IMPACT OF CONCURRENT ELEVATION IN CO_2 AND TEMPERATURE ON TUBER YIELD AND ASSOCIATED TRAITS OF POTATO GENOTYPES

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ABSTRACT : Carbon dioxide (CO_2) concentration in the atmosphere is rising continuously and consequently global average surface temperature is anticipated to rise in near future which tends to affect tuber yield, associated physiological traits of potato. This necessitate to explore some resilient cultivars to counter the adverse impact of anticipated changing climate scenario. So, in order to explore such cultivars, an investigation was carried out in open top chambers having controlled facility (CO_2 and Temperature) at ICAR-CPRS, Jalandhar, Punjab. Two advance stage heat tolerant potato genotypes *viz.,* HT/7-1105 and HT/7-1329 and two commercial varieties, *viz.,* Kufri Surya (heat tolerant) and Kufri Badshah were evaluated under three treatments, *viz.,* (i) elevated CO_2 (600 ppm) along with elevated temperature (3^0C rise over ambient); (ii) elevated CO_2 (600 ppm) and (iii) ambient. Impact of higher temperature with elevated CO_2 on tuber yield was negative only in Kufri Badshah (-10.17 t/ha). Response to CO_2 enrichment, in terms of tuber yield, was positive in case of all the genotypes i.e. Kufri Badshah, Kufri Surya, HT/7-1105 and HT/7-1329. These results suggest the overall superiority of Kufri Surya and heat tolerant cultivars in terms of productivity under high CO_2 and high temperature. Net photosynthesis (PS) rate was 34.4 µmol CO_2 $m^{-2}s^{-1}$ under elevated CO_2 in Kufri Badshah that reduced to 27.10 µmol CO_2 $m^{-2}s^{-1}$ on exposure to high temperature (around 3^oC) and CO_2. These values were statistically significant over PS rate under ambient conditions.

KEYWORDS: Potato, tuber yield, net photosynthesis, high temperature and elevated CO_2

INTRODUCTION

Potato (*Solanum tuberosum* L.) is an annual, herbaceous, dicotyledonous and vegetatively propagated tuberous crop belonging to the family solanaceae. It is the world's third largest food crop following rice and wheat (Pinhero *et al.*, 2016). Potato was originated in the area of southern Peru and extreme north-western Bolivia is believed to have domesticated independently in multiple locations approximately 7,000–10,000 years ago. It is believed that the crop has been introduced into India in the late sixteenth century, most probably by the Portuguese or the Spaniards (Anonymous, 1989). Earlier days of its introduction, potato cultivation was confined to cool summers and long days in hilly regions. Organized crop improvement through breeding and selection by ICAR - Central Potato Research Institute, Shimla adapted the crop to short winter days and now is a major *Rabi* crop in Indo-Gangetic plains from Punjab to West Bengal. Indo-Gangetic plains account for more than 85 per cent of potato acreage with hills and plateaus accounting for about 15 per cent of the total acreage under the crop (Minhas and Kumar, 2015). The potato is grown for edible tubers rich in carbohydrate content especially starch with vitamins and minerals as well as an assortment of phytochemicals, such as carotenoids and natural phenols (Zarzecka *et al.*, 2015). In India, potato is cultivated in an area of 2.17 million hectares (ha) with a total production of 50.19 million tonnes (t)

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having an average productivity of 23.12 t ha^{-1} (Anonymous, 2019). Being consumed by more than a billion people and much higher future demand for potato worldwide especially from developing nations, Food and Agriculture Organization of UN has declared potato as 'Food for future'.

Climate change is a global phenomenon due to emission of greenhouse gases (CO_2, NO_2, CH_4 *etc*.) by various natural and anthropogenic activities. Over the past 4,20,000 years, the upper limit of CO_2 concentration was about 280 ppm (Hogy and Fangmeier, 2009) and currently the average global CO_2 concentration is about 400 ppm (Abebe *et al*., 2016) have been predicted to at least 550 ppm by the middle of this century (IPCC, 2007). Exaggerated concentration of greenhouse gases (GHGs) in the atmosphere causing greenhouse effect, consequently global average surface temperature is predicted to rise 0.3–1.7°C by 2081–2100 and 2.6–4.8°C under high CO_2 emission scenarios (IPCC, 2013). The growth, development and yield of crops are greatly influenced by above as well as below ground environmental conditions (Madhu and Hatfield, 2016). It is presumed that elevation in CO_2 and rising temperature may affect the growth pattern, tuber yield, quality and other physiological processes of crops (Thinh *et al*., 2017).

Several studies have been conducted inside OTCs earlier to quantify the possible effect of CO_2. It is well known fact that increased concentration of atmospheric carbon dioxide stimulates crop growth by the carbon fertilization effect and positive effect of CO_2 enrichment on potato tuber yield was noticed in our previous studies by Minhas *et al*., 2018 and Kumar *et al.,* 2018. It is also evident that positive effect of elevated CO_2 might be offset by the adverse effect of associated global warming particularly excessive heat (Kumari *et al*., 2017).

The rise in temperature affects the phenology, growth, yield, and quality of the crop (Kaur *et al*., 2019). High temperatures delay, impede or even inhibit tuber initiation and affect the distribution of dry matter between tubers and haulms, night temperatures being especially crucial. Bushnell (1925) defined 17°C as an optimum temperature for good yield in potatoes. Minimum temperature plays an important role in tuberisation of potato and night temperature above 18°C reduce tuberisation and formation of tuber will be hold up beyond 25°C. This situation alarm potato cultivation both in view of productivity as well as regions where potato is already being grown under extreme temperatures (night temperature >=20°C) (Minhas *et al*., 2006).

Under anticipated climate change scenarios, adoption of high temperature tolerant cultivars by exploiting genetic diversity is one of the most viable option to sustain productivity of potato. Further information on responses of potato to both high CO_2 coupled with rising temperature is also very scanty. Keeping this in view, experiment was conducted inside OTCs to analyse the tuber yield and associated traits of potato genotypes and to identify the high temperature tolerant cultivars which may be further adopted to sustain potato productivity in India.

MATERIALS AND METHODS

Experimental site and soil details

The present investigation was carried out at the ICAR-Central Potato Research Station, Jalandhar, Punjab (Latitude: 31°16'26.21" N; Longitude: 75°32'46.32" E; Elevation: 233m AMSL) during the winter season of 2017-18. The experiment was conducted under controlled environment facility i.e. within open top chambers (OTCs), each of which had a dimension of 3m X 3m X 2.5m and 6.25 m^2 of open top area. The walls of OTCs were made up of 3-4 mm thick clear multi-layered, polygal grade PVC/polycarbonate sheets having 80-85 per cent transparency to solar radiation. The soil under the OTCs were sandy loam in texture having pH of 8.0, EC 0.27 ds/m, organic carbon 0.40 per cent (Walkley and Black 1934), available N 324.0 kg/ha (Subbiah and Asija, 1956), available P 19.7 kg/ha (Olsen *et al.*, 1954) and available K 292.3 kg/ha (Jackson, 1973).

Planting materials and treatments

Two potato genotypes *viz.,* HT/7-1105 and HT/7-1329 which are at advance stage of selection for heat tolerance trait and two commercial varieties, *viz.,* Kufri Surya (heat tolerant) and Kufri Badshah were evaluated. Each of the four genotypes were tested under three different treatments, *viz.,* T_1-elevated CO_2 (600 ppm) along with elevated temperature (3^0C rise over ambient); T_2-elevated CO_2 (600 ppm) and T_3-ambient (control). Temperature and carbon dioxide concentrations within and around the OTC micro-environment were recorded diurnally at one-minute interval through automated system and monitored periodically for achieving the desired levels of elevated CO_2 and temperature levels. Air temperature was measured using PT100 sensors (kept within radiation shields) and CO_2 level through non-dispersive infrared absorption (NDIR) method.

Planting and crop management practices

The seed size tubers (40-50 g) of each genotype were planted at 60 cm x 20 cm spacing on 11th October 2017. The crop was fertilized with urea, di-ammonium phosphate and muriate of potash wherein N, P_2O_5 and K_2O were applied at the rate of 240 kg, 100 kg and 150 kg per hectare, respectively. Half dose of N and full dose of P and K were applied at the time of planting, while the remaining N was applied at the time of earthing-up *i.e.* 25 days after planting. Irrigation scheduling was based on pan evaporation rate recorded using a USWB class A open pan evaporimeter at 08:30 IST daily and drip method was followed to deliver water at every 3-4 days interval depending on soil conditions. Other standard package of practices was followed for healthy crop stand (Kumar *et al.*, 2020). In each year, dehaulming was done at 110 days after planting, 20 days later tubers were harvested.

Leaf net photosynthesis measurement

Photosynthesis and stomatal conductance was measured at 40 days after planting using LI-6400 portable photosynthesis system.

Statistical analysis

Statistical analysis was done using Microsoft Excel programme and SPSS 16.0 software.

RESULTS AND DISCUSSION

Tuber yield of various potato genotypes as influenced by elevated CO_2 and temperature, elevated CO_2 only and ambient conditions

Tuber yield of various potato genotypes as influenced by elevated CO_2 and temperature conditions is presented in Figure 1. A noticeable variation in tuber yield in all the varieties was observed. Relatively higher tuber yield in all the varieties under elevated CO_2 conditions was observed with values being 40.00 t/ha in Kufri Badshah, 48.83 t/ha in Kufri Surya, 49.33 t/ha in HT/07-1105 and 42.00 t/ha in HT/7-1329 genotypes. Under elevated CO_2 and temperature conditions the tuber yield of Kufri Badshah, Kufri Surya, HT/7-1105 and HT/7-1329 was 24.50, 35.17, 41.17 and 39.33 t/ha, respectively. Under

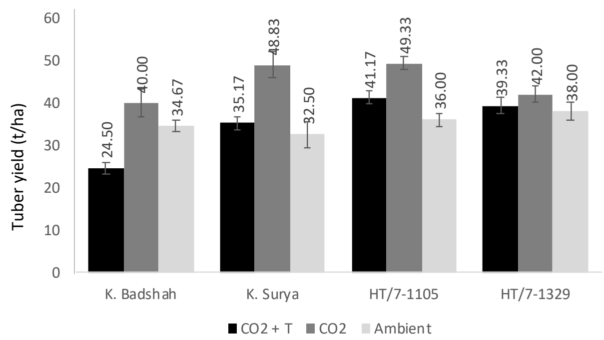

Fig. 1: *Tuber yield of various potato genotypes as influenced by elevated CO_2 and temperature, elevated CO_2 only and ambient conditions.*

ambient conditions the tuber yield was 34.67, 32.50, 36.00 and 38.00 t/ha for Kufri Badshah, Kufri Surya, HT/7-1105 and HT/7-1329, respectively.

It was further observed that the variation in tuber yield due to elevated CO_2 and temperature conditions as well as under elevated CO_2 conditions was different for different varieties when compared to ambient conditions (Figure 2). Under elevated CO_2 + temperature conditions the tuber yield of Kufri Badshah decreased by 10.17 t/ha, whereas in all the other three varieties this variation was positive with increase being 2.67, 5.17 and 1.33 t/ha in Kufri Surya, HT/7-1105 and HT/7-1329, respectively. Similarly, under elevated CO_2 conditions the

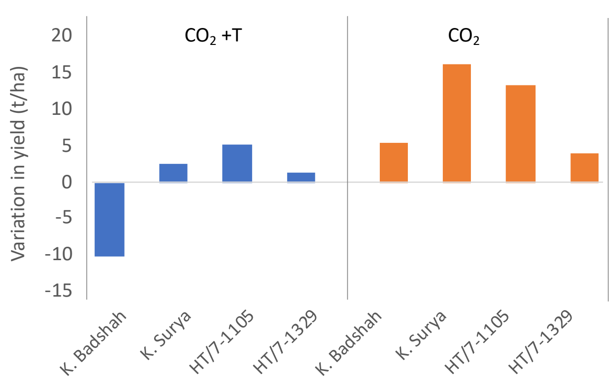

Fig. 2: *Variation in tuber yield of different potato genotypes under elevated CO_2 with temperature and elevated CO_2 only as against ambient conditions.*

tuber yield increased in all the four varieties, when compared to ambient conditions. This increase was highest in Kufri Surya (16.33 t/ha) followed by HT/7-1105 (14.33 t/ha), Kufri Badshah (5.33 t/ha) and HT/7-1329 (2.78 t/ha). A positive effect of concurrent and appropriate elevation of CO_2 and temperature was also observed by Lee *et al*. 2020. According to them such conditions promote balanced development of source and sink organs and positively affect potato productivity.

Tuber yield enhancement in Kufri Surya and HT/7-1105 as response to CO_2 enrichment was much more pronounced than in other genotypes. This may be due to source limited yield in these genotypes under ambient conditions as higher CO_2 concentration is known to enhance photosynthesis and enhanced carbohydrate availability at the source leaves (Kumar *et al.*, 2018). No negative impact of higher temperature + CO_2 on tuber yield of Kufri Surya, HT/7-1105 and HT/7-1329 could be attributed to their growth pattern particularly during tuber bulking phase when requirement of photosynthates is highest to obtain higher yield. Considering the yield potential, heat tolerance and superiority in other tuber traits, potato genotype HT/7-1329 has recently been released as "Kufri Kiran" for commercial cultivation in the country.

Impact of elevated CO_2 alone and with high temperature on important yield associated traits

Tuber yield and its response to temperature and CO_2 conditions, besides other, depend upon yield associated traits also *e.g.* leaf temperature, photosynthesis, stomatal conductance and transpiration. So, the impact of elevated CO_2 and temperature on these traits was studied and are presented in Table 1. It was observed that elevated

Table 1. Impact of elevated CO_2 alone and with high temperature on various physiological traits in potato genotypes.

Genotype	CO_2 + Temp.	CO_2	Ambient	$CD_{0.01}$
Leaf Temperature (°C)				
Kufri Badshah	27.10±1.50	23.15±1.55	18.95±0.95	NS
Kufri Surya	26.70±0.70	23.20±1.10	19.60±1.00	4.42
HT/7-1105	27.84±1.15	24.70±1.40	18.40±2.20	NS
HT/7-1329	28.00±0.80	24.54±0.75	18.95±1.95	6.02
Net photosynthesis (µmol CO_2 $m^{-2}s^{-1}$)				
Kufri Badshah	29.2±2.3	34.4±1.4	22.6±0.2	7.4
Kufri Surya	32.9±2.1	32.9±0.6	25.4±0.4	5.9
HT/7-1105	38.0±3.1	36.0±3.6	26.4±0.7	NS
HT/7-1329	32.5±0.9	35.4±1.9	27.0±2.8	NS
Stomatal conductance (mmol CO_2 $m^{-2}s^{-1}$)				
Kufri Badshah	0.31±0.06	0.54±0.24	0.64±0.08	NS
Kufri Surya	0.32±0.10	0.41±0.01	0.85±0.03	0.30
HT/7-1105	0.50±0.03	0.55±0.13	1.18±0.22	NS
HT/7-1329	0.29±0.11	0.43±0.10	1.00±0.04	0.43
Transpiration (mmol H_2O $m^{-2}s^{-1}$)				
Kufri Badshah	4.18±1.05	3.69±0.50	3.01±0.10	NS
Kufri Surya	4.10±1.30	3.40±0.40	3.69±0.40	NS
HT/7-1105	6.34±0.60	4.62±0.15	3.53±0.80	NS
HT/7-1329	4.27±0.80	4.04±1.00	3.69±1.00	NS

CO_2 and temperature do have a significant impact on leaf temperature in Kufri Surya and HT/7-1329 over ambient conditions. The values of leaf temperature under CO_2 alone and CO_2 + temperature in aforesaid varieties were at par within themselves. In other two varieties the impact on leaf temperature was non-significant. In case of photosynthesis the values of net photosynthesis were significantly higher in elevated CO_2 alone and elevated CO_2 + temperature conditions over ambient in Kufri Badshah and Kufri Surya. These values were 29.2 and 34.4 µmol CO_2 $m^{-2}s^{-1}$ under elevated CO_2 + temperature, and 32.9 and 32.9 µmol CO_2 $m^{-2}s^{-1}$ under elevated CO_2 conditions for former and later varieties. For other two varieties this impact was non-significant. Exposure to high temperature (around 3°C) and CO_2 during growing season reduced photosynthesis rate of Kufri Badshah, nevertheless, it sustained higher than control. In Kufri Surya exposure to high temperature and CO_2 did not reduced the photosynthesis rate compared to elevated CO_2 conditions but was higher than control. So far as stomatal conductance was concerned, a significant impact of elevated CO_2 and temperature was observed in two genotypes only i.e. Kufri Surya and HT/7-1329. The conductance was at par within elevated CO_2 + temperature and elevated CO_2 alone but was significantly lower than the ambient conditions. A non-significant impact of micro climatic conditions was noticed in case of transpiration.

Impact of elevated CO_2 alone and with high temperature on rate of photosynthesis and consequently tuber yield was estimated separately (figure 3). The results revealed a higher average rate of photosynthesis in elevated CO_2 (34.69 µmol CO_2 $m^{-2}s^{-1}$) followed by CO_2+ 3°C temperature elevation (33.19 µmol CO_2 $m^{-2}s^{-1}$) and ambient conditions (25.39 µmol CO_2 $m^{-2}s^{-1}$). The average tuber yield also followed similar trend with values being 44.86, 35.10 and 35.03 t/ha for CO_2

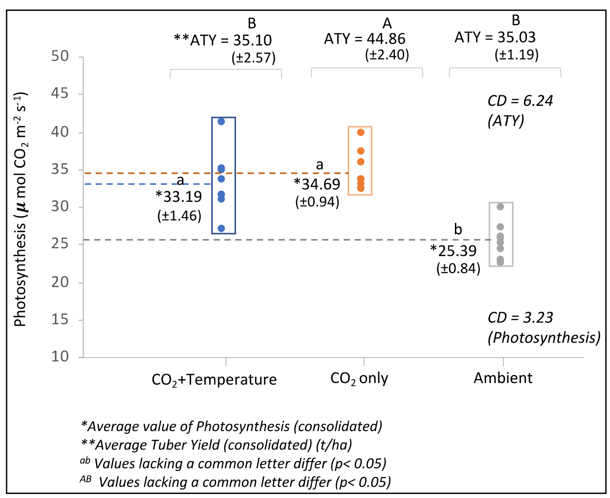

Fig. 3: *Impact of elevated CO_2 with high temperature and CO_2 alone on rate of photosynthesis in potato genotypes as compared to ambient condition.*

Table 2. Tuber yield as influenced by various yield associated traits in different potato genotypes under elevated CO_2 alone and with high temperature.

Independent variable (X)	Dependent variable (Y)	Regression equation	Coefficient of determination (R^2)
Net photosynthesis	Tuber yield	Y(Kufri Badshah) = 0.66X + 24.69	0.34
		Y(Kufri Surya) = 1.29X + 3.51	0.71
		Y(HT/7-1105) = 0.48X + 30.51	0.41
		Y(HT/7-1329) = 1.26X + 11.30	0.99
Stomatal conductance	Tuber yield	Y(Kufri Badshah) = 20.96X + 33.35	0.29
		Y(Kufri Surya) = -17.23X + 51.74	0.55
		Y(HT/7-1105) = -8.62X + 53.12	0.50
		Y(HT/7-1329) = -11.92X + 58.16	0.68
Transpiration	Tuber yield	Y(Kufri Badshah) = -2.99X + 54.62	0.07
		Y(Kufri Surya) = -8.27X + 73.54	0.20
		Y(HT/7-1105) = 0.69X + 43.39	0.04
		Y(HT/7-1329) = 12.68X + 0.56	0.48
Leaf Temperature	Tuber yield	Y(Kufri Badshah) = -0.54X + 56.28	0.11
		Y(Kufri Surya) = 0.87X + 22.56	0.22
		Y(HT/7-1105) = 0.49X + 35.15	0.25
		Y(HT/7-1329) = 0.83X + 31.56	0.49

alone, CO_2 + temperature elevation and ambient conditions, respectively.

In order to understand the association of these physiological traits with yield, regression analysis for each trait and for each genotype was done (Table 2). A few of these equations can be used to predict tuber yield on the basis of these yield associated physiological traits. These equations reflect a +ve linkage of tuber yield with net photosynthesis. In other traits the influence was mixed (+ve as well as -ve in some varieties)

CONCLUSION

Briefly, it can be concluded that like other agricultural crops, potato crop is also vulnerable to climate change. So, the understanding and impact assessment of this anticipated climate change on potato production of different genotypes, revealed in the present investigation, can prove to be crucial to frame future food security policies in general and potato production in particular. Two heat tolerant and one commercial genotype evaluated in the present study can counter the anticipated impact of climate change in coming decades. One of the heat tolerant potato genotype HT/7-1329 has already been released for commercial cultivation.

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