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Elevated carbon dioxide and temperature effects on rooting behaviour of grape cuttings

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ABSTRACT

An experiment was laid out to study the impact of eCO_2 (550ppm), eT (+3ºC) and their interaction (eCO_2+eT) on rooting behaviour of cuttings of three grape varieties- Thompson Seedless, Bangalore Blue, and Dogridge in FATE and OTC facilities. Observations were recorded at 50 and 80 days after planting (DAP) and root growth data was recorded and analysed using WinRHIZO root scanner and its software. Analysis revealed that, among the selected grape varieties, Thompson Seedless cuttings has shown highest number of roots, root volume and dry biomass under eCO_2 and eCO_2+ eT conditions, while total root length and root length density were highest with Bangalore Blue. Under eT condition, Bangalore Blue showed highest number of roots, total root length and root length density, while root volume and dry biomass was highest with Thompson Seedless. The *per se* values of root parameters under all conditions and their response to eCO_2 was lowest with Dogridge. Though eT condition reduced all the root parameters, their performance improved under eCO_2+ eT indicating the presence of higher concentration of CO_2 reduced the ill effects of high temperature. Overall, eCO_2 and eCO_2+eT conditions improved root parameters of grape varieties, while eT reduced them as compared to their performance under ambient condition and varietal variation is significant.

Key words: eCO_2, root growth, stem cuttings, varieties, WinRHIZO

Climate change is a global issue and expected to impact agricultural productivity and its quality. The changing patterns of climatic parameters like rise in atmospheric CO_2, temperature, changes in precipitation patterns, UV radiation and higher incidence of extreme weather events such as floods, heat waves are emerging as major threats for agricultural production. The climate change is a result of emission of greenhouse gases such as CO_2, CH_4, N_2O etc., which will cause atmosphere warming (IPCC 2007) and will affect all levels of life from species to ecosystem. Atmospheric concentrations of CO_2 have steadily increased from approximately 315 ppm in 1959 to a record high concentration of 417.2 ppm in May 2020. At this rate of increase, the concentration of CO_2 is projected to reach between 700 and 1000 ppm by 2100 (IPCC 2014). Rising concentrations of carbon dioxide will potentially increase global average surface temperatures by 1.4-5.8ºC. Therefore, it is important to quantify the interactive effects of increasing CO_2 and temperature on crop production. Grapes (*Vitis vinifera* L.) are sensitive to different environmental factors, including temperature, water availability and CO_2. Like other C_3 plants, grapevine photosynthesis is CO_2 limited (Mullins *et al*., 1992) and any increase of atmospheric CO_2 concentration could enhance accumulation of vegetative biomass and increase fruit yield (Bowes 1993; Rogers *et al*., 1994). It is observed that in the future grape yield increase as compared to the current climate (Kadbhane and Manekar (2020). Impact analyses of plant responses to elevated atmospheric CO_2 have focused largely on aboveground processes and very limited studies were on root growth and development especially with fruit crops. It is necessary to understand the response of roots towards elevated CO_2 condition as roots are interface between the lithosphere and biosphere. Root health in crop plants will play a major role in providing sustainable productivity as it enables to cope with changed climatic conditions. Keeping this in view the present research work was carried out with the objective to study the effect of elevated carbon dioxide and temperature on rooting behaviour of grape cuttings as well as variability in response of three popular grape cultivars.

MATERIALS AND METHODS

Plant materials

Hard wood stem cuttings of 25-30 cm length having 5-6 nodes of three popular grape varieties i.e. Thompson Seedless, Bangalore Blue, Dogridge were collected from the winter pruning of grape plants. Hard wood stem cuttings were treated with standard 1500 ppm IBA (Lab grade) solution and planted in poly bags. The poly bags are of 23×12×12 cm and filled with potting mixture of FYM+ red soil in 1:1 proportion and 15 number of cuttings each were exposed to ambient control, eCO_2, eT and eCO_2+eT conditions. The planted cuttings were kept under specially designed Open Top Chambers (OTC) and Free Air Temperature Enrichment (FATE) facilities in rabi 2017 at ICAR-CRIDA. The observations were recorded on three cuttings of each variety from all the conditions (ambient control, eCO_2, eT and eCO_2+eT) on number of roots, fresh and dry weight of roots (g pl^{-1}), root volume (ml pl^{-1}), total root length (cm), root diameter (mm) and root length density at 50 and 80 days after planting (DAP).

Treatments and experimental conditions

To study the rooting pattern, the cuttings planted in polybags were exposed to elevated carbon dioxide of 550 ppm in OTCs and elevated temperature (ambient+3°C), elevated carbon dioxide (550 ppm) + elevated temperature in FATE facility. In OTC (3x3x3 m) the desired levels of CO_2 (550 ppm) concentration was maintained by continuous injection of CO_2 into the plenum of OTCs, where it was mixed with air from air compressor before entering chamber and the set level of CO_2 concentration was maintained with the help of solenoid valves, rotometers, programme Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA) software.

Free Air Temperature Elevation (FATE) facility consisting of six rings fitted with 24 arrays of 2000 W capacity ceramic infrared heaters above the canopy to maintain elevated crop canopy temperature (eT) of ambient +3°C. Among these, three rings were also provided with CO_2 release system at 0.3m height from base of the ring to study the interactive effects of temperature and CO_2 (eT+eCO_2). The polyurethane (PU) tubing with perforations releases the CO_2 within the ring to maintain the elevated concentration of 550 ppm. The CO_2 in turn regulated by SCADA based control system linked with CO_2 analyser, wind direction and wind speed. The ambient control was maintained without any enhancement of CO_2 and temperature. WinRHIZO is an image analysis system specially designed for root measurement in different forms. The cuttings were harvested at 50 and 80 DAP and the roots were thoroughly washed to remove all soil particles. Scanning and image analysis was carried out using WinRHIZO root scanner (LA-1600) for root characteristics and the root morphology and architecture measurements such as total root length, root diameter, root length density and root volume were done by WinRHIZO program.

RESULTS AND DISCUSSION

Understanding the dynamics of crop roots is important from the point of view of management of available resources to increase the productivity of crops. Root parameters like number of roots, fresh and dry weight of roots, root volume, total root length, root diameter and root length density of three grape varieties were recorded at 50 and 80 days after planting under ambient control, eCO_2, eT and eCO_2+eT conditions.

Root number

At 50 DAP, Thompson Seedless (10.2±0.182) and Dogridge (6.3±0.54) showed maximum number of roots under eCO_2+eT, whereas in Bangalore Blue the maximum number of roots were found under eT (10.3±0.23) condition. While at 80 DAP, all the three varieties have shown highest number of roots under eCO_2 condition (Fig.1a). Among the three grape varieties, Thompson Seedless has shown higher number of roots under eCO_2 and eCO_2 + eT, while Bangalore Blue under eT and Dogridge under ambient conditions (Fig.1a).

At 50 DAP, increase in number of roots was 105 per cent (eCO_2), 216 per cent (eT), and 225 per cent (eCO_2+eT) in Thompson Seedless as compared with the ambient condition (Fig.1b). In Bangalore Blue there was 21, 121 and 79 per cent increase at eCO_2, eT, and eCO_2+eT, respectively over the control. Whereas, no response for

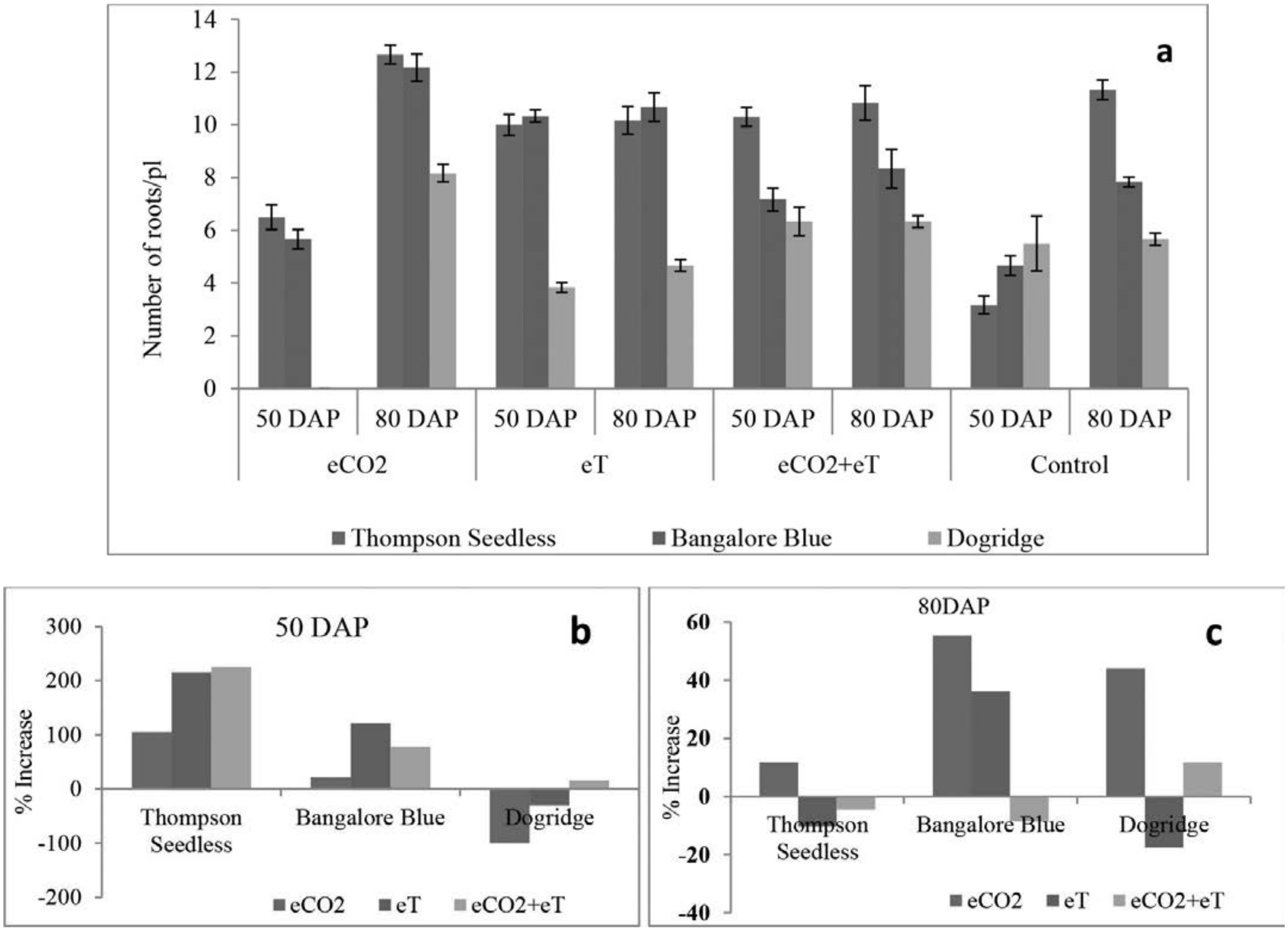

Fig. 1: (a) Number of roots of grape varieties under eCO_2, eT, eCO_2+eT and control conditions at 50 and 80 DAP; Percentage increase in number of roots over control (b). at 50 DAP and (c). at 80 DAP

number of roots under eCO_2 was observed with Dogridge while eT condition decreased it by 30 per cent, however, CO_2 in combination with eT (eCO_2+eT) increased root number by 15 per cent over ambient control (Fig.1b).

At 80 DAP, eCO_2 has shown 12, 55 and 14 per cent increase in number of roots in Thompson Seedless, Bangalore Blue and Dogridge, respectively over control. While eT has shown a decrease of 10 and 18 per cent in Bangalore Blue and Dogridge, respectively while an increase of 30 per cent was recorded with Thompson Seedless over control. At eCO_2+eT there was a decrease in number of roots of 4 and 9 per cent in Thompson Seedless and Bangalore Blue respectively while Dogridge showed 12 per cent increase in root number over control (Fig. 1c).

Root growth of most of the crops is enhanced under elevated atmospheric CO_2 (Rogers *et al*., 1994; Pritchard and Amthor, 2005), often to a greater extent than leaves, stem, and reproductive structures (Norby *et al*., 2001 and Kimball *et al*., 2002). According to Madhu and Jerry (2015), high CO_2 might have inhibited the growth at early stage of crop but due to adoptive mechanism to high CO_2 plants were recovered and responded physiologically at later stage. This is in accordance with Dogridge cuttings under eCO_2 at 50 DAP. The eCO_2 increases the carbon flow to the rhizosphere by increasing photosynthetic activity which in turn improves root production in plants (Rajkumar *et al*., 2013). More roots at all depths of the soil profile have been observed in sorghum when exposed to elevated CO_2 (Chaudhuri *et al*., 1986).

Total root length **(cm)**

At 50DAP, Thompson Seedless (309.0±30.4 cm) and Bangalore Blue (365.4±24.5 cm) have shown higher root length under eCO_2+eT while Dogridge has

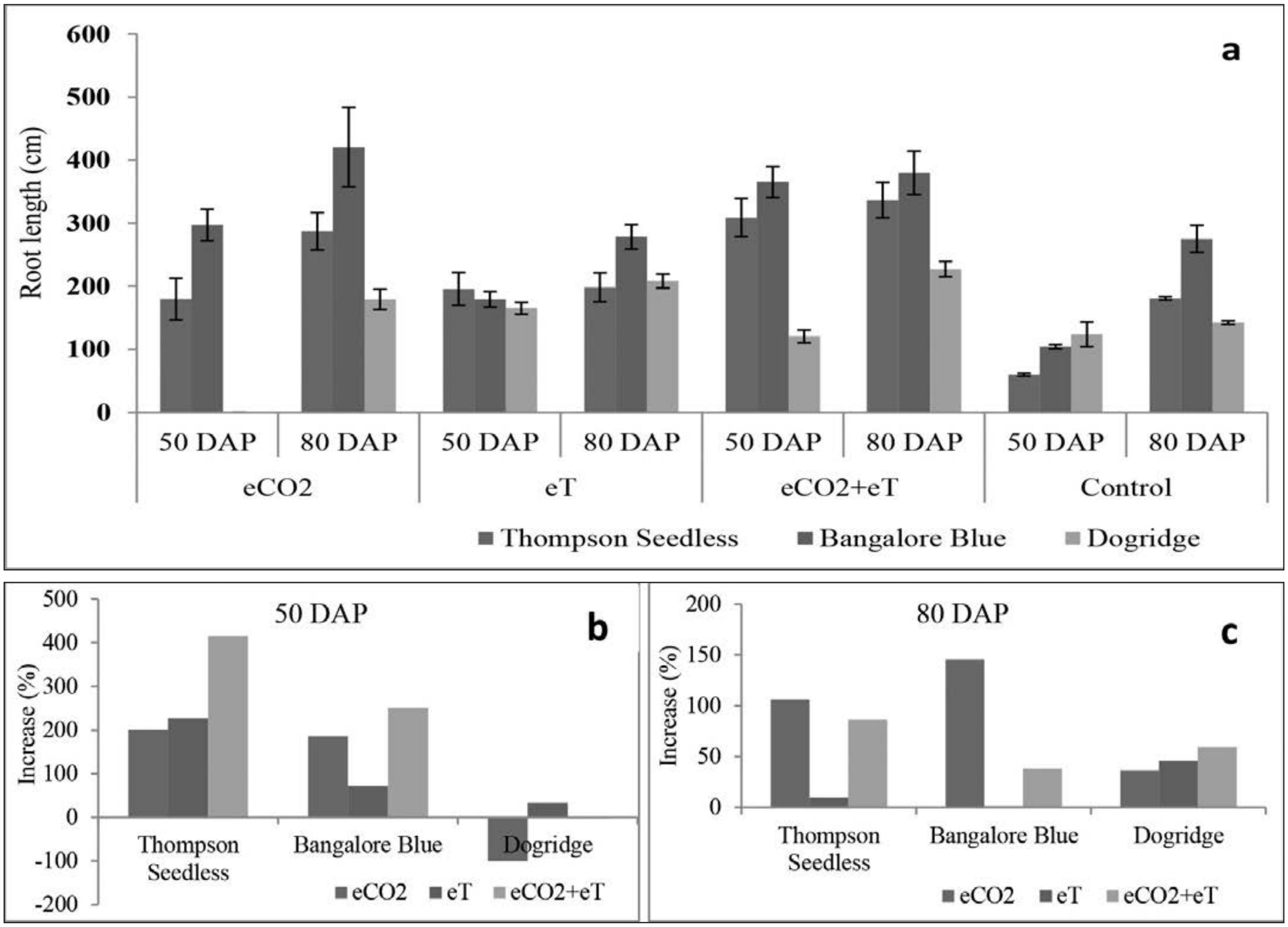

Fig. 2: (a) Total root length of grape varieties under eCO_2, eT, eCO_2+eT and control conditions at 50 and 80 DAP; Percentage increase in root length over control (b). at 50 DAP and (c). at 80 DAP

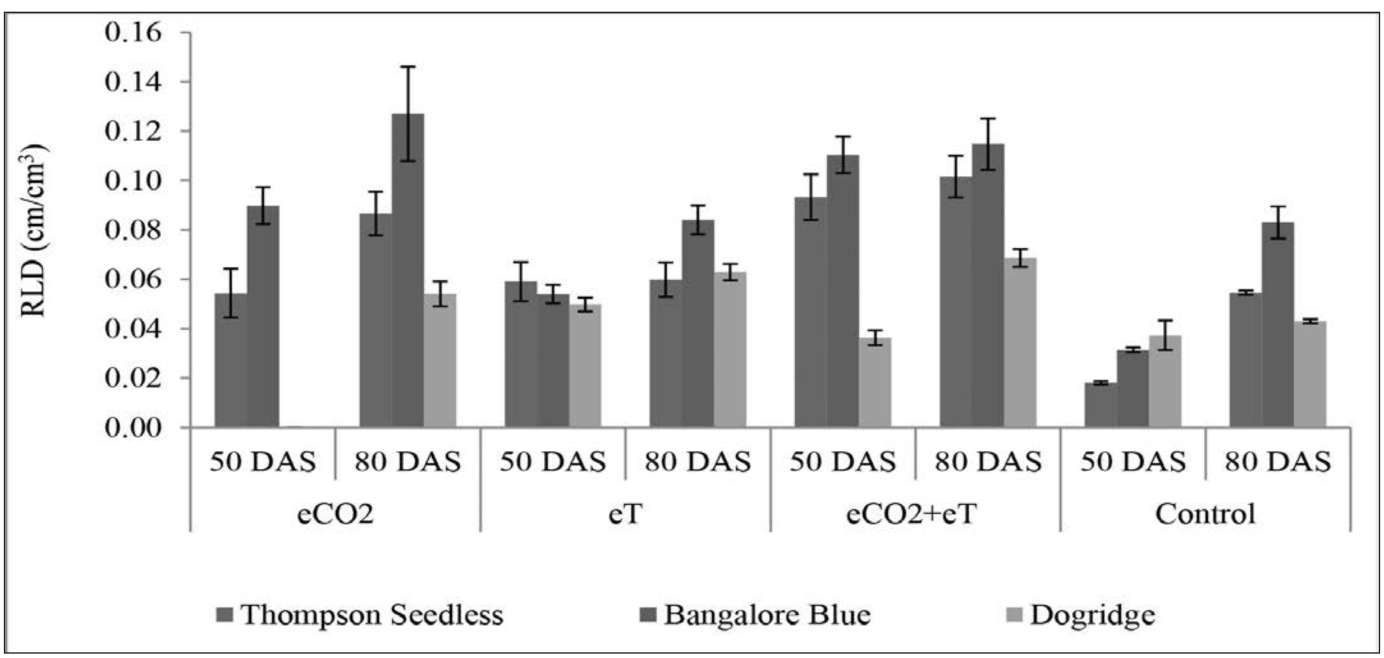

Fig. 3: Root Length Density of grape varieties to different treatments at 50 and 80 DAP

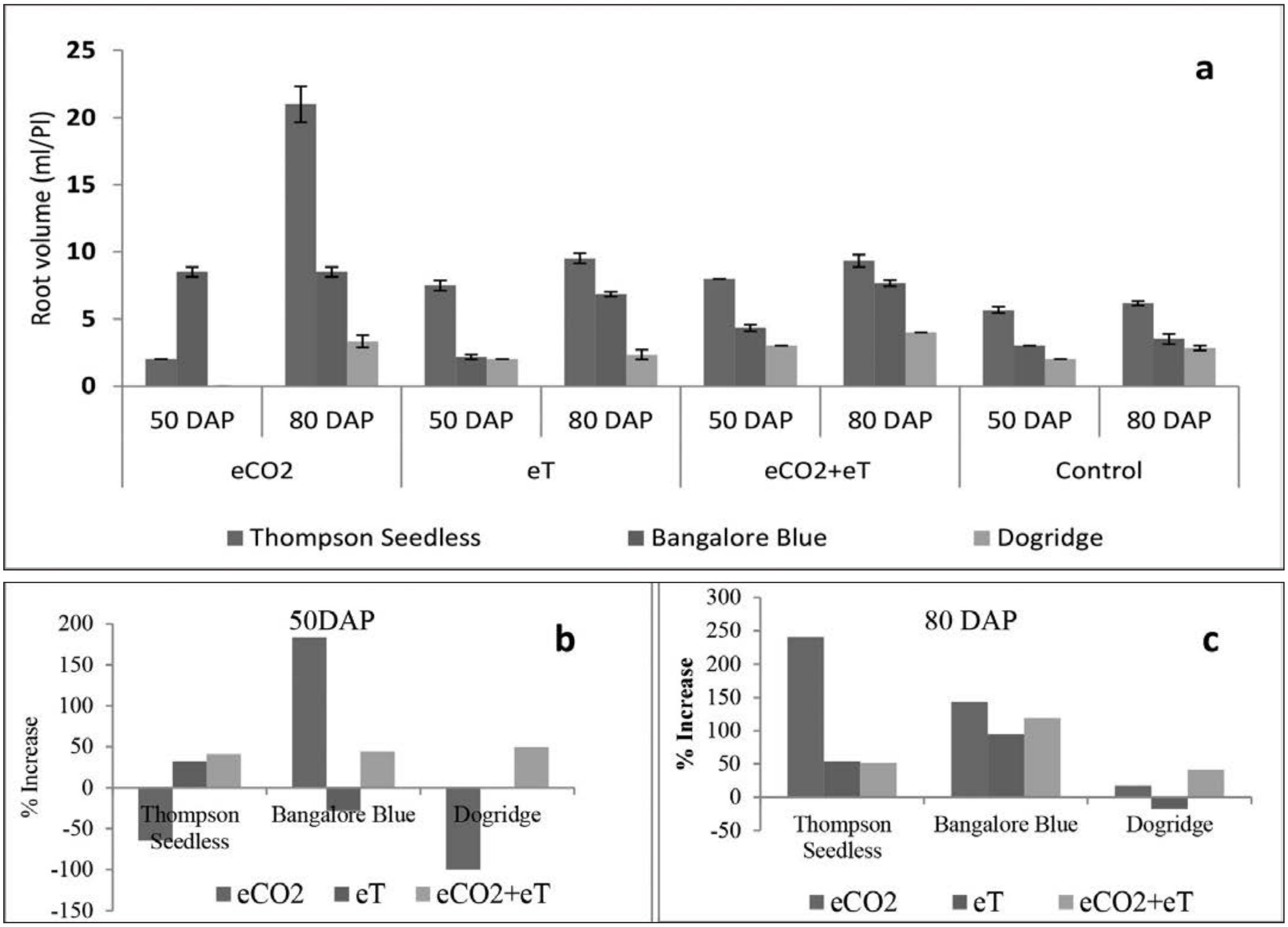

Fig 4: (a) Total root volume of grape varieties under eCO_2, eT, eCO_2+eT and control conditions at 50 and 80 DAP; Percentage increase in root volume over control (b). at 50 DAP and (c). at 80 DAP

shown higher root length under eT (165.0±9.2 cm). At 80 DAP Thompson Seedless (336.6±27.8 cm) and Dogridge (227.2±12.1 cm) has shown highest root length under eCO_2+eT, while Bangalore Blue under eCO_2 (420.5±63.1 cm) (Fig. 2a)

At 50 DAP, Thompson Seedless has shown an increase in total root length of 200, 226.4 and 415.5% under eCO_2, eT and eCO_2+eT respectively over control while it was 185.3, 71.8 and 250.1% respectively with Bangalore Blue. (Fig. 2b).

At 80 DAP, all the three varieties has shown an increase in root length under three treatments over control. Increase in root length was 106.3, 9.6 and 86.1% under eCO_2, eT and eCO_2+eT respectively with Thompson Seedless over control, while it was 145.4, 1.1 and 38.1% for Bangalore Blue and 36.6, 46.1 and 59.4% for Dogridge respectively (Fig. 2c). This clearly indicating that individual condition of eCO_2 promoted higher root length while eT showed very less impact especially in Thompson Seedless and Bangalore Blue and the combined conditions of eCO_2 and eT also improved the root length though with lesser magnitude, indicating the impact of eCO_2 even at higher temperature on this trait. Though Dogridge registered no response for root length under eCO_2 recorded better response under eT and eCO_2+eT revealing its tolerance to higher temperature.

Wang *et al*. (2013) recorded increased root length in tomato at elevated CO_2 than ambient CO_2 condition. Davis and Potter (1983) observed that elevated CO_2 increased root length and dry weight of several ornamentals.

Root length density (cm cm^{-3})

Thompson Seedless has shown higher RLD under eCO_2+eT at 50 DAP (0.09±0.01) and 80 DAP (0.10±0.01), while Bangalore Blue has shown higher RLD under eCO_2+eT (0.11±0.01) at 50DAP, and under

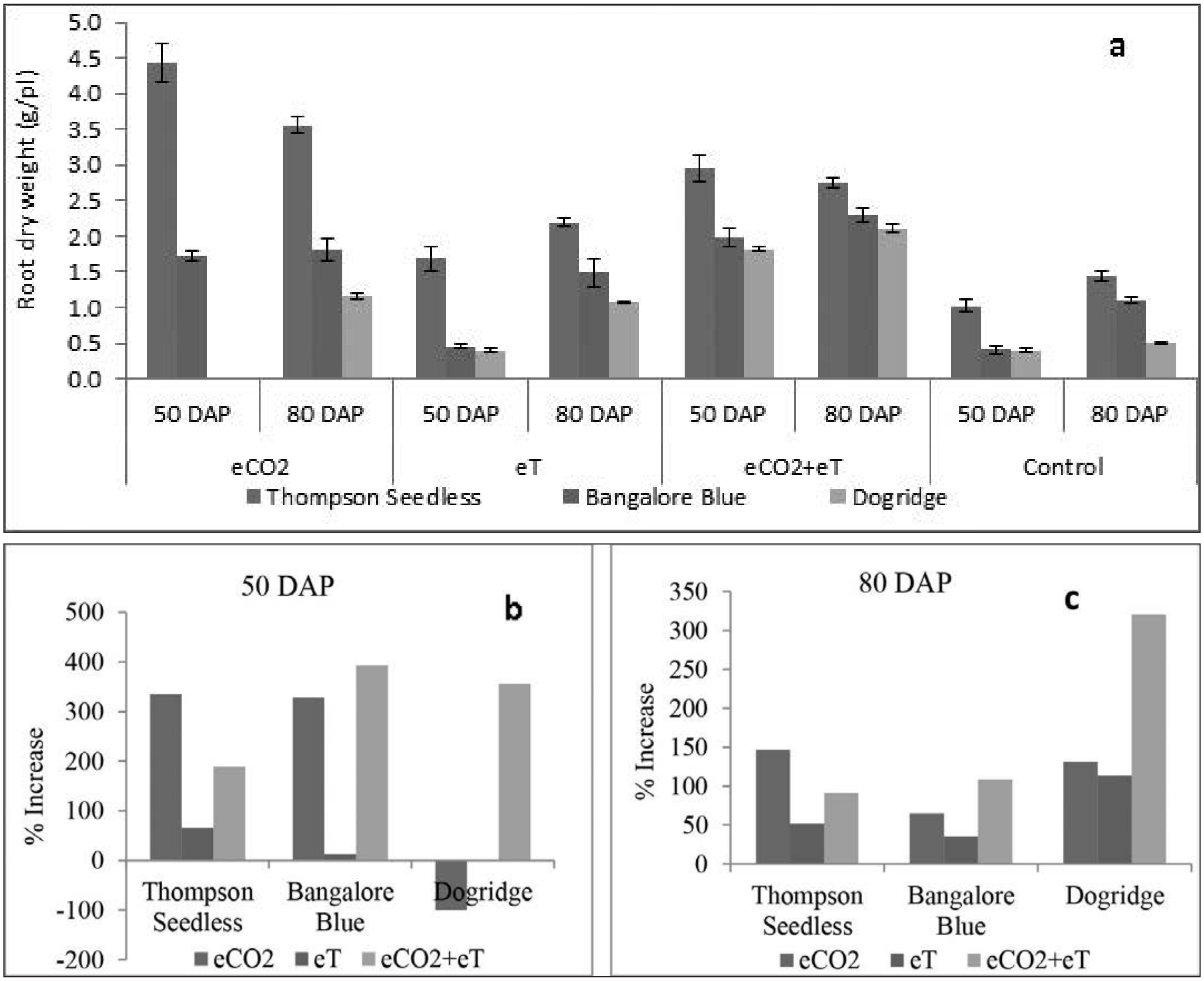

Fig 5: (a) Total root dry weight of grape varieties under eCO_2, eT, eCO_2+eT and control conditions at 50 and 80 DAP; Percentage increase in root dry weight over control (b). at 50 DAP and (c). at 80 DAP

eCO_2 (0.13±0.02) at 80DAP. However, Dogridge has shown higher RLD under eT (0.05±0.00) at 50DAP, and under eCO_2+eT (0.07±0.00) at 80DAP (Fig. 3).

Among the three varieties, Bangalore Blue has shown higher RLD than Thompson Seedless and Dogridge under all the treatments. This may be because of the difference in root system of Bangalore Blue like having more root length, producing a greater number of roots, and production of number secondary roots and root hairs. From these results it can be concluded that RLD is higher when cuttings exposed to eCO_2 alone or in combination with high temperature (eCO_2+eT).

***Root volume* (ml pl^{-1})**

At 50 DAP, Thompson Seedless has shown higher root volume under eCO_2+eT (8.0 ml/pl). Though the root volume of Thompson Seedless was less under eCO_2 at 50DAP (2.0 ml/pl), however by 80 DAP it was highest (21.0ml/pl). In Bangalore Blue the root volume was highest under eCO_2 and similar (8.5±0.37) at both 50 and 80 DAP. While in Dogridge highest root volume was under eCO_2+eT at 50 (3.0±0.0) and 80 (4.0±0.0) DAP. Under eCO_2 and control conditions there was no significant difference in root volume of Bangalore Blue at 50 and 80 DAP, whereas a significant difference plants under eT and eCO_2+eT shown at 50 and 80 DAP. At final sampling Thompson Seedless has shown higher root volume under all the three treatments (Fig. 4a) as compared with ambient control.

At 50 DAP, Thompson Seedless and Dogridge has shown a decrease of 64.7 and 100% in root volume under eCO_2, whereas Bangalore Blue has shown an increase of

183.3% over control. While under eT Thompson Seedless has recorded an increase of 32.4% in root volume over control, whereas Bangalore Blue has shown a decrease of 27.8%. The root volume of Dogridge under eT and control plants was similar. At eCO_2+eT, an increase of 41, 44, 50% was recorded by Thompson Seedless, Bangalore Blue, Dogridge respectively over control (Fig.4b).

At 80 DAP, Thompson Seedless, Bangalore Blue and Dogidge has shown an increase of 240, 54 and 51% in root volume under eCO_2 over control. While under eT, Thompson Seedless and Bangalore Blue has shown an increase of 54 and 95% of root volume respectively over control while Dogridge has shown a decrease of 18%. Under eCO_2+eT Thompson Seedless, Bangalore Blue and Dogidge has shown an increase of 51, 119 and 41% in root volume over control (Fig. 4c).

***Dry weight of roots* (g pl^{-1})**

Maximum root biomass of Thompson Seedless (4.4±0.27) and Bangalore Blue (1.7±0.07) has shown under eCO_2, while Dogridge has shown the highest root biomass under eCO_2+eT (0.8±0.03) at 50 DAP. At 80 DAP Thompson Seedless (3.6±0.12) and Dogridge (1.2±0.05) roots have shown maximum dry weight under eCO_2, however Bangalore Blue has shown maximum root biomass under eCO_2+eT (2.3±0.10). Among the selected three different varieties, maximum biomass was accumulated by Thompson Seedless and lowest by Dogridge under all the four treatments at both 50 and 80DAP while plants under ambient condition recorded lowest biomass in all the three varieties (Fig. 5a).

At 50 DAP there was an increase of 334, 65 and 189% root biomass over the control under eCO_2, eT and eCO_2+eT respectively in Thompson Seedless, while in Bangalore Blue there was an increase of root biomass of 328, 12 and 393% under eCO_2, eT and eCO_2+eT respectively over control. Dogridge has shown an increase of 356% root biomass over control under eCO_2+eT. The root dry weights of Dogridge plants grown under eT and control were similar (Fig.5b).

At 80 DAP, all the three varieties has shown an increase of dry weight at all the three treatments viz., eCO_2, eT, and eCO_2+eT over control. Thompson Seedless has shown an increase of 146, 52 and 91% under eCO_2, eT and eCO_2+eT respectively, while in Bangalore Blue there was an increase of 65, 35 and 105% under eCO_2, eT and eCO_2+eT respectively. While Dogridge has shown an increase of 131% of root dry mass under eCO_2 over control. A 113 and 320% increase in root dry mass of Dogridge was observed under eT and eCO_2+eT over control (Fig. 5c). At final sampling, all the treatments have shown an increase of root dry mass over control. Under eCO_2, Thompson Seedless has shown maximum root dry weight, while Dogridge under eT and eCO_2+eT.

The dry matter accumulation is resultant effect of enhanced plant growth characters and greater photosynthetic accumulation. The amount of dry matter produced depends on the better photosynthesis obtained by large and efficient assimilating area, adequate supply of solar radiation, carbon dioxide, favourable environmental condition and efficient utilization of nutrients (Reddy *et al*., 1994). Many studies have observed a greater root biomass under elevated eCO_2 (Chaudhuri *et al*., 1990, Acock *et al*., 1990; Weigel *et al*., 1994). In 2013-15, on experiments with *Valeriana jatamansi*, Kaundal and Kumar (2020) found Elevated CO_2 significantly enhanced root biomass of *Valeriana jatamansi*. The results are in line with earlier reports on different plant species where Goudriaan and Ruiter (1983) found that doubling of eCO_2 had the largest effect on dry matter production provided nutrient supply is not limiting.

CONCLUSION

The eT condition reduced all the root parameters, their performance improved under eCO_2+ eT indicating the presence of higher concentration of CO_2 reduced the ill effects of high temperature. Overall, eCO_2 and eCO_2+eT conditions improved root parameters of grape varieties, while eT reduced them as compared to their performance under ambient condition and varietal variation happen to be significant. The amount of dry matter produced depended upon the better photosynthesis obtained by large and efficient assimilating area, adequate supply of solar radiation, carbon dioxide, favourable environmental condition and efficient utilization of nutrients.

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