Journal of Applied Horticulture, 9(2): 140-145, July-December, 2007

Minerals in pericarp of tomato (*Solanum lycopersicon L.*) fruit and its ripening behaviour

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Abstract

Two contrasting varieties of tomato (*Solanum lycopersicon* L.) fruits *i.e*. 'Pusa Gaurav' (slow ripening type) and 'Pusa Ruby' (fast ripening type) were examined for Ca, P, K, Zn, Cu and Mn contents in the fruit's pericarp portion. Fruits were examined either at different ripening stages during their maturation on the plant itself or at different intervals during storage when harvested at green mature stage. Ca was found to be higher in 'Pusa Ruby'. 'Pusa Gaurav', on the other hand, showed higher content of P, Zn, Cu, Mn but low K in comparison to 'Pusa Ruby'. The roles of these minerals were explained towards their stabilizing effect on plasma membrane and cell wall along with their involvement in the antioxidative system and thereby determining the rate of ripening.

Key words: *Solanum lycopersicon,* minerals, pericarp, ripening, tomato, fruit

Introduction

Inorganic solutes are known to play structural and regulatory roles in physiological processes. Ripening, storage behaviour and quality of fruit are influenced by mineral nutrition and mineral content within the fruit (Wills and Tirmazi, 1979; Marcelle, 1990; 1995). Among postharvest physiological events, membrane damage is the key event leading to a cascade of biochemical reactions (Marangoni *et al.,* 1996). Enhanced ion leakage due to loss of membrane integrity and increased free radical mediated damage are characteristics of senescing plant tissue and fruit ripening (Stanley, 1991; Ferrie *et al.,* 1994; Palma *et al.,* 1995) along with textural change at cell wall level (Powell and Bennett, 2002).

Ca is reported to maintain the integrity of membranes (Morre and Bracker, 1976) and delay senescence and ripening process (Poovaiah and Leopold, 1973; Tingwa and Young, 1974). P is a component and also acts as a bridge for the phospholipids (Marschner, 1998). Zn, like Ca and P, is also reported to be required for maintenance of integrity of biomembranes (Marschner, 1998). It might bind to phospholipids and sulfhydryl groups of membrane constituents or form tetrahedral complexes with cysteine residue of polypeptide chains (Vallee and Falchuk, 1993). This thereby protects membrane lipids and proteins against oxidative damage. Zn controls the generation of toxic oxygen radicals by interfering with the oxidation of NADPH as well as by scavenging $O_2^{-\cdot}$ in its function as a metal component in Cu-Zn superoxide dismutase (SOD) (Cakmak and Marschner, 1988a; 1988b). Zn deficiency is therefore, reported to cause increase in membrane permeability (Cakmak and Marschner, 1988c; 1990).

Process of ripening and senescence are characterized by peroxidation of membrane lipids through elevated levels of free oxygen radicals (Marangoni *et al.,* 1996). Plants, therefore, possess a range of defense systems for detoxification of oxygen radicals and hydrogen peroxide including SOD ($O_2^{-\cdot} \rightarrow H_2O_2$) and peroxidase/catalase ($H_2O_2 \rightarrow H_2O$). As a component of detoxifying enzyme like SOD, nutrients such as; Zn, Cu, and Mn play critical role (Elstner, 1982; Cakmak and Marschner 1988a; b; Bowler *et al.,* 1991). K, on the other hand, reduced the fruit loss due to decay in storage (Zhu and Shu, 1991) and it also has a positive effect on tomato (*Solanum lycopersicon* L.) quality besides fruit yield and fruit size (Forster, 1973).

Besides the effect of nutrients on membrane stability, the dynamic changes in the cell wall of ripening fruits are also anticipated to be under tight control by ionic conditions (Ricard and Noat, 1986; Huber and O'Donoghue, 1993; Almeida and Huber, 1999). Further, varietal variation was noticed for nutrients in pericarp and locular portions of tomato (Stevens *et al.,* 1977). It is in this context, the present study was carried out to quantify the contents of Ca, P, K, Zn, Cu and Mn in the pericarp portion of the fruits in two contrasting varieties *viz.,* 'Pusa Ruby' (fast ripening) and 'Pusa Gaurav' (relatively slow ripening) at different ripening stages of fruits directly harvested from the plants as well as at intervals during storage of fruits that were harvested at green mature stage.

Materials and methods

Seeds of tomato varieties, *viz.,* 'Pusa Ruby' and 'Pusa Gaurav' obtained from the Division of Vegetable Crops, Indian Agricultural Research Institute, New Delhi were treated with fungicide (0.5 % mercuric chloride solution) for 5 minutes and rinsed with distilled water thoroughly and sown on raised soil bed during the end of October, 2004. Grown up seedlings at five leaves stage (height 10 ±2 cm) were transplanted in experimental field already supplied with 20 tonnes ha^{-1} of organic manure in the form of farm yard manure at spacing of 75 x 45 cm. Fertilizers @ 100 kg N, 80 kg P_2O_5 and 80 kg K_2O ha^{-1} were applied. Half dose of N (urea) along with full dose of P_2O_5 and K_2O were applied to the soil at the time of transplanting and rest of N was applied as top dressing after 5th week of transplanting. Uniform irrigation was given whenever required. Other cultural practices, were followed as per recommendations. Healthy tomato fruits having comparable

size and weight in a range of 60-70 g were harvested manually at required ripening stage/s at the end of March, 2005. For ripening stages description as given by United Fresh Fruit and Vegetable Association (UFFVA, 1975) was followed. Fruits were gently and properly washed under running tap water followed by three times rinsing in double-distilled (DD) water and then air dried for further experimental use.

As required, harvested fruits were either directly subjected to estimations or they were stored in well-ventilated plastic baskets under room conditions. For storage purpose, three replications, each represented by 30 tomatoes, at green mature stage, were used. From each replications, 15 fruits were used to assess the ripening index (RI %), percentage for red ripe tomato (RRT %) and shelf life (days). Rest of 15 fruits were divided randomly in five equal lots, each having 3 fruits. They were marked for their respective sampling at 0, 5, 8, 10 and 14 days after harvest (DAH). These marked fruits were used for sample preparation at their respective DAH towards the analysis of nutrients. Likewise, 3 fruits at specific ripening stages, as attained on the plant, were also analyzed for the content of nutrients.

RI (%): This measures the extent of ripening for a given lot of tomato fruits. Methodology as described by Wang and Morris (1993) was followed.

RRT (%): It was calculated as per the method of Wills and Ku (2002). The number of tomato fruits reached to red ripe stage [whole fruit became red ripe in colour as per UFFVA (1975)] out of total number of fruits at required days intervals were counted and expressed in percentage. It also indicated the extent of ripening.

Shelf life: It was calculated as per the method of Wills and Ku (2002). Ripe tomatoes were examined routinely to assess for external appearance. The end of shelf life in days *i.e.*, DAH was the time when fruit showed either a moderate level of shriveling or an extent of black spots that could make fruit unacceptable for marketing.

Nutrient analysis

Procedures for sample preparation, digestion and estimations of nutrients as described by Tandon (1998) and Jones (2001) were followed as such or with minor modifications as described below:

Sample preparation: Composite samples of three fruits (selected randomly) from each of the replications were collected for both the varieties at different ripening stages and at required DAH. Fruits were washed gently under running tap water followed by rinsing thrice with DD water. The pericarp tissue was separated from the jelly and the seeds. It was again rinsed twice with DD water and blotted dry and kept in oven at 75 ^{o}C till the samples dried properly. Dried pieces of pericarp tissues were then grinded thoroughly in motor and pestle (made up of glass) to a fine power. Sample wise, powder was stored in butter paper bag inside the desiccator till further use.

Digestion: Just before the use, the powder was again heated for 2-3 h at 75 ^{o}C to make it free from any moisture and then 1.0 g of dry powder was transferred into the digestion tube. Tissue samples were predigested by adding 10 mL of concentrated HNO_3 in digestion tubes for overnight. Next day, additional 15 mL of concentrated HNO_3 was added followed by 5 mL of $HClO_4$ for its complete digestion in diacid mixture of HNO_3 and $HClO_4$ in a ratio of 5:1(v/v). Samples were then heated at 60 ^{o}C for 30 minutes, 120 ^{o}C for 30 minutes and 255 ^{o}C for 2 h or till the digestion mixture became transparent on digestion block. On complete digestion, only 3-4 mL of digestion mixture had been left in the tube. Tubes were then removed from the block and allowed to cool down to room temperature. The content was diluted to 25 mL by adding DD water and then it was filtered through Whatman filter paper (number 42). For each sample, final volume was made up to 50 mL in volumetric flasks. Now samples along with control in replicates were used for the estimation of Ca, P, K, Zn, Cu and Mn. Standard solutions for each nutrient elements were also prepared to make standard curves for respective element.

Ca and K: Ca and K were analysed using flame photometer of Elico make, India with facility of internal calibration. Air pressure was kept constant at 10 psi. Characteristic emission of K and Ca was recorded at optical wavelength of 768 nm and 622 nm, respectively.

P: P was estimated by colorimetric method by developing vanadomolybdo phosphoric acid yellow coloured complex with aliquot of diacid digest. Actual P was then calculated from the standard curve prepared for P.

Mn, Zn and Cu: These were determined using atomic absorption spectrophotometer (Electronic Corporation of India Limited). Absorptions were recorded at 279.5, 213.9 and 324.8 nm for Mn, Zn and Cu, respectively using standard specifications and their respective standard curves. Content of nutrients were expressed either in mg g^{-1} dry weight (dw) or in µg g^{-1} dw.

Statistical analysis: The obtained replicated data were statistically analysed using two factor complete randomized design. Mean values were then ranked using Duncan's Multiple Range Test using MSTAT-C statistical software. Statistical procedures as described by Gomez and Gomez (1984) were followed.

Results

Ripening: Variety 'Pusa Ruby' showed faster ripening rate in comparison to 'Pusa Gaurav' (Table 1). At 14 DAH, fruits of 'Pusa Ruby' attained 86 and 45% while 'Pusa Gaurav' had the values of 55 and 8% for RI and RRT, respectively. The shelf life of 'Pusa Ruby' was 12-15 days in comparison with 20-22 days for 'Pusa Gaurav' when fruits were harvested at green mature stage and stored at room temperature (31.2 ±6 ^{0}C) and relative humidity (36.1 ±5 %). (data not presented).

Ca: Progress of ripening of fruits attached with plants, in both the varieties, had no effect on the Ca content (Table 2A). Further the Ca content was also comparable in these two contrasting varieties. Storage duration also could not affect the levels of Ca significantly (Table 3A) but, on an average, higher Ca content was recorded in 'Pusa Ruby' (538.83 µg) in comparison with 'Pusa Gaurav' (388.18 µg) during storage (Table 3A). 'Pusa Gaurav', inspite of being relatively slow ripening variety, maintained lower total Ca content than 'Pusa Ruby'.

P: No fixed pattern of change was observed with the progress in ripening of tomato fruit on the plant (Table 2B). Comparison of

Table 1. Effect of storage duration on ripening of tomato fruits harvested at green mature stage in two varieties

Days after harvest (DAH)	Ripening index (RI %)			Red ripe tomatoes (RRT %)		
	'Pusa Ruby'	'Pusa Gaurav'	Mean (DAH)	'Pusa Ruby'	'Pusa Gaurav'	Mean (DAH)
5	35.3^{ef}	24.2^{f}	29.7^{d}	0.0^{b}	0.0^{b}	0.0^{b}
8	50.0^{cd}	39.2^{de}	41.0^{c}	4.0^{b}	0.0^{b}	2.0^{b}
10	70.9^{b}	47.3^{cde}	59.1^{b}	14.2^{b}	0.0^{b}	5.1^{b}
14	86.2^{a}	55.1^{c}	70.6^{a}	45.4^{a}	8.2^{b}	26.8^{a}
Mean (V)	60.6^{a}	41.4^{b}		14.9^{a}	2.0^{b}	
LSD (*P*= 0.01)	V = 6.25, DAH = 9.28, V x DAH = 12.62			V = 9.12, DAH = 13.20, V x DAH = 18.25		

Values followed by different alphabetic letter/s are significant over one another.
Tomato fruits were stored at temperature of 31.2 ±1 ^{0}C and RH 34.5 ±5 %.

two varieties, irrespective of their ripening stages, indicated that 'Pusa Gaurav' (1240.14 µg) had 17.5 % more of P content than the 'Pusa Ruby' (1055.49 µg) (Table 2B). Unlike ripening of fruit on plant itself, storage of fruits harvested at green mature stage showed gradual increase in P content in both the varieties (Table 3B). Again higher P content in 'Pusa Gaurav' (1738.54 µg) than the 'Pusa Ruby' (1203.60 µg) was recorded (Table 3B).

K: Comparable trend for K was observed in fruits undergoing ripening either on the plant (Table 2C) or during storage (Table 3C). With progress of ripening, no significant change was recorded but 'Pusa Ruby' always maintained higher K content than the 'Pusa Gaurav'. Like the Ca, K was also less in slow ripening ('Pusa Gaurav') than the fast ripening variety ('Pusa Ruby').

Zn: Turning and pink stages for attached fruits showed maximum content of Zn and both the varieties had at par level of Zn during ripening (Table 2D). Storage duration had no significant effect on Zn level but, 'Pusa Gaurav' did show higher Zn level (28.62 µg) than the 'Pusa Ruby' (20.81 µg) (Table 3D).

Cu: Fruits of 'Pusa Gaurav' undergoing ripening on plant (5.72 µg) or during storage (6.03 µg) had higher Cu content than the 'Pusa Ruby' under similar conditions with values of 3.69 µg and 4.33 µg, respectively (Table 2E and 3E). Neither ripening stage nor the DAH had any significant effect on Cu content.

Mn: Comparison revealed significant fluctuations in Mn content for attached fruits during the course of ripening (Table 2F) than for the fruits harvested and stored (Table 3F). Further, significantly higher values were recorded for Mn in 'Pusa Gaurav' (5.37 and 9.08 µg) than the 'Pusa Ruby' (1.93 and 4.68 µg) for ripening of fruits under attached and detached conditions respectively.

Discussion

Varietal variation was noted in ripening behaviour of tomato fruit (Stevens and Rick, 1986). Results presented in Table 1 revealed that 'Pusa Gaurav' was comparatively slow ripening variety than 'Pusa Ruby'. Therefore, these two contrasting varieties were selected for evaluation of nutrients' content in the pericarp region of the fruit during ripening on the plant as well as during storage of fruits that were harvested at green mature stage.

Attached and detached conditions for ripening of tomato fruits differentially affected the Ca content. Differences were observed only during storage where inspite of being a slow ripening type, 'Pusa Gaurav' showed lower Ca although; DAH had no effect on Ca content (Table 2A and 3A). During storage, Almeida and Huber (1999) also reported relatively constant levels of Ca during the ripening in pericarp tissues of tomato fruits. Low fruit Ca levels have been associated with reduced postharvest life and increased rate of softening (Wills *et al.,* 1977; Poovaiah *et al.,* 1988). Delayed ripening response with increase in fruit Ca levels has been reported in tomato (Wills and Tirmazi, 1982). Detailed studies on the changes in soluble and bound Ca (Suwwan and Poovaiah, 1978; Rigney and Wills, 1981) revealed that it was the bound Ca content rather than total along with the process of Ca solubilization that played detrimental role for ripening related changes in tomato fruit. Increasing the Ca content of fruits by spraying or postharvest dip of fruits in $CaCl_2$ solution was also reported to increase the firmness of the fruit (Cooper and Bangerth, 1976) and delayed or even prevented the fruit ripening (Wills *et al.,* 1977). However, correlations between the decrease in bound Ca and fruit ripening might not always occur. For example, during degradation of the middle lamella by methyl esterase new binding sites for Ca were reported to be formed (Burns and Pressey, 1987). Likewise in mango fruit also, increasing the Ca content delayed the ripening and extended the shelf life (Wills *et al.,* 1988; Singh *et al.,* 2000). But, recently contradictory report by Joyce *et al.* (2001) showed that the Ca treated mango fruits exhibited no difference when compared with control fruits since Ca did not extended the shelf life for any of the four cultivars of mango.

Slower rate of ripening for fruits of 'Pusa Gaurav' in comparison to 'Pusa Ruby' inspite of lower total Ca content emphasized the role and importance of bound and soluble levels of Ca in determining the rate of ripening and extent of storability as demonstrated in tomato by Suwwan and Poovaiah (1978) and Rigney and Wills (1981) besides the alternation of Ca binding sites on the cell walls by enzymatic action of methyl esterase (Burns and Pressey, 1987), genotypical differences (Marschner, 1998) and other reported factors (Huber, 1983; Kumar *et al.,* 1998).

At different ripening stages, no fixed pattern was noticed for P content (Table 2B). But, during storage, higher P content was recorded at 8, 10 and 14 DAH when compared to 0 DAH (green mature stage) (Table 3B). Almeida and Huber (1999) too found the increase in P content with ripening when compared with green mature tomato fruits that were harvested and stored. This therefore, indicated the mobilization of P into the pericarp tissue from other parts of the fruit during storage. P provides the stability to membranes as it is component of phospholipids and also bridges adjoining phospholipids of membranes (Ratnayake *et al.,* 1978; Marschner, 1998). So, the higher P content in 'Pusa

Table 2. Ca, P, K, Zn, Cu and Mn in the pericarp tissue of tomato fruits in relatively fast ('Pusa Ruby') and slow ('Pusa Gaurav') ripening varieties. Fruits, at different ripening stages, were harvested directly from the plant on the same date

Ripening stage (RS)	'Pusa Ruby'	'Pusa Gaurav'	Mean (RS)
A.		Ca (µg g^{-1} dw)	
Green mature	573.45	430.09	501.77
Breaker	622.96	359.13	491.05
Turning	456.41	473.65	465.03
Pink	424.10	491.60	457.85
Light red	390.96	282.13	336.54
Red	446.10	453.80	449.95
Mean (V)	485.66	415.06	
LSD	V = NS, RS = NS, V x RS = NS		
B.		P (µg g^{-1} dw)	
Green mature	1071.49	1304.67	1188.08b
Breaker	1001.36	989.10	995.23c
Turning	944.18	1230.47	1087.32bc
Pink	896.89	1038.99	967.92c
Light red	1221.77	1530.06	1375.92a
Red	1197.25	1347.52	1272.43ab
Mean (V)	1055.49^{b}	1240.14^{a}	
LSD	V = 103.73**, RS = 179.70**, V x RS = NS		
C.		K (mg g^{-1} dw)	
Green mature	22.15	18.81	20.48
Breaker	28.34	15.99	22.16
Turning	19.39	18.21	18.80
Pink	25.64	22.06	23.85
Light red	27.91	12.13	20.02
Red	24.65	12.81	18.73
Mean (V)	24.68^{a}	16.67^{b}	
LSD	V = 5.18**, RS = NS, V x RS = NS		
D.		Zn (µg g^{-1} dw)	
Green mature	16.24	25.17	20.71^{b}
Breaker	24.10	29.27	26.68^{ab}
Turning	38.88	31.18	35.03^{a}
Pink	35.49	34.09	34.79^{a}
Light red	20.59	30.34	25.46^{ab}
Red	22.32	25.37	23.85^{b}
Mean (V)	26.28	29.24	
LSD	V = NS, RS = 9.60*, V x RS = NS		
E.		Cu (µg g^{-1} dw)	
Green mature	3.63	5.08	4.36
Breaker	4.46	5.18	4.82
Turning	2.91	6.08	4.50
Pink	2.38	6.07	4.23
Light red	3.89	5.68	4.78
Red	4.91	6.25	5.58
Mean (V)	3.69^{b}	5.72^{a}	
LSD	V = 1.07*, RS = NS, V x RS = NS		
F.		Mn (µg g^{-1} dw)	
Green mature	5.16	7.65	6.40^{a}
Breaker	1.65	6.02	3.83^{ab}
Turning	0.57	4.99	2.78^{b}
Pink	0.29	2.96	1.62^{b}
Light red	1.89	4.09	2.99^{b}
Red	2.02	6.50	4.26^{ab}
Mean (V)	1.93^{b}	5.37^{a}	
LSD	V = 2.03**, RS = 2.59*, V x RS = NS		

Values followed by different alphabetic letter/s are significant over one another. LSD at P = 0.05 (*) or P = 0.01 (**)

Table 3. Ca, P, K, Zn, Cu and Mn in the pericarp tissue of tomato fruits in relatively fast ('Pusa Ruby') and slow ('Pusa Gaurav') ripening varieties. Fruits were harvested at green mature stage and stored for 14 days at room conditions

Days after harvest (DAH)	'Pusa Ruby'	'Pusa Gaurav'	Mean (DAH)
A.		Ca (µg g^{-1} dw)	
0	573.45	430.08	501.77
5	499.54	393.04	446.29
8	485.98	332.77	409.38
10	610.58	309.00	459.79
14	524.62	476.00	500.31
Mean (V)	538.83^{a}	388.18^{b}	
LSD	V = 116.77**, DAH = NS, V x DAH = NS		
B.		P (µg g^{-1} dw)	
0	1071.49	1304.67	1188.08^{c}
5	1175.62	1463.78	1319.69^{bc}
8	1202.45	1807.96	1505.20^{b}
10	1137.30	1910.66	1523.98^{ab}
14	1431.15	2138.54	1784.84^{a}
Mean (V)	1203.60^{b}	1738.54^{a}	
LSD	V = 225.35**, DAH = 2261.30*, V x DAH = NS		
C.		K (mg g^{-1} dw)	
0	22.15	18.81	20.48
5	21.69	12.62	17.16
8	21.75	16.04	18.89
10	25.62	17.20	21.41
14	27.19	20.77	23.98
Mean (V)	23.68^{a}	17.76^{b}	
LSD	V = 4.36*, DAH = NS, V x DAH = NS		
D.		Zn (µg g^{-1} dw)	
0	16.24	25.17	20.71
5	14.11	22.35	18.23
8	27.19	32.01	29.60
10	28.16	36.79	32.48
14	18.33	26.75	22.54
Mean (V)	20.81^{b}	28.62^{a}	
LSD	V = 7.79*, DAH = NS, V x DAH = NS		
E.		Cu (µg g^{-1} dw)	
0	3.63	6.42	4.36
5	5.08	4.43	4.80
8	4.67	6.99	5.47
10	4.94	4.41	5.72
14	4.52	6.71	5.56
Mean (V)	4.33^{b}	6.03^{a}	
LSD	V = 1.41*, DAH = NS, V x DAH = NS		
F.		Mn (µg g^{-1} dw)	
0	5.16	7.65	6.40
5	3.82	7.01	5.41
8	2.65	10.14	6.39
10	5.13	8.07	6.60
14	6.64	12.55	9.59
Mean (V)	4.68^{b}	9.08^{a}	
LSD	V = 3.10**, DAH = NS, V x DAH = NS		

Values followed by different alphabetic letter/s are significant over one another. Tomato fruits were stored at temperature of 31.2 ±1 ^{0}C and RH 34.5 ±5 %. LSD at P = 0.05 (*) or P = 0.01 (**)

Gaurav', irrespective of attached or detached conditions of fruits, could be associated with its slow ripening behaviour.

For individual variety, ripening of tomato fruits either on plant or during storage had no effect on the level of K (Table 2C and 3C). Level of K in the bulk sap of pericarp was also reported to

remain relatively constant during ripening (Almeida and Huber, 1999). Comparison of two varieties, on the other hand, revealed significantly lower K content for 'Pusa Gaurav' than the 'Pusa Ruby'. A comparative study of non-ripening mutant (*rin*) and normal tomato fruit of variety 'Rutgers' revealed that mutant (non-ripening type) had lower K content in the pericarp tissue especially late during the developmental stages of fruits (Suwwan and Poovaiah, 1978). Further, Chun and Huber (1998) reported that there was need for optimum amount of K for realization of maximum polyglacturonase activity in tomato. Therefore, relatively lower content of K in 'Pusa Gaurav' might have also contributed for slower rate of ripening in this variety.

Ripening of fruit under attached (Table 2D) and detached (Table 3D) conditions showed differential effect on Zn content. The Zn was found to be higher in 'Pusa Gaurav' only for detached fruits. Zn is not only involved in maintenance of integrity of biomembranes (Cakmak and Marschner, 1988c; Pinton *et al.,* 1993) but it also protects membrane lipids and proteins against oxidative damage (Cakmak and Marschner, 1988a; 1988b). Since, loss of membrane integrity and enhanced free radical mediated damage are associated with senescing plant tissue or ripening of fruits (Marangoni *et al.,* 1996) therefore counter action of Zn might assist in delaying the damage done to membranes and free radical production. Significantly higher levels of Zn in fruits of 'Pusa Gaurav' during storage period in comparison with 'Pusa Ruby', could have delayed the ripening process.

Higher levels of Cu in fruits of 'Pusa Gaurav' for attached as well as detached conditions (Table 2E and 3E) and its slow ripening feature in comparison with 'Pusa Ruby' could be due to its antioxidative role through Cu-Zn SOD enzyme. The enzyme is directly involved in the detoxification of superoxide radicals (Elstner, 1982). It has role in protecting membrane lipids from the peroxidation and thereby delaying the process of senescence (Sandalio and del Rio, 1987).

Mn is a metal component of Mn SOD enzyme, which scavenge superoxide radicals (Bowler *et al.,* 1991). In transgenic plants of tobacco, higher Mn SOD caused lower solute leakage from mitochondria and chloroplast in comparison with control plants with low levels of Mn SOD (Bowler *et al.,* 1991). Low Mn content was also responsible for higher peroxidase activity in tomato and cucumber (Valenzuela *et al.,* 1993). It has been proposed that conditions such as ageing or stress that contributed to the loss of photosynthetic output below a certain threshold levels or loss in the integrity of chloroplast membrane might produce signal that initiate senescence process (Smart, 1994; Quirino *et al.,* 2000). Deficiency or low Mn causes decrease in chlorophyll content, glycolipids and polyunsaturated fatty acids (all are typical constituents of thylakoid membranes) (Constantopoulus, 1970), change in ultrastructure of thylakoid membrne due to loss of PS II associated with the stacked region of thylakoid membranes (Simpson and Robinson, 1984) and alternation in O_2 evolution (as Mn is also an essential part of water splitting system associated with PSII of photosynthetic machinery) (Kriedemann *et al.,* 1985). In view of above-mentioned roles of Mn, higher Mn content in 'Pusa Gaurav' (Tables 2F and 3F) appeared to contribute for its slow ripening behaviour along with Zn, Cu and P in comparison with fruits of 'Pusa Ruby'.

The study indicated the differences in the levels of some of the mineral elements in the pericarp tissue of the tomato fruits in two varieties with contrasting ripening behaviour. As these nutrients influence the ripening or ripening associated changes therefore obtained differences in the level of these nutrients could also be attributed as one of the causes for varietal differences in ripening behaviour. Data indicated that possibly the higher bound form, rather than total content of Ca and more of P, Zn, Cu and Mn along with low of K contributed for slower ripening for the fruits of 'Pusa Gaurav' in comparison to 'Pusa Ruby' possibly by delaying the ripening associated deterioration of cell wall and membranes along with the potential damaging effects due to enhanced oxidative system during the course of ripening.

References

Almeida, D.P.F. and D.J. Huber, 1999. Apoplastic pH and inorganic ion levels in tomato fruit: A potential means for regulation of cell wall metabolism during ripening. *Physiol. Plant.,* 105: 506-512.

Bowler, C., L. Slooten, S. Vandenbranden, R. De Rycke, J. Botterman, C. Sybesma, M. Van Montagu and D. Inze, 1991. Manganese superoxide dismutase can reduce cellular damage mediated by oxygen radicals in transgenic plants. *EMBO,* 10: 1723-1732.

Burns, J.K. and R. Pressey, 1987. Ca^{2+} in cell walls of ripening tomato and peach. *J. Am. Soc. Hort. Sci.,* 112: 783-787.

Cakmak, I. and H. Marschner, 1988a. Enhanced superoxide radical production in roots of zinc deficient plants. *J. Exp. Bot.,* 39: 1449-1460.

Cakmak, I. and H. Marschner, 1988b. Zinc-dependent changes in ESR signals, NADPH oxidase and plasma membrane permeability in cotton roots. *Physiol. Plant.,* 73: 182-186.

Cakmak, I. and H. Marschner, 1988c. Increase in membrane permeability and exudation of roots of zinc deficient plants. *J. Plant Physiol.,* 132: 356-361.

Cakmak, I. and H. Marschner, 1990. Decrease in nitrate uptake and increase in proton release in zinc deficient cotton, sunflower and buckwheat plant. *Plant Soil,* 129: 261-268.

Chun, J.P. and D.J. Huber, 1998. Polygalacturonase-mediated solubilization and depolymerization of pectin polymers in tomato fruit cell wall: Regulation by pH and ionic conditions. *Plant Physiol.,* 117: 1293-1299.

Constantopoulus, G. 1970. Lipid metabolism of manganese deficient algae. I. Effect of manganese deficiency on the greening and the lipid composition of *Euglena gracilis. Z. Plant Physiol.*, 45: 76-80.

Cooper, T. and F. Bangerth, 1976. The effect of Ca and Mg treatment on the physiology, chemical composition and bitter pit development of 'Cox orange' apples. *Scientia Hortic.,* 5: 49-57.

Elstner, E.F. 1982. Oxygen activation and oxygen toxicity. *Annu. Rev. Plant Physiol.,* 33: 73-96.

Ferrie, B.J., N. Beaudoin, W. Burkhart, C.G. Bowsher and S.J. Rothstein, 1994. The cloning of two tomato lipoxygenase genes and their differential expression during fruit ripening. *Plant Physiol.,* 106: 109-118.

Forster, J. 1973. Relationship between the nutrition and appearance of 'green back' and 'blossom end rot' in tomato fruits. *Acta Hortic.,* 29: 319-325.

Gomez, K.A. and A.A. Gomez, 1984. *Statistical Procedures for Agricultural Research*, 2nd edn. John Wiley and Sons, Singapore.

Huber, D.J. 1983. The role of cell wall hydrolases in fruit softening. *Hort. Rev.,* 5: 169-219.

Huber, D.J. and E.M. O'Donoghue, 1993. Polyuronides in avocado (*Persea americana*) and tomato (*Lycopersicon esculentum*) fruits exhibit markedly different patterns of molecular weight down-shifts during ripening. *Plant Physiol.,* 102: 473-480.

Jones, J.B. Jr. 2001. *Laboratory Guide for Conducting Soil Tests and Plant analysis*. CRC Press, Boca Raton, London, New York, Washington, DC.

Joyce, D.C., A.J. Shorter and P.C. Hockings, 2001. Mango fruit calcium levels and the effect of postharvest calcium infilteration at different maturities. *Scientia Hortic.,* 91: 81-99.

Kriedemann, P.E., R.D. Graham and J.T. Wiskich, 1985. Photosynthetic disfunction and *in vitro* changes in chlorophyll 'a' fluorescence from manganese deficient wheat leaves. *Aust. J. Agric. Res.,* 36: 157-169.

Kumar, A., U.K. Kohli and D.K. Mehta, 1998. Inheritance of some morphological traits affecting whole fruit firmness in tomato. *The Hort. J.,* 11: 45-52.

Marangoni, A.G., T. Palma and Dw Stanley, 1996. Membrane effects in postharvest physiology. *Postharvest Biol. Technol.,* 7: 193-217.

Marcelle, R.D. 1990. Predicting storage quality from pre-harvest fruit mineral analysis. *Acta Hortic.,* 274: 305-313.

Marcelle, R.D. 1995. Mineral nutrition and fruit quality. *Acta Hortic.,* 383: 219-226.

Marschner, H. 1998. *Mineral Nutrition of Higher Plants.* 2nd edn., Academic Press, London.

Morre, D.J. and C.E. Bracker, 1976. Ultrastructural alternation of plant plasma membranes induced by auxin and calcium ions. *Plant Physiol.,* 58: 544-547.

Palma, T., A.G. Marangoni and Dw Stanley, 1995. Environmental stresses effect tomato microsomal membrane function differently than natural ripening and senescence. *Postharvest Biol. Technol.,* 6: 257-273.

Pinton, R., I. Cakmak and H. Marschner, 1993. Effect of zinc deficiency on proton fluxes in plasma membrane enriched vesicles isolated from bean roots. *J. Exp. Bot.,* 44: 623-630.

Poovaiah, B.W., G.M. Glenn and A.S.H. Reddy, 1988. Calcium and fruit softening physiology and biochemistry. *Hort. Rev.,* 10: 107-149.

Poovaiah, B.W. and A.C. Leopold, 1973. Deferral of leaf senescence with calcium. *Plant Physiol.,* 52: 236-239.

Powell, A.L.T. and A.B. Bennett, 2002. Tomato. In: *Fruit and Vegetable Biotechnology*. V. Valpuestra (Ed.), Woodhead Publisher Limited, Cambridge, England.

Quirino, B.E., Y.S. Noh, E. Himelblau and M. Amasino, 2000. Molecular aspects of leaf senescence. *Trends in Plant Sciences,* 5: 278-282.

Ratnayake, M., R.T. Leonard and A. Menge, 1978. Root exudation in relation to supply of phosphorus and its possible relevance to mycorrhizal infection. *New Phytol.,* 81: 543-552.

Ricard, J. and G. Noat, 1986. Electrostatic effects and the dynamics of enzyme reactions at the surface of plant cells. I. A theory of the ionic control of a complex multi-enzyme system. *Eur. J. Biochem.,* 155: 183-190.

Rigney, C.J. and R.B.H. Wills, 1981. Calcium movement, a regulating factor in initiation of tomato fruit ripening. *HortScience,* 16: 550-551.

Sandalio, L.M. and L.A. del Rio, 1987. Localization of superoxide dismutase in glyoxysomes from *Citrullus vulgaris*. Functional implications in cellular metabolism. *J. Plant Physiol.,* 127: 395-409.

Simpson, D.J. and S.R. Robinson, 1984. Freeze fracture ultra-structure of thylakoid membranes in thylakoid membranes in chloroplasts from manganese deficient plants. *Plant Physiol.,* 74: 735-741.

Singh, Z., J. Janes and S.C. Tan, 2000. Effects of different surfactants on calcium uptake and its effects on fruit ripening, quality and postharvest storage of mango, under modified atmosphere packaging. *Acta Hortic.,* 509: 413-417.

Smart, C.M. 1994. Gene expression during leaf senescence. *New Phytol.,* 126: 419-448.

Stanley, D.W. 1991. Biological membrane deterioration and associated quality losses in food tissues. *Crit. Rev. Food Sci. Nutr.,* 30: 487-553.

Stevens, M.A., A.A. Kader and M. Albright-Holton, 1977. Intercultivar variation in composition of locular and pericarp portions of fresh market tomatoes. *J. Am. Soc. Hort. Sci.,* 102: 689-692.

Stevens, M.A. and C.M. Rick, 1986. Genetics and breeding. In: *The Tomato Crop: A Scientific Basis of Improvement*. Artherton, J.G. and J. Rudich (Eds.),Chapman and Hall Ltd. London, pp. 35-110.

Suwwan, M.A. and B.W. Poovaiah, 1978. Association between elemental content and fruit ripening in *rin* and normal tomatoes. *Plant Physiol.,* 61: 883-885.

Tandon, H.L.S. 1998. *Methods of Analysis of Soils, Plants, Waters and Fertilizers*. Fertilizer Development and Consultation Organization, 204-204A Bhanot Corner, 1-2 Pamposh Enclave, New Delhi, India.

Tingwa, P.O. and R.E. Young, 1974. The effect of calcium on the ripening of avocado (*Persea americana* Mill) fruits. *J. Am. Soc. Hort. Sci.,* 99: 540-542.

United Fresh Fruit and Vegetable Association (UFFVA) (1975). *Colour classification requirements in tomatoes*. USDA Visual Aid TM-L-1. The John Henry Co., Lansing, Minch.

Valenzuela, J.L., A. del Rio, I. Lopez Cantarero, A. Sanchez and L. Romero, 1993. A method of establishing optimal endogenous N, Fe and Mn levels in tomato and cucumber. *Acta Hortic.,* 335: 443-448.

Vallee, B.L. and K.H. Falchuk, 1993. The biochemical basis of zinc physiology. *Physiol. Rev.,* 73: 79-118.

Wang, S. and S.C. Morris, 1993. Effect of borax and quazatine on ripening and postharvest diseases of tomato (cv. Flora Date). *Acta Hortic,* 343: 331-333.

Wills, R.B.H. and V.V.V. Ku, 2002. Use of 1-MCP to extend the time to ripen the green tomatoes and postharvest life of ripe tomatoes. *Postharvest Bio. Tech.,* 26: 85-90.

Wills, R.B.H. and S.I.H. Tirmazi, 1979. Effect of calcium and other minerals on ripening of tomatoes. *Aust. J. Plant Physiol.,* 6: 221-227.

Wills, R.B.H. and S.I.H. Tirmazi, 1982. Inhibition of ripening of avocados with calcium. *Scientia Hortic.,* 16: 323-330.

Wills, R.B.H., S.I.H. Tirmazi and K.J. Scott, 1977. Use of calcium to delay ripening of tomatoes. *HortScience,* 12: 551-552.

Wills, R.B.H., C.M.C. Yuen, S. Sarbari, L.D.S. Lakshmi and K. Suyanti, 1988. Effect of calcium infiltration on delayed ripening of three mango cultivars in Indonesia. *ASEAN Food J.,* 6: 221-227.

Zhu, Y.Y. and D.Z. Shu, 1991. Effects of potassium and calcium fertilizers on the yield, quality and storability of tomato. *Chinese J. Soil Sci.,* 22: 130-131.