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The influence of drought stress on morpho-physiological traits of three distinct strawberry varieties

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Abstract
To investigate the changes in strawberry growth and chlorophyll contents under drought stress, the interaction impact of polyethylene glycol (PEG) and cultivars was assessed. In the North-Eastern area, where rainfall is the main source of irrigation, this experiment was conducted to better understand the mechanisms by which strawberries may tolerate drought stress when they are exposed to inadequate water supply. Three strawberry cultivars Winter Star, Brilliance, and Winter Dawn were grown in this experiment in a sand and cocopeat (2:1) culture for 30 days to allow them to fully establish after planting. Then, 4 levels of PEG 0%, 5%, 10%, and 20% were added twice a week for 14 days to simulate drought stress before the plants were uprooted for further investigation. The outcomes of this study show that the treatments had a detrimental effect on the morpho-physiological parameters. Examined after 7 and 14 days of the therapy, shoot length, root length, and chlorophyll levels were drastically decreased. The least decreased was shown in Winter Star, followed by Winter Dawn at 0% PEG, indicating higher tolerance when taking into account the morpho-physiological characteristics. The inhibition was more prominent in 20% PEG and Brilliance cultivar.

Keywords: Drought, polyethylene glycol (PEG), strawberry cultivar**,** morpho-physiological

Introduction
Among the most significant temperate fruit is strawberry (*Fragaria* x *ananassa* Duch), which belongs to the Rosaceae family and has an X=7 basic chromosome number. It is a hybrid crop created by humans by crossing *Fragaria* x *virginiana* and *Fragaria* x *chiloensis*. Strawberry can thrive in a wide range of temperatures, including temperate, Mediterranean, subtropical, and even tropical high-altitude regions. Most of it is grown India's Mahabaleshwar, Wai, and Panchagani districts of Maharashtra, Satara districts as well as some areas of Jammu & Kashmir, Himachal Pradesh and Meghalaya. (Thokchom *et al*., 2019) [25].
Its ploidy levels range from diploids to tetraploids to pentaploids to hexaploids (single species) to octoploids. Strawberries are a herbaceous fruit that is very sensitive to water stress due to their shallow root system (approximately 50–90% of the roots are in the 0–15 cm zone). Klamkowski and Treder (2006) [12]. Due to its colour, shape, and flavour, as well as its high nutritional value, strawberries have grown to be a beloved fruit.
The majority of producers in India's northeastern region are drawn to strawberries because of their high nutritional worth and economic importance. But regrettably, during their period of growth and development, they are exposed to specific environmental challenges that impede their ability to produce. Drought is among the main environmental factors that have a harmful impact on plant growth, income, and long-term productivity. Stress brought on by heavy metals, salt, extremes of temperature, and drought is pervasive in many agricultural areas of the world. Recent agricultural droughts have highlighted the importance of water, largely due to the consequences of climate change. Plants acquire physiological, biochemical, and molecular tolerance mechanisms to adapt to the environment in response to drought stress. As a result, cultivars resistant to drought are highly sought after. This abiotic stress has a detrimental effect on the strawberry, the most important small fruit crop.
According to Rizza *et al*. (2004) [20], drought stress is associated with a variety of morphological and physiological characteristics in plants, including smaller plants, early

maturation, and lower leaf area. A decline in plant height can be linked to the storage of carbohydrates for ongoing metabolism and an accumulation of solute for osmotic adjustment by plants according to (Sunkar and Bartels 2005) [5]. While extending the root system and enhancing leaf abscission, wax deposition, number of leaves per plant, size, and lifespan, drought stress also reduces leaf area and shoot length (Shao *et al*., 2008; Jamali *et al*., 2011) [21, 11]

Reactive oxygen species (ROS) signalling is significantly influenced by drought stress, which results in oxidative cell damage. ROS like H_2O_2 increase in the roots and leaves of strawberry plants under drought stress (Neocleous *et al*., 2012) [16]. Antioxidants such catalase, superoxide dismutase, and peroxidase were produced as a result of the rise in H2O2, which altered how plants responded to water shortages (Miller *et al*., 2010; Suzuki *et al*., 2012) [14, 23]. Ascorbic acids (AsA), glutathione (GSH), tocopherol (vitamin E), flavonoids, alkaloids, and carotenoids are examples of non-enzymatic antioxidants. Enzymatic antioxidants include superoxide dismutase (SOD), peroxidases (POX), catalase (CAT), glutathione reductase (GR), glutathione-S-transferase (GST), and other molecules.

Materials and Method

The experiment was conducted in a controlled environment in a lab at the Central Agricultural University's College of Horticulture and Forestry in Pasighat, East Siang District, Arunachal Pradesh, India.

- **a) Runners collection and germination:** The strawberry runners to be used in this experiment will be collected from Zico Nursery farm, Imphal East, Manipur.
- **b) Sand preparation:** The river sand will first be thoroughly washed with water, then soaked overnight in an alkali solution (1N NaOH), and then again washed with water to remove the alkali. The same process is repeated with an acid solution (1N HCl), and the sand will be washed repeatedly until all the organic matter has been removed from the sand and the pH is balanced. The sand will be moved to clean polybags and deposited in a dry area in a shaded net house after being dried entirely in a hot air oven.
- **c) Transplanting of runners:** They will be moved into tidy polybags that are packed with sand and cocopeat (2:1).
- **d) Establishment of runners:** Until the transplanted runners have established themselves in the sand and cocopeat combination and are prepared for treatment application, they will be watered with a nutrient solution twice a week (Hoagland and Arnon, 1950) [9].
- **e) Treatment application:** The plants will be watered with nutrient solution containing the appropriate quantities of polyethylene glycol (PEG) after they have taken root in their pots. Each pot will get the nutrient solution containing treatments twice a week. Whenever necessary, irrigation with distilled water will also be carried out.
- **f) Sample collection:** At 7 and 14 days following the application of the treatment's initial dose, samples of the roots and leaves will be taken. The collected samples will then be subjected to analysis to determine the parameters which have been listed in the following pages.
- **g) Treatment details:** The experiment will be arranged in a completely randomized design with 3 replicates. The treatments which are considered for this experiment are 3 concentrations of PEG and strawberry cultivars. Untreated pots will be observed as control. The concentrations of PEG to be used are 0, 5, 10, 20%. The strawberry cultivar to be considered for this experiment Winter Star, Brilliance and Winter Dawn
- **h) Morpho-Physiological parameters**
  The plantlets were uprooted 7 and 14 days following the treatment in order to ascertain the physiology of the strawberry plantlets produced under drought stress. The roots and shoots were separated, and ten random samplings in triplicate were used to calculate the length of leaves and roots.
  1. **Shoot length (cm):** With the help of a centimetre scale in cm, the shoot lengths of 10 randomly selected plants were measured from the tallest tips to the end of the crown, and their mean values were determined.
  2. **Root length (cm):** With the use of a centimetre scale in cm, the root lengths of 10 randomly selected plants were measured from the crown end to the tip of the longest root, and their averages were calculated.
  3. **Estimation of total chlorophyll, chlorophyll a and chlorophyll b (Arnon, 1949) [3]:** Chlorophyll estimation in leaves was done as per Arnon's method (Arnon, 1949) [3]. One gram of finely cut fresh leaves was taken and ground with 20 ml of 80% acetone. The mixture was then centrifuged at 5000 rpm for 5 minutes. The supernatant was transferred and the procedure was repeated till the residue became colorless. The absorbance of the solution was read at 470, 648 and 664 nm against the solvent (80% acetone) blank.

Chlorophyll a (mg/g) = [(13.36 X Abs @664 nm)−(5.19 X Abs @645nm)] X Volume of the sample (L) / Weight of the sample (g)

- Chlorophyll b (mg/g) = [(27.43 X Abs @648 nm) −(8.12 X Abs @664 nm)] X Volume of sample(L) / Weight of the sample (g)
- Total chlorophyll (mg/g) = [5.24 (Abs @664 nm) + 22.24 (Abs @648 nm)] ×Volume of sample (L) / Weight of sample (g)
- Total carotenoid (mg/100g) = [(4.785 X Abs @470nm)+(3.657 X Abs @664) (12.76 X Abs @648)] X Vol. of sample (L) / Weight of the sample (g)

Where,
Abs= Absorbance at specific wavelengths
V= Final volume of chlorophyll extract in 80% acetone
W= fresh weight of tissue extracted.

Results

Shoot length

At 7 day observation, the size of the shoots varied from 11.22 cm to 16.01 cm. The Winter Star cultivar treated with 0% PEG levels had the longest shoots (16.01 cm), followed by the Winter Star cultivar treated with 5% PEG levels (15.80 cm), and the Brilliance treated with 20% PEG levels had the shortest shoots (11.22 cm). In Winter Star, Brilliance and Winter Dawn, it was clear that the interaction between PEG and variety resulted in less shoot growth (Table 1). Brilliance experienced a more dramatic decline than Winter Star and Winter Dawn. At 5%,10% and 20%, Winter Star showed decrease of 1.86% 4.35% and 7.45%, Brilliance showed a decrease of 1.56%, 5.53% and 20.48% and Winter Dawn showed a decrease of 6.44%,9.78% and11.20%.

After 14 days of treatment application, the size of the shoots varied from 12.11 cm to 17.50 cm. The Winter Star cultivar treated with 0% PEG levels had the longest shoots (17.50), followed by the Winter Star cultivar treated with 5% PEG levels (17.10 cm), and the Brilliance treated with 20% PEG levels had the shortest shoots (12.11cm). At 5%, 10% and 20%, Winter Star showed a decrease of 2.29%, 4.57% and 7.37%, Brilliance showed decrease of 1.83%, 6.81% and 20.69% and Winter Dawn showed a decrease of 7.35%, 13.92% and 16.27%

Root length

After 7 days of the treatments were applied, the combination between PEG treatments and cultivars resulted in a significant reduction in root growth. Between the various PEG treatments and types, a substantial difference in root length was seen. It was 3.04 cm to 11.23 cm in size. The maximum root length was discovered in Winter Star treated with 0% PEG (11.23 cm), and the minimum root length was discovered in Brilliance treated with 20% PEG (3.04 cm), showing the least amount of decrease among the treatments.

When exposed to drought stress, the root length of the variety Winter Dawn decreased by 7.7% 12.5% and 20.4% the variety Brilliance's root length decreased by 31.46%, 35.71% and 48.30% as a result of 5%, 10% and 20% PEG treatments, and the Winter Star's root length decreased by 5.34%, 10.69% and 16.03% as a result of 5%, 10% and 20% PEG treatments, which showed the least decrease percentage among the treatments.

After 14 days of treatment application, the length of the root varied from 5.01 cm to 12.3 cm. The Winter Star cultivar treated with 0% PEG levels had the longest root (12.30), followed by the Winter Star cultivar treated with 5% PEG levels (11.07 cm), and the Brilliance treated with 20% PEG levels had the shortest shoots (5.01). At 5%,10% and 20%, Winter Star showed a decrease of 4.88%, 9.79% and 14.63, Brilliance showed a decrease of 12.16%, 16.02% and 28.33% and Winter Dawn showed a decrease of 7.18%, 11.27% and 25.64%.

Chlorophyll A

At the conclusion of the observation, or 7 days after the treatments, the interaction of PEG and variety revealed substantial differences in chlorophyll 'a' content between the treatments. Chlorophyll 'a' content was found to be reduced in all of the types at increased PEG levels, with values ranging from 0.26 to 1.19 mg/g. Chlorophyll 'a' levels were highest in Winter Star plants treated with 0% PEG (1.19 mg/g), followed by Winter Star plants treated with 5% PEG (1.15 mg/g), and lowest in Brilliance, plants treated with 20% PEG (0.26 mg/g). When exposed to 5%, 10% and 20% PEG treatments as opposed to 0% PEG treatment, it was found that all kinds of chlorophyll 'a' decreased. The Winter Dawn variety percentage decline, at 6.56%, 13.11% and 21.31, followed by Brilliance at 27.91%, 32.56% and 39.53% at 5%, 10% and 20% PEG levels, respectively. Winter Star percentage decline, with 3.36%, 8.40% and 13.45 at 5%, 10% and 20% PEG levels, respectively, compared to 0% PEG level. After 14 days of treatment Chlorophyll 'a' content was found to be reduced in all of the types at increased PEG levels, with values ranging from 0.29 to 1.25 mg/g. Chlorophyll 'a' levels were highest in Winter Star plants treated with 0% PEG (1.25 mg/g), followed by Winter Star plants treated with 5% PEG (1.22 mg/g), and lowest in Brilliance, plants treated with 20% PEG (0.29 mg/g). The Winter Dawn Cultivar percentage decline, at 7.46%, 14.93% and 23.88%, followed by Brilliance at 25%, 37.5% and 48.21% at 5%,10% and 20% PEG levels, respectively. Winter Star percentage decline, with 2.4%, 6.40% and 7.2% at 5%, 10% and 20% PEG levels, respectively, compared to 0% PEG level.

Chlorophyll B

At the conclusion of the observation, the combined effects of PEG and cultivars showed a significant difference between the treatments. Chlorophyll 'b' content decreased in all the cultivars at high PEG concentrations, with values ranging from 0.09 to 0.29 mg/g. The highest concentration of chlorophyll 'b' was found in Brilliance that had been treated with 0% PEG (0.29 mg/g), followed by Brilliance that had been treated with 5% PEG (0.26 mg/g), and the lowest concentration of chlorophyll 'b' was found in Winter Star that had been treated with 20% PEG (0.09 mg/g), respectively.

In comparison to 0% PEG treatment, it was found that all kinds of chlorophyll 'b' decreased at 5%, 10% and 20% PEG concentrations. 10.34%, 27.59% and 44.83% less were seen in Brilliance, 14.29%, 28.57% and 35.71% less in Winter Dawn, and 17.39%, 26.09% and 39.13% less in Winter Dawn, respectively.

After 14 days of treatment Chlorophyll 'b' content decreased in all the cultivars at high PEG concentrations, with values ranging from 0.10 to 0.33 mg/g. The highest concentration of chlorophyll 'b' was found in Brilliance that had been treated with 0% PEG (0.33 mg/g), followed by Brilliance that had been treated with 5% PEG (0.28 mg/g), and the lowest concentration of chlorophyll 'b' was found in Winter Star that had been treated with 20% PEG (0.10 mg/g), respectively. it was found that all kinds of chlorophyll 'b' decreased at 5%, 10% and 20% PEG concentrations. 15.15%, 30.30% and 48.15% less were seen in Winter Star, 33.33%, 38.89% and 44.44% less in Winter Star, and 14.81%, 22.22% and 48.15% less in Winter Dawn, respectively

Total chlorophyll: According to Table 5, there was a change in the amount of total chlorophyll. By the end of the observation, the interaction between PEG and cultivars revealed a significant reduction in the total chlorophyll among the cultivars at higher PEG concentrations. Values were between 0.61 to 1.94 mg/g. The lowest total chlorophyll content was found in Brilliance treated with 20% PEG (0.61 mg/g), while the greatest value was found in Winter Star treated with 0% PEG level (1.94 mg/g), followed by Winter Star treated with 5% PEG level (1.88 mg/g).

In comparison to 0% PEG treatment, it was found that all kinds of total chlorophyll decreased at 5%, 10% and 20% PEG concentrations. 3.09%, 6.19% and 7.22% less were seen in Winter Star, 5.81%, 10.47% and 26.74% less in Winter Dawn, and 7.06%, 12.94% and 28.24 less in Brilliance, respectively

After 14 days of treatment Values were between 0.83 to 2.45 mg/g. The lowest total chlorophyll content was found in Brilliance treated with 20% PEG (0.83 mg/g), while the greatest value was found in Winter Star treated with 0% PEG level (2.45 mg/g), followed by Winter Star treated with 5% PEG level (2.27 mg/g). In comparison to 0% PEG treatment, it was found that all kinds of total chlorophyll decreased at 5%, 10% and 20% PEG concentrations. 7.35%, 17.55% and 20.00% less were seen in Winter Star, 5.22%, 12.17% and 22.61% less in Winter Dawn, and 8.15%, 16.30% and 38.52% less in Brilliance, respectively.

Table 1: Effect of PEG levels and cultivars on shoot length (cm) under drought stress conditions

Shoot length at 7 days					Shoot length at 14 days			
Treatments	Winter Star	Brilliance	Winter Dawn	Mean	Winter Star	Brilliance	Winter Dawn	Mean
T1(0%)	16.1	14.11	15.54	15.26	17.5	15.27	16.59	16.45
T2(5%)	15.8 (-1.86)	13.89 (-1.56)	14.54 (-6.44)	14.74	17.10 (-2.29)	14.99 (-1.83)	15.37 (-7.35)	15.82
T3(10%)	15.4 (-4.35)	13.33 (-5.53)	14.02 (-9.78)	14.25	16.7 (-4.57)	14.23 (-6.81)	14.28 (-13.92)	15.07
T4(20%)	14.9 (-7.45)	11.22 (-20.48)	13.8 (-11.2)	13.31	16.21 (-7.37)	12.11 (-20.69)	13.89 (-16.27)	14.07
Mean	15.55	13.34	15.22		16.88	14.15	15.04	
Factors	C.D.	SE(d)	SE(m)		Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.284	0.137	0.097		Factor(A)	0.368	0.177	0.125
Factor(B)	0.328	0.158	0.112		Factor(B)	0.425	0.205	0.145
Factor (A X B)	0.568	0.274	0.193		Factor (A X B)	0.736	0.354	0.251

Table 2: Effect of PEG levels and cultivars on root length (cm) under drought stress conditions

Root length at 7 days					Root length at 14 days			
Treatments	Winter Star	Brilliance	Winter Dawn	Mean	Winter Star	Brilliance	Winter Dawn	Mean
T1(0%)	11.23	5.88	9.89	9	12.30	6.99	11	10.1
T2(5%)	10.63 (-5.34)	4.03 (-31.46)	9.13 (-7.7)	7.93	11.7 (-4.88)	6.14 (-12.16)	10.21 (-7.18)	9.35
T3(10%)	10.03 (-10.69)	3.78 (-35.71)	8.65 (-12.5)	7.49	11.11 (-9.79)	5.87 (-16.02)	9.76 (-11.27)	8.91
T4(20%)	9.43 (-16.03)	3.04 (-48.3)	7.87 (-20.4)	6.78	10.5 (-14.63)	5.01 (-28.33)	8.18 (-25.64)	7.90
Mean	10.47	5.11	8.89		11.41	6.10	9.79	
Factors	C.D.	SE(d)	SE(m)		Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.149	0.072	0.051		Factor(A)	0.214	0.103	0.073
Factor(B)	0.172	0.083	0.058		Factor(B)	0.247	0.119	0.084
Factor (A X B)	0.298	0.143	0.101		Factor (A X B)	0.428	0.206	0.146

Table 3: Effect of PEG levels and cultivars on chlorophyll 'a' (mg/g) under drought stress conditions

Chlorophyll-a at 7 days					Chlorophyll-a at 14 days			
Treatments	Winter Star	Brilliance	Winter Dawn	Mean	Winter Star	Brilliance	Winter Dawn	Mean
T1(0%)	1.19	0.43	0.61	0.74	1.25	0.56	0.67	0.83
T2(5%)	1.15 (-3.36)	0.31 (-27.91)	0.57 (-6.56)	0.68	1.22 (-2.4)	0.42 (-25)	0.62 (-7.46)	0.75
T3(10%)	1.09 (-8.40)	0.29 (-32.56)	0.53 (-13.11)	0.64	1.17 (-6.4)	0.35 (-37.5)	0.57 (-14.93)	0.70
T4(20%)	1.03 (-13.45)	0.26 (-39.53)	0.48 (-21.31)	0.59	1.16 (-7.2)	0.29 (-48.21)	0.51 (-23.88)	0.65
Mean	1.12	0.32	0.55		1.20	0.41	0.59	
Factors	C.D.	SE(d)	SE(m)		Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.012	0.006	0.004		Factor(A)	0.016	0.008	0.006
Factor(B)	0.014	0.007	0.005		Factor(B)	0.019	0.009	0.006
Factor (A X B)	0.024	0.011	0.008		Factor(A X B)	0.033	0.016	0.011

Table 4: Effect of PEG levels and cultivars on chlorophyll 'b' (mg/g) under drought stress conditions

Chlorophyll-b at 7 days					Chlorophyll-b at 14 days			
Treatments	Winter Star	Brilliance	Winter Dawn	Mean	Winter Star	Brilliance	Winter Dawn	Mean
T1(0%)	0.14	0.29	0.23	0.22	0.18	0.33	0.27	0.26
T2(5%)	0.12 (-14.29)	0.26 (-10.34)	0.19 (-17.39)	0.19	0.12 (-33.33)	0.28 (-15.15)	0.23 (-14.81)	0.21
T3(10%)	0.10 (-28.57)	0.21 (-27.59)	0.17 (-26.09)	0.16	0.11 (-38.89)	0.23 (-30.30)	0.21 (-22.22)	0.18
T4(20%)	0.09 (-35.71)	0.16 (-44.83)	0.14(-39.13)	0.13	0.10 (-44.44)	0.17 (-48.48)	0.14 (-48.15)	0.14
Mean	0.11	0.23	0.18		0.13	0.25	0.21	
Factors	C.D.	SE(d)	SE(m)		Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.004	0.002	0.001		Factor(A)	0.005	0.002	0.002
Factor(B)	0.005	0.002	0.002		Factor(B)	0.006	0.003	0.002
Factor (A X B)	0.009	0.004	0.003		Factor (A X B)	0.010	0.005	0.003

Table 5: Effect of PEG levels and cultivars on total chlorophyll (mg/g) under drought stress conditions

Total chlorophyll at 7 days					Total chlorophyll at 14 days			
Treatments	Winter Star	Brilliance	Winter Dawn	Mean	Winter Star	Brilliance	Winter Dawn	Mean
T1(0%)	1.94	0.85	0.86	1.22	2.45	1.35	1.15	1.65
T2(5%)	1.88 (-3.09)	0.79 (-7.06)	0.81 (-5.81)	1.16	2.27 (-7.35)	1.24 (-8.15)	1.09 (-5.22)	1.53
T3(10%)	1.82 (-6.19)	0.74 (-12.94)	0.77 (-10.47)	1.11	2.02 (-17.55)	1.13 (16.30)	1.01 (-12.17)	1.39
T4(20%)	1.8 (-7.22)	0.61 (-28.24)	0.63 (-26.74)	1.01	1.96 (-20.00)	0.83 (-38.52)	0.89 (-22.61)	1.23
Mean	1.86	0.75	0.77		2.18	1.14	1.04	
Factors	C.D.	SE(d)	SE(m)		Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.024	0.011	0.008		Factor(A)	0.029	0.014	0.010
Factor(B)	0.027	0.013	0.009		Factor(B)	0.033	0.016	0.011
Factor (A X B)	0.047	0.023	0.016		Factor (A X B)	0.057	0.028	0.019

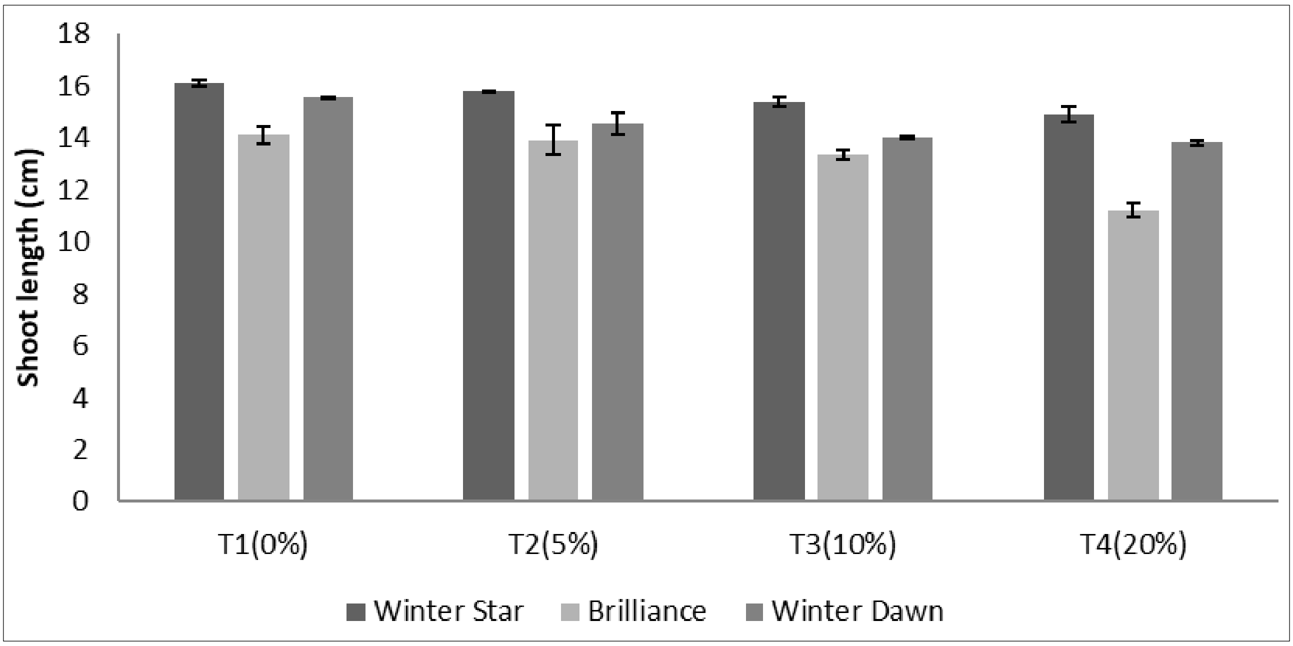

Fig 1a: Effect of drought on shoot length at 7 days interval

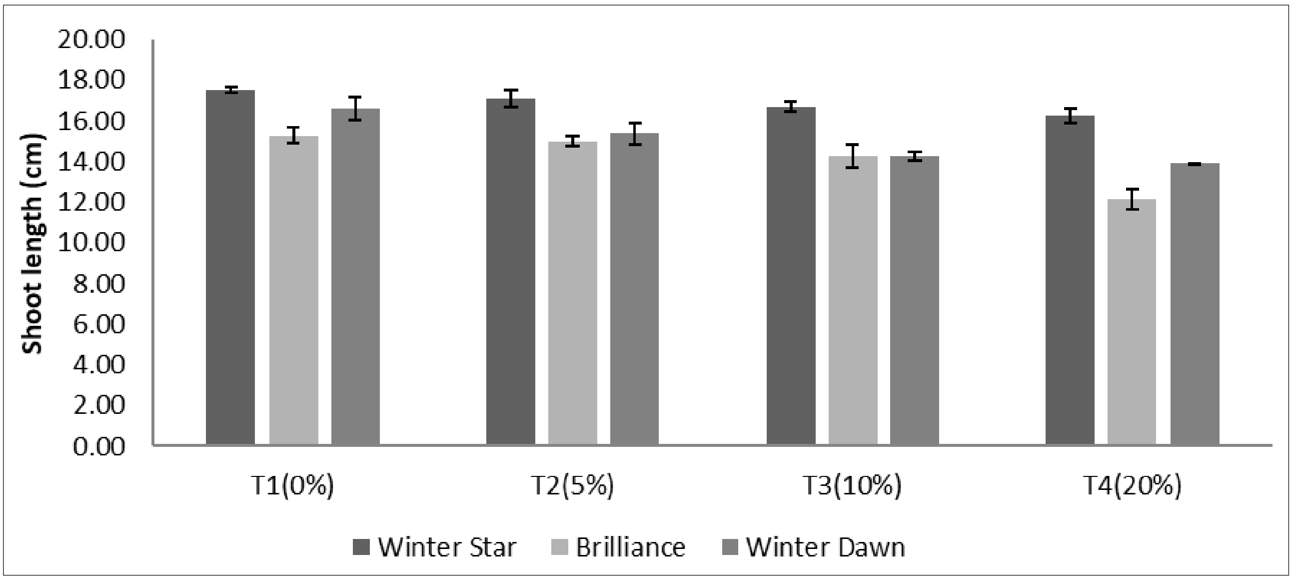

Fig 1b: Effect of drought on shoot length at 14 days interval

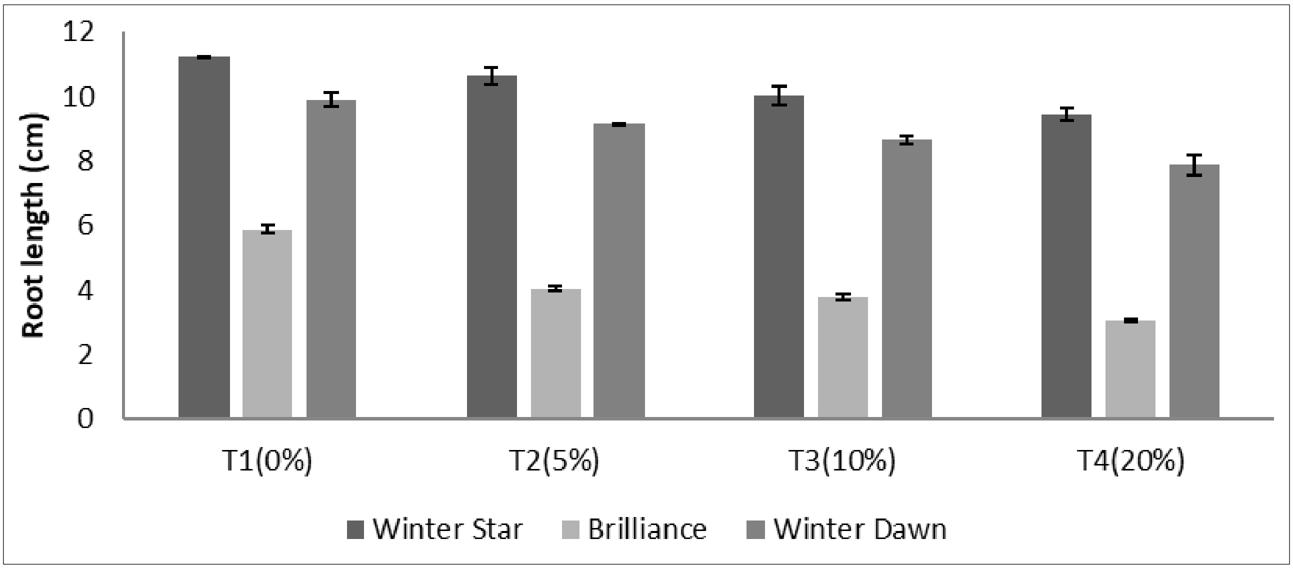

Fig 2a: Effect of drought on root length at 7 days interval

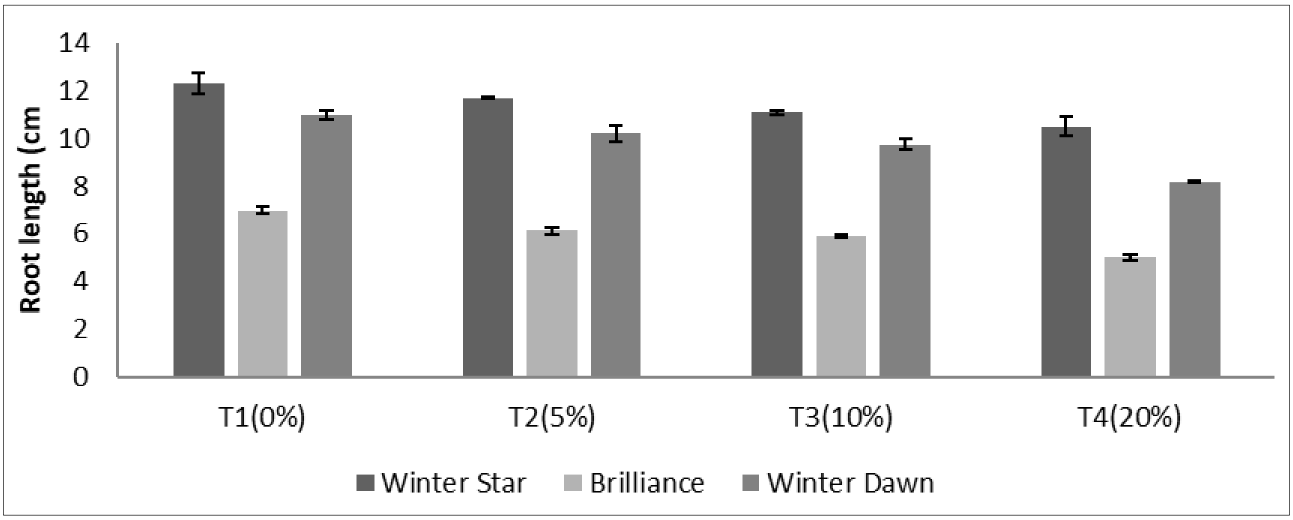

Fig 2b: Effect of drought on root length at 14 days interval

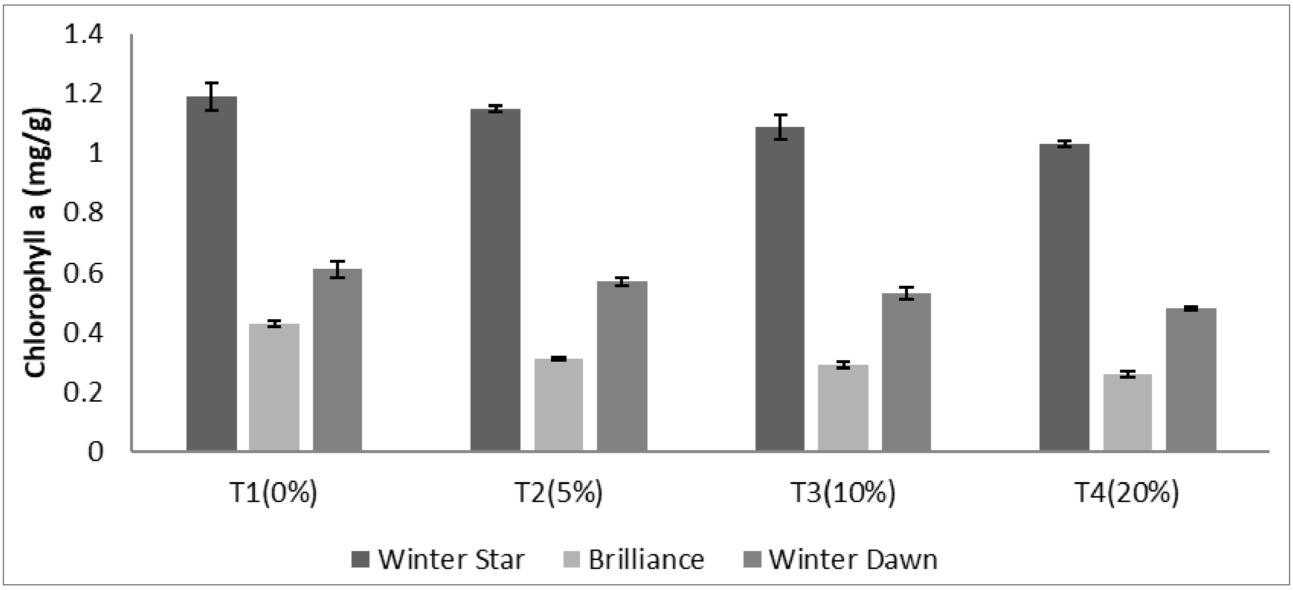

Fig 3a: Effect of drought on chlorophyll a content at 7 days interval

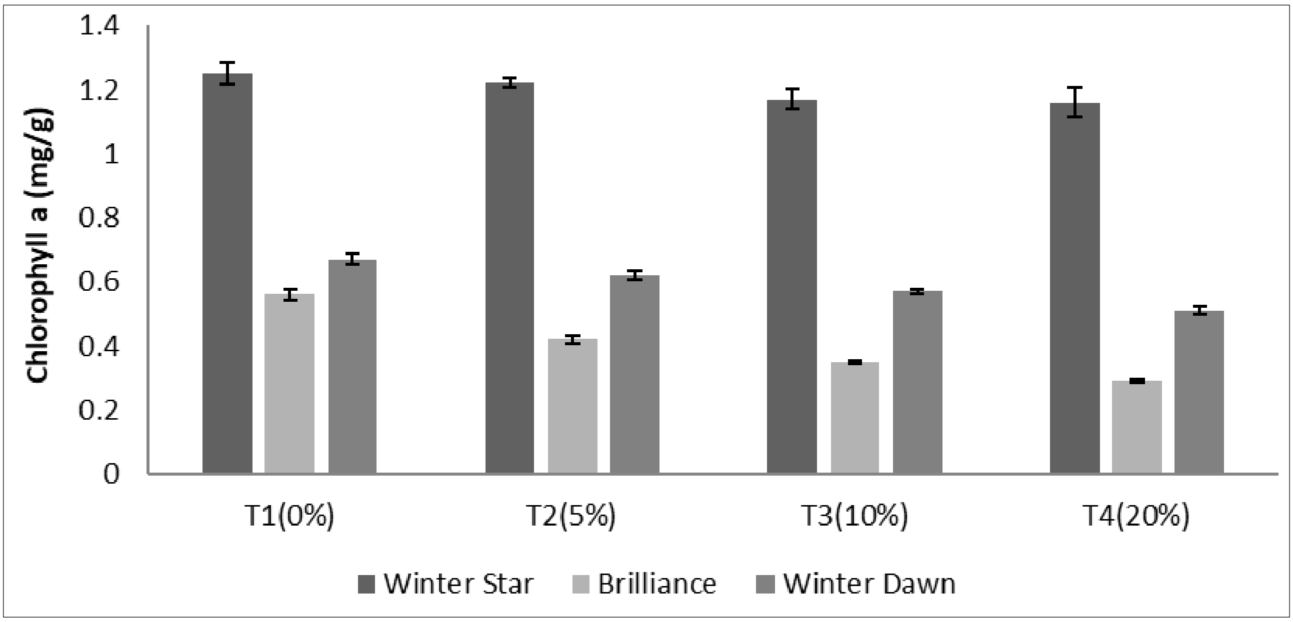

Fig 3b: Effect of drought on chlorophyll a content at 14 days interval

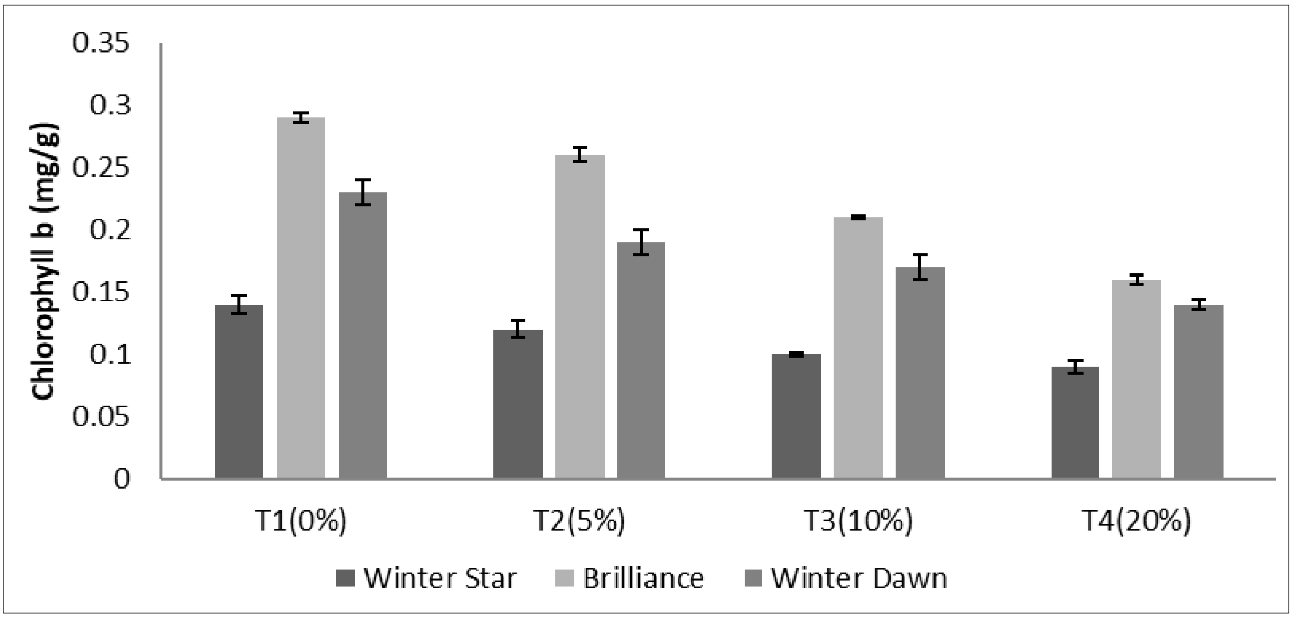

Fig 4a: Effect of drought on chlorophyll b content at 7 days interval

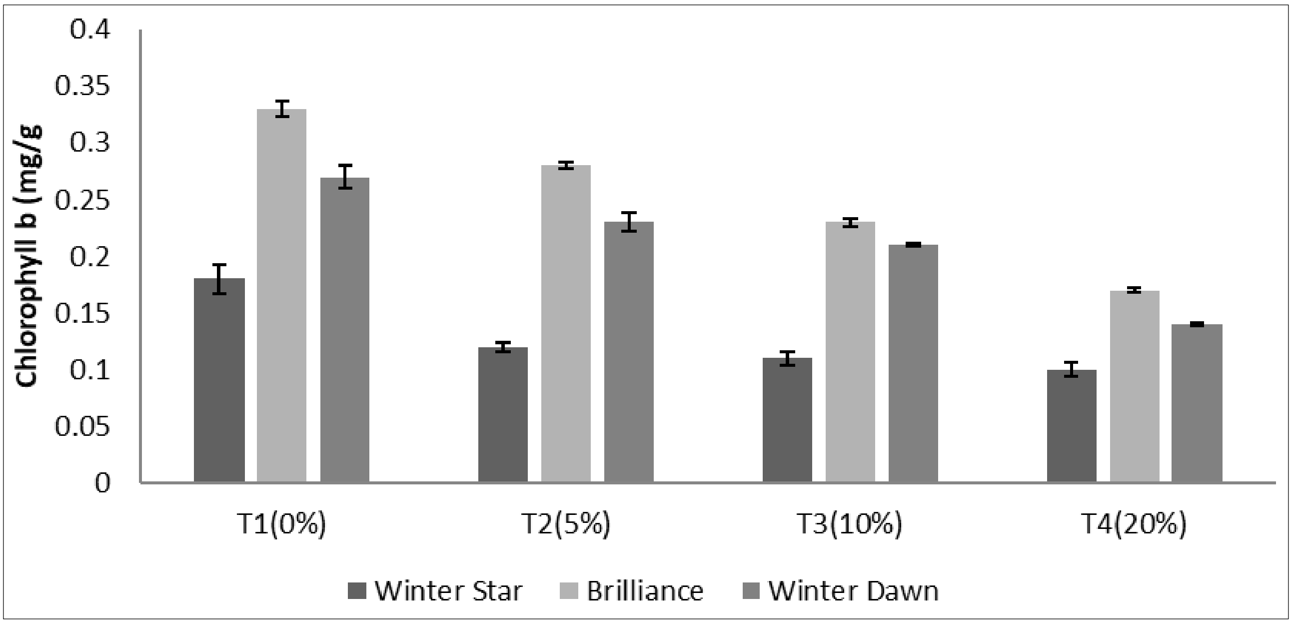

Fig 4b: Effect of drought on chlorophyll b content at 14 days interval

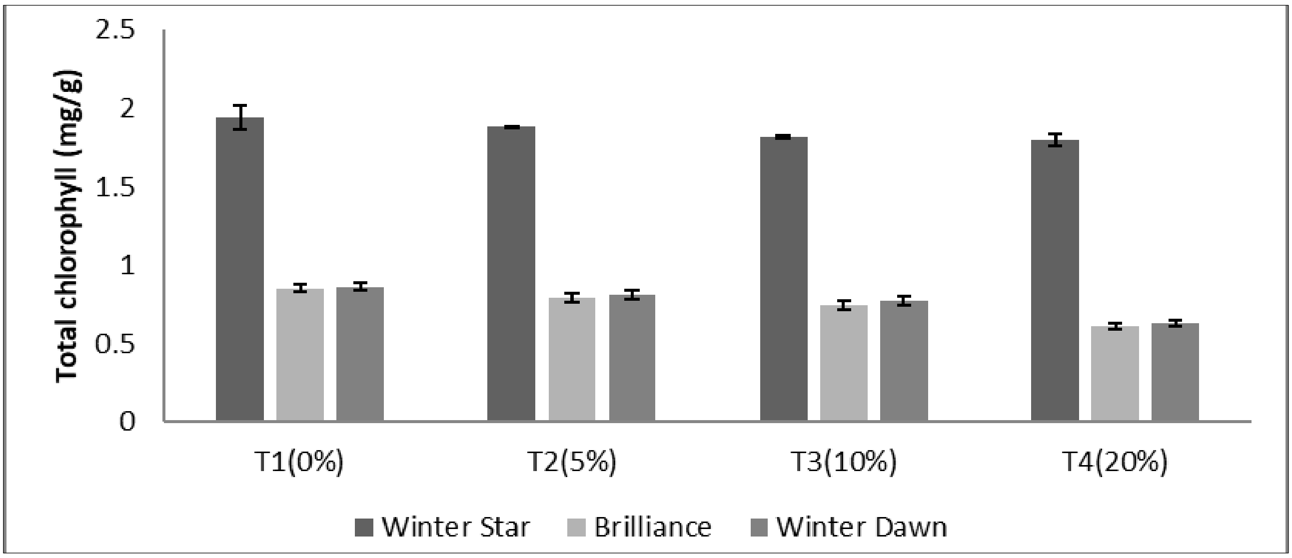

Fig 5a: Effect of drought on total chlorophyll content at 7 days interval

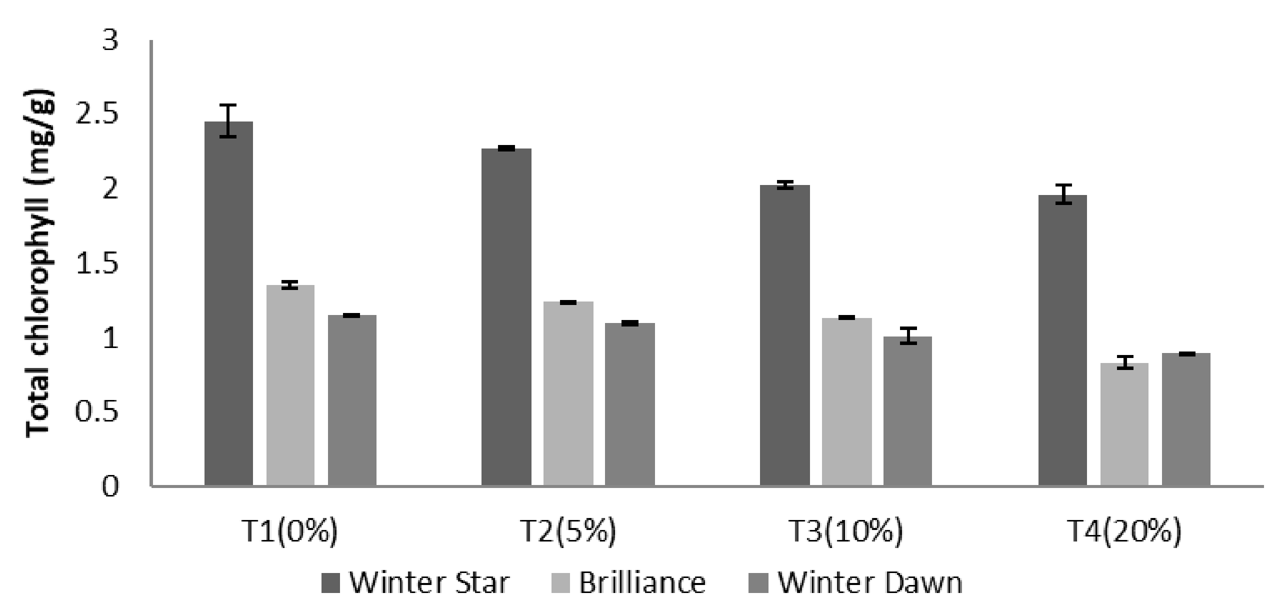

Fig 5(b): Effect of drought on total chlorophyll content at 14 days interval

Discussion

When the plants are under deficit water conditions, water supply is restricted which results in decline of cell water content, stomatal conductance, different metabolic processes and leads to reduced growth (Soni *et al.*, 2017) [22]. In strawberries, the tolerance ability to water deficit varies depending on the stage of growth, duration of the stress, systems of cultivation, growing medium and varieties (Adak *et al.*, 2017) [1]. Drought stress also results in the generation of Reactive Oxygen Species (ROS) *viz.* superoxide anion, hydrogen peroxide, hydroxyl radical and singlet oxygen (Arora *et al.*, 2002) [4] and as a result, the production of ROS leads to the oxidative damage of the cell. Plants possess a specific antioxidant activity that have the capacity to detoxify ROS and protects the cells from the oxidative damage. (Gue *et al.*, 2006) [8]. Other than anti-oxidants, osmolytes such as proline and glycine betaine that are produced under water deficit are also known to involve in the ROS sequestration and protects complex organelles and molecules (Szabados and Savoure, 2010; Moller *et al.*, 2007) [24, 15]. Different species have different anomalies to cope with oxidative damage caused by drought stress (Pirlak and Esitken, 2004) [19]. Studies had been carried out earlier in many crops to identify the mechanism of drought tolerance with fewer focused on strawberry.

Drought stress was known to cause a dynamic change in the plants system with respect to morphology, physiology and molecular aspects. As observed from the result, shoot length was found to have a significant affect due to PEG. Shoot, root length, dry weight and RWC, showed a decreasing pattern with the increase in PEG concentrations i.e., the highest reduction was recorded in 20% PEG level followed by 10% PEG. The findings ofthe reduction in shoot growth under drought are in agreement with Hussein *et al.* (2017) [10], Nezhadahmadi *et al.* (2015) [17] and Yao-jing *et al.* (2013) [26] in strawberry. Similarly, the length of the root also declined with response to PEG level with Hussein *et al.* (2017) [10] who studied drought stress in strawberry cv. Fortuna and Festival induced by polyethylene glycol (PEG) in *in vitro* condition and found that root length decreased in both the cultivar under drought. The degree of response of plant to water stress differed significantly at various levels depending upon the intensity and duration, plant species and their stage of growth (Chaves *et al.*, 2002) [6]. RWC was found to be affected by the interaction of drought severity, duration and crop species. The result is also inconformity with the work of Parvin *et al.* (2015) [15] who in their studies of the effect of different water stress levels (-1, -5, and -10 bars) and paclobutrazol application (0 and 50 mg^{-l}) on strawberry cv.

Chl a, Chl b and total chlorophyll declined in response to the level of PEG with 20% PEG showing the lowest cholophyll content followed by 10% PEG level as compared to 0% PEG. The decrease in chlorophyll content in the stressed plants might be due to photo-oxidation of the pigments, degradation of chlorophyll and also due to lowered capacity of harvesting light (Anjum *et al.*, 2011; Mafakheri *et al.* 2010) [2, 13]. Zhang and Kirkham (1996) [27] reported that decrease in chlorophyll under drought stress depends on duration and severity of the level of drought. The result of the present findings is similar with Erdogan *et al.*, (2016) [7] who found that diminishing water supply caused gradual decrease in chlorophyll content in strawberry.

These findings have significant implications for horticultural practices and plant selection, especially in regions prone to water scarcity or changing climate patterns. By prioritizing winter star cultivars and considering their exceptional drought stress tolerance, growers and landscapers can enhance the sustainability and success of their gardens and green spaces. Furthermore, this research opens doors for further exploration into the genetic and physiological mechanisms that contribute to drought resistance in these cultivars, potentially paving the way for breeding and engineering efforts to develop even more resilient plant varieties.

Conclusions

Although the levels of tolerance and the amount of stress generated varied among the cultivars, the study's findings revealed that PEG, varieties, and their treatments together had a significant negative influence on all strawberry cultivars. When the stress was applied for 7 & 14 days, the influence of PEG caused a change in the growth characteristics of the plants even at its lower concentration. Additionally, because cultivars differed in their genotypic features, they showed a poor response in growth properties when pressured.

In conclusion, the study investigated the drought stress tolerance of three strawberry cultivars, winter star cultivars, winter dawn, and brilliance. The results clearly indicate that winter star cultivars exhibited the highest level of tolerance to drought stress, showcasing their remarkable adaptability and resilience under adverse conditions. However, the brilliance cultivar emerged as the most susceptible to drought stress, highlighting its sensitivity and vulnerability in challenging environmental conditions.

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