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Effect of Using Low-Pressure Storage (LPS) on Rabbiteye Blueberry 'Premier' Fruits

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ABSTRACT. This investigation was initiated to establish the best conditions for maintaining the quality of rabbiteye blueberries using low-pressure storage (LPS) technique. Low-pressure storage experiment was conducted in a growth chamber at 4ºC using 22-quarter pressure cookers as low-pressure chambers. The desired pressures were maintained by continuously evacuating humidified air using a Belt-drive vacuum pump. The treatments were 1.0, 0.6, 0.3, and atmospheric pressure and the control fruits were held on adjacent shelves in the same chamber under normal atmospheric pressure.

The results revealed that berries stored at 1.0 atmospheric pressure lost less weight, were firm, developed less decay, and did not show any shriveling with the storage time (28 days). Juice pH increased with the storage time, but was lowest at LPS treatments. Soluble solid concentrations (SSC) increased with the storage time, but were lowest at 1.0 atmospheric pressure. Titratable acidity (TA) was highest when fruits were stored at 0.3 atmospheric pressure due to a high moisture loss. The ratio of SSC/TA varied with the storage time when the fruits were stored at 1.0 and 0.3 atmospheric pressure and tended to increase with storage time at 0.6 and the control treatments.

Introduction

Blueberry (*Vaccinium* spp.) fruits are ranked as number one among forty fruits, juices, and vegetables in antioxidant activity (Ray, 2000), and comprises more than forty compounds which might have cancer prevention properties (NABC, 2000).

Quality and shelf life are the major requirements for fruits that have relatively short storage life such as blueberries and any attempt to extend the storage duration would be of utmost importance in postharvest technology. Blueberry fruit is classified as a climacteric fruit (Windus *et al*., 1976), therefore, special information is required for selecting optimum postharvest handling strategies. A number of postharvest techniques have been examined to extend the storage life of blueberry fruits, including modified atmosphere storage (Ceponis and Cappellini, 1979), carbon dioxide-enriched atmosphere storage (Ceponis, 1983), low pressure storage (Borecka and Pliszka, 1985) and controlled atmosphere (CA) storage (Smittle and Miller, 1988).

Sub-atmospheric, hypobaric, vacuum, and low-pressure storage are terms used to describe the controlled atmosphere storage in which the total pressure is reduced under partial vacuum at a given temperature (Wills *et al.,* 1989). In the last 50 years a great deal of interest has been centered upon low-pressure storage (LPS) as a means of maintaining quality and extending the storage life of perishable horticultural commodities (Gillette, 1981; Burg, 1993; Wang and Dilley, 2000).

Low-pressure storage (LPS) is very effective in reducing the partial pressure of oxygen, and subsequently reducing respiration, ethylene synthesis and action, and the rate of other metabolic processes that are regulated by oxygen (O_2) concentration (Lougheed *et al.,* 1978). In addition, ethylene and other volatiles produced by the commodity, such as carbon dioxide, are removed from the storage. A negative factor inherent with the LPS system is that desiccation of the product may occur rapidly due to the removal of moisture in form of water vapor. Spalding and Reeder (1976) reported that average weight loss and shrivel of limes were higher under LPS than normal pressure storage.

Normal physiological processes such as an increase in respiration rate and ethylene production could be slowed down by a combination of low storage temperature, low oxygen concentration and removal of ethylene and other volatiles by continuous venting of vacuum storage chambers (Burg, 1963; Kader, 1992; and Berrios *et al.,* 1999). Storage of green-wrap tomatoes under LPS conditions of 471, 278, 102 mm Hg and 646 mm Hg (control) at 12.7ºC resulted in a reduction in fruit respiration, especially under 102 mm Hg (Wu and Salunkhe, 1972). Storing cranberries (*Vaccinium macrocarpon* Ait.) under 80 Torr of LPS exhibited a depressed rate of respiration and ethylene evolution as well as an extended shelf life (Pelter, 1975). Stenvers (1975) suggested that the reduction of partial oxygen supply in this storage system was the main factor in the delaying senescence of tomatoes. Storage duration of banana was doubled when stored at 0.5 atmospheric pressure and similar results were also obtained with other fruits such as tomatoes, avocadoes, mangoes, and limes (Burg and Burg, 1966).

Some success has been reported for LPS in delaying growth of some pathogenic fungi on several fruit crops, such as papaya, cranberries and mangos (Salunkhe and Wu, 1975; Pelter, 1975; Spalding and Reeder, 1977; Alvarez, 1980).

Effects of LPS on firmness and shelf life of avocadoes, mangos, tomatoes, apricots, peaches, sweet cherries and pears were investigated by several workers who demonstrated that fruits under LPS were firmer and had longer shelf life than those stored under normal conditions (Wu *et al.,* 1972; Salunke and Wu, 1973; Bangerth, 1974; Spalding and Reeder, 1977).

LPS of apples showed that these fruits retained the flavor and textural characteristics of freshly harvested fruit and slowed down starch and malic acid degradation (Dilley, 1977). Spalding and Reeder (1976) stated that soluble solids and total titratable acidity did not differ when limes were stored under LPS of 170 mm Hg compared to the normal pressure; however, juice content, flavor, and decay free fruits were higher when fruits were stored under LPS for 6 weeks compared to normal pressure for 2 weeks. Borecka and Pliszka (1985) observed that blueberries stored under LPS of 38 mm Hg tasted good, contained less acid, and had lower soluble solid than other treatments.

To my knowledge, there is very meager information in using LPS for storing blueberry fruits. Thus, the use of low-pressure storage may be a useful technique to prolong the storage life of blueberries. Therefore, the objective of this study was to establish the best conditions for maintaining the quality of fresh blueberries using low pressure storage (LPS) technique.

Materials and Methods

Rabbiteye blueberry ‘Premier’ fruits were obtained from Amber Blueberry Farm & Nursery, Waynesboro, Mississippi, USA. Fruits were hand-harvested, placed in 1 kg blueberry plastic buckets and then hydrocooled by immersing the plastic buckets in an ice chest containing water and crushed ice for five minutes at 12ºC. In the laboratory, the fruits were immediately placed in 0.5 kg blueberry clear plastic boxes.

The low-pressure storage (LPS) treatments were conducted in a growth chamber (Mid-South Laural, Mississippi Model 451-683) at 4ºC. Twenty two-quart pressure cookers were utilized as low-pressure chambers (Fig. 1). The chambers were continuously evacuated by a Duoseal Belt-drive pump (Welch 1402) and ventilated by admitting humidified air. The ventilated air was humidified by water bubbling through 5-gallon nalgene containers. The humidified air was flowing through a nalgene container as a filter to prevent water from getting into the pressure cookers. The air filter was one-fourth filled with water and cellulose pads were inserted to increase the humidity of the air flowing to the pressure cookers. The pressure cookers were also sealed at the lids with play dough, allowing an air tight seal. Valve regulators, located between the filter and the pressure cookers, were used to maintain the desired pressures of 0.3, 0.6, and 1.0 atmosphere by admitting air at the proper rate. The pressure within the pressure cookers was monitored with pressure gauges placed at the top of the pressure cookers. LPS was interrupted when samples were removed for determination of physical and chemical analyses. Control fruits were held in the growth chambers under normal atmospheric pressure.

FIG. 1. Low-pressure storage (LPS). (A – filter; B – inlet of humidifier air; C – storage chamber; D – pressure gauge; E – valve regulator).

The first fruit samples were drawn initially and then at weekly intervals for 4 weeks, namely, after 7, 14, 21 and 28 days of storage. The parameters recorded were percentage weight loss, shriveling and decay percentages, fruit firmness, titratable acidity (TA), juice pH, soluble solids concentration (SSC) and SSC/TA ratio. Percentage weight loss in grams was measured by placing 100 fruits in each of four boxes (each box was a replication) per treatment giving a total of 400 fruits per treatment. The same four boxes were used throughout the experiment. The initial weight of each box was recorded, and percentage weight loss was obtained by subtracting the final weight from the initial weight and multiplying by 100. Fruit shriveling was rated on a scale from 1 to 5 (1-firm, 3-neither firm nor shriveled, 5-very shriveled). Percentage decay was scored as visible fungal appearance or leaky symptoms on randomly selected fruits. Firmness was recorded in Newtons when each fruit began to release juice using an Instron Compression Universal Tester (model 1011). Force was required to compress a 10 mm cylindrical probe at crosshead and chart speed of 20 mm/min and load range 0.05 N. Titratable acidity (TA) was determined using the method as described by Scomro (1998). Juice pH was determined by Accument Basic ABI5 pH meter. Soluble solid concentration (SSC) (ºBrix) was measured by using tabletop (Bausch & Lomb Abbe 3 L) refractometer maintained at 22ºC. Soluble solid concentration to TA ratio (SSC/TA) was obtained by dividing SSC by TA.

The experimental design was a completely randomized with four replications per treatment with repeated measures. Data were analyzed using the General Linear Models (GLM) procedure of SAS. Means were separated using Fisher's protected least significant difference test (LSD).

Results and Discussion

Weight loss did not differ with the storage time at 1.0 and 0.6 atmospheric pressure treatments (Table 1). In 0.3 atmospheric pressure and the control, weight loss varied with storage time. Percentage weight loss ranged from 1.55 to 2.34 and from 1.02 to 8.94 for the control and 0.3 atmospheric pressure, respectively. The lowest weight loss was obtained when the fruits were stored for 7 days at 1.0 and 0.3 atmospheric pressure. This low weight loss percentage at 0.3 atmospheric pressure chamber at 7 days of storage could be accounted for by the keeping of non-humidified air leakage to a minimum with a play dough seal. At 14, 21, and 28 days of storage, fruits stored at 1.0 atmospheric pressure had lower weight loss percentage compared to the other treatments. Total weight loss percentage was lower (0.99) when fruits were stored at 1.0 atmospheric pressure compared to the other treatments. The overall effect of storing blueberries at 0.3 and 0.6 atmospheric pressure on weight loss percentage was negative in this experiment because the humidity was not satisfactory inside the storage chambers due to the leakage of non-humidified air at the lids. However, in 1.0 atmospheric pressure air leakage was at minimum because the valve regulator was maintained only to exchange humid air with no pressure induced. Similar findings were reported by Spalding and Reeder (1976).

Shriveling symptoms were visible with the storage time at 0.3, 0.6 atmospheric pressure and the control (Table 2). In 0.3 atmospheric pressure shriveling symptom was visible at 7 days of storage when weight loss was approximately 8% of the initial weight. In 1.0 atmospheric pressure, fruits did not show indices of shriveling with the storage time. Shriveling symptoms were visible at 7 days of storage when fruits were stored at 0.6 atmospheric pressure. At 14 days of storage, fruits stored at 0.6 atmospheric pressure showed higher shriveling indices compared to the other treatments. At 21 and 28 days of storage, fruits held at 0.3 and 0.6 atmospheric pressure showed more severe shriveling symptoms compared to the control.

TABLE 1. Effect of low pressure and storage time on weight loss (%) of rabbiteye blueberry fruits 'Premier' at 4ºC.

Storage time (days)	Treatments				LSD 0.05
	Control	1.0 Atms	0.6 Atms	0.3 Atms	
7	2.34 Ab	0.34 Ac	4.68 Aa	1.02 Dc	0.81
14	1.92 Bb	0.28 Ac	5.28 Aa	5.47 Ca	0.69
21	2.33 Ac	0.16 Ad	5.15 Ab	8.94Aa	0.93
28	1.55 Cc	0.21 Ad	4.55 Ab	7.62 Ba	0.78
LSD 0.05	0.32	0.27	1.29	0.88	
Total wt loss	8.12C	0.99D	20.02B	23.04A	

ABCD: Means having the same letter within the column are not significantly different at $P \leq 0.05$.
abcd: Means with the same letter within the row are not significantly different at $P \leq 0.05$.

TABLE 2. Effect of low pressure and storage time on shriveling (%) of rabbiteye blueberry fruits 'Premier' at 4ºC.

Storage time (days)	Treatments			
	Control	1.0 Atms	0.6 Atms	0.3 Atms
0	1.0* Ba	1.0 Aa	1.0 Da	1.0 Da
7	1.0 Bb	1.0 Ab	2.0 Ca	1.0 Db
14	1.0 Bc	1.0 Ac	3.0 Ba	2.0 Cb
21	1.0 Bb	1.0 Ab	3.0 Ba	3.0 Ba
28	2.0 Ab	1.0 Ac	4.0 Aa	4.0 Aa

*Scale from 1-5 in which 1 is firm, 5 is shrivel, and 3 neither shrivel nor firm.
ABCD: Means having the same letter within the column are not significantly different at $P \leq 0.05$.
abcd: Means with the same letter within the row are not significantly different at $P \leq 0.05$.

Generally, juice pH tended to increase with the storage time regardless of the treatments used (Table 3). Storing fruits for 7 days at 0.6 atmospheric pressure and the control resulted in higher juice pH values compared to 1.0 and 0.3 atmospheric pressure treatments. At 14 days of storage, fruits stored at 0.6 and 0.3 atmospheric pressure had lower juice pH compared to 1.0 atmospheric pressure and the control. Fruits stored at 0.3 atmospheric pressure had lower juice pH at 21 days of storage than the other treatments. At 28 days of storage, juice pH was lower at 0.3 atmospheric pressure treatment compared to the control, but did not differ from 1.0 and 0.6 atmospheric pressure treatments. It seems that juice pH tended to vary among storage time and low pressure treatments used and this variability was within a narrow range of 0.25 pH unit.

TABLE 3. Effect of low pressure and storage time on juice pH of rabbiteye blueberry fruits 'Premier' at 4°C.

Storage time (days)	Treatments				LSD 0.05
	Control	1.0 Atms	0.6 Atms	0.3 Atms	
0	2.83 Da	2.83 Ca	2.83 Da	2.83 Da	0.04
7	2.99 Ca	2.95 Bb	2.98 BCab	2.96 Bb	0.02
14	3.03 BCa	3.06 Aa	2.94 Cb	2.92 Cb	0.05
21	3.06 ABa	3.08 Aa	3.00 Bb	2.96 Bc	0.04
28	3.08 Aa	3.06 Aab	3.06 Aab	3.02 Ab	0.05
LSD 0.05	0.05	0.04	0.04	0.04	

ABCD: Means having the same letter within the column are not significantly different at $P \leq 0.05$.
abcd: Means with the same letter within the row are not significantly different at $P \leq 0.05$.

Soluble solid concentrations (SSC) increased with the storage time regardless of the treatments used; however, storing fruits at 0.3 and 0.6 atmospheric pressure resulted in higher SSC values than the other treatments (Table 4). This increase in SSC might be related to the high moisture loss in 0.3 and 0.6 atmospheric pressure treatments. Fruits stored for 7 or 14 days at 0.6 atmospheric pressure had higher SSC than the other treatments. At 21 days of storage, 1.0 atmospheric pressure and the control treatments had lower SSC compared to 0.3 and 0.6 atmospheric pressure treatments. By the end of the storage period, fruits stored at 1.0 atmospheric pressure had lower SSC compared to other treatments. In disagreement with the finding of this experiment, Spalding and Reeder (1976) stated that soluble solids did not differ when limes were stored under LPS of 170 mm Hg compared to the normal pressure, and this might be due to the type of fruits used.

Titratable acidity (TA) decreased with the storage duration in 0.6 atmospheric pressure and the control treatments (Table 5). In 1.0 and 0.3 atmospheric pressure treatments, TA varied among storage time and ranged from 0.8266 to 0.5150 and from 0.8266 to 0.6831, respectively. Comparing low-pressure treatments with the control, at 7 days of storage, TA was lower at the control treatment compared to 0.3 atmospheric pressure, but did not differ from 1.0 and 0.6 atmospheric pressure. At 14 days of storage, fruits stored at 1.0 atmospheric pressure had lower TA compared to the other treatments. At 21 days of storage,

TABLE 4. Effect of low pressure and storage time on soluble solid concentrations (SSC) of rabbiteye blueberry fruits 'Premier' at 4ºC.

Storage time (days)	Treatments				LSD 0.05
	Control	1.0 Atms	0.6 Atms	0.3 Atms	
0	10.20 Ca	10.20 Ca	10.20 Ea	10.20 Da	NS
7	10.35 Cb	10.38 Bb	10.65 Da	10.33 Db	0.10
14	10.40 BCc	10.48 Bc	11.45 Ca	11.28 Cb	0.13
21	10.70 Bb	10.68 Ab	11.75 Ba	11.73 Ba	0.36
28	11.20 Ac	10.73 Ad	12.38 Ab	12.78 Aa	0.33
LSD 0.05	0.32	0.13	0.19	0.22	

ABCD: Means having the same letter within the column are not significantly different at $P \leq 0.05$.
abcd: Means with the same letter within the row are not significantly different at $P \leq 0.05$.

TABLE 5. Effect of low pressure and storage time on titratable acidity (TA) of rabbiteye blueberry fruits 'Premier' at 4ºC.

Storage time (days)	Treatments				LSD 0.05
	Control	1.0 Atms	0.6 Atms	0.3 Atms	
0	0.8266 Aa	0.8266 Aa	0.8266 Aa	0.8266 Aa	0.0082
7	0.6445 Bb	0.6732 Bab	0.6908 Bab	0.7192 Ca	0.0517
14	0.6470 Ba	0.5317 Db	0.6930 Ba	0.6621 Da	0.0554
21	0.5768 Cb	0.5150 Db	0.6577 Ba	0.6659 Da	0.0651
28	0.6020 BCbc	0.5831 Cc	0.6634 Bb	0.7715 Ba	0.0723
LSD 0.05	0.0594	0.0310	0.0754	0.0389	

ABCD: Means having the same letter within the column are not significantly different at $P \leq 0.05$.
abcd: Means with the same letter within the row are not significantly different at $P \leq 0.05$.

fruits held at 1.0 atmospheric pressure and the control had lower TA than to 0.3 and 0.6 atmospheric pressure. By the end of the storage period, 1.0 atmospheric pressure had lower TA compared to 0.3 and 0.6 atmospheric pressure but did not differ from the control. The data from this result showed that a decrease in TA loss in the 0.3 and 0.6 atmospheric pressure treatments was related to a high moisture loss from the berries.

Soluble solid concentrations to TA ratio (SSC/TA) varied with the storage duration when fruits were stored at 1.0 and 0.3 atmospheric pressure (Table 6). SSC/TA ratio ranged from 12.34 to 18.41 and from 12.34 to 17.63 for 1.0 and 0.3 atmospheric pressure, respectively. In 0.6 atmospheric pressure and the control treatments, SSC/TA ratio increased with the storage time. Comparing low-pressure treatments with the control, at 7 days of storage, SSC/TA ratio was lower in 0.3 atmospheric pressure compared to the control, but did not differ from 1.0 and 0.6 atmospheric pressure treatments. At 14 and 21 days of storage, SSC/TA ratio was higher in 1.0 atmospheric pressure compared to the other treatments.

TABLE 6. Effect of low pressure and storage time on soluble solid concentration (SSC) to titratable acidity (TA) ratio of rabbiteye blueberry fruits 'Premier' at 4°C.

Storage time (days)	Treatments				LSD 0.05
	Control	1.0 Atms	0.6 Atms	0.3 Atms	
0	12.34 Ca	12.34 Da	12.34 Da	12.34 Da	0.13
7	16.10 Ba	15.42 Cab	15.46 Cab	14.38 Cb	2.18
14	16.07 Bb	19.70 Aa	16.66 BCb	17.04 ABb	1.51
21	18.62 Ab	20.82 Aa	17.97 ABb	17.63 Ab	2.13
28	18.83 Aa	18.41 Ba	18.72 Aa	16.60 Ba	2.44
LSD 0.05	2.13	1.19	1.98	0.99	

ABCD: Means having the same letter within the column are not significantly different at $P \leq 0.05$.
abcd: Means with the same letter within the row are not significantly different at $P \leq 0.05$.

Fruit firmness did not differ with the storage time when fruits were stored at 1.0 atmospheric pressure and the control (Table 7). In 0.6 atmospheric pressure, fruit firmness varied with the storage time and ranged from 5.23 to 7.21. In 0.3 atmospheric pressure treatment, fruit firmness increased with the storage time. Comparing low-pressure treatments with the control, firmness was not affected; however, fruit firmness in fact was higher when fruits were held at 1.0 atmospheric pressure compared to the other treatments. This could be explained on the basis of a decline in the moisture content of the berries held in the other treatments. The machine starts its reading when the probe comes in contact with the berry, so a high reading of firmness will be obtained when the berry releases its juice.

Decay indices were observed at 21 days of storage and tended to increase as the duration of storage increased (Table 8). Comparing low-pressure storage treatments with the control, at 28 days of storage, fruits stored at 1.0 atmospheric pressure had lower decay compared to the control, but did not differ from 0.3 and 0.6 atmospheric pressure treatments. The finding of this experiment was in agreement with that reported by Borecka and Pliszka (1985).

Table 7. Effect of low pressure and storage time on compression force (N) of rabbiteye blueberry fruits ‘Premier’ at 4ºC.

Storage time (days)	Treatments				LSD 0.05
	Control	1.0 Atms	0.6 Atms	0.3 Atms	
0	5.23 Aa	5.23 Aa	5.23 Ca	5.23 Ba	1.05
7	5.98 Aa	5.88 Aa	6.99 ABa	5.86 ABa	1.86
14	5.83 Aa	5.16 Aa	6.09 ABCa	5.16 Ba	1.32
21	6.16 Aa	6.73 Aa	7.21 Aa	7.52 Aa	2.16
28	6.43 Aa	6.27 Aa	5.89 BCa	6.00 ABa	2.18
LSD 0.05	1.58	1.79	1.29	2.16	

ABCD: Means having the same letter within the column are not significantly different at $P \leq 0.05$.
abcd: Means with the same letter within the row are not significantly different at $P \leq 0.05$.

Table 8. Effect of low pressure and storage time on percent decay of rabbiteye blueberry fruits ‘Premier’ at 4ºC.

Storage time (days)	Treatments				LSD 0.05
	Control	1.0 Atms	0.6 Atms	0.3 Atms	
0	0.0 Ca	0.0 Ba	0.0 Ba	0.0 Ba	NS
7	0.0 Ca	0.0 Ba	0.0 Ba	0.0 Ba	NS
14	0.0 Ca	0.0 Ba	0.0 Ba	0.0 Ba	NS
21	1.0 Ba	0.25 Ba	0.5 Ba	1.0 ABa	1.39
28	2.75 Aa	1.0 Ab	1.5 Aab	1.75 Aab	1.75
LSD 0.05	0.85	0.65	0.96	1.15	

ABCD: Means having the same letter within the column are not significantly different at $P \leq 0.05$.
abcd: Means with the same letter within the row are not significantly different at $P \leq 0.05$.

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تأثير استخدام التخزين تحت الضغط الجوي المنخفض على ثمار العنبية

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قسم علوم النبات والتربة ، كلية الزراعة وعلوم الحياة ، جامعة الميسسيبي الحكومية،
مدينة الميسسيبي ، ولاية الميسسيبي - الولايات المتحدة الأمريكية

المستخلص. أجري هذا البحث لمعرفة أنسب الظروف للمحافظة على جودة ثمار العنبية باستخدام تقنية التخزين تحت الضغط الجوي المنخفض. أُجريت تجربة التخزين تحت الضغط الجوي المنخفض في غرفة نمو على درجة حرارة ٤ ْم باستخدام قدور ضغط مقاس ٢٢ كغرف للضغط المنخفض. ولقد تم الحصول على الضغط المطلوب باستخدام طلمبة شفط للهواء الرطب باستمرار. كانت المعاملات: ٠,١، ٠,٦، ٠,٣ ضغط جوي، أما معاملة الضابط فقد تم حفظها في نفس غرفة النمو علي أرفف تحت الضغط الجوي العادي.

أوضحت النتائج أن أقل فقد في الوزن، أعلى صلابة، أقل علامات عطب، ولم يظهر انكماش بمرور فترة التخزين (٢٨ يوما) كانت على الثمار التي تم تخزينها تحت ٠,١ ضغط جوي. بينما ازدادت درجة حموضة العصير مع ازدياد فترة التخزين وقلت مع معاملات التخزين تحت الضغط المنخفض. كما زادت تركيزات المواد الصلبة الذائبة مع ازدياد فترة التخزين وأن أقل زيادة وجدت حينما خُزنت الثمار تحت ٠,١ ضغط جوي. ولقد كانت الحموضة أعلى عندما تم تخزين الثمار تحت ٠,٣ ضغط جوي وذلك نتيجة للفقد العالي للماء. تباينت النسبة المئوية للحموضة وتركيزات المواد الصلبة الذائبة مع فترة تخزين الثمار تحت معاملتي ٠,١ و ٠,٣ ضغط جوي. واتجهت هذه النسبة إلى الزيادة مع زيادة فترة التخزين في كل من معاملة التخزين تحت ٠,٦ ضغط جوي ومعاملة المقارنة.