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Impact of Elevated Atmospheric CO_2 Concentration on the Growth, and Yield in Two 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 would affect plant growth, and as well the 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}) *vs.* elevated CO_2 (570±50 µmol mol^{-1}) levels during *rabi* (winter) season of the year 2009-2010. The photosynthetic rate significantly increased in both cultivars when under high CO_2 concentration, with the enhancement being more in Kufri Chipsona-3 than in Kufri Surya. There were significantly increased accumulations of reducing, non-reducing and total sugars observed in the leaves of both cultivars as due to CO_2 enrichment. Crop Growth Rate (CGR) and Tuber Growth Rate (TGR), in both cultivars, were recorded higher in plants grown under elevated CO_2 as compared with the ambient CO_2 content. High CO_2 increased the partitioning of dry matter towards the tubers at all the harvesting stages. Potato plants grown under elevated CO_2 exhibited increased tuber yield due to the enhanced number of tubers per plant. At the final harvest, total tuber fresh weight was by 36% higher, under high CO_2 treatments, as compared with that in the ambient. The response of K. Chipsona-3 was more pronounced, to elevated CO_2 concentration, as compared with K. Surya. It is concluded that rising atmospheric CO_2 in the future climatic change scenario may be beneficial to such tuber crops like potato to enhance growth as well as tuber number and finally yield.

Keywords: Dry matter partitioning, Elevated CO_2, Photosynthesis, Potato, Sugars, Yield.

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INTRODUCTION

Rising atmospheric CO_2 is one of the important global issues under climate change scenario. Inter-Governmental Panel on Climate Change (2007) has projected that 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 would affect plant growth and productivity, because CO_2 has nutritional effect in C_3 crops promoting their growth through enhanced photosynthesis and improving transpiration efficiency (Drake *et al.,* 1997; Ghildiyal and Sharma-Natu, 2000; Long *et al.,* 2004). Potato possesses the C_3 photosynthetic pathway benefiting from a large carbohydrate sink in the form of tubers and exhibiting 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 as well as yield (Farrar and Williams, 1991; Miglietta *et al.,* 1998; Schapendonk *et al.,* 2000; Craigon *et al.,* 2002; Conn and Cochran, 2006). However, there are no reports available concerning the response of Indian potato cultivars to rising atmospheric CO_2.

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Increase in either plant growth or tuber yields under elevated CO_2 has been demonstrated to occur due to an increase in photosynthesis rather than to increased leaf area (Conn and Cochran, 2006). Katny *et al.* (2005) 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 either a reduction in the rate of transpiration or stomatal conductance in the above study (Conn and Cochran, 2006; Katny *et al.,* 2005).

In India, potato (*Solanum tuberosum* L.) is the one of the most important crops, about 34.4 million tons being produced from 1.83 million hectares under its cultivation (FAO, 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 developed for the plain region of northern India. But, no information is available on their physiological responses to rising atmospheric CO_2. Therefore, this study was carried out to analyze the effect of elevated CO_2 on photosynthesis, growth and productivity in two potato cultivars.

MATERIALS AND METHODS

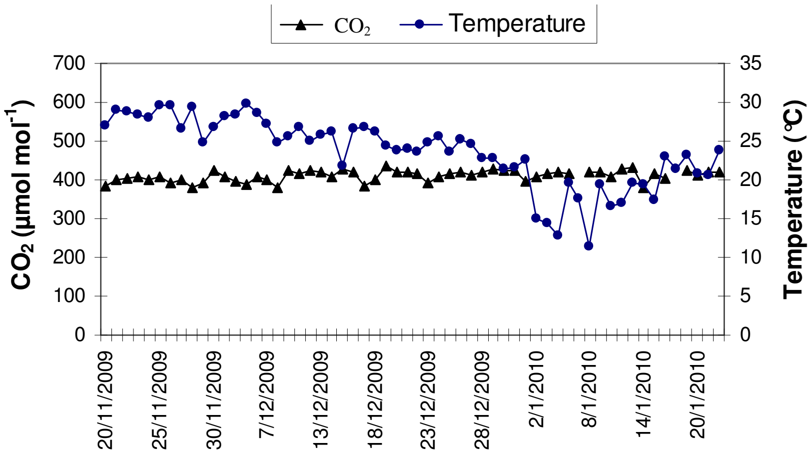
Two potato cultivars namely K. Surya (temperature tolerant) and K. Chipsona-3 (temperature sensitive) were grown inside Open Top Chambers (OTCs) maintained with ambient CO_2 (385±30 µmol mol^{-1}) *vs.* elevated CO_2 (570±50 µmol mol^{-1}**)**, during *rabi* (winter) season of the year 2009-2010 at the Division of Plant Physiology, Indian Agricultural Research Institute (IARI), New Delhi. The experiment was planned in the framework of a Randomized Complete Block Design (RCBD) with three replications. Seeds were obtained from Central Potato Research Station, Modipuram, Meerut. The soil inside OTC, at the experimental site, was non-calcareous, slightly alkaline, sandy loam in texture with an average bulk density of 1.56 Mg m^{-3}; pH of 7.3; EC 0.49 dS m^{-1}; organic C, 0.3 g kg^{-1}; total N 0.031%. The available P and K stood at 6.9 and 279.0 ppm; respectively. A number of 12 uniform sprouted potato seeds were planted in each of the OTCs. Rows and plants' spacings were maintained at 60 and 20 cm, respectively. Prior to 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 were mixed with the soil at planting time, while 10 g m^{-2} of nitrogen applied at 30 and 60 days past planting as side dressing. The OTCs were so irrigated as to have adequate moisture maintained in the soil. Weed control and earthing up were done manually at early vegetative growth and at bulking stages, respectively.

The circular structure of OTCs was fabricated using aluminum frame as described by Pal *et al.* (2004) and then fixed in the field. The OTCs were lined with transparent polyvinyl chloride (PVC) sheets. 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 the 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 being let into the chamber. The air sample from the middle of the chamber was drawn periodically into a CO_2 sensor (NDIR, make Topak, USA), the set level of CO_2 being maintained with the help of solenoid valves, Program Logic Control (PLC) and Supervisory Control along with Data Acquisition (SCADA) winlog software (Make SELCO Italy). The CO_2 data logging, control and operations were performed by use of PC through DOIP (digital input and output module) on real time basis. Carbon dioxide exposure was carried out daily during daylight. It was immediately started after crop after emergence, and continued till harvest. As for control chambers, only ambient air was supplied through blowers to maintain similar environmental conditions. The level of CO_2 concentration and temperature inside the OTCs (elevated and ambient) are illustrated in Figure 1.

Top most fully expanded leaves were selected for the photosynthetic and biochemical analyses.

Observations on rate of photosynthesis were made using LI-COR portable photosynthesis system (IRGA LI-6400 Model, LI-COR, Nebaraska, USA) during tuberization (30 Days After Emergence (DAE)) and bulking (60 DAE) stages and expressed as μmol CO_2 m^{-2} s^{-1}. Sugars were extracted from fully expanded leaf samples (1 g FW) by being boiled in 80% (v/v) ethanol and then clarified following the method of McCready *et al.* (1950). Aliquots from clarified sugar extract were used for the determination of sugar content employing Nelson's method (Nelson, 1944).

For growth analysis, three plants (in three replications) were harvested at different growth stages of: 20, 40, 70 DAE, and also at maturity stage. Plant samples were separated into leaves (including petioles), stems, root, and tubers. They were cleaned and kept in an oven at 75°C till constant weights reached. Dry matter in all the plant parts was assessed using an electronic balance. Dry matter partitioning was determined from dry mass of individual plant parts as a percentage of total plant dry mass. Crop Growth Rate (CGR) was found



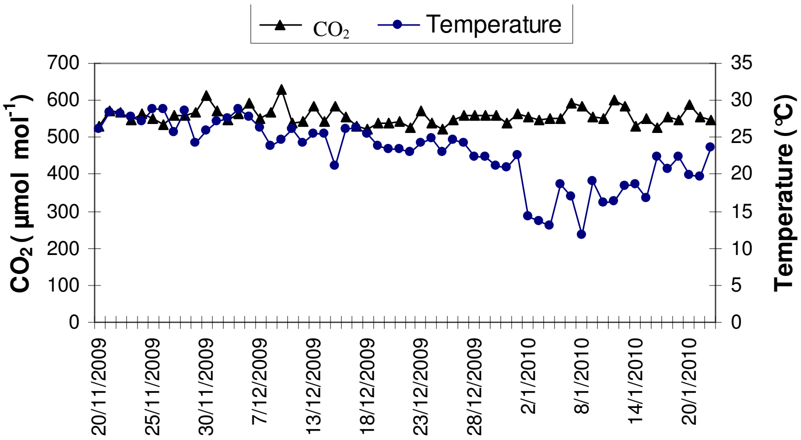


Figure 1. Level of CO_2 concentration and mean day temperature inside Open Top Chambers (OTCs) used for ambient (A) and high CO_2 exposure (B).

out through the following formula by Radford (1957).

$CGR= (W_2–W_1/t_2-t_1)\times 1/G_A$

Tuber Growth Rate (TGR) was calculated through the following formula described by Manrique (1989).

$TGR= (T_2–T_1/t_2 –t_1)\times 1/G_A$

Where, G_A standing for the ground area covered by the crop, W_2 and W_1 representing crop dry weight (g) at t_2 and t_1, and finally T_2 and T_1 denoting tuber dry weight (g) at time 2 (t_2) and time 1 (t_1).

Following harvest, the number of tubers from a number of 6 plants were counted, averaged and expressed as the number of tubers per plant with their weights recorded as mean tuber weight. For an estimation of percent tuber dry matter, from each treatments, a 100 g sample of tubers was diced and oven dried at 80°C to a constant weight. The tuber fresh weights of 6 plants (1 m^2 harvested area) were weighed immediately after harvest, using electronic balance. Analyses of variance was carried out based on RCBD using MSTATC Statistical Programme and the difference between means compared through Duncan's Multiple Range Test at 5% probability level.

RESULTS AND DISCUSSION

Rising atmospheric CO_2 has been reported to influence the growth and yield in C_3 plants due to their photosynthetic enhancement, as this process is not fully saturated at current CO_2 concentration in these plants (Drake *et al.,* 1997; Ghildiyal and Sharma-Natu, 2000). The present study reports that the effect of elevated CO_2 was significant on rate of photosynthesis in either one of the potato cultivars (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 as compared with K. Surya. The enhancements in photosynthetic rate (under elevated CO_2) were 22.2 and 24.1% in K. Chipsona-3 at 30 and 60 DAE, respectively while these were 7.6 and 10.5% in K. Surya at similar stages (Table 2). The availability of sufficient sink is important for the photosynthetic response of C_3 plants under elevated CO_2 (Long *et al.,* 2004). In this study, increase in number of tubers as

Table 1. Summary of Analysis Variance (ANOVA) for photosynthetic rate, leaf sugars concentration, yield and yield components in potato cultivars grown under elevated *vs.* ambient CO_2.

Mean sum of Square (MS) values for traits measured	Source of variance			
	Replication	Treatment	Error	CV (%)
Photosynthetic rate at 30 DAE [a]	0.098	37.1*	4.7	7.9
Photosynthetic rate at 60 DAE	2.73	83.2*	10.41	13.6
Reducing sugars at 20 DAE	0.063	9.41**	0.26	1.3
Non-reducing sugars at 20 DAE	0.14	46.58**	1.02	2.3
Total sugars at 20 DAE	0.39	96.5**	1.45	1.4
Reducing sugars at 40 DAE	1.16	271.92**	0.22	1.1
Non-reducing sugars at 40 DAE	0.36	536.39**	15.5	6.2
Total sugars at 40 DAE	0.23	1499.1**	15.65	3.7
Reducing sugars at 65 DAE	1.82	21.45**	0.33	1.4
Non-reducing sugars at 65 DAE	4.62	249.64*	19.14	6.1
Total sugars at 65 DAE	0.64	161.92**	15.9	3.5
Tuber yield	23467	94986*	12319	11.1
No. of tubers per plant	3.61	14.71**	1.11	9.9
Mean tubers weight	458.9	193.3 NS [b]	233.1	16.1
Tuber percent dry matter	0.9	1.5**	0.11	1.8

** Significant at 1%; * Significant at 5% level. [a] DAE = Days After Emergence, [b] Non Significant;

Table 2. Effect of elevated CO_2 on rate of photosynthesis in the potato cultivars.[a]

Treatments	30 DAE		60 DAE	
	Photosynthesis (μ mol CO_2 m^{-2} s^{-1})	% change	Photosynthesis (μ mol CO_2 m^{-2} s^{-1})	% change
V_1 AC	22.52[b]	-	24.80[ab]	-
V_1 EC	27.51[a]	22.2	30.77[a]	24.1
V_2 AC	28.65[a]	-	18.83[b]	-
V_2 EC	30.82[a]	7.6	20.80[b]	10.5
CD at 5%	4.33		6.45	

[a] Data with the same letters are not significantly different. DAE = Days After Emergence. V_1= K. Chipsona-3; V_2= K. Surya; AC= Ambient CO_2, and EC= Elevated CO_2.

potential sink, may be attributed to photosynthetic enhancement in either one of the two potato cultivars. Similar increase in rate of photosynthesis has been reported by Sicher and Bunce (1999) and Katny *et al.* (2005). On the other hand, Conn and Cochran (2006) did not find any increase in net photosynthesis initially, but reported 53% increase at the final stage (under elevated CO_2).

Significant differences were observed for the reducing, non-reducing as well as total sugars among the treatments (Table 1). The accumulations of reducing, non-reducing and total sugars were significantly higher in the potato leaves under elevated CO_2, indicating higher photosynthetic activity. Maximum reducing, non-reducing, and total sugars were recorded in K. Surya cultivar grown under elevated CO_2 (Table 3). Miglietta *et al.* (1998) reported that elevated CO_2 exposure significantly affected the accumulation of total non structural carbohydrates (soluble sugars+starch) in the potato leaves during a sunny day. Similarly, Ainsworth *et al.* (2002) observed a 45% increase in total non-structural carbohydrates content in soybean. Pal *et al.* (2008), also found that the concentration of such non-structural carbohydrates as sugars and starch in chickpea leaves was higher in under elevated CO_2 grown plants. Stitt (1991) and Sage (1994) have suggested that an extra accumulation of carbohydrate in leaves might be one of the most important determinants for the development of new sinks. This excess carbohydrate accumulation throughout the present study might have acted as useful in generation and development of more new sink, contributing to more productivity, as significant increase in tuber yield was recorded for both cultivars.

Elevated CO_2 exposure significantly increased total dry matter production in both of the potato cultivars (Figure 3-C). The cultivar K. Chipsona-3, grown under elevated CO_2, exhibited greater increase in biomass at all harvesting stages as compared with the ambient. At harvesting stage percentage increases in biomass were 35.8 and 28.9% in K. Chipsona-3 *vs.* K. Surya, respectively. Elevated CO_2 affected the pattern of biomass allocation in various parts of the potato crop. Carbon dioxide enrichment enhanced the partitioning of dry matter towards the tubers and decreased to it haulms at all the sampling stages (Figure 2). Conn and Cochran (2006) found no effect of CO_2 on shoot dry weight at final harvest but total tuber dry weight was 36% higher under elevated CO_2 as compared with the ambient. Miglitta *et al.* (1998) found that elevated CO_2 did not increase the above-ground dry weight of plant parts in potatoes grown in a FACE experiment. Various other studies report that elevated CO_2 exposure affect the allocation of dry biomass more towards tubers in potato as compared with the above ground plant parts, resulting in higher tuber number as well as their higher mean dry weights (Lawlor and Mitchell, 1991; Craigon *et al.,* 2002).

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Table 3. Effect of elevated CO_2 on leaf sugar concentration of potato cultivars.[a]

Treatments	20 DAE			40 DAE			65 DAE		
	Reducing sugars (mg g^{-1} dw)	Non-reducing sugars (mg g^{-1} dw)	Total sugars (mg g^{-1} dw)	Reducing sugars (mg g^{-1} dw)	Non-reducing sugars (mg g^{-1} dw)	Total sugars (mg g^{-1} dw)	Reducing sugars (mg g^{-1} dw)	Non-reducing sugars (mg g^{-1} dw)	Total sugars (mg g^{-1} dw)
V_1 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 EC	43.9^a	48.67^a	92.57^a	40.10^c	66.40^b	106.50^b	43.07^a	68.20^{bc}	111.27^{bc}
	(7.2)	(18.8)	(13.0)	(11.5)	(36.8)	(26.0)	(2.3)	(9.5)	(6.6)
V_2 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 EC	41.93^b	45.27^b	87.20^b	57.77^a	80.00^a	137.77^a	38.90^b	83.33^a	122.23^a
	(5.6)	(12.5)	(9.1)	(36.3)	(38.3)	(37.5)	(4.1)	(10.2)	(8.2)
CD at 5%	1.02	2.02	2.4	0.93	7.87	7.90	1.14	8.74	7.97

[a] 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; V_1= K. Chipsona-3; V_2= K. Surya; AC= Ambient CO_2, and EC= Elevated CO_2.

Table 4. Effect of elevated CO_2 on yield and yield components of the 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
V_1 AC	837.0^b	-	9.5^{bc}	-	87.7^a	-	19.0^a	-
V_1 EC	1182.7^a	41.3	13.4^a	41.1	88.3^a	0.7	19.4^a	2.1
V_2 AC	852.7^b	-	8.3^c	-	103.6^a	-	17.9^b	-
V_2 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	

[a] Data with the same letters are not significantly different. V_1= K. Chipsona-3; V_2= K. Surya; AC= Ambient CO_2, and EC= Elevated CO_2.

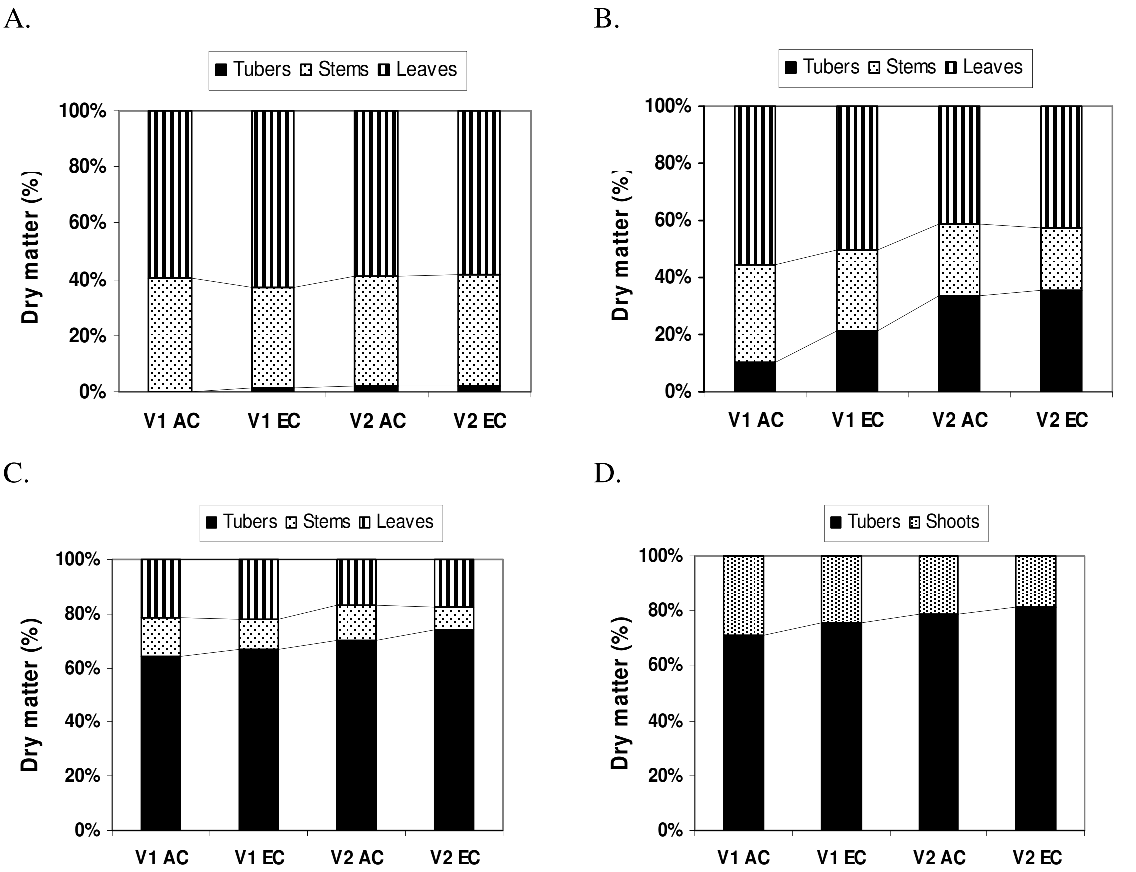

Figure 2. Dry matter partitioning in different parts of potato cultivars grown under ambient *vs.* elevated CO_2 at 20 DAE (A); 40 DAE (B); 70 DAE (C), and maturity stage (D). V_1= K. Chipsona-3; V_2= K. Surya; AC= Ambient CO_2, and EC= Elevated CO_2.

High CO_2 exposure resulted in enhanced CGR in both cultivars with the increment observed greater in K. Chipsona-3. Crop Growth Rate (CGR) in K. Surya, grown under high CO_2, sharply increased from 40 DAE stage to 70 DAE and afterwards sharply decreased while K. Chipsona-3 maintained its CGR higher than that in K. Surya (Figure 3-A). Elevated CO_2 significantly increased the TGR in both cultivars as compared with the ambient CO_2 treatment (Figure 3-B). The enhancement of CGR and TGR in both cultivars, under elevated CO_2, was found out as due to the stimulation of photosynthesis. Das (2003) 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 have been reported in rice under elevated CO_2 by Sujatha (2005).

Tuber yield in both potato cultivars significantly increased under elevated CO_2 (Table 1). Tuber 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 either one of the cultivars. The highest fresh tuber weight per plant was observed in K. Chipsona-3 under elevated CO_2 (Table 4). A number of studies have reported that potato yield increased with the doubling of the level of CO_2, but the level of enhancement varied (Schapendonk *et al.,* 2000; Craigon *et al.,* 2002; Conn and Cochran, 2006). Throughout the present study significant increase in number of tubers was observed per plant under elevated CO_2, but mean

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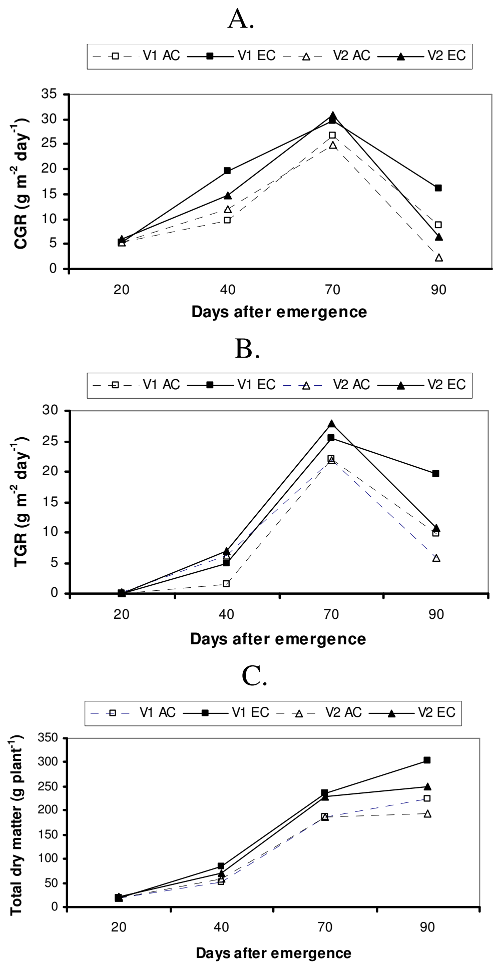

Figure 3. Effect of elevated CO_2 on Crop Growth Rate (CGR) (A); Tuber Growth Rate (TGR) (B), and total dry matter (C) at different growth stages in two potato cultivars. V1= K. Chipsona-3; V2= K. Surya; AC= Ambient CO_2, and EC= Elevated CO_2.

tuber weight and percent tuber dry matter recordings were not affected (Table 4). In contrast, Craigon *et al.* (2002) found higher mean dry weight and tuber numbers under elevated CO_2.

CONCLUSION

The study revealed that rising atmospheric CO_2 (in the future climate scenario) may fall beneficial to Indian potato crop cultivars in terms of enhanced vegetative growth, biomass development photosynthetic partitioning of dry matter to below ground parts, and tuber yield through an increased number of tubers per plant. Since the response of high temperature sensitive K. Chipsona-3 cultivar was more pronounced to high CO_2 content than K. Surya, it is expected that high CO_2 (in the future environment) may reduced sensitivity, imparting high temperature tolerance to sensitive potato cultivars.

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تاثیر افزایش غلظت CO_2 اتمسفری بر رشد و عملکرد دو رقم سیب زمینی

ا. آیین، م. پال، س. ختارپال، و س. کومار پندی

چکیده

به احتمال زیاد غلظت CO_2 اتمسفر تا اواسط قرن ۲۱ به ۵۵۰ میکرو مول بر مول افزایش می یابد. این افزایش میزان CO_2 اتمسفر، رشد و تولید گیاهان زراعی را تحت تاثیر قرار می دهد. لذا یک آزمایش مزرعه ای در داخل OTCبا غلظت فعلی CO_2 محیط (۵۰ ± ۳۸۵ میکرو مول بر مول) و غلظت زیاد CO_2(۵۰ ± ۵۷۰ میکرو مول بر مول) و با دو رقم سیب زمینی به نامهای کوفری سوریا و کوفری چیپسونا ۳ در سال زراعی ۲۰۱۰ –۲۰۰۹ در انستیتو تحقیقات کشاورزی هندوستان انجام شد. نتایج نشان داد شدت فتوسنتز در شرایط غلظت بالای CO_2 به طور معنا داری در هر دو رقم افزایش یافت و میزان افزایش درکوفری چیپسونا ۳ بیشتر ازکوفری سوریا بود. انباشت قندهای احیا شونده، غیر احیا شونده و قند کل در برگهای هر دو رقم در نتیجه افزایش غلظتCO_2 به طور معنا داری افزایش نشان داد. سرعت رشد محصول (CGR) و سرعت رشد غده (TGR) در هر دو رقم در شرایط غلظت بالای CO_2 در مقایسه با غلظت موجود CO_2 محیط، بالاتر بود. افزایش غلظت CO_2، تسهیم ماده خشک به سمت غده ها را در تمامی مراحل نمونه برداری افزایش داد. عملکرد غده در بوته های رشد یافته در شرایط غلظت بالایCO_2 ، به دلیل افزایش تعداد غده در بوته، بیشتر بود. وزن کل غده ها (عملکرد غده) در شرایط افزایش غلظت CO_2 در مقایسه با غلظت CO_2فعلی محیط، ۳۶ درصد بیشتر بود. عکس العمل کوفری چیپسونا۳ نسبت به افزایش غلظت CO_2 در مقایسه با کوفری سوریا بهتر بود. بنابراین می توان نتیجه گیری نمود که افزایش CO_2اتمسفر در پدیده تغییرات آب و هوایی جهانی در آینده، می تواند برای محصولات غده ای مانند سیب زمینی از نظر رشد و همچنین عملکرد غده مفید باشد.

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