Middle East Journal of Agriculture Research
ISSN 2077-4605

Volume : 07 | Issue : 02 | April-June | 2018
Pages:399-407

Mineral remobilization from senescent leaves to fruits in three tomato genotypes and its relation to fruit quality parameters

Kassem A. S. Mohammed[1], Safaa S. Abozed[2] and Abdel Khalek Selim[1]

[1]Plant Nutrition Dept., [2]Food and Technology Dept., National research Centre, Cairo, Egypt.

Received: 22 Feb. 2018 / Accepted: 19 April 2018 / Publication date: 07 May 2018

ABSTRACT

Greenhouse experiments were carried out to study mineral remobilization from senescent leaves to fruits and quality parameters in fruits of three cherry tomato genotypes (Dimple Idoia and Dohne). Two weeks old seedlings were planted in plastic pots filled with a mixture of coarse sand and peat moss. Plants were fertilized once a week for six weeks with six doses of nutrients. All plants were pruned over the third truss and the excessive branches were directly removed. Fruits were harvested and were preserved at -18 °C for analysis. Minerals were determined in both leaves and fruits using standard procedures. Sugars, acidity, radical scavenging activity, ascorbic acid and phytochemical components were also determined in fruits.

Data revealed that, the remobilization of Ca, Mg, and Mn from senescent leaves to fruits was relatively lower compared with that of K, Fe, Zn, and Cu. However, despite high mobility of P via phloem, P concentration in senescent leaves was higher than P concentration in fruits.

Results indicated that, Dohne genotype contained higher number of fruits about 50 fruits per plant followed by Dimple (35), Idoia genotype recorded the lowest number of fruit (28). Idoia genotype recorded the highest value of the mean fresh fruit weight.

Concentration of K, Fe and Zn in leaves were not influenced by different genotypes. K concentration in tomato leaves reached zero due the very high K resorption efficiency Although, Dohne genotype had the highest concentration of calcium in leaves, their fruit recorded the lowest concentration of Ca. and that in turn caused appearing of blossom-end rot symptoms.

Idoia was associated with lower sugar concentration and higher concentration of acidity in their fruits. Genotypes had no significant effect on the fruits pH value. Also, Idoia genotype had the lowest brix value than other genotypes. TSS values in the three genotypes were 10.0, 9.0 and 8.8 % for Dimple, Idoia and Dohne respectively. Fruit of Dohne genotype contained the highest concentration of ascorbic acid as compared with other genotypes. Genotype had no effect on lycopene or carotene content in the fruits.

Key words: Mineral remobilization, senescent leaves, tomato genotypes, quality parameters

Introduction

About half of the world population is suffering from Fe and Zn deficiency (Cakmak and Kirkby 2008). Thus, increasing mineral allocation to fruits could be useful for enhancing nutritional value of fruits. Remobilization of short or mid-term storage of macro-and micronutrients within the plant occurs during vegetative growth. When availability of minerals in soil is inadequate, then source leaves support growth of new organs (Malagoli *et al.,* 2005 and Abdallah *et al.,* 2010). Remobilization process also occurs during generative growth as soon as root activity and nutrient uptake have been depressed while new sink organs are emerging (Malagoli et al 2005). Finally, remobilization of nutrients is regularly associated with foliar senescence, consequently nutrients availability for younger plant organs (fruit for example) is enhanced (Himelblau and Amasino 2001, Fischer 2007, Avice and Etienne 2014).With exception of Ca, macronutrient have high mobility via phloem, while micronutrient have moderate mobility via phloem with exception of Mn (white 2012). A few studies described remobilization of nutrients during plant senescence (Hocking and Pate1977; Himelblau and Amasino 2001; Waters and Grusak 2008; Moreira 2009; Maillard et al 2015) they

Corresponding Author: Kassem A. S. Mohammed, Plant Nutrition Dept., National Research Centre, Cairo, Egypt. E-mail: kassem.mohammed@alumni.hu-berlin.de

reorted that macro-and micronutrient mobility within plant varies depending on plant species (Hocking and Pate1977; Himelblau and Amasino 2001 Maillard *et al.* 2015).

Furthermore, nutrient remobilization of different ecotypes of the same species were investigated where, with exception of K, remobilization of some nutrient was genetically affected whereas Ca, Mg and Mn were not-remobilized (Waters and Grusak, 2008).

Tomato is one of the most widely consumed vegetables in the world. It ranks second after potato in the global vegetable production (FAO, 2016). China, the USA, Turkey, Egypt, and India are the most important producing countries. Tomato fruits contain many bioactive components, including those that act as antioxidant, such as vitamins C and E and many carotenoids and the main carotenoid in tomato is lycopene. Sometimes tomatoes is assumed to be responsible for the positive health effect as seen with increased intake (Nguyen and Schwartz, 1999; Canene-Adams *et al.,* 2005). The small sized tomatoes (cherry) contain high sugar content and low acidity - the major contributors to tomato flavor. In plant-breeding programs, they used both traditional and molecular methods to increase lycopene in tomatoes (Ronen *et al.,* 2000; Thompson et al 2000). Also, the modification of flavonoid and other phenols biosynthesis pathway lead to increase of antioxidant (Muir *et al.* 2001; Tomas-Barberan and Espin 2001; Bovy *et al.,* 2002; Verhoeyen *et al.,* 2002; Schijlen *et al*. 2004). Selection of small and highly colored tomatoes (high pigment genes) by growers and market distribution chains optimizes fruit levels of carotenoids, flavonoids, and vitamin C, and consequently its nutritional value and health benefits. Recently, cherry tomato has higher concentration of lycopene followed by cluster and round tomato genotypes (Kuti and Konuru, 2005).

Thus, new genotype of tomato along with enhanced nutritional value and potential health benefits are being developed Therefore, the aims of the current study werefirstlyto determine nutrient remobilization from senescent leaves to tomato fruits, and secondly toassess the correlation among nutrients and some quality parameters in three different tomato genotypes (Dimple, Idoia and Dohne).

Material and Methods

The experiments were carried out in greenhouse at Experimental farm of the NRC. Substrate was prepared from mixtures of the coarse sand and peat moss (1:1) by volume, the substrate was placed in plastic pots (10 cm diameter) each pot contained one kg substrate. Seeds of three tomato varieties from Syngenta Co. (Dimple Idoia and Dohne) were sown in germinating tray. Two weeks after sowing, seedlings were transferred to individual plastic pots (one plant per pot) and three replicates for each treatment. Fertilization started after 34 days from sowing where, plants were fertilized once a week for six weeks with six doses of nutrients. The total added amount of N and K was 1.2 g $pots^{-1}$ the rest of nutrients (P, Ca, Mg and S) were 0.6 g pot^{-1}.

All plants were pruned over the third truss and the excessive branches were directly removed. Plants were harvested at senescence stage of their leaves. Fruits and shoots were harvested and saved at -18 ^{0}C and 65 ^{o}C for analysis respectively.

Determination of minerals

Total concentrations of K, Mg and other elements in plant material was determined by ICP=OES (IRS/AP) with the pretreatment of dry-ash at 550 °C for 5 h.

pH values: pH points were determined with a pH meter equipped with calomel and glass electrodes.

Determination of total soluble solids:

Total soluble solids of the tomato samples were determined (in triplicate) as °Brix by using Abbe's refractometer.

Determination of sugars

The soluble sugar fraction was measured. Soluble sugars in the collected extracted were determined using the anthrone method (Seifter *et al.* 1950).

Determination of acidity

Acidity of the samples were determined (in triplicate) by acid base titration (Lacey *et al.,* 2009). Percentage acid = Titer x acid factor x 10/10 (ml juice) Factor for citric acid is 0.0064(citrus fruit)

Radical scavenging activity

Radical Scavenging Activity (RSA) of freshly prepared tomato juice was assayed with DPPH (2, 2-diphenyl-1-picrylhydrazyl) (10 – 4 M) previously dissolved in methanol according to Ramadan *et al.* (2003). % DPPH radical scavenging activity = [(Ao– A1 /Ao) x 100]

Where
Ao is the absorbance of the control,
A1 is the absorbance of sample extract

Determination of ascorbic acid

Ascorbic acid measuring by titration of tomato extraction against 0.02% 2.6 Dichloroindophenol dye until the juice turned to permanent pink (Subramanian *et al.* 2006). Similar titration was performed for standard ascorbic acid solution (100 mg ascorbic acid in 100 ml of 4% oxalic acid).

Determination of total phenolic content (TPC):

Total phenols were measured using the Folin-Ciocalteau method (Spanos and Wrolstad 1990), Modified by Lister and Wilson (2001).

Phytochemical components:

Lycopene and β-carotene contents were calculated according to the Nagata and Yamashita (1992).

Results and Discussion

Three genotypes of tomato were supplied with optimal amount of nutrients, plants were pruned by cutting the main stem after second truss. Photos of three different genotypes revealed that Idoia stem was in straight position in comparison to stems of Dimple and Dohne genotypes which tended to be in spiral position, that means Dimple and Dohne genotype had to be hung with a thread to the ceiling of the greenhouse (Fig.1). Obviously, nutrient deficiency symptoms appeared on below leaves due to remobilization of most mobile nutrients to above leaves or fruits, last fruit was harvested when most leaves were already in senescence stage. That caused reduction in nutrient resorption proficiency in leaves.

All parameters related to fruits were significantly affected by genotype, Dohne contained higher number of fruit about 50 fruits per plant followed by Dimple (35), and Idoia genotype recorded the lowest number of fruit (28). Idoia genotype recorded the highest value of the mean fresh fruit weight (10.4 g), mean of surface area (30.9 cm^2) and mean of fruit volume (13.7 cm3 fruit-1), (Table 1 a). In contrast, Dimple genotype had the lowest values of mean fresh fruit mass (4.7 g), surface area of fruit (18.8 cm2) and fruit volume (6.3 cm3) as this genotype has the smallest fruits. The important parameter is surface area to fruit volume ratio, where, this ratio was 3.0 in Dimple genotype whereas, Idoia genotype recorded the lowest ratio (2.3). The increment of this ratio indicated that fruits have the opportunity for accumulation of lycopene because, it is well documented that lycopene concentrates in fruit peel (Papaioannou and Karabelas, 2012).

Quality parameters of the studied fruits varieties were estimated by the determination of their content of sugar, acidity, and TSS and pH value. Data in Table (1) summarize the quality evaluation parameters of the tomato fruits. The data comparison between Dimpel, Idoia and Dohne genotype, Idoia was associated with lower sugar concentration and higher concentration of acidity in their fruits.

Genotypes had no significant effect on the pH value in fruits, Dimpel genotype had the higher°brix value than other genotypes. °Brix in the three genotypes were 10.0, 9.0 and 8.8 % in Dimpel, Idoia and Dohne respectively. The results of titratable acidity extractions are displayed in the same table. The highest concentration of TA was observed in the Dohne genotype (83.50%), while the lowest was in the Idoia (60.60%). The soluble solid content and titratable acidity were the major factor of acceptable flavor quality of fruits (Pattee, 1985 & Eskin, 1991).

Dimpel genotype Idoia genotype Dohne genotype

Fig. 1: Three genotypes of cherry tomato plants supplied with the same amount of nutrients

Tomato fruit extracts were used to study their phytochemical compounds and antioxidant activity. Plants produce such compounds for defense against insect infection or pathogens. For humans, these, compounds have important role in scavenging free radical from their bodies. Scavenging the steady DPPH model is a widely-used technique to estimate antioxidant activity. DPPH is a stable free radical with distinguishing absorption at 517 nm and antioxidant compounds react with DPPH and convert it to 2.2-diphenyl 1-picrylhydrazine. The degree of discoloration indicates the scavenging prospective of the antioxidant compounds extract, which is attributed to the hydrogen donating ability (Van Gadow *et al.,* 1997). DPPH radical-scavenging abilities of the three tomato fruit varieties extracts are shown in Table (1)

Mean values were found to be 39.3, 42.5 and 42.6 % in Dimpel, Idoia and Dohne genotypes respectively. The most important vitamin in fruits and vegetables for human nutrition is ascorbic acid (Vitamin C). Vitamin C is a water-soluble antioxidant which is scavenging free radical from human body and therefore, it is considered important for human health (Lee *et al.,* 2000; Bello and Fowoyo, 2014). For cherry genotype extracts, the ascorbic acid mean values were in the range 10.7 to 15.3 mg /100g. Fruit of Dohne genotype contained the highest concentration of ascorbic acid as compared with other genotypes. Phenols are very important plant constituents because of their scavenging capability of free radical due to their hydroxyl groups (Hemi *et al.,* 2002). The total phenolic content for all genotype extracts are shown in Table (1). The TPC mean values were of the range 57.9 to 49.9 mg/100g. Dimpel genotype recorded the highest TPC compared with Idoia and Dohne genotypes. The relation between RSA and TPC is due to substitution of hydroxyl groups in the aromatic rings of phenolic, thus contributing to their hydrogen-donating ability (Yen *et al.,* 2005). The most efficient carotenoid antioxidant is lycopene. Lycopene is an important intermediate in biosynthesis of vitamin A precursor carotenoids like ß-carotene and ß-kryptoxanthin (Fraser and Bramley 2004). Lycopene content as mg/100g fruit in three cherry tomato showed in Table (1). Data revealed that genotypes had no effect on lycopene content or carotene concentration in their fruits.

Table 1: Fruit parameters and health-promoting compounds concentration in fruits of three tomato genotypes (Dimple, Idoia and Dohne) grown in peat and sand substrate.

Growth parameters	Dimple	Idoia	Dohne
	a) Fruit parameters		
Number of fruit	35±1b	28± 2c	48±0.3 a
Mean of fruit surface area (cm^2 $fruit^{-1}$)	18.8±0.3 c	30.9±0.7 a	23.9±0.6 b
Mean of fruit weight (g $fruit^{-1}$)	4.7±0.1 c	10.4±0.3 a	7.1±0.5 b
Mean of fruit volume (cm^3 $fruit^{-1}$)	6.3±0.2 c	13.7±0.4 a	8.7±0.6 b
Surface area of fruit: mean of fruit volume	3.0 ±0.2 a	2.3 ±0.1c	2.8±0.2b
	b) Taste parameters		
pH values	4.04± 0.02	3.94± 0.03	4.02± 0.01ns
^{0}Brix values	10.0± 0.2 a	8.8± 0.2 b	9.0± 0.1 b
Sugar % (based on FM)	2.61±0.21 a	1.82±0.10 b	2.35±0.04 a
Acidity% (based on FM)	64± 2 b	84± 4 a	61± 1 b
Taste values (sugars to acidity)	0.04 ±0.002a	0.02 ±0.001b	0.04± 0.002a
	c) Health-promoting compounds		
RSA %	39.3± 1.1	42.5± 2.2	42.6± 0.3 ns
Ascorbic acid (mg 100 g -1 FM)	11.1± 0.3b	10.7± 0.3b	15.3± 0.9a
Phenols (mg 100 g -1 FM)	57.9± 2.8	54.0± 1.6	49.9± 0.4 ns
Lycopene (mg 100 g -1 FM)	3.4± 0.3	3.0± 0.1	3.2± 0.1ns
Carotene (mg 100 g^{-1} FM)	1.9± 0.3	1.4± 0.2	1.6± 0.2ns

*ns,*non-significant or significant at P≤0.05 respectively. Different letters within each column indicate significant differences according to Tukey-Kramer test at 0.05. Data are expressed as average (n=3) ±SE*

Plants were harvested at senescence stage of their leaves, therefore, the nutrient content in leaves reflects resorption proficiency of nutrients (the portion of the nutrient pool in leaves which was not transported to fruits) (Farahata and Linderholm. 2015). There were significant differences among tomato genotypes with respect to Ca, Mg, P and Mn concentration in their leaves. However, tomato genotype had no significant effects on nutrient concentration in fruit. Dohne genotype was associated with higher Ca concentration in leaves (33mg g^{-1} dm) as compared to Idoia and Dimple genotypes (28 mg g^{-1} dm). In comparison of Dimple and Dohne, Idoia was associated with higher Mg concentration in leaves. However, P concentration increased in leaves of Dohne plants followed by Idoia genotype whereas, P concentration in leaves of Dimple genotype was the lowest concentration of K, Fe and Zn in leaves were not influenced by different genotypes. Concentration of K in tomato leaves almost zero due to net remobilization of most K from leaves to fruits. Although, Dohne genotype contained the highest concentration of calcium in leaves, their fruit contains the lowest concentration of Ca. and that in turn caused appearance of blossom-end rot symptoms (Fig.2) which is a physiological disease associated with localized shortage of Ca in the fruits (Douglas 2010). Ca and particularly Mg concentration in fruits of different genotype are severely low in comparison with their concentration in leaves. It is well documented that Ca having low phloem mobility (Maillard *et al.,* 2015) but Mg is relatively mobile via phloem (White, 2012).

Fig. 2: Blossom end rot symptoms on Dohne genotype fruits of tomato

The obtained results indicate no differences between Ca and Mg in respect of their remobilization within tomato tissues, both elements have low mobility in phloem. Also, surprisingly P concentration in senescent leaves were higher than its concentration in fruit which consequently leads to increased P resorption proficiency in senescent leaves. Zn and Cu concentration in fruits tended to be higher than their concentration in leaves, in contrast Mn concentration in fruits was severely lower than its concentration in leaves. Mn concentration in fruits represented 13 % of Mn concentration in senescent leaves, seemingly due to the low Mn phloem mobility (White 2012, Maillard *et al.,* 2015).

On the other hand, Fe concentration in fruit was extremely higher than its concentration in leaves, these results illustrated that plants contained adequate content of amino acid because these elements require amino acid as a carrier for micronutrient transport via phloem. These results also revealed that tomato plants have high selectivity in terms of micronutrients remobilization from senescent leaves to fruits.

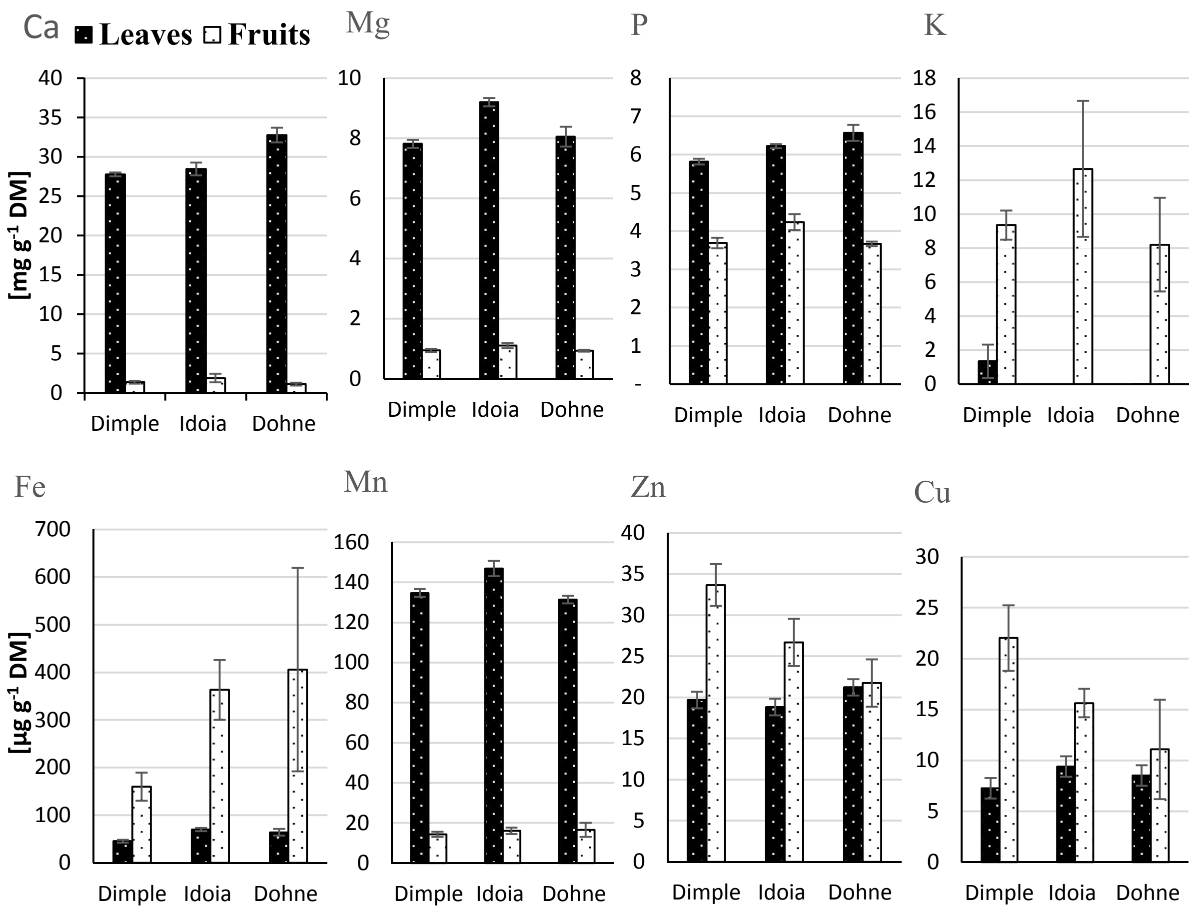

Fig. 3: Nutrients concentration in leaves and fruits of three different varieties of tomatoes.

Relationship between different parameters

The positive correlation between health-promoting compounds and nutrient composition as well as among nutrients themselves is observed in Table 2. Nutrient composition and phytochemical-antioxidant were strongly correlated r = 0.803 to 1.000 (Table 2). Acidity and lycopene were correlated to macronutrient (Ca, Mg P and K). This correlation results from the role of these nutrients in balance the charges of soluble organic anions and inorganic in cytosol (White 2012). The positive correlation between K and lycopene indicates the role of K in regulating lycopene formation in tomato fruit by stimulation of specific enzymes (Bramely, 2002). K plays a role in carotenoid biosynthesis process by activating enzymes (pyruvate kinase and phosphofructokinase) that regulate carbohydrate metabolism (Li *et al.,* 2006, Fanasca *et al.,* 2006), Also, K effect on the precursors of isopentenyl diphosphate (pyruvate and glyceraldehyde 3-phosphate) was reported by Serio *et al.* (2007).

Phytochemical-antioxidant and nutrient composition. Parameters Ca highly correlated to Zn concentration. On the other hand, the antioxidant activity when assayed by RSA methods revealed a higher level of correlation (r = 0.999) between antioxidant activity and Fe (r=0.999) or Mn (r=0.953). The positive correlation between acidity and macronutrient (Ca, Mg, P and K) was observed, this was attributed to the produced organic acids by plant. The positive correlations among macronutrient (Ca, Mg, P and K) can be attributed to balanced fertilization. Furthermore, Mohammed (2013) found synergistic effect between K and Mg with reduced K supply led to decrease not only in K but also Mg concentration in tomato fruits, despite high Mg concentration in source leaves (Mohammed 2013). There were no positive correlations between macro- (Ca, Mg, P and K) and micronutrients (Fe, Mn and Zn). Fe was positively correlated with Mn. Results indicated high correlations among nutrients themselves and no correlation between nutrients and other growth parameters in tomato fruits.

Generally, results showed strong correlation and high level of relationship between nutrient composition and phytochemical content.

Table 2: Correlation coefficients (r) phytochemical-antioxidant and nutrient composition.

Parameters	Ca	Mg	P	K	Fe	Mn	Zn
Acidity	0.984	0.995	0.995	0.990	0.300	0.039	0.625
RSA	0.168	0.433	0.435	0.201	0.999	0.953	-0.523
Phenols	0.336	0.064	0.061	0.305	-0.891	-0.979	0.873
Lycopene	0.981	0.890	0.888	0.974	-0.068	-0.327	0.866
Carotene	0.212	-0.065	-0.068	0.179	-0.942	-0.997	0.803
Ca	1	0.961	0.961	0.999	0.127	-0.138	0.231
Mg	0.961	1	1.000	0.970	0.395	0.140	-0.046
P	0.961	1.000	1	0.969	0.398	0.143	-0.049
K	0.999	0.970	0.969	1	0.16	-0.105	0.198
Fe	0.127	0.395	0.398	0.160	1	0.965	-0.936
Mn	-0.138	0.14	0.143	-0.105	0.965	1	-0.996
Zn	0.231	-0.046	-0.049	0.198	-0.936	-0.996	1

References

Abdallah, M., L. Dubousset, F. Meuriot, P. Etienne, J. C. Avice and A. Ourry, 2010. Effect of mineral sulphur availability on nitrogen and sulphur uptake and remobilization during the vegetative growth of *Brassica napus* L. J. Exp. Bot., 61, 2635–2646.

Avice, J.C. and P. Etienne, 2014. Leaf senescence and nitrogen remobilization efficiency in oilseed rape (*Brassica napus* L.). J. Exp. Bot., 65, 3813–3824.

Bello, A.A. and P.T. Fowoyo, 2014. Effect of heat on the ascorbic acid content of dark green leafy vegetables and citrus fruits. African Journal of Food Science and Technology, Vol. 5(4) pp. 114-118.

Bovy, A., R. de Vos, M. Kemper, E. Schijlen, P.M. Almenar, S.Muir, G. Collins, S. Robinson and M. Verhoeyen, 2002. High flavonol tomatoes resulting from the heterologous expression of the maize transcription factor genes LC and C1. Plant Cell., 14:2509–2526.

Bramley, P. M., 2002. Regulation of carotenoid formation during tomato fruit ripening and development. Journal of Experimental Botany, 53, 2107–2113.

Cakmak, I. and E.A. Kirkby, 2008. Role of magnesium in carbon partitioning and alleviating photooxidative damage. Physiologia Plantarum 133, 692-704.

Canene-Adams, K., J.K. Campbell, S. Zaripheh, E.H. Jeffery and J.W. Erdman, 2005. The tomato as a functional food. JN the Journal of Nutrition, 135, 1226-1230.

Douglas, S. M., 2010. Blossom-end Rot of Tomato the Connecticut Agricultural Experiment Station.www.ct.gov/caes/lib/caes/.../fact.../blossom-end_rot_of_tomato_11-04-10_r.pdf

Eskin, N.A.M. (ed.)., 1991. Quality and preservation of fruits. CRC Press, Boca Raton, Fl, p.212.

Fanasca, S., G. Colla, G. Maiani, E. Venneria, Y. Rouphae, E. Azzini, and F. Saccardo, 2006. Changes in antioxidant content of tomato fruits in response to cultivar and nutrient solution composition. Journal of Agricultural and Food Chemistry, 54, 4319–4325.

FAO, 2016. Agricultural data FAOSTAT. Food and Agriculture Organization of the United Nations. Rome, Italy.

Farahata, E. and H. W. Linderholm, 2015. Nutrient resorption efficiency and proficiency in economic wood trees irrigated by treated wastewater in desert planted forests. Agricultural Water Management 155, 67–75

Fischer, A. M., 2007. Nutrient remobilization during leaf senescence," in Annual Plant Reviews, Vol. 26, Senescence Processes in Plants, ed S. Gan (Oxford: Blackwell Publishing Ltd.), 87–107.

Fraser, P. D. and P. M. Bramley, 2004. The Biosynthesis and Nutritional Uses of Carotenoids. Progress in Lipid Research, Vol. 43, No. 3 pp. 228-265.

Hemi, K.E., A.R. Taigliaferro and D.J.Bobilya, 2002. Flavonoids antioxidant chemistry, metabolism and structure activity relationship. The Journal of Nutrition Biochemistry 13, 572–584.

Himelblau, E., and R. M. Amasino, 2001. Nutrients mobilized from leaves of Arabidopsis thaliana during leaf senescence. J. Plant Physiol. 158, 1317–1323.

Hocking, P. J., and J. S. Pate, 1977. Mobilization of minerals to developing seeds of legumes. Ann. Bot. 41, 1259–1278.

Kuti, J.O. and H.B. Konuru, 2005. Effects of genotype and cultivation environment on lycopene content in red-ripe tomatoes., J Sci. Food Agric. 85:2021–2026.

Lacey, K., N. Hancock and H. Ramsey, 2009. Measuring internal maturity of citrus. Department of agriculture and food farm note, ISSN 0726-934X: 1-4.

Lee, S.K., A.A. Kader, 2000. Pre-harvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biology and Technology, 20: 207–220.

Li, S., Y. Xu, W. S. White, S. Rodermel and H. Taber, 2006. Lycopene concentration in tomato fruit is increased by enhanced potassium nutrition. The FASEB Journal, 20:A1059

Lister, E. and P. Wilson, 2001. Measurement of total phenolics and ABTS assay for antioxidant activity (personal communication). Lincoln, New Zealand: Crop Research Institute.

Maillard, A., S. Diquélou, V. Billard, P. Laîné, M. Garnica, M. Prudent, J. Garcia-Mina, J. Yvin and A. Ourry 2015. Leaf mineral nutrient remobilization during leaf senescence and modulation by nutrient deficiency. Frontiers in Plant Science 6, 1-15

Malagoli, P., P. Laine, L. Rossato and A. Ourry, 2005. Dynamics of nitrogen uptake and mobilization in field-grown winter oilseed rape (*Brassica napus*) from stem extension to harvest: I. Global N flows between vegetative and reproductive tissues in relation to leaf fall and their residual N. Ann. Bot. 95, 853–861. doi: 10.1093/aob/mci091

Mohammed, K. A. S., 2013. .Effect of nutrient limitation on physiological and morphological plant traits related to growth and quality of tomato *PhD. Humboldt Uni. Berlinedoc Publication server*https://edoc.hu-berlin.de/handle/18452/17437

Moreira, N. K. F., 2009. Yield, uptake, and retranslocation of nutrients in banana plants cultivated in upland soil of central Amazonian. J. Plant Nutr. 32, 443–457.

Muir, S.R., G.J. Collins, S. Robinson, S. Hughes, A. Bovy, C.H.R. De Vos, van A.J. Tuinen and M.E. Verhoeyen, 2001. Overexpression of petunia chalcone isomerase in tomato results in fruit containing increased levels of flavonols. Nat Biotechnol 19:470–474.

Nagata, M. and I. Yamashita, 1992. Simple method for simultaneous determination of chlorophyll and carotenoids in tomato fruit. Journal of Japanese Society of Food Science and Technology, 39, 925-928.

Nguyen, M.L. and S.J. Schwartz, 1999. Lycopene: chemical and biological properties. Food Technol 53:38–45.

Papaioannou, E H. and A. J. Karabelas, 2012. Lycopene recovery from tomato peel under mild conditions assisted by enzymatic pre-treatment and non-ionic surfactants. Acta Biochimica Polonica ABP, 59,71-74.

Pattee, H.E.(ed.), 1985. Evaluation of quality of fruits and vegetables.AVI Publ.Co., Inc., Westport, CT, P.410

Ramadan, M.F., L.W. Kroh and J.T. Moersel, 2003. Radical scavenging activity of black cumin (Nigella sativa L.), coriander (*Coriandrum sativum* L.) and niger (*Guizotia abyssinica* Cass.) crude seed oils and oil Fractions. Journal of Agriculture and Food Chemistry 51, 6961- 6969.

Ronen, G., L. Carmel-Goren, D. Zamir and J. Hirschberg, 2000. An alternative pathway to b-carotene formation in plant chloroplasts discovered by map-based cloning of Beta (B) and old-gold (og) colour mutations in tomato. Proc Natl Acad Sci., 97:11102–11107.

Schijlen, E.G.W.M., C.H. Ric de Vos, A.J. van Tunen and A.G. Bovy, 2004. Modification of flavonoid biosynthesis in crop plants. Phytochemistry 65:2631–2648.

Seifter S., Seymour, B. Novic and E. Muntwyler, 1950. Chemical procedures for analysis of polysaccharides I. Determination of glycogen and starch. Colowick SP, NO Kaplan (Eds.), Methods in Enzymology, Vol. III Academic Press, New York pp. 34-40.

Serio F., L. Leo, A. Parente and P. Santamaria, 2007 Potassium nutrition increases the lycopene content of tomato fruit. Journal of Horticultural Science & Biotechnology 82 (6) 941–945

Spanos, G.A. and R.E. Wrolstad, 1990. Influence of processing and storage on the phenolic composition of Thompson seedless grape juice. Journal of Agricultural & Food Chemistry 38, 1565-1571.

Subramanian, K.S., P. Santhanakrishnan and P. Balasubramanian, 2006. Responses of field grown tomato plants to arbuscular mycorrhizal fungal colonization under varying intensities of drought stress. Scientia Horticulturae, 107, 245-253.

Thompson, K.A., M.R. Marshall, C.A. Sims, C.I. Wei, S.A. Sargent and J.W. Scott 2000. Cultivar, maturity, and heat treatment on lycopene content in tomatoes. J Food Sci., 65:791–795.

Tomas-Barberan, F.A. and J.C. Espin, 2001. Phenolic compounds and related enzymes as determinants of quality in fruits and vegetables. J Sci Food Agric., 81:853–876.

Van Gadow, A., E. Joubert and C.T. Hannsman, 1997. Compression of the antioxidant activity of aspalathin with that of other plant phenols of roolobs tea (*Aspalanthus linearis*), a-tocoferol BHT, and BHA. Journal of Agriculture and Food Chemistry 45, 632–638.

Verhoeyen, M.E., A. Bovy, G. Collins, S. Muir, S. Robinson, C.H.R. deVos and S. Colliver, 2002. Increasing antioxidant levels in tomatoes through modification of the flavonoid biosynthetic pathway. J Exp Bot., 53:2099–2106.

Waters, B. M., and M. A. Grusak, 2008. Whole-plant mineral partitioning throughout the life cycle in Arabidopsis thaliana ecotypes Columbia, Landsberg erecta, Cape Verde Islands, and the mutant line ysl1ysl3. New Phytol., 177, 389–405.

White, P. 2012. Long-distance transport in the xylem and phloem. in Marschner's Mineral Nutrition of Higher Plants, 3rd Edn., ed P. Marschner (Berlin: Elsevier), 49–70.

Yen, W.J., L.W. Change and P.D. Duh, 2005. Antioxidant activities of peanut seed test and its antioxidative component. Ethyl protocatechuate. Lebensmittel-Wissenschaft and Technologie, 38, 193–200.