Original article

Physiological and quality changes during postharvest ripening of purple passion fruit (*Passiflora edulis* Sims)

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Physiological and quality changes during postharvest ripening of purple passion fruit (*Passiflora edulis* Sims).

Abstract – Introduction. Postharvest physiology and ripening in passion fruit are not well documented, which is an impediment in designing handling and storage regimes. **Materials and methods**. Passion fruits harvested at four different maturity stages were studied for postharvest ripening behaviour and to determine the correct stage of harvesting. **Results and discussion**. The respiratory climacteric peak was attained in all stages irrespective of harvest maturity, while the ethylene evolution rate increased by almost 8.15 times the initial value to peak levels of 505.35 µL $C_2H_4 \cdot kg^{-1} \cdot h^{-1}$ in fruits harvested at the 50% colour turning stage. Changes in Hunter *L*a*b** values indicated development of optimum colour only in fruits harvested after 50% colour turning. Fruit quality attributes were also better in fruits harvested after half (50%) colour turning than fruits harvested earlier. **Conclusion**. Passion fruit should be harvested only after 50% of fruit surface colour has developed, so as to allow for optimum postharvest storage, proper ripening, and development of characteristic flavour and fruit quality attributes.

Passiflora edulis **/ passion fruits / fruits / postharvest ripening / maturity / quality**

Changements physiologiques et qualité après-récolte durant la maturation du fruit de la grenadille (*Passiflora edulis* Sims).

Résumé – Introduction. La physiologie après récolte et la maturation des fruits de la grenadille n'est pas bien documentée, ce qui gène la mise au point des techniques de conservation. **Matériel et méthodes**. Des grenadilles récoltées à quatre stades de maturité différents ont été étudiés vis-à-vis de leur maturation après-récolte afin de déterminer le bon stade de récolte. **Résultats et discussion**. Pour tous les stades maturité considérés, le pic respiratoire climatérique a été atteint quelle que soit la maturité du fruit à la récolte, tandis que, au cours du stockage, le taux de dégagement d'éthylène a augmenté de près de 8 fois par rapport à son taux de départ, jusqu'à une concentration maximale de 505.35 µL $C_2H_4 \cdot kg^{-1} \cdot h^{-1}$ dans les fruits récoltés au stade à 50 % de coloration. Les variations des valeurs de Hunter *L* a* b** indiquent un développement de couleur optimum dans les seuls fruits récoltés après le virage de coloration de 50 %. Les attributs de qualité des grenadilles ont été également meilleurs dans les fruits récoltés à 50 % de coloration que dans les fruits récoltés à un stade antérieur. **Conclusion**. Les grenadilles ne devraient être récoltées qu'après avoir développé une coloration de surface de 50 % afin de permettre une conservation optimale en stockage, une maturation adéquate et le développement de l'arôme caractéristique et des attributs de qualité de fruits.

Passiflora edulis **/ grenadille / fruits / maturation après récolte / maturité / qualité**

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1. Introduction

Passion fruit (*Passiflora edulis* Sims) is popularly grown in the tropics and sub-tropics, and valued for its captivating flavour, nutritional benefits and medicinal properties [1]. It is reported to have been widely used in folk medicine to treat anxiety, asthma, bronchitis, urinary infection, diabetes, etc. [2]. The economic potential of passion fruit has been felt in India, where there has been continuous increase in its area and production [3]. In addition, passion fruit has positioned itself in a preferential place within the international market due to high demand in European countries[1].

Our knowledge on the postharvest ripening behaviour of passion fruit is limited and fragmented, and passion fruit still remains a minor underutilised fruit crop. A few studies [4–6] have established the fruit to be climacteric in nature with very high ethylene evolution after harvest [7]. Contrasting reports suggest that the climacteric rise in passion fruit occurs while the fruit is still attached to the plant [8]. Interestingly, in Brazil, where passion fruit is commercially produced, growers are recommended to harvest or collect the fruits when they naturally abscise and drop from the vine. The harvested fruits are thus likely to be in a post-climacteric stage [9]. On the other hand, there is development of an unripe flavour in fruits that are harvested before proper maturity [10]. Harvesting at the right stage of maturity is therefore one of the most important factors that determine postharvest quality [11].

To our knowledge, there is still no concrete study on the effect of fruit maturation on ripening potential in passion fruit. Our study was therefore conducted to study the postharvest ripening behaviour of passion fruit harvested at different maturity stages. Physiological and fruit quality changes during postharvest ripening of purple passion fruit are presented. They will provide baseline information to assist in development of postharvest management protocols for passion fruit.

[1] Centre for the promotion of imports from developing countries CBI (2012) Fresh exotic fruits: promising EU export markets, http://www.cbi.eu/marketinfo/cbi/docs/fresh_exotic_fruit_promising_eu_export_markets.

2. Materials and methods

2.1. Fruit material

The passion fruits studied were sourced from a private grower in Mokokchung (lat. 26.33° N, long. 94.53° E, alt. 1325 m above sea level), Nagaland (India). The fruits were harvested at four different maturity stages, *viz.*, the physiologically mature stage (stage I), 25% colour turning (stage II), 50% colour turning (stage III), and 75% colour turning (stage IV). Harvesting was done in the early morning hours, and healthy, uniform-sized fruits were sorted out. The fruits were then air-transported to New Delhi. On arrival at the Division of Postharvest Technology, Indian Agricultural Research Institute, the fruits were pre-cooled and later stored in a ripening chamber at (20 ± 1) °C and 80–90% RH. The time gap between harvest and final storage did not exceed 24 h. The experiment was laid out in a completely randomised design, and included four maturity stages (factors) and three replications (each replicate contained five individual fruits). Physiological and fruit quality parameters were recorded at 5-day intervals for 30 days.

2.2. Physiological loss in weight and colour

An electronic weighing balance, with accuracy of 0.01 g, was used to measure the weight of fruits. The physiological loss in weight was calculated as the difference between the initial weight and the weight at the time of measurement, and expressed as a percentage (% of initial weight). Colour was determined using the Hunter colour difference meter (Miniscan XE PLUS model).

Calibration was done with black and white tiles, and verification of accuracy against standard tiles was performed before evaluation. Results were expressed as Hunter L^* a^* b^* values. L^* is the luminance or lightness component, which ranges from 0 to 100 (black to white), and parameters a^* (from green to red) and b^* (from blue to yellow) are the two chromatic components, which range from –120 to 120 [12]. The same fruits were used for weight loss and colour measurements until the termination of the experiment.

2.3. Respiration and ethylene evolution rate

The post-storage respiration and ethylene evolution measurements were recorded using a static headspace technique [13]. Five fruits from each replication were randomly selected and enclosed in a hermetically sealed container (1 L) with a twist-top lid fitted with a silicone rubber septum. After an hour of incubation at 25 °C, the headspace gas was sucked through a hypodermic hollow needle and the respiration rate was quantified by using an auto gas analyser (model: Checkmate 9900 O_2/CO_2, PBI Dansensor, Denmark). The respiration rate was expressed as mL $CO_2 \cdot kg^{-1} \cdot h^{-1}$. To determine the ethylene evolution rate, a volume of 1 mL of the headspace gas was withdrawn through the septum using a Hamilton gas-tight syringe and injected into a gas chromatograph (model: Hewlett Packard 5890, USA). The gas chromatograph had previously been calibrated using standard ethylene gas (EDT Research, London, UK), and was equipped with a flame ionisation detector (FID) and Porapak-N 80/100 mesh packed stainless steel column. Nitrogen was used as the carrier gas at a flow rate of 30 mL·min^{-1}, while the flow rates of the fuel gases, H_2 and air, were maintained at (30 and 300) mL·min^{-1}, respectively. The temperatures in the injector, column and detector were adjusted to (110, 60 and 275) °C, respectively. Results were expressed in microlitres of ethylene released per kg of fruit per hour (µL·kg^{-1}·h^{-1}).

2.4. Pulp yield

The fruit was weighed, cut and opened. The pulp was manually scooped out and weighed. Pulp yield was expressed as a percentage (%) of total fruit weight at the time of measurement. Thereafter, the pulp was sieved through a nylon cheesecloth, and the recovered juice was used for measurement of fruit quality parameters.

2.5. Fruit quality analysis

For determination of total soluble solids (TSS), one drop of the juice was used with a calibrated digital refractometer. Titratable acidity (TA) was determined by titrating 1 mL of fruit juice as the amount of 0.1 N NaOH needed to obtain a pH of 8.1 [14]; the results were expressed as grams of citric acid per 100 mL of fruit juice. Ascorbic acid (AA) in passion fruit was determined based on the reduction of 2, 6-dichlorophenol-indophenol by ascorbic acid, and results were expressed as mg·100 mL^{-1}. Total phenolics in passion fruit juice were determined by the method described by Singleton and Rossi [15] with slight modifications using Folin-Ciocalteu reagent. Gallic acid was used to prepare the standard calibration curve, and results were expressed as mg gallic acid equivalent (GAE)·100 mL^{-1} fruit juice. Total carotenoids were determined by extracting the pigments in acetone by macerating in a pestle-mortar, followed by separation of the extract using petroleum ether (60–80 °BP). After making up the volume to 100 mL with petroleum ether, absorbance was measured at 452 nm using a spectrophotometer. Results were expressed as mg·L^{-1}.

2.6. Statistical analysis

The data obtained for different parameters during the storage period were subjected to analysis of variation (ANOVA) with maturity stages and storage time as the sources of variation. The comparison among means was performed using the HSD Tukey test at a significance level of $P < 0.05$. All the analyses were performed using procedures of the

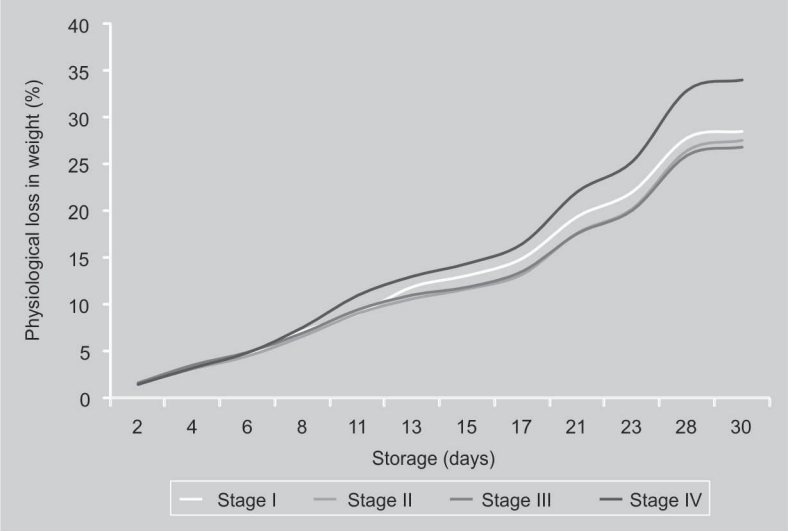

Figure 1.
Changes in the physiological loss in weight (%) during postharvest ripening of purple passion fruit at (20 ± 1) °C and 80–90% RH.

Statistical Analysis System (SAS Inst. Inc., Cary, NC, USA) [16].

3. Results and discussion

3.1. Physiological loss in weight

There was progressive increase in the loss of weight during postharvest storage of passion fruit. At the end of the 30-day storage, the physiological loss in weight ranged from 26.84% to 34.04% in the four stages, respectively (*figure 1*). These results are comparable with the findings of Schotsmans *et al.* [6] but are considerably lower than those observed by Singh *et al.*, who reported about 52.35% physiological loss in weight in passion fruit after 25 days of storage at 26.5 °C and 65.7% RH [17]. The lower temperature [(20 ± 1) °C] and higher humidity (80-90% RH) in our study must have led to the comparatively lower physiological loss in weight. Fruits harvested at stage III recorded lower physiological loss in weight towards the end of the storage period.

3.2. Colour changes during ripening

The results revealed significant differences among maturity stages, intervals and their interaction for colour changes in passion fruit. Even though passion fruit is a climacteric fruit, if the fruits are harvested at the green mature stage, the fruits do not develop an attractive purple colour and the pulp has an offensive woody flavour [5]. According to our results, fruits harvested at both stage I and stage II had negative a^* values at the start of storage (–4.43 and –1.3, respectively) (*figure 2*). At the end of the 30-day storage, these values had gradually increased to 3.57 and 3.84, thus indicating degradation of chlorophyll and synthesis of anthocyanin pigments. However, the most significant desirable change in colour was observed in fruits harvested at the 50% colour turning stage (stage III). The a^* value of 6.48 at the beginning of storage showed an increasing trend up to 15 days (12.02) and gradually decreased down to 6.62 by the 30th day. This decrease in the a^* value may be attributed to the degradation of anthocyanins at the later stage of ripening [4]. Interestingly, the fruits harvested at 75% colour turning (stage IV) showed a declining trend in the a^* value right from the commencement of storage (10.35) until the end of the storage period (4.66). This may indicate that the fruits at this stage were already in the post-climacteric stage at the time of harvest and thus the degradation process of anthocyanins had already started.

Progressive decline in L^* values of fruits (*figure 2*) harvested at all stages indicates the increase in blackness as the fruits turn from green to purple. Similarly, a steady decline in b^* values (*figure 2*) in stage-I fruits (26.86 to 14.40), as well as fruits in stage II (15.61 to 9.80), was noted during the ripening period. This was due to an increase in anthocyanin formation in the pericarp during ripening of the fruits. Stage-III fruits, on the other hand, initially showed a decrease in the b^* value up to 15 days (12.46 to 9.51), and thereafter, there was an increase in the value until the end of the storage period (13.23). This is in conformation with the trend observed in the case of the a^* value, whereby degradation of anthocyanins is responsible for decrease in the a^* value or increase in the b^* value during the later stage of fruit ripening. These results suggest that fruits harvested in stage IV are ideal for

immediate consumption or direct sales, whereas those in stage III would be suitable for storage up to 15 days, which would facilitate transportation to distant markets or export.

3.3. Changes in respiration rate during ripening

Data recorded with respect to the respiration rate (*figure 3*) depicted a pattern typical in climacteric fruits. In stages I and II, there was a decrease in the rate of respiration for the initial 5 days of storage, after which this rate increased; it attained peak levels at 20 days after storage, before declining further until the termination of the experiment. Stage-IV fruits showed a steep rise in respiration and the climacteric peak (147 mL·kg^{-1}·h^{-1}) was achieved after 10 days of storage. Thereafter, the respiration rate declined rapidly to 73.28 mL·kg^{-1}·h^{-1} by the end of the storage, which was comparable with those in stages I and II. An increase in the respiration rate was also observed in stage-III fruits although, initially, up to 10 days, the rate was lower than those recorded in stage-IV fruits. The peak rate (143 mL·kg^{-1}·h^{-1}) was recorded after 15 days of storage, after which a gradual decline in the rate of respiration was observed.

The respiration rates, ranging from (60.42 to 147) mL·kg^{-1}·h^{-1}, obtained in our study are similar to those reported by Pruthi [4] and Shiomi *et al.* [7], but comparatively higher than the 32.57–37.85 mL·kg^{-1}·h^{-1} reported by Schotsmans *et al.* [6]. The increase in respiration with the progress of storage depicts the heightened metabolic activity associated with ripening of passion fruit. As can be gauged from the data presented for ethylene production, it is evident that the steep rise in ethylene evolution is preceded by an increase in the rate of respiration, and vice versa.

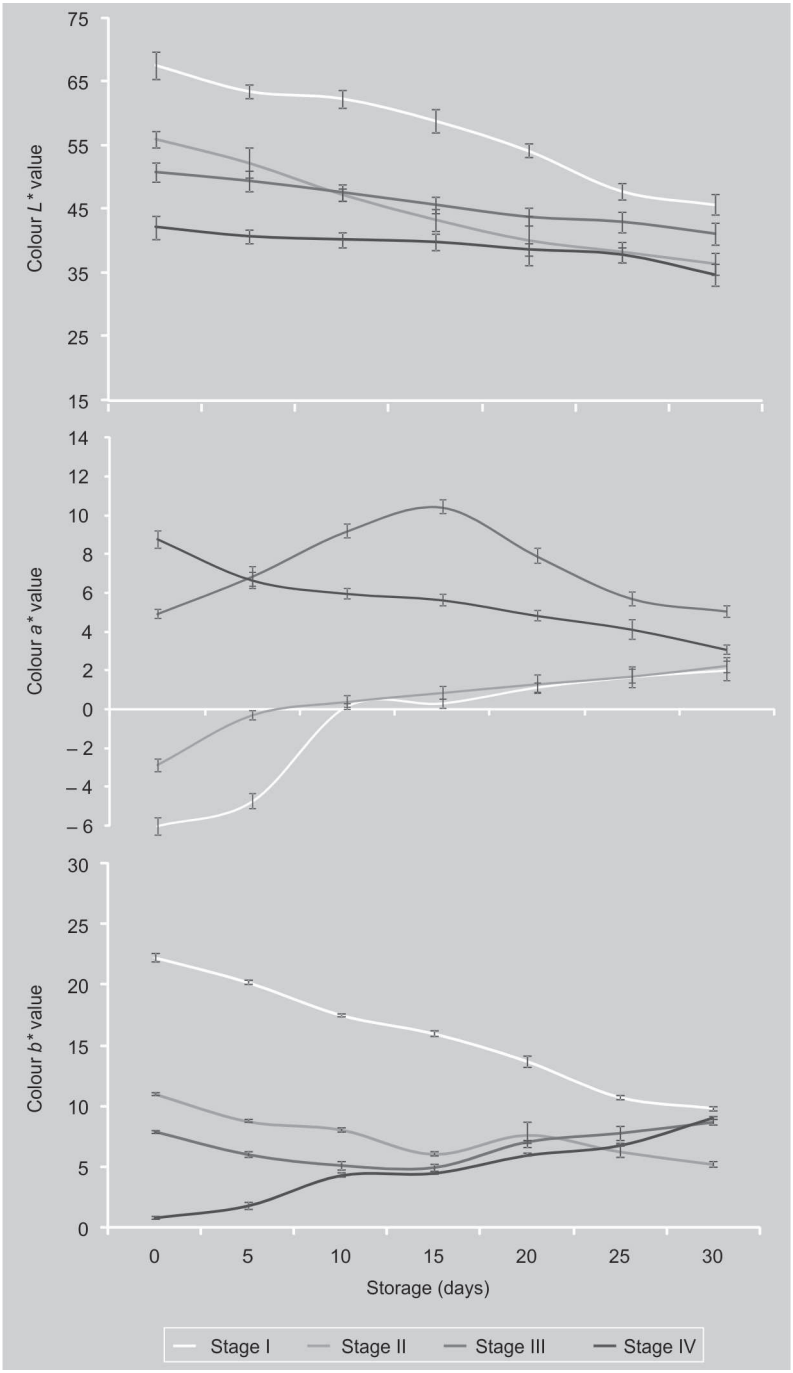

Figure 2.
Changes in the Hunter *L*a*b** values during postharvest ripening of purple passion fruit at (20 ± 1) °C and 80–90% RH. Vertical bars indicate ± standard error of the mean values.

3.4. Ethylene evolution rate during ripening

There was production of high amounts of ethylene during postharvest ripening of passion fruit. In all the four stages studied, an increase in the ethylene production was observed, though the amounts varied significantly among stages, as well as among the different storage times (*figure 4*). Fruits harvested at stage I produced the lowest amounts of ethylene from the beginning

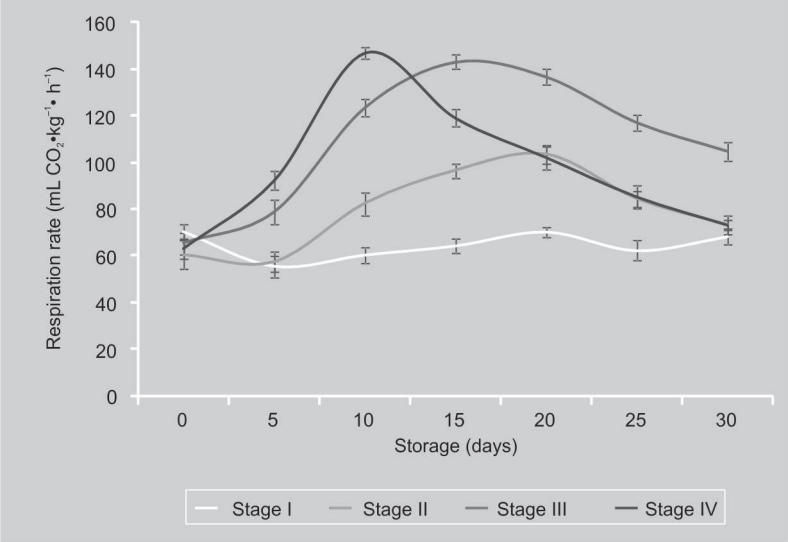

Figure 3.
Changes in the respiration rate during postharvest ripening of purple passion fruit at (20 ± 1) °C and 80–90% RH. Vertical bars indicate ± standard error of the mean values.

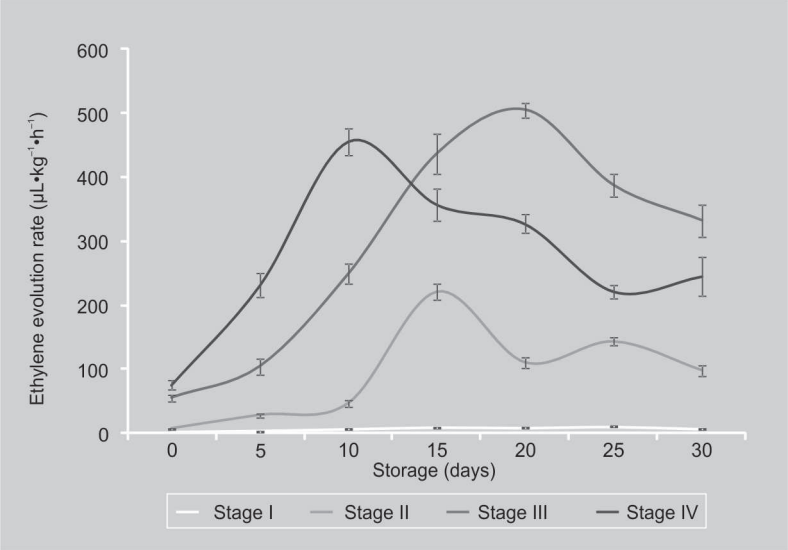

Figure 4.
Changes in the ethylene evolution rate during postharvest ripening of purple passion fruit at (20 ± 1) °C and 80–90% RH. Vertical bars indicate ± standard error of the mean values.

until the end of storage. In stage II the climacteric peak (221.26 µL C_2H_4·kg^{-1}·h^{-1}) was achieved after 15 days of storage and, thereafter, showed a decreasing trend in the ethylene evolution rate. A typical climacteric rise and fall in ethylene production was observed in stage-III fruits. From an initial rate of 55.24 µL C_2H_4·kg^{-1}·h^{-1}, it drastically increased to a high of 505.35 µL C_2H_4·kg^{-1}·h^{-1} after 20 days. It then decreased to 332.32 µL C_2H_4·kg^{-1}·h^{-1} at the termination of the experiment. Interestingly, fruits harvested at stage IV had the highest ethylene evolution rate (75.35 µL C_2H_4·kg^{-1}·h^{-1}) at the commencement of storage. The peak ethylene evolution rate (456.34 µL C_2H_4·kg^{-1}·h^{-1}) was observed after only 10 days in storage. This suggests that stage-IV fruits had already commenced ethylene biosynthesis when still attached to the vine, and achieved the climacteric peak way earlier than those in the other stages.

Our results are in conformity with the earlier findings of Shiomi *et al.* [7]. Attainment of a typical climacteric pattern and production of high amounts of ethylene in purple passion fruit, as observed in our study, was also recorded by Akamine *et al.* [18]. Fruit harvested at stage III showed an almost 815% increase in the rate of ethylene evolution from its initial value. The sudden burst in the rate of ethylene evolution with the progression of ripening in passion fruit has been attributed to the significant increase in expression of the ethylene biosynthetic genes *PE-ACS1* and *PE-ACO1* during ripening [19]. The ethylene evolution in passion fruit is comparable with that found in apples [20]. However, despite the high ethylene production even in fruits of stages I and II, concurrent development of desired flavour and colour changes was not noticed. This suggests that although the production and presence of ethylene results in its further biosynthesis, ethylene is not solely responsible for triggering ripening-related changes in passion fruit. Notwithstanding the high ethylene evolution rate recorded in passion fruits harvested at all stages, fruit maturity at harvest is the deciding factor for optimum development of flavour and desirable fruit quality changes [21].

3.5. Pulp yield

There was considerable variation in pulp yield among fruits harvested at different maturity stages (*figure 5*). The initial pulp yield was highest (44.35%) in fruits harvested at stage IV, while it was lowest (37.5%) in stage-I fruits. In stage I, there was an increase in pulp weight up to 15 days of

storage, after which a decrease was observed. However, in the remaining three stages the pulp yield increased up to 25 days before recording a decrease in pulp yield, thereafter, towards the end of the storage period. At that time the highest pulp yield was recorded in stage IV (58.75%), followed by stage II (58.45%). Statistical analysis revealed significant differences among maturity stages for pulp yield, while there were no significant differences among storage intervals.

Pulp recovery is an important quality attribute in passion fruit because it reflects directly on the edible economic part. It is interesting to note that, despite the loss in weight, there was an increase in the pulp yield with the progress of the storage period. This is attributed to the loss of moisture from the pericarp, a similar trend to which has also been reported [4, 6]. Thus, the edible part (pulp) remains intact despite an increase in physiological loss in weight, and shrivelling does not necessarily imply a decrease in the amount of the edible portion. The decrease in pulp yield towards the end of the storage period indicates the loss of moisture from the pulp. Schotsmans *et al.* observed a decrease in pulp yield after an initial increase for 19 days of storage [6]. A point of contention is whether a balance can be struck between weight loss and pulp yield, so as to ascertain the level to which weight loss or shrivelling in passion fruit can be tolerated. In the case of peach fruits the acceptable level of weight loss is 5% [22], above which the fruits show symptoms of shrivelling and wilting, and are liable to fetch a lower price in the market or even become unsalable in higher-end supermarkets. Schotsmans *et al.* did not find significant weight loss of the edible part of passion fruit even at 21% physiological loss in weight [6]. It has often been observed that locals in passion fruit-growing areas prefer shrivelled fruits for fresh consumption. This suggests a higher level of physiological loss in weight may be acceptable in passion fruit despite visible fruit shrivelling. However, currently we do not have enough reliable information to justify such a balance between weight loss and pulp yield. Besides, large variability in pulp yield was recorded by Pruthi [4] and Schotsmans *et al.* [6], as well as in our study.

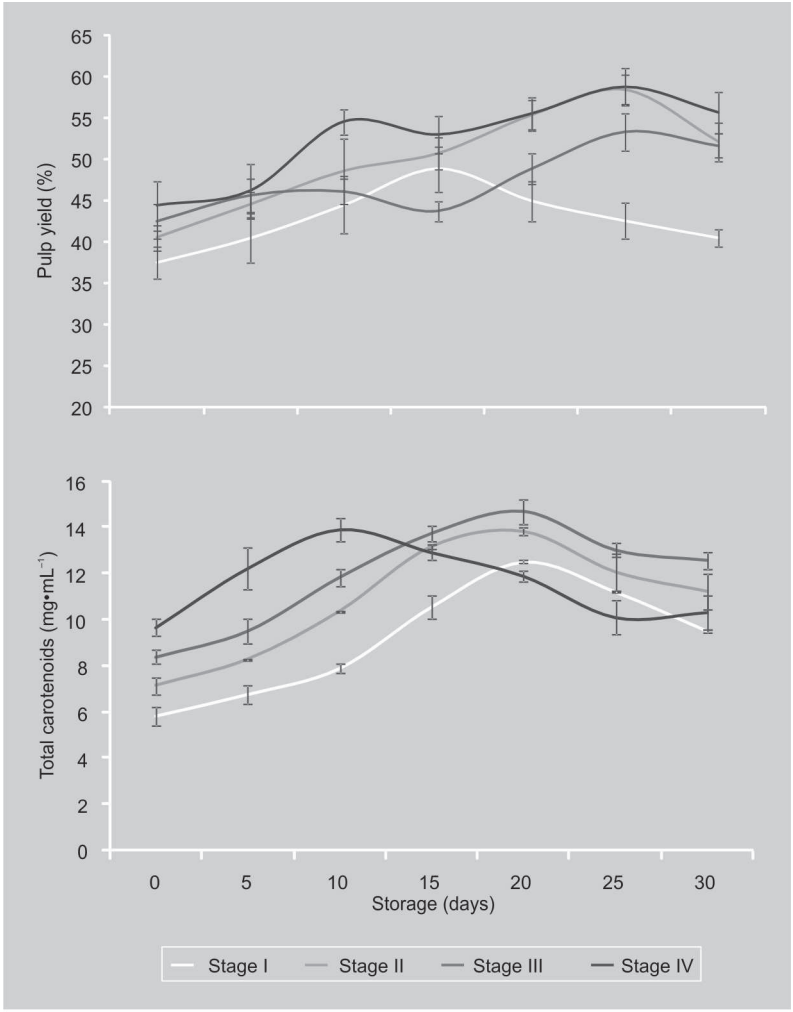

Figure 5.
Changes in the pulp yield and total carotenoids during postharvest ripening of purple passion fruit at (20 ± 1) °C and 80–90% RH. Vertical bars indicate ± standard error of the mean values.

3.6. Changes in fruit quality attributes during ripening

3.6.1. Total soluble solids

In all the stages, an increasing trend in total soluble solids was observed with progression of storage, which declined after attaining peak values (*table I*). Fruits in stages I and II, which recorded (8.80 and 9.85) °Brix at the start of the storage period, attained total soluble solids of (11.10 and 11.7) °Brix, respectively, after 20 days. On the other hand, fruits in stage III and stage IV had

Table I.
Changes in total soluble solids, titratable acidity, total phenolics and ascorbic acid during postharvest ripening of purple passion fruit at (20 ± 1) °C and 80–90% RH.

Soluble solids (ºBrix)

Storage period (d)	Maturity stages			
	Stage I	Stage II	Stage III	Stage IV
0	8.80 ± 0.25 aB	9.85 ± 0.13 aA	11.45 ± 0.35 bA	13.24 ± 0.61 cA
5	9.20 ± 0.06 aB	10.64 ± 0.09 aAB	13.27 ± 0.40 bAB	14.37 ± 0.69 bA
10	9.80 ± 0.20 aBC	11.32 ± 0.10 aAB	14.38 ± 0.43 bAB	16.10 ± 0.67 cA
15	10.70 ± 0.36 aCD	11.30 ± 0.06 aAB	15.25 ± 0.52 bB	15.45 ± 1.00 bA
20	11.10 ± 0.21 aD	11.70 ± 0.72 aB	16.20 ± 0.80 bB	14.21 ± 0.60 bA
25	9.80 ± 0.31 aBC	11.50 ± 0.51 abAB	15.40 ± 0.81 cB	13.26 ± 0.68 bcA
30	7.50 ± 0.29 aA	11.20 ± 0.20 bAB	13.24 ± 1.09 bAB	12.34 ± 1.12 bA

Titratable acidity (g citric acid·100 mL^{-1})

Storage period (d)	Maturity stages			
	Stage I	Stage II	Stage III	Stage IV
0	4.32 ± 0.04 cF	4.16 ± 0.06 cC	3.04 ± 0.06 bC	2.53 ± 0.06 aD
5	4.22 ± 0.05 dEF	4.00 ± 0.07 cC	2.91 ± 0.04 bBC	2.46 ± 0.04 aD
10	4.10 ± 0.07 dE	3.84 ± 0.06 cC	2.75 ± 0.07 bB	2.34 ± 0.05 aCD
15	3.78 ± 0.04 cD	3.36 ± 0.15 bB	2.40 ± 0.08 aA	2.21 ± 0.05 aBC
20	3.58 ± 0.05 dC	3.14 ± 0.05 cB	2.34 ± 0.08 bA	2.08 ± 0.05 aAB
25	3.36 ± 0.03 dB	2.62± 0.07 cA	2.30 ± 0.05 bA	1.95 ± 0.05 aA
30	3.17 ± 0.03 dA	2.53 ± 0.09 cA	1.98 ± 0.08 bA	1.89 ± 0.03 aA

Total phenolics (mg gallic acid equivalent·100 mL^{-1})

Storage period (d)	Maturity stages			
	Stage I	Stage II	Stage III	Stage IV
0	79.75 ± 2.25 abD	81.65 ± 2.11 abE	77.37 ± 2.89 aD	89.41 ± 2.97 bD
5	81.28 ± 3.03 aD	82.37 ± 2.44 aE	80.20 ± 2.28 aD	85.45 ± 2.28 aD
10	60.58 ± 3.32 aC	67.44 ± 3.55 aD	62.59 ± 2.27 aC	61.31 ± 1.74 aC
15	57.27 ± 2.41 aC	60.59 ± 2.73 aCD	62.35 ± 1.95 aC	59.49 ± 3.10 aC
20	50.33 ± 2.88 aBC	53.49 ± 1.74 aBC	57.53 ± 2.71 aBC	52.55 ± 1.69 aBC
25	43.52 ± 2.22 aAB	47.61 ± 2.37 aB	50.30 ± 2.24 aB	48.44 ± 2.33 aB
30	33.35 ± 2.80 aA	34.76 ± 0.70 aA	39.54 ± 1.73 aA	35.42 ± 1.05 aA
20	29.32 ± 3.26 aAB	28.56 ± 0.62 aAB	27.22 ± 1.29 aA	25.48 ± 1.24 aA

Table I.
Continued.

Ascorbic acid (mg·100 mL^{-1})

Storage period (d)	Maturity stages			
	Stage I	Stage II	Stage III	Stage IV
0	37.30 ± 1.10 aB	36.61 ± 2.13 aC	34.26 ± 1.73 aB	33.32 ± 1.73 aC
5	34.38 ± 0.73 aAB	34.76 ± 2.08 aBC	35.48 ± 1.71 aB	32.28 ± 1.15 aBC
10	31.40 ± 1.76 aAB	31.53 ± 1.74 aABC	29.42 ± 1.67 aAB	28.59 ± 1.82 aABC
15	29.84 ± 2.09 aAB	28.32 ± 1.13 aAB	29.47 ± 2.28 aAB	26.58 ± 0.66 aAB
20	29.32 ± 3.26 aAB	28.56 ± 0.62 aAB	27.22 ± 1.29 aA	25.48 ± 1.24 aA
25	28.17 ± 1.14 aA	28.16 ± 1.96 aAB	26.45 ± 0.67 aA	24.57 ± 1.78 aA
30	27.53 ± 1.24 aA	26.46 ± 1.60 aA	25.36 ± 1.04 aA	23.45 ± 1.33 aA

Values represent means ± standard error (n = 15; three replicates of five fruits per maturity stage).
a, b, c, d: in each table, mean values within the same storage time followed by the same letters are not significantly different ($P < 0.05$, HSD Tukey test);
A, B, C, D, E, F: in each table, mean values within the same maturity stage followed by the same letters are not significantly different ($P < 0.05$, HSD Tukey test).

initial total soluble solids values of (11.45 and 13.24) °Brix, respectively. The highest total soluble solids (16.2 °Brix) was recorded in stage-III fruits after 20 days of postharvest storage, while, in stage IV, it took 10 days of ripening to attain a high of 16.10 °Brix. The increase in total soluble solids was recorded to the amount of 41.4% in stage-III fruits, while the corresponding increase was 26.14% and 18.78% in stage-I and stage-II fruits, respectively. These results suggest that passion fruit harvested too early (stage I and stage II) does not develop optimum total soluble solids, even though a clear increase from initial values is recorded. Stage-III and stage-IV fruits, because of their significantly higher total soluble solids and lower titratable acidity content, maintain a desirable sugar-acid blend and result in better flavoured pulp. The levels of sugars and organic acids are already known to govern fruit flavour [23–25].

3.6.2. Total phenolics

Phenolics are responsible for the antioxidant activity of fruits. The total phenolic content in passion fruit ranged between a low of 33.35 mg gallic acid equivalent·100 mL^{-1} and a high of 89.41 mg gallic acid equivalent·100 mL^{-1} during the entire period of postharvest ripening (*table I*). In all the stages, a declining trend in the phenolic content was observed as ripening progressed. Fruits in stage IV recorded higher phenolics in the beginning but, after 15 days of storage, stage-III fruits showed a slower decline in the total phenolic content, and retained a higher level until the end of storage.

3.6.3. Total carotenoids

Carotenoids are widely regarded as effective quenchers of singlet oxygen, triplet oxygen and peroxy radicals [26]. In our study, the total carotenoids in purple passion fruit ranged from (5.81 to 14.67) mg·L^{-1} and their content increased during ripening up to 20 days in stage I, stage II and stage III. The highest carotenoids (14.67 mg·L^{-1}) were obtained after 20 days in stage-III fruits. Stage-IV fruits showed higher carotenoid content at the beginning (9.66 mg·L^{-1}) and up to 10 days of storage (13.90 mg·L^{-1}). In all the stages, there was decline in the carotenoid content after attainment of the peak

values. Pruthi also observed concurrent biosynthesis of carotenoids in the pulp along with the development of external purple colour (anthocyanin pigments) during ripening of passion fruit [4]. The decrease in carotenoids towards the later part of the storage period may be due to the degradation of carotenoid pigments. Oxidative protection of carotenoids by ascorbic acid has previously been reported [27]. The decline in the content of natural ascorbic acid during passion fruit ripening may, therefore, also have led to the degradation of carotenoids.

3.6.4. Titratable acidity

Titratable acidity declined during postharvest storage in all fruits harvested at different maturity stages (*table I*). Statistical analysis showed significant differences among maturity stages as well as intervals with regard to acidity. Fruits in stage I and stage II had (4.32 and 4.16) g citric acid·100 mL^{-1}, respectively, at the start, which gradually declined to (3.17 and 2.53) g citric acid·100 mL^{-1}, respectively, after 30 days of storage. The lowest acidity values were recorded in stage-III (1.98 g citric acid·100 mL^{-1}) and stage-IV (1.89 g citric acid·100 mL^{-1}) fruits. Though the percentage decline in acidity was similar in all fruits irrespective of maturity stage, the final retention was higher in stage-I and stage-II fruits. Since fruits harvested in stage I and stage II recorded significantly lower total soluble solids and higher acidity than those of stage-III and stage-IV fruits throughout the ripening period, this could probably explain the report of Campbell *et al.* of the development of unripe-woody flavour if fruits are harvested before proper maturity [10].

3.6.5. Ascorbic acid

The results obtained for the contents of ascorbic acid (*table I*) revealed that there was continuous decline in ascorbic acid content of passion fruit throughout the storage period. Fruits harvested in stage I contained the highest ascorbic acid content (37.30 mg·100 mL^{-1}) at the start of storage and retained a higher value than the other stages throughout the storage period. Contrastingly, stage-IV fruits showed the lowest ascorbic acid content among the different stages. Statistical analysis of the data revealed significant differences among different maturity stages for ascorbic acid content, whereas it was non-significant among storage intervals. The ascorbic acid available in passion fruit is thus much higher than in pineapple, pear, grape, mango, apple and plums, and comparable with that found in lemon, orange and grapefruit [28]. High intake of ascorbic acid and other antioxidant micronutrients has been linked to health promotion.

4. Conclusions

In conclusion, purple passion fruit exhibited a typical climacteric pattern during postharvest ripening. Respiration and ethylene production increased exponentially during ripening and attained climacteric peaks in all maturity stages. The ethylene evolution rate increased by about 8.15 times from the initial value in stage III. Also, optimum colour of passion fruit developed only in stage-III and stage-IV fruits. Notwithstanding loss in weight and fruit shrivelling, there was increase in pulp yield. This confirmed that fruit shrivelling was due to loss of moisture from the pericarp, while the edible portion remained unchanged in quantity. Thus, shrivelling in passion fruit does not necessarily mean loss of quality or quantity. Fruits harvested in stage III and stage IV maintained significantly higher total soluble solids and lower acidity than those in stage I and stage II, throughout the storage period. This explains the development of unripe-woody flavour in fruits harvested before proper maturity (stage I and stage II), as also reported by other authors. Also, fruit quality analysis revealed considerably high bioactive compounds such as phenolics, ascorbic acid and carotenoids in stage-III harvested fruits. We conclude that passion fruit should be harvested only after fruits have attained 50% colour turning (stage III). This would assist growers in scheduling harvest for distant markets or export, so that optimum fruit quality attributes may be developed by the time consumers procure them.

References

[1] Patel S.S., Morphology and pharmacology of *Passiflora edulis*: a review, J. Herb. Med. Toxicol. 3 (2009) 1–6.

[2] Zibadi S., Watson R.R., Passion fruit (*Passiflora edulis*): Composition, efficacy and safety, Evid.-based Integr. Med. 1 (2004) 183–187.

[3] Sema A., Maiti C.S., Passion fruit - Industry in North East India, in: Chadha K.L., Singh A.K., Patel V.B. (Eds.), Recent Initiatives in horticulture, Hortic. Soc. India, New-Delhi, India, 2008, 457–469.

[4] Pruthi J.S., Physiology, chemistry and technology of passion fruit, Adv. Food. Res. 12 (1963) 203–282.

[5] Shiomi S., Wamocho L.S., Agong S.G., Ripening characteristics of purple passion fruit on and off the vine, Postharvest Biol. Technol. 7 (1996) 161–170.

[6] Schotsmans W.C., Nicholson S.E., Pinnamaneni S., Mawson A.J., Quality changes of purple passion fruit (*Passiflora edulis*) during storage, Acta Hortic. 773 (2008) 239–244.

[7] Shiomi S., Kubo Y., Wamocho L.S., Koaze J., Nakamura R., Inaba A., Postharvest ripening and ethylene biosynthesis in purple passion fruit, Postharvest Biol. Technol. 8 (1996) 199–207.

[8] Biale J.B., Synthetic and degrading process in fruit ripening, in: Haard N.F., Salunkhe D.K. (Eds.), Postharvest Biology and Handling of Fruits and Vegetables, AVI Pub., Westport CT, U.S.A., 1975, 5–18.

[9] Matta F.B., Arjona H.E., Garner J.O., Silva J.L., Studies on postharvest quality of passion fruit, Miss. Agric. For. Exp. Stn. Bull. 1153 (2006).

[10] Campbell C.W., Knight R.J., Production de gandadilla, Minist. Agric. Pesca Alim., Canary Islands, Spain, 1983, 223–231.

[11] Patel P.R., Gol N.B., Ramana Rao T.V., Physiochemical changes in sunberry (*Physalis minima* L.) fruit during growth and ripening, Fruits 66 (2011) 37–46.

[12] León K., Mery D., Pedreschi F., León J., Color measurement in *L*a*b** units from RGB digital images, Food Res. Int. 39 (2006) 104–1091.

[13] Sharma S., Sharma R.R., Pal R.K., Jhalegar M.D., Singh J., Srivastav M., Dhiman M.R., Ethylene absorbents influence fruit firmness and activity of enzymes involved in fruit softening of Japanese plum (*Prunus salicina* Lindell) cv. Santa Rosa, Fruits 67 (2012) 257–266.

[14] Anon., Official methods of analysis, 17th ed., Assoc. Off. Anal. Chem. (AOAC), Gaithersburg, MD, U.S.A., 2000.

[15] Singleton V.L., Rossi J.A., Colorimetry of total phenolics with phosphomolybdic phosphotungstic acid reagents, Am. J. Vitic. Enol. 16 (1965) 144–158.

[16] Panse V.G., Sukhatme P.V., Statistical methods for agricultural workers, ICAR, New Delhi, India, 1984, 288–290.

[17] Singh A., Yadav D.S., Patel R.K., Nath A., Bhuyan M., Wax coating and padding materials influence quality and shelf-life of purple passion fruit during storage, Indian J. Hortic. 68 (2011) 246–249.

[18] Akamine E.K., Young R.E., Biale J.B., Respiration and ethylene production in the purple passion fruit, Proc. Am. Soc. Hortic. Sci. 69 (1957) 221–225.

[19] Mita S., Kawamura S., Yamawaki K., Nakamura K., Hyodo H., Differential expression of genes involved in the biosynthesis and perception of ethylene during ripening of passion fruit (*Passiflora edulis* Sims), Plant Cell Physiol. 39 (1998) 1209–1217.

[20] Apelbaum A., Burgoon A.C., Anderson J.D., Lieberman M., Polyamines inhibit biosynthesis of ethylene in higher plant tissue and fruit protoplasts, Plant Physiol. 68 (1981) 453–456.

[21] Kader A.A., Fruit maturity, ripening, and quality relationships, Acta Hortic. 485 (1999) 203–208.

[22] Crisosto C.H., Garner D., Andris H.L., Day K.R., Controlled delayed cooling extends peach market life, Hortic. Technol. 14 (2004) 99–104.

[23] Chen M., Jiang Q., Yen X., Lin Q., Chen J., Allen A.C., Xu C., Chen K., Effect of hot air treatment on organic acid- and sugar-metabolism in Ponkan (*Citrus reticulata*) fruit, Scientia Hortic. 147 (2012) 118–125.

[24] Kader A.A., Flavor quality of fruits and vegetables, J. Sci. Food Agric. 88 (2008) 1863–1868.

[25] Obenland D., Collin S., Mackey B., Sievert J., Fjeld K., Arpaia M.L., Determinants of flavor acceptability during the maturation of navel oranges, Postharvest Biol. Technol. 52 (2009) 156–163.

[26] Lowe G.M., Young A.J., Antioxidant and prooxidant properties of carotenoids, Arch. Biochem. Biophys. 385 (2001) 20–27.

[27] Biacs P.A., Daood H.G., Lipoxygenase-catalysed degradation of carotenoids from tomato in the presence of antioxidant vitamins, Biochem. Soc. Trans. 28 (2000) 839–845.

[28] Szeto Y.T., Tomlinson B., Benzie I.F.F., Total antioxidant and ascorbic acid content of fresh fruits and vegetables: implications for dietary planning and food preservation, Br. J. Nutr. 87 (2002) 55–59.

Cambios fisiológicos y calidad postcosecha durante la maduración del fruto de la granadilla (*Passiflora edulis* Sims).

Resumen – Introducción. Ni la fisiología postcosecha ni la maduración de los frutos de la granadilla están bien documentadas, lo que entorpece la elaboración de las técnicas de conservación. **Material y métodos**. En relación a su maduración postcosecha, se estudiaron granadillas cosechadas en cuatro estados de madurez diferentes, con el fin de determinar el mejor estado de cosecha. **Resultados y discusión**. El pico respiratorio climatérico se alcanzó en todos los estados de madurez considerados, independientemente de la madurez del fruto en el momento de la cosecha; mientras que, durante el almacenamiento, el índice de desprendimiento de etileno aumentó de cerca de 8 veces en relación a su índice inicial hasta alcanzar una concentración máxima de 505.35 µL $C2H4 \cdot kg^{-1} \cdot h^{-1}$ en los frutos cosechados en el estado del 50 % de coloración. Las variaciones de los valores de Hunter L* a* b* indican un óptimo desarrollo del color sólo en los frutos cosechados tras el cambio de coloración del 50 %. Los atributos cualitativos de las granadillas también fueron mejores en los frutos cosechados al 50 % de coloración que en aquéllos cosechadas en un estado anterior. **Conclusión**. Las granadillas deberían cosecharse únicamente después de haber desarrollado una coloración superficial del 50 % con el fin de ofrecer una óptima conservación durante el almacenamiento, una maduración adecuada y el desarrollo tanto del aroma característico como el de los atributos cualitativos del fruto.

***Passiflora edulis* / granadilla / frutas / maduración en postcosecha / madurez / calidad**