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EFFECT OF CALCIUM CARBIDE ON PHOTOSYNTHETIC CHARACTERISTICS, GROWTH AND YIELD OF TOMATO CULTIVARS

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In order to ascertain the growth, yield and photosynthetic responses of tomato (*Lycopersicon esculentum* Mill.) cultivars to ethylene releasing compound calcium carbide (CaC_2), a pot trial was conducted. Response of three tomato cultivars "Rio Grande" "Tenzila" and "F-1 3560-S" to different rates of CaC_2 was observed. Polyethylene coated CaC_2 was applied at different rates (0,100, 200 and 300 mg pot^{-1}) two weeks after transplantation of nursery plants into pots and data on photosynthetic characters; net photosynthetic rate (P_N), carboxylation efficiency, photosynthetic water use efficiency, plant water use efficiency (WUE) and agronomic parameters; plant height, root and shoot dry weight, number of days to flower and fruit yield per plant were recorded. Results revealed that P_N, carboxylation efficiency and photosynthetic water use efficiency were increased by 40, 33 and 10%, respectively in Rio Grande; 16, 36 and 42%, respectively in Tenzila and 37, 48 and 29%, respectively in F-1 3560-S cultivar compared with control by applying 200 mg pot^{-1} coated CaC_2. Plants treated with 100 mg pot^{-1} CaC_2 improved 13, 17 and 28 % WUE in all three cultivars, respectively. Application of CaC_2 reduced plant height, number of days to flower while improved number of fruits set per plant. The rate of CaC_2 @ 300 mg pot^{-1} gave the best results in improving number of fruits and yield per plant.
Keywords: Tomato cultivars, calcium carbide, photosynthesis, water use efficiency, yield

INTRODUCTION

Photosynthesis is the main driving force for biomass accumulation. Different intrinsic and extrinsic factors at both the cellular and organ levels control photosynthesis (Lawlor, 2001). Among these various factors plant hormones are important in regulating photosynthesis and growth processes (Brenner and Cheikh, 1995) delivering photosynthetic responses by altering photosynthesis and respiration balance (Makeev *et al.*, 1992). They have the capacity to direct the translocation and accumulation of nutrients in plants and hence change efficiency of carboxylation (Foroutan-Pour *et al.*, 1997; Kuiper *et al.*, 1989). Ethylene as a plant hormone influences many aspects of plant growth (Abeles *et al.*, 1992; Yaseen *et al.* 2005, 2006) and photosynthesis (Pierik *et al.*, 2006; Acharya and Assmann, 2009). Grewal *et al.* (1993), Khan *et al.* (2000), Khan (2004) and Mir *et al.* (2009a) have reported increased photosynthesis by ethrel (an ethylene releasing compound) spray. Therefore, there is dire need to generate precise information regarding the optimum requirement of growth regulating substances which help in better growth habit, fruiting and yield. Calcium carbide is one of such compounds which can be a source of ethylene when introduced into the soil under the influence of soil moisture. Due to its reaction with water and conversion into acetylene and ethylene gases (Lurssen, 1991; Arshad and Frankenberger, 2002) it is mostly applied into soil in some encapsulation form so that a sustained supply of gases. In the present study, different doses of coated CaC_2 were applied to the soil to investigate the optimum dose of CaC_2 for better growth and yield of tomato cultivars and to find out its effect on photosynthesis and related physiological traits including carboxylation efficiency, photosynthetic water use efficiency and plant water use efficiency (WUE).

MATERIALS AND METHODS

Glazed pots with the capacity of 12 kg soil per pot lined with polyethylene bags were used during the experiment. Three tomato cultivars (Rio Grande, Tenzila and F-1 3560-S) were grown in our study. Recommended doses of NPK fertilizers @ 100-90-60 kg ha^{-1} were applied in all pots. Two seedlings of each cultivar from thirty days old nursery were transplanted into pots and finally one plant was maintained in each pot. Four rates of polyethylene coated CaC_2 0, 100, 200 and 300 mg pot^{-1} were applied two weeks after transplantation of nursery. Coating of CaC_2 granules was processed by adopting procedure described by Mahmood (2009). Required rates of CaC_2 were placed 6 cm deep in soil in the center of pots. In control treatments calcium chloride was added to adjust the amount of calcium added from CaC_2. Canal water was used to water the plants throughout the growth period. Imidacloprid (a.i. 25%) insecticide was sprayed @ 1 g L^{-1} once during the whole growth period to control the mild attack of aphid. The experiment was laid out according to completely randomized design (CRD) in factorial arrangement with three replications. All the pots were observed regularly. The measurements of photosynthetic rate (P_N), stomatal conductance (Gs), and intercellular carbon dioxide concentration $(CO_2)_i$ were done with an Infrared Gas Analyser (IRGA, model ADC, Bioscientific Ltd., England) at 1100-1200 h when above the plant canopy photosynthetic active radiations (PAR; 1060 µmol m^{-2} s^{-1}) were present. The inside temperature of the leaf cuvette was set at 30 ± 2 °C. The light responses curves were carried out at ambient CO_2 concentrations (300-350 µmol mol^{-1}). Care was taken to select fully expanded leaves of the uniform size and age to record photosynthesis data in control and treated plants. Photosynthetic indices were calculated by using the following formulae:

Carboxylation efficiency $_{(\%)} = P_N / (CO_2)_i$

(Farquhar and Sharkey, 1982)

Photosynthetic water use efficiency $_{(\mu mol\ mole^{-1})} = P_N / (Gs)$

(Mir *et al.*, 2010)

Plant water use efficiency $_{(mg\ g^{-1})}$

= plant dry mass / transpiration

(Van den-Boogard *et al.*, 1996)

Number of days recorded upon 50% completion of flowering in each plot. The experimental data regarding plant height, number of days for flowering, root and shoot dry weights, total number of fruits per plant and yield of fruits per plant at the time of harvesting were also recorded and analyzed by using ANOVA procedures and means were compared according to the LSD test at 5% probability level (Steel *et al*., 1997).

RESULTS

***Photosynthetic characters*:** Experimental data regarding the effect of various rates of coated CaC_2 had a pronounced effect on the photosynthetic rate (P_N), carboxylation efficiency, photosynthetic water use efficiency and plant water use efficiency (Table 1). However, the minimum values of these photosynthetic characteristics were observed in control (without CaC_2). Mean maximum values for P_N, carboxylation efficiency and photosynthetic water use efficiency (25.3 µ mol m^{-2} s^{-1}, 10.1% and 63.5 µmol $mole^{-1}$, respectively) were observed in plants treated with CaC_2 @ 200 mg pot^{-1} while minimum values (17.7 µ mol m^{-2} s^{-1}, 4.4% and 35.3 µmol $mole^{-1}$, respectively) were observed in control plants (without CaC_2). Therefore, minimum values were actually a response of fertilizers alone. Plan t water use efficiency was also improved in response to applied CaC_2 at lower rate but it was reduced at higher rate of CaC_2 however, still it was higher than control. Maximum WUE (5.4 mg g^{-1}) was noted in plants treated with CaC_2 @ 100 mg pot^{-1} and minimum (4.2 mg g^{-1}) was observed in control plants. Statistical comparison among mean values reveals that CaC_2 affected the photosynthetic activity of tomato cultivars, but the extent of effect was not similar. Differential increase of 40, 33 and 10% regarding P_N, carboxylation efficiency and photosynthetic water use efficiency, respectively compared with control were recorded in Rio Grande and 16, 36 and 42 %, respectively in Tenzila when CaC_2 was applied @ 200 mg pot^{-1}.

Growth and yield

***Plant height*:** Reduction in plant height was noted by the application of CaC_2 as compared to control where only fertilizer was applied (Table 3). However, there was a lot of variation observed regarding reduction in plant height both due to variable rates of CaC_2 and tomato cultivars. Application of all rates of CaC_2 showed significant reduction in plant height. Mean minimum plant height (39.1 cm) was observed in plants treated with polyethylene coated CaC_2 @ 200 mg $pot^{-1}$and mean maximum plant height (52.9 cm) was in the control plants. It means that fertilizer treatment showed common response or effect of increasing plant height. According to comparison of means, mostly CaC_2 application @ 200 mg pot^{-1} was more effective in reducing plant height than 100 and 300 mg pot^{-1} CaC_2. However, later two rates of CaC_2 remained insignificant among each other in reduction of plant height. Comparison of tomato cultivars showed reduction in plant height in order as Tanzila > F-1 3560-S > Rio Grande.

***Number of days required for flowering*:** A reduction in time to initiate flowering in tomato cultivars was noted where CaC_2 was applied compared to control plants. Comparison among means indicates that application of high level of CaC_2 (300 mg pot^{-1}) caused significant early initiation of flowering among all rates of CaC_2. Maximum number of days (37) required for flower initiation were noted in untreated plants (control) of cultivar F-1 3560-S whereas the minimum number of days (27) for flowering were recorded in treatment where coated CaC_2 applied at 300 mg pot^{-1} (Table 3). A reduction of 21.6 % in mean time period for flower appearance in treated plants was recorded. Data is therefore, evident that CaC_2 application stimulate early flowering. Differences regarding the number of days taken by the cultivars for flowering were statistically highly significant (Table 2). Among various cultivars, Rio Grande took minimum period of 27 days to flower whereas, Tenzila flowered in 29 days.

***Root dry weight*:** It is evident from the data that all rates of CaC_2 and cultivars were statistically different from one another regarding effect on dry weight of root. Application of coated CaC_2 on root weight of tomato plants presented in Table 3 reveals that root weight greatly responded to application of CaC_2 (Table 2). Maximum increase in root weight (6.1 g pot^{-1}) was observed by the application of 200 mg pot^{-1} coated CaC_2. But minimum root weight (2.9 g pot^{-1}) was observed in control. It is also obvious from the data in

Table 1. Effect of different rates of polyethylene coated calcium carbide on photosynthetic characteristics of tomato cultivars

Rate of CaC_2 (mg pot^{-1})	Photosynthetic rate (μ mol m^{-2} s^{-1})			Carboxylation efficiency (%)			Photosynthetic water use efficiency (μmol $mole^{-1}$)			Water use efficiency (mg g^{-1})		
	Rio Grande	**Tenzila**	**F-1 3560-S**	**Rio Grande**	**Tenzila**	**F-1 3560-S**	**Rio Grande**	**Tenzila**	**F-1 3560-S**	**Rio Grande**	**Tenzila**	**F-1 3560-S**
0	18.1 i*	17.7 j-l	18.0 i	7.0 d-g	4.4 l	6.8 kl	45.3f	35.3h	45f	4.5 d-g	4.2 fg	4.2 g
100	21.3 d-i	17.2 kl	20.3 e-k	7.6 d-f	5.0 j-l	6.1 g-j	50.1e-g	45.5	49.8e-g	5.1 a-d	4.9 a-e	5.4 a
200	25.3 a	20.6 e-k	24.7 a-d	9.3 bc	6.0 g-j	10.1 a	63.5 a	50.2e-g	58.3bc	4.9 a-e	4.5 d-g	4.5 d-g
300	23.3 b-f	19.1 h-k	21.7 c-h	7.5 d-f	5.0 i-l	7.5 de	56.9d	45.5	51.5e-g	4.7 b-g	4.6 c-g	4.2 fg
Mean	[a] 22.0A	18.6C	21.2B	7.8A	5.1B	7.6A	53.9A	44.1C	51.1B	4.8A	4.5B	4.6A

*Values sharing common letter(s) in each column in table body (non bold) and (a) last row (bold) do not differ significantly at P < 0.05 according to LSD test

Table 2. Mean squares from analysis of variance of data for growth and yield parameters of three tomato cultivars (Rio Grande, Tenzila and F-1 3560-S) with calcium carbide application in different rates

Effects	Df	Plant height	Days to flower	Root dry wt	Shoot dry wt	No. of frt. $plant^{-1}$	Frt. yield $plant^{-1}$
Rate(R)	9	145.09*	23.46**	2.54**	581.07**	120.6*	213740**
Cultivar (C)	2	2232.5*	233.10**	4.31**	162.32*	179.2*	198679*
R× C	18	42.06*	1.66^{NS}	0.63**	137.2*	7.16^{NS}	12364*

*, **= significant at 0.05 and 0.01 levels, respectively, NS = non-significant

Table 3. Effect of different rates of polyethylene coated calcium carbide on growth and yield of tomato cultivars

Parameter	Rate of CaC_2 (mg pot^{-1})	Tomato cultivar: Rio Grande	Tenzila	F-1 3560-S	Mean
Plant height (cm)	0	63.7(±1.0)[a*]	42.7(±2.1)[efg]	52.3(±1.1)[bcd]	52.9 A
	100	49.0(±0.8)[c]	36.3(±1.9)[ghi]	46.3(±0.8)[c-f]	43.9 BC
	200	47.0(±0.8)[cdf]	33.2(±0.9)[i]	37.0(±1.4)[g-i]	39.1 C
	300	57.3(±1.1)[b]	32.3(±1.2)[i]	44.3(±1.5)[d-f]	44.7 B
No. of days to flower	0	34(±1.2)[bc]	34(±2.0)[bc]	37(±2.1)[a]	35 A
	100	29(±1.1)[d]	32(±1.7)[c]	34(±1.5)[bc]	32 B
	200	28(±1.5)[def]	29(±1.0)[d]	34(±1.1)[bc]	32 B
	300	27(±2.0)[f]	29(±1.4)[d]	32(±1.0)[c]	29 C
Root dry weight (g pot^{-1})	0	3.2(±0.9)[e]	2.9(±0.3)[f]	3.3(±0.4)[de]	3.1 C
	100	3.7(±1.0)[c]	3.9(±0.2)[bc]	3.7(±0.4)[c]	3.8 B
	200	6.1(±0.4)[a]	4.2(±0.4)[b]	4.0(±0.1)[b]	4.8 A
	300	4.0(±0.3)[b]	3.9(±0.3)[bc]	3.4(±0.2)[d]	3.8 B
Shoot dry weight (g pot^{-1})	0	53.8(±0.3)[g]	50.1(±0.4)[h]	54.9(±0.2)[fgj]	52.9 CD
	100	71.9(±0.2)[b]	67.4(±0.2)[c]	81.2(±0.3)[a]	73.5 A
	200	46.9(±0.1)[i]	59.4(±0.3)[d]	57.2(±0.3)[efg]	53.4 BC
	300	57.5(±0.4)[efg]	52.0(±0.5)[g]	54.8(±0.1)[fgh]	54.8 B
No. of fruits per plant	0	29(±1.8)[f]	26(±2.2)[g]	29(±1.3)[f]	28 D
	100	37(±1.6)[d]	32(±1.7)[e]	41(±1.8)[ab]	37 C
	200	40(±2.1)[b]	38(±2.1)[cd]	39(±1.9)[bc]	39 AB
	300	41(±1.4)[ab]	36(±1.8)[de]	43(±2.1)[a]	40 A
Yield of fruit (g pot^{-1})	0	1254.0(±2.3)[j]	1258.3(±1.1)[j]	1358.7(±2.4)[I]	1290.3 C
	100	1596.7(±2.5)[fg]	1430.0(±1.0)[hi]	1692.7(±1.1)[bcd]	1573.1 B
	200	1653.3(±1.6)[bcd]	1614.7(±0.9)[dg]	1676.3(±2.3)[cde]	1793.4 A
	300	1738.0(±2.8)[b]	1708.7(±1.8)[bc]	1924.0(±1.6)a	1790.2 A

*Values sharing common letter(s) in table body (non bold) (a) last column do not differ significantly at P < 0.05 according to LSD (± = SE of means)

Table 3 that application of CaC_2 @ 200 mg pot^{-1} was most prominent among all levels of CaC_2. Comparison of means also shows that root weight decreased with the increase in rate of CaC_2. Among all the cultivars, Rio Grande showed the highest response to applied CaC_2 and produced maximum root dry matter.

***Shoot dry weight*:** Shoot dry weight of tomato plants was significantly increased in the treatments where CaC_2 was applied @ 100 mg pot^{-1} compared to control and all other treatment with higher dose of CaC_2 application (Table 3). Comparative effect of coated CaC_2 on shoot dry weight shows that maximum shoot weight (81.2 g pot^{-1}) was noted in treatment where CaC_2 @ 100 mg pot^{-1} was applied. Minimum shoot dry matter (50.1 g pot^{-1}) was noted in control. Comparison of means for rates of CaC_2 illustrates that effect of higher rates of CaC_2 like 200 and 300 mg pot^{-1} on shoot dry weight was statistically at par compared to control.

***Number of fruits per plant*:** Difference in fruit setting in response to applied CaC_2 is shown in Table 3. Data regarding fruit development showed that response of tomato cultivars to various doses of CaC_2 for fruit sets per plant was highly significant. Statistically, effect of application of CaC_2 at the rate of 300 mg pot^{-1} showed most significant results among all rates of CaC_2. Minimum number of fruit per plant (26.0) was found in control which was increased to 43 fruits in plants treated with 300 mg pot^{-1} coated CaC_2. Treatment means indicates approximately 43 % increase in fruits number over control. Comparison among cultivars at $p<0.01$ (Table 2) indicates that F-1 3560-S was at the top, which produced mean maximum number of fruits per plant by applying CaC_2.

***Fruit yield per plant*:** Data on fruit yield per plant reveal highly significant differences ($p < 0.01$) among rates of CaC_2, tomato cultivars and their interactions (Table 2). Data in Table 3 show that maximum fruit yield (1924 g pot^{-1}) was noted where CaC_2 was applied @ 300 mg pot^{-1}, while minimum yield (1254 g pot^{-1}) was found in control. Data in mean column show that the mean maximum yield was actually 39 % more over control. Statistically, effect of CaC_2 application at the rate of 300 mg pot^{-1} showed most significant results among all doses of CaC_2. Statistical comparison among cultivars reveals that cultivar F-1 3560-S showed higher fruit yield than other two cultivars.

DISCUSSION

Differential response of tomato cultivars in terms of photosynthetic characteristics like P_N and carboxylation efficiency due to the application of coated CaC_2 is owing to the ethylene production as Mir *et al.* (2009 a,b) and Lone *et al.* (2010) reported enhanced photosynthesis by the application of ethylene source ethrel. Ethylene released from CaC_2 reduced plant height, number of days to flowering while improved number of fruits set per plant. These parameters ultimately contributed to increase tomato fruit yield. Reduced plant height, in response to CaC_2 application is due to classical triple response of plant exposure to ethylene (Freney *et al.*, 2000; Mahmood *et al.*, 2009; Siddiq *et al.*, 2009; Kashif *et al.*, 2008). Yield of tomato also depends upon the parameters which directly or indirectly contribute to it. Increase in fruit yield in our study may be due to better early and better root growth and then to early flowering, increase in number of fruits per plant. Enhanced radial expansion of root system in response to ethylene (Rao and Fritz, 1987; Tanimoto *et al.*, 1995) actively explores more volume of soil and could help to fetch more nutrients from the soil (Abbasi *et al.*, 2009) and thus contribute to increase in yield of tomato. This all happened most probably due to addition of CaC_2 in the soil environment. The treatments of CaC_2 @ 300 mg pot^{-1} gave the best results in improving number of fruits and yield per plant. This rate provided the optimal level of ethylene essential for plant growth and development. The other CaC_2 treatments also followed this rate in improving the growth and yield of tomato and thus produced significantly more fruit yield compared to control. Similar yield improvement by application of CaC_2 has also been reported by other researchers (Mahmood *et al.*, 2010; Kashif *et al.*, 2012). The results obtained in our study also highlighted improved root growth by application of CaC_2. Ethylene released from CaC_2 probably stimulated adventitious roots of the plant as reported by other researchers (Rao and Fritz, 1987; Chaiwanakupt *et al.*, 1996; Yaseen *et al.*, 2006). Experimental data in our study clearly indicated that application of CaC_2 @ 200 mg pot^{-1} markedly influenced photosynthetic characteristics. The higher photosynthetic rate with application of CaC_2 may be the result of higher ethylene production in the rhizosphere of the plant which increased vegetative growth by increasing availability of nutrient (more N uptake) to the plants (Keerthisinghe *et al.*, 1996; Seneweera *et al.*, 2003, Siddiq *et al.*, 2009). The higher ethylene evolution led to higher leaf area, increased chlorophyll content per unit area (Grewal *et al.*, 1993) and thus more light interception and net photosynthesis (Woodrow and Grodzinski, 1989). Many workers have also been reported similar results of improved leaf area index and enhanced net photosynthetic rate in various crop species with application of ethylene releasing compounds (Khan *et al.*, 2004; Abbasi *et al.*, 2009; Mir *et al.*, 2009b, 2010). Taylor and Gunderson (1989) also showed a relationship between ethylene-enhanced stomatal conductance and photosynthesis. Enhanced carboxylation efficiency due to ethylene releasing compound CaC_2 determines the mesophyll effects. This is characterized by product of CO_2 binding capacity and the electron transport capacity. The effect of ethylene on photosynthesis also has influence on plant water use efficiency and associated with higher

Rubisco (ribulose 1,5 bisphosphate carboxylase) activity or rate of electron transport (Van den Boogard *et al*., 1996). The higher plant water use efficiency observed in our study might be due to lower transpiration rate in association with improved vegetative growth and dry mass production. Similar results have also been reported by Mir *et al.* (2010). It is thus concluded that CaC_2 affects photosynthesis through ethylene-induced increase in stomatal conductance, carboxylation efficiency and also through light interception because of increased leaf area and dry mass production which ultimately resulted in increase in water use efficiency in tomato plants. It is also obvious from the results that CaC_2 markedly affect plant vegetative growth, with the extension of lateral branches and reduced plant height. Ethylene released from CaC_2 significantly inhibits elongation and promotes radial expansion because of its more impact on cell enlargement instead of division of cells (Kieber *et al*., 1993). These results suggest that application of CaC_2 with proper rate could be recommended by general use on farmer's field.

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