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Influence of growth stage specific water stress on the yield, physico-chemical quality and functional characteristics of tomato grown in shallow basaltic soils

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ABSTRACT

Various options of deficit irrigation (DI) were tested for accumulation of functional food compounds on tomato included; (i) continuous deficit irrigation i.e. applying irrigation water equally (0.6, 0.8 and 1.0 evapotranspiration (ET)), (ii) DI at vegetative, flowering and fruiting stages (0.6 ET for 30 days), (iii) DI at vegetative and flowering, vegetative and fruiting, flowering and fruiting stage (0.6ET for 30 days at each stage) and (iv) withholding of irrigation at vegetative, flowering and fruiting stage for 15 days. Fruit quality and functional food properties improved with DI. Color (a/b* ratio) and the concentrations of vitamin C increased by 82 and 70% with irrigation of 0.6 ET continuous DI compared to control. Withholding irrigation during fruit development induced color development (52%), vitamin C content (16%) and recorded better lycopene content (10.2 mg/100 g). The total phenolics and flavonoids ranged between 16 and 42 mg gallic acid equivalent/100 g and 4–10 mg catechin equivalent/100 g respectively with higher values recorded under DI at fruiting stage. Antioxidant activity (AOA) tested with different in vitro assays revealed the positivity of DI on improvement of bioactive compounds. Superoxide dismutase activity was significantly higher in DI treatments at fruiting stage compared to catalase activity. DI or withholding irrigation at fruiting stage could improve the quality of tomato due to redox oriented homeostasis of biologically active compounds and their biosynthesis.

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1. Introduction

Sustainability in agriculture is possible only through adoption of appropriate water management practices as demand for water is increasing due to industrialization in many parts of the world. Water deficits and insufficient water are the main limiting factors affecting worldwide crop production (Patane et al., 2011). Deficit irrigation (DI) is a best management tool in a situation where water is scarce (Costa et al., 2007; Favati et al., 2009), particularly in arid, semi-arid and sub-humid regions. DI involves irrigating the root zone with less water than required for evapotranspiration (Zegbe-Dominguez et al., 2003). The consumption of fruits and vegetables has been associated with lower risk of chronic human health problems like cardiovascular diseases, cancer, hypertension and

diabetes due to their high contents in dietary bioactive compounds (Raffo et al., 2006). Tomato, a versatile vegetable crop has the highest area under cultivation among vegetables in the world and also has a high water requirement. Regular consumption of tomatoes has been correlated with a reduced risk of various types of cancer and heart diseases (Guichard et al., 1999). The pulp and juice are digestible, mild aperients, a promoter of gastric secretion, blood purifier and has antiseptic properties against intestinal infections, canker and sore mouth. They are good sources of antioxidants, particularly carotenoids (lycopene), ascorbic acid, vitamin E, phenols and flavonoids (Giovannelli and Buratti, 2009; Leonardi et al., 2000).

The fruit with high quality is pre-requisite to fetch higher price in the market. It has been predicted that the tomato consumption and profitability for producers would increase with the quality of tomato fruit. Among all the factors that seem to be effective in enhancing the phytochemicals concentrations in fruits and vegetables, stress emerges as promising. This make sense considering that DI/RDI (Regulated Deficit Irrigation) strategies are conducive to oxidative stress in plants and that oxidative signaling controls synthesis and accumulation of secondary metabolites (Ho, 1996;

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Harmanto et al., 2005). Several studies in the past have demonstrated that fruits and vegetables with DI strategies are endowed with nutritional properties (Pulupol et al., 1996; Johnstone et al., 2005; Favati et al., 2009; Patane et al., 2011). However the benefit of tomato fruit quality by deficit irrigation is often lead to undesirable reduction in yield (Nuruddin et al., 2003; Marouelli et al., 2004). Generally, the response of tomato to deficit irrigation at various growth stages was different, depending on the period and the degree of water deficit. DI during vegetative stage did not adversely affect the tomato yield and quality whereas yield was sensitive to water deficit during fruit development and ripening stage (Nuruddin et al., 2003). In spite of much research, the influence of DI on tomato fruit yield and quality are poorly defined due of its complexity (Marouelli et al., 2004; Favati et al., 2009; Patane et al., 2011). The incompatible relationship between yield and fruit quality should be taken into consideration when regulating tomato fruit quality through irrigation management.

Consequently, before using deficit irrigation strategies to regulate tomato yield and fruit quality, it is important to obtain adequate information about the relationships between tomato yield, fruit quality and water deficit with its timings and magnitudes. Even though many researchers opined that tomato quality depends on the cultivar and growing conditions, limited data is available to support these assertions, especially in terms of antioxidant activity and functional health benefits of tomato. Considering the above points, the present study aimed at assessing the response of tomato to water stress, linking with fruit yield and quality. This paper will contribute to fulfilling the gap by comparing the concentration of compounds contributing to quality of fruits and measuring indicators of oxidative stress, namely the antioxidant enzymes.

2. Materials & methods

2.1. Experimental site

The experiment was carried out at the research farm of ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati, Pune, Maharashtra, India located at 18°09'29.06"N 74°30'07.97"E elevation of 568 m above MSL during October–February, 2013–2014. The experimental site is highly prone to drought and characterized by low and erratic rainfall. The soil is porous, gravelly, low in organic matter and poor in water retention capacity. The long term average annual rainfall is 580 mm of which about 70% is received during the four months of south-west monsoon season (June–September). Post monsoon season (October–December) receives only 21% of the annual rainfall and characterized by very high variability (CV, 87%), indicating high risk associated with rainfall. The average maximum temperature 27.7 °C, minimum temperature 18.5 °C; seasonal averages of daily relative humidity and wind speed were found to be 60.3% and 5.8 km h⁻¹, respectively.

2.2. Irrigation experiment

Land was ploughed with the help of mold board plough for primary tillage and harrowed twice to pulverize the soil. Well decomposed spent mushroom substrate (10 t ha⁻¹) was added prior to second harrowing and planking, leveled and ridges and furrows were created using the mini tractor. Tomato (*Lycopersicon esculentum* Mill.) cultivar Ryna® (Rasi Seeds, India), at the stage of 3rd–4th true leaf of 25 days old were transplanted at a distance of 40 cm between plants and 90 cm between rows. The single lateral lines of 16 mm diameter Linear low density polyethylene (LLDPE) pipes were laid along the eachrow of the crop. The laterals were provided with in-line dripper of 4 l/h discharge capacity at a pres-

sure of 1 kg/cm² and spaced at a distance of 40 cm. The average emission uniformity of drip irrigation system was estimated as 90%. The presowing irrigation of 5 cm was applied before transplanting. The experiment was conducted in a randomized complete block design with four replicates and 12 irrigation treatments (Table 1). All irrigation treatments were imposed ten days after transplanting.

After the initial distribution of water at transplanting, the amount of water (l/day) to be applied through drip irrigation for imposing treatments were calculated by the climatological approach method (Doorenbos and Pruitt 1977). Reference crop evapotranspiration (ET_o) was computed on a daily basis using Penmann–Monteith approach (Allen et al., 1998) wherein ground heat flux was approximated as 12% of the net radiation based on observations on the shallow basaltic soil of the locality. Crop coefficient (K_c) utilized were those obtained in a similar environment, with the values of 0.35 from transplant up to establishment, 0.55 up to the early stages of blooming; 0.90 during blooming-fruit setting; 1.1 during berry growth-fruit maturity and 0.85 from the maturity to final harvest of fruits. Considering the crop factor as per stages and wetted area factor, the daily water requirement of the crop was computed using following equation (Pawar et al., 2013).

$$V = ET_r \times K_c \times L_s \times E_s \times \frac{W_a}{\eta}$$

where, V, Volume of water applied (l/day/plant); ET_r, Reference evapotranspiration (mm/day); K_c, Crop coefficient; L_s and E_s, lateral and emitter spacing; W_a, wetted area factor; η emission uniformity of the drip system.

Before transplanting, 75, 50 and 50 kg/ha of N (as Urea and Diammonium Phosphate (DAP)), P (as DAP) and K (as Muriate of Potash (MOP)) respectively were applied as basal dose. A month after transplanting further 75 kg/ha of N, 50 kg/ha of P and 50 kg/ha K were applied through fertigation in 5 equal splits at fortnight interval throughout the growth period. Secondary nutrient mixture, having Ca, Mg and S was also applied twice at 20 kg/ha a month after transplanting and 80 days after transplanting. The experimental site was kept weeds free by periodic hand weeding. Mites during the initial period of growth stage and aphids during flowering to fruiting stage were controlled by using acaricides and insecticides. Standard cultural practices were followed uniformly for all the treatments. All the weather parameters were measured using an automatic weather station (AWS) installed inside the research farm of NIASM. Specifications for component sensors of the AWS were as follows: rain gauge (H-340, Water Log), air temperature/relative humidity (H-380, Rotronic), solar radiation (SP-110, Apogee) and wind speed/wind direction (85,000, RM Young). Wind was actually measured at 3 m height and converted to equivalent wind speed at 2 m height using conversion factor from standard table and used for calculating evapotranspiration. A datalogger (H-500 XL, Water Log) controlled all the sensors and computed averages at every two minutes interval and further averaging was done on a half-hourly basis. These values were later processed using Microsoft Excel (MS Office, 2010) for computation of daily values and other relevant statistics.

2.3. Yield parameters

The fruits were harvested manually from 10 tagged plants in each replication when they were ripened about 70–80% (pink stage). At harvest total fruit yield (t/ha fresh weight (FWB)) was determined and marketable yield (t/ha FWB) was measured considering red and disease free, fresh, graded, firm fruits from the plots. After every harvest (6–7 pickings), total and marketable fruits were weighed and totalled after the last harvest.

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