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Eggplants, Peppers and Tomatoes: Factors Affecting the Quality and Storage Life of Fresh and Fresh-cut (Minimally Processed) Produce

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ABSTRACT

Factors affecting the composition, quality and storage life of fresh tomatoes (*Lycopersicon esculentum* Mill.), peppers (*Capsicum annuum* L.) and eggplants (*Solanum melongena* L.) as well as fresh-cut (minimally processed) produce are discussed both in the light of European Union (EU) quality standards and on the basis of recent research findings. The fruit of all three Solanaceous species are highly perishable and careful manipulation of the storage conditions is required in order to preserve quality at an acceptable level. The stage of harvest and the storage techniques applied relate largely to the climacteric or non-climacteric nature of the fruit, and the role of ethylene in fruit ripening is discussed. Tomato, pepper and eggplant fruit are all rich sources of antioxidants, and these substances are implicated in the prevention of cardiovascular and other human diseases. Apart from epidemiological studies on the relationship between antioxidant intake and disease occurrence, several studies have concentrated on the changes in antioxidant levels during fruit growth and maturation, as well as on the fate of antioxidants during storage and processing. The fruit of all three species are susceptible to chilling injury and this susceptibility restricts the temperature at which storage can be carried out. However, a number of studies have indicated the beneficial effects of enclosing fruit in plastic film of specific gas permeability. Because of the increasing demand for fresh-cut (minimally processed) salads, research has been directed at studying the behaviour of fresh-cut produce (e.g. pepper rings, cut tomato salads) during storage and marketing. Because of the increased perishability of fresh-cut produce and the danger of microbial activity, stringent packaging and storage techniques must be applied. This review is concluded with a brief consideration of future research perspectives.

Keywords: antioxidants, *Capsicum annuum*, ethylene, harvest, *Lycopersicon esculentum*, modified atmospheres, packaging, quality standards, *Solanum melongena*, storage

Abbreviations: ACC, 1-aminocyclopropane-1-carboxylic acid; **AVG**, 1-aminoethoxyvinylglycine; **CFU**, colony forming unit; **CHD**, coronary heart disease; **DW**, dry weight; **EU**, European Union; **FW**, fresh weight; **LDL**, low-density lipoprotein; **MA**, modified atmosphere; **MACC**, 1-(malonylamino)cyclopropane-1-carboxylic acid; **1-MCP**, 1-methylcyclopropene; **PPO**, polyphenol oxidase; **RH**, relative humidity; **NAA**, naphthaleneacetic acid; **NOA**, β-naphthoxyacetic acid; **SOD**, superoxide dismutase

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Invited Review

INTRODUCTION

Comparison of the ripening physiology of eggplants (*Solanum melongena* L.), sweet peppers (*Capsicum annuum* L.) and tomatoes (*Lycopersicon esculentum* Mill.) reveals an interesting pattern of differences between the three species. The tomato fruit has long been classed as climacteric, whereas the fruit of eggplant is non-climacteric. Although pepper is generally considered to be non-climacteric, some cultivars show climacteric characteristics. As a general rule, non-climacteric fruits are harvested at the stage of commercial maturity, which may be an immature, unripe stage (eggplant and green peppers) or a ripe stage (fully coloured yellow or red peppers). The storage life of non-climacteric fruits is relatively short even under optimum conditions. By contrast, climacteric fruits, such as tomato, may be harvested on completion of their growth cycle (i.e. they are physiologically mature) but prior to ripening. Fruits may then be stored until the onset of the climacteric, after which they ripen to reach the stage of commercial maturity. These differences in ripening behaviour significantly affect the timing of harvest of the fruit of each species and the subsequent post-harvest handling and storage technology employed.

The aim of the present paper is to highlight recent research into the quality characteristics of the Solanaceous crops (eggplant, pepper and tomato) and the post-harvest techniques investigated for quality retention during storage and marketing. Because of the increasing importance of fresh-cut (minimally processed) products within the fruit and vegetable market, we also present research findings concerning quality retention in minimally processed Solanaceous products.

QUALITY REQUIREMENTS AND DETERMINATION FOR EGGPLANTS, PEPPERS AND TOMATOES

The European Union (EU) common quality standards apply to eggplants (EC 1981), sweet peppers (EC 1999) and tomatoes (EC 2000) at all stages of distribution, including produce that is for export and that which is for domestic consumption. The minimum requirements state that the produce of all classes must be whole, fresh in appearance, sound (i.e. not affected by disease or deterioration), clean and free of external moisture or foreign smell and/or taste. The fruit should be developed and in a condition that is able to withstand transport and handling so as to arrive at their destination in a satisfactory condition. In both eggplants and peppers, the calyx and a portion of the peduncle must be attached to the fruit, whereas in tomatoes the requirement for calyx retention depends on local market preference. For each commodity, there are additional provisions concerning sizing, tolerances, presentation and marking (**Fig. 1**). Eggplants and tomatoes are graded for size either by diameter or weight, whereas sweet peppers are graded either by shoulder diameter or maximum equatorial diameter or even by length (in the case of cultivars of *C. annuum* L. var. *longum* with long pods). Particularly for the highest grades (Class I in all cases, plus 'Extra' in tomatoes), fruit should be virtually free of defects in colour, shape and mechanical injuries. All fruit within a particular package should be at the same stage of ripeness and therefore uniform in colour, although for peppers fruits of different colour may be boxed together and marked 'mixed peppers' (EC 2002).

Quality assessment throughout all stages within the post-harvest chain is of considerable importance for all vegetable commodities, and especially for those, such as tomato, eggplant and pepper, that are highly perishable. Apart from the application of EU quality standards as indicated above, research continues to suggest new methods that may be of value in improving product quality. Recently, for

Fig. 1 Packaging and presentation of produce. (**A**) Tomato, class 1, conforms to EU quality requirements. (**B**) Pepper, class 1, conforms to EU quality requirements. (**C**) Eggplant not conforming to EU quality requirements. Note mechanical injury due to poor handling and over-packing, unlabelled crate of poor appearance.

example, a non-destructive ultrasonic method was proposed to monitor the firmness and sugar content of tomatoes (Mizrach 2007). After harvest, fruit at the light red (turning) stage were stored at 20°C and 85% RH. The transducers of a low frequency ultrasonic pulser-receiver were placed in contact with the fruit and acoustic signals were transmitted through the fruit tissues at daily intervals throughout the shelf life of the fruit. The attenuation of the acoustic waves was measured as they passed through the tissues and was found to correlate with fruit firmness over eight days of storage provided that the ultrasonic excitation occurred at the same location on the fruit surface at each measurement time.

Another interesting development for non-destructive fruit quality assessment is the 'electronic nose', which monitors the head space gas above the fruit during storage. Gomez *et al.* (2008) attempted to correlate electronic nose measurements with indicators of tomato fruit quality, such as soluble solids, pH and firmness, at various stage of ripeness during storage for 12 days after harvest in bags or boxes at 20°C and 50-60% RH. These authors used an electronic 'nose' device incorporating 10 metal oxide sensors to detect aroma components (primarily alkanes and aromatic compounds) within the headspace above the tomatoes. Although the 'nose' appeared to distinguish storage time, it showed only a poor correlation with the quality attributes (total soluble solids, acidity and firmness).

Although ultrasonic and 'electronic nose' techniques are still in their infancy and not applicable to current EU regulations for the quality control of fresh fruit and vegetables, we believe that they warrant further research and refinement.

FRUIT COMPOSITION

Comparative composition of eggplant, pepper and tomato fruit

The chemical composition of the fruit of eggplant, sweet peppers and tomato is presented in **Table 1**. The data in this table give an overall indication of the relative nutritive value of each species at the time of commercial utilization. Comparatively, it may be seen that the major constituents (e.g. total carbohydrate, protein, lipid levels) as well as the water content are similar in all three species. The principal differences are the increased fibre content of eggplants and the higher concentrations of vitamin A and vitamin C 100 g^{-1} FW of peppers. Beyond this there are significant differences in sugar and organic acid constituents that relate to the stage of ripening as well as to the species or cultivar. For example, the fruit of 12 Italian tomato ecotypes were found to differ significantly in glucose, citric acid and amino acid content (Ercolano *et al.* 2008). In particular the 'Vesuvio' genotypes showed a high level of sweetness and aroma and an intermediate level of acidity. Such characteristics are valuable for incorporation into breeding programmes aimed at improving tomato flavour.

Further differences in composition may arise from variations in the climatic conditions, the nutritional status of the plant and the stage of ripeness at harvest. For example, during the transition from the mature green to fully red ripe stage of tomato, the titratable acidity decreases from about 115 to 83 meq $H^+ kg^{-1}$ FW while the concentration of reducing sugars increases from about 15 to 48 g kg^{-1} FW (Gautier *et al.* 2008). In peppers, the transition from green to red stages of ripeness is similarly accompanied by an increase in soluble solids (the °Brix increases from 4.3 to 7.0), but the titratable acidity increases from 0.03 to 0.11 (% citric acid) (Martinez *et al.* 2007). The titratable acidity and sugar content of eggplant fruits also change during their development and maturation. Titratable acidity is particularly high one week after fruit set (190-270 mg malic acid 100 g^{-1} FW) but declines to less than 160 mg by the second week and subsequently increases to about 180-200 mg 100 g^{-1} FW by full maturity. Total sugars and reducing sugars also fluctuate, showing an initial increase within the first 10 days after fruit set, followed by a decline as sugars are consumed for active fruit growth (day 15) and a subsequent increase until about day 40 when fruit are fully mature (Esteban *et al.* 1992). At the time of fresh consumption the total sugar concentration of eggplant fruit is about 2.35% (**Table 1**), almost all of which is in the form of reducing sugars (Esteban *et al.* 1992).

Table 1 Approximated composition of fresh eggplant, pepper and tomato fruit at the stage of commercial consumption (adapted from the USDA 2007).

Constituent	Amount 100 g^{-1} fresh weight		
	Eggplant	Pepper (red)	Tomato (red)
Water	92.4%	92.2%	94.5%
Carbohydrates	5.7%	6.0%	3.9%
Protein	1.0%	1.0%	0.9%
Fat	0.2%	0.3%	0.2%
Fibre	3.4%	2.1%	1.2%
Sugars (total)	2.35%	4.2%	2.6%
Calcium	9 mg	7 mg	10 mg
Magnesium	14 mg	12 mg	11 mg
Phosphorus	25 mg	26 mg	24 mg
Iron	0.24 mg	0.43 mg	0.27 mg
Potassium	230 mg	210 mg	237 mg
Vitamin A	27 IU	3100 IU	830 IU
Thiamine	0.04 mg	0.054 mg	0.04 mg
Riboflavin	0.037 mg	0.085 mg	0.02 mg
Niacin	0.65 mg	0.98 mg	0.6 mg
Vitamin C	2.2 mg	127.7 mg	12.7 mg
Energy	24 kcal	31 kcal	18 kcal

In tomato and pepper volatile and non-volatile compounds contribute to the aroma and flavour of the fruit. Whilst over 400 aromatic compounds have been identified in tomato and tomato products, only a small number are essential for tomato flavour and aroma, of which 3-hexenal, hexanal, 1-octen-3-one, methional, 1-penten-3-one and 3-methylbutanal are considered to be the most odour active (Krumbein and Auerswald 1998). Although the relative concentrations of aromatic constituents within the fruit vary with cultivar (cherry, extended life and conventional round tomatoes), changes in most of these compounds during storage show similar trends (Krumbein *et al.* 2004). In pepper *C. chinense*, 34 volatiles were identified, of which the most abundant were hexyl esters of pentanoic acid, dimethylcyclohexanols, humulene and esters of butanoic acid (Teixeira Sousa *et al.* 2006). In chili peppers (*C. annuum* var. *annuum* cv. 'Kulai') the principal volatiles were hexanal, 2-isobutyl-3-methoxypyrazine, 2,3-butanedione, 3-carene, *trans*-2-hexenal and linalool. During ripening, hexanal (green aroma) and 2-isobutyl-3-methoxypyrazine (grassy aroma) decreased, whereas 2,3-butanedione, 3-carene, *trans*-2-hexenal and linalool (all of which contribute to a sweet, fruity aroma) increased (Mazida *et al.* 2005). Similarly, in bell pepper (*C. annuum* cv. 'Mazurka'), a decrease in volatiles that contribute to pungent, grassy, rancid odours was observed during the transition from green to the red ripe stage, while hexanal and hexanol (sweet odours) increased (Luning *et al.* 1994). Hence the volatile and aroma characteristics are seen to change both with cultivar and with the stage of ripening. In eggplant aroma plays a less important role and the possible role of aromatic volatiles has yet to be investigated.

In recent years, the value of antioxidants for human health has frequently been stressed and a high dietary intake of fruit and vegetables is recommended to reduce the risk of degenerative diseases, such as cancer, cardiovascular disease and neural disorders (Fairfield and Fletcher 2002; Garcia-Closas *et al.* 2004). Vitamins, provitamins, flavonoids, and other phenolic compounds are particularly important antioxidants within vascular plants, including eggplants, peppers and tomatoes (Vinson *et al.* 1998; Kong *et al.* 2003). Garcia-Closas *et al.* (2004) carried out a cross-sectional study to assess the principal food sources of antioxi-

Table 2 Estimated life expectancy at birth of populations (both sexes combined) from countries of the Mediterranean Basin, northern Europe and North America[a].

Geographical region	Life expectancy at birth (years) for five year periods:		
	2000-2005	2005-2010	2010-2015
Mediterranean (EU)			
Cyprus	79.0	79.0	79.7
France[b]	79.6	80.7	81.3
Greece	78.3	79.5	80.1
Italy	79.9	80.5	81.1
Spain	80.0	80.9	81.5
Northern Europe (EU)			
Belgium	78.2	79.4	80.1
Denmark	77.3	78.3	79.0
Germany	78.7	79.4	80.0
Netherlands	78.7	79.8	80.3
Poland	74.6	75.6	76.4
United Kingdom	78.5	79.4	80.1
North America			
U.S.A.	77.4	78.2	78.9

[a]Source of data: United Nations Department of Economic and Social Affairs, Population Division (2007)
[b]Borders on the Mediterranean to the south

dants and free radical scavengers within a Spanish cohort of 41,446 healthy volunteers (25,812 women and 15,634 men). The median intake values for vitamin C, vitamin E and total carotenoids were 138.1, 8.5 and 4.8 mg day^{-1} respectively. Fresh fruit (citrus and non-citrus) contributed 51.1% of the daily vitamin C intake, compared with 20.3% from fruiting vegetables (12.0% from tomatoes and 7.2% from sweet peppers). Fruiting vegetables also contributed 7.4% to the daily vitamin E intake, 6.0% of this amount being derived from tomatoes, compared with 11.6% from citrus and non-citrus fruit and 7.9% from nuts and seeds. Of the specific carotenoids studied, 81.6% α-carotene came from carrots, 17.2% β-carotene and 71.6% lycopene from tomatoes, plus 24.1% lycopene from tomato sauce. Tomatoes also contributed 3.4% of the dietary intake of lutein, while sweet peppers provided 2.3% and 12.6% of β-cryptoxanthin and zeaxanthin, respectively. In Spain, as in other countries of the Mediterranean Basin such as Greece and Portugal, the *per capita* consumption of fresh fruit and vegetables is higher than in the industrialized countries of North America and northern Europe and the principal sources of vitamins and antioxidants in the Spanish diet are fresh fruit and vegetables, as opposed to processed or fortified food in the USA, Canada and northern European countries (Garcia-Closas *et al.* 2004). Observational studies have supported an inverse association between the intake of vitamin C, vitamin E, β-carotene, lycopene and other carotenoids and the occurrence of chronic disease and cancer (Fairfield and Fletcher 2002) and it is noteworthy that Spain has the lowest CHD mortality rate and, together with Portugal and Greece, the lowest cancer mortality rate in Europe (Garcia-Closas *et al.* 2004). Moreover, the estimates of life expectancy at birth for typical populations within the Mediterranean region are relatively higher than those of populations for the highly industrialized countries of northern Europe and North America (**Table 2**), indicating a significant contribution of a healthy diet to human longevity.

Although most of the evidence for the health benefits of antioxidant intake is derived from population-based studies, Rao (2002) reported that healthy human subjects ingesting lycopene in the form of tomato sauce and oleoresin soft gel capsules for a week had significantly lower levels of low-density lipoprotein (LDL) in the blood compared to the controls. LDL is thought to play a significant role in atherosclerosis and coronary heart disease, with its oxidation considered to be a primary step leading to its uptake by macrophages in the arterial wall and the subsequent formation of foam cells and atherosclerotic plaque. Studies *in vitro* have indicated that lycopene can protect native LDL from oxidation and so suppress cholesterol synthesis, and *in vivo* the ingestion of lycopene has been correlated with a reduction in plasma LDL cholesterol levels. Although, as discussed by the author, it is not possible to attribute lower levels of LDL oxidation solely to the presence of lycopene, it is of interest that in a case-control study with subjects from 10 European countries to evaluate the relationship between antioxidant status and acute myocardial infarctions, lycopene (but not β-carotene) was found to be protective (Rao 2002).

Eggplant

Some differences have been observed in the composition of purple, green and white eggplant fruit. For example, white-fruiting cultivars have a higher crude fibre content than purple or green cultivars, whereas the amino acid content of purple-coloured fruit is higher than that of white fruit. The occurrence of glycoalkaloids in fruit, especially at high concentrations (>20 mg 100 g^{-1} FW), may cause bitterness (Lawande and Chavan 1998). The peel of eggplant contains a high quantity of anthocyanins, especially in purple coloured cultivars, whereas the flesh has a high content of phenolic compounds. The vitamin C concentration within the flesh of eggplant is lower than that of tomato or pepper (**Table 1**). During the first 20 days after fruit set, the vitamin C content of eggplant is negligible, but progressively rises to a maximum (between 7 and 20 mg whole fruit^{-1}) by day 40 (Esteban *et al.* 1992).

Whitaker and Strommel (2003) investigated the principal class of phenolics (hydroxycinnamic acid conjugates) in the flesh of seven eggplant cultivars and found the predominant compound to be chlorogenic acid (5-*o*-caffeoylquinic acid). The total content of hydroxycinnamic acid conjugates ranged from 0.5-1.5% on a dry weight basis, which ranks eggplant as among the highest in phenolic acid content. The free radical scavenging capacity of crude and partially purified eggplant extracts correlates strongly with the chlorogenic acid content (Tateyama and Igarashi 2006), although the concentrations of this and other phenolics vary with the cultivar and within the different tissues of the fruit (Whitaker and Strommel 2003). The total polyphenol concentration also declines with storage (Esteban *et al.* 1989). Hanson *et al.* (2006) prepared extracts from a range of eggplant cultivars and tested them for their superoxide scavenging potential. Although differences in superoxide scavenging activity were observed between cultivars, these were not associated with fruit colour, but were influenced by the environmental conditions during cultivation.

Anthocyanins are present mainly in the peel of purple coloured eggplant fruit and were not detected in the peel of white or green cultivars (Tateyama and Igarashi 2006). Matsuzoe *et al.* (1999) determined the anthocyanin constituents of the peel of 14 eggplant cultivars from Japan and Bangladesh. The major anthocyanin of 13 of these cultivars was identified as nasunin (delphinidin 3-*p*-coumarylrhamnosyl-glucoside-5-glucoside), whereas in one cultivar 79.5% of the anthocyanin total consisted of delphinidin 3-glucosyl-rhamnoside. Nasunin has been isolated in crystalline form from the peel of eggplant fruit (Noda *et al.* 1998). In addition, the structure of nasunin isolated in methanolic extracts of eggplant peel has been investigated by Ichiyanagi *et al.* (2005), who concluded that it comprised both *cis*- and *trans*-isomers of the *p*-coumaric acid moiety. Both forms were interconvertible under illumination.

Nasunin (both *cis*- and *trans*- forms) is rapidly absorbed within the gastrointestinal tract of rats (Ichiyanagi *et al.* 2005) and has been demonstrated to impart a number of potentially beneficial properties within the animal (and possibly human) organism. For example, 1 μM nasunin significantly protected against lipid peroxidation in brain homogenates (Noda *et al.* 1998, 2000) and suppressed microvessel outgrowth in an *ex vivo* angiogenesis assay using a rat aortic ring (Matsubara *et al.* 2005), indicating both antioxidant and antiangiogenic properties. In other experiments, the inclusion of nasunin in the diet of rats prevented liver injury and oxidative stress caused by the intraperitoneal administration of D-galactosamine (Sugimoto *et al*. 2003).

The possibility of using eggplant extracts to scavenge the free radicals generated by the use of an anti-tumor drug (doxorubicin) was investigated in rats by Ferreira *et al.* (2003). It was found that animals that had been treated simultaneously with doxorubicin and eggplant extract developed significantly fewer chromosomal aberrations than those treated with doxorubicin alone.

Pepper

Sweet peppers are a particularly good source of vitamins, especially vitamins A and C. Vitamin C concentrations are higher in red or yellow peppers than in green ones (127.7, 183.5 and 80.4 mg 100 g-1 FW respectively, according to the USDA National Nutrient Database). Vitamin A concentrations are much higher in red peppers than in yellow or green fruit (3131, 200 and 370 IU 100 g^{-1} FW, respectively). Martinez *et al.* (2007) found that the vitamin C concentration of green 'Arnoia' peppers harvested from the plant was higher than that of fruit purchased from the supermarket (109 and 58 mg 100 g^{-1} FW respectively) indicating a rapid loss of vitamin C post harvest. During studies of pepper 'Fresno de la Vega' ripening over a two year period, Martinez *et al.* (2005) noted an increase in the vitamin C content of fruit during the transition from the green to breaker and full red stages (106-1009 to 127-131 to 149-160 mg 100 g^{-1} FW respectively).

The red colour of sweet pepper derives from the various carotenoid pigments, which include β-carotene with provitamin A activity and oxygenated carotenoids, such as capsanthin, capsorubin and cryptocapsin, which are effective free radical scavengers. Red peppers also contain neutral phenolics or flavonoids, specifically quercetin, luteolin and capsaicinoids. In addition to varying with genotype, the concentration of antioxidants in peppers depends on the environmental conditions during cultivation, hence studies of antioxidants in different cultivars must be carried out over more than one season to be reliable (Deepa *et al*. 2006).

Recent research suggests that sweet peppers grown in organic systems exhibit a different nutrient composition from those grown with conventional agricultural methods. Thus organically grown ripe peppers had a higher intensity of red or yellow colour at maturity and a higher content of minerals and carotenoids, although at the green stage differences were either absent or less (Perez-Lopez *et al.* 2007). Organically grown peppers had a total carotenoid concentration of 3231 mg kg^{-1} FW at the red stage, compared with 1829 mg kg^{-1} FW in conventionally grown red fruit, thus indicating a significantly higher antioxidant activity in the organic product. In further experiments, organically grown peppers were shown to have higher peroxidase activity at both the green and red stages, and a higher concentration of total phenolic compounds. Moreover, based on the inhibition of fungal growth, capsidiol activity in mature red fruit was higher in the organic product, indicating that organically grown sweet peppers may have a greater disease resistance than conventionally grown peppers (Del Amor *et al.* 2008).

Tomato

Despite the fact that tomatoes have a lower vitamin C and vitamin A content per unit FW than sweet peppers (**Table 1**), they are considered to make a greater contribution of these vitamins to the human diet due to their relatively higher consumption. Total ascorbate in cherry tomato was found to increase from about 210 mg kg^{-1} FW at the mature green stage to almost 400 mg kg^{-1} FW in mature red fruit. This change was due mainly to an increase in the reduced form of ascorbate, since the oxidized form decreased rapidly over the same period (Gautier *et al.* 2008).

Although it is difficult to quantify the daily intake of any particular vegetable commodity, it has been estimated that the daily intake of total tomato products ranges from 49-175 g in Italy to about 65 g in Spain and about 30 g in the United Kingdom. The major contribution to this intake appears to be fresh fruit, and to a lesser extent cooked tomatoes and processed tomato products (Porrini and Riso 2005). Although the optimum human intake of tomatoes has not been quantified, it has been shown that an intake of 6-8 mg lycopene day^{-1} improves lymphocyte protection from oxidative damage (Porrini and Riso 2005).

Due to the beneficial effects of antioxidants on human health, lycopene extraction from tomato for inclusion in diet supplements has recently been promoted. Hoppe *et al.* (2003) studied the bioavailability of lycopene from tomato-based and synthetic sources and found that both sources induced an increase in serum total lycopene levels in comparison with a parallel placebo treatment. Moreover, neither lycopene source affected the other serum carotenoids. Synthetic lycopene is a red crystalline powder that is soluble in most organic solvents, but is insoluble in water. By contrast, lycopene-containing powders produced from tomato paste or concentrate are water soluble and contain 5-10% lycopene that is readily bioavailable.

Quaglia *et al.* (2007) treated a concentrate from cherry tomatoes with β-cyclodextrin followed by spray drying. The resulting powder had a lycopene content of 0.4-1.09 mg g^{-1} and was readily dispersed in water. Moreover, the lycopene concentration of the powder correlated with the antioxidant activity. In view of this and other similar studies, it is likely that the manufacture of health products and food supplements with lycopene-based antioxidant properties will increase in the future. However, care must be taken during processing since other important dietary constituents may be affected. For example, the vitamin C content of tomato products (juice, sauce and cooked tomatoes) decreases during thermal treatment, although the levels of phenolics and water soluble antioxidants may increase (Gahler *et al.* 2003). Heat may also induce *cis*-isomerization of *trans*-lycopene, which is the predominant form found in fresh tomatoes. Interestingly, it appears that *cis*-lycopene is the form that is preferentially absorbed, although it is not certain that this will affect total serum lycopene levels (Hoppe *et al.* 2003).

Frusciante *et al.* (2007) grew 18 tomato genotypes under strictly controlled conditions and analysed the fruit for their antioxidant properties. Variations in total carotenoids, β-carotene, lycopene, flavonoids and vitamin E were detected between the different genotypes. Based on the results of this experiment and on data reported in the literature, the authors constructed an index of antioxidant nutritional quality to assist breeders in selecting antioxidant-rich genotypes.

PRE-HARVEST FACTORS AFFECTING FRUIT QUALITY

Eggplant

Eggplant is a thermophyllic species with optimum vegetative growth occurring at temperatures of 27-32°C during the day and 21-27°C at night (Oscar 1980), although fruit growth may be favoured by somewhat lower temperatures (22-26°C) (Kurklu *et al.* 1998). Eggplant fruit that are to be used for human consumption are harvested when they have reached the stage of physiological maturity, but while still unripe, and some time before they reach their final size (Esteban *et al.* 1992). The timing of harvest is important not only for yield but also for quality. At harvest, fruits should be firm (but not hard) with a smooth skin, well developed colour and a glossy sheen. The fruit dimensions (length, diameter) vary with cultivar, and fruit shape varies from elongated to oval, flask or even bottle type. Once fruit have been cut they will not ripen further. However, fruit left on the plant will start to ripen and quality decreases because they lose their glossy appearance, the colour changes, the texture becomes softer and the seeds mature and harden.

Eggplant fruits produced under cover during spring and early summer in southern Europe are suitable for harvest from about 25-30 days after flowering, depending on the cultivar and temperature (Passam, unpublished). At this stage colour development is maximal and fruit have a firm texture and a glossy appearance. Nothmann *et al*. (1979) reported that colour development varied with cultivar and occurred at a faster rate in fruits developing from primary flowers (those connected by a pedicel to the main stem) than in the secondary flowers (formed on a separate axis). If fruit are harvested too early, colour and texture is inferior. Fruit colour is also affected by the cultivation season. Thus, Zipelevish *et al*. (2000) noted that the colour intensity of fruits of cv. 'Classic' cultivated under cover in Israel between October and May was higher during the warm growth period (October-December) than during the cold period (February-April). Colour intensity was not significantly affected by the level of K or P application.

Sugars, titratable acids and polyphenols are largely responsible for the flavour quality of eggplants and, according to Esteban *et al.* (1992), the concentrations of these substances within the fruit, as well as that of vitamin C, are maximal 42 days after flowering irrespective of cultivar. The concentration of alkali-soluble pectin (protopectin) within the fruit also increases up to 42 days after flowering, after which the subsequent decline in its concentration is associated with fruit softening. By contrast, the concentrations of oxalate-soluble and total pectic polysaccharides increase during ripening (Esteban *et al.* 1993). Polyphenol oxidase (PPO) activity is lower in green-fruiting cultivars than in purple-fruiting ones, which may explain the milder flavour of the former (Flick *et al.* 1977).

Low temperatures affect the pollen viability and germination of eggplant, which in turn leads to poor fertilization and the formation of fruit with few or even no seeds. In such fruit, the placentae do not develop fully, resulting in the formation of hollow cavities within the flesh. To overcome this problem and to improve fruit set and quality, eggplants may be treated with growth regulators, such as β-naphthoxyacetic acid (NOA) or naphthaleneacetic acid (NAA), at the time of flowering. The use of plant growth regulators for fruit set during the winter months is a common practice for eggplants cultivated in unheated greenhouses within the Mediterranean region. Indeed, a reduction in the number of seeds in fruit that have been set with the assistance of growth regulators is a positive quality factor, since the seeds of eggplant become hard as they mature and they may impart bitterness, due to the increased presence of phenols associated with them in the placental tissue. This is particularly the case in fruits that have been left too long on the plant, because seeds within the fruit mature approximately 45-50 days after flowering. A more recently evolved method to improve fruit quality is the introduction of genetically modified parthenocarpic eggplants, which produce seedless fruit of high quality under both field and greenhouse conditions (Donzella *et al.* 2000; Acciarri *et al.* 2002).

Pepper

The size and quality of sweet (bell) peppers is determined to a significant extent by the success of pollination and fertilization. Low night temperatures for example reduce pollen viability (Mercado *et al.* 1997), thereby decreasing the number of seeds per fruit and increasing the number of seedless fruit (Rylski and Spigelman 1982). Seedless fruit are usually small and flattened with a persistent, protruding, thick style; thus market quality is low or unacceptable. Fruit malformation may also occur, however, in fruit that contain seeds due to unfavourable conditions (low temperatures) during the early stages of flower development (Ali and Kelly 1993; Rylski and Aloni 1994). Although hormones have been used to increase fruit set in pepper, the resulting fruit remain small and are of low market quality. In this respect peppers differ markedly from eggplants and tomatoes, where hormones may be used to set commercially acceptable fruit under adverse weather conditions. When ethephon was applied to plants of field chilli peppers (*C. annuum*) at 1.75 l ha^{-1} to promote uniform ripening and thus assist mechanical harvesting, it caused excessive fruit drop in some cultivars and so could not be universally recommended (Wall *et al*. 2003).

Niklis *et al.* (2002) reported a highly significant effect of fruit maturity at harvest on the ascorbic acid content of the fruit of two pepper cultivars. Immature green fruit of cv. 'P-14' and 'Florinis' had 86 and 32% less ascorbic acid than the red, commercially mature fruit, indicating the immature fruit to have a significantly lower nutritional value than the mature fruit. A similar correlation between fruit ripeness and ascorbic acid content was reported by Martinez *et al.* (2005). In addition, these authors reported that the ascorbic acid content of fruit harvested at the mature green or breaker stage increased during storage at 20°C for 10 days, reaching about the same level as that found in plant-ripened fruit. By contrast red ripe peppers show a progressive decrease in ascorbic acid content during storage. The activity of antioxidant enzymes such as SOD, is higher in red fruit than in green fruit, whereas monodehydroascorbate reductase and dehydroascorbate reductase activities are higher at the green stage (Jimenez *et al.* 2003). These enzymes, as well as catalase and ascorbate peroxidase, are likely to influence the total antioxidant capacity and ascorbate content of the fruit during ripening and storage. The genotype and harvest date also affect the dry matter and soluble solids content of fruits, as do environmental factors, such as mean temperature, day length and light intensity (Fox *et al.* 2005).

The method of harvest does not appear to affect fruit quality during subsequent storage, since fruit that were harvested with either cut or torn peduncles showed no difference in the percent water loss (Smith *et al*. 2006). This led these authors to suggest that, unlike eggplant (Diaz-Perez 1998), the calyx of pepper fruit has relatively little effect on the rate of water loss. Diaz-Perez *et al.* (2007), however, conclude that in fact 26% of water loss in mature fruit occurs via the calyx. Since water loss does not relate to fruit size, it appears that the cuticle acts as an effective barrier against water loss, even though the abundance of epicuticular wax does not appear to be a decisive factor (Smith *et al*. 2006). Seasonal differences in pepper storage attributes indicate an effect of the pre-harvest environment, whereas differences between cultivars indicate an effect of genotype.

If fruit are harvested at a very immature stage (e.g. 15 days after flowering) the seeds will not have matured and may turn brown in colour. Seed browning is associated with cell damage, the leakage of electrolytes and the accumulation of phenolics. The extent of discoloration depends on the storage temperature and relates to the activities of enzymes such as PPO, phenylalanine ammonia lyase, SOD and lipoxygenase (Boonsiri *et al.* 2007). Both the development of seeds within the fruit and the composition of the pericarp are significantly affected by the atmospheric composition of the locular space. When the oxygen level was reduced (15%), seed weight decreased, whereas in the absence of CO_2 the starch and sucrose content of the fruit wall was less (Blasiak *et al.* 2006).

Tomato

The impact of mineral nutrition and salinity on tomato fruit quality was reviewed by Passam *et al.* (2007) and therefore will not be further discussed here. While it has long been known that the soluble solids and organic acid content of tomatoes is influenced by the growth environment, recent research has turned to the effects of temperature and light on the antioxidant content of the fruit. Gautier *et al.* (2008) reported that under increased fruit irradiance the concentrations of ascorbate, lycopene, β-carotene, rutin and caffeic acid derivatives rose in ripening fruit. By contrast, increasing temperatures progressively reduced the content of total carotene, ascorbate and lycopene. According to Riga *et al.*

(2008), tomato quality (e.g. firmness, soluble solids, phenolics) is more affected by the cumulative air temperature than by the photosynthetically active radiation.

In view of changing climatic conditions, it is likely that crops within warm, dry areas such as the Mediterranean will become increasingly subjected to stress, not only due to salinity and a lack of good quality irrigation water, but also due to high solar irradiation. The importance of this subject to the future of horticulture may be gauged by the increasing number of research papers concerned with stress related problems (see review by Passam *et al*. 2007). Torres *et al.* (2006) investigated the effect of photo-oxidative stress on tomato fruit and found that surface bleaching resulted mainly from visible light, whereas high temperatures inactivated the processes of photosynthesis. Exposure of fruit to natural sunlight in the presence or absence of UV filters for up to 5 h resulted in a reduction in ascorbate concentration within the exocarp, while the activity of antioxidant enzymes (e.g. SOD, ascorbate peroxidase and catalase) increased, indicating an activation of mechanisms within the fruit to protect against photo-oxidative stress and damage. In the study of Torres *et al.* (2006), the maximum exposure time of fruit to stress conditions was 5 h. However, spring and summer grown crops within the Mediterranean basin are exposed to such conditions, or even more extreme, for periods of maybe 8 h or longer each day. This means that a very high level of temperature and photo-irradiation stress is exerted on the crop, and the defense mechanism of the plant may not be sufficient to cope with this, resulting in stress symptoms and decreased quality.

ETHYLENE AND THE CLIMACTERIC

Eggplant

The eggplant fruit is non-climacteric and, according to Rodriguez *et al.* (1999), the rate of endogenous ethylene synthesis falls from about 14 μl kg^{-1} h^{-1} at the stage of petal drop to 2 μl kg^{-1} h^{-1} on day 7, and subsequently remains at a low value (1.4 μl kg^{-1} h^{-1}) until commercial maturity. The exogenous application of ethylene to harvested fruit has no practical application for commercial eggplant since fruit are harvested at the stage of market acceptability.

Pepper

Like eggplant, pepper too is generally considered to be a non-climacteric fruit. Thus, in the case of sweet (bell) pepper cv. 'California', a typical non-climacteric pattern of fruit growth and maturation is observed. The rate of respiration and ethylene production is high at the time of fruit set, but declines thereafter and remains low throughout the subsequent growth and maturation of the fruit. Treatment of mature green fruit with propylene did not enhance the rate of colour change and only under stress induced by silver thiosulphate was an increase in respiration and ethylene production observed (Pretel *et al.* 1995).

In contrast to the above, sweet pepper cv. 'Domino' exhibits a climacteric pattern of fruit ripening. Respiration and ethylene production are high at the time of fruit set and subsequently decline. However, at the time of colour change a climacteric-like peak in both CO_2 and ethylene production is observed (Tadesse *et al.* 2002). Similar climacteric behaviour has been observed in a hot pepper cv. 'Chooraehong' (Gross *et al.* 1986). Villavicencio *et al.* (1999) studied the production of ethylene and CO_2 by fruit in 13 cultivars of pepper and identified two patterns of CO_2 production: (a) higher rates at the mature green stage and progressive decrease throughout ripening and (b) lower rates at the mature green stage, but with a transient increase at the stage of colour change or when fruit are totally red. Considerable variation in the rates of respiration were observed (16.5-440.3 mg CO_2 kg^{-1} h^{-1}), while ethylene production was low (0.002 to 1.1 μl kg^{-1} h^{-1}). Gross *et al.* (1986) also observed that despite the climacteric respiratory response of cv. 'Chooraehong' the maximum rate of ethylene production was only 0.7 μl kg^{-1} h^{-1}.

Because of the relatively long period of time required from fruit set to full fruit ripening (60-70 days), a number of experiments have studied the effect of post-harvest application of ethylene on the ripening and quality of fruit harvested at different colour stages. Fox *et al.* (2005) harvested bell peppers at five stages of fruit maturation and ripening (from 10% red to full red) during early winter and two stages (10% red and full red) in spring. The fruit were exposed to a storage atmosphere containing ethylene (100 μl l^{-1}) at 20°C and 90% RH. Ethylene treatment was found to reduce the time to ripening in comparison with the untreated control in both experiments, irrespective of fruit maturity at harvest. Neither harvest maturity nor ethylene treatment affected the pulp soluble solids, total acidity or pH. Moreover, ethylene did not affect the concentrations of total carotenoids, ascorbic acid or soluble phenolics at the different stages of harvest maturity. Cerqueira-Pereira *et al.* (2007) treated both yellow and red fruited cultivars of bell pepper with ethylene (120 μl l^{-1} at 22°C and 80% R.H.). These authors, in contrast with Fox *et al.* (2005), found that ethylene treatment not only accelerated the rate of colour development of the red cultivar, but also increased the soluble solids content. In neither the red nor the yellow cultivar did ethylene application affect the ascorbic acid, titratable acidity or pH of the fruit.

Liu *et al.* (2005) identified a *GH3*-like gene (*CcGH3*) in fruits of the pungent pepper (*Capsicum chinense* L.) cv. 'Habenero' and related its induction to the presence of auxin and ethylene within the developing fruit. Although the fruit of this pepper species is non-climacteric, the active role of ethylene in the fruit maturation and ripening process is indicated at a molecular level, where the expression of *CcGH3* correlated with small, but detectable, increases in ethylene concentration at the stage of fruit maturation, whereas treatment of tissue discs with 1-MCP, an inhibitor of ethylene action, caused an inhibition both in *CcGH3* expression and colour change. *GH3* genes are considered to be auxin-responsive genes (Hagen and Guilfoyle 2002), but in pepper cv. 'Habenero' auxin was present in both immature and mature fruit, and *CcGH3* expression occurred at a stage when auxin levels were anticipated to decrease. Liu *et al.* (2005) concluded that *CcGH3* might act as a point of intersection in the signaling response of both auxin and ethylene, with the role of amplifying the ethylene response.

Tomato

Tomato belongs to the group of climacteric fruit that show a characteristic increase in the rate of respiration and ethylene production at the start of ripening. Saltveit (1993) observed a climacteric rise in ethylene concentration while fruit ripened on the plant, but did not observe a similar peak in CO_2 production. This led the author to conclude that maybe the respiratory climacteric was not essential for fruit ripening, but was perhaps an artifact of fruit ripened after harvest. However, Knee (1995) concluded that changes in the photosynthetic activity of fruit attached to the plant obscured the climacteric increase in CO_2 levels during ripening, and thus suggested that even on the plant tomato fruit behaved in a climacteric way.

The role of ethylene in the respiratory climacteric and the ripening processes of tomato has been the subject of a large volume of research, stimulated even further by the discovery that 1-MCP delays fruit ripening by a transient inhibition of ethylene biosynthesis and respiration (Wills and Ku 2002; Ergun *et al.* 2006). Because this subject was recently reviewed by Passam *et al.* (2007), it will not be discussed in detail here. Suffice it to add that more recently Choi and Huber (2008) confirmed earlier findings that the immersion of tomatoes at an early stage of ripening in solutions of 1-MCP delays the onset of the climacteric and other metabolic activities associated with ripening. The response of tomatoes to 1-MCP is similar in different cultivars

(Guillén *et al.* 2006), but depends on the 1-MCP concentration and the duration of application (Guillén *et al.* 2007). Choi and Huber (2008) went on to show that the 1-MCP threshold levels for ripening suppression differed between internal and external fruit tissues, indicating a penetration effect of the 1-MCP.

FRUIT QUALITY IN RELATION TO STORAGE CONDITIONS AND POST-HARVEST TREATMENTS

Eggplant

Storage conditions

Because of their susceptibility to chilling injury, the recommended storage temperatures for eggplant fruits are 10-12°C. Relative humidity must be high (>90%) in order to restrict water loss. Alternatively, fruit may be enclosed in polyethylene or some other suitable protective film (Lawande and Chevan 1998). Hydrocooling prior to storage offers relatively little benefit because the surface area to volume ratio of eggplant fruit (especially flask-shaped types) is too low to enable rapid cooling. In addition, water spotting of the fruit may reduce quality (Ryall and Lipton 1979).

Weight (water) loss

Water (weight) loss occurs mainly through transpiration, the rate of which is inversely proportional to fruit size and therefore the surface area/mass ratio. According to Diaz-Perez (1998), 60% of eggplant fruit transpiration occurs via the calyx. Therefore, in small fruit, where the calyx area ratio is higher, the proportion of water transpired through the calyx is greater than in large fruit. Excessive water loss from eggplants results in a rapid loss of quality due initially to a loss of glossiness, followed by fruit softening, shriveling and browning of the calyx.

Fruit appearance - freshness

The surface gloss and weight of eggplant fruits decrease quadratically with the length of storage at 20°C and 80-84% RH for up to 96 hours, with major changes being detected within even 48 hours (Jha *et al.* 2002). Surface gloss, stiffness and density measurements were used to develop a freshness index for eggplants. The values of the index decreased exponentially with the length of storage at 25 ± 2°C and 90 ± 5% RH and correlated linearly with the price of eggplants, indicating its possible value for estimating market prices (Jha and Matsuoka 2002). In further experiments, these same authors investigated the relationship between gloss and weight loss and the fruit surface electrical resistance, measured with a galvanometer, during storage at 20°C and 80-84% RH for up to 96 hours (Jha and Matsuoka 2004). It was found that the surface resistance increased quadratically with storage time, but varied inversely with fruit gloss and weight.

Chilling injury

Eggplant fruits are susceptible to chilling injury at temperatures of less than 7-10°C, resulting externally in surface pitting, bronzing and scald, and internally in the darkening of the pulp and seeds. The precise temperature at which chilling injury occurs varies between cultivars and also depends on the maturity and size of the fruit at harvest. According to Fallik *et al.* (1995), eggplants harvested during the winter (December-January) in Israel were more susceptible to chilling than those harvested in spring (March-April), reflecting an effect of pre-harvest growth conditions on post-harvest susceptibility to chilling.

Concellon *et al.* (2007) investigated the development of chilling symptoms in eggplant fruits stored at 0°C. External discoloration was detected after two days storage at this temperature, followed by a loss of brightness, pitting and seed discoloration after day 6, and internal pulp browning and skin scald by day 13. Significant leakage of electrolytes from the pulp cells was observed after 6 days and electron micrographs of the tissues showed that the plasma membrane had separated from the cell wall and intercellular spaces were present, although the extent of cell damage was considered to be modest. After 15 days exposure to 0°C, however, cellular disruption was severe. Browning is largely due to the oxidation of naturally occurring phenolic compounds by PPO and eggplant fruits have a relatively high phenol content. For example, Lawande and Chavan (1998) report the concentration of *o*-dihydroxyphenols in eggplant cultivars to vary between 75 and 330 mg 100 g^{-1} DW. Concellon *et al*. (2004) studied the specific activity of soluble and insoluble fractions of PPO in eggplant fruit during 12 days storage at chilling (0°C) and non-chilling (10°C) temperatures. At 10°C, the specific activity of both fractions increased after 6-8 days. However, at 0°C, both soluble and insoluble PPO activity in the pulp remained unchanged for 6 days, at which time browning occurred, and then subsequently declined.

Eggplant is a non-climacteric fruit and under non-chilling conditions of storage, the internal concentration of ethylene is very low, or even below the level of detection. Concellon *et al.* (2005) reported an increase in the concentration of 1-aminocyclopropane-1-carboxylic acid (ACC) in eggplant fruits exposed to chilling (0°C) for 24 hours, and an increase in 1-(malonylamino)cyclopropane-1-carboxylic acid (MACC) after 48 hours. Parallel measurements of the internal ethylene concentration showed that ethylene could be detected after 24 hours storage at 0°C and the level of ethylene remained the same until day 6 (0.04 µl kg^{-1} FW), after which it fell to below the level of detection. The authors concluded that ACC synthesis was the chilling-stimulated step, rather than the conversion of ACC to ethylene. However, the appearance of chilling symptoms on day 6 coincided with a decrease in ACC, MACC and ethylene levels. The induction of chilling injury at 0°C is also characterized by an increase in the fructose, glucose and maltose concentrations of the pulp (day 2), followed by a sharp decrease from day 4, and a subsequent increase in the concentrations of malic and citric acid (Kozukue *et al.* 1978). The ascorbic acid (vitamin C) content of fruit decreased by as much as 75% during storage for 18 days at 10 or 20°C, whereas at 5°C the rate of loss of ascorbic acid was lower (Esteban *et al*. 1989).

Modified atmosphere storage – film wraps

MA packaging is a technique that is of particularly valuable for highly perishable produce such as eggplant, pepper and tomato fruit and fresh-cut (minimally processed) produce. The aim of MA packaging is to generate a sufficiently low O_2 and/or high CO_2 concentration within the package so as to reduce the rate of produce metabolism, thereby increasing the length of storage life and reducing undesirable changes such as degeneration, softening and senescence. This is achieved by the use of appropriate semi-permeable films for produce wraps (Lange 2000), taking into account the response of the produce to high CO_2 concentrations within the package (Watkins 2000), and the most effective storage conditions (especially temperature).

At 10-12°C, the storage life of eggplants is about 10-15 days, but enclosure of fruit in polyethylene bags extends storage life to as much as 20 days even at ambient temperatures. Polyethylene wrapping has also been reported to delay or inhibit chilling injury in eggplant (Fallik *et al.* 1995). However, in other experiments where this technique was employed for the storage of eggplant at 8-9°C for 17 days, fruit rapidly deteriorated on return to ambient temperature (Mohammed and Sealy 1986).

Controlled or modified atmospheres do not appear to have a significantly beneficial effect on eggplant storage. Low levels of oxygen (3-5% O_2) may reduce the onset and rate of deterioration by a few days, whereas high carbon dioxide levels (>7% CO_2) can cause injury. Some improvement in external quality and an extension of storage life was achieved by storing fruits in atmospheres of 3% O_2 + 3% CO_2 or by wrapping in polyvinyl chloride bags (Kaynas *et al.* 1995).

Pepper

Storage conditions

Peppers are consumed either at a physiologically mature but unripe stage (green) or at a fully ripe stage (red, or yellow). As in climacteric fruit (tomato) colour change is a reliable index of maturity and therefore quality. Both fruit firmness and the concentration of total soluble solids within the pericarp correlate with colour change, and optimum values for cv. 'Domino' are considered to be 35 N and 6 °Brix, respectively (Tadesse *et al.* 2002).

Recommended storage conditions for sweet peppers are 8-9°C and 95-98% RH (Ryall and Lipton 1979). At temperatures lower than 7°C fruit are prone to chilling injury, but as the temperature rises above 10°C fruit are increasingly susceptible to water loss and shriveling, leading to a loss of quality. Hydrocooling is more beneficial to peppers than to eggplants because the pericarp of peppers is relatively thin and cooling is rapid. However, hydrocooling may promote decay, particularly if fruit are not blasted with cool air after they leave the hydrocooler (Ryall and Lipton 1979).

Weight (water) loss

Water loss is a major factor affecting post-harvest quality of peppers (Smith *et al.* 2006; Diaz-Perez *et al.* 2007) and occurs mainly via the cuticle. Initial symptoms of shriveling due to water loss develop when the fruit loses 5% of its original weight (Gonzalez and Tiznado 1993). There is a clear relationship between the rate of water loss, the size of the fruit and the stage of ripeness. The fruit surface area/FW ratio and rate of water loss were both highest in immature fruit and the mean weight loss of individual fruit decreased with increasing fruit size and fruit ripening. Although the water vapour permeance of the calyx of mature fruit was significantly higher than that of the cuticle (398 and 29 $\mu mol\ m^{-2}\ sec^{-1}\ kPa^{-1}$, respectively), only about 26% of water loss occurred via the calyx (Diaz-Perez *et al.* 2007). Pepper genotypes that are susceptible to high rates of water loss have been shown to possess low amounts of total lipids, phospholipids and fatty acids, with the exception of linoleic acid the level of which was high. By contrast, genotypes with lower susceptibility to water loss contained higher amounts of lipids, except linoleic acid (Maalekuu *et al.* 2006). These authors concluded that membrane damage, a loss of membrane integrity and consequently membrane ion leakage and fruit water loss was due to the lipoxygenase-catalysed oxidation of the membrane lipids. Although fruit FW, pericarp weight, pericarp surface area, pericarp thickness, initial water content and dry matter are all highly related to each other, their relation to the rate of water loss is less than that of lipoxygenase activity and the total amount of cuticular wax (Kissinger *et al.* 2005).

Reduction of water loss by waxing or enclosure in film

To prevent water loss through transpiration, peppers may be waxed or enclosed in polyethylene. Lerdthanangkul and Krochta (1996) tested different coatings based on mineral oils, cellulose or milk proteins on the storage of green bell peppers. None of the coatings tested reduced the respiration rate of the fruit or affected fruit colour, and only the coating based on mineral-oil significantly reduced water loss and so contributed to the maintenance of fruit freshness and quality. Conforti and Ball (2002) compared lipid-based and lipid-hydrocolloid-based coatings on the quality of mature green bell peppers over a 4-week storage period. No significant differences were detected between uncoated and coated peppers with respect to respiration rate, firmness (puncture force), ascorbic acid and chlorophyll content. The rate of weight loss was lowest in the fruit that were coated with lipid-hydrocolloids, but significantly increased with storage time. For commercial application of waxing, care has to be taken that the wax treatment does not adversely affect the ease of gas exchange between the internal tissues and the storage atmosphere. The accumulation of CO_2 or ethylene within the fruit may cause off-flavours and a decrease in quality. This is especially the case in climacteric fruit (e.g. mango, *Mangifera indica* L.), where the rate of respiration, and therefore gas exchange, varies appreciably with the stage of fruit maturation and ripening (Passam 1982). In pepper, the non-climacteric behaviour of the fruit during ripening permits the use of relatively high concentrations of wax emulsion without the danger of internal CO_2 accumulating to excessive levels. For example, Hagenmaier (2005) reported that the permeance of bell peppers coated with 10-22% candelilla wax to CO_2 and ethane did not differ from that of the unwaxed control, while the internal CO_2 concentration and rate of CO_2 production also did not differ from the control.

Gonzalez and Tiznado (1993) combined waxing with enclosure in polyethylene bags and found this dual treatment to be more successful in reducing colour change and weight loss than waxing alone. Gonzalez-Aguilar *et al.* (1999) used a hot water treatment (45°C for 15 min, or 53°C for 4 min) to control decay during storage. Although the incidence of fungal infection was reduced by this treatment, fruit shriveled. However, when hot water treatment was supplemented by enclosure in polyethylene, fruit quality was maintained for up to 28 days at 8°C. Raffo *et al.* (2007) also combined hot water treatment (53°C for 4 minutes) with storage in polyethylene bags (water permeability rate = 0.541 $g\ m^{-2}\ h^{-1}\ atm^{-1}$ at 38°C and 90% RH) for 21 days at 7.5°C. Wrapped red fruit lost less than 1% weight throughout storage compared with 10% in unwrapped fruit. Although hot water treatment prior to packaging slightly increased weight loss (to just over 1%), firmness was not affected. Moreover, hot water treatment and polyethylene packaging did not affect fruit sugar or acid content. A small, but statistically significant, decrease in ascorbic acid content (<10%) was attributed to the hot water treatment, but the concentrations of hydroxycinnamic acid derivatives were unaffected. These authors therefore concluded that brief hot water treatment for disease control will not adversely affect fruit quality. In subsequent experiments, Raffo *et al.* (2008) stored red peppers, with or without hot water treatment, in polystyrene trays wrapped with polyvinyl chloride film (water permeability rate = 31.25 $g\ m^{-2}\ h^{-1}\ atm^{-1}$ at 38°C and 90% RH) at 4 or 8°C for 9 days. As might be expected, the use of a film with greater water permeability resulted in higher water loss (<3% at 4°C but >10% at 8°C), and due to this a relative increase in sugar content and organic acids was observed on a dry weight basis, particularly at the higher temperature. Hot water treatment tended to inhibit phenolics synthesis and carotenoid accumulation at 8°C, as well as depleting total carotenoids at 4°C. Hence, the effect of hot water treatment appears to relate both to subsequent storage temperature and the physical properties of the film used for packaging.

In other experiments (Koide and Shi 2007), green peppers were enclosed in either biodegradable polylactic acid-based film or low density polyethylene, and stored for 7 days at 10°C. The microbial levels of coliform bacteria increased by 0.2 log CFU g^{-1} in the biodegradable film package, compared with 2.3 log CFU g^{-1} in sealed polyethylene and 0.9 log CFU g^{-1} in perforated polyethylene bags. Physicochemical properties, such as colour, weight loss, firmness and ascorbic acid content, were not affected by the type of packaging, hence biodegradable film may be more beneficial than polyethylene for the maintenance not only of fruit quality but also sanitary conditions, and it may be of further interest to examine the application of hot water treatment in combination with enclosure in biodegradable films.

Chilling injury

Chae *et al*. (2007) studied the development of chilling injury in bell pepper at three stages of ripeness (mature green, breaker and red ripe). Storage of fruit at 1°C resulted in increased water loss, respiration, ethylene production and electrolyte leakage. These symptoms were higher in fruit at the breaker stage than in the mature green or red ripe fruit. Severe surface pitting was also observed in fruit at the breaker stage after exposure to 1°C for 2 weeks, whereas pitting was less in mature green fruit and absent from red ripe fruit over this time period. No pitting was observed in fruit stored at 5 or 10°C. From these results it was concluded that bell peppers are most sensitive to chilling injury at the breaker stage, i.e. the onset of ripening.

Modified atmosphere packaging

Modified atmosphere (MA) packaging using different polymeric films is a particularly useful way of reducing water loss, maintaining fruit quality and extending shelf life. Moreover, since bell peppers are essentially non-climacteric in their post-harvest respiratory behaviour they respond to MA packaging in a stable and predictable way. Chen *et al*. (2000) packed bell peppers individually in film-covered packages and stored them at four different temperatures (0, 12, 20 and 30°C). Stable gas conditions were found within the packages because the temperature dependence of the film permeability corresponded closely to the temperature effect on fruit respiration. According to Serrano *et al.* (1997) MA packaging also reduces the severity of chilling injury in mature green bell pepper fruit stored at 2°C. The reduction in chilling injury correlated with a reduction in ACC and ethylene concentrations within the MA package, due probably to inhibition by the high level of CO_2 (4.5%). Luo and Mikitzel (1996) stored green bell peppers in various mixtures of oxygen and nitrogen (10, 30, 50, 70 ml O_2 l^{-1} and air) for up to 4 weeks at 10°C. The internal concentration of ethylene in fruit stored for 4 weeks under reduced oxygen concentrations was lower than in fruit stored in air, whereas the internal CO_2 concentration was significantly reduced only at the lowest level of oxygen (10 ml O_2 l^{-1}). Colour changes were also less under low oxygen concentrations. The incidence of decayed fruit after 2 weeks storage was 9% in the 10 ml O_2 l^{-1} treatment, compared with 33% and 35% in air and 70 ml O_2 l^{-1}, respectively. After 4 weeks, however, although decay was still much lower at 10 ml O_2 l^{-1} than in the other treatments, it was unacceptably high (about 30%) for practical purposes. Thus, although modified atmospheres with low oxygen concentrations may retard fruit ripening and decay, the length of useful storage does not appear to be longer than about two weeks at 10°C. This conclusion is supported by Banaras *et al*. (2005) who found the maximum storage life of MA-packed fruit at 8 and 20°C was approximately 17-21 days and 17 days respectively, compared with 10-14 days and 5 days for air-stored fruit at the corresponding temperatures. More recently, Srinivasa *et al.* (2006) suggested that an eco-friendly chitosan film was preferable to low-density polyethylene film not only because of its environmentally favourable properties, but also because fruit quality was retained over a longer period.

Other post-harvest treatments

Another possible method to improve bell pepper storage was proposed by Vicente *et al*. (2005), who found that the irradiation of fruit of cv. 'Zafiro' with UV-C light (7 kJm^{-2}) reduced decay during subsequent storage at 10°C. Treated fruit remained firmer, while sugar content was unaffected. When irradiated fruit were stored at 0°C for 15 or 22 days followed by 4 days at 20°C, the incidence and severity of chilling injury was reduced in comparison with the non-irradiated control. The photochemical treatment also reduced the amount of total phenols, the respiration rate and the percent electrolyte leakage. A further interesting alternative has been suggested by Wang (2006), who found that two naturally occurring volatiles (methyl jasmonate and methyl salicylate) will delay the onset of chilling injury and reduce the severity of symptoms in peppers and other chilling-sensitive fruit. According to this author, both volatiles enhance the resistance of tissues to chilling injury by increasing the gene expression of heat shock proteins, pathogenesis-related proteins and the mitochondrial alternative oxidase. In addition, methyl jasmonate was shown to increase the antioxidant and free-radical scavenging capacity of fruit tissues suggesting that it reduced chilling injury by protecting tissues from free radical injury.

Tomato

Storage conditions

Tomatoes are consumed at various stages from mature green to full red and the post-harvest technology that has evolved within the tomato industry varies considerably according to the demands of consumers and processors, the location of production in relation to market and the levels of technological development within the region of production and consumption. Like pepper and eggplant, tomato is subject to chilling injury, which therefore limits the level to which temperature may be reduced during storage. In tomato, the degree of sensitivity to chilling depends on the stage of ripening and recommended storage conditions are approximately 13-15°C at the pre-climacteric stage (mature-green, turning), and 8-10°C or less after the climacteric peak (rose, full red). At all stages of ripeness, RH must be high (90-95%) to restrict water loss (Ryall and Lipton 1979).

Post-harvest processes during tomato handling and marketing were outlined by Saltveit (2005), while research on various post-harvest treatments and storage conditions were reviewed by Passam *et al.* (2007). Some more recent research activities are described below.

Post-harvest treatments

Because tomatoes ripened naturally on the vine possess better quality, both on a sensorial and a compositional basis, attempts have been made to extend their shelf life. For example, treatment of post-climacteric fruit with 1-MCP reduced the rate of softening and change of red colour without affecting the soluble solids content (Rinaldi *et al.* 2007). In other experiments, light red cherry tomatoes were subjected to hot water treatment (54°C for 5 minutes) prior to enclosure in plastic film to create a modified atmosphere during storage at 5-7°C. After 28 days storage, the combined hot water and modified atmosphere treatment resulted in higher fruit quality than that which was either not subjected to heat or not enclosed in plastic. The authors attributed this to the beneficial effect of hot water against chilling injury and pathogen activity, as well as to a delay in the ripening processes (Akbudak *et al.* 2007).

Exposure of full-ripe tomatoes to low levels of ozone prior to storage at 13°C was found to increase the consumer acceptability of fruit based on visual and sensory evaluation. Fruit firmness and soluble sugar content was retained better in ozone-treated fruit than in the untreated control, whereas the concentrations of antioxidants, vitamin C and phenolics were not affected. Since ozone also possesses anti-microbial properties, the use of ozone enrichment was suggested as a potentially useful method for application to tomato storage (Tzortzakis *et al.* 2007). Alternatively, Mathew *et al.* (2007) recommended the exposure of tomatoes to low doses (1 and 2 kGy) of γ-irradiation, in conjunction with MA packaging, as a means of extending storage life and retaining fruit quality. More recently, Wang *et al.* (2008) proposed another non-chemical technique for tomatoes. These authors exposed mature green fruit to high electrostatic fields for 2 h at 20°C followed by storage at 13 ±_1°C and 85-90% RH for 30 days. The results of the experiments indicated that a negative electrostatic field of -2 kV cm^{-1} delayed the onset of the climacteric and the subsequent rate of fruit ripening.

The use of natural volatiles as an alternative to synthetic fungicides and other sanitation techniques for tomato storage was proposed by Tzortzakis and Economakis (2007). Fruit that were exposed to methyl jasmonate or ethanol and subsequently stored in air showed less decay than untreated fruit. Moreover, volatile-treated fruit tended to remain firmer, while the soluble sugar content of ethanol-treated fruit and the ascorbic acid content of methyl jasmonate-treated fruit were higher than that of the untreated controls. In experiments with other natural volatiles, the exposure of main crop and cherry tomatoes to eucalyptus or cinnamon oil showed a difference in response between the two tomato types. Thus, while the exposure of fruit of both types to oil vapours stimulated the levels of total soluble sugars during treatment, this result persisted only in the case of cherry tomato. Fruit that were treated with either oil vapour showed no differences in the subsequent rate of weight loss, sweetness, organic acid content or phenolics content (Tzortzakis 2007). From these two studies, and that of Wang (2006) with pepper, it appears that volatiles produced from natural oils are potentially valuable for commercial application to the storage of tomatoes, peppers and possibly other perishable commodities, although further research is required and, as pointed out by Tzortzakis (2007), their efficacy under commercial conditions has yet to be proved.

FRESH-CUT (MINIMALLY PROCESSED) PRODUCE

Minimally processed produce, such as fresh-cut salads, fruit salads and pre-prepared vegetables for rapid cooking, is occupying an increasingly important niche within the fresh fruit and vegetable market. This particularly applies to large urban communities, where modern lifestyles and the demand for speed and convenience of food preparation outweigh the extra cost incurred. Tomatoes and peppers are important components of many fresh-cut salads and other minimally processed produce whereas eggplants, which are only consumed after cooking, are not.

If storage and handling conditions are not optimal after processing, freshly cut produce will deteriorate rapidly, due to continued respiration, transpiration and the enzymatic activity of the living tissue. Consumers evaluate the quality of minimally processed products on the basis of visual parameters such as colour intensity and brightness (e.g. for peppers or tomatoes), the absence of discolouration (browning of cut surfaces or yellowing of green vegetables) and the overall presentation of the product.

Spoilage, modified atmospheres

A major change in the appearance of fresh-cut tomato during storage is the formation of translucent areas in the pericarp and shrinkage of the locular gel, while in some slices the columella may become water-soaked. Translucent slices are redder and darker than non-translucent slices at the same stage of maturity (Lana *et al.* 2006). In addition, spoilage may occur due to the proliferation of invasive microorganisms. Brown discolouration, due to oxidation and enzymatic activity of the cut surfaces, also constitutes an important quality defect of fresh-cut vegetables. Moreover, some defects in flavour or aroma may be induced by changes in the storage atmosphere within the package and/or by microbial activity. The severity of these defects largely depends on the duration of exposure to sub-optimal conditions (e.g. high levels of CO_2 or low levels of O_2) or to the extent of microbial activity.

Minimally processed products are usually stored under modified atmospheres at temperatures below 5°C. The CO_2 and O_2 concentrations within the package equilibrate in accordance with the respiration rate of the produce and the gas permeability of the package cover. Conesa *et al.* (2007) studied the effect of high CO_2 and O_2 on the microbial activity and sensory quality of fresh-cut pepper cubes from two bell pepper cultivars ('Meteor' and 'Requena'). The growth of spoilage microorganisms was significantly reduced in atmospheres containing a high concentration of O_2 and CO_2 (50 kPa O_2, 15 kPa CO_2, 35 kPa N_2 or 80 kPa O_2, 15 kPa CO_2, 5 kPa N_2), compared with that in air. A high level of CO_2 was essential for this result, since high O_2 in the absence of high CO_2 failed to inhibit microbial growth. Although differences in the organic acid content and some other quality attributes of the cubes were observed between the initial and stored fresh-cut product, the overall sensory quality of both pepper cultivars was reported to be retained under high CO_2 and O_2 for 9-10 days storage at 5°C. The beneficial effect of high CO_2 levels was also reported by Amodio *et al.* (2003), who stored minimally processed pepper slices at 5°C in air, 30% CO_2 in N_2 or 5% O_2 + 25% CO_2 in N_2 and found that the produce stored under high CO_2 levels showed a lower rate of increase of mesophilic and pshychrotrophic bacteria, better appearance and texture than that stored in air.

Chilling injury and senescence

Because low temperatures are used for storage, peppers and tomatoes, which are both susceptible to low-temperature (chilling) injury, may present chilling symptoms, such as softening. Chilling has also been indicated to cause the development of translucent, water soaked areas in fresh-cut fruit, particularly the pericarp tissues, although as noted below this hypothesis may require revision (see Lana *et al.* 2006). Sensitivity to chilling injury may relate to the gas permeability of the package film and to the composition of the atmosphere within the package (Hong and Gross 2001). In other climacteric fruit, such as melon, it has been shown that the inhibition of ethylene synthesis through the expression of an antisense ACO cDNA, results in increased resistance to chilling injury. However, when such fruit were treated with ethylene prior to cold storage, the sensitivity to chilling injury was restored. The deleterious effect of ethylene on chilling appeared to be associated with a reduction in the activity of free radical scavenging enzymes (Ben Amor *et al.* 1999). In fresh-cut tomato, however, ethylene removal from the storage atmosphere increases the sensitivity to chilling (Hong and Gross 2001). Thus, chilling injury of fresh-cut slices of two tomato cultivars ('Mountain Pride' and 'Sunbeam') was higher in perforated packages than in those with no perforations. Moreover, when ethylene absorbent pads were included in the sealed package, the percent chilling injury was higher than in containers without pads. Chilling injury was also higher in slices treated with 1-aminoethoxyvinylglycine (AVG), aimed at inhibiting ethylene synthesis, than in untreated slices (Hong and Gross 2000). Cultivation conditions that promote the synthesis of ethylene by tomato slices appear to confer a resistance to chilling injury (Hong *et al.* 2000), although more recently it has been suggested that the water-soaked symptoms considered to be so characteristic of chilling injury are in fact an ethylene-mediated symptom of senescence (Jeong *et al.* 2004). Moreover, Lana *et al.* (2006) reported that translucency developed in fruit slices at non-chilling temperatures (e.g. 12-13°C), but not in intact fruit stored at 5°C. These authors also found that slices from mature fruit were more prone to translucency than those from less mature fruit, whereas fruit are more sensitive to chilling sensitivity prior to ripening. It therefore appears that translucency, or the formation of water soaked tissue, is not primarily a product of chilling injury as previously thought.

Vitamins and antioxidants

The maintenance of quality of minimally processed, fresh-cut, products also implies the retention of beneficial fruit components, such as vitamins and antioxidants, during processing and marketing. Aguayo *et al*. (2004) stored tomato slices or wedges in passive and active modified atmospheres (3 kPa O_2 + 0 kPa CO_2 and 3 kPa O_2 + 4 kPa CO_2) at 0 and 5°C. After 7 days, the tomato pieces stored at 0°C had a better aroma, appearance and overall quality than those stored at 5°C, without differences between the MA treatments. After 14 days, only the MA treated product at 0°C exhibited good flavour, texture and quality, whereas at 5°C the quality of the tomato pieces in all the treatments was poor. Although the main factors influencing quality were the temperature and duration of storage, better overall quality was recorded in slices than in wedges, and an adherent placenta and optimal maturity stage at harvest were also considered important. In further experiments, fresh cut tomatoes of six cultivars were stored in a modified atmosphere (5% O_2+5% CO_2) at 4°C (Odriozola-Serrano *et al.* 2008). It was found that processing did not affect the concentration of lycopene, vitamin C or phenolic compounds. Moreover, the colour (lycopene) and vitamin C content were maintained over a storage period of 3 weeks, indicating that under these conditions the antioxidant capacity, and therefore the health value, of the product did not decline. According to Lana and Tijskens (2006), the major factor determining the levels of antioxidants in fresh-cut tomatoes during storage is the initial concentration at the time of harvest: the riper the fruit the higher the antioxidant activity.

Fluctuations in temperature and storage atmosphere

A problem inherent to the preparation and distribution of minimally processed produce, beyond that of the relatively short shelf life of the produce, is the fluctuation in temperatures that occur at the various stages within the distribution chain. Low temperatures must be maintained during product preparation, but during distribution temperatures may fluctuate within the refrigerated vans and during transfer from and to the vans. In addition, the refrigerated units used for product display within the retail stores may not control temperatures efficiently, as also may be the case for the domestic refrigerators of the consumers. Changes in temperature create problems in the establishment of a modified CO_2–O_2 equilibrium within the package because the respiration rate of the produce is affected more than the gas permeability of the plastic film used for packaging. Hence a film that produces a favourable atmosphere at a designated temperature for a particular product may cause undesirable CO_2 accumulation and/or O_2 depletion at a higher temperature due to increased respiration, resulting in the development of off-flavours, a loss of aroma, the development of foreign odours as well as increased microbial activity and growth. In contrast, when the same package is subjected to lower than optimum temperatures, the respiration rate is reduced and O_2 may accumulate, so that the modified atmosphere becomes less effective. Jacxsens *et al.* (2002) investigated the microbial and sensory quality of chopped bell peppers in packages with an equilibrium modified atmosphere under temperature fluctuations within a simulated cold distribution chain. Storage temperature control was shown to be of the utmost importance for the sensory quality and microbial safety of the produce, while changes in the gas composition of the package atmosphere could be predicted by an integrated mathematical system developed earlier by these authors.

Control of microbial activity

The control of microbial activity is the most important single factor for the development of minimally processed vegetable produce, and considerable work has been reported on microbial growth and methods to ensure consumer safety. Although this falls largely outside the scope of the present review, the possibility of using naturally occurring compounds in conjunction with physical methods (MA, low temperatures) is of particular interest. Recently, for example, it has been reported that treatment of fresh-sliced tomatoes with natural volatiles, such as methyl jasmonate, ethanol, their combination, tea tree oil and garlic oil, followed by storage at 5°C for 15 days resulted in an extension of the shelf life. Treatment with methyl jasmonate combined with ethanol was more effective in suppressing microbial proliferation than the individual treatments with each natural volatile compound. Moreover, this treatment preserved the colour and firmness attributes of the slices better than the other treatments, whereas slices that had been treated with methyl jasmonate maintained higher concentrations of lycopene, ascorbic acid and phenolic compounds than the other treatments (Ayala-Zavala *et al.* 2008).

The exposure of fresh-cut tomatoes to ozone-enriched air has been proposed as a means of reducing microbial growth. Ozone (0.7 $\mu l\ l^{-1}$) was found to be more effective against bacteria than fungi, without causing damage or off-flavours (Aguayo *et al.* 2006). However, although hydrogen peroxide treatment also reduced microbial populations on tomato slices stored at 10°C for 7 days, antioxidant and carotenoid content were adversely affected (Kim *et al.* 2007). Exposure of green bell peppers to chlorine dioxide (ClO_2) reduced the occurrence of decay during storage at 10°C for 40 days, the optimum concentration being 50 mg l^{-1}. At this concentration, ClO_2 also inhibited the rate of respiration, but promoted chlorophyll degradation, whereas the vitamin C concentration, titratable acidity and total soluble solids were unaffected (Du *et al.* 2007).

Treatments to increase firmness

The vacuum infiltration of pericarp discs with 50 mM $CaCl_2$ increased their firmness. However, this increase in firmness was retained throughout subsequent storage at 2°C for 5 days only in the case of turning and ripe fruit, but not in mature green fruit. The pH of the buffer medium used to incubate discs for 4 hours after vacuum infiltration and prior to storage at 2°C also affected tissue firmness. For example, discs that had been incubated in buffer at pH 7.0 were 23% (turning stage) and 38% (ripe stage) firmer than corresponding fruit discs incubated at pH 4.5, and this increase in firmness was retained throughout subsequent storage. The firmness of mature green fruit, on the other hand, was not affected by pH (Pinheiro and Almeida 2008). Heat treatment (35°C for 6 hours) of fresh-cut tomatoes prior to storage at 2°C in air or MA (2.5% O_2 and 5% CO_2) for six or twelve days had a positive effect on seed discoloration, while the total soluble solids and ascorbic acid content were higher than in untreated slices. However, weight loss and electrolyte leakage were higher, the titratable acidity decreased, and quality declined with the length of storage, especially in the air stored fruit (Hakim *et al.* 2002).

CONCLUSION AND FUTURE PERSPECTIVES

Today, the demand for quality is the overriding factor in the production and post-harvest handling and presentation of fresh vegetables, such as tomato, pepper and eggplant, as well as fresh-cut (minimally processed) products. It is natural, therefore, that a major research input continues to be made to improve and maintain quality throughout the post-harvest period. Furthermore, physiological factors relating to fruit quality (e.g. the role of ethylene, respiration, water loss, chilling injury, fruit constituents) form a major research interest.

Within the Solanaceae, research has concentrated principally on tomato and to a lesser extent pepper and eggplant. Thus over the period 2006-present, the relative publication incidence for each of these three species is approximately 74% (tomato), 22% (pepper) and only 4% (eggplant), reflecting their relative importance worldwide. However, since certain post-harvest aspects of tomato formed the subject of a recent review (Passam *et al.* 2007), the present review has placed rather more emphasis on peppers and eggplants.

Because of the increasing awareness of the health value of antioxidants in fresh produce, it is expected that research will continue to focus on antioxidant levels in tomato, pepper and eggplant, as well as the metabolic role of antioxidants (e.g. lycopene) within the body. However, the more these substances are indicated to protect against chronic diseases, the more likely it is that synthetic forms will be prepared and promoted (e.g. lycopene capsules). Studies of the effects of environmental stress on fruit quality are increasingly important in view of the changing climatic conditions on Earth. In the Mediterranean region, for example, crops are frequently subjected to stress from drought, high light intensity and salinity.

Other areas that are worthy of further research include the use of biodegradable materials for packaging, the use of non-destructive techniques for quality assessment, and the use of natural products (e.g. volatiles) for the maintenance of produce quality. Because of the expanding market for fresh-cut (minimally processed) products, research into methods for quality assessment and maintenance is likely to increase.

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