Pak. J. Bot., 44(5): 1543-1550, 2012.

EFFECT OF ENCAPSULATED CALCIUM CARBIDE APPLICATION AT DIFFERENT GROWTH STAGES ON POTATO (*SOLANUM TUBEROSUM* L.) GROWTH, YIELD AND TUBER QUALITY

NADEEM AKHTAR ABBASI*, MUHAMMAD ZAHOOR, HAMMAD AZIZ KHAN AND ABDUL AHAD QURESHI

Department of Horticulture, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi. Pakistan.
**Corresponding author E-mail: nadeemabbasi65@yahoo.com*

Abstract

Plant growth substances play a vital role in growth and development of plants and have been implicated intensively and extensively in the vegetable production. In recent years, calcium carbide (CaC_2) has proved to be a good source of acetylene (nitrification inhibitor) and ethylene (plant hormone). The experiment was conducted to evaluate the effects of encapsulated calcium carbide (ECC) on the growth, yield and tuber quality of potato. ECC was applied @ 60 kg/ha for each treatment except control at different growth stages of potato (sprout development, vegetative growth, tuber initiation, tuber bulking) and their combinations. The results of this work revealed significant effects of ECC application on number of days to sprouting, number of leaves and stems, plant height, tuber size, yield, weight loss %, shrivillage % and reducing sugars of potato while sprouting percentage, disease incidence %, specific gravity, TSS, total starch, non-reducing sugars and total sugars could not demonstrate significant effects of ECC application. Moreover, it was concluded that different growth stages responded differently against ECC, however, vegetative growth stage showed remarkable effects on potato growth, yield and tuber quality compared to all other stages and their combinations. The enhanced growth, yield and quality of potato indicated the possible role of acetylene and ethylene at active growth stages.

Introduction

Potato (*Solanum tuberosum* L.) is one of the widely grown vegetables of the world as well as Pakistan being a rich source of nutrients for human nutrition. It contains about 79% water, 18% starch, 2% protein, 1% vitamins, minerals and many trace elements (Ahmad *et al*., 2011) . In Pakistan, potato is grown over an area of 149 thousand hectares with production at the rate of 19.4 tonnes per hectare (Anon., 2010). Environmental conditions, varietal characteristics and cultural practices are the major factors influencing the yield and quality of potato. Yield per hectare of potato in Pakistan is far less (19.9 t/ha) than other potato producing countries like Turkey (27 t/ha), Japan (31.9 t/ha), Australia (35.9 t/ha), New Zealand (50.2 t/ha) and North America (41.2 t/ha) (Anon., 2008). Potato yield has been reported to reach 100 t/ha under ideal conditions (Ewing, 1997), although commercial production is very low (about 50 t/ha) in the world. Pakistani farmers are producing three crops of potato in a year i.e. spring and autumn in plain areas and summer crop in hilly areas. Farmers are facing many issues in potato production like unavailability of disease free certified seed potatoes, poor soil and plant nutrition and lack of improved crop management practices which lead to low yield per unit area. Increasing production of vegetables is always a challenge for scientists to feed the ever increasing population especially in developing countries like Pakistan.

Exogenous application of hormones is one of the important techniques to improve crop production, especially for horticultural crops. Recent changes in crop production systems have increased the practicality of using chemical growth regulators. Ethylene is a unique plant growth regulator involved in almost all the phases of plant growth and development, ranging from seed germination to organs senescence in potato (Coleman, 1998). The use of ethylene as an exogenous application has been reported to increase the agricultural production through plant growth improvement (Yaseen *et al*., 2010) including agronomic crops, vegetables and fruit crops (Muromtsev *et al*., 1991).

Ethylene is gaseous in nature so it is very difficult to apply it in its natural form leading toward limited use of ethylene in agriculture production. To overcome this problem, ethylene releasing compounds are being used in agricultural systems. Precursor of ethylene like calcium carbide (CaC_2) is encapsulated to make its availability over longer time (Zeshan *et al*., 2006). Calcium carbide is rich source of acetylene (nitrification inhibitor) and ethylene (plant hormone). It releases acetylene gas upon reacting with water. This acetylene, in the presence of nitrogenase, is then reduced to ethylene by the action of microorganism. Ethylene formed from biotic reduction of acetylene may accumulate in soil at physiologically active concentrations. Acetylene also inhibits the activity of ammonia-oxidizing enzyme involved in the nitrification process (Ahmed *et al*., 2003; Kashif *et al*., 2007) which further improves the efficient use of fertilizers.

Calcium carbide has been reported to increase the tuber formation, yield and postharvest quality of potato (Bibik *et al*., 1995; Abbasi *et al*., 2009). Ethylene have been also found to promote root elongation in many species including broad been, rice, tomato, and maize. Similarly, ethephon has also increased seedling root length in watermelon which ultimately increased yield (Mattoo & Suttle, 1991). Ethylene is also known to affect the potato fry color and reducing sugars showing positive effects on quality (Barbara *et al*., 2005a). Moreover, ethylene treated pineapple fruits had greater shelf life and more organoleptic characteristics (Bediako *et al*., 2007). The effectiveness of encapsulated calcium carbide at various growth stages and different dozes is demonstrated in the results of various studies (Yaseen *et al*., 2010; Mahmood *et al*., 2007; Abbasi *et al*., 2009). The application of hormones at different growth stages has been found useful for increasing production in crops like potato, wheat, rice and cotton (Ahmed *et al*., 2004; Barbara *et al*., 2005b). For improvement in potato production, it is important to consider the critical stages of potato growth and development. Potato development is typically divided into five growth stages i.e. sprout development, vegetative growth, tuber initiation, tuber bulking and tuber maturation (Malik, 2005).

Keeping in view the earlier work done, present study was planned to find out the most suitable potato development stage for application of encapsulated calcium carbide (ECC) and to find out the effect of soil application of ECC on post-harvest quality of potato tuber.

Materials and Methods

The experiment was conducted on potato variety "Sante" at the Research Farm, Department of Horticulture, PMAS- Arid Agriculture University Rawalpindi (33°36`N, 73°4`E), during September 2009. The experiment was laid out according to Randomized Complete Block Design. Field plot measuring 15 m x 6 m ($90m^2$) was ploughed thoroughly and five soil samples were taken from different locations of the plot to determine the fertility status of field. Well rotten farmyard manure was incorporated in the soil and NPK were also added at the time of field preparation according to standard recommendation with respect to fertility status of soil. Field plot was divided into 8 blocks which were further divided into 3 sub-plots measuring 3.3 m^2 area (1.82 m x 1.82 m). Sowing was done with plant-to-plant distance of 30 cm and row-to-row distance of 75 cm. Calcium carbide was filled in capsules, to be placed close to the tubers. Growth stages were described according to the time taken to reach that growing stage after sowing. Encapsulated calcium carbide (ECC) was applied @ 60 kg per hectare (Abbasi *et al.*, 2009) at different developmental stages of potato plant and tuber growth as mentioned below.

Treatments:

T_1= Control
T_2= ECC application at 0 week
T_3= ECC application at 3 weeks of sowing
T_4= ECC application at 6 weeks of sowing
T_5= ECC application at 8 weeks of sowing
T_6= ECC application at 0 week + 3 weeks of sowing
T_7= ECC application at 0 week + 3 weeks + 6 weeks of sowing
T_8= ECC application at 3 weeks + 6 weeks of sowing
(Where treatments at: 0 week = sprout development, 3 weeks = vegetative growth, 6 weeks = tuber initiation, 8 weeks = tuber bulking)

All the cultural practices kept same for all the treatments when needed.

Preharvest studies: Different parameters were studied and measured during the life cycle and at the maturity of potato plant. For that, number of days for seed tuber sprouting in each plot was counted from sowing to fifty percent tuber sprouting. Tuber sprouting percentage was taken by dividing the number of tubers sprouted in the plot by total number of tuber sown in the plot multiply by hundred. Number of stems per plant and number of leaves per plant of ten plants in each replication was counted at the maturity and then averaged. Plant height was measured with the help of scale from surface of soil to the top of the plant at maturity. Potato plants were inspected for disease incidence on regular basis throughout growth period and percentage was calculated.

Potato plants were harvested at maturity and number and weight of small (less than 35 mm in diameter), medium (35 mm to 55 mm) and large (greater than 55 mm) potatoes were counted and weighed. Similarly, total number of potatoes and their weight was also measured at the time of harvesting from each replication in a treatment. Yield per plot was obtained and converted to kg/ha.

Postharvest studies: To evaluate the tuber quality as affected by ECC application at different growth stages of potato, the treated tubers (20 tubers per replication) were stored at room temperature (25 ± 5°C) for 28 days in Post-Harvest Laboratory, Department of Horticulture PMAS-Arid Agriculture University Rawalpindi.

During this study, weight loss percentage was calculated after every week of storage. Sprout percentage was counted by sprouted tubers from total tubers. Similarly, shrivillage percentage of tubers from total tubers was also calculated. The total soluble solids (TSS) of harvested tubers were measured by Digital Refractometer (model: FG 103) at room temperature and expressed as °BRIX value. pH value was measured by electronic pH meter (model: Knick 646) according to Anon., (1990) method no 981.12. Specific gravity was calculated by weighing the cleaned tubers in air (W1) and then completely immersed in a container of water (W2). Calculation was made by the formula given by Talburt & Smith (1959):

$$\text{Specific gravity} = W1/(W1-W2)$$

The starch contents were calculated following the formula given by Talburt & Smith (1959). Reducing sugars of juice were estimated by method described by Horowitz (1990). For estimation of total sugars, 25 ml of aliquot already prepared for reducing sugars was taken in 100 ml volumetric flask. 20 ml distilled water and 5 ml concentrated HCl was added and solution was kept overnight to convert non-reducing sugar into reducing sugars. Then it was neutralized with 50% concentrated NaOH solution and volume was made 100 ml with distilled water. This solution was taken in burette and titrated against 10 ml Fehling's solution as in reducing sugars. Total sugars were calculated by:

$$\%\ \text{Total sugars} = 25 \times (X/Z)$$

where
X= ml of standard sugar solution used against 10 ml Fehling's solution
Z = ml of sample aliquot used against 10 ml Fehling's solution

Statistical analysis: The experiment was laid out in the field according to Randomized Complete Block Design. The data obtained were statistically analyzed for analysis of variance. The treatments exhibiting significant difference were further subjected to Duncan's Multiple Range (DMR) test for comparison of their means (Steel *et al.*, 1997).

Results

Preharvest observations

Number of days required for seed tuber sprouting and tuber sprouting percentage: Statistical analysis showed significant effects of ECC application on number of days required to sprouting and tuber sprouting percentage (Table 1). T_1 and T_8 required maximum days for sprouting while other ECC treated tubers required lesser days and showed mixed behaviour. Tuber sprouting percentage was greater in the T_2 and T_6 and minimum tuber sprouting percentage was noted in T_1.

Table 1. Effect of ECC application at different growth stages of potato on potato growth and yield attributes.

Treatments	Number of days required for seed tuber sprouting (days)	Tuber sprouting Percentage	No. of stems/plant (n)	No. of leaves/plant (n)	Plant height (cm)	Disease incidence (%)	Yield (kg/ha)
T1	24.00 ± 0.57	73.33 ± 3.30	2.407 ± 0.15	16.71 ± 1.35	39.81 ± 0.99	23.28 ± 3.96	10260 ± 766.6
T2	20.00 ± 0.33	90.00 ± 3.23	2.553 ± 0.29	32.59 ± 2.40	30.09 ± 3.44	11.11 ± 6.42	13800 ± 520.7
T3	20.00 ± 0.57	86.67 ± 3.33	3.183 ± 0.13	36.29 ± 3.11	22.91 ± 1.42	7.870 ± 5.53	17530 ± 78.26
T4	20.33 ± 0.88	76.67 ± 8.82	1.533 ± 0.29	24.71 ± 2.38	20.89 ± 1.75	26.85 ± 3.34	8698 ± 205.6
T5	21.33 ± 0.88	80.00 ± 5.78	1.723 ± 0.34	22.03 ± 2.64	31.59 ± 2.23	23.15 ± 6.48	15340 ± 587.7
T6	20.00 ± 2.08	90.00 ± 5.78	2.000 ± 0.25	34.61 ± 1.61	33.54 ± 1.73	23.60 ± 2.57	14760 ± 371.3
T7	20.00 ± 0.57	86.87 ± 3.33	2.287 ± 0.29	25.93 ± 2.60	32.85 ± 1.63	24.81 ± 2.59	15200 ± 709.4
T8	24.00 ± 0.57	76.67 ± 3.33	2.083 ± 0.10	20.74 ± 2.14	29.67 ± 1.33	14.91 ± 3.73	13490 ± 439.8
LSD(p≤0.05)	**2.870**	**14.57**	**0.7405**	**7.017**	**5.841**	**13.72**	**2993**

Treatments:
T1= Control
T2= ECC application at 0 week
T3= ECC application at 3 weeks of sowing
T4= ECC application at 6 weeks of sowing
T5= ECC application at 8 weeks of sowing
T6= ECC application at 0 week + 3 weeks of sowing
T7= ECC application at 0 week + 3 weeks + 6 weeks of sowing
T8= ECC application at 3 weeks + 6 weeks of sowing

LSD = Least significant difference
± = Standard error
wt = Weight
n = Number
cm = Centimetre
% = Percentage
kg = Kilogram
ha = Hectare

Number of stems/ plant, leaves/plant and plant height: Table 1 presents significant results for these parameters. Maximum number of stems was produced by T_3 (ECC application after three weeks of sowing) while minimum was produced by T_4. Higher numbers of leaves per plant were observed in those treatments where ECC was applied at initial stages of growth i.e., T_3 and T_6 and minimum number of leaves was observed in T_4. Plant height worked differently as compared to other parameters because control produced maximum plant height than other treatments.

Disease incidence: Minimum disease incidence percentage was obtained in T_3 (ECC application after three weeks of sowing) (7.870%) while maximum (26.85%) disease incidence was received in T_4 (ECC application after six weeks of sowing) (Table 1). Other treatments like T_5, T_6, T_8, T_2 and T_1 (control) showed almost non-significant difference to each other. Potato crop was infected by late blight during the stage of tuber initiation and sprayed with Bordeaux mixture to control disease.

Yield: The average values for yield in the Table 1 indicated significant superiority of T_3 with 17530 kg/ha over all other treatments while T_4 and T_1 responded poorly with yield 8698 and 10260 kg/ha, respectively.

Number and weight of small and medium size tubers per plant: Minimum number and weight of small size tubers per plant was found in ECC treated tubers while maximum was found in T_1 (Table 2). Higher number and weight of medium size tubers was recorded in T_3 while minimum was observed in T_1 as shown in Table 2. Moreover, greater number of large tubers was found in T_5 followed by T_3 while maximum weight was noted in T_3. Data regarding total number and weight of tubers per plant was evident that T_3 showed significant superiority over all other treatments. Other treatments responded intermediately as shown in Table 2.

Postharvest observations

Weight loss percentage, sprout percentage and shrivillage percentage during storage: Significant difference was observed in all treatments and storage intervals (Fig. 1). T_3 showed better performance for weight loss percentage (2.980) with respect to storage intervals over all other treatments. Maximum sprouting (13.78%) was reported by T_1 while minimum (3.330%) in T_3. Sprout percentage and shrivillage percentage increased with increase in storage intervals significantly. Similarly, T_3 showed better performance with respect to storage interval as compared to other treatments. Minimum shrivillage percentage was observed in T_1 while other treatments showed intermediary results.

Table 2. Effect of ECC application at different growth stages of potato on number of tubers and tuber weight.

Treatments	small tubers/plant		medium tubers/plant		large tubers/plant		total tubers/plant	
	(n)	(wt)	(n)	(wt)	(n)	(wt)	(n)	(wt)
T1	6.10±0.15	137.5±2.07	3.833±1.17	148.0±5.78	2.13±0.08	128.6±4.64	11.73 ±0.21	406.7 ±7.77
T2	4.13±0.14	111.5±3.83	7.533±0.12	223.4±4.94	2.90±0.11	153.1±4.32	14.57 ±0.12	354.7 ±2.91
T3	2.56±0.17	80.32±4.87	9.067±0.23	338.0±4.17	3.63±0.14	253.3±5.30	15.27 ±0.18	642.7 ±2.86
T4	5.10±0.11	130.1±4.61	4.467±0.12	207.2±2.76	1.73±0.17	106.7±4.42	11.30 ±0.10	451.4 ±6.40
T5	3.76±0.23	95.51±4.77	6.567±0.17	235.4±3.89	4.07±0.14	224.3±6.11	14.40 ±0.36	552.8 ±4.04
T6	5.76±0.20	131.7±6.54	7.867±0.14	287.1±8.86	2.67±0.23	235.1±11.38	14.93 ±0.08	584.1 ±8.41
T7	4.40±0.15	131.7±3.49	4.933±0.14	202.7±5.69	2.87±0.08	139.4±5.43	14.93 ±0.12	537.2 ±11.07
T8	3.50±0.17	109.9±5.76	4.567±0.14	202.1±5.80	3.13±0.20	184.6±12.71	11.13 ±0.33	496.6 ±16.18
LSD(p≤0.05)	**0.516**	**14.02**	**0.4834**	**16.50**	**0.4709**	**22.37**	**0.6476**	**146.5**

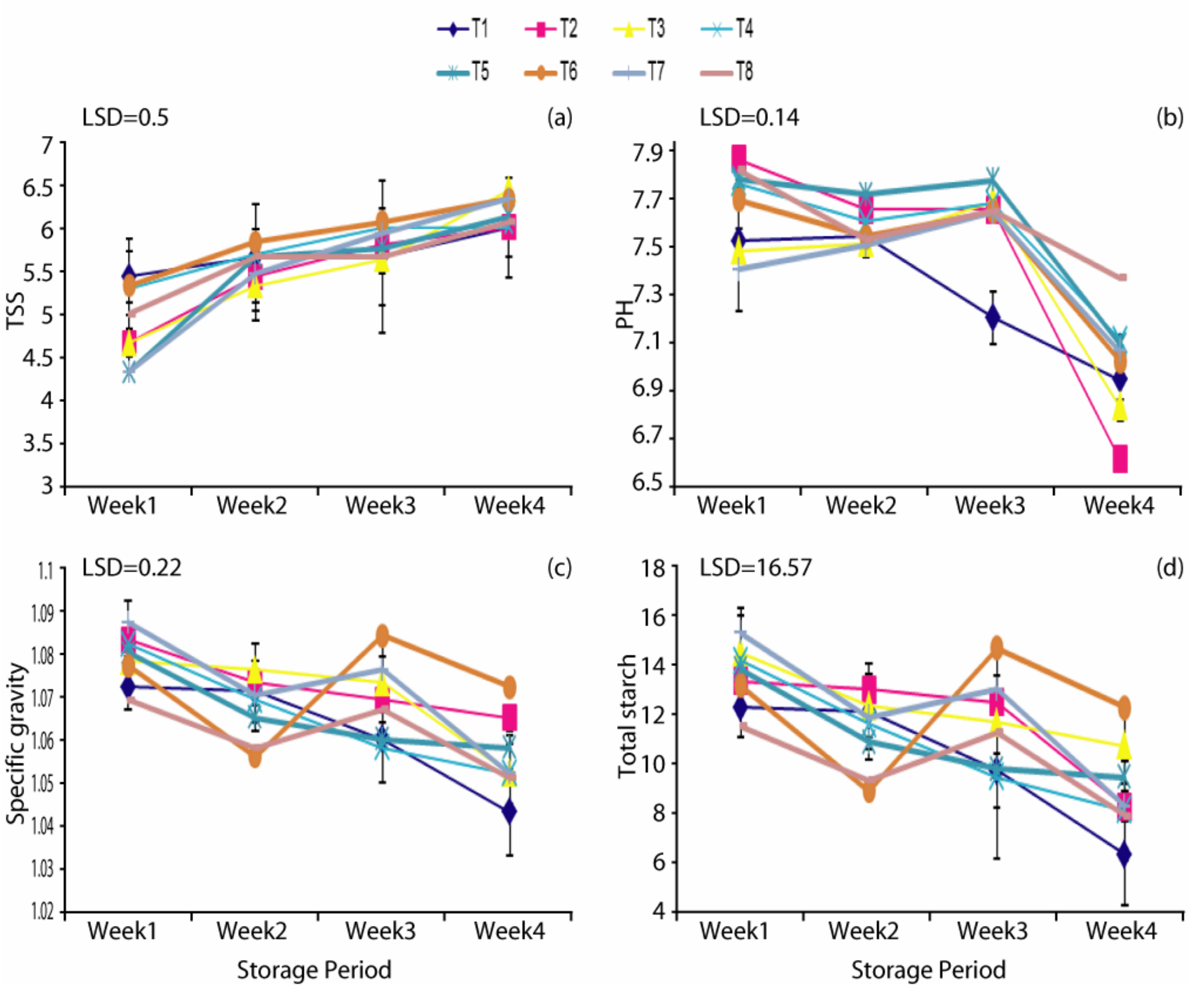

Fig. 1. Effect of ECC application at different growth stages of potato on (a) weight loss percentage, (b) shrivillage percentage, (c) sprout percentage of potato during storage.

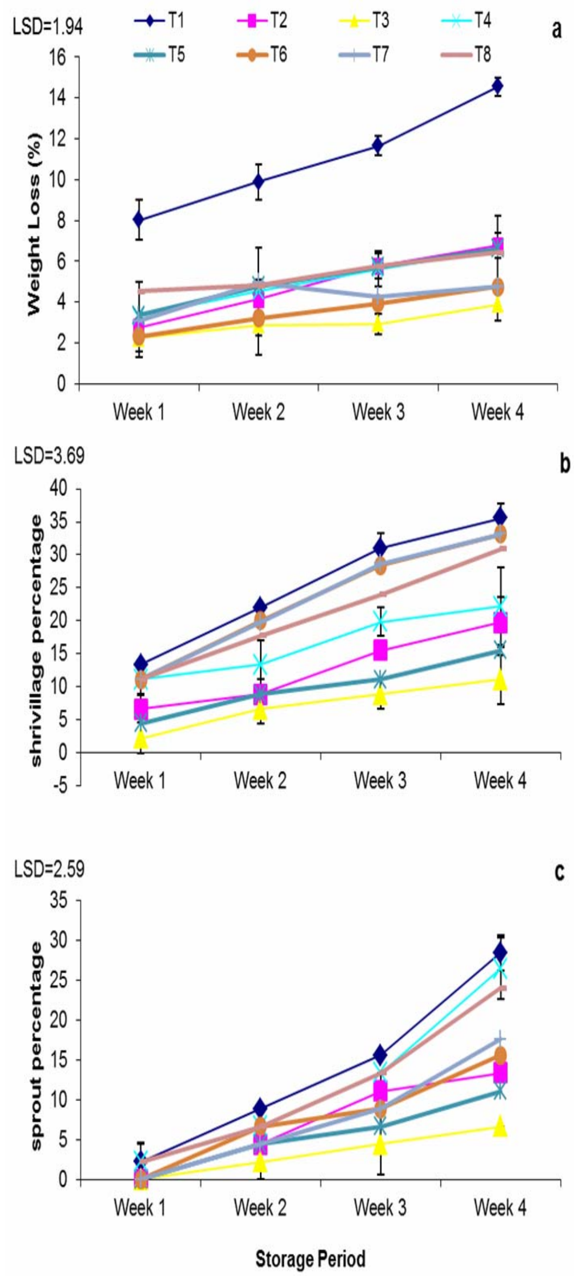

Fig. 2. Effect of ECC application at different growth stages of potato on (a) total soluble solids, (b) pH, (c) specific gravity and (d) total starch contents of potato during storage.

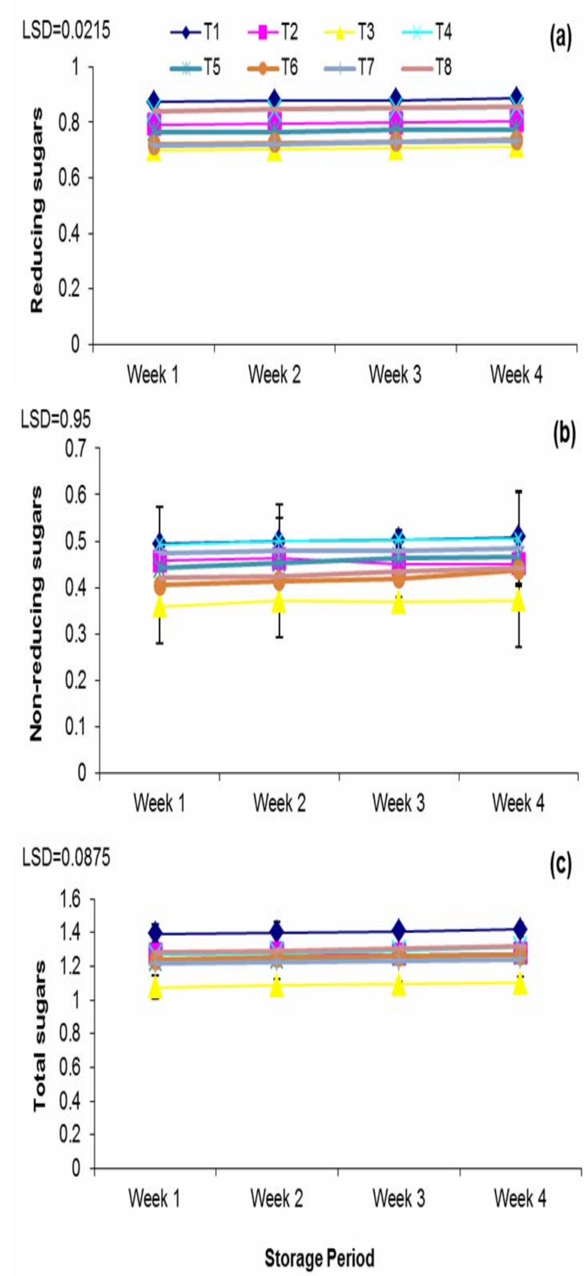

Fig. 3. Effect of ECC application at different growth stages of potato on (a) reducing sugars, (b) non-reducing sugars and (c) total sugars of potato during storage.

Total soluble solids and pH: All treatment showed non-significant behaviour to each other for TSS and pH, however, maximum TSS (5.892) were noted in T_6 and minimum TSS (5.475) were observed in T_2 while an increasing trend in TSS was observed as storage proceeds (Fig. 2). Lowest pH (7.303) was recorded in T_1 while maximum pH (7.592) in T_5 but it remained at par with T_8. In addition, T_3 and T_7 showed non-significant results to each other by producing pH as 7.377 and 7.302, respectively.

Specific gravity: Pre-harvest application of ECC at different growth stages on potato tubers showed non-significant effect on specific gravity. Maximum specific gravity was recorded in T_3 while minimum in T_8 and T_1. However, storage interval had positive effect on all treatments (Fig. 2).

Total starch: Pre-harvest application of ECC at different growth stages did not affect total starch contents significantly in all the treatments (Fig. 2). Higher starch contents were obtained in T_3 and minimum in T_8. Similarly storage interval had also non-significant effect on total starch.

Reducing sugars, non-reducing sugars and total sugars: ECC application at different growth stages of potato affected the reducing sugars significantly (Fig. 3). T_1 produced maximum number of reducing sugars followed by T_4 and T_8. However, T_3, T_6 and T_7 turned to be statistically identical to each other. Moreover reducing sugars were not affected by storage interval statistically. Maximum non-reducing sugars were observed in T_1 and T_4 whereas minimum non-reducing sugars were obtained in T_3 (0.367). All others treatments showed statistically similar results to each other. On the other hand storage intervals had no effect on non-reducing sugars as it doesn't change with storage intervals. Application of ECC at different growth stages had pronounced effect on total sugars of potato. Minimum total sugars were obtained in T_3. Other treatments showed statistically similar results to each other. Non-significant difference was observed in all storage intervals.

Discussion

Preharvest observations

Number of days required for seed tuber sprouting and tuber sprouting percentage: Better performance of ECC treatments for tuber sprouting percentage might be due to the dual effects of ethylene produced from ECC which increased the respiration rate resulting in breakdown of dormancy in potato tuber (Michael and Pratt, 1972; Bibik *et al.*, 1995; Muromstev *et al.*, 1991) as well as by reducing the concentration of sprout inhibiting hormone (ABA) produced in dormant potato (Tanaka *et al.*, 2005). The results are supported by the fact that ABA is sprouting inhibiting agent in potato while application of ethylene reduces ABA level (Coleman, 1998). This might be the reason that T_2, T_6 and T_7, where ECC was applied at sowing, sprout rapidly with maximum tuber sprouting percentage as compared to other treatments.

Number of stems/ plant, leaves/plant and plant height: Treatments receiving ECC at early growth stages gave better results for number of stems and leaves as ECC produced acetylene which reduced the nitrification process increased the nitrogen use efficiency while ethylene triggered the adventitious root formation (Keerthisinghe *et al.*, 1996) and ultimately increases the vegetative growth (Kashif *et al.*, 2008). Ethylene enhanced the root formation in different crops which was responsible for the better nutrients uptake and hence enhanced vegetative growth (Seenewera *et al.*, 2003). This might be reason for maximum number of stems in T_3 where ECC was applied at the time of sprouting because at this stage roots were initiated and availability of ethylene made their number maximum. Untreated plants produced maximum plant height which clearly indicates the effect of ethylene released by ECC. Ethylene inhibits the movements of auxin in stem tissue, possibly reducing auxin's ability to promote stem elongation (Morgan and Gausman, 1966). Vertical reduction in plant height causes increase in horizontal expansion of plant by decreasing the internodal distance (Kashif *et al.*, 2008). This behaviour was also reported in tomato (Mahmood *et al.*, 2010), wheat (Yaseen *et al.*, 2009) and potato (Abbasi *et al.*, 2009).

Disease incidence: Minimum disease incidence percentage in T_3 may be due to the effect of ethylene. Plant defence mechanisms are regulated by complex signaling pathways involving ethylene and induce resistance when applied before infection (T_3) but, when applied after appearance of disease symptoms, stimulates disease progress (Loon *et al.*, 2006) that is why higher disease incidence was observed where ECC was applied later growth stages.

Yield: Higher yield may be due to the more vegetative growth through availability of N from soil due to inhibitory effect of ECC on nitrification (Yaseen *et al.*, 2009). Additionally, the formation of ethylene might have also contributed in promoting the growth and eventually yield of treated tubers (Kashif *et al.*, 2008).

Number and weight of small and medium size tubers per plant: Optimum level of ethylene at vegetative growth phase results efficiently in triggering adventitious roots formation (Ahmad *et al.*, 2009a). Exposure of plant to ethylene for longer time may result in inhibition of stolons extension (Vreugdenhil *et al.*, 1989) which may be reason for smaller sized tubers. It also relates with the number of leaves per plant, smaller the number of leaves lower will be photosynthesis rate and hence limiting the accumulation of photosynthates in tuber formation process (Abbasi *et al.*, 2009). Good nutrients absorption as affected by acetylene and adventitious roots formation affected by ethylene (Ahmad *et al.*, 2009b) at early growth phases (T_2, T_3 and T_6) develops maximum number of medium size tubers per plant. Balanced provision of ethylene and acetylene in T_3 and T_6 ensure effective utilization of nutrients and thus promoting good vegetative growth which results in higher rate of translocation of photosynthates from vegetative portion to the tubers. The photosynthates accumulation is directly proportional to the number of leaves and stems (Early & Slife, 1969) might be the reason for maximum number of large size tubers in T_3. Increase in weight of large size tubers in T_3 reflects the effects of ECC on different developmental stages of potato. Poorest response in T_4 (tuber bulking stage) is because of increase in respiration rate by ethylene (Ibrahim and Liyanage, 1984) which slows down the process of food reserve accumulation. Secondly, older roots might not respond as effectively as younger roots resulting in low number of large size tubers.

Postharvest observations

Weight loss percentage, sprout percentage and shrivillage percentage during storage: Data reveals that ECC treated tubers showed lesser weight loss percentage with respect to storage intervals. Weight loss is directly affected by water loss during storage. Nutrient utilization increases due to acetylene. Perhaps thick rind (periderm) of tubers, developed by high uptake of nitrogen, didn't allow the water loss ultimately preventing weight loss (Burton, 1989). Abbasi *et al*., (2009) also reported that ECC treated tuber have minimum weight loss as compared to other. Minimum weight loss in T_3 might be due to the maximum uptake of nitrogen as young roots are more effective in utilization of resources. However with the increase in the storage interval it might get loosened and shrivillage percentage increases. At harvest, potato tubers are dormant and do not sprout. As the period of post-harvest storage is extended, tuber dormancy is broken and sprout growth commences. Extra accumulation of ethylene results in low sprout percentage in ECC treated tubers because in correlation with ABA it extends the dormancy during storage. It is possible that the actions of ethylene and ABA are mutually interdependent, with the effects of one mediated by the other (Suttle, 1998). Conversely, it has been reported that both preharvest and postharvest applications of the ethylene-releasing agent resulted in significant extensions of tuber dormancy (Korableva *et al.*, 1989; Cvikrova *et al.*, 1994).

Total soluble solids and pH: Proteins, sugars, acids and other soluble salts are important constituents of TSS and it increase with the increase in the storage. Small change in TSS might be due to the decreased osmotic potential that facilitates the accumulation of soluble solids (Levy *et al.*, 1988; Levy, 1992). As ECC treated tubers tend to maintain osmotic potential, minimum change was observed. Girardi *et al*., (2005) worked on peaches and quoted that ethylene did not significantly alter the total soluble solids. pH is the hydrogen ion concentration and in storage it changes with the change in organic acid concentration like citric acid, malic acid (Lisi and Owski, 2003). Ethylene treated treatments decreased pH more rapidly as compared to the control however mechanism of decrease in pH of ethylene treated treatments was unknown (Nourian *et al.*, 2002).

Specific gravity: Statistically specific gravity was not affected by ethylene as different treatments showed similar results. Maximum specific gravity in T_3 might be due to the better vegetative growth which resulted in more reserve food accumulation in tubers as compared to other treatments. Decrease in specific gravity during storage is due to metabolism of starch (Thornton, 2002). There is inverse relation between specific gravity and water loss (Yosuke *et al.*, 2000) so minimum water loss and decreased respiration in T_3 resulted in maximum specific gravity as compared to other treatments.

Total starch: ECC stimulate the vegetative parameters as in T_3 so maximum starch contents were noted for it. Although treated tubers slow down the respiration in storage (Daniel-Lake *et al.*, 1969) but temperature effect is more visible. Tubers respire to keep themselves alive and it is triggered by storage temperature (Thornton, 2002).

Reducing sugars, non-reducing sugars and total sugars: Sucrose, glucose and fructose are the major sugars which accumulate in potato tubers. High levels of reducing sugars (glucose and fructose) lower the suitability of tubers for processing. Minimum reducing sugars in T_3 might be due to the effect of thick rind (periderm) which doesn't allow the electrolytes leakage resulting in decreased sugar accumulation as electrolytes leakage is directly related with sugar accumulation (Spychalla & Desbotough, 1990; Barbara *et al.*, 2005b). However increasing trends of reducing sugars during storage interval might be due to the breakdown of starch (Smith *et al*., 2005). It is also reported by Fauconnier *et al*., (2002) that membrane permeability is inversely related with the sucrose accumulation in potatoes at 20^{o}C. As ECC treated tubers (T_3) develop thick rind which allows minimum water loss, thus results in minimum non-reducing sugars accumulation. Lesser accumulation of both reducing and non-reducing sugars in ECC treated tubers results in lower total sugars. Controlling factor might be ethylene which thickened the periderm that controlled water content of tubers and hence sugar accumulation (Burton, 1989). These results are also supported by Patel & Nickerson (2006) and Fauconnier *et al*., (2002).

Conclusion

ECC application enhanced the growth, yield and quality of potato. Moreover, vegetative stage is the best stage to apply ECC for potato because active growth stage responded very well as compared to solely on other growth stages and their combinations. In future, it is desired to work on the biochemical mechanisms which are involved in growth enhancement or retardation of potato at different growth stages toward ECC application.

References

Abbasi, N.A., A. Hussain, M. Maqbool, I.A. Hafiz and A.A. Qureshi. 2009. Encapsulated calcium carbide enhances production and postharvest performance of potato (*Solanum tuberosum* L.) tubers. *New Zealand J. Crop & Hort. Sci*., 37: 131-139.

Ahmad, N., A. A. Khan, N. A. Khan, R. Binyamin and M. A. Khan. 2011. Identification of resistance source in potato germplasm against PVX and PVY. *Pak. J. Bot*., 43(6): 2745-2749.

Ahmad, Z., F. Azam, T. Mahmood, M. Arshad and S. Nadeem. 2004. Use of plant growth regulators on enhancing crop productivity I: Effect of calcium carbide as a source of ethylene on some agronomic parameters of wheat. *J. Agron*., 3(1): 68-71.

Ahmad, Z., M. Abid and F. Azam. 2009a. Enhancement of salinity tolerance in wheat through soil applied calcium carbide. *Soil Environ*., 28(1): 75-80.

Ahmad, Z., M. Abid, F. Azam and S. Tahir. 2009b. Microbial influence on release of acetylene and ethylene from calcium carbide and its impact in nitrification inhibition. *J. Agri. Biol*., 4(1): 106-109.

Ahmad, Z., M. Yaseen, S. Nadeem and M.K. Nadeem. 2003. Effect of time of application of calcium carbide with and without N, P and K fertilizer on nutrient uptake efficiency of cotton crop. *Pakistan J. Agron*., 2(2): 59-69.

Anonymous. 1990. Official Methods of Analysis. Association of Official Analytical Chemists. Inc., Arlington, Virginia, USA.

Anonymous. 2008. Global potato economy. International year of potato 2008. http//www.fao.org/en/potato/fact sheets.html.

Anonymous. 2010. Economic Survey of Pakistan. Ministry of Finance, Government of Pakistan, Islamabad.

Barbara, D.L., P. Robert and W. John. 2005a. Carbon dioxide and ethylene: A combined influence on potato fry color. *J. Hort. Sci*., 40: 1824-1828.

Barbara, J., D. Lake, R.K. Prange, J. Nowak, S.K. Asiedu and J.R. Walsh. 2005b. Sprout development and processing quality changes in potato tubers stored under ethylene: 1. Effects of ethylene concentration. *American J. Potato Res*., 82: 389-397.

Bediako, E.A., F.A. Showemimo, J.N. Buah and A.O. Ntow-Manu. 2007. Quality of pineapple as influenced by floral induction in Ghana. *American J. Food Technol*., 2(2): 100-103.

Bibik, N.D., S.V. Letunova, E.V. Druchek and G.S. Muromtsev. 1995. Effectiveness of soil acting ethylene producers in obtaining sanitized seed potatoes. *Russian Agric. Sci*., 9:19-21.

Burton, W.G. 1989. The Potato. (3rd Ed). Longman Scientific and Technical Essex, England.

Coleman, W.K. 1998. Carbon dioxide, oxygen and ethylene effects on potato tuber dormancy release and sprout growth. *Ann. Bot*., 82: 21-27.

Cvikrova, M., L.S. Sukhova and N.P. Korableva. 1994. Possible involvement of ABA, ethylene and phenolic aids in potato tuber dormancy. *Plant Physiol. Biochem*., 32:685-691.

Daniels-Lake, R., K. Prange, J. Nowak, S.K. Asiedu and J.R. Walsh. 1969. Development and processing quality changes in potato tubers stored under ethylene: 1. Effects of ethylene concentration. *American J. Potato Res*., 82(5): 389-397.

Early, E.B. and F.W. Slife. 1969. Effect of ethrel on growth and yield of corn. *Agron. J*., 61: 821-823.

Ewing, E.E. 1997. Potato. In: *The Physiology of Vegetable Crops*. (Ed.): H.C. Wien. CAB International, United Kingdom. pp. 295-344.

Fauconnier, M.L., J. Rojas-Beltran, J. Delcarte, F. Dejaeghere, M. Marlier and P.D. Jardin. 2002. Lipoxygenase pathway and membrane permeability and composition during storage of potato tubers (*Solanum tuberosum* L. cv. Bintje and Desiree) in different conditions. *Plant Biol*., 4(1): 77-85.

Girardi, C.L., A.R. Corrent, L. Lucchetta, M.R. Zanuzo, T.S. Costa, A. Brackmann, R.M. Twyman, F.R. Nora, L. Nora, J.A. Silva and C.V. Rombaldi. 2005. Effect of ethylene, intermittent warming and controlled atmosphere on postharvest quality and the occurrence of woolliness in peach (*Prunus persica* cv. Chiripa) during cold storage. *Postharvest Biol. Technol*., 38: 25-33.

Horowitz, W. 1990. Official and Tentative Methods of Analysis (9th Ed). Association of Official Agricultural Chemists, Washington, DC.

Ibrahim, M.N.M. and M.D.S. Liyanage. 1984. Efficiency of calcium carbide and leaves of Croton aromaticus and Arerrhea nilinbi in breaking dormancy of Dioscorea yams. *Cocos*, 2: 1-9.

Kashif, S.R., M. Yaseen, M., Arshad and M. Abbas. 2007. Evaluation of calcium carbide as a soil amendment to improve nitrogen economy of soil and yield of okra. *Soil Environ*., 26(1): 69-74.

Kashif, S.R., M. Yaseen, M., Arshad and M. Ayub. 2008. Response of okra (*Hibiscus esculuntus* L.) to soil given encapsulated calcium carbide. *Pak. J. Bot*., 40(1): 175-181.

Keerthisinghee, D.G., L.X. Jian, L. Oixiang, A.R. Mosier, X.J. Lin and Q.X. Luo. 1996. Effects of encapsulated calcium carbide and urea application methods on denitrification and nitrogen loss from flooded rice. *Fert. Res*., 45(1): 31-36.

Korableva, N.P., L.S. Sukhova, M.Z. Dogonadze and I. Machackova. 1989. Hormonal regulation of potato tuber dormancy and resistance to pathogens. In: *Signals in Plant Development*. (Eds.): J. Kredule and R. Seidlova. SPB Academic Publishers, The Hague. pp. 65-71.

Levy, D. 1992. Osmotic potential of potatoes subjected to a single cycle of water deficit. *Potato Res*., 35: 17-24.

Levy, D., E. Fogelman and Y. Itzhak. 1988. The effect of water salinity on potatoes (*Solanum tuberosum* L.): Physiological indices and yielding capacity. *Potato Res*., 31: 601-610.

Lisi, G. and K.A. Owski. 2003. Organic acids in potato tubers: Part 1-The effect of storage temperatures and time on citric and malic acid contents of potato tubers. *Food Chem*., 38(4): 255-261.

Loon, L.C.V., B.P.J. Geraats and H.J.M. Linthorst. 2006. Ethylene as a modulator of disease resistance in plants. *Trends Plant Sci*., 11(4): 184-191.

Mahmood, R., M. Yaseen and M. Arshad. 2007. Effect of rate and time of calcium carbide application on nitrogen use efficiency of applied urea and growth of wheat. *Pak. J. Bot*., 39(2): 497-502.

Mahmood, R., M. Yaseen, M. Arshad and A. Tanvir. 2010. Comparative effect of different calcium carbide based formulation on growth and yield of wheat. *Soil Environ*., 29(1): 33-37.

Malik, N.J. 2005. Potatoes in Pakistan: a handbook. World Mart, Islamabad.

Matto, A.K. and J.C. Suttle. 1991. The plant hormone ethylene. CRC Press, Boston, London.

Michael, S. and H.K. Pratt. 1972. Effect of ethylene on potato tuber respiration. *J. Plant Physiol*., 49: 252-255.

Morgan, W. and H.W. Gausman. 1966. Effects of ethylene on auxin's transport. *Plant Physiol*., 41: 45-52.

Muromtsev, G.S., N.P. Krasinskaya, S.V. Letunono and L.G. Baresh. 1991. Application of an ethylene producing preparation with soil acidity on citrus crops. *Leina Zrameni Akedem*, 1(5): 9-11.

Muromtsev, G.S., S.V. Letunono and S.A. Alekseeva. 1988. Soil ethylene as a plant growth regulators and ways to identify its formation in soil. *Res. Inst. Biotechnol. Moscow*, 5: 731-738.

Nourian, F.H., S. Ramaswamy and A.C. Kushalappa. 2002. Kinetics of quality change associated with potatoes stored at different temperatures. *Lesbenian Technol*., 36(1): 49-65.

Patel, K.N. and T.A. Nickerson. 2006. Influence of sucrose, glucose and lactose of water from solutions. *J. Food Sci*., 36(3): 495-497.

Seeneweera, S., S.K. Aben, A.S. Basra, B. Jones and J.P. Conroy. 2003. Involvement of ethylene in the morphological and developmental response of rice to elevated atmospheric CO_2 concentrations. *Plant Growth Regul*., 39(2): 143-145.

Smith, A.M., S.C. Zeeman and S.M. Smith. 2005. Starch degradation. *Annual Rev. Plant Biol*., 56: 73-98.

Spychalla, J.P. and S.L. Desbotough. 1990. Fatty acids, membrane permeability and sugars of stored potato tubers. *Plant Physiol*., 94: 1207-1213.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and procedures of statistics: A biometrical approach. (3rd Ed.) McGraw Hill Book Co. Inc.

Suttle, J.C. 1998. Involvement of ethylene in potato micro tuber dormancy. *Plant Physiol*., 118: 843-848.

Talburt, W.F. and O. Smith. 1959. Potato processing. The AVI Publishing Company, Inc. Westport CT, USA.

Tanaka, Y., T. Sano, M. Tamaoki, N. Nakajima, N. Kondo and S. Hasezawa. 2005. Ethylene inhibits abscisic acid-induced stomatal closure in Arabidopsis. *Plant Physiol*., 138: 2337-2343.

Thornton, M.K. 2002. Effect of heat and water stress on the physiology of potatoes. Idaho Potato Conference, Idaho.

Vreugdenhil, D. and W. Dijk. 1989. Effects of ethylene on tuberization of potato (*Solanum tuberosum* L.) cuttings. *Plant Growth Regul*., 8(1): 31-39.

Yaseen, M., M. J. Ashraf and M. Ahmad. 2010. Response of Wheat to soil applied calcium carbide for growth, yield and nitrogen use efficiency. *Pak. J. Bot*., 42(5): 3083-3090.

Yaseen, M., S. A. Hussain, S. R. Kashif and M. Arshad. 2009. Effect of encapsulated calcium carbide on growth, yield and N use efficiency of rice (*Oryza sativa* L.). *Pak. J. Bot*., 41(4): 1619-1625.

Yosuke, M., F. Kevin, N. Tomohiro, S. Toshiro, S. Hiroaki, M. Shinji and T. Katsumi. 2000. Property changes in potato tubers (Solanum tuberosum) during cold storage at 0 and 10^oC. *Food Preserv. Sci*., 26(3): 153-159.

Zeshan, R., Z. Hassan and M. Arshad. 2006. Calcium carbide improves crop yields. http//www.pakissan.com.

(Received for publication 12 February 2011)