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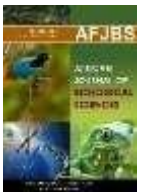

Long-term storage of tomatoes by regulating gas exchange using lemon

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Abstract

The shelf life of fresh tomatoes (climateric fruit) is short and this leads to post-harvest losses during periods of abundance. The aim of this study was to evaluate the effect of lemon (fruit not climateric) on tomato shelf life. To this end, healthy fruit of two tomato varieties (Cobra and Amiral) harvested at the mature green stage were conserved with lemons (0; 5; 10; 15 and 20) also harvested at the mature green stage in a split-plot design with four replicates. The number of tomatoes in each storage chamber was 20 fruits. During one month storage, the physical and biochemical parameters of the tomato fruits and the concentrations of CO_2, O_2 and C_2H_2 in the storage chambers were assessed and quantified respectively. The results show that Cobra fruits coupled with 5 lemons recorded the lowest loss rates in tomato number (20%) and mass (0.04%), and the highest lycopene (2.5 mg/100g), vitamin (14.3 mg/100g), protein (0.8%), lipid (0.26%) and acidity (5.75%) contents. Respiratory quotients and intensities in storage chambers with 5 lemons were the lowest. At the end of this study, tomato storage was possible for three weeks if these green tomatoes were stored with a quantity of mature lime equal to 25% of the number of tomatoes to be conserved.

Keywords: storage, tomato, lemon, gas exchanges

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widely grown crops in the world (Shankara *et al*., 2005). It is a vegetable fruit with many nutritional benefits (Dembélé *et al*., 2019). It is an essential source of minerals and vitamins and helps to reduce micronutrient deficiency in consumers (Boumendjel and Boutebba, 2003; Housssou *et al*., 2015; Sawadogo *et al*., 2015). The red color of ripe tomatoes is one of the first visual qualities attracting consumers, leading growers to wait until the tomato is fully ripe before picking it up (Pankaj et *al*., 2012). However, ripe tomatoes are more susceptible to bruising, contamination, and disease during and after harvest (Shankara *et al*., 2020). According to Cantwell and Kasmire (2002), tomatoes, as a climacteric fruit, can be harvested in the early stages of ripening, which will subsequently occur during storage or shipping. The shelf life of fresh tomatoes after harvest is short (4 to 7 days), as is their storage under ambient conditions (Shankara et *al*., 2005). As a result, growers find it difficult to sell their fruit, particularly during periods of abundance. During these periods, the selling price per kilogram of tomato falls sharply, forcing growers to sell regardless out of fear of losing their production.

Some market gardeners are now trying to find ways of preserving fruit and vegetables. Several methods have been explored. One of these is tomato drying, which has the disadvantage of reducing nutritional content to a greater or lesser extent, depending on the type of dryer used. In addition, tomato powder is not well-known (Ndjouenkeu et *al*., 2003; Touzi and Merzaia, 2008). Refrigerated storage is a technique that is not available to all farmers. Lemon juice is also used to preserve fresh tomatoes. However, when applied, it is unlikely that anyone knows the exact pH of each canned tomato, so this procedure is only relevant to the tomato canning industry (Heflebower and Washburn 2010). As tomatoes are climacteric fruit, their ethylene production is subject to an autocatalytic mechanism, hence their effectiveness in ripening green fruit (Gilli et *al*., 2014).

The aim is to lower tomatoes' respiratory and biochemical metabolism, in other words, to slow their ripening process using lemon (a non-climacteric fruit). To this end, fresh tomatoes and whole lemons were stored in the same chamber to study the behavior of gases in the storage chambers and the effect of varying the quantities of ripe lime on the quality parameters of green tomatoes after harvesting.

2. Materials and methods

2.1 Plant material

The experiment was conducted on two mature green-stage tomato varieties: the Cobra F1 (table tomatoes) and the Amiral F1 (industrial tomatoes). The mature green lemon variety used in the experiment was Eureka.

After harvesting, the lemons and fresh green and mature tomatoes were sorted. The tomatoes were free of damage or pathological infection, of 35-45 grade, and weighed between 40 and 80 g. Mature and unripe lemons were graded between 35 and 40. The fruit was then washed and air-dried.

2.2 Experimental set-up

The experiments were conducted in a greenhouse from 10 September to 08 October 2021. The average temperature in the greenhouse was 32.43°C. The trial was conducted in a two-factor split-plot design with four treatment repetitions. The main factor was the tomato variety with two modalities (Cobra F1 and Amiral F1), and the subsidiary factor was the number of lemons with five levels (0, 5, 10, 15, and 20 lemons). A transparent 9 L chamber, at an average ambient temperature of 33.2°C, contained 20 tomatoes and one of the five levels of the subsidiary factor. To prevent contamination, the chambers and tomatoes were cleaned with 70° alcohol for 1 minute at each measurement (ISO 9001 certification, 2015).

2.3 Trapping of respiratory gases and ethylene in preservation chambers

Water was used as a solvent for trapping respiratory gases (O_2 and CO_2) and ethylene. The principle of this trapping is to have a concentrated flow of ethylene, O_2, and CO_2 at high pressure that water can fix. The water comes into contact with the target molecules for adsorption. The trapping capacity is determined by the sampling time. Sampling efficiency is considered to be the maximum at 100 % (Langlois *et al.* 2021). To achieve this, three wide-necked plastic collection bottles containing 200 mL of distilled water were placed in hermetically sealed storage chambers. At the end of each week of storage, the contents of each flask were collected for quantification of the various gases, and the flask was refilled.

2.3.1 Measurement of fruit respiration parameters during storage

Oxygen was measured using a Senso-Direct 150 oximeter to measure dissolved oxygen in water (Agnieszka and Weronika, 2022). The total CO_2 trapped in water was determined using the method of Hakmi (2006).

NaOH (N/40) was introduced into a 200 mL flask. The quantity doubled when the water contained more than 50 mg of CO_2 per liter, then topped up to the mark with the water to be analyzed; 6-8 drops of φφ (Phenolphthalein) were added, and the flask was sealed with a clean rubber stopper. The flask was then turned upside down several times to homogenize the solution, which should turn pink. Finally, the 0.1N hydrochloric acid solution was titrated until discoloration. A blank test (CO_2 free distilled water) was carried out under the same conditions.

Respiratory intensity (RI) was calculated as the difference between the volume of gas at the end of the week and the volume in the jar at the beginning of the week. The respiratory quotient RQ is obtained by the ratio between $RICO_2$ and RIO_2 (Ducamp *et al.*, 2000).

$$\mathbf{RI_{O2}}\left(\frac{\mathrm{Cm^3}}{\mathrm{kg.\,h}}\right) = \frac{\mathrm{V_{O2\ start\ of\ week}} - \mathrm{V_{O2\ end\ of\ week}}}{(Fruit\ weight)(168\ h)}$$

$$\mathbf{RI_{CO2}}\left(\frac{\mathrm{Cm^3}}{\mathrm{kg.\,h}}\right) = \frac{\mathrm{V_{CO2\ start\ of\ week}} - \mathrm{V_{CO2\ end\ of\ week}}}{(Fruit\ weight)(168\ h)}$$

$$\mathbf{RQ} = \frac{\mathrm{RI_{CO2}}}{\mathrm{RI_{O2}}}$$

2.3.2 Estimation of ethylene production during storage

The ethylene trapped in water was determined by gas chromatography with sampling using the static mode headspace (HS) method. Disinfection of residual compounds was done in a 200 L Autester - E Selecta autoclave. The gas used was oxyfume® 2002, a mixture of oxirane, CHClF2, and CHClF-CF3 (ethylene mixture 22.7 % by volume) at 25°C. In a series

of 7 vials identical to the one used for the test, each containing 150 mL of dimethyl-acetamide R, 0 mL, 0.05 mL, 0.10 mL, 0.20 mL, 0.50 mL, 1 mL, and 2 mL of ethylene solution were introduced respectively (Fiserova *et al*., 2008; FNOR XP T 90-124, 2009; CWEA E-III-4V2, 2014).

The vials were capped, crimped, and placed in an oven at 70 ± 1°C for 16 h. 1 mL of the hot gas contained in each vial was injected onto the column, and the calibration curve was constructed from the peak heights and the mass of ethylene contained in each vial. 10 mL of each water sample was taken and introduced into a 250 mL vial containing 150 mL of dimethyl-acetamide R. The vial was closed with a suitable cap and crimped. The flask was then placed in an oven at 70 ± 1°C for 16 h. A 1 mL sample of the hot gas in the vial was injected into the column. The ethylene content of the vial was calculated using the calibration curve and the obtained peak area.

2.4 Tomato quality measurements

2.4.1 Measurement of physical parameters

Tomatoes were removed from storage when they were wrinkled, soft, or deteriorated. The rate of loss was determined as follows:

$$\text{Loss rate} = \left(\frac{F_S - F_R}{F_S}\right) \times 100$$ (**Kouamé *et al.* 2013**)

FS is the initial number of fruits and **FR** is the number of remaining fruits.

Mass reduction after storage: $R_{ms} = \frac{(M_{bs} - M_{as})}{M_{bs}}$ (Agassounon *et al*., 2012)

R_{ms} = sample mass reduction after storage, $\mathbf{M_{bs}}$ = sample mass before storage,

$\mathbf{M_{as}}$ = sample mass after storage.

The evolution of tomato coloration was assessed weekly using a guide illustrating the colors and color percentages of the tomato surface for each ripening stage (Tuner, 2022).

Green stage: From entirely green for at least 10 % yellow to pink on the surface. Pink stage: Tomatoes turn pink or red over 30 % of their surface but no more than 60 %. Red stage: Tomatoes turn pinkish or red over 60 % to over 90 % of their surface.

2.4.2 Measurement of tomato physicochemical parameters

The acidity titer was determined using the method of Ikay and Aziz (2011). Acidity titration was carried out with sodium hydroxide solution (NaOH (0.1N)) in the presence of phenolphthalein as a color indicator. In a beaker, 10g of tomato were introduced, 50 mL of recently boiled distilled water were added and cooled, and then the whole was mixed until a homogeneous liquid was obtained. The contents were heated in a water bath for 30 minutes, and after cooling in a 100 mL volumetric flask, the mixture was made up to the mark with distilled water. After filtration, 10 mL of the filtrate was taken, to which drops of phenolphthalein were added and titrated with NaOH (0.1N) until a persistent pink color was obtained.

Lycopene is a fat-soluble pigment. It was identified by spectrophotometer at 472 nm using the method described by Benakmoum *et al*. (2008). 0.1 g of the powder in 10 mL of (hexane-acetone-ethanol (50/50/1), shaken for 10 min, then centrifuged at 5000 rpm for 15 min, 1 mL of the organic phase was extracted and then diluted in 10 mL of hexane.

The vitamin C content of tomatoes from the various treatments was determined by the indirect iodometric titration method (Massot, 2010).

Determining vitamin C content in tomatoes was carried out by weighing 200 g of tomato fruit and crushing it. The resulting puree was filtered through fine cloth and filter paper to collect the juice. The pH of the filtrate was read using a pH meter, then 25 mL of the solution was taken and introduced into a 250 mL conical flask, topping up to 100 mL with distilled water. 1 mL of 1M H_2SO_4 sulfuric acid was added, followed by 1 mL of 1% aqueous starch solution. The filtered juice solution was titrated with 0.005 M di-iodine solution.

The KJELDAHL method was used to determine protein content (B.I.P.E.A., 1976). This method comprises two main stages: digestion and distillation, followed by a hydrochloric acid-based titration.

Total sugars were determined using the Dubois *et al.* (1956) method. Briefly, 5 g of tomato paste sample was infused in 50 mL of distilled water at 60°C. The solution was topped up to 100 mL with distilled water and transferred to tubes. Afterward, 0.8 mL of distilled water, 0.2 mL of 5% phenol, and 1 mL of concentrated sulfuric acid (H_2SO_4) were added to 0.2 mL of the water-soluble extract. This reaction mixture was incubated in a boiling water bath for 5 minutes, followed by a second incubation in the dark for 30 minutes, after which 2 mL of distilled water was added. Optical density (OD) was read using a spectrophotometer at 490 nm. The sugar-free control was subjected to the same treatment. Total sugar levels were obtained using a calibration curve. Total sugar content was determined using glucose as the standard.

The Soxhlet method is the reference method used to determine plant fat (Amalou *et al*., 2013). In this assay, 1 g of sample was introduced into an extraction cartridge (Wattman cartridge) inserted into the extraction bulb. A pre-weighed round-bottomed flask (P_1) was filled to 2/3 with hexane. This flask was connected to the rest of the refrigeration system for 6 hours, during which the fat was extracted. The solvent was recovered by evaporation. The fat flask was heated in an oven at 130 °C for 30 minutes, then cooled in a desiccator and weighed to obtain the weight (P_2).

3. Data processing and analysis

The data collected were subjected to a two-factor analysis of variance using R software version 4.0.2. Specifically, a classical ANOVA was performed for the physicochemical parameters of tomatoes on day 21. A repeated-measures ANOVA was run for respiratory and physical parameters. Application conditions were verified using Mauchly's sphericity test. When sphericity was not verified, the Greenhouse-Geisser test was applied. Then, a post hoc test, notably the Bonferroni test, was applied to identify homogeneous groups.

4. Results and discussion

4.1 Fruit respiration parameters

Between treatments, respiratory intensities in tomatoes stored varied significantly ($P < 0.001$). Rates were higher in the jars of the lemon and tomato controls.

The highest respiratory intensities were recorded in the enclosure's controls, with 10 (170.42) and 15 lemons (79.36). However, the 5-lemon control, with a rate of 37.96, had the lowest respiratory intensity among the lemon controls.

The tomato Amiral and cobra controls, with 69.99 and 72.39, respectively, have significantly the same but lower respiratory intensities than the 10 and 15 lemon controls.

Amiral or cobra tomatoes, coupled with lemons, significantly maintained the lowest respiratory intensities. However, these respiratory intensities varied significantly with the number of lemons. Only Amiral and Cobra tomatoes, each coupled with 05 lemons, maintained the lowest respiratory intensities, at 17.83 and 19.94, respectively (Figure 1).

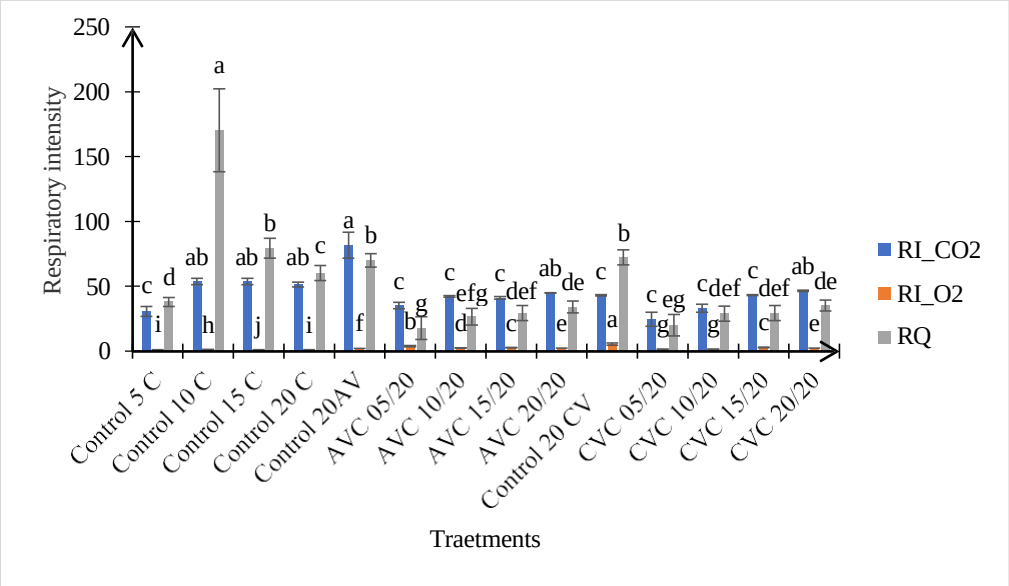

Figure 1. Effects of lemons on respiratory intensity in chambers storage**.**

Means assigned the same letter do not differ significantly according to Tukey's test at the 5% level.

RI_CO2, RI_O2, and RQ indicate carbon dioxide, oxygen, and respiratory quotients. Control 5 C (5 lemons), Control 10 C (10 lemons), Control 15 C (15 lemons), Control 20 C (20 lemons), Control 20 AV (20 green Amiral tomatoes), AVC 05/20 (20 Amiral fruits stored with 05 lemons), AVC 10/20 (20 Amiral fruits stored with 10 lemons), AVC 15/20 (20 Amiral fruits stored with 15 lemons), AVC 20/20 (20 Amiral fruits stored with 20 lemons), Control 20 CV (20 green Cobra tomatoes), CVC 05/20 (20 Cobra fruits stored with 05 lemons), CVC 10/20 (20 Cobra fruits stored with 10 lemons), CVC 15/20 (20 Cobra fruits stored with 15 lemons) and CVC 20/20 (20 Cobra fruits stored with 20 lemons).

4.2 Effects of lemons on ethylene production in enclosures during storage

During storage, ethylene production varied significantly (P<0.001) between varieties, different quantities of lemon, and pairings (lemon/tomato). Three main groups of ethylene emissions can be identified (Figure 2).

Low ethylene emissions, below 30 µg/L, were observed in the *enclosures* of control lemons 05 C (18.99 µg/L); 10 C (20.63 µg/L); 15 C (24.082 µg/L) and 20 C (29.734µg/L) and in those of tomatoes associated with AVC 10/20 (16.186 µg/L); CVC 15/20 (16.918 µg/L) and CVC 05/20 (24.598 µg/L). The ethylene content of the lemon controls varied with the number of lemons. Average ethylene emissions ranging from 30 to 50 µg/L were recorded in the AVC 05/20 (37.566 µg/L); AVC 15/20 (37.104 µg/L); AVC 20/20 (43.068 µg/L); Control 20 CV (30.262 µg/L); CVC 10/20 (39 µg/L) and CVC 20/20 (39.308 µg/L) chambers. Lastly, the highest emissions of over 50 µg/L occurred in the jars of control 20 AV (52.724 µg/L.)

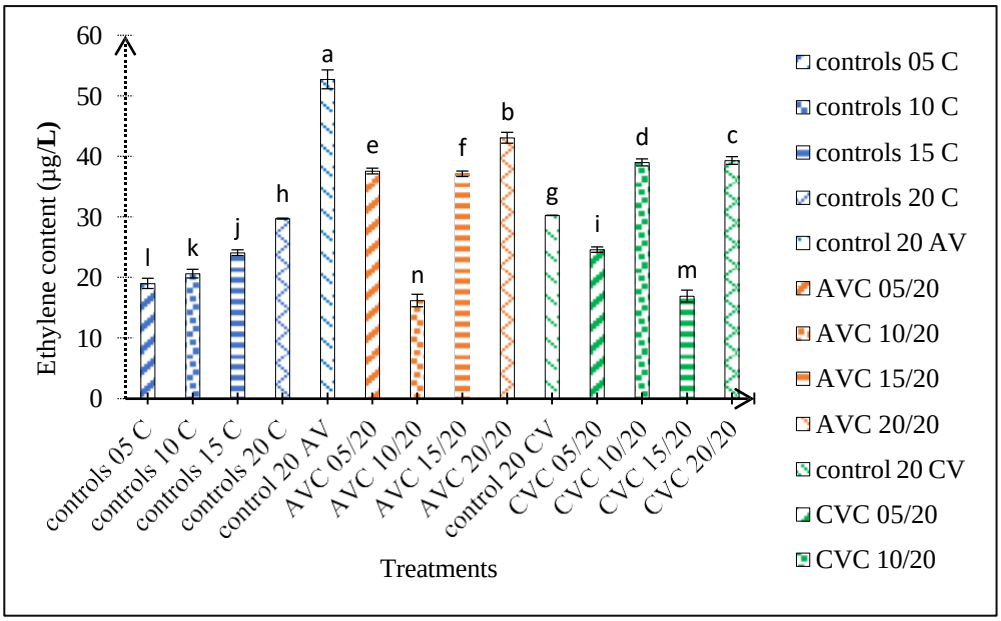

Figure 2. Effect of lemons on ethylene levels during storage.

Control 20 AV (20 green Amiral tomatoes), AVC 05/20 (20 Amiral stored with 05 lemons), AVC 10/20 (20 Amiral stored with 10 lemons), AVC 15/20 (20 Amiral stored with 15 lemons), AVC 20/20 (20 Amiral stored with 20 lemons) Control 20 CV (20 green Cobra tomatoes), CVC 05/20 (20 Cobra tomatoes stored with 05 lemons), 10/20 (20 Cobra tomatoes stored with 10 lemons), CVC 15/20 (20 Cobra tomatoes stored with 15 lemons) and CVC 20/20 (20 Cobra tomatoes stored with 20 lemons).

4.3 Physical parameters

Table 1 shows the results for rotting rates and mass loss of tomato fruit during storage.

4.3.1 Tomato rot rate

Between treatments, ANOVA showed a significant difference ($P < 0.001$). Tomato rot were higher in the jars of Amiral control (64 %) and cobra (48 %) tomatoes. Tomato losses were highest in jars of Amiral tomatoes paired with lemons, ranging from 46 to 55 %, while those of cobra tomatoes paired with lemons varied from 23 to 39 %. Only cobra tomatoes coupled with 5 and 10 lemons showed the lowest fruit rot rates, at 23 % each.

4.3.2 Tomato mass loss rate

The mass losses of tomatoes stored by different quantities of lemon varied significantly ($P < 0.05$), whatever the number of lemons used for the couplings. However, mass losses were very low in cobra tomatoes stored with 5 and 10 lemons, with losses of 0.09 g each. Amiral (0.22 g), cobra (0.21 g), and Amiral tomato controls coupled with 15 lemons (0.2 g) recorded the highest mass losses.

Table 1: Rate of ratting and loss of tomatoes mass during storage according to treatments

Traitements	Rot rate	Mass loss rate
Control 20 AV	64 a	0.22 a
AVC 05/20	55 ab	0.17 ab
AVC 10/20	52 abc	0.13 ab
AVC 15/20	50 abc	0.2 a
AVC 20/20	46 abc	0.14 ab
Control 20 CV	48 abc	0.21 a
CVC 05/20	23 d	0.09 b
CVC 10/20	23 d	0.09 b
CVC 15/20	39 bcd	0.15 ab
CVC 20/20	36 cd	0.13 ab
CV (%)	**31,28**	**6,65**
P-value	**0,00**	**0,00**

Means marked with the same letter in a column do not differ significantly according to the Tukey test at the 5 % level.

Control 20 AV (20 green Amiral tomatoes), AVC 05/20 (20 Amiral stored with 05 lemons), AVC 10/20 (20 Amiral stored with 10 lemons), AVC 15/20 (20 Amiral stored with 15 lemons), AVC 20/20 (20 Amiral stored with 20 lemons) Control 20 CV (20 green Cobra tomatoes), CVC 05/20 (20 Cobra stored with 05 lemons), 10/20 (20 Cobra stored with 10 lemons), CVC 15/20 (20 Cobra stored with 15 lemons) and CVC 20/20 (20 Cobra stored with 20 lemons), CV (coefficient of variation)

4.4 Effects of lemons on the color change of tomatoes in the chambers during 28 days of storage

The effects of lemons on the color change of tomatoes during storage are shown in Table 2. The analysis did not reveal any significant difference between the treatments. After seven days in the presence of different quantities of lemons, almost all the tomatoes turned red, with a rate of between 80 and 100 %. Only 5-20 % of tomatoes turned pink. None of the Amiral tomatoes remained green after seven days' storage, whatever the quantity of lemon, while 5% of the cobra tomatoes stored with 5 and 15 lemons remained green after seven days.

Table 2. Effects of lemon on the color change of green tomatoes seven days after storage.

Treatments	G. T. start (%)	7D. G. T (%)	7D. P. T (%)	7D. T. Rg (%)
Control 20 AV	100 a	0 a	0 a	100 a
AVC 05/20	100 a	0 a	5 a	95 a
AVC 10/20	100 a	0 a	15 a	85 a
AVC 15/20	100 a	0 a	10 a	90 a
AVC 20/20	100 a	0 a	10 a	90 a
Control 20 CV	100 a	0 a	0 a	100 a
CVC 05/20	100 a	5 a	5 a	90 a
CVC 10/20	100 a	0 a	20 a	80 a
CVC 15/20	100 a	5 a	10 a	85 a
CVC 20/20	100 a	0 a	15 a	85 a
CV (%)	**0**	**50.8**	**18.28**	**0.55**
p-value	**1**	**0.536**	**0.398**	**0.456**

Means with the same letter in a column do not differ significantly according to the Tukey test at the 5% level.

D. (Days), G. T. (Green tomato), P.T. (Pink tomato), T.R.g. (Red tomato), Control 20 AV (20 green Amiral tomatoes), AVC 05/20 (20 Amiral stored with 05 lemons), AVC 10/20 (20 Amiral stored with 10 lemons), AVC 15/20 (20 Amiral stored with 15 lemons), AVC 20/20 (20 Amiral stored with 20 lemons) Control 20 CV (20 green Cobra tomatoes), CVC 05/20 (20 Cobra stored with 05 lemons), 10/20 (20 Cobra stored with 10 lemons), CVC 15/20 (20 Cobra stored with 15 lemons) and CVC 20/20 (20 Cobra stored with 20 lemons), CV (coefficient of variation).

4.5 Biochemical parameters of tomatoes

Results relating the effects of lemon on tomato biochemical parameters evaluated during storage are presented in Table 3. These include acidity, lycopene and vitamin C content, and carbohydrate, protein and lipid rates.

4.5.1 Acidity

The acidity levels of tomatoes stored with different quantities of lemons varied significantly ($P < 0.001$). The Amiral tomatoes stored with ten lemons and the control cobra tomatoes (6.22%) had the lowest acidity levels. However, the other treatments had acidity levels between 5.38 and 5.88 %.

4.5.2 Lycopene content

Lycopene levels varied slightly between treatments. Nevertheless, with a significant difference ($P < 0.001$), cobra tomatoes stored with five lemons (2.5 mg/100g) had the highest lycopene levels than the other treatments.

4.5.3 Vitamin C

Statistical analyses of the vitamin C content of the treated tomatoes showed a significant difference ($P < 0.001$). Cobra tomatoes stored with five lemons (14.3 mg/100g) and 20 lemons (14.08 mg/100g) had higher vitamin levels than the Amiral (13.68 mg/100g) and cobra controls (13.75 mg/100g).

4.5.4 Protein content

Analyses of protein content observed in tomatoes after 21 days of storage varied significantly ($P < 0.001$). Only the cobra tomatoes stored with five lemons (0.8 %) had higher protein contents than the control Amiral (0.66 %) and cobra tomatoes.

4.5.5 Carbohydrate (Glucid) content

The carbohydrate content of tomatoes after 21 days of storage showed a significant difference between treatments ($P < 0.001$). Only Amiral tomatoes paired with 15 lemons (1.80 %) and cobra tomatoes paired with five lemons (1.72 %) showed higher carbohydrate content than control cobra tomatoes (1.7 %).

4.5.6 Lipid content

The effects of 21 days of treatment on the lipid content of stored tomatoes varied significantly ($P < 0.001$). Amiral tomatoes stored with 15 lemons (0.25 %) and cobra tomatoes stored with five lemons (0.26 %) had the highest lipid content compared with the other treatments.

Table 3 : Effects of lemon on tomato physicochemical parameters evaluated during storage

Treatements	Acidity	Lycopene	Vitamin C	Protein	Glucid	Lipid
Control 20 AV	5.75 c	1.9 c	13.68 d	0.66 c	1.59 f	0.2 c
AVC 05/20	5.65 e	1.68 g	13.35 g	0.63 d	0.88 i	0.22 cb
AVC 10/20	6.22 a	2.08 b	12.88 h	0.61 e	1.63 e	0.213 cb
AVC 15/20	5.88 b	1.62 h	13.48 f	0.65 c	1.8 a	0.25 a
AVC 20/20	5.6 f	1.8 f	12.88 h	0.63 d	1.63 e	0.18 d
Control 20 CV	6.22 a	1.85 e	13.75 c	0.68 b	1.7 c	0.22 cb
CVC 05/20	5.75 c	2.5 a	14.3 a	0.8 a	1.72 b	0.26 a
CVC 10/20	5.38 g	1.88 d	12.88 h	0.58 f	0.92 h	0.18 d
CVC 15/20	5.88 b	1.58 i	13.58 e	0.63 d	1.5 g	0.23 b
CVC 20/20	5.68 d	1.5 j	14.08 b	0.68 b	1.68 d	0.22 cb
CV (%)	**1,03**	**3,48**	**0,91**	**1,93**	**5,13**	**2,85**
P-value	**0,000**	**0,000**	**0,000**	**0,000**	**0,000**	**0,000**

Means with the same letter in a column do not differ significantly according to the Tukey test at the 5% level.

Control 20 AV (20 green Amiral tomatoes), AVC 05/20 (20 Amiral stored with 05 lemons), AVC 10/20 (20 Amiral stored with 10 lemons), AVC 15/20 (20 Amiral stored with 15 lemons), AVC 20/20 (20 Amiral stored with 20 lemons) Control 20 CV (20 green Cobra tomatoes), CVC 05/20 (20 Cobra tomatoes stored with 05 lemons), 10/20 (20 Cobra tomatoes stored with 10 lemons), CVC 15/20 (20 Cobra tomatoes stored with 15 lemons) and CVC 20/20 (20 Cobra tomatoes stored with 20 lemons), CV (coefficient of variation)

7. Discussion

The respiratory activity of the fruit consisted of a decrease in the oxygen rate and an increase in the carbon dioxide rate in the chambers. The main reason seems linked to the high respiratory metabolism and the ambient temperature (25-30° C on average). Respiration involves the consumption of oxygen and the production of carbon dioxide. There was no

stabilization of the composition of the internal atmosphere in all the chambers used; certainly, due to the high temperature, this result is consistent with that obtained by Yao *et al.* (2014), who found that there was no stabilization of gaseous constituents as in the case of controlled atmosphere storage. Analysis of the quantities of oxygen absorbed and carbon dioxide released by the two tomato varieties harvested shows that during fruit storage, respiration in all chambers intensified with significant variation at the second and third weeks of storage.

This is due to the low level of respiratory activity at the beginning and end of the ripening period and the higher level of activity in the middle of the ripening period. During ripening, the transition from the green to the red stage increases respiratory intensity. The effect of variety on the fruit's respiratory metabolism was practically non-existent; thus, between the Amiral and cobra cultivars, CO_2 release and O_2 uptake did not vary significantly, as shown in Table I. These results contradict those of Abdullah *et al.* (1991), whose studies on bananas of the Latunda cultivar produced a release of 140 mg $CO_2.kg^{-1}.h^{-1}$ (at 20°C), i.e. approximately 3.18 mmol CO_2. $kg^{-1}.h^{-1}$, whereas bananas of the Senorita cultivar reached, at the same temperature, 200 mg $CO_2.kg^{-1}.h^{-1}$, i.e. 4.55 mmol CO_2. $kg^{-1}.h^{-1}$.

In reality, it is the quantities of CO_2 and O_2 present in the enclosure that will have an impact on the preservation of the fruit. It is, therefore, preferable to consider the ideal quantity of CO_2 and O_2 for good preservation in the chambers. This is why the quantity of fruit used for packaging is so important. The variation of 05 to 20 lemons associated with the 20 tomatoes in each enclosure would make it possible to identify the ideal number for better tomato conservation. In addition, to avoid the accumulation of CO_2, the parameters were measured every weekend to air the fruit and reconstitute the initial atmosphere in the preservation chambers. Regardless of the tomato variety used in our study, respiratory intensity decreased with the reduction in the number of lemons added to the tomatoes. This reduction would affect the carbon dioxide respiratory intensity parameter (IR_CO_2). A respiratory quotient (RQ) value greater than 1 would mean that the respiratory physiology of the fruit would be modified as a function of the number of lemons.

Therefore, since the respiratory quotients of the different treatments were greater than 1, the effect of lemons in hermetically sealed enclosures containing tomatoes coupled with lemons would act on respiration by increasing R_CO_2 and decreasing R_O_2. Citrus fruits are among the fruits that breathe very little. The respiration coefficient in the preservation chambers decreases with the number of lemons. The initial atmosphere in the chambers is ambient air (20.946 % O_2; 0.033% CO_2). Over time, oxygen is consumed to produce CO_2, resulting in a decrease in oxygen and an accumulation of CO_2. The rate at which oxygen is consumed and CO_2 is released is often very rapid, which means that CO_2 could increase rapidly and cause physiological disorders that could subsequently influence respiration, which would become anaerobic. During 21 days of treatment, only the tomatoes stored with five lemons had the lowest respiration rates. In these chambers, R_CO_2 accumulation was the lowest, with R_O_2 consumption being neither the lowest nor the highest. In our study, 05 lemons were the proper ratio to pair with 20 tomatoes to ensure a good modified atmosphere. This ratio made it possible to control the O_2 uptake necessary for a good release of the CO_2 rate in the chambers (chambers) to maintain the fruit in good condition at the green stage over three weeks.

However, the lower respiration rates on day 28 were due to its storage chambers' high fruit loss rates. Respiration was low on day 7. The lemons and the Amiral and Cobra tomatoes had low respiration rates at the start of storage. This low respiration did not affect the emission of ethylene into the chambers. This resulted in ethylene concentrations in the chambers of climacteric fruits such as Amiral and cobra tomatoes varying from 100 to 194 µg. L^{-1} on the seventh day of storage. However, ethylene rates ranged from 55 to 85 µg. L^{-1} for lemons were low. Since lemons are citrus fruits, they are among the non-climacteric fruits whose ethylene synthesis is not accompanied by a climacteric crisis (Sinha et al., 2012). In citrus fruits, ethylene is synthesized in small quantities sufficient to trigger their ripening processes (Sinha et al., 2012). The respiratory quotient of tomatoes stored with five lemons was less than 1. Coupling the 05 lemons with the 20 tomatoes at seven days of storage had a low respiratory intensity varying from 0.35 in the chambers of Amiral tomatoes to 0.5 for those of cobra tomatoes. This number of fruits in the 9-liter chambers at one week's storage allowed more O_2 to be absorbed (1.06 and 1.18 $cm^3.kg^{-1}.h^{-1}$) and released less CO_2 (0.37 and 0.59 $cm^3.kg^{-1}.h^{-1}$). The respiratory intensity of IR_CO_2 in the preservation chamber was lower than that of IR_O_2.

The resulting respiratory quotient gave a value of less than 1. The IR_CO_2 / IR_O_2 combination of less than 1 did not affect ethylene emission in a hermetically sealed storage jar. Similarly, on day 14, Amiral (13.49 to 15.58) and cobra (13.59 to 16.16) tomatoes paired with lemons had lower respiratory quotients than the control Amiral (22.55) and cobra (22.43) tomatoes. The IR_CO_2 of the coupled tomatoes is much lower than that of the control tomatoes, while the IR_O2 of the coupled tomatoes is slightly higher than that of the control tomatoes. This increase in CO_2, followed by a decrease in O2 in the chambers, is thought to underlie the drop in ethylene on day 14. Low O_2 and high CO_2 rates, therefore, reduce ethylene production. Our results corroborate those of Souty *et al*. (1952), who showed in their work on conservation in a controlled atmosphere that the permanent action of CO_2 in the presence of a low quantity of O_2 seems to partially inhibit the production of ethylene, for the duration of the experiment, without preventing the increase in respiratory intensity. Medlicott *et al.* (1987) suggested that the reduction in oxygen in the atmosphere surrounding the fruit reduces its metabolic activity and ethylene production.

Kerbel *et al.* (1988) also showed that enzyme activity decreased when the fruit was stored in an atmosphere with 10 % CO_2. Respiratory quotients on day 21 were very high. This sudden increase in respiratory intensity was due to a very high release of CO_2 in all the chambers. The action of CO_2 on ethylene could act as a brake on ethylene emission. Our observations are in agreement with those of Liu *and al.* in 2003 and 2004, who stated that the activation of NADP-dependent isocitrate dehydrogenase (NADP-IDH) corresponds to the climacteric peak of green bananas treated with propylene, the chemical structure of which is close to ethylene. However, this enzymatic activity is strongly suppressed when the fruit is exposed to CO_2. In addition, the climacteric peak is suppressed at high CO_2 rates. This finding is reinforced by the work of Happi et *al*. (2007), who indicated that high CO_2 rates inhibit the action of ethylene.

Losses of Amiral tomato fruit ranging from 30 to 65% after the seventh day of storage were due to damage caused by heavy rainfall, which initiated softening through major

changes to the cell wall. The high rate of tomato loss observed during the shelf-life examination was due to the fragility of the Amiral variety. Fruit with bruises and lesions resulted in reduced firmness and greater susceptibility to rotting during storage. Mechanical damage during storage had a more significant effect on the pericarp and favored areas where microorganisms could develop, leading to softening of the intact tissues. The work of Kansié (2017) corroborates these results, which showed that the yield obtained in their study was very low for some varieties and high for others. This difference can be explained by bad weather and high relative humidity, which caused the fruit to burst and rot.

Loss and rot rates were low in chambers of cobra tomatoes stored with 5 and 10 lemons. According to Retamales *et al.* (2003), high levels of CO_2 (20-30 kPa) combined with low levels of O2 (5-10 kPa) helped to control rot and extend the shelf life of cherries transported from Chile to Japan. The bruising observed in Amiral tomatoes resulted in greater water loss, reflected in a significant mass loss from the 14^{th} day of storage in all treatments. Storing the tomatoes with lemons did not affect color development. Although the high CO_2 rate inhibited ethylene, this inhibition did not affect color development. Our results are contrary to those of Buescher (1979), who stated that a high level of CO_2 inhibited ethylene synthesis during tomato ripening, which limits color change.

Biochemical parameters from tomatoes stored with 10, 15, and 20 lemons were lower than those from the Amiral or Cobra controls. However, the biochemical parameter rates from cobra tomatoes stored with five lemons were either equal to or higher than those from the Amiral and cobra controls. Small increases in CO_2 followed by small decreases in O_2 led to changes in biochemical parameters. The RI increased as the number of lemons coupled with tomatoes increased. This increase in RI is due to a sharp increase in CO_2 content followed by a sharp decrease in O_2 content. The high CO_2 levels inhibited the evolution of the biochemical parameters in the chambers of tomatoes with a high number of lemons. Our results align with Thai's (2000) work, which focused on the effect of different coatings on the freshness characteristics of mango. His work showed that all the coatings blocked the evolution of specific biochemical parameters, such as titratable acidity, pH, and soluble dry extract of the fruit. In the case of coated fruit, this inhibition is directly linked to the reduction in RI. Indeed, applying a coating increases CO_2 content and decreases O_2 content inside the fruit (Drake *et al*., 1987; Mainnheim and Soffer, 1996).

8. Conclusion

This study has shown that preserving Amiral and cobra tomatoes produced under the right conditions for three weeks is possible if these green tomatoes are stored with a whole lemon. In addition, these results should encourage growers to disregard the variety to be stored, as they can store several varieties of tomato depending on their growing area and keep them together in the same enclosures. The link between ripening and respiration suggests that, in order to extend the survival of tomato fruit and increase shelf life in the fresh state, it should be sufficient to place green tomatoes and limes in the same hermetically sealed enclosure, in quantities equal to 25 % of the number of tomatoes to be stored. This will create an atmosphere around the fruit that is slightly enriched in carbon dioxide and highly depleted in oxygen, which can vary slightly over seven days. Low levels of O2 and high levels of CO2

inhibit the production of ethylene, which is necessary for activating the genes involved in ripening in terms of color changes and the degradation of cell walls to soften the flesh.

This process makes it easy to produce gaseous compositions favorable to tomato varieties. It is easy to control and rectify any high CO_2 concentration and very high O_2 depletion by regular aeration of the storage enclosure. This aeration helps to prevent the accumulation of carbon dioxide and also replenishes the storage chamber with oxygen. At each aeration, the enclosure must be cleaned with alcohol to remove deteriorated tomatoes, lemons, and spills from deteriorating fruit.

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