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Impact of Elevated Atmospheric CO_2 Concentration on Growth and Yield of Potato Cultivars

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Abstract: Concentration of CO_2 in the atmosphere is likely to increase up to 550 µmol mol^{-1} by the middle of 21st century. Such an increase in the atmospheric CO_2 may effect plant growth and productivity of crop plants. A field experiment was conducted with two potato cultivars namely Kufri Surya and Kufri Chipsona-3 grown inside Open Top Chambers (OTCs) at ambient (385±30 µmol mol^{-1}) and elevated CO_2 (570±50 µmol mol^{-1}), during *rabi* season of the year 2009-2010. The experiment was planned in a randomized complete block design under factorial arrangement with three replications. The photosynthetic rate significantly increased in both the cultivars under high CO_2 and enhancement was greater in K. Chipsona-3 than K. Surya. There was increased accumulation of reducing, non-reducing and total sugars in the leaves of both the cultivars due to CO_2 enrichment. Crop growth rate (CGR) and tuber growth rate (TGR) in both cultivars was higher in plants grown under elevated CO_2 compared with ambient. High CO_2 increased more partitioning of dry matter towards the tubers at all harvesting stages. Potato plants grown under elevated CO_2 exhibited increased tuber yield due to enhanced number of tubers per plant. At the final harvest, total tuber fresh weight was 36% greater under high CO_2 treatments compared to ambient. Among the two cultivars the response of K. Chipsona-3 was better to increased CO_2 concentration compared with K. Surya. The study concludes that rising atmospheric CO_2 in future climate change scenario may be beneficial for tuber crops like potato to enhance growth as well as tuber yield.

Key words: Elevated CO_2 · Growth · Photosynthesis · Yield · Potato

INTRODUCTION

Rising atmospheric CO_2 is one of the important global issues under climate change scenario. IPCC [1] has projected that concentration of CO_2 in the atmosphere is likely to increase up to 550 µmol mol^{-1} by middle of 21st century. Such an increase in the atmospheric CO_2 may affect plant growth and productivity, because CO_2 has fertilization effect in C_3 crops and promotes their growth through enhanced photosynthesis and improve transpiration efficiency. Potato possesses the C_3 photosynthetic pathway and have a large carbohydrate sink in the form of tubers and exhibit apoplastic phloem loading of sucrose. Various studies conducted abroad have reported positive response of potato plant grown under high CO_2 in terms of increase in growth, photosynthesis and yield [2-6]. However, there are no reports available about the response of Indian potato cultivars to rising atmospheric CO_2.

Increase in plant growth or tuber yields under elevated CO_2 has been shown due to an increase in photosynthesis rather than increased leaf area [6]. Katny *et al.* [7] have reported up to 40% increase in photosynthesis in potato plants grown under long-term exposure to elevated CO_2. Apart from photosynthetic response, elevated CO_2 improved photosynthetic water use efficiency through reduction in rate of transpiration or stomatal conductance in above study.

In India potato (*Solanum tuberosum*) is the one of the most important crop and produces about 34.4 million tons from 1.83 million hectares under the crop (F.A.O, 2009). Various high yielding potato cultivars have been developed by Central Potato Research Institute (CPRI) Shimla, including recently released high temperature tolerant cultivar K. Surya for plain region of northern India. But, no information is available on their physiological response to rising atmosphere CO_2. Therefore, this study was carried out to analyse the effect

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of elevated CO_2 on photosynthesis, growth and productivity of two potato cultivars K.Surya (temperature tolerant) and K.Chipsona-3 (temperature sensitive).

MATERIAL AND METHODS

3 Two potato cultivars namely K. Surya and K. Chipsona-3 were grown inside Open Top Chambers (OTCs) maintained with ambient CO_2 (385±30 µmol mol^{-1}) and elevated CO_2 (570±50 µmol mol^{-1}), during *rabi* (winter) season of the year 2009-2010 at Division of Plant Physiology, Indian Agricultural Research Institute (IARI), New Delhi. Seed materials were obtained from Central Potato Research Station, Modipuram, Meerut. The experiment was planned in a randomized complete block design under factorial arrangement with three replications. In OTC, 12 uniform sprouted potato seeds were planted. Rows and plants spacing was maintained 60 and 20 cm, respectively. Before planting, potato seeds were treated with 2% Bavistin fungicide solution. Five g m^{-2} nitrogen, 10 g m^{-2} phosphorus, 15 g m^{-2} potassium and 1 kg m^{-2} FYM w ere mixed in the soil at planting time. 10 g m^{-2} nitrogen was applied at 30 and 60 days after planting as side dressing. Other recommended cultural practices were followed to raise a healthy crop as described by CPRI, Shimla.

The circular structure of OTCs was fabricated using aluminum frame as described by Madan Pal *et al*. [8] and fixed in the field. Pure CO_2 gas (99.7% v/v CO_2 and less than 10 µ mol mol^{-1} CO) was purchased from M/S Gas Associates, New Delhi and released from a commercial grade cylinder fitted with a regulator (DURA, make ESAB, India) through solenoid valve and PVC tubing connected to air-exhaust blower mounted at base of each OTC. To maintain elevated levels of CO_2 (570 µ mol mol^{-1}) at crop canopy level, continuous injection of pure CO_2 into plenum of OTC was done and mixed with air from air compressor before entering into the chamber. The air sample from the middle of the chamber was drawn periodically into a CO_2 sensor (NDIR, make Topak, USA) and the set level of CO_2 was maintained with the help of solenoid valves, Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA) winlog software (Make SELCO Italy). CO_2 data logging,

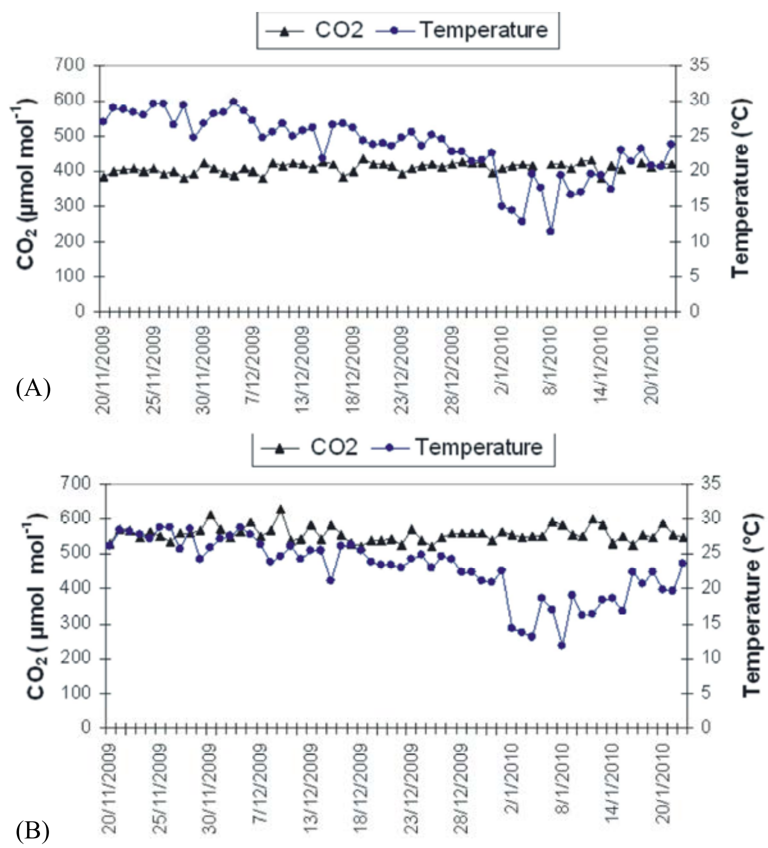

Fig. 1: Level of CO2 concentration and mean day temperature inside Open Top Chambers (OTCs) used for ambient (A) and high CO2 exposure (B).

control and operation was performed by PC through DOIP (digital input and output module) on real time basis. Elevated level of CO_2 was maintained from morning 8 AM to evening 6 PM from the day of emergence and continued till harvesting. The chambers were washed frequently with a gentle stream of water to remove the dust and to maintain transparency. The level of CO_2 concentration and temperature inside the OTCs (elevated and ambient) are illustrated in Fig. 1.

Observations on rate of photosynthesis were obtained using LI-COR portable photosynthesis system (IRGA LI-6400 Model, LI-COR, Nebaraska, USA) during tuberization and bulking stages and expressed as μmol CO_2 m^{-2} s^{-1}. Sugars were extracted from leaf sample (1 g FW) by boiling in 80% (v/v) ethanol in water and clarified following the method of McCready *et al*. [9]. The aliquot of clarified sugar extract was used for the determination of sugar content using Nelson's method [10].

For growth analysis plants were harvested at different growth stages viz. 20, 40, 70 DAE and at maturity stage. Plant samples were separated into leaves including petioles, stems, root and tubers and cleaned and then were kept in an oven at 75°C till constant weights were reached. Dry matter of all the plant parts was recorded using an electronic balance. Dry matter partitioning was determined from dry mass of individual plant parts as a percentage of total plant dry mass.

After harvesting, the number of tubers from 6 plants were counted, averaged and expressed as number of tuber per plant and their weight was recorded as mean tuber weight. For estimation of percent tuber dry matter, 100 g of tubers was diced and oven dried at 80°C to a constant weight. The tuber fresh weight of 6 plants (1 m^2) were weighed immediately after harvesting by using electronic balance. The analyses of variance was carried out using MSTATC Statistical Programme.

RESULTS AND DISCUSSION

The present study reports significantly higher rate of photosynthesis in both the potato cultivars grown under elevated CO_2 (Table 1). Maximum enhancement in rate of photosynthesis was observed at 30 DAE (tuber initiation stage) in K. Surya and at 60 DAE (bulking stage) in K. Chipsona-3. The response of elevated CO_2 exposure on photosynthesis was higher in K. Chipsona-3 compared to K. Surya. The enhancement in photosynthetic rate under elevated CO_2 was 22.2% and 24.1% in K. Chipsona-3 at 30 and 60 DAE, respectively while it was 7.6% and 10.5% in K. Surya at similar stages (Table 2). Rising atmospheric CO_2 has been reported to influence the growth and yield of C_3 plants due to their photosynthetic enhancement as this process is not fully saturated at current CO_2 concentration in these plants [11, 12]. The increase in photosynthesis under elevated CO_2 has been attributed to increases the velocity of carboxylation and inhibition of oxygenation reaction [13]. Similar increase in rate of photosynthesis has been reported by Sicher and Bunce [14] and Katny *et al*. [7]. On the other hand, Conn and Cochran [6] did not find any increase in net photosynthesis initially but reported 53% increase at final stage under elevated CO_2.

The accumulation of reducing, non-reducing and total sugars was significantly higher in the potato leaves under elevated CO_2 which indicated higher photosynthetic activity (Table 1). Maximum reducing, non-reducing and total sugars were recorded in K. Surya cultivar grown under elevated CO_2 (Table 3). Miglietta *et al*. [3] reported that elevated CO_2 exposure had a significant effect on the accumulation of total non structural carbohydrates (soluble sugars + starch) in the potato leaves during a sunny day. Similarly, Ainsworth *et al*. [1] observed a 45% increase in total non-structural carbohydrates content in soybean. Pal *et al*. [16] also found that the concentration of non-structural carbohydrates such as sugars and starch in chickpea leaves was higher under elevated CO_2 grown plants. Stitt [17] and Sage [18] have suggested that the excessive accumulation of carbohydrate in leaves might be one of the most important determinates for development of new sinks. This excess carbohydrate accumulation in this study might have been useful in generation and development of more new sink and contributed to productivity, as significant increase in tuber yield was recorded in both the cultivars.

Elevated CO_2 exposure significantly increased total dry matter production in both the potato cultivars (Fig. 3.C). K. Chipsona-3 grown under elevated CO_2 exhibited greater increase in biomass at all harvesting stages compared to ambient. At harvesting stage percentage increase in biomass was 35.8% and 28.9% in K. Chipsona-3 and K. Surya, respectively. Elevated CO_2 affected the pattern of biomass allocation in various parts of potato. CO_2 enrichment enhanced the partitioning of dry matter towards the tubers and decreased to haulms at all the sampling stages (Fig. 2). Conn and Cochran [6] found no effect of CO_2 on shoot dry weight at final

Table 1: Summary of analysis variance (ANOVA) for photosynthetic rate, leaf sugars concentration, yield and yield components in potato cultivars.

Mean sum of square (MS) values for traits measured	Source of variance: Cultivar	CO_2	Cultivar x CO_2	Error	CV (%)
Photosynthetic rate at 30 DAE	66.8**	38.5*	5.96^{NS}	4.7	7.9
Photosynthetic rate at 60 DAE	190.4**	47.2*	12.0^{NS}	10.41	13.5
Leaf reducing sugars at 20 DAE	7.84*	20.02**	0.37^{NS}	0.261	1.3
Leaf non-reducing sugars at 20 DAE	12.8*	121.6**	5.3^{NS}	1.021	2.3
Leaf total sugars at 20 DAE	40.7**	240.3**	8.5*	1.446	1.4
Leaf reducing sugars at 40 DAE	434.4**	286.2**	95.2**	0.218	1.1
Leaf non-reducing sugars at 40 DAE	393.3**	1202.2*	13.9^{NS}	15.505	6.2
Leaf total sugars at 40 DAE	1654.4**	2661.1**	181.7*	15.694	3.7
Leaf reducing sugars at 65 DAE	59.4**	4.7**	0.24^{NS}	0.328	1.4
Leaf non-reducing sugars at 65 DAE	607.8**	138.7*	2.4^{NS}	19.144	6.1
Leaf total sugars at 65 DAE	287.1**	194.4*	4.2^{NS}	15.899	3.5
Tuber yield	1976.3*	277856.3**	5125.3^{NS}	12319	11.1
No. of tubers per plant	7.05*	36.75**	0.33^{NS}	1.11	9.9
Mean tubers weight	556.2^{NS}	8.2^{NS}	15.6^{NS}	233.1	16.1
Tuber percent dry matter	4.08**	0.4^{NS}	0.01^{NS}	0.11	1.8

**Significant at 1%; * Significant at 5% level; NS = non significant; DAE = Days after emergence

Table 2: Effect of elevated CO_2 on rate of photosynthesis of two potato cultivars

Treatments	30 DAE: Photosynthesis (μ mol CO_2 m^{-2} s^{-1})	% Change	60DAE: Photosynthesis (μ mol CO_2 m^{-2} s^{-1})	% Change
K. Chipsona-3 (V_1)	25.01	-	27.78	-
K. Surya (V_2)	29.73	-	19.82	-
Ambient CO_2 (AC)	25.58	-	21.82	-
Elevated CO_2 (EC)	29.17	14	25.78	18.1
V_1 x AC	22.52^{b}	-	24.80^{ab}	-
V_1 x EC	27.51^{a}	22.2	30.77^{a}	24.1
V_2 x AC	28.65^{a}	-	18.83^{b}	-
V_2 x EC	30.82^{a}	7.6	20.80^{b}	10.5
CD at 5%	4.33		6.45	

*Data with the same letters are not significantly different. DAE = days after emergence

Table 3: Effect of elevated CO_2 on leaf sugar concentration of two potato cultivars

Treatments	20 DAE: Reducing sugars (mg g^{-1} dw)	Non-reducing sugars (mg g^{-1} dw)	Total sugars (mg g^{-1} dw)	40 DAE: Reducing sugars (mg g^{-1} dw)	Non-reducing sugars (mg g^{-1} dw)	Total sugars (mg g^{-1} dw)	65 DAE: Reducing sugars (mg g^{-1} dw)	Non-reducing sugars (mg g^{-1} dw)	Total sugars (mg g^{-1} dw)
K. Chipsona-3 (V_1)	42.43	44.82	87.25	38.03	57.47	95.50	42.58	65.25	107.83
K. Surya (V_2)	40.82	42.75	83.57	50.07	68.92	118.98	38.13	79.48	117.62
Ambient CO_2 (AC)	40.33	40.6	80.93	39.17	53.18	92.35	39.73	68.97	108.70
Elevated CO_2 (EC)	42.92 (6.4)	46.97 (15.7)	89.88 (11.1)	48.93 (24.9)	73.2 (37.6)	122.13 (32.2)	40.98 (3.1)	75.77 (9.9)	116.75 (7.4)
V_1 x AC	40.97^{b}	40.97^{c}	81.93^{c}	35.97^{d}	48.53^{d}	84.50^{c}	42.10^{a}	62.30^{c}	104.40^{c}
V_1 x EC	43.9^{a} (7.2)	48.67^{a} (18.8)	92.57^{a} (13.0)	40.10^{c} (11.5)	66.40^{b} (36.8)	106.50^{b} (26.0)	43.07^{a} (2.3)	68.20^{bc} (9.5)	111.27^{bc}(6.6)
V_2 x AC	39.7^{c}	40.23^{c}	79.93^{c}	42.37^{b}	57.83^{c}	100.20^{b}	37.37^{c}	75.63^{ab}	113.00^{b}
V_2 x EC	41.93^{b} (5.6)	45.27^{b} (12.5)	87.20^{b} (9.1)	57.77^{a} (36.3)	80.00^{a} (38.3)	137.77^{a} (37.5)	38.90^{b} (4.1)	83.33^{a} (10.2)	122.23^{a}(8.2)
CD at 5%	1.02	2.02	2.4	0.93	7.87	7.90	1.14	8.74	7.97

*Data with the same letters are not significantly different. Values in parentheses indicate percent change due to elevated CO_2 exposure; DAE = days after emergence.

Table 4: Effect of elevated CO_2 on yield and yield components of two potato cultivars

Treatments	Total yield ($g\ m^{-2}$)	% Change	No. of tuber $plant^{-1}$	% Change	Mean tuber weight (g)	% Change	Tuber percent dry matter (%)	% Change
K. Chipsona-3 (V_1)	1009.8		11.4		88.0		19.2	
K. Surya (V_2)	984.2		9.9		101.6		18.0	
Ambient CO_2 (AC)	844.8	-	8.9	-	95.7		18.4	-
Elevated CO_2 (EC)	1149.2	36	12.4	33.3	94.0	-1.8	18.8	2.2
V_1 x AC	837.0^{b}	-	9.5^{bc}	-	87.7^{a}	-	19.0^{a}	-
V_1 x EC	1182.7^{a}	41.3	13.4^{a}	41.1	88.3^{a}	0.7	19.4^{a}	2.1
V_2 x AC	852.7^{b}	-	8.3^{c}	-	103.6^{a}	-	17.9^{b}	-
V_2 x EC	1115.7^{a}	30.8	11.5^{ab}	33.6	99.7^{a}	-3.8	18.2^{b}	1.7
CD at 5%	221.7		2.1		30.5		0.66	

*Data with the same letters are not significantly different.

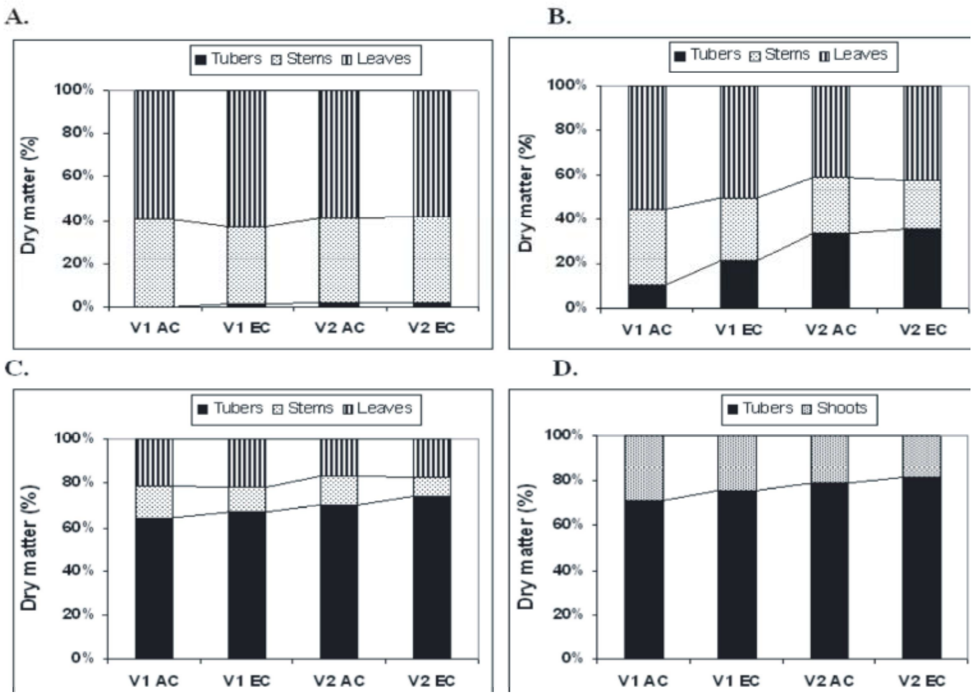

Fig. 2: Dry matter partitioning in different parts of potato cultivars grown under ambient and elevated CO_2 at 20 DAE (A); 40 DAE (B); 70 DAE (C) and maturity stage (D). V1= K. Chipsona-3; V2= K. Surya; AC= ambient CO_2 and EC= elevated CO2.

harvest but total tuber dry weight was 36% higher under elevated CO_2 compared to ambient. Miglitta *et al*. [3] found that elevated CO_2 did not increase above-ground dry weight of potatoes grown in a FACE experiment. Various other studies reports that elevated CO_2 exposure affect the allocation of dry biomass more towards tubers in potato compared to above ground and resulted in higher tuber number as well as mean dry weights [5, 19].

High CO_2 exposure resulted in enhanced CGR in both cultivars and increment was greater in K. Chipsona-3. CGR in K. Surya grown under high CO_2 sharply increased from 40 DAE to 70 DAE and afterwards sharply decrease while K. Chipsona-3 maintained the CGR higher than K. Surya (Fig. 3.A). Elevated high CO_2 significantly increased the TGR in both cultivars as compared to the ambient CO_2 (Fig. 3.B). The enhancement of CGR and TGR in both cultivars under elevated CO_2 was due to the stimulation of photosynthesis. Das [20] reported that elevated CO_2 caused significant increase in NAR, RGR and CGR at each stage of growth in *Brassica*. Similarly higher CGR and NAR has been reported in rice under elevated CO_2 by Sujatha [21].

Tuber yield of both the potato cultivars significantly increased under elevated CO_2 (Table 1). Total tuber fresh yield increased by 41.3% in K. Chipsona-3 and 30.8% in K. Surya. Enhancement in tuber yield in response to elevated CO_2 was 36% for both cultivars. The highest fresh tuber weight per plant was observed in K. Chipsona-3 under

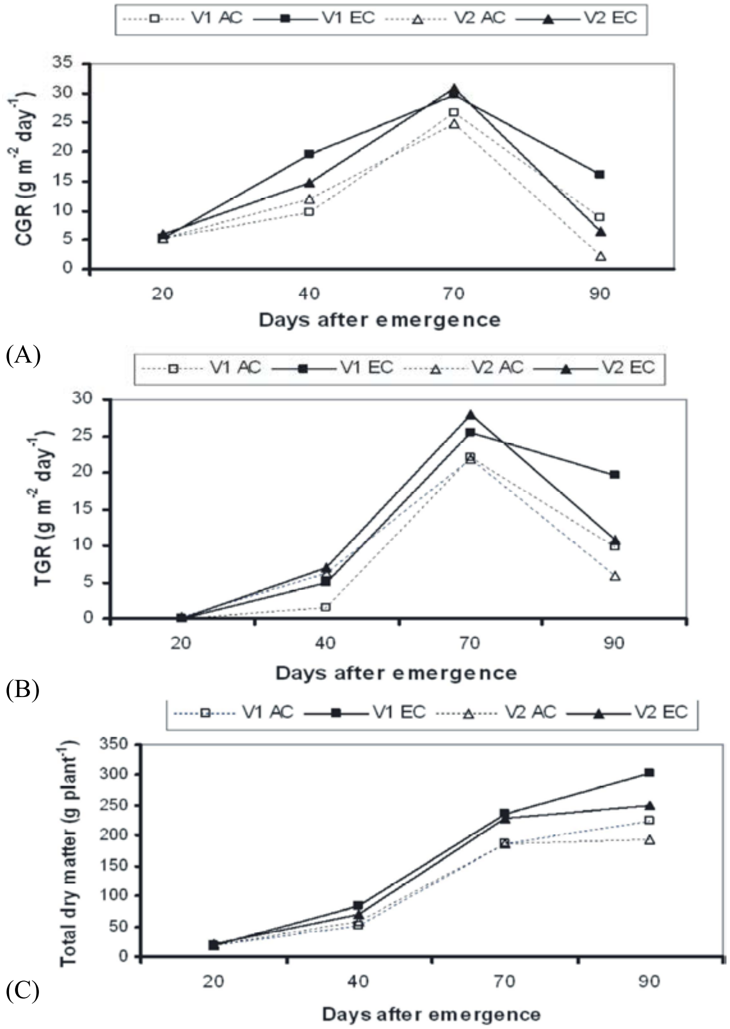

Fig. 3: Effect of elevated CO_2 on CGR (A), TGR (B) and total dry matter (C) at different growth stages in two potato cultivars. V1= K. Chipsona-3; V2= K. Surya; AC= ambient CO2 and EC= elevated CO_2.

elevated CO_2 (Table 4). A number of studies reported that potato yield increased with doubling the level of CO_2, but the level of enhancement varies [4-6].

In this study we observed significant increase on number of tubers per plant under elevated CO_2, but mean tuber weight and percent tuber dry matter was not affected (Table 4). In contrast, Craigon *et al*. [5] found higher mean dry weight and tuber numbers under elevated CO_2.

CONCLUSION

The study concludes that rising atmospheric CO_2 in future climate scenario may be beneficial for Indian potato cultivars in terms of enhanced vegetative growth, biomass, photosynthesis partitioning of dry matter to below ground and tuber yield through increased number of tubers per plant. Since the response of high temperature sensitive K. Chipsona-3 was better to high CO_2 than K Surya, it is expected that high CO_2 in future environment may impart high temperature tolerance in potato cultivars.

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