Evaluation of post-harvest performance of naranjilla (*Solanum quitoense* Lam.) fruits packed under modified atmosphere

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Evaluation of post-harvest performance of naranjilla (*Solanum quitoense* Lam.) fruits packed under modified atmosphere (MA).

Abstract — Introduction. Naranjilla is a native fruit of the Andes with an important local market and a potential for export on account of its attractive flavour and the green colour of the juice. Nevertheless, fruits harvested unripe in order to minimize mechanical damage during transport quickly reach their optimal state for consumption (6–8 d) when stored at ambient temperature (25 °C) resulting in a very short period for marketing. **Materials and methods**. Physicochemical characteristics of fruit between harvest and senescence were assessed during storage at 25 °C to determine the optimum stage for consumption. To evaluate simple handling systems for the storage of unripe fruit, a number of experiments were carried out under MA, using polyethylene bags of varying gas permeability, in the presence of an ethylene absorber under refrigeration conditions. **Results and discussion**. The climacteric behavior of naranjilla was studied, revealing a post-harvest increase respiration rate, reaching a peak of 28 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$. Fruit with physiological maturity can be maintained green during 9 d in good condition at ambient temperature in a sealed polyethylene bag of high gas permeability; 15 d if an ethylene absorber is added; 25 d if fruits are stored at 7.5 °C and 50 d if the three methods are combined. **Conclusion**. To increase shelf life of naranjilla, it is recommended that the fruit be packed in high permeability plastic film for local market, alternatively, refrigeration of 7.5 °C or addition of an ethylene absorber should be used if a longer storage period is required for foreign market. (© Elsevier, Paris)

Colombia / *Solanum quitoense* (fruit) / controlled atmosphere storage / keeping quality / respiratory metabolism

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Étude du comportement post-récolte de la naranjille (*Solanum quitoense* Lam.) emballée sous atmosphère modifiée (AM).

Résumé — Introduction. En raison de la couleur verte de son jus et de son arôme très parfumé, la naranjille, originaire de la région andine, dispose d'un marché local porteur et d'un marché potentiel pour l'exportation. Cependant, le fruit, cueilli vert pour supporter les pressions mécaniques imputables au transport, atteint très rapidement (6 d) son stade de maturité optimal lorsqu'il est stocké à température ambiante (25 °C), cela limite les possibilités de commercialisation. **Matériel et méthodes**. Afin de définir le stade optimal de maturité, les caractéristiques physico-chimiques du fruit stocké à 25 °C ont été suivies depuis sa récolte au stade vert jusqu'à sa sénescence. Pour définir des méthodes simples de conservation du fruit vert, des essais de stockage en AM ont été effectués en utilisant des sacs de polyéthylène de différentes perméabilités aux gaz, en présence d'un absorbeur d'éthylène, puis avec réfrigération. **Résultats et discussion**. Le comportement climactérique de la naranjille se traduit, immédiatement après la récolte, par un pic de respiration qui atteint 28 mg de $CO_2 \cdot kg^{-1} \cdot h^{-1}$. Le fruit ayant atteint la maturité physiologique peut être conservé vert, à 25 °C, pendant 9 d, dans un sac de polyéthylène scellé, très perméable aux gaz, 15 d si un absorbeur d'éthylène est ajouté, 25 d si les fruits sont stockés à 7,5 °C et 50 d si les trois méthodes sont combinées. **Conclusion**. Pour allonger la durée de conservation de la naranjille alimentant les marchés locaux, les fruits doivent être emballés sous un film plastique très perméable, et pour les marchés extérieurs, un absorbeur d'éthylène doit être ajouté ou, selon la durée de vie utile requise, les fruits doivent être réfrigérés à 7,5 °C. (© Elsevier, Paris)

Colombie / *Solanum quitoense* (fruit) / stockage en atmosphère modifiée / aptitude à la conservation / métabolisme respiratoire

1. introduction

Naranjilla or lulo (*Solanum quitoense* Lam.) is a native fruit tree of the Andes where it is cultivated and consumed principally in Ecuador, Colombia and Central America. Its bright green pulp yields a pleasantly flavoured juice which is of interest for tropical mix drinks. Volatile constituents of naranjilla fruit juice have been studied by several authors [1, 2] who found a large variety of fruity flavour components.

In Colombia, this fruit is usually cultivated in temperate climate, on the fertile, well-drained slopes of high valleys found at 1 500 m above sea level. Temperatures vary from 16 to 22 °C, and rainfall ranges from 1 500 to 2 500 mm·year^{-1}. Production areas are scattered and frequently located far from major markets; this factor, together with infrequent and inappropriate transport conditions, induces very high post-harvest losses that are estimated to be more than 60% [3]. Ripe fruits are highly susceptible to mechanical damage and fungal attacks, with the consequence that they must be marketed before they reach the optimal state for consumption. For these reasons, the fruit is usually harvested green but when the fruit diameter is at its maximum (> 4.5 cm) to ensure that they have reached their physiological maturity. At this stage, the fruit is more easily managed and marketing can take longer. Even so, at ambient temperatures (25–27 °C), the shelf life for the variety studied is only 6–8 d long after harvest – a relatively short period for marketing. For that reason, Dupaigne reports that, besides the commercial interests, exportation attempts to the USA or Europe have been a failure because of a too high volume of fruits rejected [4].

To delay ripening of fruits or conserve them in their pre-climacteric stage, modified atmosphere has been tested on a wide range of produce and successfully applied during transport [5]. Our study aimed to assess potential application of naturally generated modified atmosphere applied to the storage of tropical fruits such as naranjilla. Actually, there is a crucial need for growers in developing countries to use inexpensive appropriate post-harvest technologies that would extend the marketing period to obtain better economic yield on local market and, eventually, reach potential international market.

2. materials and methods

2.1. selecting fruits

Naranjilla fruits *(Solanum quitoense)* were sampled from the landrace "Lulo de Castilla" for its acceptability to local markets, obtaining fruits from Genova (department of Quindío, Colombia) and Neira (department of Caldas). Average temperatures of these districts vary between 15 and 20 °C and relative humidity between 75 and 85%. We harvested only the fruits that growers considered physiologically mature from their observation based on two main physical characteristics: the ovoid fruit average diameters which must be more than 4.5 cm for Castilla varieties grown in the Colombian highlands, and the facility to remove the brown fuzzy hairs on the skin. Fruits were harvested with disinfected pruning scissors, taking care to remove the peduncle which permits fungi to enter and attack the fruits from inside. The fruits were then washed with clean tap water and immersed for 5 min in a solution containing 3 ppm active ingredient of a fungicide (Thiabendazola). The fruit surface, which is slightly rough in texture, was gently air-dried with a fan. The fruits were then classified according to their diameter (fruits harvested by error with a lower diameter of 4.5 cm were rejected), their weight (more than 80 g), wholesomeness (no visible defects), and fully green colour. Colour is a good indicator of the stage of maturity. The entire surface of an unripe fruit is green; a "half ripe" fruit has less than 80% of its surface orange; and a completely ripe fruit is entirely orange.

2.2. quality evaluation

Juice composition was characterised, using completely orange fruits, that is, those that were in an optimal stage of maturity for consumption. Juice was extracted manually by carefully separating the pulp from the peel with a spoon. The pulp was then homogenised in a blender set at low speed, so not to break the white seeds. Gross materials and seeds were removed from the juice by filtration through a cheese cloth. The juice obtained was then frozen at –20 °C for later analysis. All chemical analysis were conducted according to methods agreed by AOAC [6].

Fruit diameter was measured at the equator, and firmness was assessed with an Effegi penetrometer. The highest puncture resistance of three tests at any point on the fruit equator, but on the less coloured surface, with a point of 8 mm head diameter (0.5 cm^2), was reported.

2.3. respiration curves

Fruit respiration was evaluated indirectly, using a closed system (*figure 1*) in which the level of carbon dioxide caught in a potassium hydroxide solution was measured. All the system was maintained in a chamber with control of temperature (T = 25 °C) and humidity (85%). Air was circulated in the system, using a suction pump, through a highly concentrated potassium hydroxide solution (at 1.0 N) to catch all carbon dioxide and provide the fruit with oxygen. Then, the CO_2 released during the fruit respiration was sucked through two weaker potassium hydroxide solutions (0.1 N and 0.5 N). Every 24 h, solutions were renewed and the CO_2 concentration in the solutions was assayed with 0.5 N HCl in the presence of phenolphthalein. Results were reported in mg of carbon dioxide released per hour by 1 kg of fruit.

2.4. storage experiments

To study the conservation of green, preclimacteric naranjilla fruits in a modified atmosphere, polyethylene bags with an utile volume of approximately 1 300 cm^3 and of different density were used (*table I*). In some experiments, a small sachet of ethylene absorber (Ethylene Control Inc., Selma, California, USA), composed of potassium permanganate impregnated on porous alumina, was introduced into the bags at the equivalent rate of 0.75 g of potassium permanganate per kg of fruit. A refrigerated chamber, with appropriate control of relative humidity and temperature, was also used. All tests were done with 400 to 450 g of fruit per bag corresponding to 4 to 5 fruits (0.30–0.35 kg of fruits per liter of bag), and the bags were thermally sealed.

For the determination of lowest safe storage temperature, fruits were stored at different temperature and at 85% relative humidity in a refrigerated chamber, with appropriate control of parameters (± 0.5 °C for temperature and ± 5% for relative humidity).

Before evaluating the fruit characteristics after storage, fruits were always left to ripen outside the bags in a well-ventilated chamber in which temperatures were maintained at 25 °C until fruits turned orange over more than 90% of their surface.

2.5. sensory evaluation

The sensory evaluation of juices prepared from stored fruits was performed by a taste panel of 23 untrained tasters. Using

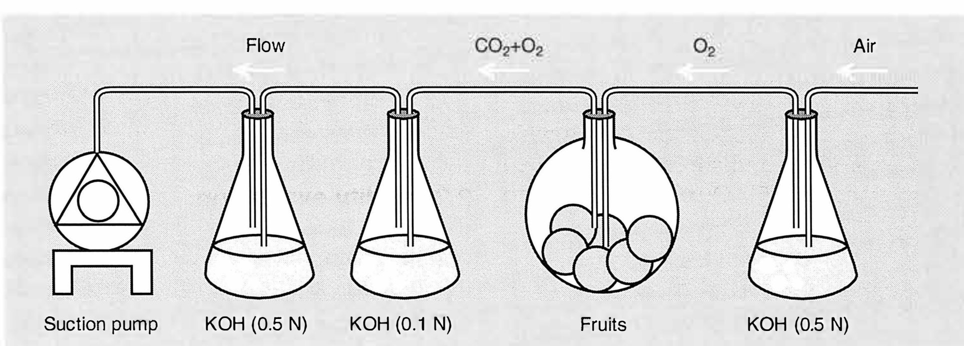

Figure 1.
Schematic representation of the closed system used to evaluate fruit respiration.

Table I.
Characteristics of low density polyethylene films (density 910–920 kg·m^{-3}) used to pack naranjilla fruits and to delay ripening of fruits according to data provided by manufacturer.

Polyethylene thickness (µm)	Permeability ($g \cdot m^{-2} \cdot bar^{-1} \cdot d^{-1}$)			Average selectivity O_2/CO_2
	Water vapour[1]	O_2[2]	CO_2[2]	
76	–	6.00 ± 2	3.92	1.53
40	8.70	8.70 ± 2	6.70	1.30
29	12.60	10.80 ± 1	14.00	0.77

[1] Permeability at 38 ± 2 °C with 90% relative humidity.
[2] Permeability at 30 ± 2 °C with 0% relative humidity.

the triangle method, the panellists were asked to distinguish between drinks containing juice from stored fruits and juice obtained from fresh fruits. To permit comparisons within the same sample, juice extracted from fresh fruits was frozen. Drinks were prepared with 150 mL of juice, 50 mL of water, and 22 g of refined sugar. We reported that no differences were detected between samples, at least at confidence level of 5%, when more than 14 tasters out of the 23 failed to distinguish the right sample.

3. results and discussion

3.1. changes during ripening

In Colombia, naranjilla fruit is usually harvested green to comply with transport requirements. Usually, when fruits are transported and stored at ambient temperature (25 °C), the optimal stage for consumption occurs 7 to 8 d after harvesting the green fruits. Like most other Solanaceae species, the post harvest system used for naranjilla fruits in Colombia proves that the fruit is climacteric. Once separated from the plant, green fruits begin a pre-climacteric crisis which can be observed by measuring the respiration rate (*figure 2*). When stored at 25 °C, with good ventilation, respiration begins to increase steadily from 15 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$, 2 d after harvest, to almost 28 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$ which is the peak reached 8 d after harvest. After reaching the peak respiration rate, the fruits begin to senesce. This curve pattern is typical of climacteric fruit, and respiration rate is very similar to that of tomato, even if it reaches a higher peak of 40 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$ during ripening in the same conditions [7]. During the pre-climacteric crisis, the chemical composition of the juice also changes: soluble solids (measured as ° Brix) increase while acidity decreases (*figure 3*). As a consequence, the correlation between the two parameters also increases, principally during the 2 d before reaching optimal maturity. This correlation between soluble solids and acidity represents a good ripening index by which to screen naranjilla fruits for optimal maturity. Results show that when this index is higher than 3, fruits are fully ripe and reach their optimum eating qualities.

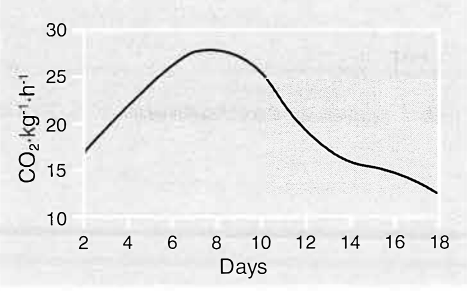

Figure 2.
Typical respiratory at 25 °C of naranjilla fruits (*Solanum quitoense*) after harvest.

Physical changes also occur during maturing at ambient temperature, the thick and leathery skin of the fruit soften to average puncture resistance of 26 kg·cm^{-2} loosing 50% of their firmness. Also colour of skin changes from green to light orange, then fruits are considered commercially in their optimal stage for consumption showing a bright green almost translucent and gelatinous pulp (*figure 4*) when they are cut longitudinally. At this point, fruits show specific physical characteristics (*table II*) and yield 71.5 ± 6% of a juice with good organoleptic characteristics and good nutritional properties, as shown by its chemical composition in *table III*. The characteristic fruity aroma is then strong, and the soft inner layer of the peel can be easily separated from the pulp.

3.2. storing unripe fruits in modified atmosphere

Once the typical climacteric behaviour of naranjilla fruits was confirmed, it was attempted to delay the beginning of the pre-climacteric crisis to maintain the fruit green and firm in order to better resist transport and storage. Wills [5] suggested that, by lowering oxygen supply, the beginning of the pre-climacteric crisis is considerably delayed. Modifying the atmosphere around the fruits is easily achieved with materials such as polyethylene films that restrict gas exchange between the fruits and outside atmosphere. The thickness and density of polyethylene bags are directly related to the permeability of the plastic film to certain gases such as water vapour, oxygen and carbon dioxide. For our purpose, only low density polyethylene films were used (density 910–920 kg·m^{-3}), but thickness of plastic films used to pack fruits were varied. These plastic films have different permeability to the main gases (*table I*).

After 3 and 5 d, fruits stored at 25 °C in bags with thickness of 76 µm and 40 µm, respectively, failed to ripen normally when exposed to a ventilated atmosphere (*table IV*), probably because of irreversible physiological disorders caused by anaerobic respiration. Permeability to oxygen and especially carbon dioxide is quite low for these films

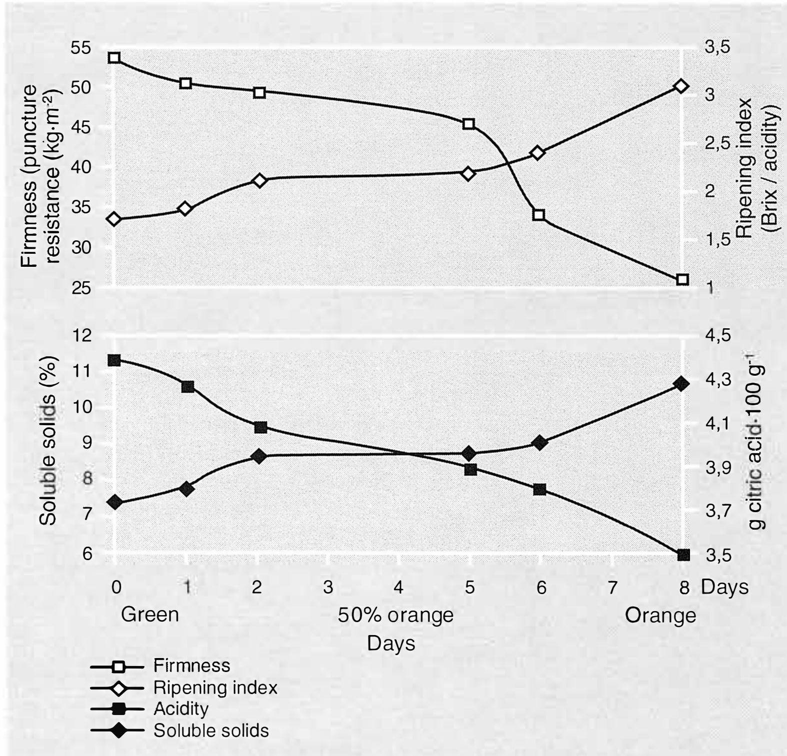

Figure 3.
Some physico-chemical changes that occur during the ripening of naranjilla left to ripen at 25 °C and 85% of relative humidity.

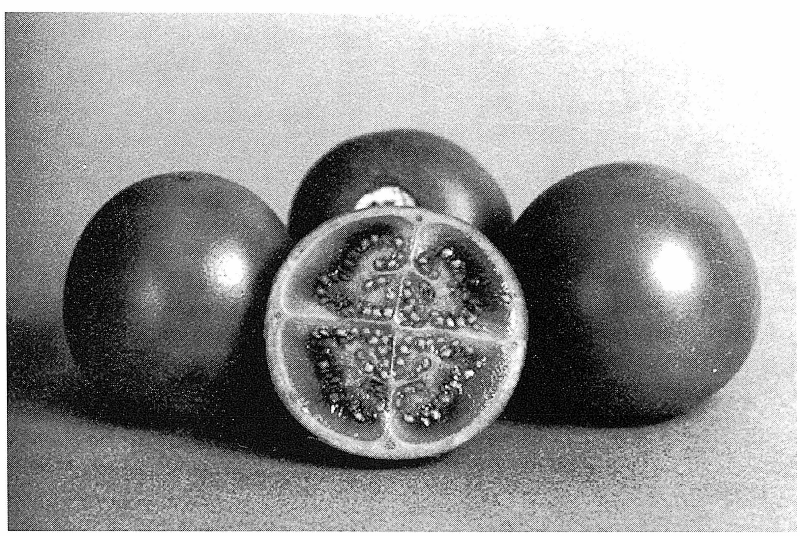

Figure 4.
Naranjilla fruits (*Solanum quitoense*, landrace Lulo de Castilla) at optimum stage of maturity (8 d after being harvested green).

Table II.
Physical characteristics of ripe naranjilla fruits, locally named lulo de Castilla (*Solanum quitoense*). Average of 25 fruits sorted at random.

Juice yield (%)	Weight (g)	Diameter at equator (cm)	Length (cm)	Firmness ($kg \cdot cm^{-2}$)
71.5 (6.0)	74.0 (6.8)	5.3 (0.5)	4.8 (0.5)	26 (1)

Values in parentheses refer to standard deviation.

and selectivity for both films (permeability of O_2 divided by permeability of CO_2) is higher than 1 (respectively 1.5 and 1.3) which induces an accumulation of carbon dioxide inside the bags. A too high concentration of carbon dioxide and lack of oxygen around the fruits produced a change in the metabolism [8]. These experiments were stopped after 3 and 5 d, because the green fruits turned slightly brown, showing necrosis of the skin, and started to exude liquid. When these fruits were stored outside the bags in the ventilated chamber, they kept their brown-green colour, did not ripen and were severely dehydrated, indicating that their tissues were dead. Apparently, the fruits suffered irreversible damage and they were not apt for consumption because of a strong fermented aroma.

Fruits stored for 9 d at 25 °C in polyethylene bags of 29 µm thickness could maintain their green colour and were able to enter climacteric crisis when taken out of the bags into a well-ventilated chamber. For this film, selectivity between oxygen and carbon dioxide is around 0.8 which induces inside the bags an atmosphere with relatively lower concentration of carbon dioxide without lack of oxygen.

After storage, the fruits were put to ripen and it can be observed that the climacteric crisis was accelerated as optimal maturity was reached by day 6 instead of day 8 for unstored fruits. Juices made with these fruits did not taste significantly different to juices made from unstored fruits.

After more than 9 d of storage in polyethylene bags of 29 µm thickness, at the

Table III.
Analysis of fresh juice from ripe naranjilla fruits locally named lulo de Castilla (*Solanum quitoense*).

a) Chemical composition of 100 g of juice.

Titrable acidity (g citric acid)	Fat (mg)	Proteins (mg)	Calcium (mg)	Phosphorus (mg)	Iron (mg)	Starch (iodine test)	Ash (g)
3.65 (0.1)	0.10.6	(0.1)	6.3	12.2	1.2	Negative	0.7

b) Sugar, pectin and vitamin C content.

Total solids ($g \cdot L^{-1}$)	Soluble solids (° Brix)	Total sugar ($g \cdot L^{-1}$)	Reducing sugars ($g \cdot L^{-1}$ glucose eq.)	Pectin ($g \cdot L^{-1}$)	Vitamin C (UI)
80 9.5 (0.5)	30 (2)	18 (1)	0.64	19 (1)	

c) Other characteristics.

Calories ($J \cdot 100 \cdot g^{-1}$)	pH ($kg \cdot m^{-3}$)	Density at 20 °C
102	3.1 (0.1)	1 030 (10)

Values in parentheses refer to standard deviation.

Table IV.
Performance of green but physiologically mature fruits of naranjilla (*Solanum quitoense*) when they are stored at 25 °C, in polyethylene bags of varying thickness.

Thickness of bag (µm)	Maximum number of days of storage	° Brix	Acidity (g citric acid·100 g^{-1})	Ripening index	pH	Results of organoleptic tests
76.0	3	7.8	3.6	2.2	2.9	Fruits did not ripen Fermented flavour
40.0	5	7.1	2.9	2.4	3.0	Fruits did not ripen Fermented flavour
29.0	9	8.4	3.4	2.5	3.0	Fruits ripened Juice flavour not significantly different from that of test juice
29.0 + ethylene absorber	15	9.3	3.5	2.6	3.0	Fruits ripened Juice flavour not significantly different from that of test juice

same temperature, some fruits started to turn orange, which was interpreted as the beginning of the pre-climacteric phase. Fruits kept in the bags during climacteric crisis turned orange more slowly and reached the optimum stage for consumption after 15 d of storage. Their juice did not taste significantly different from fresh juice. Modified atmosphere in thin polyethylene plastic films (29 µm) of low density allows to delay not only climacteric crisis, but ripening and senescence too. It proves that to slow down fruit metabolism without changing to anaerobic respiration, gas restriction must be relatively low and selectivity must induce inside bags the lowest concentration of carbon dioxide.

Placing an ethylene absorber in polyethylene bags of lower thickness considerably increased shelf life; the fruits could be maintained completely green in a pre-climacteric phase for 15 d. As in the previous experiment, fruits stored 15 d in polyethylene bags were left to ripen outside the bags in a ventilated chamber for 6 d. No significant differences were detected in the flavour of juices made with the stored fruits. If left for more than 15 d in the polyethylene bags with ethylene absorbers, some fruits started to turn orange and reach optimum maturity within 21 d of storage.

3.3. determination of the lowest safe storage temperature

The influence of temperature during storage was also evaluated. Naranjilla fruits suffer severe physiological injury at temperatures of 4 and 5 °C after 2 to 3 d of storage. Symptoms of chilling injury can be observed externally as skin turns partially brown and internally as fruits cut longitudinally show a soft and viscous placental intralocular tissue. Fruits stored in a well-ventilated chamber at 25 °C failed to ripen and pulp turned completely brown certainly due to the breakdown of cell compartmentation and the action of polyphenol oxidases. This physiological disorder is irreversible and a severe dehydration observed when fruits were put to ripen indicates that the tissues are dead.

When stored at 6 °C, the fruits do not present physiological disorders, even after 15 d. The fruits maintained their green colour and ripened in 4 d after exposure to a temperature of 25 °C, developing their characteristic flavour and colour. The threshold temperature for cold injury in naranjilla fruits was thus established as being 5 °C and the lowest safe storage temperature is 6 °C. We therefore recommend that storage temperature should be no less

Table V.
Physico-chemical changes occurring during ripening of naranjilla fruits harvested "green" and stored, at 7.5 °C, in low density polyethylene (29 µm thickness) containing an ethylene absorber.

Number of days of storage	Soluble solids ° Brix	Acidity (g citric acid.100 g-1)	pH	Ripening index	Weight loss %	Firmness loss %	Colour estimate
0	7.0	4.4	3.1	1.6	0.0	0	100 green
34	6.5	3.3	3.3	2.0	0.5	5	100 green
50	7.5	3.0	3.3	2.5	1.0	18	100 green

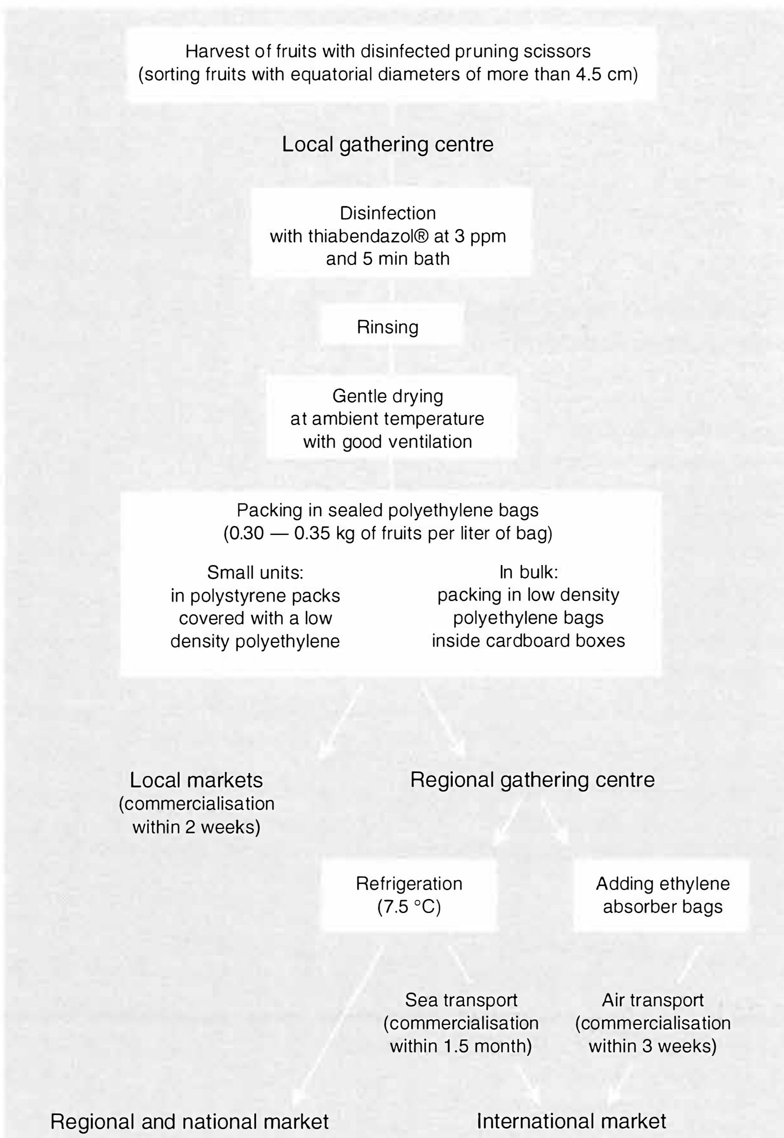

Figure 5.
Recommended post-harvest handling system for fruits of naranjilla (*Solanum quitoense*).

than 7.5 °C, taking into account the temperature fluctuations that can occur during marketing.

3.4. long term storage assay

To verify our recommendation, we stored fruits at 7.5 °C in low density 29 µm thick polyethylene bags containing an ethylene absorber. Under these conditions, fruits are maintained completely green and kept in their pre-climacteric state for 50 d (*table V*). Once exposed to a temperature of 25 °C in a ventilated chamber, the fruits ripened in 4 d. Juices made with these fruits tasted significantly different to juice made from fresh fruits. Sixteen tasters out of the 23 found the right sample but surprisingly, however, the juice made with stored fruits was considered better because of lower acidity. This finding was corroborated by biochemical analysis which showed that green fruits stored at 7.5 °C had decreased titrable acidity.

During storage after 50 d with ethylene control, the fruits weight was almost constant (weight loss reached only 1%) and fruits lost some firmness (18%).

4. conclusions

Naranjilla fruit is a climacteric fruit with a relatively low respiration rate even during the climacteric peak (28 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$). In its green stage, the fruit resists quite well to mechanical stress which allows its marketing in good conditions. On the basis of the results, easy post-harvest handling system for fruits of naranjilla can be implemented according to the target market (*figure 5*). For local markets, green naranjilla fruits should be packed in polystyrene packs covered with low density 29 μm thick polyethylene. For export market, green fruits can be packed in polyethylene bags inside carton boxes and stored for 15 d at 7.5°C. If refrigeration is not available or too expensive as it is the case for air transportation, inside polyethylene bags, an ethylene absorber can be included to prolong green shelf life until 21 d. If longer storage period is required, fruits packed inside polyethylene bags with an ethylene absorber and refrigerated at 7.5 °C should have a 50 d shelf life.

Low density polyethylene package are quite inexpensive and are affordable by most growers association in developing countries. Packed naranjilla fruits become less perishable, and better economic yield can be obtained as commercialisation can be done on markets distant in time and space.

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Estudio del comportamiento pos-cosecha de la naranjilla (*Solanum quitoense* Lam.) bajo atmósfera modificada (AM).

Resumen — Introducción. Debido al color verde del jugo y su atractivo aroma, la naranjilla es una fruta originaria de la región Andina que posee un mercado local importante y un mercado potencial para la exportación. Sin embargo, la fruta cosechada verde para soportar las presiones mecánicas durante el transporte, alcanza su estado optimo de madurez muy rápidamente (6 d) a temperatura ambiente (25 °C) lo que limita considerablemente su comercialización. **Material y métodos**. Se hizo un seguimiento físico-químico del fruto cosechado verde hasta su senecencia con el fin de definir el estado óptimo de consumo. Para estudiar métodos simples de conservación de la fruta en su estado pre-climatérico, se realizaron diferentes ensayos de almacenamiento en AM utilizando, bolsas de polietileno de diferentes permeabilidades a los gases, un absorbedor de etileno y refrigeración. **Resultados y discusión**. Se observo el comportamiento climatérico de la naranjilla inmediatamente después de la cosecha traducido por un aumento de la tasa de respiración hasta 28 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$. Las frutas con madurez fisiologica se lograron preservar verdes hasta 9 d a 25 °C empacadas en bolsas de polietileno muy permeables a los gases, 15 d adicionando un controlador de etileno, 25 d refrigerado a 7,5 °C y 50 d combinando los tres métodos. **Conclusión**. Para alargar la vida util de la naranjilla y abastecer el mercado local, se recomienda empacar los frutos bajo ún film plástico con alta permeabilidad y para los mercados de exportación, según la vida útil requerida se recomienda añadir un absorbedor de etileno o combinar este empaque con un transporte refrigerado a 7,5 °C. (© Elsevier, Paris)

Colombia / *Solanum quitoense* (fruta) / almacenamiento atmósfera controlada / aptitud para la conservación / metabolismo respiratorio