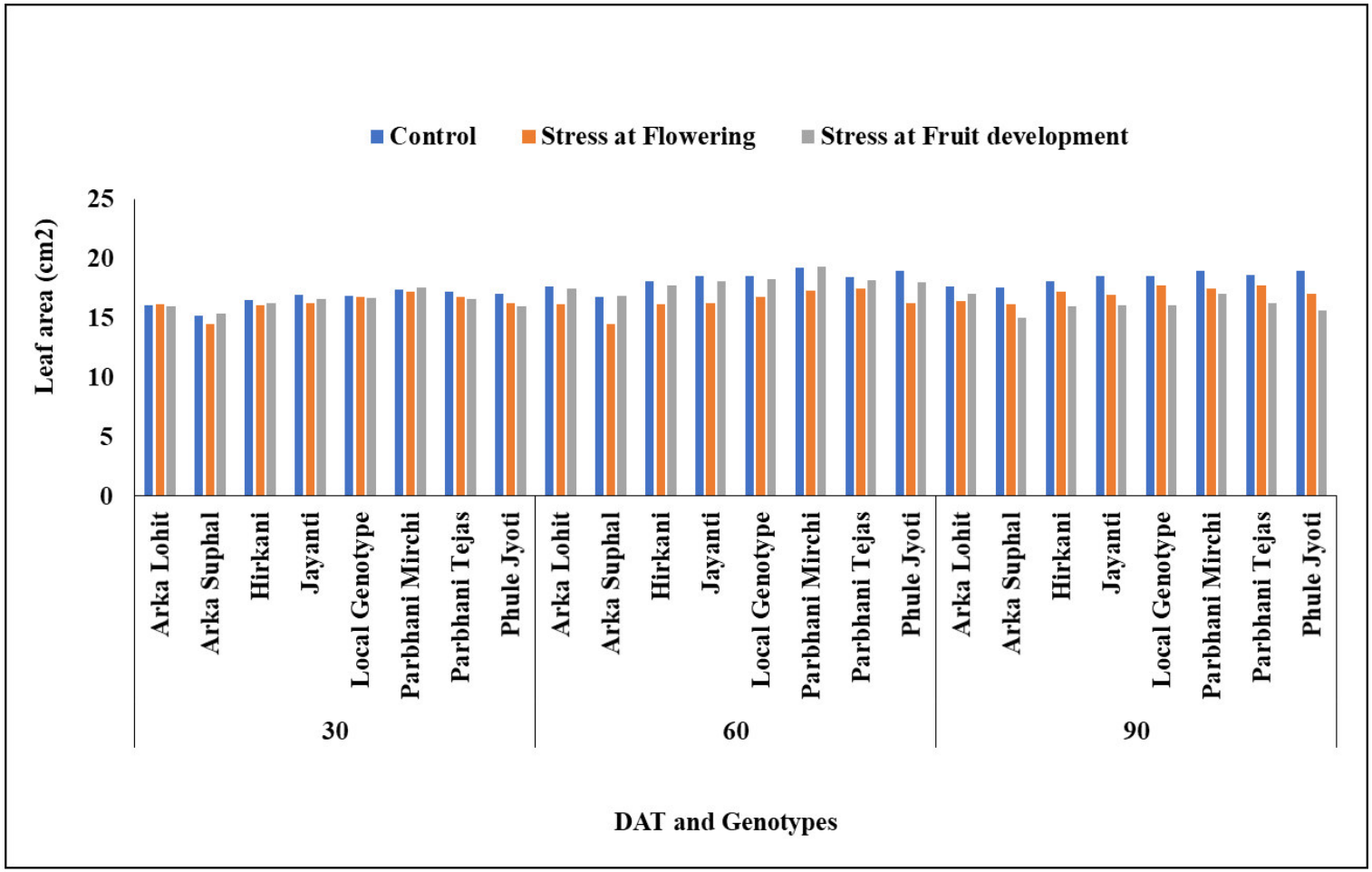


Fig. 5 Effect of drought stress imposed at different growth stages on leaf area (cm^2) of different chilli genotypes

Along with this, reduction in leaf area might be a defensive mechanism adopted by plant to avoid loss of water through transpiration. Above results found in agreement with Phimchan *et al*. (2012), Khan *et al*. (2012), Thakur *et al*. (1993).

4.2.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress imposed at different growth stages found non-significant on leaf area throughout the crop period.

4.4 Physiological parameters

4.4.1 Chlorophyll fluorescence (*Fv/Fm*)

Data on chlorophyll fluorescence for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 8 and graphically depicted in Fig.6.

4.4.1.1 Genotypes

The effect of genotypes on maximum quantum efficiency as indicated by Fv/Fm was not significant at any of the growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively. This suggests that the there was no significant differences among the genotypes with respect to photosystem II efficiency in the set of genotypes of chilli chosen for the study.

4.4.1.2 Effect of drought stress

Drought stress significantly affected the photosynthetic efficiency of plants, when imposed at flowering and fruit development; which was recorded at 60 and 90 days after transplanting. When stress imposed at flowering stage, maximum quantum yield was significantly reduced to 0.67 while that of control treatments was 0.73. Similarly, during fruit development, plants in control showed quantum yield of 0.76 whereas stressed plants showed 0.67. These results clearly indicate that the photosystem efficiency was affected when drought stress was imposed either at flowering or fruit development.

Chlorophyll fluoresces measurement is a non-destructive, rapid and relatively simple technique for studying the equilibrium between metabolic and energy evolving processes during photosynthesis, that is often affected by both temperature and drought stresses. It is an indication of the fate of excitation energy in the photosynthetic apparatus, which has been used as an early, *in vivo*, indication of many types of plant stress. Schreiber *et al*., (1993) make the argument that one of the first

responses of a plant to environmental stress (either water or temperature) is an increase in non-radiative energy indulgence, which is reflected by the amount of chlorophyll fluorescence. The ratio of variable ($Fv = Fm - F_0$) to maximal (Fm) fluorescence of dark-adapted leaves has also been used widely as an indication of plant stress because it is a rapid determination of changes in the maximum quantum efficiency of PSII phytochemistry. *Fv/Fm* is considered a quantitative measure of maximal or potential photochemical efficiency or optimal quantum yield of PSII. Fv declines with, and F0 increases with, increasing levels of several types of stress (e.g., heat, water, and light) such that *Fv/Fm* and F_0 are generally highly and negatively correlated. Nevertheless, the error in measuring *Fv/Fm* is less than that in measuring F_0, leading Yamada *et al*. (1996) to conclude that *Fv/Fm* is a better choice.

The photosystem II (PSII) is highly sensitive to environmental limiting factors and PSII reaction center and its chemical reactions being adversely affected by drought stress. It has been shown that under high radiation conditions, drought stress enhances inhibition of electron transport. Drought stress decreases variable fluorescence (*FV*), initiative fluorescence (F_0) and quantum yield (*Fv/Fm*). This value varies between 0.7 to 0.8 in non-stressed plants and shows a close association with net photosynthesis and quantum yield in intact plant leaves. Declining slope of *Fv/Fm* is a valuable criterion for evaluation of photoinhibition in plants that are subjected to environmental stresses, such as drought and high temperatures accompanied with high radiation intensity. Above results are found in agreement with Arani *et al*. (2017) in fenugreek, Paknejad *et al*. (2007) in wheat cultivars, Zewdie *et al* (2007) in two enset clones, Geetha *et al*. (2017) in sunflower genotypes. Our results clearly indicate that soil moisture stress affects PS-II efficiency in leaves of chilli genotypes when imposed at flowering or fruiting stage.

4.4.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on chlorophyll fluorescence during the crop period.

4.4.2 Canopy temperature (^{0}C)

Data on chlorophyll fluorescence for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 9 and graphically depicted in Fig.7.

4.4.2.1 Genotypes

The effect of genotypes on canopy temperature found non – significant during all growth stages *viz.*, vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively.

4.4.2.2 Effect of drought stress

Drought stress significantly increased the canopy temperature of plants, when imposed at flowering and fruit development; which was recorded at 60 and 90 days after transplanting. When stress imposed at flowering stage, canopy temperature was significantly increased to 31.98^{0}C as that of canopy temperature in control treatments shown 29.34^{0}C. Similarly, during fruit development, plants in control shown canopy temperature of 28.46^{0}C whereas stressed plants showed 31.21^{0}C. When drought stress was imposed either at flowering or fruit development, canopy temperature was significantly increased, and negatively affecting other metabolic activities of plants which are in association with growth and yield contributing attributes.

Canopy temperature is generally measured with infrared thermometers. As drought stress exceed, soil water content goes on decreasing. Jackson *et al*. (1981) used canopy temperature as an indicator of environmental stresses such as drought as well as heat stress. Advantageous since crops respond to both the soil and aerial environment (evaporative demand). The behavior of plant canopy temperature both under stress and non-stress conditions provides signs of crop water status and yield performance during drought conditions. This is based on the fact that process of transpiration reduces leaf temperature relative to air temperature; the reduction being greater at relatively high vapor pressure deficit (VPD) values compared to low VPD values. Leaf temperature increases when the supply of water to a plant limits transpiration and when radiant energy is not dissipated via evaporation (Jackson *et al*. 1981). Above findings were in agreement with Çolaka *et al*. (2015) in eggplant, Rezaei *et al*. (2014) in pea, Paknejad *et al*. (2007) in wheat cultivars, Ndiso *et al*. (2016) in cowpea varieties .

4.4.4.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on canopy temperature during the crop period.

Table 8. Effect of drought stress imposed at different growth stages on chlorophyll fluorescence (*Fv/Fm*) of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor A: Genotypes				
G_1	Parbhani Tejas	0.72	0.70	0.73
G_2	Parbhani Mirchi	0.74	0.72	0.71
G_3	Phule Jyoti	0.72	0.71	0.72
G_4	Jayanti	0.72	0.70	0.70
G_5	Hirkani	0.72	0.71	0.71
G_6	Arka Lohit	0.74	0.71	0.71
G_7	Arka Suphal	0.73	0.71	0.70
G_8	Local Genotype	0.74	0.72	0.71
S.E ±		0.0047	0.050	0.0045
C.D at 1%		N/S	N/S	N/S
Factor B : Stress Stages				
S_1	No stress	0.73	0.73	0.76
S_2	Stress at Flowering	0.73	0.67	0.71
S_3	Stress at Fruit development	0.73	0.73	0.67
S.E ±		0.00187	0.00192	0.002
C.D at 1%		N/S	0.00567	0.0057
Interaction Effect (G X S)				
T01	G_1S_1	0.74	0.75	0.77
T02	G_1S_2	0.71	0.64	0.73
T03	G_1S_3	0.72	0.72	0.70
T04	G_2S_1	0.73	0.73	0.76
T05	G_2S_2	0.74	0.68	0.71
T06	G_2S_3	0.74	0.74	0.66
T07	G_3S_1	0.71	0.71	0.77
T08	G_3S_2	0.73	0.69	0.71
T09	G_3S_3	0.72	0.72	0.68
T10	G_4S_1	0.72	0.72	0.75
T11	G_4S_2	0.70	0.66	0.70
T12	G_4S_3	0.72	0.72	0.66
T13	G_5S_1	0.74	0.74	0.77
T14	G_5S_2	0.71	0.67	0.70
T15	G_5S_3	0.71	0.71	0.66
T16	G_6S_1	0.71	0.71	0.75
T17	G_6S_2	0.75	0.67	0.71
T18	G_6S_3	0.75	0.75	0.67
T19	G_7S_1	0.74	0.74	0.74
T20	G_7S_2	0.73	0.67	0.72
T21	G_7S_3	0.72	0.72	0.64
T22	G_8S_1	0.74	0.74	0.75
T23	G_8S_2	0.74	0.68	0.72
T24	G_8S_3	0.75	0.75	0.67
S.E ±		0.0047	0.015	0.0135
C.D at 1%		N/S	N/S	N/S

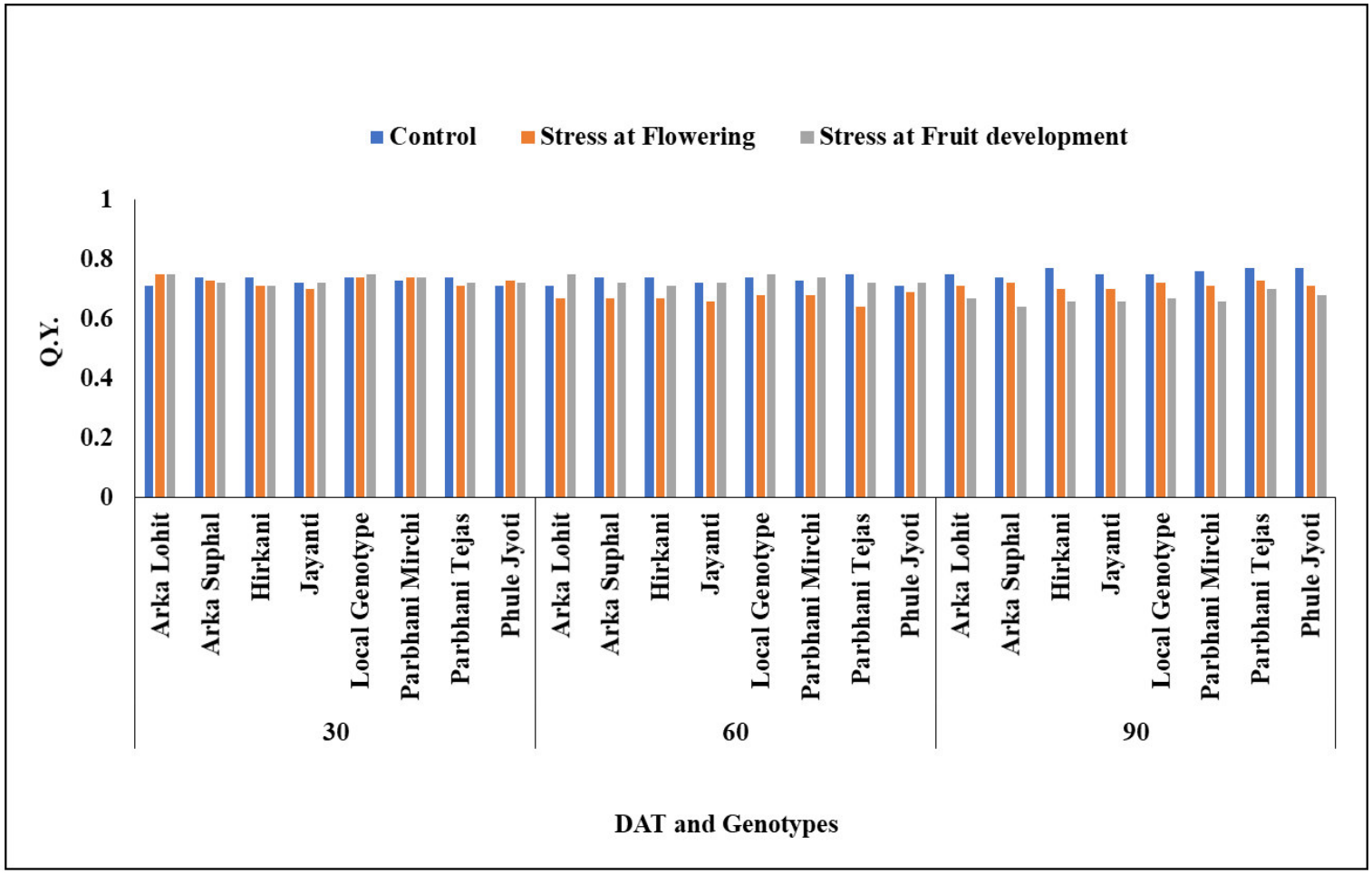


Fig. 6 Effect of drought stress imposed at different growth stages on chlorophyll fluorescence (*Fv/Fm*) on different chilli genotypes

Table 9. Effect of drought stress imposed at different growth stages on canopy temperature (^{0}C) of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor G : Genotypes				
G_1	Parbhani Tejas	28.11	30.71	29.90
G_2	Parbhani Mirchi	27.84	29.88	28.84
G_3	Phule Jyoti	28.34	30.52	29.71
G_4	Jayanti	28.49	30.51	29.78
G_5	Hirkani	28.69	30.51	30.31
G_6	Arka Lohit	28.98	30.43	30.06
G_7	Arka Suphal	28.66	30.14	29.86
G_8	Local Genotype	28.25	29.90	29.79
S.E ±		0.148	0.159	0.126
C.D at 1%		NS	NS	NS
Factor S : Stress Stages				
S_1	No stress	28.28	29.34	28.46
S_2	Stress at Flowering	28.46	31.98	29.67
S_3	Stress at Fruit development	28.52	29.66	31.21
S.E ±		0.055	0.060	0.047
C.D at 1%		NS	0.176	0.139
Interaction Effect (G X S)				
T01	G_1S_1	28.07	29.56	27.98
T02	G_1S_2	28.17	32.48	30.24
T03	G_1S_3	28.09	30.10	31.50
T04	G_2S_1	27.62	29.33	28.01
T05	G_2S_2	27.73	30.71	28.93
T06	G_2S_3	28.18	29.59	29.58
T07	G_3S_1	28.03	29.59	28.51
T08	G_3S_2	28.36	32.00	29.98
T09	G_3S_3	28.65	29.98	30.65
T10	G_4S_1	28.20	28.94	28.54
T11	G_4S_2	28.50	32.30	29.63
T12	G_4S_3	28.78	30.30	31.16
T13	G_5S_1	28.79	29.66	28.60
T14	G_5S_2	28.72	32.21	30.39
T15	G_5S_3	28.56	29.66	31.95
T16	G_6S_1	29.10	29.60	28.80
T17	G_6S_2	29.16	32.23	29.70
T18	G_6S_3	28.67	29.46	31.69
T19	G_7S_1	28.46	29.03	28.44
T20	G_7S_2	28.66	32.45	29.14
T21	G_7S_3	28.87	28.95	32.00
T22	G_8S_1	27.98	28.99	28.80
T23	G_8S_2	28.38	31.49	29.40
T24	G_8S_3	28.39	29.23	31.16
S.E ±		0.443	0.477	0.377
C.D at 1%		NS	NS	NS

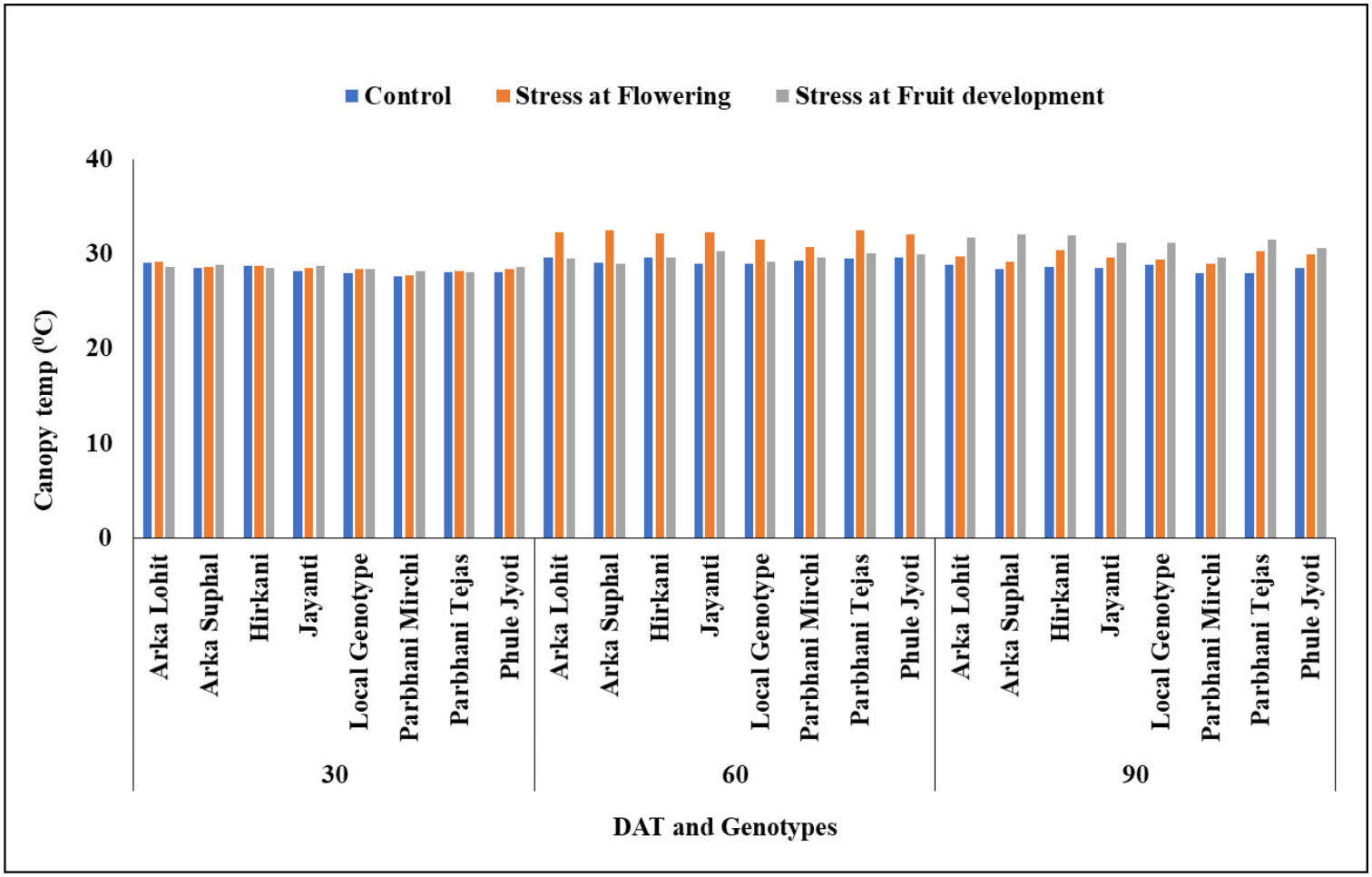


Fig. 7 Effect of drought stress imposed at different growth stages on canopy temperature (^{0}C) of different chilli genotypes

4.4.3 Normalized Difference Vegetation Index (NDVI)

Data on NDVI for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 10 and graphically depicted in Fig.8.

4.4.3.1 Genotypes

The effect of genotypes on NDVI found non – significant during all growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively.

4.4.3.2 Effect of drought stress

Drought stress significantly decreased NDVI value of plants, when imposed at flowering and fruit development stage; which was recorded at 60 and 90 days after transplanting respectively. When stress imposed at flowering stage, NDVI was significantly reduced to 0.25 as than control treatments shown 0.43. Similarly, during fruit development, plants in control showed NDVI of 0.38 whereas stressed plants showed 0.22. When drought stress was imposed either at flowering or fruit development, NDVI was significantly lowered. NDVI was observed to study the influence of drought stress, executed at different stages: flowering and fruit development, which was measured at 60 and 90 DAT. NDVI was elevated under controlled condition as compared to stressed condition.

Normalized Difference Vegetation Index (NDVI) is micro remote sensing approach, used to assess whether the target being observed contains live green vegetation or not (wikipedia.org/wiki/NDVI). The green canopy of plants absorbs the large part of the incident visible light and reflects those in the near infrared region. Normalized difference vegetation index (NDVI) expresses the ratio of reflectance of active photosynthetic radiation in visible and near infrared regions of the spectrum (Rouse *et al.*1974).

NDVI index showed the green color indicating water conditions in soil at field capacity, in which the plant performs photosynthesis under controlled irrigation. As soil water content depletes, the green color of foliage gradually turns to pale shade, which was indicated by lowered NDVI value. Water-stressed plants absorbs less light in the visible region and more light in the near-infrared region of the spectrum than irrigated, i.e., unstressed plants. Decreased NDVI value indicates the hampered photosynthetic ability, which finally results into decreased yield. Thus, NDVI can be an effective tool to assess the health of plant under particular condition.

Table 10. Effect of drought stress imposed at different growth stages on NDVI of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor G : Genotypes				
G_1	Parbhani Tejas	0.37	0.36	0.33
G_2	Parbhani Mirchi	0.39	0.39	0.35
G_3	Phule Jyoti	0.40	0.37	0.32
G_4	Jayanti	0.37	0.37	0.31
G_5	Hirkani	0.37	0.34	0.32
G_6	Arka Lohit	0.40	0.35	0.30
G_7	Arka Suphal	0.39	0.38	0.30
G_8	Local Genotype	0.37	0.39	0.31
S.E ±		0.0116	0.0053	0.0050
C.D at 1%		NS	NS	NS
Factor S : Stress Stages				
S_1	No stress	0.39	0.43	0.38
S_2	Stress at Flowering	0.38	0.25	0.28
S_3	Stress at Fruit development	0.38	0.42	0.22
S.E ±		0.004	0.0020	0.0019
C.D at 1%		NS	0.0058	0.0056
Interaction Effect (G X S)				
T01	G_1S_1	0.42	0.44	0.41
T02	G_1S_2	0.35	0.25	0.31
T03	G_1S_3	0.34	0.40	0.26
T04	G_2S_1	0.38	0.46	0.43
T05	G_2S_2	0.44	0.25	0.32
T06	G_2S_3	0.37	0.44	0.29
T07	G_3S_1	0.42	0.40	0.43
T08	G_3S_2	0.38	0.26	0.29
T09	G_3S_3	0.41	0.45	0.24
T10	G_4S_1	0.35	0.44	0.40
T11	G_4S_2	0.37	0.25	0.32
T12	G_4S_3	0.38	0.42	0.22
T13	G_5S_1	0.41	0.37	0.39
T14	G_5S_2	0.32	0.27	0.31
T15	G_5S_3	0.39	0.38	0.25
T16	G_6S_1	0.39	0.42	0.37
T17	G_6S_2	0.39	0.23	0.29
T18	G_6S_3	0.42	0.39	0.23
T19	G_7S_1	0.40	0.46	0.39
T20	G_7S_2	0.40	0.26	0.27
T21	G_7S_3	0.38	0.42	0.25
T22	G_8S_1	0.38	0.43	0.40
T23	G_8S_2	0.37	0.29	0.31
T24	G_8S_3	0.36	0.45	0.22
S.E ±		0.035	0.0158	0.0151
C.D at 1%		NS	NS	NS

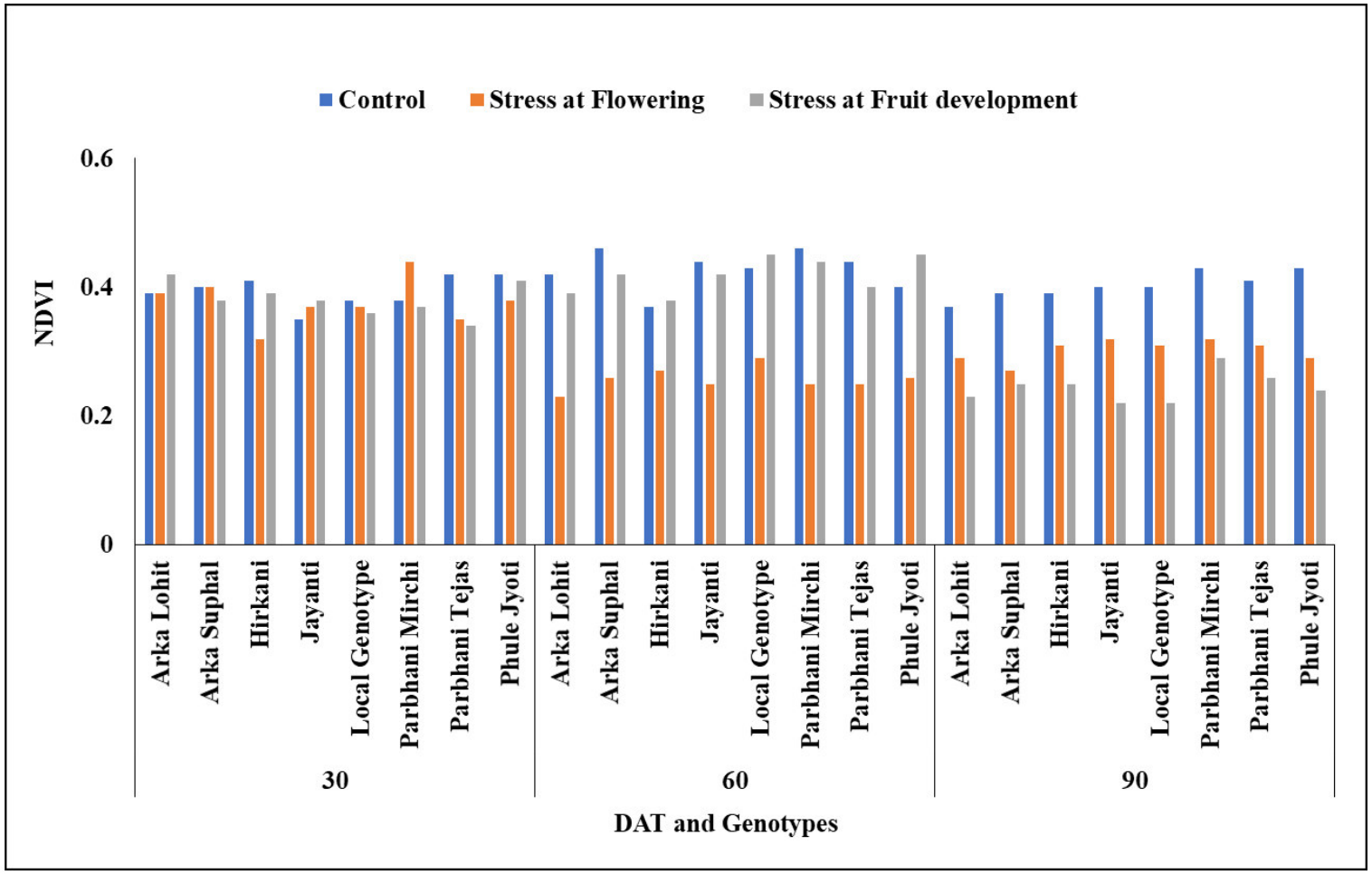


Fig. 8 Effect of drought stress imposed at different growth stages on NDVI of different chilli genotypes

Above findings were supported by Silva *et al*. (2015) in culture bean, Bayoumi *et al*. (2015) in wheat genotypes, Ihuoma *et al*. (2017), Nemeskéri *et al*. (2019).

4.4.3.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on NDVI during the crop period.

4.4.4 Stomatal Conductance (mmol $m^{-2}s^{-1}$)

Data on stomatal conductance for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 11 and graphically depicted in Fig.9.

4.4.4.1 Genotypes

The effect of genotypes on stomatal conductance found non – significant during all growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively.

4.4.4.2 Effect of drought stress

Drought stress significantly decreased stomatal conductance of plants, when imposed at flowering and fruit development stage; which was recorded at 60 and 90 days after transplanting respectively. When stress imposed at flowering stage, stomatal conductance was significantly reduced to 81.22 mmol $m^{-2}s^{-1}$ as than control treatments shown 246.16 mmol $m^{-2}s^{-1}$. Similarly, during fruit development, plants in control shown stomatal conductance of 215.07 mmol $m^{-2}s^{-1}$ whereas stressed plants showed 124.57 mmol $m^{-2}s^{-1}$. When drought stress was imposed either at flowering or fruit development, stomatal conductance was significantly lowered however it was observed more under controlled condition.

Stomatal conductance is the measure of the rate of passage of carbon dioxide (CO_2) entering, or water vapor exiting through the stomata of a leaf. The turgor pressure and osmotic potential of guard cells is directly related to the stomatal conductance. Stomatal conductance is a function of stomatal density, stomatal aperture, and stomatal size.

Stomatal conductance was measured by using steady state porometer. It measures the vapor concentration at two different locations in the diffusion path. It computes vapor flux from the vapor concentration measurements and the known conductance of the diffusion path. Reduction in stomatal conductance due to drought stress is closely associated with decreased rate of transpiration and other essential

metabolic activities of plants which play important role in regulating growth and development of plant. Under drought stress, stomatal aperture gets sunken which ultimately reduces the rate of passage of carbon dioxide (CO_2) entering, or water vapor exiting through the stomata. Because of this effect, transpiration rate of plant gets reduced, which helps the plant to restore the water inside the cell, to protect the organelles of the leaf that are sensitive to water stress (Thompson *et al*. 1997). Thus, reduction in stomatal conductance can be a defensive mechanism of plant to drought stress up to some extent; wherever, drought exceeds and available water goes below threshold level, shows steep decline in stomatal activities which might be non - retainable. And this impact, leads to decrease photosynthesis, and increase the rate of respiration, which ultimately results into wilting of plant. Therefore, decreased stomatal conductance due to water stress can be used as an indicator for drought susceptibility. Above findings are in agreement with Delfine *et al*. (1999), Naderikharaji *et al*. (2008), Riaz *et al*. (2013), Bhatt *et al*. (2014), Bayoumi *et al*. (2015), Ihuoma *et al.* (2017).

4.4.4.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on stomatal conductance during the crop period.

4.4.5 Relative Water Content (%)

Data on RWC for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 12 and graphically depicted in Fig.10.

4.4.5.2 Genotypes

The effect of genotypes on relative water content found significant during all growth stages viz., flowering and fruit development which was recorded at 60 and 90 DAT respectively.

At 60 DAT, Parbhani Mirchi (67.58%) shown maximum leaf water content amongst all genotypes; however Hirkani shown least RWC (59.90%). Parbhani Mirchi was followed by Local genotype (65.65%) and Parbhani Tejas (64.00%); whereas remaining genotypes found at par with each other.

Table 11. Effect of drought stress imposed at different growth stages on stomatal conductance (mmol $m^{-2}s^{-1}$) of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor A: Genotypes				
G_1	Parbhani Tejas	164.07	196.32	183.37
G_2	Parbhani Mirchi	163.19	199.68	195.13
G_3	Phule Jyoti	161.07	188.36	176.63
G_4	Jayanti	170.30	177.08	168.94
G_5	Hirkani	155.82	180.40	168.75
G_6	Arka Lohit	165.42	188.26	167.30
G_7	Arka Suphal	169.31	171.13	167.95
G_8	Local Genotype	155.35	200.26	179.49
S.E ±		4.25	4.74	3.21
C.D at 1%		NS	NS	NS
Factor B : Stress Stages				
S_1	No stress	164.53	246.16	215.07
S_2	Stress at Flowering	162.44	81.22	188.20
S_3	Stress at Fruit development	162.23	235.68	124.57
S.E ±		1.594	1.78	1.20
C.D at 1%		NS	4.98	3.38
Interaction Effect (G X S)				
T01	G_1S_1	164.49	258.78	215.34
T02	G_1S_2	161.15	83.00	193.26
T03	G_1S_3	166.58	247.18	141.50
T04	G_2S_1	167.44	256.86	227.50
T05	G_2S_2	163.39	101.53	198.98
T06	G_2S_3	158.75	240.66	158.90
T07	G_3S_1	161.95	249.49	210.31
T08	G_3S_2	157.38	90.45	188.86
T09	G_3S_3	163.89	225.14	130.71
T10	G_4S_1	169.55	233.69	215.64
T11	G_4S_2	166.49	65.00	182.28
T12	G_4S_3	174.85	232.56	108.90
T13	G_5S_1	161.30	229.00	209.31
T14	G_5S_2	155.81	87.66	188.91
T15	G_5S_3	150.35	224.55	108.01
T16	G_6S_1	157.49	253.98	213.09
T17	G_6S_2	177.86	67.39	180.48
T18	G_6S_3	160.91	243.41	108.34
T19	G_7S_1	174.41	228.53	210.14
T20	G_7S_2	164.70	65.98	182.73
T21	G_7S_3	168.81	218.90	110.99
T22	G_8S_1	159.64	258.93	219.21
T23	G_8S_2	152.74	88.79	190.09
T24	G_8S_3	153.68	253.08	129.18
S.E ±		12.75	14.21	9.64
C.D at 1%		NS	NS	NS

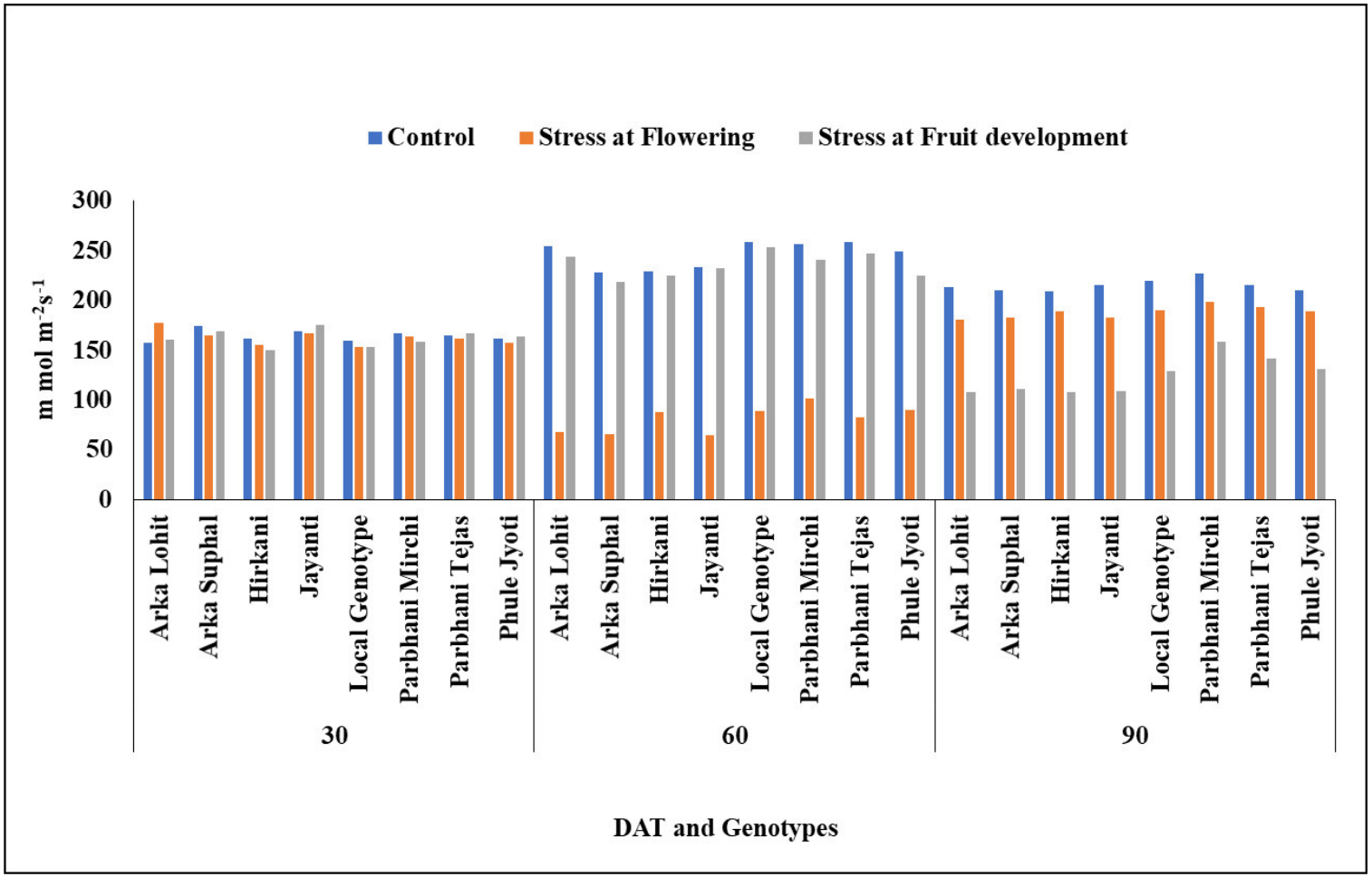


Fig. 9 Effect of drought stress imposed at different growth stages on stomatal conductance (mmol $m^{-2}s^{-1}$) of different chilli genotypes

Similarly, at 90 DAT, Parbhani Mirchi (64.57%) showed maximum RWC which was followed by Parbhani Tejas (62.67%) and Local genotype (61.82%); whereas remaining genotypes found at par with each other. However, Hirkani (57.27%) shown least RWC amongst all.

The mean values of RWC of selected genotypes significantly differed from each other, indicated that the high range of variability amongst genotypes under particular region. Environment appeared to have more or less impact on the leaf anatomy of genotypes, which is responsible to get varied water potential and osmotic adjustment (OA). Different cultivars can have different leaf RWC, indicating a corresponding difference in leaf hydration, differential response of leaves to water deficit conditions and physiological water status. Hence; RWC is an appropriate estimate of plant water status in terms of cellular hydration under the possible effect of both leaf water potential and OA. And hence, above results were found in agreement with Phimchan *et al*. (2012), Gideon Okunlola *et al.* (2017), Gobu *et al*. (2017).

4.4.5.2 Effect of drought stress

Drought stress significantly decreased relative water content of leaves, when imposed at flowering and fruit development stage; which was recorded at 60 and 90 days after transplanting respectively. When stress imposed at flowering stage, relative water content was significantly reduced to 38.91% as that of control treatments shown 76.62%. Similarly, during fruit development, plants in control shown relative water content of 75.86% whereas stressed plants showed 40.42%. When drought stress was imposed either at flowering or fruit development, relative water content was significantly lowered however it was observed more under controlled condition.

Relative water content (RWC) is probably the most appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit. It is one of the best physico-chemical indices revealing the stress intensity. Decrease in RWC in plants under drought stress may depend on plant vigor reduction and have been observed in many plants (Liu *et al*., 2002). Under water deficit, cell membrane subjects to changes such as increase in penetrability and decrease in sustainability. Microscopic investigations of dehydrated cells, revealed damages including cleavage in the membrane and sedimentation of cytoplasm content. Probably, in these conditions, ability to osmotic adjustment is reduced. And decreased ability to osmotic adjustment, eventually leads to poor photosynthesis. And thus, it ultimately leads to

fewer yields. Above findings are in agreement with Dar *et al*. (1981), Kuhad *et al*. (1986), Thakur *et al*. (1993), Phimchan *et al*. (2012), Okunlola *et al*. (2017), Gobu *et al*. (2017).

4.4.5.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on relative water content during the crop period.

4.4.6 Chlorophyll Index (SPAD value)

Data on chlorophyll index for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 13 and graphically depicted in Fig.11.

4.4.6.1 Genotypes

The effect of genotypes on Chlorophyll Index found non-significant during all growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively.

4.4.6.2 Effect of drought stress

Drought stress significantly decreased Chlorophyll Index of leaves, when imposed at flowering and fruit development stage; which was recorded at 60 and 90 days after transplanting respectively. When stress imposed at flowering stage, Chlorophyll Index was significantly reduced to 39.20 as that of control treatments shown 47.07. Similarly, during fruit development, plants in control showed Chlorophyll Index of 44.86 whereas stressed plants showed 38.15. When drought stress was imposed either at flowering or fruit development, Chlorophyll Index was significantly lowered however it was observed more under controlled condition.

Chlorophyll Index (SPAD value) was measured with chlorophyll meter (SPAD-502Plus). The SPAD-502 Plus determines the relative amount of chlorophyll present by measuring the absorbance of the leaf in two wavelength regions. Transmission in the infrared range provides a measurement related to leaf thickness, and a wavelength in the red light range is used to determine greenness. The ratio of the transmission of the two wavelengths provides a chlorophyll content index that is referred to as CCI or alternatively as a SPAD index. CCI is a linear scale, and SPAD is a logarithmic scale (Knighton and Bugbee, 2003). The instrument has a self-

Table 12. Effect of drought stress imposed at different growth stages on Relative Water Content (RWC) of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor G : Genotypes				
G_1	Parbhani Tejas	68.57	64.00	62.67
G_2	Parbhani Mirchi	66.55	67.58	64.47
G_3	Phule Jyoti	69.14	63.50	61.82
G_4	Jayanti	67.01	62.04	60.29
G_5	Hirkani	74.15	59.90	57.27
G_6	Arka Lohit	70.97	62.86	59.82
G_7	Arka Suphal	71.45	60.89	58.77
G_8	Local Genotype	70.77	65.65	61.67
S.E ±		0.82	0.61	0.58
C.D at 1%		NS	1.81	1.71
Factor S : Stress Stages				
S_1	No stress	70.45	75.46	76.31
S_2	Stress at Flowering	69.98	38.70	65.35
S_3	Stress at Fruit development	69.05	75.75	40.89
S.E ±		0.309	0.22	0.22
C.D at 1%		NS	0.65	0.64
Interaction Effect (G X S)				
T01	G_1S_1	69.70	76.06	77.76
T02	G_1S_2	69.10	39.14	66.86
T03	G_1S_3	66.92	76.79	43.40
T04	G_2S_1	66.83	80.16	80.21
T05	G_2S_2	65.14	42.39	68.38
T06	G_2S_3	67.68	80.19	44.84
T07	G_3S_1	68.56	76.84	77.57
T08	G_3S_2	71.05	38.61	65.92
T09	G_3S_3	67.82	75.07	41.99
T10	G_4S_1	68.34	74.09	75.36
T11	G_4S_2	64.82	37.29	65.18
T12	G_4S_3	67.88	74.75	40.33
T13	G_5S_1	76.08	70.78	72.76
T14	G_5S_2	74.56	37.43	62.45
T15	G_5S_3	71.83	71.51	36.61
T16	G_6S_1	72.87	74.34	75.03
T17	G_6S_2	71.21	38.68	64.92
T18	G_6S_3	68.82	75.56	39.52
T19	G_7S_1	70.15	72.57	74.63
T20	G_7S_2	73.27	36.12	64.11
T21	G_7S_3	70.91	73.99	37.56
T22	G_8S_1	71.05	78.89	77.15
T23	G_8S_2	70.71	39.94	65.02
T24	G_8S_3	70.56	78.13	42.86
S.E ±		2.47	1.75	1.73
C.D at 1%		NS	NS	NS

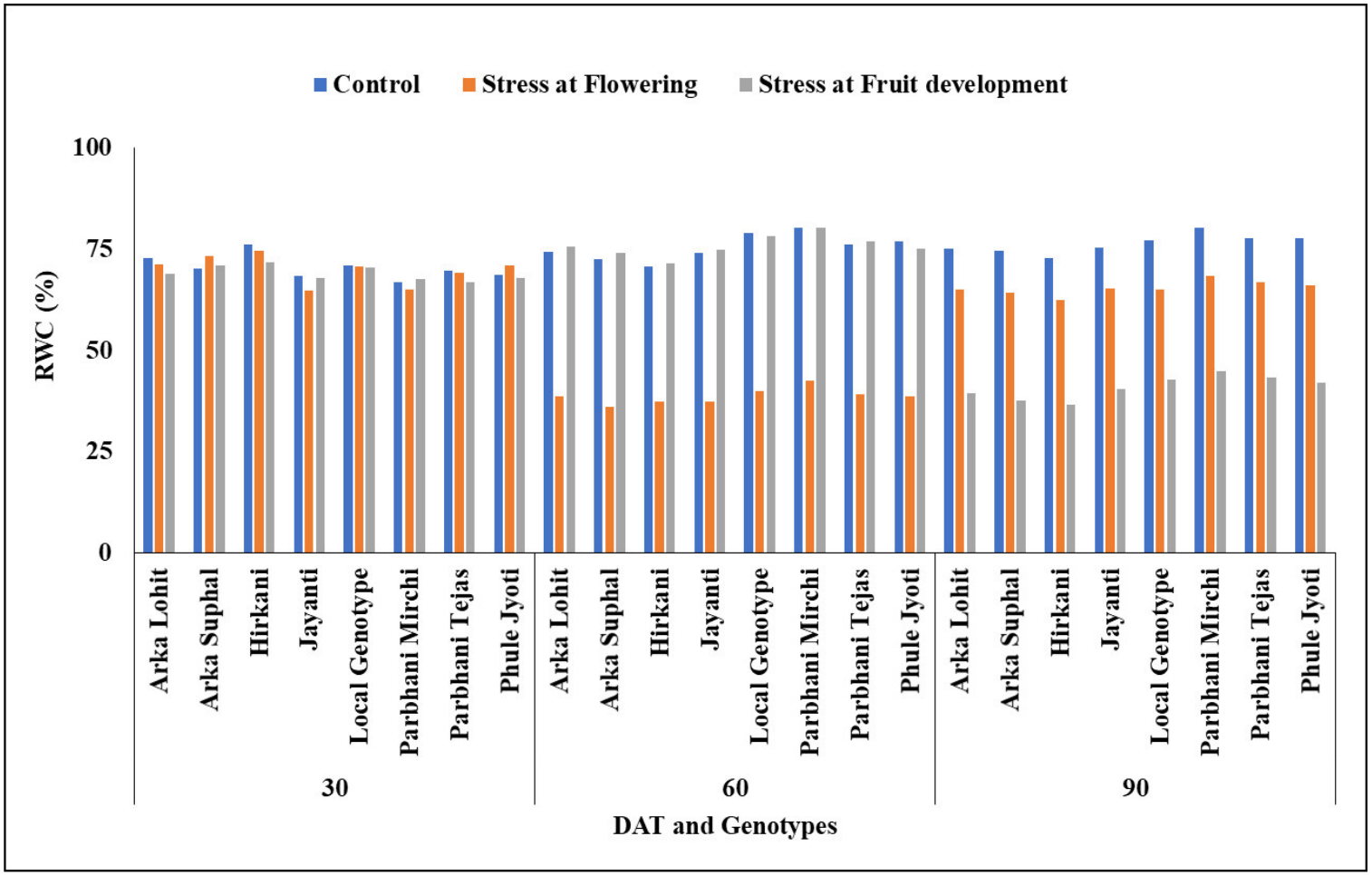


Fig. 10 Effect of drought stress imposed at different growth stages on RWC (%)of different chilli genotypes

contained light source for a uniform lighting over the sampled leaf surface and two detectors, one sensitive to red light (645nm) and the other sensitive to infrared radiation (790nm). The sensors convert the light into electrical currents for the calculation of the SPAD value; SPAD = A(log(Ior/Ir)-log(Iof/If) + B, where A and B are constant, Ir and If are respectively currents from red and infrared detectors with sample and no sample in place (Ior and If). A relatively low spectral reflectance on leaf shown by 39.20 and 38.15 SPAD values at flowering and fruit development stress respectively indicated disturbed photosynthetic activity. Above finding are in agreement with Naderikharaji *et al*. (2008), Sivakumar and Srividhya (2016), Gobu *et al*. (2017).

4.4.6.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on chlorophyll index (SPAD value) during the crop period.

4.4.7 Chlorophyll content (mg g^{-1})

Data on chlorophyll content for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 14 and graphically depicted in Fig.12.

4.4.7.1 Genotypes

The effect of genotypes on chlorophyll content found non-significant during all growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively.

4.4.7.2 Effect of drought stress

Drought stress significantly reduced leaf pigments like chlorophyll content, when imposed at flowering and fruit development stage; which was recorded at 60 and 90 days after transplanting respectively. When stress imposed at flowering stage, Chlorophyll content was significantly reduced to 1.70 mg g^{-1} as that of control treatments shown 2.79 mg g^{-1}. Similarly, during fruit development, plants in control shown Chlorophyll content of 2.45 mg g^{-1}whereas stressed plants showed 1.67 mg g^{-1}. When drought stress was imposed either at flowering or fruit development, Chlorophyll content was significantly lowered however it was observed more under controlled condition.

Table 13. Effect of drought stress imposed at different growth stages on chlorophyll index (SPAD value) of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor G : Genotypes				
G_1	Parbhani Tejas	47.83	44.25	42.03
G_2	Parbhani Mirchi	48.28	45.60	43.62
G_3	Phule Jyoti	47.16	44.05	42.57
G_4	Jayanti	47.26	42.99	41.42
G_5	Hirkani	46.85	42.36	40.25
G_6	Arka Lohit	44.83	43.37	41.34
G_7	Arka Suphal	43.60	42.33	40.88
G_8	Local Genotype	46.74	47.60	42.74
S.E ±		0.59	0.67	0.41
C.D at 1%		NS	NS	NS
Factor S : Stress Stages				
S_1	No stress	47.14	47.07	44.86
S_2	Stress at Flowering	46.26	39.20	42.55
S_3	Stress at Fruit development	46.31	45.94	38.15
S.E ±		0.22	0.25	0.16
C.D at 1%		NS	0.74	0.46
Interaction Effect (G X S)				
T01	G_1S_1	48.08	47.47	45.55
T02	G_1S_2	48.41	39.04	42.22
T03	G_1S_3	47.01	46.25	38.32
T04	G_2S_1	48.65	48.55	46.50
T05	G_2S_2	47.54	40.71	44.05
T06	G_2S_3	48.65	47.55	40.30
T07	G_3S_1	47.06	47.36	45.79
T08	G_3S_2	46.37	38.73	43.40
T09	G_3S_3	48.05	46.07	38.54
T10	G_4S_1	47.68	46.67	44.61
T11	G_4S_2	46.97	37.34	41.54
T12	G_4S_3	47.14	44.95	38.10
T13	G_5S_1	48.70	45.46	42.70
T14	G_5S_2	46.21	37.12	41.75
T15	G_5S_3	45.63	44.50	36.31
T16	G_6S_1	46.46	46.17	44.25
T17	G_6S_2	45.49	38.49	42.00
T18	G_6S_3	42.54	45.45	37.77
T19	G_7S_1	43.39	45.11	44.19
T20	G_7S_2	42.14	38.27	42.06
T21	G_7S_3	45.28	43.62	36.38
T22	G_8S_1	47.08	49.78	45.30
T23	G_8S_2	46.96	43.90	43.42
T24	G_8S_3	46.19	49.11	39.51
S.E ±		1.77	2.00	1.24
C.D at 1%		NS	NS	NS

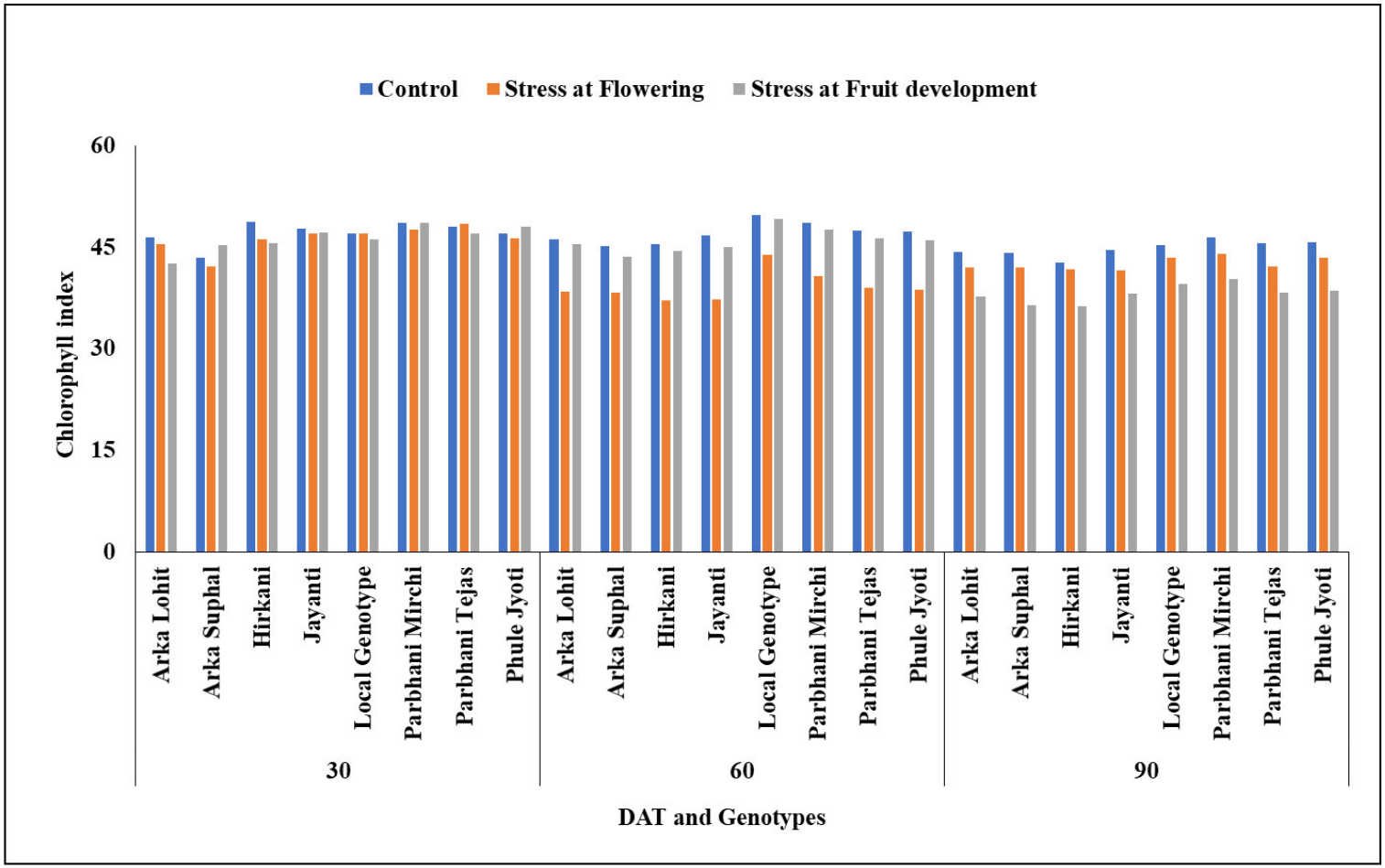


Fig. 11 Effect of drought stress imposed at different growth stages on chlorophyll index (SPAD value) of different chilli genotypes

Chlorophyll is one of the major chloroplast components for photosynthesis, and relative chlorophyll content has a positive relationship with photosynthetic rate. The decrease in chlorophyll content under drought stress has been considered a typical symptom of oxidative stress and may be the result of pigment photo-oxidation and chlorophyll degradation. Photosynthetic pigments are important to plants mainly for harvesting light and production of reducing powers. Both the chlorophyll a and b are prone to soil dehydration. Decreased or unchanged chlorophyll level during drought stress has been reported in many species, depending on the duration and severity of drought. Loss of chlorophyll contents under water stress is considered a main cause of inactivation of photosynthesis. Furthermore, water deficit induced reduction in chlorophyll content has been ascribed to loss of chloroplast membranes, excessive swelling, distortion of the lamellae vesiculation, and the appearance of lipid droplets. Low concentrations of photosynthetic pigments can directly limit photosynthetic potential and hence primary production. From a physiological perspective, leaf chlorophyll content is a parameter of significant interest in its own right. Studies by majority of chlorophyll loss in plants in response to water deficit occurs in the mesophyll cells with a lesser amount being lost from the bundle sheath cells. Above findings are in agreement with Kirnak *et al*. (2001), Guerfel *et al*.(2009), Isoda *et al*. (2010), Okunlola *et al*. (2017), Baghbani-Arani *et al*. (2017).

4.4.7.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on chlorophyll content during the crop period.

4.4.8 Proline content (mg g^{-1} f w)

Data on proline content for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 15 and graphically depicted in Fig.13.

4.4.8.1 Genotypes

The effect of genotypes on proline content found non-significant during all growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively.

Table 14. Effect of drought stress imposed at different growth stages on chlorophyll content (mg g^{-1}) of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor G : Genotypes				
G_1	Parbhani Tejas	2.26	2.33	2.16
G_2	Parbhani Mirchi	2.29	2.46	2.20
G_3	Phule Jyoti	2.30	2.32	2.02
G_4	Jayanti	2.25	2.45	2.15
G_5	Hirkani	2.24	2.34	2.10
G_6	Arka Lohit	2.24	2.41	2.20
G_7	Arka Suphal	2.25	2.31	1.98
G_8	Local Genotype	2.28	2.70	2.13
S.E ±		0.02	0.09	0.04
C.D at 1%		NS	NS	NS
Factor S : Stress Stages				
S_1	No stress	2.25	2.79	2.45
S_2	Stress at Flowering	2.28	1.70	2.23
S_3	Stress at Fruit development	2.27	2.74	1.67
S.E ±		0.01	0.03	0.01
C.D at 1%		NS	0.09	0.04
Interaction Effect (G X S)				
T01	G_1S_1	2.32	2.60	2.62
T02	G_1S_2	2.27	1.72	2.22
T03	G_1S_3	2.19	2.69	1.65
T04	G_2S_1	2.29	2.75	2.56
T05	G_2S_2	2.24	1.88	2.11
T06	G_2S_3	2.36	2.75	1.93
T07	G_3S_1	2.25	2.76	2.38
T08	G_3S_2	2.33	1.69	2.04
T09	G_3S_3	2.33	2.50	1.64
T10	G_4S_1	2.23	2.67	2.73
T11	G_4S_2	2.30	1.73	2.06
T12	G_4S_3	2.23	2.96	1.67
T13	G_5S_1	2.15	2.82	2.25
T14	G_5S_2	2.27	1.69	2.46
T15	G_5S_3	2.31	2.50	1.58
T16	G_6S_1	2.29	2.94	2.44
T17	G_6S_2	2.14	1.60	2.51
T18	G_6S_3	2.28	2.69	1.64
T19	G_7S_1	2.27	2.63	2.31
T20	G_7S_2	2.33	1.59	2.16
T21	G_7S_3	2.16	2.70	1.48
T22	G_8S_1	2.17	3.19	2.32
T23	G_8S_2	2.34	1.73	2.31
T24	G_8S_3	2.32	3.16	1.77
S.E ±		0.05	0.26	0.11
C.D at 1%		NS	NS	NS

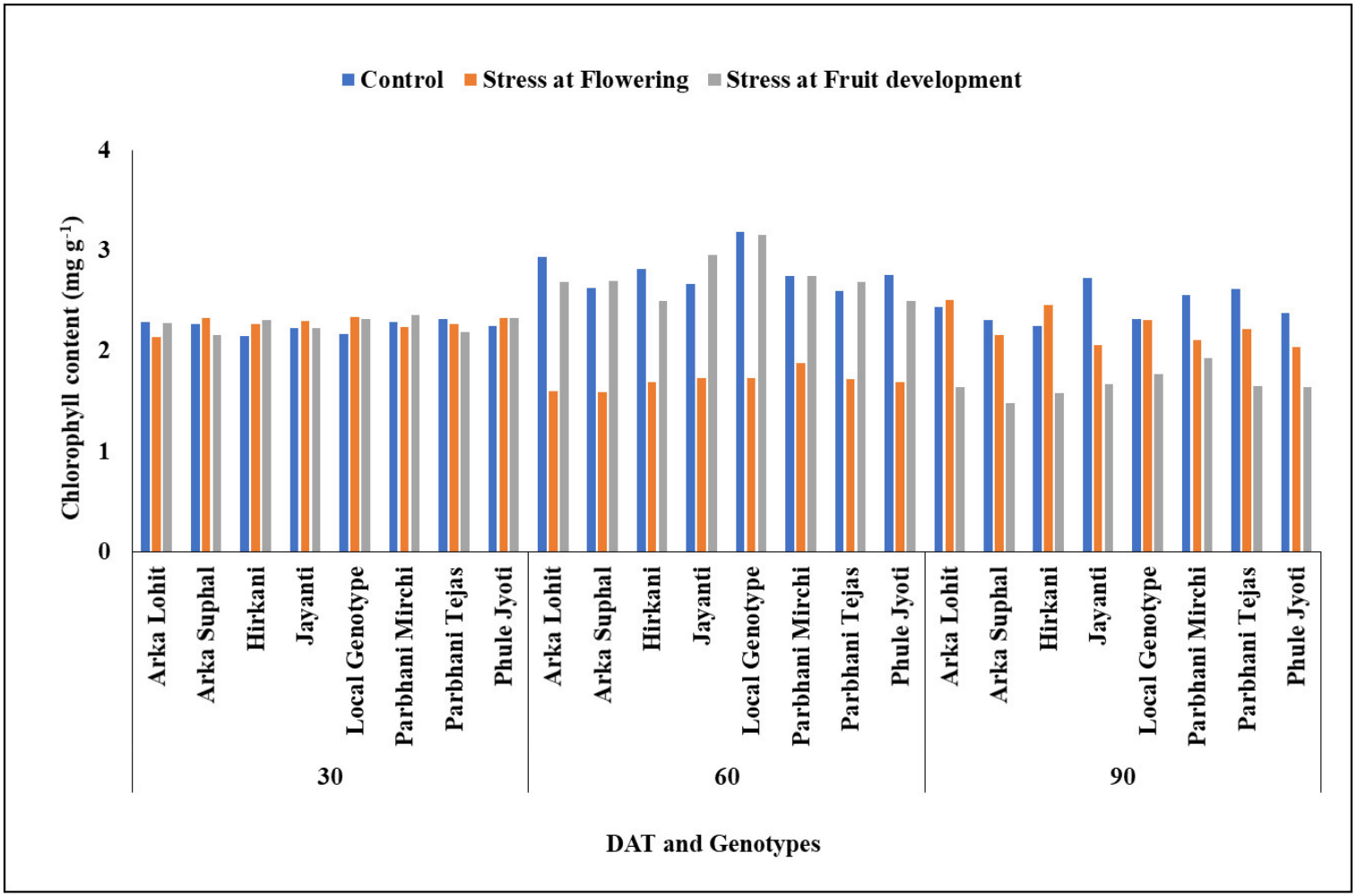


Fig. 12 Effect of drought stress imposed at different growth stages on chlorophyll content (mg g^{-1}) of different chilli genotypes

4.4.8.2 Effect of drought stress

Drought stress significantly increased proline content, when imposed at flowering and fruit development stage; which was recorded at 60 and 90 days after transplanting respectively. When stress imposed at flowering stage, Proline content was significantly increased to 0.31 mg g^{-1}fw as that of control treatments shown 0.14 mg g^{-1} f w. Similarly, during fruit development, plants in control showed Proline content of 0.14 mg g^{-1}f w whereas stressed plants showed 0.32 mg g^{-1} f w. When drought stress was imposed either at flowering or fruit development, Proline content was significantly raised however it was observed less under controlled condition.

Plants accumulate different types of organic and inorganic solutes in the cytosol to lower osmotic potential thereby maintaining cell turgor. Under drought, the maintenance of leaf turgor may also be achieved by the way of osmotic adjustment in response to the accumulation of proline, sucrose, soluble carbohydrates, glycinebetaine, and other solutes in cytoplasm improving water uptake from drying soil. The process of accumulation of such solutes under drought stress is known as osmotic adjustment which strongly depends on the rate of plant water stress. Proline accumulation is the first response of plants exposed to water-deficit stress in order to reduce injury to cells. Proline can act as a signaling molecule to modulate mitochondrial functions, influence cell proliferation or cell death and trigger specific gene expression, which can be essential for plant recovery from stress. Accumulation of proline under stress in many plant species has been correlated with stress tolerance, and its concentration has been shown to be generally higher in stress-tolerant than in stress-sensitive plants. It influences protein solvation and preserves the quaternary structure of complex proteins, maintains membrane integrity under dehydration stress and reduces oxidation of lipid membranes or photoinhibition. Additionally, it also contributes to stabilizing sub-cellular structures, scavenging free radicals, and buffering cellular redox potential under stress conditions. Hence, above findings are in agreement with Budiyati Ichwan *et al*. (2017), Khan *et al*. (2012) and Lakshmi *et al*. (2015) in chilli, Sivakumar *et al*. (2014) in tomato.

4.4.8.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on proline accumulation during the crop period.

Table 15. Effect of drought stress imposed at different growth stages on proline content (mg g^{-1} f w) of different chilli genotypes

Treatment No.	Treatment details	30 DAT	60 DAT	90 DAT
Factor G : Genotypes				
G_1	Parbhani Tejas	0.090	0.201	0.236
G_2	Parbhani Mirchi	0.095	0.201	0.239
G_3	Phule Jyoti	0.086	0.199	0.236
G_4	Jayanti	0.091	0.198	0.232
G_5	Hirkani	0.090	0.196	0.233
G_6	Arka Lohit	0.091	0.196	0.220
G_7	Arka Suphal	0.091	0.197	0.219
G_8	Local Genotype	0.094	0.198	0.222
S.E ±		0.0009	0.0010	0.0024
C.D at 1%		NS	NS	NS
Factor S : Stress Stages				
S_1	No stress	0.091	0.14	0.14
S_2	Stress at Flowering	0.092	0.31	0.23
S_3	Stress at Fruit development	0.090	0.14	0.32
S.E ±		0.00034	0.0004	0.0009
C.D at 1%		NS	0.0011	0.0027
Interaction Effect (G X S)				
T01	G_1S_1	0.0905	0.1437	0.1403
T02	G_1S_2	0.0926	0.3188	0.2333
T03	G_1S_3	0.0879	0.1408	0.3358
T04	G_2S_1	0.0958	0.1402	0.1412
T05	G_2S_2	0.0954	0.3196	0.2393
T06	G_2S_3	0.0943	0.1445	0.3353
T07	G_3S_1	0.0879	0.1405	0.1488
T08	G_3S_2	0.0888	0.3167	0.2340
T09	G_3S_3	0.0813	0.1389	0.3253
T10	G_4S_1	0.0865	0.1393	0.1401
T11	G_4S_2	0.0932	0.3119	0.2395
T12	G_4S_3	0.0918	0.1413	0.3175
T13	G_5S_1	0.0900	0.1402	0.1455
T14	G_5S_2	0.0897	0.3082	0.2245
T15	G_5S_3	0.0913	0.1394	0.3280
T16	G_6S_1	0.0908	0.1415	0.1462
T17	G_6S_2	0.0903	0.3035	0.2096
T18	G_6S_3	0.0915	0.1419	0.3046
T19	G_7S_1	0.0904	0.1463	0.1375
T20	G_7S_2	0.0917	0.3011	0.2235
T21	G_7S_3	0.0905	0.1428	0.2969
T22	G_8S_1	0.0923	0.1415	0.1472
T23	G_8S_2	0.0939	0.3084	0.2198
T24	G_8S_3	0.0951	0.1429	0.2975
S.E ±		0.003	0.0029	0.0073
C.D at 1%		NS	NS	NS

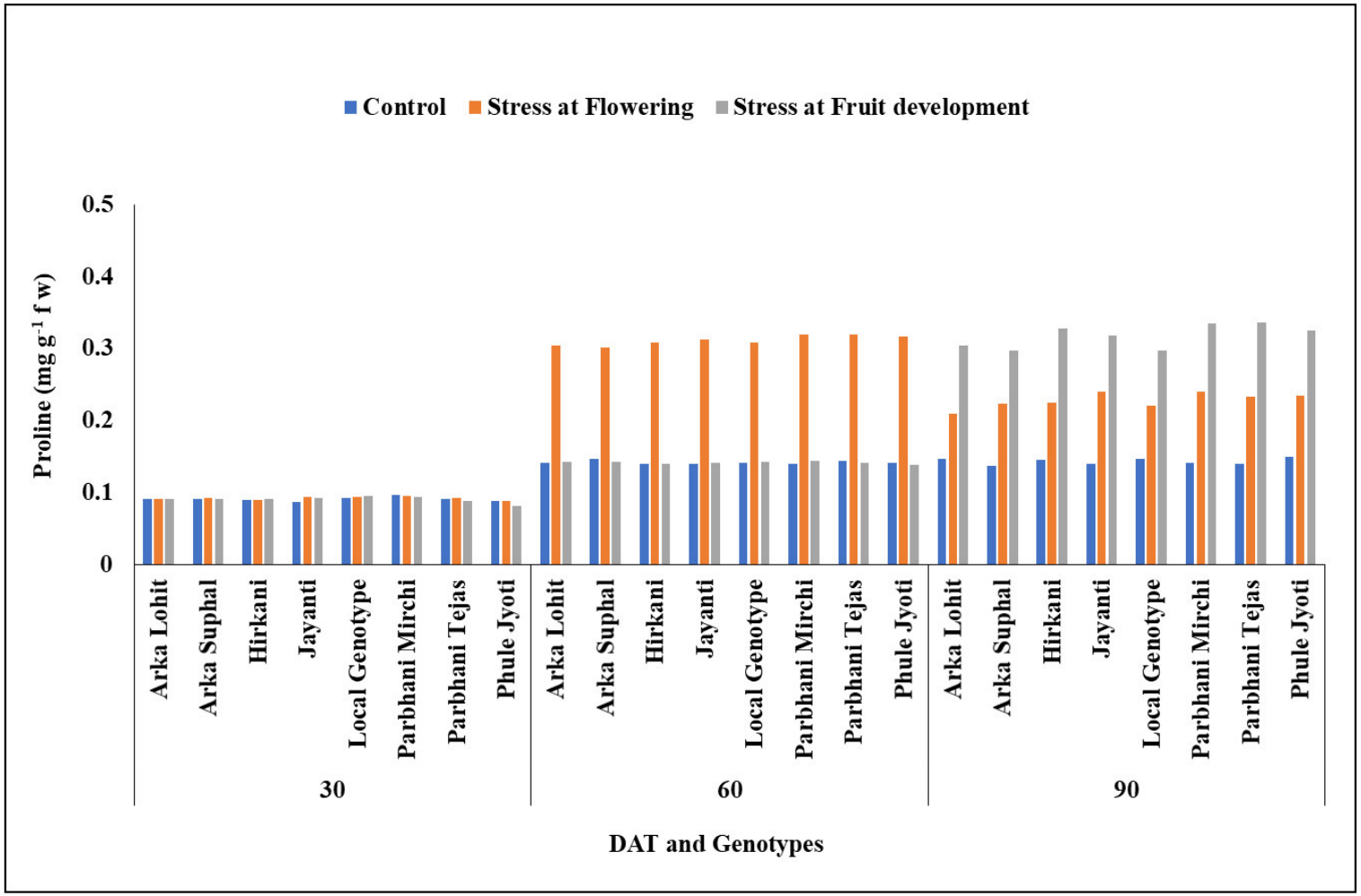


Fig. 13 Effect of drought stress imposed at different growth stages on proline content (mg g^{-1} f w) different chilli genotypes

4.5 Flowering parameters

4.5.1 Days to initiate first flower

4.5.1.1 Genotypes

The effect of genotypes on flower initiation found non-significant during crop period.

4.5.1.2 Effect of drought stress

Effect of drought stress which was imposed at flowering and fruit development stage found non-significant for flower initiation.

4.5.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on flower initiation during the crop period.

4.5.2 Flower drop (%)

Data on flower drop for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 16 and graphically depicted in Fig.14.

4.5.2.1 Genotypes

The effect of genotypes on flower drop found significant during crop period. Genotypes differed significantly for flower drop amongst themselves. Hirkani (44.86%) shown highest flower drop percent, followed by Arka Suphal (42.20%) and Arka Lohit (42.08%) whereas Parbhani Mirchi shown least flower drop (33.51%). However, Phule Jyoti and Local Genotype found at par with each other.

The mean performances of selected genotypes for flower drop indicated that the high range of variability amongst genotypes, which was recorded to study the performance of particular genotypes under particular region. Environment appeared to play an important role in expression of genotypes, regarding flower drop and other phenological parameters. And hence, above results were found in agreement with Phimchan *et al*. (2012) in chilli, Sivakumar *et al*. (2014) and Sivakumar and Srividhya (2016) in tomato.

4.5.2.2 Effect of drought stress

Effect of drought stress which was imposed at flowering and fruit development stage found significant for flower drop. Drought stress significantly

increased flower drop percent as compared control. Drought stress imposed at flowering and fruit development stage, showed 65.17% and 35.62% flower drop respectively; however plants under control treatment showed 17.45% flower drop.

Due to lowered water potential in plants, under drought conditions, flowers couldn't get enough water to carry further developmental processes. Along with this, water scarcity might leads to drying of stigmatic fluid, which adversely affected pollination and this resulted into poor pollination. And due to poor pollination, flower drop occurred. Flower drop can clearly explain about marketable yield of plant. Above findings are on agreement with Ferrara *et al*. (2011), Phimchan *et al*. (2012) in chillil, R. Sivakumar *et al*. (2014) and Sivakumar and Srividhya (2016) in tomato.

4.5.2.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on flower drop during the crop period.

4.6 Fruiting parameters

4.6.1 Days to initiate first fruit

4.6.1.1 Genotypes

The effect of genotypes on fruit initiation was found non-significant during crop period.

4.6.1.2 Effect of drought stress

Effect of drought stress which was imposed at flowering and fruit development stage found significant for fruit initiation. Fruit setting was initiated early in plants which were subjected to drought stress, imposed at flowering stage (78.02). However, plants under controlled treatment started fruiting after 80.73 days of transplanting.

Reproduction is the crucial stage to be affected by any abiotic stress in any crop. Imposed drought at flowering stage accelerates fruit development. This early fruit development might be due to rapid phenological development in order to complete the life cycle under unfavorable environmental conditions ~~(Srivastava *et al*., 2012)~~. Above results are supported by Rao and Padma (1991), Showemimo *et al*. (2007) in eggplant, Sivakumar and Srividhya (2016) in tomato.

Table 16. Effect of drought stress imposed at different growth stages on flowering parameters of different chilli genotypes

Treatment No.	Treatment details	Days to initiate first flower	Flower drop (%)
Factor A : Genotypes (G)			
G_1	Parbhani Tejas	56.72	36.19 (21.58)
G_2	Parbhani Mirchi	57.37	33.51 (19.9)
G_3	Phule Jyoti	57.75	36.85 (21.99)
G_4	Jayanti	57.42	42.03 (25.23)
G_5	Hirkani	57.67	44.86 (27.1)
G_6	Arka Lohit	57.10	42.08 (25.23)
G_7	Arka Suphal	57.25	42.20 (25.39)
G_8	Local Genotype	57.27	37.58 (22.45)
S.E ±		0.30	0.46
C.D at 1%		NS	1.30
Factor B : Stress Stages (S)			
S_1	No stress	57.72	17.45 (10.21)
S_2	Stress at Flowering	56.90	65.17 (41.37)
S_3	Stress at Fruit development	57.33	35.62 (21.22)
S.E ±		0.111	0.17
C.D at 1%		NS	0.49
Interaction Effect (G X S)			
T01	G_1S_1	57.00	15.33 (8.96)
T02	G_1S_2	56.66	60.70 (38.02)
T03	G_1S_3	56.50	32.54 (19.32)
T04	G_2S_1	58.00	13.60 (7.95)
T05	G_2S_2	57.10	58.92 (36.73)
T06	G_2S_3	57.00	28.01 (16.55)
T07	G_3S_1	57.75	15.55 (9.01)
T08	G_3S_2	57.75	64.49 (40.85)
T09	G_3S_3	57.75	30.51 (18.07)
T10	G_4S_1	57.75	20.97 (12.31)
T11	G_4S_2	57.25	67.64 (43.30)
T12	G_4S_3	57.25	37.5 (22.40)
T13	G_5S_1	57.75	21.92 (12.88)
T14	G_5S_2	57.25	71.85 (46.73)
T15	G_5S_3	58.00	40.81 (24.52)
T16	G_6S_1	57.75	17.69 (10.36)
T17	G_6S_2	57.04	65.79 (41.85)
T18	G_6S_3	56.50	42.77 (25.76)
T19	G_7S_1	57.75	17.46 (10.22)
T20	G_7S_2	56.00	69.94 (44.14)
T21	G_7S_3	58.00	39.21 (23.49)
T22	G_8S_1	58.00	17.10 (10.01)
T23	G_8S_2	56.18	62.03 (38.99)
T24	G_8S_3	57.63	33.61 (19.97)
S.E ±		0.89	1.39
C.D at 1%		NS	NS

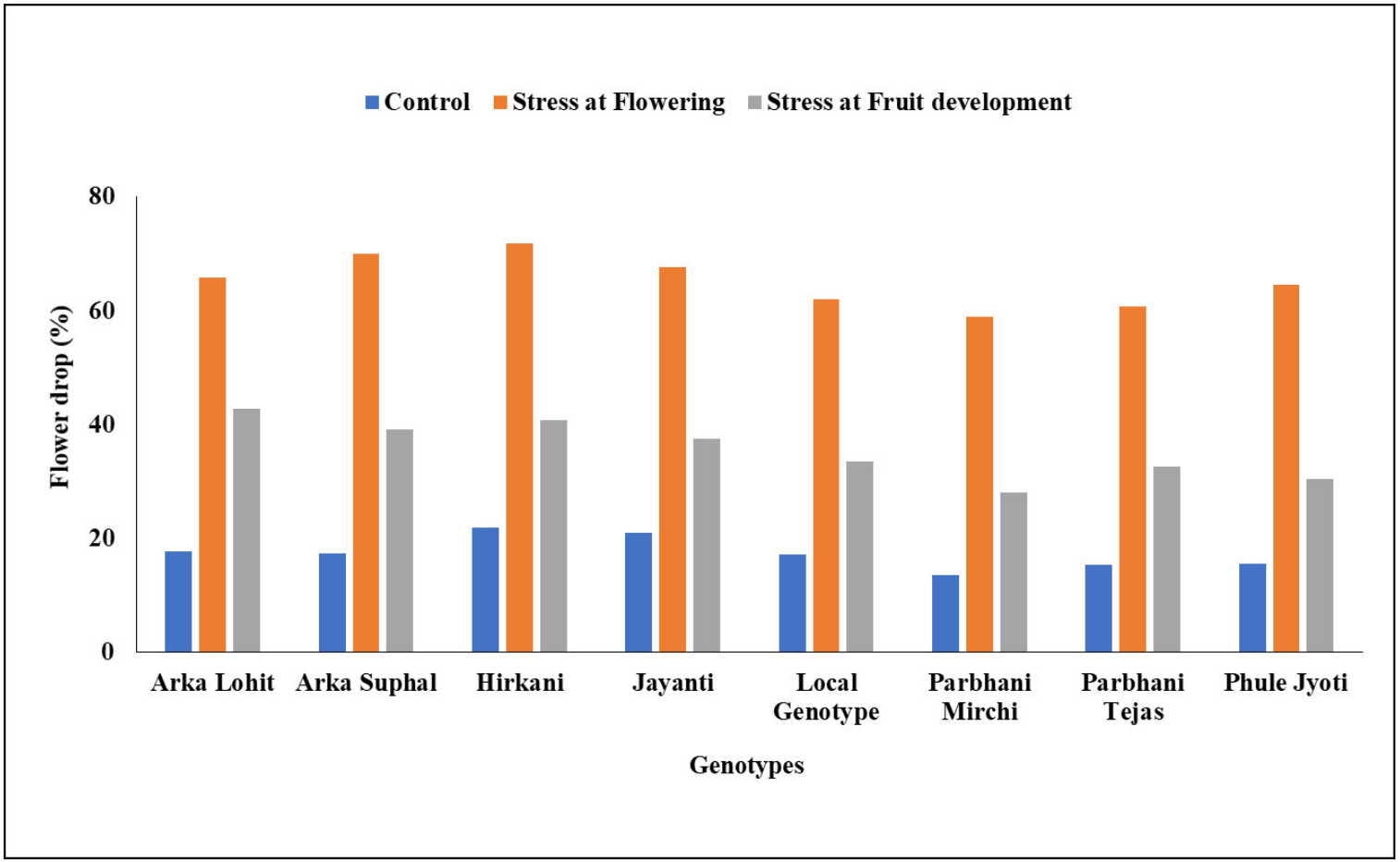


Fig. 14 Effect of drought stress imposed at different growth stages on flower drop (%) of different chilli genotypes

4.6.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on fruit initiation during the crop period.

4.6.2 Number of fruits per plant

Data on number of fruits per plant for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 17 and graphically depicted in Fig.15.

4.6.2.1 Genotypes

Genotypes differed significantly amongst themselves in production of fruits per plant. Genotype - Parbhani Mirchi (54.97) produced maximum numbers of fruits per plant followed by Parbhani Tejas (52.11) and Phule Jyoti (51.47); however Hirkani (44.82) showed lowest numbers of fruits per plant amongst all genotypes. While remaining genotypes were found to be at par with each other.

It is interpreted that the variation in fruit production per plant in the experiment was mainly because of genetic variation. This variation is due to different physiological responses under different regions. Similar observations were recorded in drought experiments conducted by Sivakumar *et al*. (2014) in eighteen genotypes of tomato, Lakshmi *et al.* (2015) in eleven varieties of chilli, Khan *et al*. (2008), in two cultivars of chilli.

4.6.2.2 Effect of drought stress

Effect of drought stress which was imposed at flowering and fruit development stage was found significant for number of fruits per plant. Production of fruits was decreased in plants which were subjected to drought stress, imposed at both flowering (29.83) and fruit development stage (51.28). However, plants under controlled treatment produced 67.84 fruits per plant.

When drought stress imposed at flowering stage, majority flower were dropped down; hence, there would very less fruit setting was observed. Furthermore, plants subjected to drought stress at fruit development stage, adversely affected the fruits; by hindering their further developmental processes from tiny fruitlets to matured fruits. Similar results were given by Sivakumar *et al*. (2014) in tomato, Khan *et al*. (2008) in chilli, Showemimo *et al*. (2007) in sweet pepper.

Table 17. Effect of drought stress imposed at different growth stages on fruiting parameters of different chilli genotypes

Treatment No.	Treatment details	Days to initiate first fruit	No. of fruits per plant
Factor G : Genotypes			
G_1	Parbhani Tejas	79.29	52.11
G_2	Parbhani Mirchi	79.46	54.97
G_3	Phule Jyoti	79.88	51.47
G_4	Jayanti	79.46	48.37
G_5	Hirkani	79.29	44.82
G_6	Arka Lohit	78.79	48.10
G_7	Arka Suphal	79.88	46.07
G_8	Local Genotype	80.50	50.10
S.E ±		0.30	0.52
C.D at 1%		NS	1.54
Factor S : Stress Stages			
S_1	No stress	80.73	67.84
S_2	Stress at Flowering	78.02	29.38
S_3	Stress at Fruit development	79.95	51.28
S.E ±		0.113	0.20
C.D at 1%		0.316	0.58
Interaction Effect (G X S)			
T01	G_1S_1	81.63	68.82
T02	G_1S_2	76.25	32.00
T03	G_1S_3	80.00	55.50
T04	G_2S_1	81.38	72.42
T05	G_2S_2	77.63	34.00
T06	G_2S_3	79.38	58.47
T07	G_3S_1	80.63	68.60
T08	G_3S_2	77.38	31.00
T09	G_3S_3	81.63	54.81
T10	G_4S_1	80.63	66.11
T11	G_4S_2	78.50	29.00
T12	G_4S_3	79.25	50.00
T13	G_5S_1	81.63	65.50
T14	G_5S_2	76.25	25.00
T15	G_5S_3	80.00	43.95
T16	G_6S_1	80.38	67.29
T17	G_6S_2	77.50	28.00
T18	G_6S_3	78.50	49.00
T19	G_7S_1	79.63	66.58
T20	G_7S_2	80.00	26.00
T21	G_7S_3	80.00	45.64
T22	G_8S_1	80.00	67.43
T23	G_8S_2	80.63	30.00
T24	G_8S_3	80.88	52.88
S.E ±		0.90	1.56
C.D at 1%		NS	NS

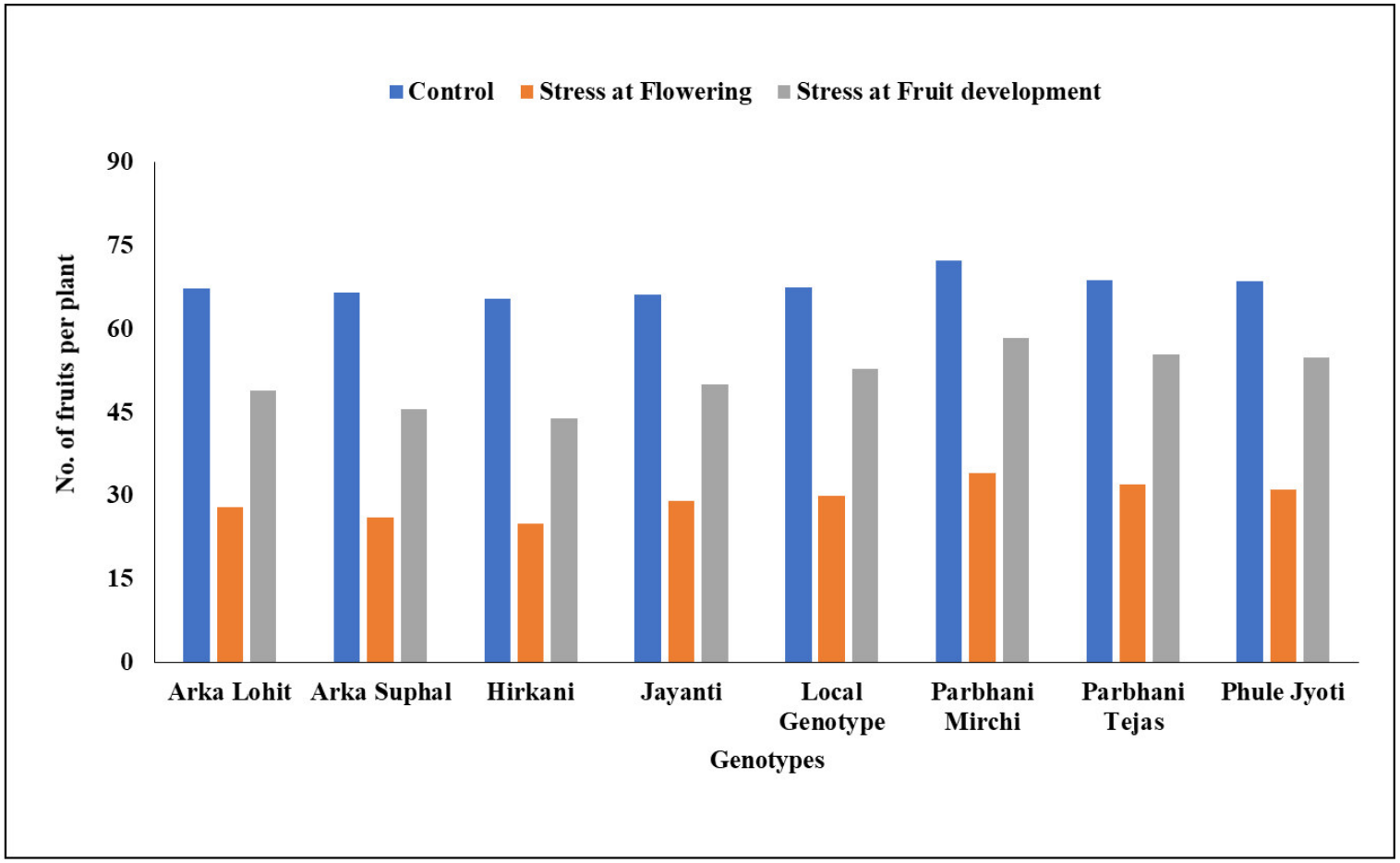


Fig. 15 Effect of drought stress imposed at different growth stages on number of fruits per plant of different chilli genotypes

4.6.2.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages found non-significant on number of fruits per plant during the crop period.

4.7. Yield parameters

Data on yield parameters for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 18 and graphically depicted in Fig.16,17 and 18.

4.7.1 Number of pickings

4.7.1.1 Genotypes

The effect of genotypes on number of pickings was found to be non-significant throughout the life cycle.

4.7.1.2 Effect of drought stress

Drought stress significantly reduced number of pickings. Plants subjected to drought stress at flowering showed 3.89 while plants under drought stress imposed at fruit development showed 5.41 pickings across the harvesting span. However plants under controlled conditions given 7.00 pickings, which were more than that of plants under stressed conditions.

Plants under drought stress, imposed at different growth stages shown decreased fruit production as compared to controlled condition. Plants which were subjected to stress at flowering, produced very less numbers of fruits which resulted into very less number of pickings. Because, soil moisture depleted at flowering stage, initiate flower abscission due to accumulation of ABA and ethylene in plants, which are responsible for heavy flower drop in plants. And hence, in this stress treatment plants failed to produce enough numbers of fruits. In addition, plants under stress at fruit development, attributed with malformed or under developed fruit formation, sometimes fruitlets under this treatment fall down pre-maturely because of moisture scarcity; therefore, such treatment of imposing drought stress at fruit development stage, presented less numbers of pickings as compared to controlled plants. Similar results were observed by Rao and Padma (1991) in tomato, Kirnak *et al* (2002), in eggplant cv. Pala, Dorji *et al* (2005) in chilli cv. Ancho St. Luis.

4.7.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages was found to be non-significant on number of pickings across the harvesting span.

4.7.2 Fruit yield per plant (g)

4.7.2.1 Genotypes

Genotypes differed significantly amongst themselves in fruit yield per plant. Genotype - Parbhani Mirchi (189.55 g) given maximum fruit yield per plant followed by Parbhani Tejas (169.20 g) and Phule Jyoti (162.14 g); however Arka Suphal (116.44 g) given lowest fruit yield per plant amongst all genotypes. While remaining genotypes were found to be at par with each other.

It is interpreted that the variation in fruit yield per plant in the experiment was mainly because of genetic variation. This variation is due to different physiological responses of plants like Relative Water Content, which represents water potential of leaves, ultimately it indicates the health and ability to carry out different metabolic activities; which are essential to produce yield. Similar observations were recorded in drought experiments, conducted by Sivakumar *et al*. (2014) in eighteen genotypes of tomato, Lakshmi SU and Krishna MSR (2015) in eleven varieties of chilli, Khan *et al*. (2008), in two cultivars of chilli, Rezaei *et al*. (2014), in ten hybrid lines of garden pea.

4.7.2.2 Effect of drought stress

Drought stress significantly reduced fruit yield per plant. Plants subjected to drought stress at flowering stage given yield of 79.59 g per plant which was lowest among the selected set of stress treatments while plants under drought stress imposed at fruit development given 147.78 g of yield per plant which stood intermediate. However plants under controlled conditions given highest yield 207.85 g, which were more than that of plants under stressed conditions.

Yield is basically the complex integration of the different physiological processes. Most of these physiological processes are negatively affected by the drought stress. The negative impacts of drought on the yield mainly depend upon the severity of the stress and the plant growth stage. Plants which are subjected drought stress at reproductive stage – flowering stage, attributed with maximum flower drop percent, which ultimately turned out to be very susceptible stage, giving lowest fruit yield. The apparent marked reduction in fruit yield could be attributed to restricted

fruit set caused by dehydration and reduced assimilate partitioning (Farooq *et al* 2009b). Along with this, plants subjected for drought at fruit development stage, showed pre mature fruit drop due to moisture scarcity or despite of that fruits were developed, they would show malformed morphological appearance, which not be preferred in market. Above findings are supported by Rezaei et al. (2014) in ten hybrid lines of pea, Kirnak *et al*., (2001) in eggplant, Nahar *et al*. (2011) in tomato, Khan *et al*. (2008) in chilli, Sivakumar *et al*. (2014) in tomato.

4.7.2.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages was found to be non-significant on fruit yield per plant across the harvesting span.

4.7.3 Percent reduction in yield due to drought stress (%)

4.7.3.1 Genotypes

Effect of genotypes was found to be significant on percent reduction in yield due to drought stress. Genotypes - Parbhani Tejas (72.21%) and Parbhani Mirchi (72.21%) produced maximum yield, indicating reduction of 27.79% for both, which were minimum as compared loss occurred in remaining genotypes. Parbhani Mirchi and Parbhani Tejas were followed by Phule Jyoti (71.38%) and Local Genotype (70.77%). However, minimum percentage of yield was observed in Arka Suphal (64.91%) and Hirkani (65.74%), indicating maximum reduction up to 35.09% and 34.26% respectively. Genotypes –Phule Jyoti and Local Genotype was found to be at par with each other.

It is understood that the variation in percent reduction of fruit yield in the experiment was mainly because of genetic variation. This variation is due to different physiological responses of plants like Relative Water Content and others, which represents water potential of leaves, ultimately it indicates the health and ability to carry out different metabolic activities; which are essential to produce yield. Similar observations were recorded in drought experiments, conducted by Kirnak *et al*., (2001) in eggplant; Nahar *et al*. (2011) in tomato.

4.7.3.2 Effect of drought stress

Drought stress significantly increased the percent reduction in fruit yield. Treatment of regular watering *i.e.*, no stress (control) has given optimum yield that

would be considered as 100% in each genotype. While plants subjected to drought stress imposed at flowering and fruit development stage has reported percent yield of 37.94% and 70.66% yield respectively as compared to control. From this, it is revealed that plants subjected to flowering stage, showed maximum percent reduction in yield that is up to 62%.

Drought stress imposed at any growth stage, adversely affect the physiological processes of plants, which leads to poor growth and development in plants. Stressed plants poorly perform photosynthesis and other necessary processes which ultimately results into decreased yield of plant. Plants which are subjected drought stress at reproductive stage – flowering stage, attributed with maximum flower drop percent, which ultimately turned out to be very susceptible stage, giving lowest fruit yield. Along with this, plants subjected for drought at fruit development stage, showed pre mature fruit drop due to moisture scarcity. And hence, above findings are supported by Kirnak *et al*. (2001) in eggplant where he reported drought reduced yield by 68%; Nahar *et al*. (2011) in tomato, where he reported 50% yield loss due to drought.

4.7.3.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages was found to be non-significant on percent reduction in yield due to drought stress.

4.7.4 Total yield (t ha^{-1})

4.7.4.1 Genotypes

Effect of genotypes was found to be significant on total yield. Parbhani Mirchi (7.02 t ha^{-1}) gave maximum yield which was followed by Parbhani Tejas (6.27t ha^{-1}) and Phule Jyoti (6.01 t ha^{-1}). Whereas Arka Suphal (4.31 t ha^{-1}) given lowest yield amongst all, while remaining genotypes was found at par with each other.

Variation in yield indicated the high range of genetic variability amongst genotypes, which was recorded to study the performance of particular genotypes under particular region. Environment appeared to play an important role in expression of genotypes, regarding yield and yield contributing attributes. And hence, above results are found in agreement with Khan *et al.* (2008) in chilli; Sivakumar R. and Srividhya S. (2016) in tomato.

4.7.4.2 Effect of drought stress

Drought stress significantly decreased the total yield. Plants under no stress condition given optimum yield of 7.70 t ha^{-1} however stress at flowering and fruit development reduced yield, up to 2.95 t ha^{-1} and 5.47 t ha^{-1} respectively.

Depleting soil water level confined the productivity of plant by hampering its growth and development. Reduced soil moisture level might be responsible for creating drought like situations. And under this type of situation, plants failed to perform all obligatory activities like photosynthesis. And hence, the drought stress is found to be the major limiting factor of yield. Plants which are subjected drought stress at reproductive stage – flowering stage, showed maximum flower drop percent, because of poor pollination and poor fertilization as well, which ultimately turned out to be very susceptible stage, giving lowest fruit yield. Along with this, plants subjected for drought at fruit development stage, showed pre mature fruit drop due to moisture scarcity. And hence, above findings are supported by Vijay *et al*. (1979) in chilli; K. Dorji *et.al* (2004) in chilli cv. Ancho St. Luis; Showemimo *et al*. (2007), in sweet pepper cv. L5962-2.

4.7.4.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages was found to be non-significant on total yield.

4.8. Fruit parameters

Data on fruit parameters for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 19 and graphically depicted in Fig.19, 20.

4.8.1 Fruit weight (g)

4.8.1.1 Genotypes

The effect of genotypes on weight of single fruit was found to be significant. Single fruit of genotype - Parbhani Mirchi showed maximum weight of 3.41 g which was followed by fruit of Parbhani Tejas (3.19 g) and Phule Jyoti (3.11 g). Lowest weight of single fruit was observed in genotype – Arka Suphal (2.45 g). Genotypes – Jayanti, Hirkani, Arka Suphal, Arka Lohit was found to be at par with each other.

Variation in single fruit weight indicated the high range of genetic variability amongst genotypes, which was recorded to study the performance of particular genotypes under particular region. Environment appeared to play an important role in

expression of genotypes, in concern with different fruit morphological characters. And hence, above results are found in agreement with Techawongstien *et al*. (1992) in fifteen cultivars of chilli; Khan *et al*. (2008) in two chilli cultivars.

4.8.1.2 Effect of drought stress

Drought stress significantly reduced weight of single fruit. Weight of single fruit of plants, which were subjected to drought stress at flowering stage showed 2.68 g while fruit of plants under drought stress imposed at fruit development showed 2.86 g. However fruit of plants under controlled condition, weighed up to 3.05 g, which was more than that of fruit developed under stressed conditions.

Stressed plants, having lower water potentials than the plants under control treatment, would be expected to produce fruits of less fresh weight. However, the specific mechanism of fruit fresh weight reduction is unclear. Apoplastic water status strongly influences water flow in the phloem. The water potential gradient between the fruit and the plant controls phloem-driven expansive growth of particular fruit (Johnson *et al*. 1992). In this study, the reduced water potential of the stressed treatment plants may have reduced the driving force for water flow into the fruit. These processes require carbohydrates, and apparently restricted carbohydrate supply of the water-stressed plants would further decrease ability of fruit to accumulate water. And hence, it finally resulted in to lowered weight of individual fruit. Above results are supported by Ferrara *et al.* (2011) in Capsicum cv. Peppone; Kirnak *et. al* (2002) in eggplant cv. Pala; Gunawardena *et al*. (2014) in chilli cv. MI2.

4.8.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages was found to be non-significant on weight of single fruit.

4.8.2 Fruit length (cm)

4.8.2.1 Genotypes

The effect of genotypes on length of single fruit was found to be non-significant.

4.8.2.2 Effect of drought stress

Drought stress significantly reduced length of single fruit. Plants, which were subjected to drought stress at fruit development stage (4.73cm) produced shortest fruits, while plants under drought stress imposed at flowering, produced fruits of

Table18. Effect of drought stress imposed at different growth stages on yield parameters of different chilli genotypes

Treatment No.	Treatment details	Number of pickings	Fruit yield per plant(g)	Reduction in yield (%)	Total yield per ha(t ha^{-1})
Factor G : Genotypes					
G_1	Parbhani Tejas	5.50	169.20	72.21 (46.23)	6.27
G_2	Parbhani Mirchi	5.46	189.55	72.21 (46.23)	7.02
G_3	Phule Jyoti	5.58	162.14	71.38 (45.55)	6.01
G_4	Jayanti	5.42	130.83	69.22 (43.80)	4.85
G_5	Hirkani	5.21	119.97	65.74 (41.10)	4.44
G_6	Arka Lohit	5.21	119.65	69.83 (44.29)	4.43
G_7	Arka Suphal	5.46	116.44	64.91 (40.47)	4.31
G_8	Local Genotype	5.63	152.81	70.77 (45.05)	5.66
S.E ±		0.06	1.93	0.71	0.07
C.D at 1%		NS	5.70	2.10	0.21
Factor S : Stress Stages					
S_1	No stress	7.00	207.85	100 (90)	7.70
S_2	Stress at Flowering	3.89	79.59	37.94 (22.30)	2.95
S_3	Stress at Fruit development	5.41	147.78	70.66 (44.96)	5.47
S.E ±		0.02	0.72	0.27	0.027
C.D at 1%		0.07	2.14	0.79	0.079
Interaction Effect (G X S)					
T01	G_1S_1	7.00	234.69	100 (90)	8.69
T02	G_1S_2	3.88	93.36	39.82 (23.46)	3.46
T03	G_1S_3	5.63	179.55	76.81 (50.19)	6.65
T04	G_2S_1	7.00	262.59	100 (90)	9.73
T05	G_2S_2	4.50	111.08	42.33 (25.05)	4.11
T06	G_2S_3	4.88	194.99	74.30 (47.98)	7.22
T07	G_3S_1	7.00	227.15	100 (90)	8.41
T08	G_3S_2	3.88	91.14	40.10 (23.64)	3.38
T09	G_3S_3	5.88	168.11	74.05 (47.78)	6.23
T10	G_4S_1	7.00	189.02	100 (90)	7.00
T11	G_4S_2	4.00	72.02	38.08 (22.38)	2.67
T12	G_4S_3	5.25	131.46	69.58 (44.09)	4.87
T13	G_5S_1	7.00	182.49	100 (90)	6.76
T14	G_5S_2	3.50	60.26	33.02 (19.28)	2.23
T15	G_5S_3	5.13	117.15	64.20 (39.94)	4.34
T16	G_6S_1	7.00	171.31	100 (90)	6.34
T17	G_6S_2	3.38	66.66	39.01 (22.96)	2.47
T18	G_6S_3	5.25	120.97	70.48 (44.82)	4.48
T19	G_7S_1	7.00	179.43	100 (90)	6.65
T20	G_7S_2	3.63	55.67	31.04 (18.09)	2.06
T21	G_7S_3	5.75	114.22	63.69 (39.56)	4.23
T22	G_8S_1	7.00	216.09	100 (90)	8.00
T23	G_8S_2	4.38	86.56	40.11 (23.64)	3.21
T24	G_8S_3	5.50	155.77	72.20 (46.22)	5.77
S.E ±		0.19	5.79	2.14	0.21
C.D at 1%		NS	NS	NS	NS

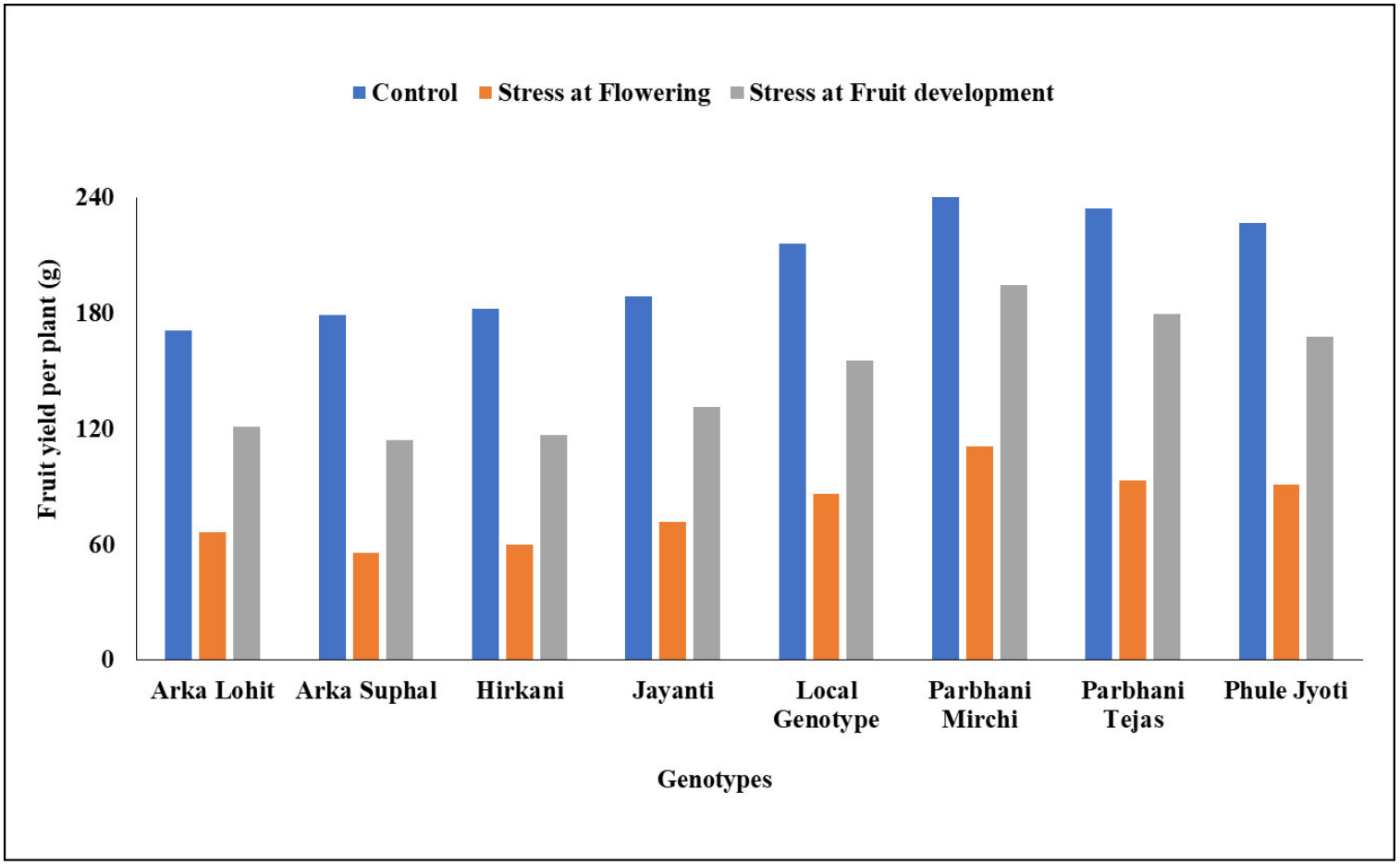


Fig. 16 Effect of drought stress imposed at different growth stages on fruit yield per plant (g) of different chilli genotypes

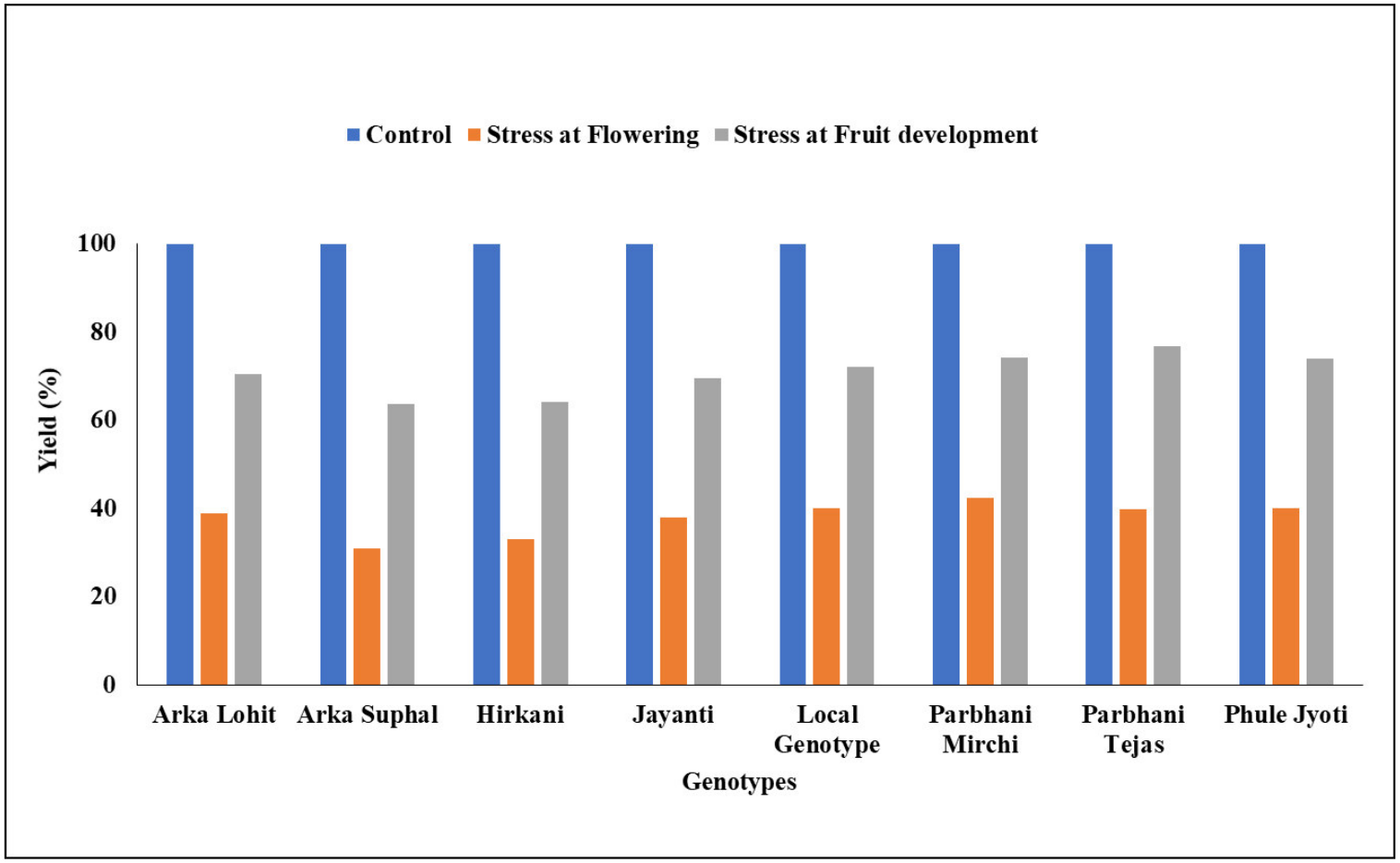


Fig. 17 Effect of drought stress imposed at different growth stages on percent reduction in yield of different chilli genotypes

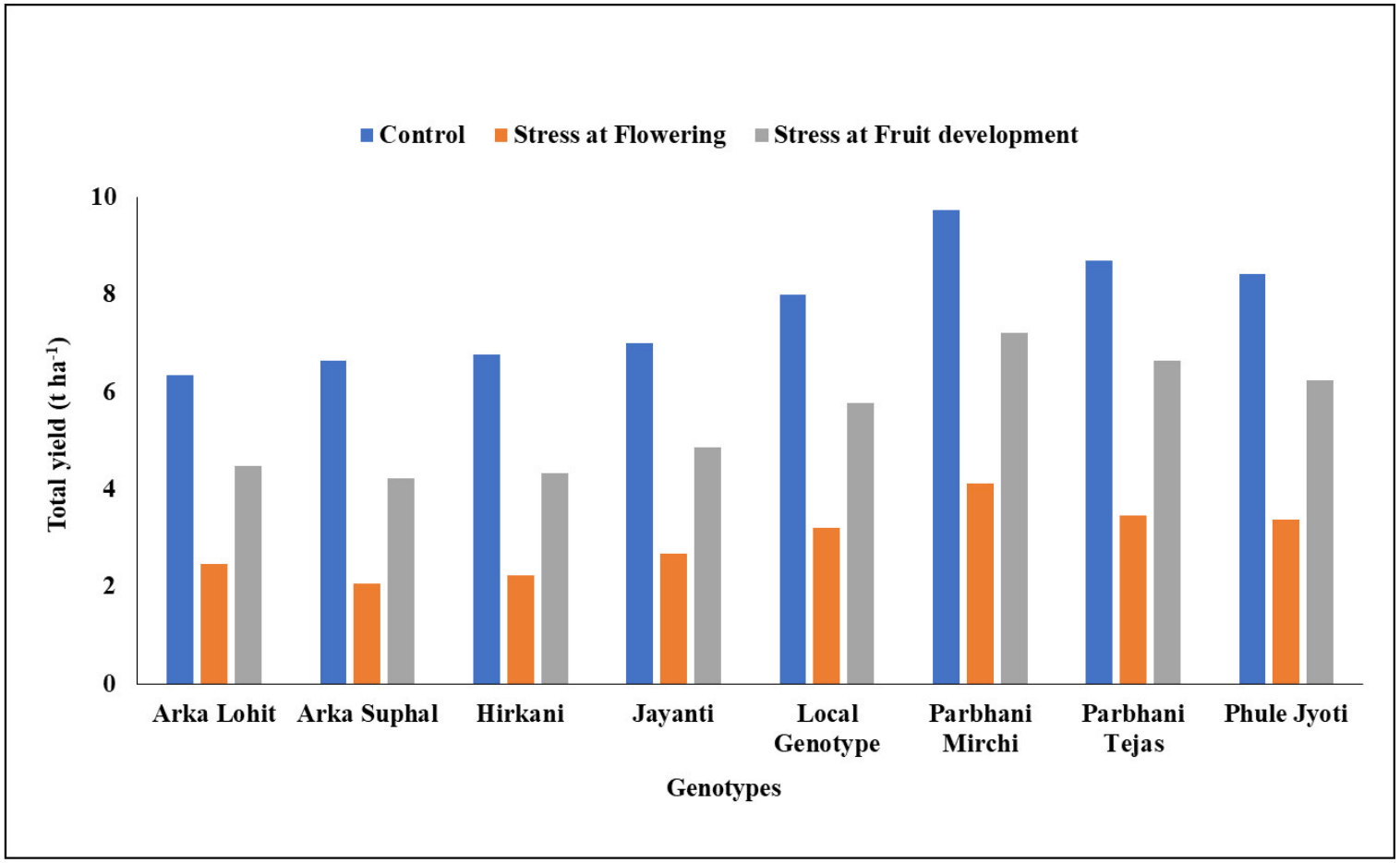


Fig. 18 Effect of drought stress imposed at different growth stages on total yield ($t\ ha^{-1}$) of different chilli genotypes

expression of genotypes, in concern with different fruit morphological characters. And hence, above results are found in agreement with Techawongstien *et al*. (1992) in fifteen cultivars of chilli; Khan *et al*. (2008) in two chilli cultivars.

4.8.1.2 Effect of drought stress

Drought stress significantly reduced weight of single fruit. Weight of single fruit of plants, which were subjected to drought stress at flowering stage showed 2.68 g while fruit of plants under drought stress imposed at fruit development showed 2.86 g. However fruit of plants under controlled condition, weighed up to 3.05 g, which was more than that of fruit developed under stressed conditions.

Stressed plants, having lower water potentials than the plants under control treatment, would be expected to produce fruits of less fresh weight. However, the specific mechanism of fruit fresh weight reduction is unclear. Apoplastic water status strongly influences water flow in the phloem. The water potential gradient between the fruit and the plant controls phloem-driven expansive growth of particular fruit (Johnson *et al*. 1992). In this study, the reduced water potential of the stressed treatment plants may have reduced the driving force for water flow into the fruit. These processes require carbohydrates, and apparently restricted carbohydrate supply of the water-stressed plants would further decrease ability of fruit to accumulate water. And hence, it finally resulted in to lowered weight of individual fruit. Above results are supported by Ferrara *et al.* (2011) in Capsicum cv. Peppone; Kirnak *et. al* (2002) in eggplant cv. Pala; Gunawardena *et al*. (2014) in chilli cv. MI2.

4.8.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages was found to be non-significant on weight of single fruit.

4.8.2 Fruit length (cm)

4.8.2.1 Genotypes

The effect of genotypes on length of single fruit was found to be non-significant.

4.8.2.2 Effect of drought stress

Drought stress significantly reduced length of single fruit. Plants, which were subjected to drought stress at fruit development stage (4.73cm) produced shortest fruits, while plants under drought stress imposed at flowering, produced fruits of

Table18. Effect of drought stress imposed at different growth stages on yield parameters of different chilli genotypes

Treatment No.	Treatment details	Number of pickings	Fruit yield per plant(g)	Reduction in yield (%)	Total yield per ha(t ha^{-1})
Factor G : Genotypes					
G_1	Parbhani Tejas	5.50	169.20	72.21 (46.23)	6.27
G_2	Parbhani Mirchi	5.46	189.55	72.21 (46.23)	7.02
G_3	Phule Jyoti	5.58	162.14	71.38 (45.55)	6.01
G_4	Jayanti	5.42	130.83	69.22 (43.80)	4.85
G_5	Hirkani	5.21	119.97	65.74 (41.10)	4.44
G_6	Arka Lohit	5.21	119.65	69.83 (44.29)	4.43
G_7	Arka Suphal	5.46	116.44	64.91 (40.47)	4.31
G_8	Local Genotype	5.63	152.81	70.77 (45.05)	5.66
S.E ±		0.06	1.93	0.71	0.07
C.D at 1%		NS	5.70	2.10	0.21
Factor S : Stress Stages					
S_1	No stress	7.00	207.85	100 (90)	7.70
S_2	Stress at Flowering	3.89	79.59	37.94 (22.30)	2.95
S_3	Stress at Fruit development	5.41	147.78	70.66 (44.96)	5.47
S.E ±		0.02	0.72	0.27	0.027
C.D at 1%		0.07	2.14	0.79	0.079
Interaction Effect (G X S)					
T01	G_1S_1	7.00	234.69	100 (90)	8.69
T02	G_1S_2	3.88	93.36	39.82 (23.46)	3.46
T03	G_1S_3	5.63	179.55	76.81 (50.19)	6.65
T04	G_2S_1	7.00	262.59	100 (90)	9.73
T05	G_2S_2	4.50	111.08	42.33 (25.05)	4.11
T06	G_2S_3	4.88	194.99	74.30 (47.98)	7.22
T07	G_3S_1	7.00	227.15	100 (90)	8.41
T08	G_3S_2	3.88	91.14	40.10 (23.64)	3.38
T09	G_3S_3	5.88	168.11	74.05 (47.78)	6.23
T10	G_4S_1	7.00	189.02	100 (90)	7.00
T11	G_4S_2	4.00	72.02	38.08 (22.38)	2.67
T12	G_4S_3	5.25	131.46	69.58 (44.09)	4.87
T13	G_5S_1	7.00	182.49	100 (90)	6.76
T14	G_5S_2	3.50	60.26	33.02 (19.28)	2.23
T15	G_5S_3	5.13	117.15	64.20 (39.94)	4.34
T16	G_6S_1	7.00	171.31	100 (90)	6.34
T17	G_6S_2	3.38	66.66	39.01 (22.96)	2.47
T18	G_6S_3	5.25	120.97	70.48 (44.82)	4.48
T19	G_7S_1	7.00	179.43	100 (90)	6.65
T20	G_7S_2	3.63	55.67	31.04 (18.09)	2.06
T21	G_7S_3	5.75	114.22	63.69 (39.56)	4.23
T22	G_8S_1	7.00	216.09	100 (90)	8.00
T23	G_8S_2	4.38	86.56	40.11 (23.64)	3.21
T24	G_8S_3	5.50	155.77	72.20 (46.22)	5.77
S.E ±		0.19	5.79	2.14	0.21
C.D at 1%		NS	NS	NS	NS

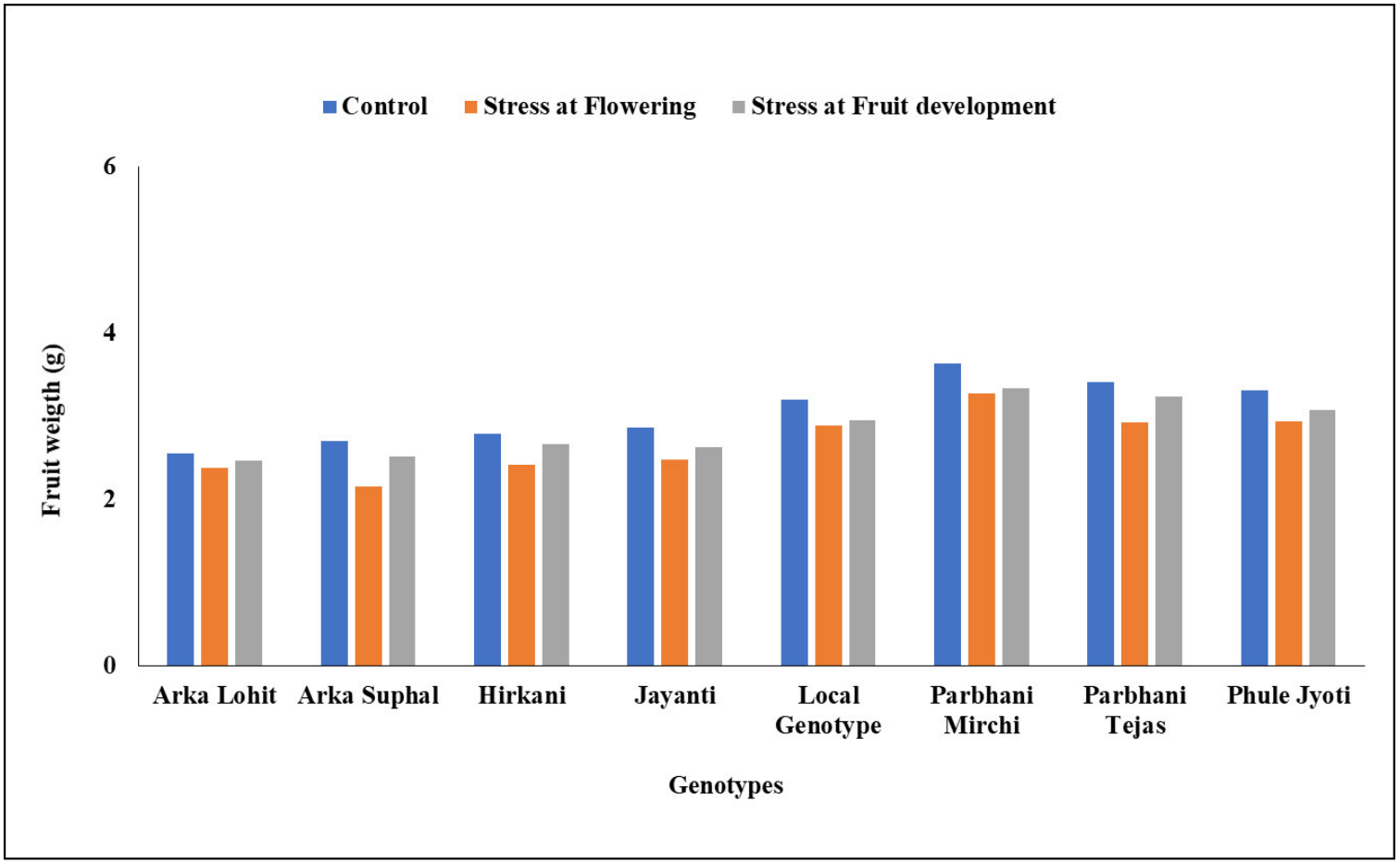


Fig. 19 Effect of drought stress imposed at different growth stages on fruit weight (g) of different chilli genotypes

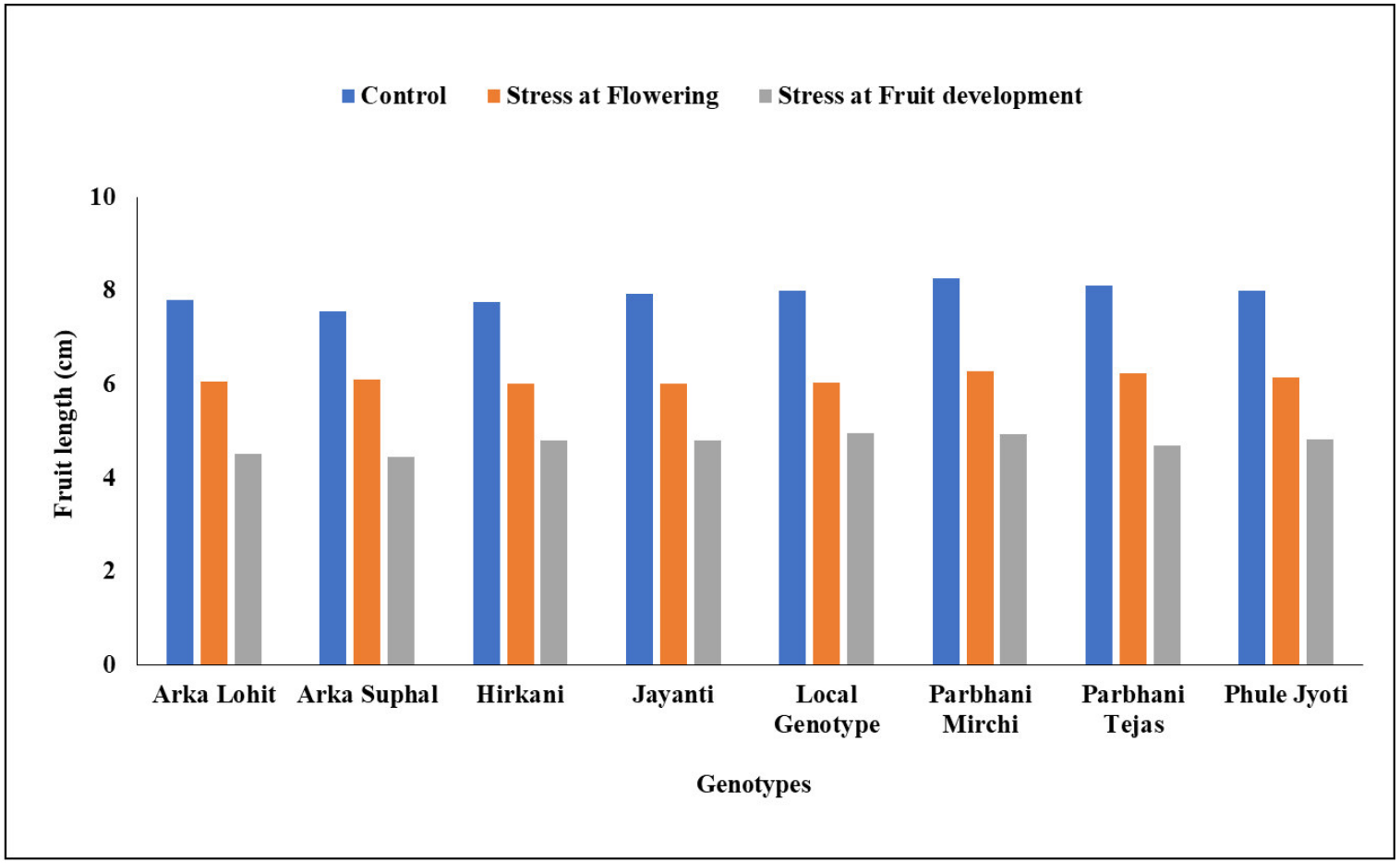


Fig. 20 Effect of drought stress imposed at different growth stages on fruit length (cm) of different chilli genotypes

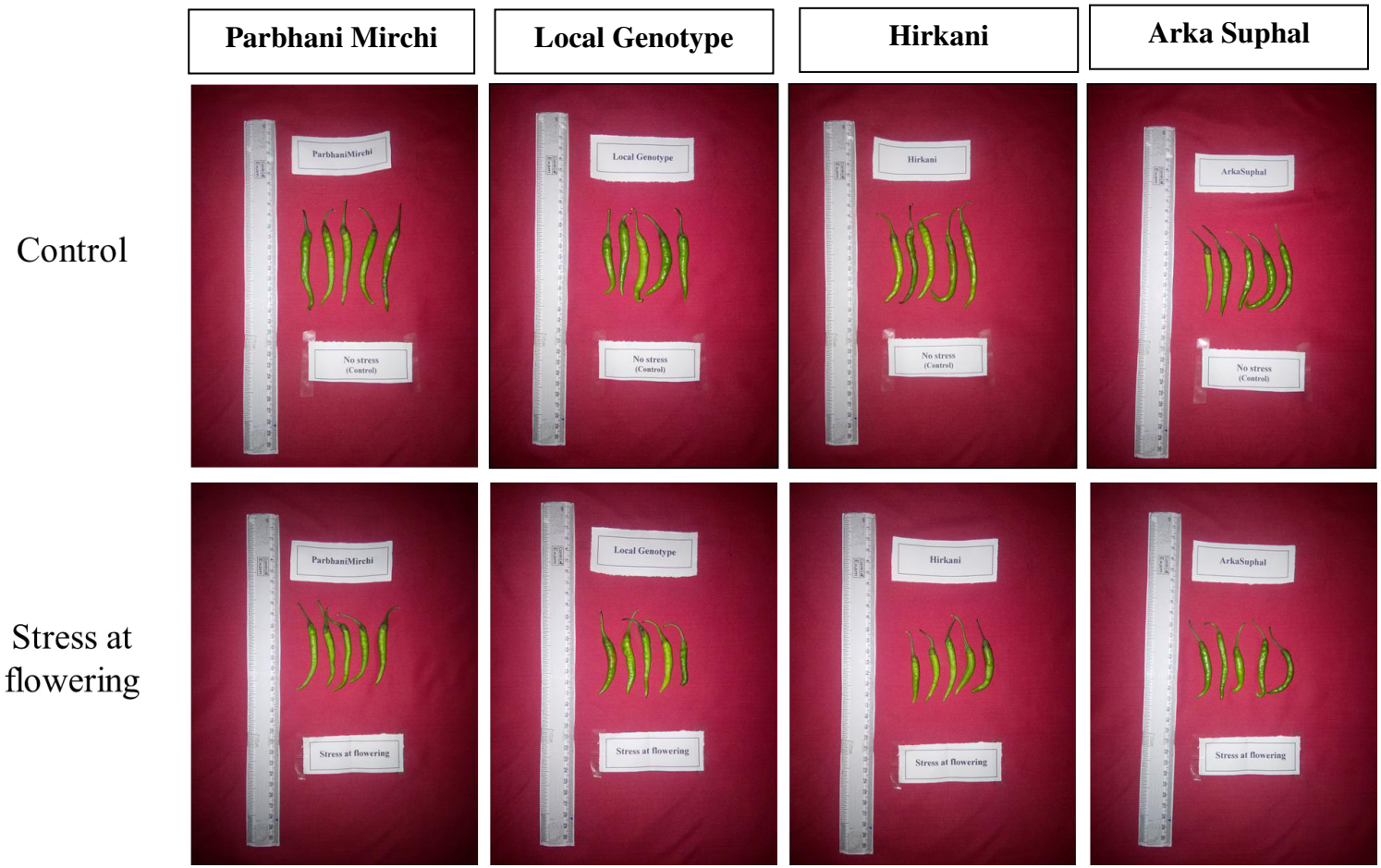


Plate 2. Effect of drought stress at flowering stage on fruits of genotypes – Parbhani Mirchi, Local genotype, Hirkani and Arka Suphal

Plate3. Effect of drought stress at fruit development stage on fruits of genotypes – Parbhani Mirchi, Local genotype, Hirkani and Arka Suphal

drought stress at flowering stage – 0.26%. However, fruits from control treatment are showed less capsaicin content – 0.15%.

Capsaicin (8-methyl-N-vanillyl-6-nonenamide) is an active component of chili peppers, which plants are belonging to the genus *Capsicum*. Capsaicin and several related compounds are called capsaicinoids and are produced as secondary metabolites by chili peppers. Pure capsaicin is a hydrophobic, colorless, highly pungent, and crystalline to waxy solid compound (wikipedia.org/wiki/Capsaicin). From the above mentioned results, it is interpreted that, fruits from stressed plants show higher concentration of capsaicin while fruits from watered plants show lower concentration as compared to fruits from stressed plants. Fruits from control treatment have enough water content; hence this water content is responsible for depletion of capsaicin content; whereas fruits from stressed plants are lack of moisture, so the fruits from these plants would show higher concentration. Similar results are observed by Sung *et al*., (2005) in chilli; Jeeatid *et al*. (2018) in hot pepper.

4.9.1.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages was found to be non-significant on capsaicin content.

4.9.2 Ascorbic acid content (mg $^{-100g}$)

4.9.2.1 Genotypes

The effect of genotypes was found to be non-significant on ascorbic acid content.

4.9.2.2 Effect of drought stress

Drought stress significantly reduced ascorbic acid content. Fruits, produced on plants which were subjected to drought stress at fruit development showed lowest value – 79.66 mg-100g while fruits from plants which were subjected to drought stress at flowering stage showed 86.61 m-100g. However, fruits from control treatment are showed maximum ascorbic acid content – 88.43 m-100g.

The proposed route for vitamin C synthesis commences from D – glucose (Counsel & Horning, 1981). When plants experience moisture stress, stomata close followed by a decline in the CO_2 fixation. A reduction in the D – glucose synthesis would have occurred during the period of stress, which in turn may have reduced the

synthesis of vitamin C. Moisture stress may have reduced the substrate concentration for vitamin C synthesis. Reduction in the substrate may possibly be due to reduced photosynthetic rate.

Another possibility of reduction in the vitamin C content is due to increased leaf temperature. The increase in leaf temperature may be due to lowering of the rate of transpiration which is responsible for cooling the canopy temperature with the onset of stress. Vitamin C is very sensitive to changes in environmental conditions. It gets oxidized very rapidly when exposed to high temperatures (Davies *et al*., 1991). The leaf temperature progressively builds up as a consequence of moisture stress and contributes towards the reduction of vitamin C. Similar results were reported by Mahendran *et al*. (2000), Lerma *et al*. (2011) and Ahmed *et al*. (2014) in chilli crop.

4.9.2.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages was found to be non-significant on ascorbic acid content.

4.10 Dry weight (g)

Data on dry weight for different chilli genotypes under the influence of drought stress, imposed at flowering and fruit development, is presented in Table 21 and graphically depicted in Fig.23.

4.10.1 Genotypes

The effect of genotypes was found to be significant on dry weight of plants. Parbhani Mirchi (5.57 g) showed highest shoot dry weight which was followed by Parbhani Tejas (4.96 g), Local genotype (4.80 g)and Phule Jyoti (4.58 g). Whereas genotype – Arka Suphal (3.90 g) showed lowest shoot dry weight. However, remaining genotypes were found to be at par with each other.

Variation in dry weight of plants indicated the high range of genetic variability amongst genotypes, which was recorded to study the performance of particular genotypes under particular region. Environment appeared to play an important role in expression of genotypes, regarding biomass of particular genotype. Similar results were observed by Techawongstien *et al*. (1992) in fifteen cultivars of chilli; Khan *et al*. (2008) in two chilli cultivars; Budiyati Ichwan *et al.* (2017) in eight red chilli cultivars.

Table 20. Effect of drought stress imposed at different growth stages on quality parameters of different chilli genotypes

Treatment No.	Treatment details	Capsaicin content (%)	Ascorbic acid content (mg/100g)
Factor G : Genotypes			
G_1	Parbhani Tejas	0.23	85.81
G_2	Parbhani Mirchi	0.25	86.50
G_3	Phule Jyoti	0.24	84.73
G_4	Jayanti	0.28	84.19
G_5	Hirkani	0.27	83.47
G_6	Arka Lohit	0.24	85.29
G_7	Arka Suphal	0.26	84.39
G_8	Local Genotype	0.26	85.18
S.E ±		0.01	0.34
C.D at 1%		NS	NS
Factor S : Stress Stages			
S_1	No stress	0.15	88.57
S_2	Stress at Flowering	0.26	86.61
S_3	Stress at Fruit development	0.36	79.66
S.E ±		0.002	0.13
C.D at 1%		0.007	0.36
Interaction Effect (G X S)			
T01	G_1S_1	0.17	88.78
T02	G_1S_2	0.21	87.63
T03	G_1S_3	0.33	81.03
T04	G_2S_1	0.13	90.77
T05	G_2S_2	0.24	87.95
T06	G_2S_3	0.37	80.78
T07	G_3S_1	0.14	88.12
T08	G_3S_2	0.28	86.02
T09	G_3S_3	0.31	80.05
T10	G_4S_1	0.13	87.75
T11	G_4S_2	0.30	86.10
T12	G_4S_3	0.41	78.73
T13	G_5S_1	0.18	87.26
T14	G_5S_2	0.25	86.02
T15	G_5S_3	0.40	77.12
T16	G_6S_1	0.13	88.99
T17	G_6S_2	0.25	86.62
T18	G_6S_3	0.33	80.27
T19	G_7S_1	0.18	87.59
T20	G_7S_2	0.25	85.98
T21	G_7S_3	0.34	79.61
T22	G_8S_1	0.13	89.31
T23	G_8S_2	0.28	86.53
T24	G_8S_3	0.38	79.71
S.E ±		2.85	1.03
C.D at 1%		NS	NS

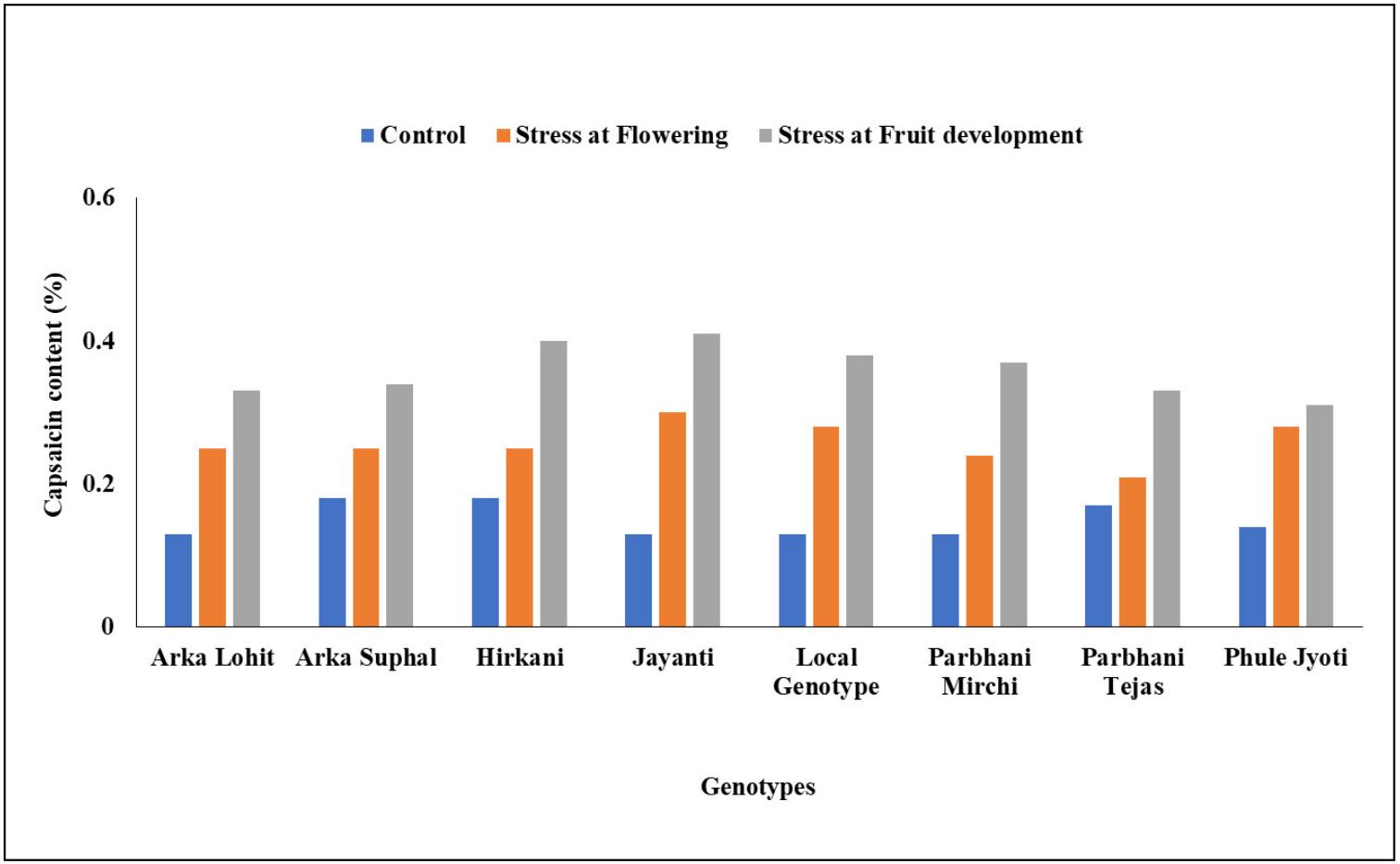


Fig. 21 Effect of drought stress imposed at different growth stages on capsaicin content (%) of different chilli genotypes

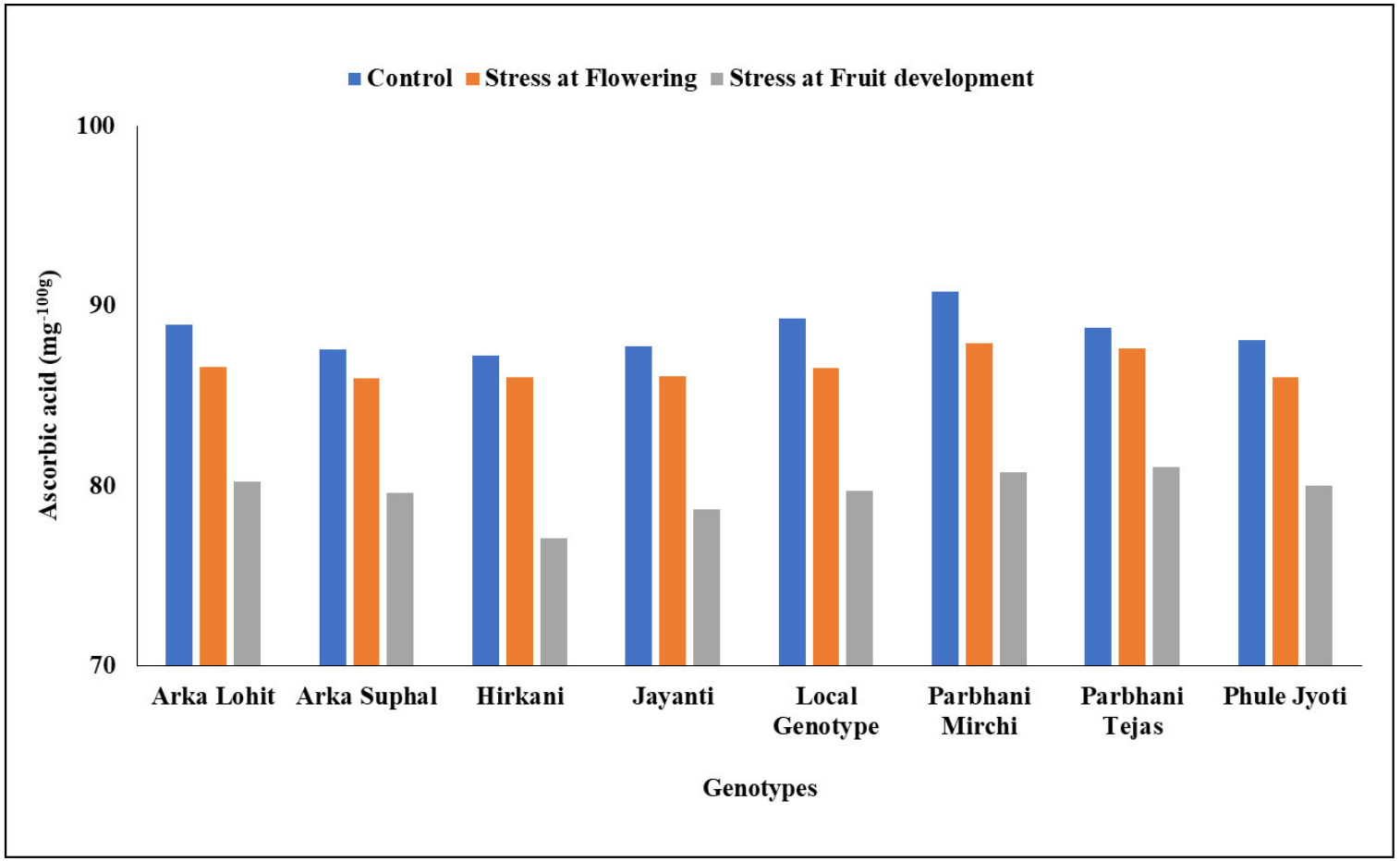


Fig. 22 Effect of drought stress imposed at different growth stages on ascorbic acid content (mg^{-100g}) of different chilli genotypes

4.10.2 Effect of drought stress

Drought stress significantly reduced dry weight of plants. Plants which were subjected to drought stress at flowering stage showed lowest dry weight – 3.20 g, while plants under drought stress imposed at fruit development stage showed – 3.74 g. However, plants under control treatment, weighed up to 6.69 g.

Depleted soil moisture level is inversely proportional to biomass accumulation. Plants under water stress conditions failed to grow and develop like plants under regular irrigation. Such stressed plants are attributed with poor carbohydrate accumulation and tissue development as well. So such plants would show moisture scarcity within their cells, which ultimately resulted in to less biomass production. And thus, dry weight loss would often resultant of many of these activities like shedding of leaves, dropping of flowers and fruits, poorly developed branches etc. And hence, dry weight of stressed plants was lowered as compared to plants under regular watering. Above results are supported by Khan *et al*. (2012) in chilli, Budiyati Ichwan *et al*. (2017) in red chillies, Byari *et al*. (1995) in eggplant.

4.10.3 Interaction effect

Interaction effect of various chilli genotypes and drought stress forced at different growth stages was found to be non-significant on dry weight.

4.11 Phenotyping parameters

Data on phenotyping parameters for different chilli genotypes under the influence of depleted soil moisture level is presented in Table 22 and graphically depicted in Fig.24, 25, 26, 27, 28.

4.11.1 NIR value / Tissue Water Content (Kilo pixels)

4.11.1.1 Genotypes

Effect of genotypes was found to be significant on tissue water content which is expressed by imaging based on NIR reflectance. Arka Suphal (0.182 Kilo pixels) showing highest pixel count that explained less tissue water level in leaves. Arka Suphal was followed by Hirkani (0.176 Kilo pixels) and Arka Lohit (0.173 Kilo pixels); while Parbhani Mirchi showed least NIR pixel count – 0.157 Kilo pixels, representing ample amount of tissue water availability. However, genotypes – Parbhani Tejas, Phule Jyoti and Local Genotype were found to be at par with each other.

Table 21. Effect of drought stress imposed at different growth stages on dry weight of different chilli genotypes

Treatment No.	Treatment details	Dry weight (g)
Factor G : Genotypes		
G_1	Parbhani Tejas	4.96
G_2	Parbhani Mirchi	5.57
G_3	Phule Jyoti	4.58
G_4	Jayanti	4.39
G_5	Hirkani	4.11
G_6	Arka Lohit	4.05
G_7	Arka Suphal	3.90
G_8	Local Genotype	4.80
S.E ±		0.05
C.D at 1%		0.16
Factor S : Stress Stages		
S_1	No stress	6.69
S_2	Stress at Flowering	3.20
S_3	Stress at Fruit development	3.74
S.E ±		0.021
C.D at 1%		0.061
Interaction Effect (G X S)		
T01	G_1S_1	7.24
T02	G_1S_2	3.46
T03	G_1S_3	4.19
T04	G_2S_1	7.67
T05	G_2S_2	4.17
T06	G_2S_3	4.86
T07	G_3S_1	6.56
T08	G_3S_2	3.21
T09	G_3S_3	3.95
T10	G_4S_1	6.52
T11	G_4S_2	3.02
T12	G_4S_3	3.62
T13	G_5S_1	6.20
T14	G_5S_2	2.90
T15	G_5S_3	3.24
T16	G_6S_1	6.29
T17	G_6S_2	2.82
T18	G_6S_3	3.02
T19	G_7S_1	6.09
T20	G_7S_2	2.57
T21	G_7S_3	3.04
T22	G_8S_1	6.97
T23	G_8S_2	3.42
T24	G_8S_3	4.00
S.E ±		0.165
C.D at 1%		NS

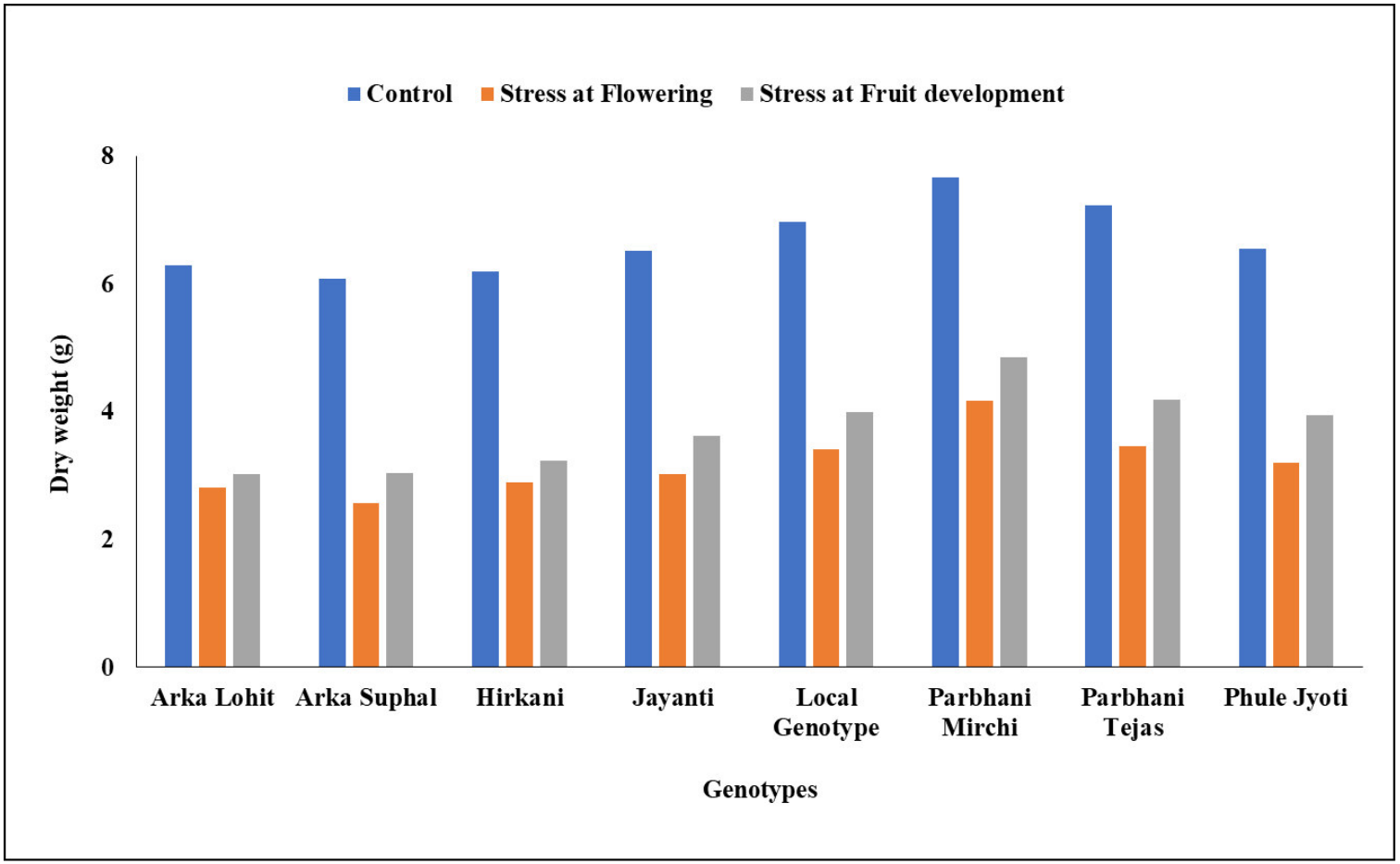


Fig. 23 Effect of drought stress imposed at different growth stages on dry weight (g) of shoot of different chilli genotypes

This differential response of genotypes to tissue water status was due to genetic variability amongst genotypes. Environment appeared to have more or less impact on the leaf anatomy of genotypes, which is responsible to get varied water potential and osmotic adjustment (OA). This differential status of tissue water in different genotypes is responsible for varied phenotyping expressions and physiological parameters too.

Similar results were reported in drought experiment by Neilson *et al*. (2015) in hybrid sorghum and grain sorghum where he reported, hybrid sorghum showed least NIR pixel count, indicating higher level of tissue water content.

4.11.1.2 Effect of drought stress

Drought stress significantly increased pixel count of NIR image, indicating depletion in tissue water level from plant, as drought exceeds. NIR images of plants which were subjected to restricted water supply i.e., stressed were observed more conspicuous as compared to NIR images of plants under normal watering. Hence pixel count of stressed plant image (0.180 Kilo pixels) was higher than that of control plant (0.159 Kilo pixels).

As soil moisture depleted, tissue water level of plants also get lowered, because of utilization of tissue water in transpiration. The rate of transpiration was increased, to maintain canopy temperature at optimum level in stressed plants as compared to controlled plants which led to loss of more water. But at a certain point, plant feels moisture scarcity and then plant respond accordingly, in this situation reduced gas exchange and stomatal closure could be observed. And to study this phenomenon, a new, non-invasive technology – "NIR imaging" is available now a days. In this type of imaging, images of plants were captured at wavelength of 700 – 900 nm. Plants with lack of tissue water will reflect more NIR radiation after incidence and will give very sharp and distinct image. However, plants having ample tissue water will absorb NIR radiation, giving dark image. And thus, images of stressed plants would show more pixel count as compared to images of regularly watered plants. Above results are supported by Neilson *et al*. (2015) in sorghum.

4.11.1.3 Interaction Effect

Interaction effect of various chilli genotypes and drought stress was found to be non-significant on tissue water content.

4.11.2 Area (Kilo pixels)

4.11.2.1 Genotypes

Effect of genotypes was found to be significant on area which is expressed by visible imaging approach. Parbhani Mirchi (367.78 Kilo pixels) showing highest pixel count that explained maximum area has been covered by biomass contributing aspects, majorly leaves and branches. Parbhani Mirchi was followed by Parbhani Tejas (329.94 Kilo pixels) and Phule Jyoti (313.40 Kilo pixels); Arka Suphal while showed least pixel count – 220.58 Kilo pixels, representing very less biomass production. However, genotypes – Jayanti, Hirkani and Arka Lohit were found to be at par with each other.

This differential response of genotypes to area was due to genetic variability amongst each other. Environment appeared to have more or less impact on morphological development of genotypes especially on shoot growth. By computing area of plant image, it can be easy to interpret how genotype responding to particular environment by developing its canopy, plant height, branching pattern etc. Above results are supported by Neilson *et al*. (2015) in sorghum.

4.11.2.2 Effect of drought stress

Drought stress significantly decreased pixel count of VIS image, indicating depletion in biomass covering area of plant, as drought exceeds. Area of plants under controlled irrigation treatment (382.45 Kilo pixels) was observed to be more than that of area under stress treatment (201.46 Kilo pixels).

As soil water level decreased, plants could not get enough amount of water to carry out regular physiological processes which adversely affect the morphological and reproductive development of plant. Such stressed plants would show symptoms like shrinkage of leaves, decreased scorching angle between branches. Hence, this finally resulted into decreased lowering biomass contributing aspects. Above results are supported by Neilson *et al*. (2015) in sorghum.

4.11.2.3 Interaction Effect

Interaction effect of various chilli genotypes and drought stress was found to be non-significant on area.

4.11.3 Caliper length (Kilo pixels)

4.11.3.1 Genotypes

Effect of genotypes was found to be significant on caliper length which is expressed by visible imaging approach. Parbhani Mirchi (1.59 Kilo pixels) showing highest pixel count for caliper length that explained Parbhani Mirchi was the tallest genotype amongst all. Parbhani Mirchi was followed by Parbhani Tejas (1.54 Kilo pixels), Local Genotype (1.46 Kilo pixels) and Phule Jyoti (1.45 Kilo pixels); Arka Suphal while showed least pixel count – 1.19 Kilo pixels, representing very less biomass production. However, genotypes – Jayanti, Hirkani and Arka Lohit were found to be at par with each other.

This differential response of genotypes to caliper length was due to genetic variability amongst each other. Environment appeared to have more or less impact on morphological development of genotypes especially on shoot growth. Caliper length is used to study the plant height. Above results are supported by Neilson *et al*. (2015) in sorghum.

4.11.3.2 Effect of drought stress

Drought stress significantly decreased caliper length of plant by showing decreased pixel count. Caliper length of plants under controlled irrigation treatment (1.60 Kilo pixels) was observed to be more than that of caliper length under stress treatment (1.18 Kilo pixels).

Under water deficit conditions, plants could not get required amount of water to carry out regular metabolic activities. Hence, due to water scarcity, the process of cell elongation is negatively affected, which resulted in to restricted plant growth. Therefore, plants under water stress condition, failed to attend growth like plants under controlled condition. Above results are supported by Neilson *et al*. (2015) in sorghum.

4.11.3.3 Interaction Effect

Interaction effect of various chilli genotypes and drought stress was found to be non-significant on Caliper length.

4.11.4 Digital volume (Mega pixels)

4.11.4.1 Genotypes

Effect of genotypes was found to be significant on digital volume which is expressed by 3D-visible imaging approach. Parbhani Mirchi (194.45 Mega pixels) showing highest pixel count for digital volume that explained Parbhani Mirchi was having well defined shoot architecture which indicate the distinct canopy development. Parbhani Mirchi was followed by Parbhani Tejas (163.70 Mega pixels), Local Genotype (153.38 Mega pixels) and Phule Jyoti (145.32 Mega pixels); Arka Suphal while showed least pixel count – 86.77 Mega pixels, representing very poorly developed shoot that explained Arka Suphal was having very weak canopy. However, genotypes – Jayanti, Hirkani and Arka Lohit were found to be at par with each other.

Digital volume is used to study the canopy development of plant. This differential response of genotypes to digital volume was due to genetic variability amongst each other. Expressions of genotypes especially, shoot architecture which comprise the growth habit as well as growth pattern of plant is mainly influenced by environment.

4.11.4.2 Effect of drought stress

Drought stress significantly decreased digital volume of plant by showing decreased pixel count. Digital volume of plants under controlled irrigation treatment (212.26 Mega pixels) was observed to be more than that of digital volume under stress treatment (60.38 Mega pixels).

Depleted soil moisture level adversely affected the shoot growth of plant which led to confined canopy development. Under drought like condition which was triggered by depleted soil water level, plants failed to attend their optimum growth because of hampered metabolic processes. And this under developed canopy, can be an indicator of stress effect.

4.11.4.3 Interaction Effect

Interaction effect of various chilli genotypes and drought stress was found to be non-significant on digital volume.

4.11.5 Biomass (g)

4.11.5.1 Genotypes

Effect of genotypes was found to be significant on biomass which is measured by conventional approach to justify acquired image analyzed data of phenotyping

traits. Parbhani Mirchi (30.33g) showing highest biomass accumulation which was followed by Parbhani Tejas (25.83g), Local Genotype (22.83g) and Phule Jyoti (18.17g). While Arka Suphal (12.83g) showed lowest biomass, representing very poorly developed shoot that explained Arka Suphal was having very weak canopy. However, genotypes – Jayanti, Hirkani and Arka Lohit were found to be at par with each other.

Biomass is the most trusted and conventionally used parameter to interpret the genotypic variability within genotypes. Ability of genotypes is different to store energy in response to environment. Different genotypes have different capability for osmotic adjustment; hence they can show varied response to store carbohydrates and other biomass contributing factors. Therefore, genotypes were showing differential response regarding biomass. Above results are supported by Techawongstien *et al*. (1992) in fifteen cultivars of chilli; Khan *et al*. (2008) in two chilli cultivars; Ichwan *et al.* (2017) in eight red chilli cultivars.

4.11.5.2 Effect of drought stress

Drought stress significantly decreased biomass of plant. Biomass of plants under controlled irrigation treatment (27.63g) was observed to be more than that of biomass under stress treatment (11.96 g).

Depleted soil moisture level lowered field capacity which led to create drought like situation which adversely affected the growth and development of plant. Due to this adverse impact, plants failed to attain their optimum size and remained under developed. This under development of plant was observed due to lack of moisture within plant cells. This moisture scarcity in cells led to produce shortened internodal distance, weak stems, less leaves and poorly developed vascular system. And all these, finally tended to lowered yield. Therefore, all these sum up to show decreased biomass. And hence, biomass of stressed plants was lowered as compared to plants under regular watering. Above results are supported by Khan *et al*. (2012) in chilli, Ichwan *et al*. (2017) in red chillies, Byari *et al*. (1995) in eggplant.

4.11.5.3 Interaction Effect

Interaction effect of various chilli genotypes and drought stress was found to be non-significant on biomass.

Table 22. Effect of depleted soil moisture level on phenotyping (image based) parameters and biomass of different chilli genotypes

Treatment No.	Treatment details	Tissue Water Content (Kilo pixels)	Area (Kilo pixels)	Caliper length (Kilo pixels)	Digital Volume (Mega pixels)	Biomass (g)
Factor G : Genotypes						
G_1	Parbhani Tejas	0.164	329.94	1.54	163.70	25.83
G_2	Parbhani Mirchi	0.157	367.78	1.59	194.45	30.33
G_3	Phule Jyoti	0.166	313.40	1.45	145.32	20.17
G_4	Jayanti	0.172	275.82	1.34	124.43	18.17
G_5	Hirkani	0.176	265.16	1.22	109.47	13.17
G_6	Arka Lohit	0.174	252.68	1.30	113.03	15.00
G_7	Arka Suphal	0.182	220.58	1.19	86.77	12.83
G_8	Local Genotype	0.168	310.29	1.46	153.38	22.83
S.E ±		0.003	87.64	0.24	10.10	1.09
C.D at 1%		0.009	241.02	0.66	27.77	3.22
Factor S : Stress Stages						
S_1	Control	0.16	382.45	1.60	212.26	27.63
S_2	Stress	0.18	201.46	1.18	60.38	11.96
S.E ±		0.013	21.911	0.06	2.53	4.37
C.D at 1%		0.037	60.25	0.16	6.94	12.89
Interaction Effect (G X S)						
T01	S_1G_1	0.154	429.40	1.68	250.50	37.67
T02	S_1G_2	0.149	454.38	1.75	294.97	41.33
T03	S_1G_3	0.155	419.43	1.63	223.23	27.67
T04	S_1G_4	0.161	373.80	1.52	199.17	24.67
T05	S_1G_5	0.164	363.44	1.49	173.30	18.67
T06	S_1G_6	0.165	312.67	1.61	180.50	20.33
T07	S_1G_7	0.166	296.66	1.44	137.70	18.67
T08	S_1G_8	0.159	409.80	1.66	238.70	32.00
T09	S_2G_1	0.174	230.48	1.40	76.90	14.00
T10	S_2G_2	0.165	281.17	1.43	93.93	19.33
T11	S_2G_3	0.178	207.37	1.27	67.40	12.67
T12	S_2G_4	0.183	177.83	1.17	49.70	11.67
T13	S_2G_5	0.188	166.87	0.96	45.63	7.67
T14	S_2G_6	0.183	192.70	1.00	45.57	9.67
T15	S_2G_7	0.198	144.50	0.93	35.83	7.00
T16	S_2G_8	0.177	210.78	1.25	68.07	13.67
S.E ±		0.003	19.48	0.05	2.24	0.97
C.D at 1%		NS	NS	NS	NS	NS

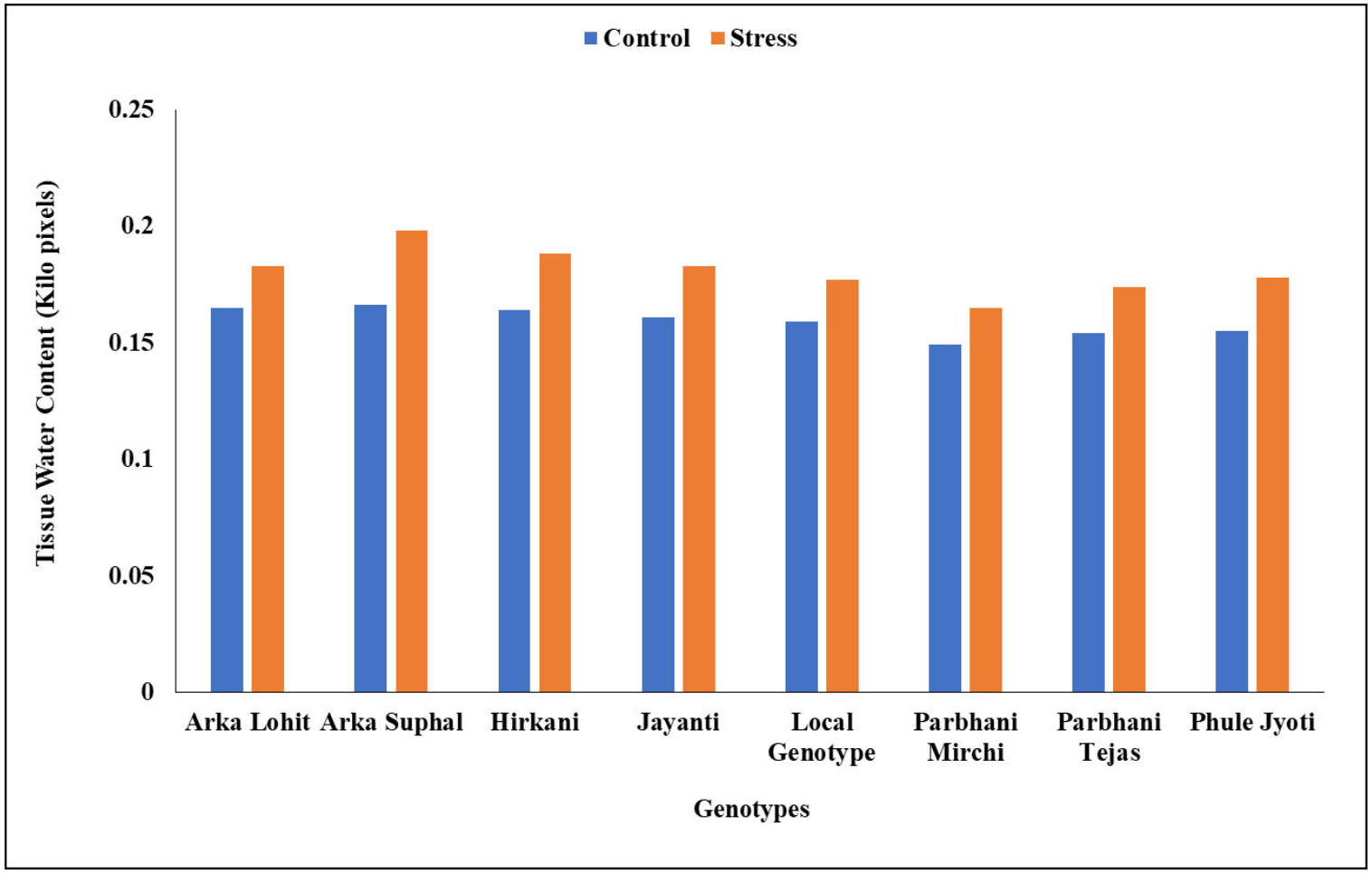


Fig. 24 Effect of depleted soil moisture level on tissue water content / NIR value (Kilo pixels) of different chilli genotypes

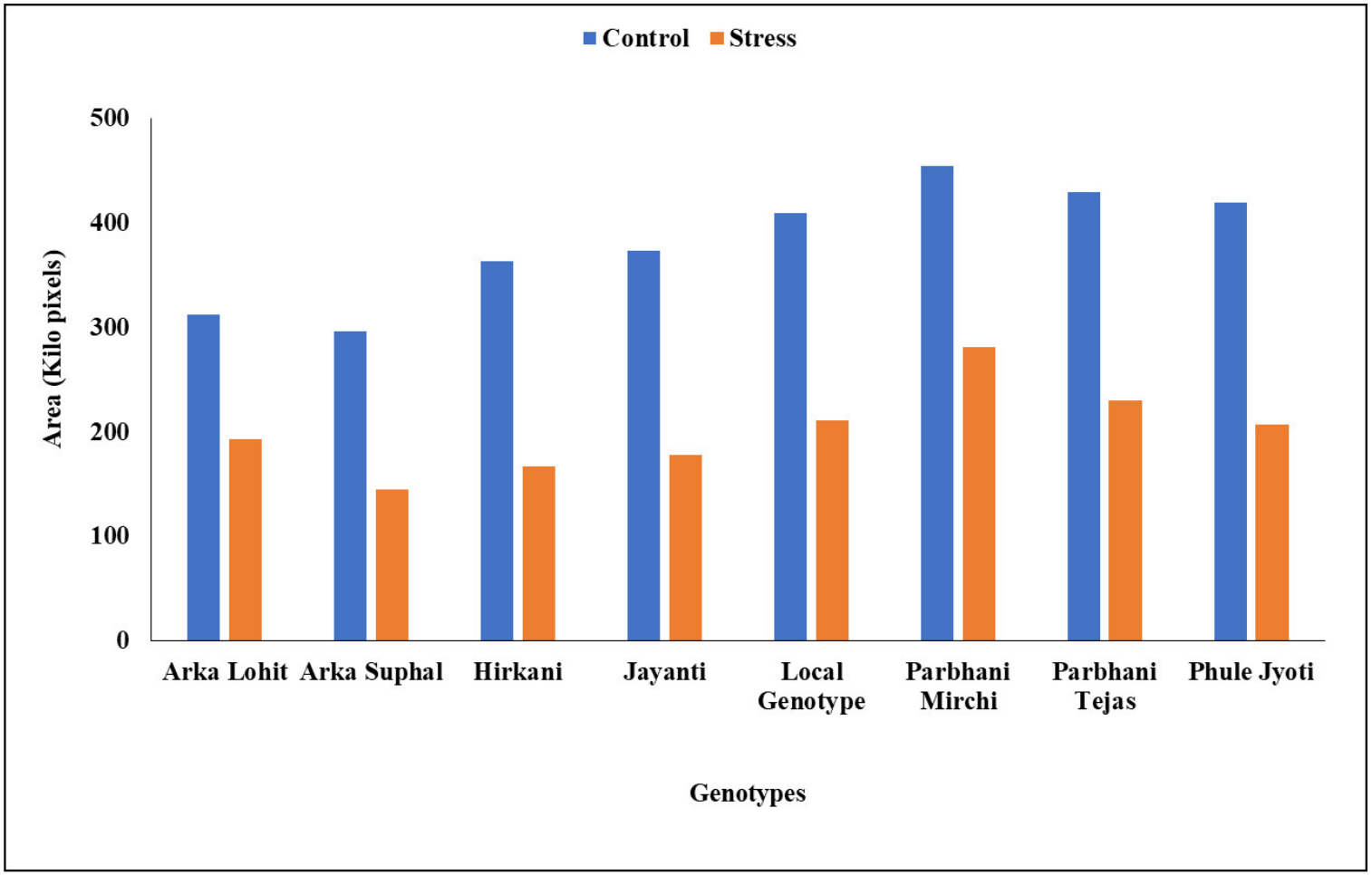


Fig. 25 Effect of depleted soil moisture level on area (Kilo pixels) of different chilli genotypes

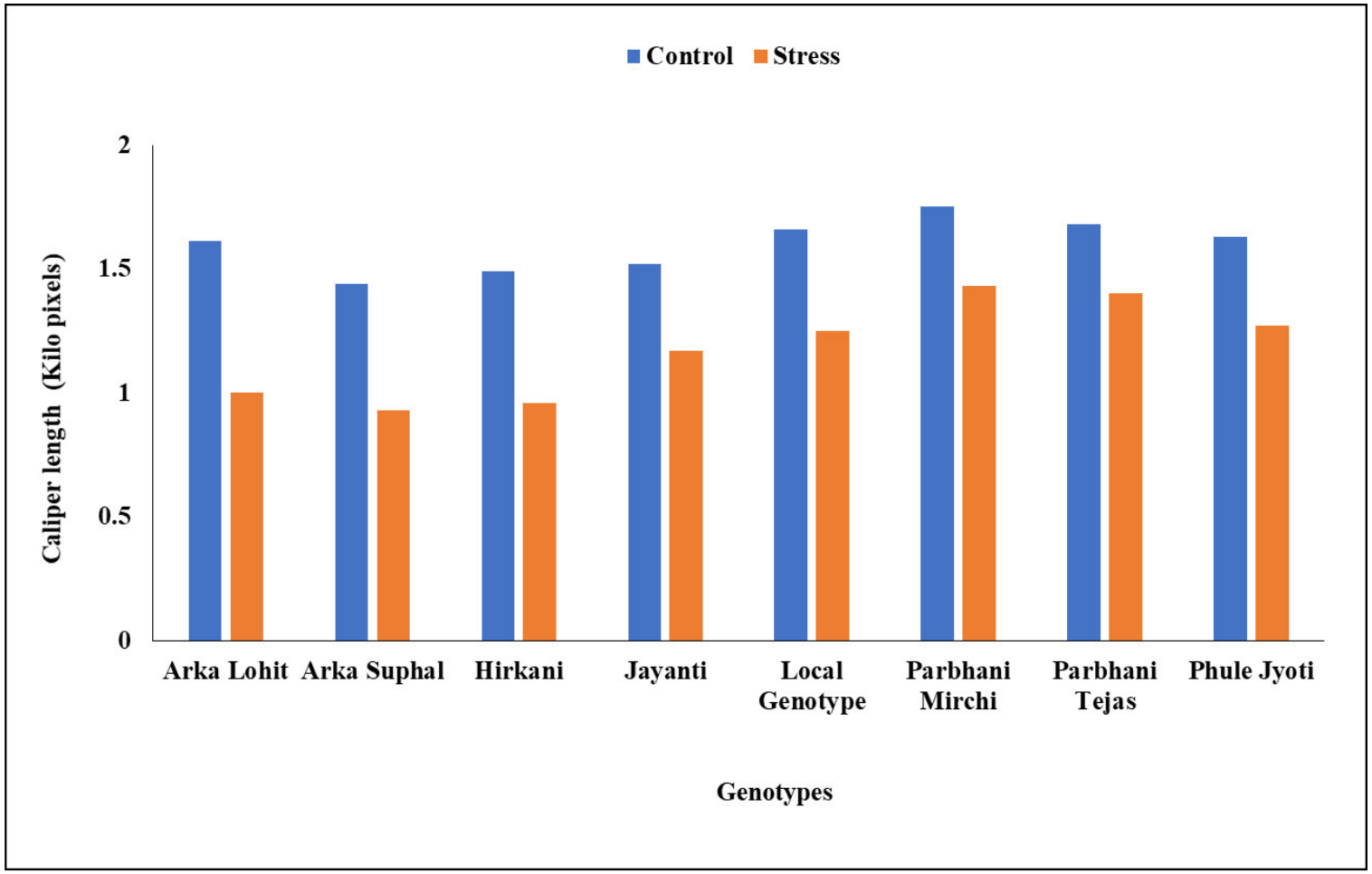


Fig. 26 Effect of depleted soil moisture level on caliper length (Kilo pixels) of different chilli genotypes

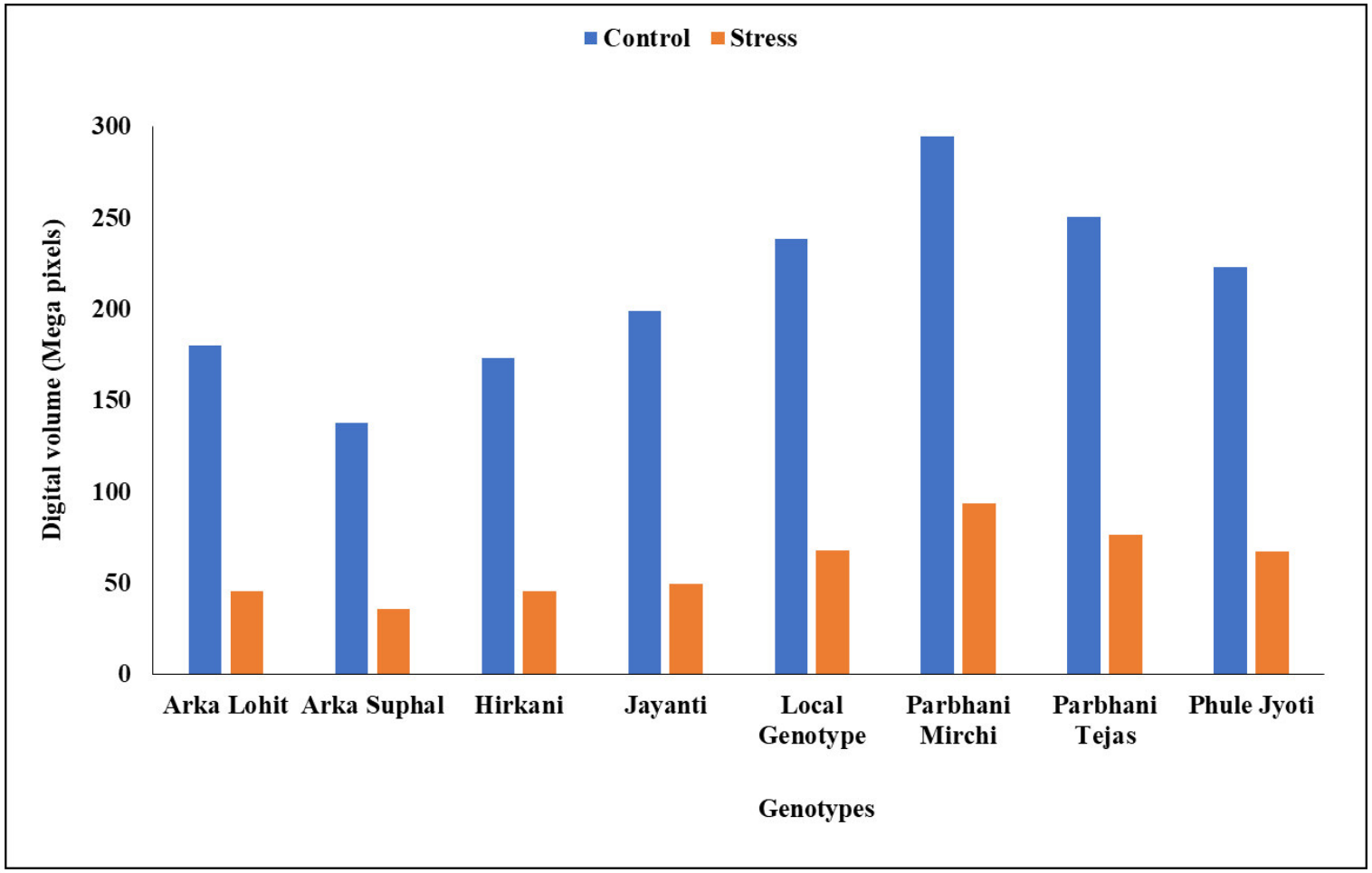


Fig. 27 Effect of depleted soil moisture level on digital volume (Mega pixels) of different chilli genotypes

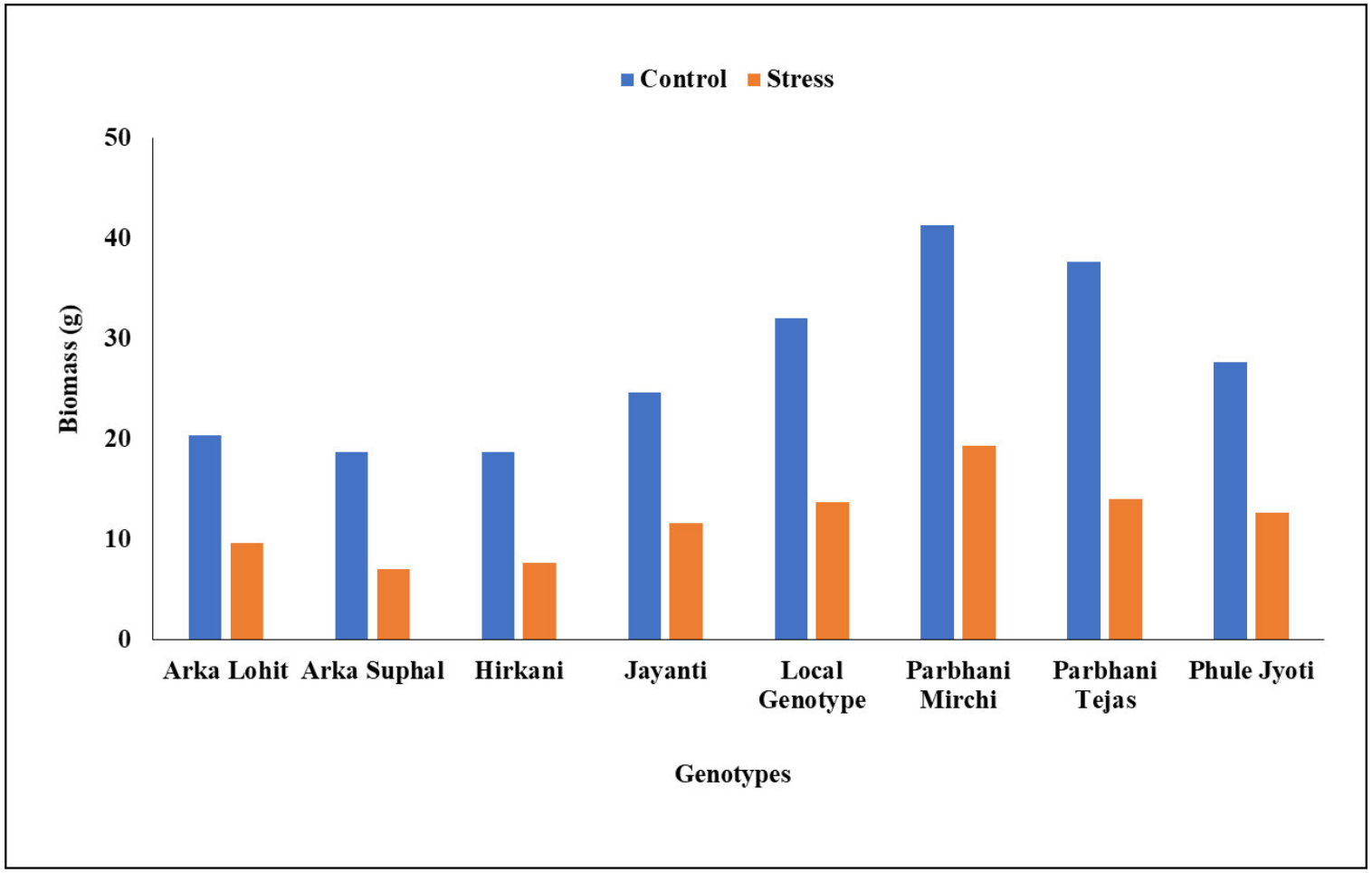


Fig. 28 Effect of depleted soil moisture level on biomass (g) of different chilli genotypes

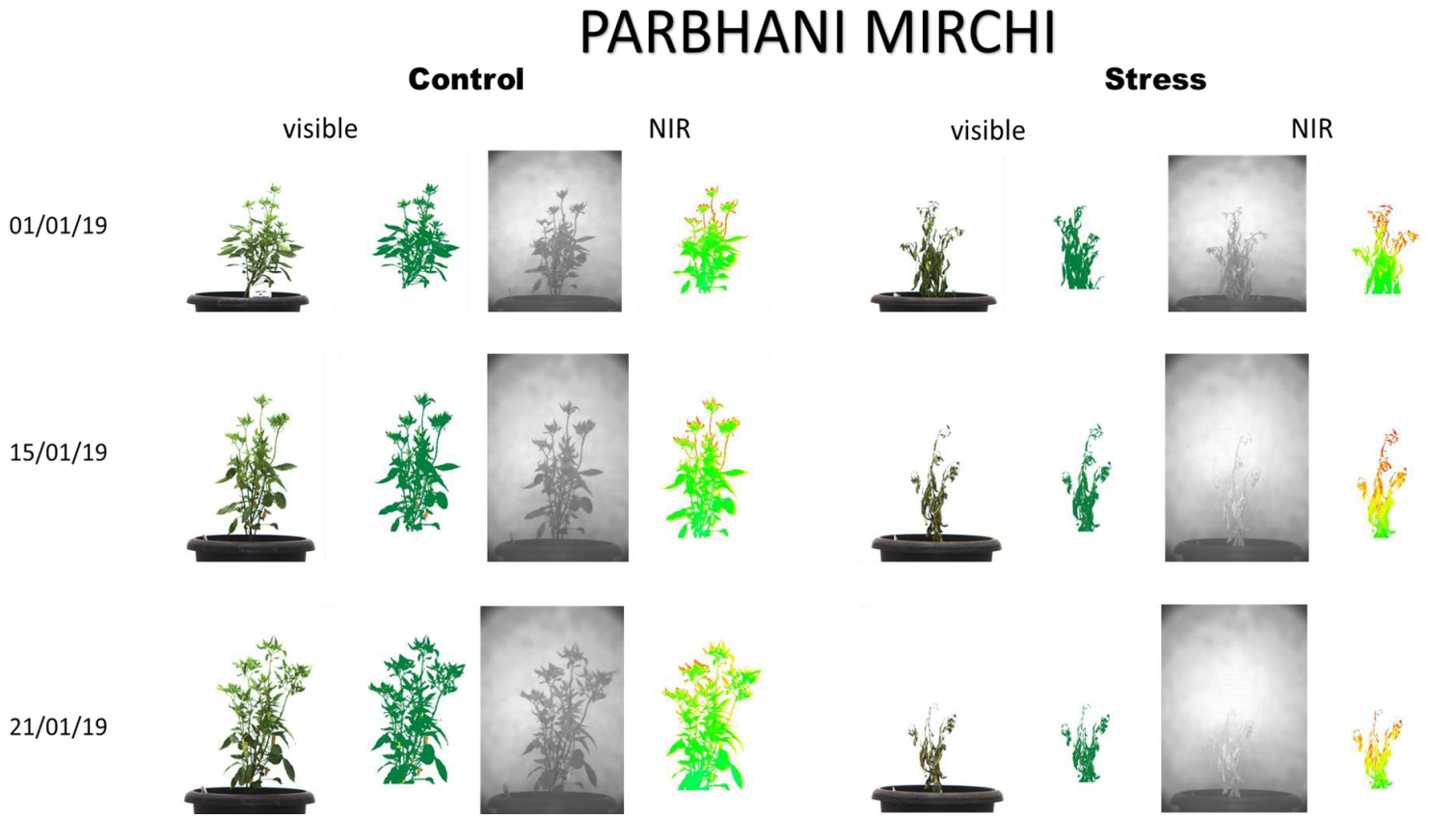


Plate 4. Phenotyping images of genotype "Parbhani Mirchi" under control and stressed conditions

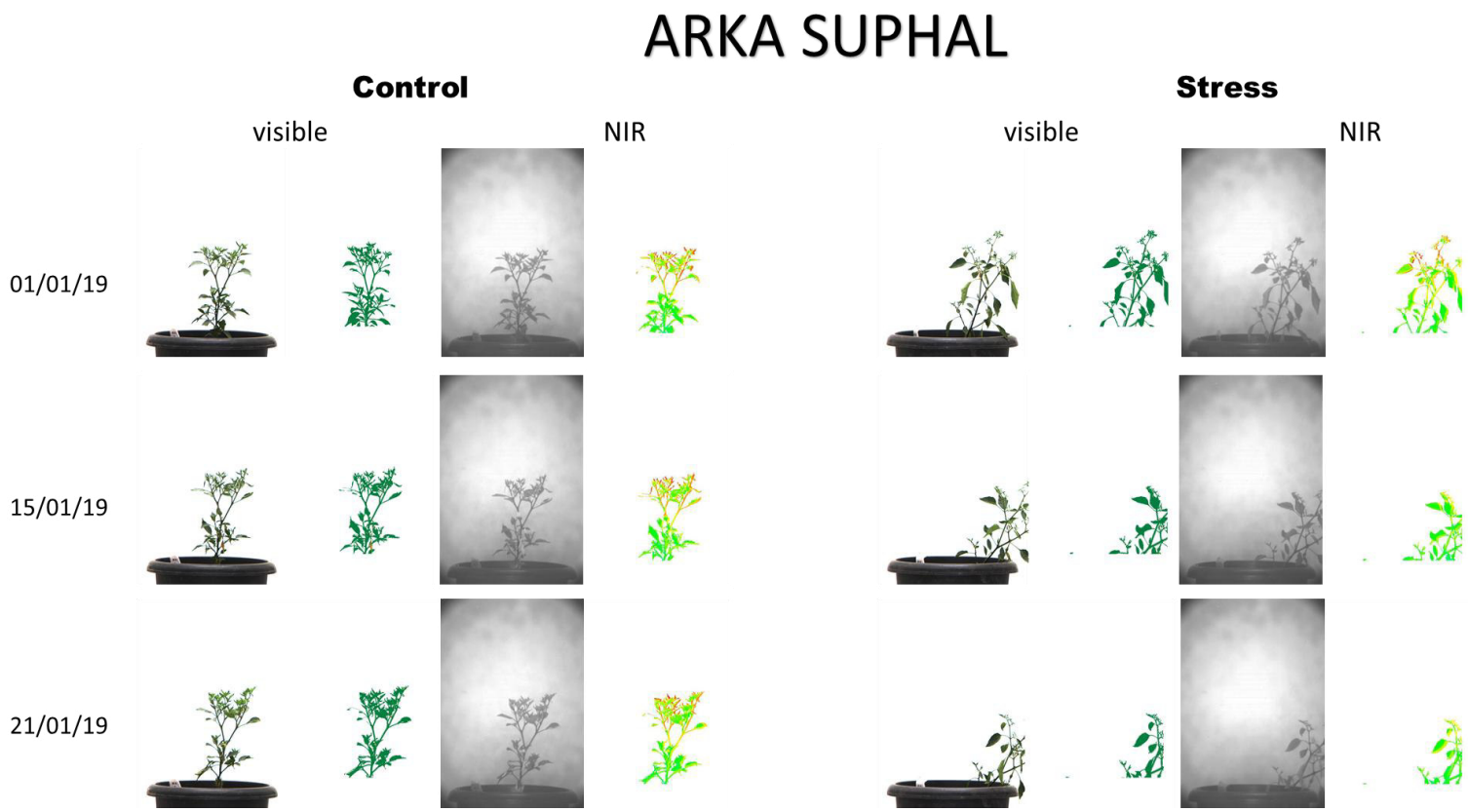


Plate 5. Phenotyping images of genotype "Arka Suphal" under control and stressed conditions

SUMMARY AND CONCLUSION

CHAPTER - V

SUMMARY AND CONCLUSION

The present investigation entitled "Assessment of drought responses of Chilli (*Capsicum annum* L.) genotypes using modern Plant Phenomics tools" was undertaken at ICAR – National Institute of Abiotic Stress Management, Malegaon Kh. (Baramati) - 413115, District Pune in *Rabi* season 2018. Above instigation were conducted to study the impact of depleted soil moisture level on morpho-physiological characters of various chilli genotypes and to associate these changes with image based plant phenomics parameters for the purpose of identifying the promising genotype showing tolerance to soil moisture stress.

A total of eight genotypes were planted in pots under three stress treatments *viz*., no stress (control), stress at flowering and stress at fruit development with two replications under the shade net. Further each replication had four separate pots for each of the treatments, thus the mean values mentioned for different parameters are from eight observations. To understand the influence of depleting soil moisture on plants, morpho-physiological attributes, yield contributing traits and quality traits were recorded at different stages of plant growth. In addition, same genotypes were planted to study the response of different phenotypic traits under control and simulated drought condition by using modern plant phenomics facility.

The observations were recorded for different parameters such as growth parameters *viz*; plant height, stem girth; leaf area; physiological parameters *viz*., canopy temperature, chlorophyll fluorescence, SPAD index, NDVI, total chlorophyll content, stomatal conductance, RWC, proline content; flowering parameters *viz*; days to initiate first flowering and flower drop; fruiting parameters *viz*; time required for initiation of fruit setting and number of fruits per plant; yield parameters *viz*; fruit yield per plant, number of pickings, percent reduction in yield due to drought and total yield per ha; fruit parameters *viz*; fruit weight, fruit length and fruit diameter; quality parameters *viz*; capsaicin content and ascorbic acid content. Modern plant phenomics facility was employed to study the response of shoot architecture and tissue water content in plants under stress treatment. Along with all these parameters, conventional

approaches were also studied *viz*., shoot (including leaves) dry weight from the experiment set under natural conditions.

5.1 Soil moisture content (%)

The effect of genotypes on soil moisture content was found to be non – significant during all growth stages. This indicated that the trend of soil moisture depletion was nearly same for all the genotypes. Whereas drought stress imposed at different growth stages: flowering and fruit development stage, significantly reduced soil moisture content. In control condition, soil moisture content was 35% however, the same was 19% in plants subjected to soil moisture stress indicating that the control plant had access to nearly two folds soil moisture as compared to stressed plants (55% of control). Similarly, stress imposed at fruit development stage, significantly lowered soil moisture content to 19%; however in control it was 37%. Thus, stress imposed resulted in depletion of soil moisture to a level equivalent to almost 51.04% of control.

5.2 Growth parameters

5.2.1 Plant height (cm)

Genotype - Parbhani Mirchi (42.54cm) was found to be the tallest genotype amongst all throughout the growth period while lowest plant height was recorded for genotype Hirkani (33.54cm). Drought stress also found to be significant for reducing plant height, when it was imposed at flowering (30.86cm) and fruit development stage (37.06cm). However, plants under control treatment was not affected for plant height throughout the growth period and shown height of 40.05cm. Genotype - Parbhani Mirchi was found to be the tallest among all even under drought stress imposed at both flowering (33.63cm) and fruit development (35.00cm) whereas Hirkani was reported to be the most influenced genotype for drought stress imposed at similar stages: 29.50 cm at flowering stage while 34.63 at fruit development stage as it responded with the lowest plant height due to stress.

5.2.2 Stem girth (mm)

The effect of genotypes was found to be non-significant on stem girth through-out the growth period; however drought stress imposed at flowering and fruit development stage was found to be significant which was recorded at 60 DAT and 90 DAT respectively. When stress imposed at flowering stage, stem girth was

significantly reduced to 8.62mm as that of plants in control treatments showed stem girth of 13.54mm. Similar trend was observed when drought stress imposed at fruit development stage recorded at 90 DAT, where plants in control treatment showed girth of 19.69mm whereas stressed plants showed 16.04mm.

5.3 Leaf parameters

5.3.1 Leaf area (cm^2)

The effect of genotypes was found to be non-significant on leaf area through-out the growth period; however drought stress imposed at flowering and fruit development stage was found to be significant which was recorded at 60 DAT and 90 DAT respectively. When stress imposed at flowering stage, leaf area was significantly reduced to 16.37cm^2 as that of plants in control treatments showed leaf area of 18.29cm^2. Similar trend was observed when drought stress imposed at fruit development stage recorded at 90 DAT, where plants in control treatment showed girth of 18.37cm^2 whereas stressed plants showed 16.16cm^2.

5.4 Physiological parameters

5.4.1 Chlorophyll fluorescence (*Fv/Fm*)

The effect of genotypes was found to be non-significant on chlorophyll fluorescence through-out the growth period. This suggests that the there was no significant differences among the genotypes with respect to photosystem II efficiency in the set of genotypes of chilli chosen for the study. However drought stress significantly reduced photosynthetic efficiency. When stress imposed at flowering stage, maximum quantum yield was significantly reduced to 0.67 while that of control treatments was 0.73. Similarly, during fruit development, plants in control showed quantum yield of 0.76 whereas stressed plants showed 0.67.

5.4.2 Canopy temperature (^{0}C)

The effect of genotypes on canopy temperature found non – significant during all growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively. However drought stress significantly raised canopy temperature of stress imposed plants which were subjected to flowering and fruit development stage as compared to plants under control treatment. When stress imposed at flowering stage, canopy temperature was significantly increased to 31.98^{0}C as that of canopy temperature in control treatments shown 29.34^{0}C. Similar

trend was observed in plant which were subjected to stress at fruit development, plants in control shown canopy temperature of 28.46^{0}C whereas stressed plants showed 31.21^{0}C.

5.4.3 Normalized Difference Vegetation Index (NDVI)

The effect of genotypes on NDVI found non – significant during all growth stages viz., vegetative, flowering and fruit development which was recorded at 30, 60 and 90 DAT respectively. This suggests that the light absorbing capacity of all genotypes was not significantly different. Whereas drought stress significantly decreased NDVI value of plants. When stress imposed at flowering stage, NDVI was significantly reduced to 0.25 as than control treatments shown 0.43. Similarly, during fruit development, plants in control showed NDVI of 0.38 whereas stressed plants showed 0.22.

5.4.4 Stomatal Conductance (mmol $m^{-2}s^{-1}$)

The effect of genotypes on stomatal conductance found non – significant during all growth stages, suggesting that all genotypes do not have significant difference in stomatal activity. However, drought stress significantly decreased stomatal conductance, when plants were subjected to stress at flowering and fruit development stage. When drought stress imposed at flowering stage, stomatal conductance was significantly reduced to 81.22 mmol $m^{-2}s^{-1}$ as than control treatments shown 246.16 mmol $m^{-2}s^{-1}$. Similarly, during fruit development, plants in control shown stomatal conductance of 215.07 mmol $m^{-2}s^{-1}$ whereas stressed plants showed 124.57 mmol mmol $m^{-2}s^{-1}$.

5.4.5 Relative Water Content (%)

The effect of genotypes on relative water content was found to be significant during all growth stages. This significant difference was observed due to genotypic variability. At 60 DAT, Parbhani Mirchi (67.58%) shown maximum leaf water content amongst all genotypes; however Hirkani shown least RWC (59.90%). Similar trend was observed at 90 DAT, when drought stress imposed at fruit development, here also Parbhani Mirchi (64.57%) shown maximum RWC while Hirkani (57.27%) shown least RWC amongst all.

5.4.6 Chlorophyll Index (SPAD value)

The effect of genotypes on Chlorophyll Index found non-significant during all growth stages while drought stress significantly decreased chlorophyll index measured at 60 and 90 DAT. When stress imposed at flowering stage, Chlorophyll Index was significantly reduced to 39.20 as that of control treatments shown 47.07. Similarly, during fruit development, plants in control showed Chlorophyll Index of 44.86 whereas stressed plants showed 38.15.

5.4.7 Chlorophyll content (mg g^{-1})

The effect of genotypes on chlorophyll content was found to be non-significant during all growth stages whereas drought stress imposed at different growth stages significantly reduced chlorophyll content, which recorded at 60 and 90 DAT. When stress imposed at flowering stage, chlorophyll content was significantly reduced to 1.70 mg g^{-1} as that of control treatments shown 2.79 mg g^{-1}. Similarly, during fruit development, plants in control shown chlorophyll content of 2.45 mg g^{-1} whereas stressed plants showed 1.67 mg g^{-1}.

5.4.8 Proline content (mg g^{-1} f w)

The effect of genotypes on proline content was found to be non-significant during all growth stages while drought stress significantly increased proline content when plants subjected to drought stress at flowering and fruit development stage which was recorded at 60 and 90 DAT. Proline content was significantly increased to 0.31 mg g^{-1}f w as that of control treatments shown 0.14 mg g^{-1} f w. Similarly, during fruit development, plants in control showed Proline content of 0.14 mg g^{-1}f w whereas stressed plants showed 0.32 mg g^{-1} f w.

5.5 Flowering parameters

5.5.1 Days to initiate first flower

Effect of genotypes and drought stress treatment imposed at different growth stages such as flowering and fruit development stage was found to be non-significant.

5.5.2 Flower drop (%)

Genotypes and drought stress treatment both significantly affected flower drop which was recorded at 60 and 90 DAT. Genotype – Parbhani Mirchi (33.51%) showed less flower drop while Hirkani (44.86%) showed highest flower drop. However, plants under no stress (17.45%) responded with least flower drop while

stress at flowering stage (65.17%) given maximum flower drop whereas stress at fruit development stage (35.62%) stood intermediate.

5.6 Fruiting parameters

5.6.1 Days to initiate first fruit

The effect of genotypes on fruit initiation was found non-significant during crop period. Whereas drought stress significantly brought earliness in fruit initiation. Plants which were subjected to drought stress imposed at flowering stage (78.02) produced early fruit lets as compared to plants subjected stress at fruit development stage (79.95) and plants under no stress condition (80.73).

5.6.2 Number of fruits per plant

Genotypes differed significantly amongst themselves in production of fruits per plant. Genotype - Parbhani Mirchi (54.97) produced maximum numbers of fruits per plant; however Hirkani (44.82) showed lowest numbers of fruits amongst all genotypes. Along with genotypes, drought stress also found to be significantly effective on fruit production per plant which was recorded through out the fruiting span of plants. Plants under control treatment (67.84) produced maximum numbers of fruits per plant which was followed by plants subjected to drought stress imposed at fruit development (51.28) and plants under drought stress imposed at flowering stage (29.83) produced very less number of fruits per plant as maximum flower drop was recorded in the same treatment.

5.7 Yield parameters

5.7.1 Number of pickings

The effect of genotypes was found to be non-significant on number of pickings through out fruiting span. However, drought stress significantly reduced number of pickings. Plants subjected to drought stress at flowering stage gave 3.89 while plants under drought stress, imposed at fruit development gave 5.41 pickings across the harvesting span. While plants under controlled conditions given 7.00 pickings.

4.7.2 Fruit yield per plant (g)

Genotypes differed significantly amongst themselves in fruit yield per plant. Genotype - Parbhani Mirchi (189.55g) given maximum fruit yield per plant however Arka Suphal (116.44g) given lowest fruit yield per plant amongst all genotypes.

Along with genotypes, treatment of drought stress also found to be significant on fruit yield per plant. Maximum fruit yield per plant was observed in plants under control treatment (207.85g) while plants subjected to drought stress imposed at flowering stage (79.59g) given lowest yield and plants subjected to drought stress imposed at fruit development stage (147.78g) was found to be intermediate for fruit yield.

5.7.3 Percent reduction in yield due to drought stress (%)

Effect of genotypes was found to be significant on percent reduction in yield due to drought stress. Genotypes - Parbhani Tejas and Parbhani Mirchi produced yield up to 72.21% overall, indicated that 27.79% of loss occurred due to stress. These two genotypes showed maximum retention of yield among all genotypes. However, minimum percentage of yield was observed in Arka Suphal (64.91%) and Hirkani (65.74%), indicating maximum reduction in yield of 35.09% and 34.26% respectively. Along with genotypes, treatment of drought stress which was imposed at flowering and fruit development stage also found to be significant for reducing yield percentage. Treatment of regular watering *i.e.*, no stress has given optimum yield that would be considered as 100% in each genotype. While drought stress imposed at flowering and fruit development stage has reported 37.94% and 70.66% yield respectively as compared to control.

5.7.4 Total yield (t ha^{-1})

Effect of genotypes was found to be significant on total yield. Parbhani Mirchi (7.02 t ha^{-1}) was reported with maximum yield while Arka Suphal (4.31 t ha^{-1}) given lowest yield among all. Treatment of drought stress significantly reduced the total yield. Plants under no stress condition *i.e.*, control given optimum yield of 7.70 t ha^{-1} however stress at flowering and fruit development reduced yield, up to 2.95 t ha^{-1} and 5.47 t ha^{-1} respectively.

5.8 Fruit parameters

5.8.1 Fruit weight (g)

The effect of genotypes on weight of single fruit was found to be significant. Single fruit of genotype - Parbhani Mirchi showed maximum weight (3.41g) while lowest weight of single fruit was observed in genotype – Arka Suphal (2.45g). Treatment of drought stress also found to be significant by reducing fruit weight as compared to control treatment. Maximum fresh fruit weight was observed in no stress

condition (3.05g) while drought stress imposed at flowering and fruit development stage produced fruit which was weighed up to 2.68g and 2.86g respectively.

5.8.2 Fruit length (cm)

The effect of genotypes on length of single fruit was found to be non-significant. Drought stress which was imposed at flowering and fruit development stage significantly reduced length of fruit. Plants, which were subjected to drought stress at fruit development stage (4.73cm) produced shortest fruits, while plants under drought stress imposed at flowering, produced fruits of length (6.10cm). However fruit of plants under controlled condition (7.93cm), were the tallest amongst all.

5.8.3 Fruit girth (mm)

The effect of genotypes and drought stress imposed at flowering and fruit development stage was found to be non- significant on girth of single fruit.

5.9 Quality parameters

5.9.1 Capsaicin content (%)

The effect of genotypes was found to be non – significant on capsaicin content. Drought stress significantly increased capsaicin content. Fruits, produced on plants which were subjected to drought stress at fruit development showed highest capsaicin content – 0.36% which was followed by fruits from plants which were subjected to drought stress at flowering stage – 0.26%. However, fruits from control treatment are showed less capsaicin content – 0.15%.

5.9.2 Ascorbic acid content (mg^{-100g})

The effect of genotypes was found to be non-significant on ascorbic acid content while drought stress which was imposed at flowering and fruit development stage significantly reduced ascorbic acid content. Fruits, produced on plants which were subjected to drought stress at fruit development showed lowest value – 79.66 mg^{-100g} while fruits from plants which were subjected to drought stress at flowering stage showed 86.61 mg^{-100g}. However, fruits from control treatment are showed maximum ascorbic acid content – 88.43 mg^{-100g}.

4.10 Dry weight (g)

The effect of genotypes was found to be significant on shoot dry weight. Parbhani Mirchi (5.57g) showed highest shoot dry weight while Arka Suphal (3.90g)

showed lowest shoot dry weight. Along with genotypes, drought stress which was imposed at flowering and fruit development stage also found significant. Plants which were subjected to drought stress at flowering stage (3.20 g) showed lowest dry weight, while plants under drought stress imposed at fruit development stage showed – 3.74 g. However, plants under control treatment, weighed up to 6.69 g.

5.11 Phenotyping parameters

5.11.1 NIR value / Tissue Water Content (Kilo pixels)

Effect of genotypes was found to be significant on tissue water content which is expressed by imaging based on NIR reflectance. Arka Suphal (0.182 Kilo pixels) showing highest pixel count that explained less tissue water level in leaves while Parbhani Mirchi (0.157 Kilo pixels) showed lowest NIR pixel count suggesting more tissue water content. Along with genotypes, treatment of soil moisture stress has also significantly increased NIR pixel count. Stressed plants (0.180 Kilo pixels) showed higher NIR pixel count as compared non stressed plant (0.159 Kilo pixels).

5.11.2 Area (Kilo pixels)

Effect of genotypes was found to be significant on area which is expressed by visible imaging approach. Parbhani Mirchi (367.78 Kilo pixels) showed highest pixel count while Arka Suphal (220.58 Kilo pixels) showed lowest pixel count. Along with genotypes, stress treatment was also found to be significant by reducing area. Area of plants under controlled irrigation treatment (382.45 Kilo pixels) was observed to be more than that of area under stress treatment (201.46 Kilo pixels).

5.11.3 Caliper length (Kilo pixels)

Effect of genotypes was found to be significant on caliper length which is expressed by visible imaging approach. Parbhani Mirchi (1.59 Kilo pixels) showed highest pixel count for caliper length while Arka Suphal (1.19 Kilo pixels) while showed lowest pixel count. Along with genotypes, stress treatment was also found to be significant by reducing caliper length. Caliper length of plants under controlled irrigation treatment (1.60 Kilo pixels) was observed to be more than that of caliper length under stress treatment (1.18 Kilo pixels).

5.11.4 Digital volume (Mega pixels)

Effect of genotypes was found to be significant on digital volume which is expressed by 3D-visible imaging approach. Parbhani Mirchi (194.45 Mega pixels)

showed highest pixel count for digital volume while Arka Suphal (86.77 Mega pixels) showed lowest pixel count. Along with genotypes, stress treatment was also found to be significant by reducing digital volume. Digital volume of plants under controlled irrigation treatment (212.26 Mega pixels) was observed to be higher than that of digital volume under stress treatment (60.38 Mega pixels).

5.11.5 Biomass (g)

Effect of genotypes was found to be significant on biomass of plant which was measured by conventional approach to justify acquired image analyzed data of phenotyping traits. Parbhani Mirchi (30.33g) showed highest biomass while Arka Suphal (12.83g) showed lowest biomass. Along with genotypes, stress treatment was also found to be significant by reducing biomass. Biomass of plants under controlled irrigation treatment (27.63g) was observed to be higher than that of biomass under stress treatment (11.96 g).

CONCLUSION

Eight chilli genotypes were screened for drought tolerance in terms of morpho-physiological parameters, yield and quality attributes, along with phenotyping traits by employing modern plant phenomics tools. Genotypes were screened under three drought stress conditions at different growth stages *viz*., no stress (control), stress at flowering and stress at fruit development. From the overall results, it may be concluded that-

1. Maximum plant height was recorded in the genotype - Parbhani Mirchi under both the control and stressed conditions (at both flowering and fruit development stage).
2. Stem girth was significantly reduced in all genotypes under drought stress imposed at flowering and fruit development stage.
3. Similarly, leaf area also reduced due to drought stress imposed at flowering and fruit development stage.
4. Physiological traits like RWC, chlorophyll fluorescence, chlorophyll content, chlorophyll index recorded by SPAD, stomatal conductance, NDVI and canopy temperature were negatively influenced by drought stress, indicating the influence of drought stress at different growth stages would give lower yield. However, Parbhani Mirchi responded with less reduction

in RWC even under drought stress, which is suggestive of comparatively improved yield over the other genotypes.

5. Drought stress imposed at flowering stage (65.17%) was found to be responsible for maximum flower drop. Maximum flower drop was recorded in Hirkani (44.86%) while lowest flower drop was observed in Parbhani Mirchi (33.51%). The lowered flower drop in Parbhani Mirchi could be attributed to comparatively higher yield of the genotype.
6. Plants subjected to drought stress at flowering stage, produced early fruits to complete their life cycle as early as possible. However, plants under same stress produced lowest numbers of fruits per plant. Parbhani Mirchi found dominating in fruit yield under all stress treatments (including control) whereas Hirkani produced least numbers of fruits per plant.
7. Maximum depletion in yield was observed under plants which were subjected to drought stress imposed at flowering stage. However Parbhani Mirchi yielded significantly higher even under stressed condition, while Arka Suphal responded with lowest yield among all genotypes.
8. Morphological attributes of fruits like fruit weight and fruit length was reduced due to drought stress imposed at both flowering and fruit development stage while fruit girth remained unaffected under both the control and stressed conditions.
9. Quality parameters like capsaicin content, and ascorbic acid content was also influenced by drought stress. Fruits produced on plants which were subjected to stress at fruit development stage were found to be more pungent than fruits from other treatments indicating more capsaicin content. However, ascorbic acid content was observed more under control conditions.
10. Drought stress imposed at flowering stage caused maximum depletion in shoot dry weight. Parbhani Mirchi retained higher shoot dry weight even under depleting soil moisture conditions.
11. Nowadays non-invasive phenotyping tools are used to assess the influence of soil moisture stress on plant. Imaging parameters like digital volume, area, caliper length are helpful in understanding the impact of depleted soil moisture on shoot architecture, while NIR images used to interpret the tissue water status under both control and stress conditions.

12. Parameters like area, caliper length, digital volume are reduced due to depleted soil moisture level. Parbhani Mirchi was observed to sustain even under stressed conditions by maintaining its vigor. In Parbhani Mirchi, very less reduction was observed in vigor as compared to other genotypes.
13. Depleted tissue water level is the indication of soil moisture stress which is responsible for creating drought like situation in future. NIR images are analyzed to interpret the level of tissue water in plants subjected to stress in comparison with non-stressed plants. Increased NIR pixel count is the indicator of lowered tissue water status. Arka Suphal (0.180 Kilo pixels) has reported maximum NIR pixel count.
14. Parbhani Mirchi showed highest biomass in all stress treatments among all genotypes while Arka Suphal reported lowest biomass.
15. Digital volume can explain actual biomass (fresh weight) when tissue moisture in leaves is not completely depleted.

Overall, from the present study it is evident that Parbhani Mirchi has outstanding performance among all the eight genotypes tested. Therefore the genotype can be considered suitable for sustainable cultivation of chilli crop in water stress-prone areas of the country. The present study was conducted only for one year, for further recommendations one or two experimental trials should be conducted in future. Additionally the genotype also appears suitable as parent in breeding experiments that are targeted towards stress tolerance and yield improvement in chilli.

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APPENDIX

APPENDIX - I

Weekly weather data (2018-2019)	Temperature (^{0}C)		Relative Humidity (%)		Wind speed (km hr^{-1})	BSS (hrs)	Rain fall (mm)	Evaporation (mm)
	max	min	max	min				
01 Oct - 07Oct	32.6	20.8	87.4	50.0	5.6	7.6	11.0	5.4
08 Oct - 14Oct	33.7	20.1	88.0	30.3	5.1	7.7	0.0	6.2
15 Oct - 21 Oct	33.2	20.0	76.9	36.9	4.8	8.6	0.6	5.5
22 Oct - 28 Oct	33.2	19.1	73.1	31.7	4.7	8.5	0.0	5.8
29 Oct - 04 Nov	31.9	17.2	67.3	34.7	5.8	9.1	0.0	6.2
05 Nov - 11 Nov	33.2	19.3	75.6	37.4	4.5	8.1	0.0	5.0
12 Nov - 18 Nov	32.3	14.3	73.9	30.7	3.4	9.2	0.0	4.8
19 Nov - 25 Nov	30.1	17.5	89.7	55.1	4.0	5.3	1.9	3.1
26 Nov -02 Dec	29.1	12.6	80.9	32.9	3.8	8.4	0.0	3.9
03 Dec - 09 Dec	30.5	15.9	82.4	38.9	3.5	7.1	0.0	3.7
10 Dec - 16 Dec	29.9	13.6	73.1	32.1	4.7	6.9	0.0	4.6
17 Dec - 23 Dec	27.4	12.0	81.4	41.0	4.3	8.2	0.0	3.7
24 Dec - 30 Dec	29.2	11.7	78.1	29.3	4.4	8.2	0.0	4.3
31 Dec – 6 Jan	29.5	8.6	68.4	20.4	3.4	9.2	0.0	3.9
7 Jan – 13 Jan	29.9	9.7	75.3	25.6	3.5	8.7	0.0	3.9
14 Jan – 20 Jan	30.8	12.4	74.4	29.1	3.6	8.5	0.0	4.1
21 Jan – 27 Jan	29.9	11.3	75.7	5.2	8.2	8.2	0.0	4.8
28 Jan – 3 Feb	28.3	12.1	67.1	31.3	5.1	8.6	0.0	4.4
4 Feb – 10 Feb	30.4	11.5	71.1	24.1	6.4	9.5	0.0	6.1
11 Feb – 17 Feb	32.5	15.0	68.3	24.4	5.4	9.4	0.0	6.1
18 Feb – 24 Feb	34.9	16.3	73.9	21.3	4.4	9.3	0.0	6.1
25 Feb – 3 Mar	33.4	13.7	61.7	16.6	6.0	9.7	0.0	7.5
4 Mar – 10 Mar	34.6	14.9	72.0	16.6	6.7	9.2	0.0	7.7
11 Mar – 17 Mar	36.2	17.1	48.0	15.1	6.1	8.9	0.0	8.6
18 Mar – 24 Mar	36.8	17.2	48.0	13.9	6.1	8.9	0.0	9.2
25 Mar – 31 Mar	39.4	20.2	54.1	13.6	6.2	8.6	0.0	9.7

Meteorological data recorded during experiment at NIASM, Malegaon (Baramati)

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VITAE

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