Original article

Changes in some chemical components and in the physiology of rambutan fruit (*Nephelium lappaceum* L.) as affected by storage temperature and packing material

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Changes in some chemical components and in the physiology of rambutan fruit (*Nephelium lappaceum* L.) as affected by storage temperature and packing material.

Abstract – **Introduction**. Rambutan (*Nephelium lappaceum* L.) is a kind of tropical fruit with high commercial value in international trade. However, harvested rambutan fruits suffer from a short shelf life and show rapid postharvest deterioration problems due to spintern browning and flesh decay. **Materials and methods**. Rambutan fruit (cv. 'Baoyan 5') were harvested in 2009 and 2010. Changes in some chemical components and the physiology of fruits were investigated at different storage temperatures (25 °C and 10 °C) and with different packing materials (regular low-density polyethylene and anti-moisture polyethylene bags). **Results and discussion**. Changes in the development of the browning index, and contents of total soluble solids, titratable acidity and vitamin C greatly decreased during low temperature storage (10 °C); moreover, low temperature storage (10 °C) could maintain a significantly higher level of superoxide dismutase activity and lower values of malondialdehyde and cell membrane permeability. The effects of packing material were different according to the different storage temperatures. At 10 °C, the beneficial effects of anti-moisture polyethylene bags on fruit quality and physiology were observed. However, at 25 °C, fruit packed with regular low-density polyethylene proved to be of better quality than those packed with anti-moisture polyethylene bags. **Conclusion**. The overall results suggest that packing with anti-moisture polyethylene bags and storage at 10 °C were the most suitable conditions to maintain quality and to extend the storage life of rambutan fruit.

China / *Nephelium lappaceum* / fruits / storage / temperature / packing material / chemical composition / postharvest physiology

Modifications de quelques composantes chimiques et de la physiologie des fruits de ramboutan (*Nephelium lappaceum* L.) en fonction de leur température de stockage et du matériel d'emballage.

Résumé – **Introduction**. Le rambutan (*Nephelium lappaceum* L.) est une espèce tropicale qui présente une grande valeur économique dans le commerce international. Toutefois, après leur récolte, les fruits du ramboutan ont une courte durée de vie et ils se détériorent rapidement en raison du brunissement de leurs épines et de la détérioration de leur chair. **Matériel et méthodes**. Des fruits de rambutan (cv. 'Baoyan 5') ont été récoltés en 2009 et 2010. Les modifications de certaines composantes chimiques et les changements physiologiques de ces fruits ont été étudiés en fonction de la température de stockage (25 °C et 10 °C) et du matériel d'emballage utilisé (polyéthylène standard de basse densité et sac en polyéthylène anti-humidité). **Résultats et discussion**. La valeur de l'index de brunissement et les teneurs en solides solubles totaux, acidité titrable et vitamine C ont fortement diminué au cours du stockage à basse température (10 °C) ; par ailleurs, le stockage à basse température (10 °C) a permis de maintenir un meilleur niveau d'activité de la superoxyde dismutase, ainsi que des faibles teneurs en malondialdéhyde et un moindre taux de perméabilité de la membrane cellulaire. La nature de l'emballage a eu des effets différents selon les températures de stockage testées. À 10 °C, le sac en polyéthylène anti-humidité a montré des effets bénéfiques sur la qualité des fruits et leur physiologie. Toutefois, à 25 °C, les fruits emballés avec du polyéthylène standard de basse densité se sont révélés être de meilleure qualité que ceux conservés en sac en polyéthylène anti-humidité. **Conclusion**. Les résultats globaux indiquent que les conditions les plus appropriées pour maintenir la qualité et prolonger la durée de stockage des ramboutans seraient un emballage en sac de polyéthylène anti-humidité, stocké à 10 °C.

Chine / *Nephelium lappaceum* / fruits / stockage / température / matériel de conditionnement / composition chimique / physiologie après récolte

1. Introduction

Rambutan (*Nephelium lappaceum* L.) is a popular tropical fruit widely cultivated in many Asian countries including Sri Lanka, Vietnam, Thailand and the Philippines. In China, there are only a few areas suitable for rambutan growing. Baoting County of Hainan province in China is one of the most suitable areas for producing rambutan fruit [1], which is becoming a very popular tropical fruit because of its attractive appearance, bright color and delicious taste [2]. However, fruit browning and decay can occur from 1 to 3 days after harvest and during storage and transportation. So, the enlargement in the cultivation area and long-distance transportation of rambutan fruit are seriously restrained by the postharvest losses [3].

The quality and storage life of fruit can be influenced by many factors, which include the effects of storage temperature [4]. Low temperature storage is considered to be one of the most basic and efficient methods for the storage of fruit, vegetables and other agricultural products [5, 6]. However, many reports have revealed chilling injury of tropical fruit [7]. Rambutan fruit is a typical tropical fruit; it has a greater sensitivity to low temperature, and shows symptoms of chilling injury during low temperature storage [8]. In our previous work, we reported that rambutan fruit suffered obvious chilling injury, fruit browning and rot when stored at 4 °C for 4 days [9]. Ohare also found that rambutan fruit showed serious browning and dehydration when stored at room temperature for 72 h [10]. Thus, a suitable low temperature seems to be very important for rambutan fruit.

The relative humidity in storage conditions is another important factor that affects the storage quality of fresh and living products. Usually, higher relative humidity is useful to maintain fruit water contents, thus inhibiting weight loss and preventing fruit browning. However, excess moisture in the storage environment or packing bags resulted in fruit browning and rot [11, 12]. The packing method, shape and materials have a significant impact on the storage quality and shelf life of fresh products [13, 14].

To date, there have been few reports about postharvest handling and technology in rambutan fruit. Latifah *et al.* reported that polyethylene film could be used as liner for bulk packing of rambutan for local and export markets [8]. The objective of our study was to investigate the effects of different storage temperatures and packing materials using anti-moisture polyethylene on storage quality, and the postharvest physiology of rambutan fruit.

2. Materials and methods

2.1. Fruit materials

Fully mature and medium size (about 35 g weight per fruit) rambutan fruits cv. 'Baoyan 5' were harvested in June, 2009, and July, 2010, from a local orchard located in Baoting County of Hainan province (the national standardization sample base of rambutan in China). The harvested fruit were transported within 3 h to the horticultural laboratory of Hainan University. Firstly, the branches of fruit were sorted into single fruits with a 0.5-cm stem, then the diseased, bruised and injured fruit were rejected, and sound fruit of uniform size and appearance were randomly distributed into different lots.

2.2. Treatments

The sample fruit were divided into four groups: the first group was put into regular low-density polyethylene (RPB) (0.02-mm thick, bought from a supermarket, the popular brand 'Lubao' in China). The second group was put into anti-moisture polyethylene bags (APB) (0.02-mm thick, provided by the Key Laboratory for Postharvest Science and Technology of Fruit and Vegetables in Guangdong Province, China); the main function of anti-moisture polyethylene bags is to prevent condensation of excess water in the bag. These first two groups of packed fruits were stored at 25 °C (kept in a thermostatic container, Saifu, China). A third group was put into regular low-density polyethylene, and a fourth group was put into anti-moisture polyethylene bags, which were stored at 10 °C. Each bag with nine fruits was sealed; the ambient relative humidity was controlled at 90%.

Four treatments, each in three replicates of three fruits for a total of nine rambutan fruits, were used at each sampling date: samples were picked, randomly, to be analyzed at two-day intervals.

2.3. Quality evaluation

The browning index was assessed based on the surface of the fruit and the spinterns that had turned brown [15]. The grades of browning incidence were noted as follows: 0: no browning; 1: 1/3 surface browning; 2: 1/2 surface browning; 3: 1/2–3/4 surface browning; and 4: 3/4 or more of surface area browning. The browning index was calculated according to the formula: Browning index = $\Sigma (G \times N_G) \times 100 / (G_H \times N_T)$, where G represents the browning grade (0 to 4), N_G represents the number of fruit at the corresponding grade, G_H represents the highest grade and N_T represents the total number of measured fruits. The soluble solids (%) in fruit flesh were determined using a temperature-compensated digital refractometer (ATAGO, Japan). The titratable acidity content was determined by acid-base titration, and the content of vitamin C was determined by 2,6-dichloroindophenol according to Wang [16].

2.4. Physiological determination

2.4.1. Cell membrane permeability

Tissue discs (3-mm diameter) were prepared from the central section of the peel. Fifteen discs from three fruits (five discs per fruit) were put into a 50-mL tube with 25 mL deionized water; the tube was placed for 3 h at room temperature and conductivity (C1) was measured by a conductivity instrument (ECOSCAN, Singapore). Then, the covered tube was heated and boiled for 10 min and cooled to room temperature. Conductivity (C2) was measured as (C1). The cell membrane permeability was expressed by relative conductivity [(C1 / C2) × 100].

2.4.2. Malondialdehyde content and superoxide dismutase activity

Malondialdehyde content was measured by the thiobarbituric acid reaction method [17]. Superoxide dismutase activity was assayed according to Beauchamp and Fridovich [18] with a small modification. Samples of flesh (1.0 g) were homogenized in 50 mM phosphate buffer (pH 7.0) containing 1% (w/v) polyvinylpyrrolidone (PVP). The homogenate was centrifuged at 10,000 *g* for 20 min at 4 °C and the supernatant was used as a source of enzyme rude extract solution. One unit of activity was defined as the amount of enzyme required to cause a 50% inhibition of the reduction of nitroblue tetrazolium (NBT, bought from Fluka, USA) at 560 nm.

2.5. Statistical analysis

Data were analyzed and plotted using Sigma Plot 10.0 software (Jandel Scientific, San Rafael, CA, USA), and the significance of differences between means was determined by Tukey's test at the level of $P = 0.05$.

3. Results and discussion

3.1. Fruit browning index

The browning index in the peel and spinterns of rambutan fruit increased gradually with extension of storage time (*table I*), confirming previous findings [11]. Firstly, the browning index was significantly affected by storage temperature (*figure 1*). On the same storage day, the peel and spintern browning indices of rambutan fruit stored at 25 °C were much higher than that stored at 10 °C ($P < 0.05$), which suggests that low temperature inhibited the fruit browning; similar results have been reported by Srilaong *et al.* [19] and Sivakumar *et al.* [20]. On the other hand, the effects of packing material on the browning index between different storage temperatures were obviously different. At 25 °C, the speed of the increase in the browning index of fruit in anti-moisture polyethylene bags was faster than that

Table I. Changes in the fruit browning index of rambutan fruit as affected by packing material, storage temperature and storage time.

Packing material	Storage temperature (°C)	Rambutan part	Storage time (days)					
			0	2	4	6	8	10
Regular Low-Density Polyethylene (RPB)	25	Peel	0.0	27.6 b	39.6 b	65.5 b	77.7 b	100.0
		Spinterns	0.0	35.5 A	52.7 B	76.8 A	88.1 A	100.0
	10	Peel	0.0	28.2 b	48.4 b	56.6 c	71.5 b	93.5
		Spinterns	0.0	32.3 A	53.7 B	66.8 B	78.8 A	100.0
Anti-moisture Polyethylene Bag (APM)	25	Peel	0.0	42.0 a	60.5 a	87.7 a	93.3 a	100.0
		Spinterns	0.0	47.3 A	80.3 A	93.4 A	97.1 A	100.0
	10	Peel	0.0	20.5 b	31.3 c	46.5 c	65.5 c	93.3
		Spinterns	0.0	24.6 B	46.8 B	57.8 B	71.2 B	98.8

Using Tukey's test ($P = 0.05$): in each column, means followed by a different letter (a or b) are significantly different from each other for the browning index of peel; means followed by a different letter (A or B) are significantly different from each other for the browning index of spinterns.

of fruit in regular low-density polyethylene. The lower value of the browning index in fruit packed in anti-moisture polyethylene bags than those packed in regular low-density polyethylene was observed in the fruits stored at 10 °C.

Some previous findings suggested that there were close relationships among the degree of fruit browning, the water status and the storage temperature. The different combinations of temperature and packing bags could lead to the great differences in fruit browning. Both excess moisture and excess dry conditions accelerated the browning of fruit and rot [21, 22]. In our study, the anti-moisture polyethylene bags combined with higher temperature (25 °C) storage probably resulted in excess dry conditions, which contributed to browning problems of fruit. However, at lower temperature, anti-moisture polyethylene bags might supply a suitable water status and could inhibit the browning of fruit. This result seemed to be in agreement with previous reports about storage conditions of pomegranate fruit, at 8 °C combined with 70–75% relative humidity and 25 °C combined with 40–60% RH [23].

3.2. Contents of total soluble solids, titratable acidity and vitamin C

The contents of total soluble solids, titratable acidity and vitamin C are very important properties of fruit quality and nutrition.

Our results showed that the total soluble solids contents of rambutan fruit stored at 10 °C were significantly higher than those of fruit stored at 25 °C ($P < 0.01$) (*figure 2*). They revealed that lower temperature was very effective in maintaining total soluble solids content. The same effects of low storage temperature on titratable acidity content and vitamin C content could be seen too. These results confirmed previous reports showing that lower temperature was better for maintaining quality and nutrition of fruits [24]. Furthermore, according to our results, the effects of the packing material on contents of total soluble solids, titratable acidity and vitamin C were more complex than storage temperature (*figure 2*).

Firstly, anti-moisture polyethylene bag packing of rambutan maintained the high contents of total soluble solids and titratable acidity during storage at both 25 °C

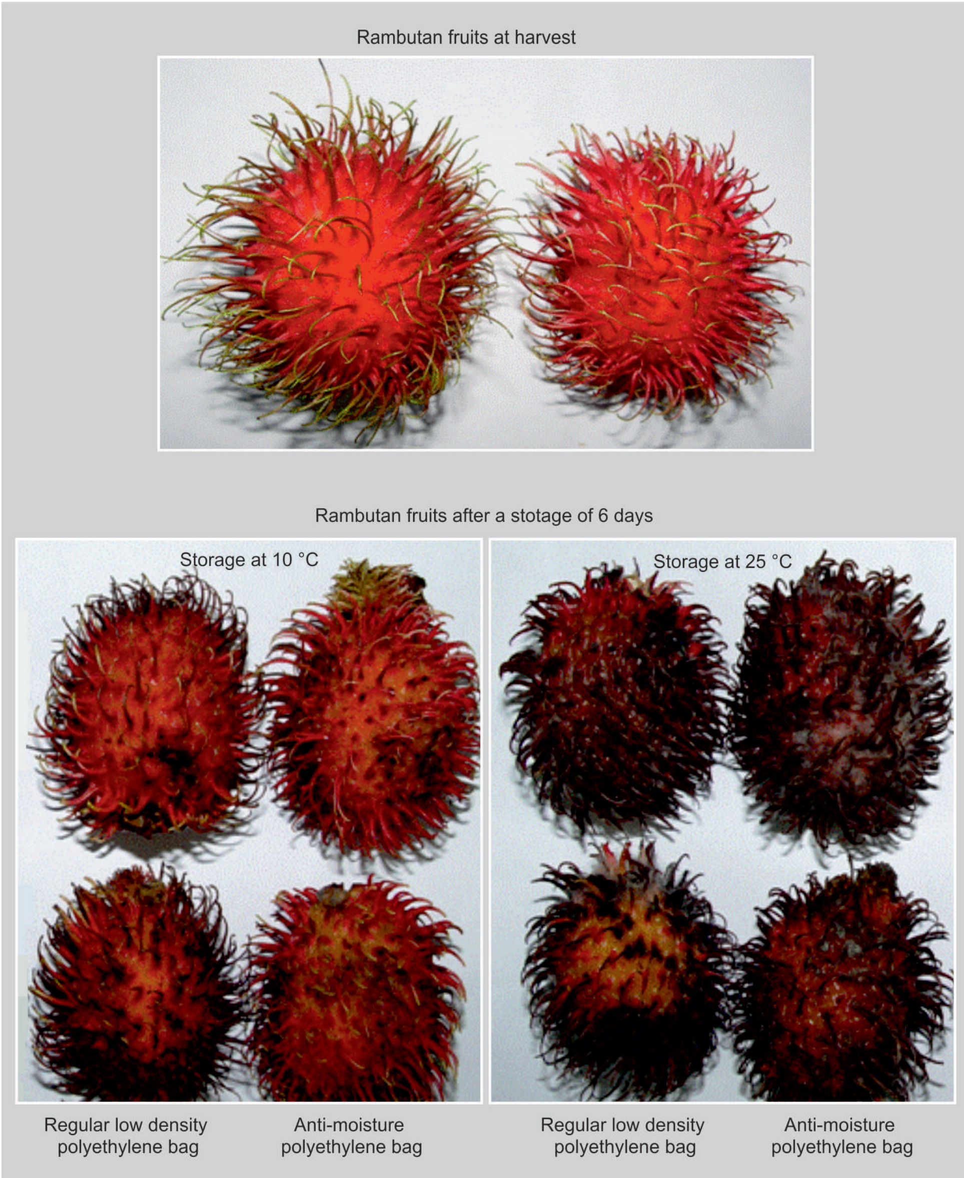

Figure 1.
Fruit of rambutan at harvest, then changes after 6 days of storage at two different temperatures (10 °C or 25 °C) and in two different packing materials (regular low-density polyethylene or anti-moisture polyethylene bags).

and 10 °C; similar maintenance of total soluble solids and titratable acidity by suitable film wrapping was reported by Latifah *et al.* [8] and many fruits and vegetables, including carambola fruit [25], pomegranate fruit [23] and broccoli [26], have been reported. On the other hand, there was no significant difference ($P > 0.05$) between different packing materials in vitamin C content at the same storage temperature (*figure 2*).

The fruit flavor is a very important parameter for customer acceptability. High sugar and relatively high acid content are required for good fruit flavor. In our study, the fruit flavor of rambutan fruit packed in anti-moisture polyethylene bags and stored at low temperature (10 °C) was better than that of fruit packed in regular low-density polyethylene and stored at high temperature (25 °C), which might be attributed to its ability to maintain higher contents of total soluble

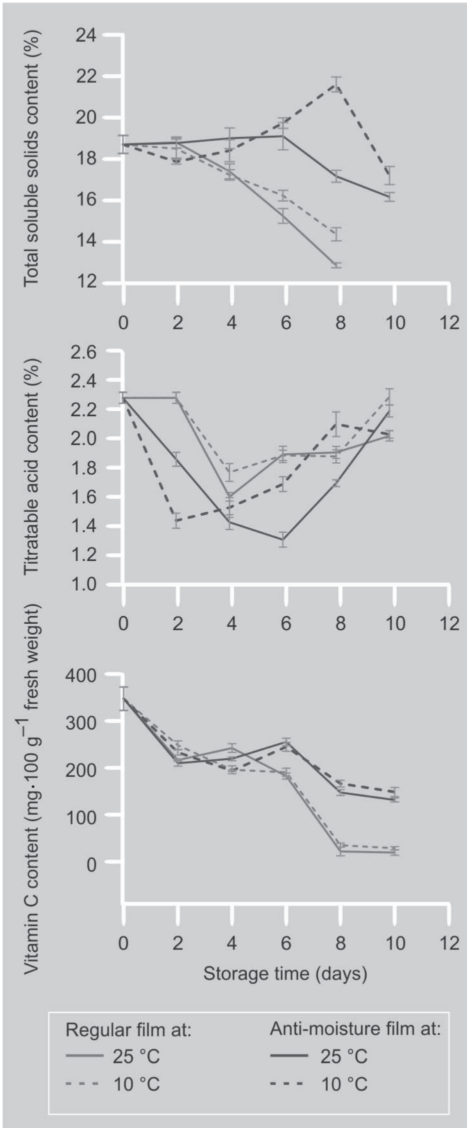

Figure 2.
Changes in contents of total soluble solids, titratable acidity and vitamin C in rambutan fruit as affected by storage temperature and packing material. Each bar represents the mean ± standard error of the results from three replicates.

solids, titratable acidity and vitamin C during storage of rambutan fruit (*figure 2*). Similar results have been reported by Sopee *et al.* [27].

3.3. Cell membrane permeability

The cell membrane permeability can show the degree of damage of cells and tissue [28]. The cell membrane permeability of rambutan fruit increased with increase in storage duration, and this change was obviously affected by storage temperature

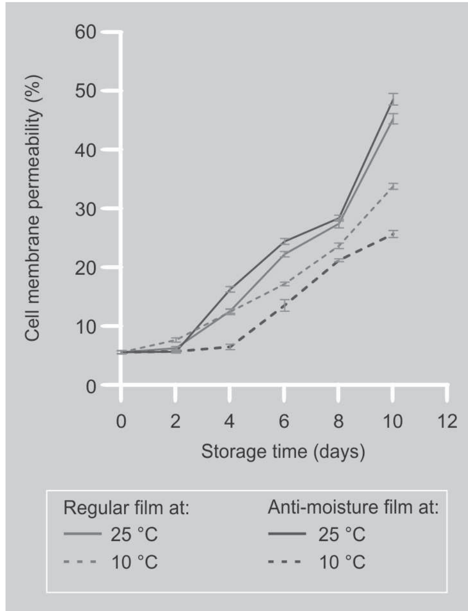

Figure 3.
Changes in cell membrane permeability of rambutan fruit as affected by storage temperature and packing material. Each bar represents the mean ± standard error of the results from three replicates.

(*figure 3*). The increase in cell membrane permeability of rambutan fruit was greatly inhibited ($P < 0.01$) by storing at lower temperature, both for general film-packed fruit and for anti-moisture-packed fruit. These results are in agreement with Concellon *et al.*, who reported there was lower cell membrane permeability in eggplant fruit under cold temperature storage than in those at room temperature [29].

Mansour [30] and Janeczko *et al.* [31] reported close relationships between the senescence of plants and cell membrane permeability. Higher cell membrane permeability reflected plant cell damage or that growth development had stopped. However, from another point of view, the lower cell membrane permeability could prove the freshness and delicious quality of rambutan fruit stored at low temperature as compared with fruit stored at higher temperature. As for packing material, no significant difference ($P > 0.05$) in cell membrane permeability between general packing and anti-moisture polyethylene packing was observed at the same storage temperature (*figure 3*).

3.4. Activity of superoxide dismutase activity and content of malondialdehyde

During storage of rambutan fruit, superoxide dismutase activity exhibited a peak tendency (*figure 4*). Higher levels ($P < 0.01$) of superoxide dismutase activity were observed in the fruits stored at 10 °C than in those stored at 25 °C, as noticeable not only in general film packing but also in anti-moisture film packing. At both 10 °C and 25 °C, anti-moisture polyethylene bags could greatly enhance the superoxide dismutase activity ($P < 0.01$) compared with the fruits packed in regular low-density polyethylene (*figure 4*). The results obtained suggested that cold storage and packing with anti-moisture polyethylene bags could maintain a higher level of superoxide dismutase activity of rambutan fruit during storage.

A gradual increasing trend was shown in the content of malondialdehyde during storage at 10 °C and 25 °C (*figure 4*). The storage temperature and packing material could clearly influence the malondialdehyde content. During the early days of storage (especially on the 4th day), the malondialdehyde contents in fruit stored at 10 °C were higher than those in fruit stored at 25 °C ($P < 0.05$). However, in the later storage days (from the 6th day), malondialdehyde contents in fruit stored at 25 °C increased sharply. There were remarkable differences ($P < 0.01$) among the four treatments (*figure 4*).

Superoxide dismutase activity is regarded as a kind of protective enzyme in the plant [32], and malondialdehyde is the product of cell membrane lipid peroxidation in plants [33]. Many studies have demonstrated that stresses, such as low temperature [31], low moisture [34] and high NaCl [35], could enhance the activity of superoxide dismutase activity to protect the cell from injury and death. Meanwhile, the malondialdehyde content of stressed plants was lower than those with no stress. According to our results, higher superoxide dismutase activity and lower malondialdehyde content in fruit packed in anti-moisture polyethylene bags at low temperature (10 °C) correlated well with each other; it might be another important reason for delaying the senescence, maintaining the quality and prolonging the storage life of rambutan fruit.

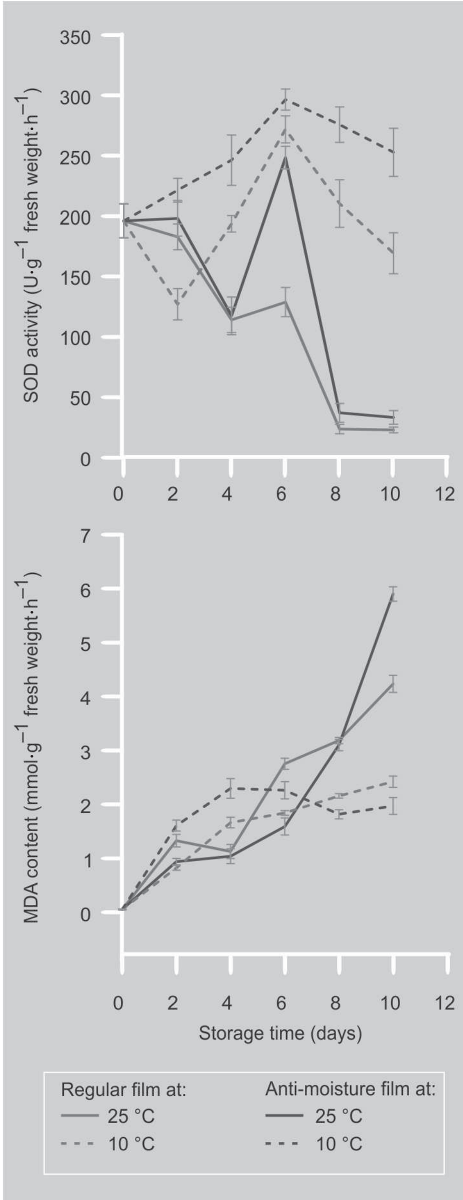

Figure 4.
Changes in superoxide dismutase activity and malondialdehyde content of rambutan fruit as affected by storage temperature and packing material. Each bar represents the mean ± standard error of the results from three replicates.

4. Conclusions

Anti-moisture film packing and a temperature of 10 °C are most beneficial for maintaining peel color, flavor and storage life of rambutan fruit; indeed, this treatment inhibited the browning of peel, reduced the degradation of total soluble solids, titratable acidity and vitamin C, increased the activity of superoxide dismutase activity, and suppressed the increase in cell membrane permeability and malondialdehyde content. These results suggest that regular low-density polyethylene is an alternative for storage and transportation of rambutan fruit at room temperature. However, if low temperature conditions are present, anti-moisture film packing is the best choice for storing rambutan fruit.

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Modificaciones de algunos compuestos químicos y de la fisiología de los frutos de rambután (*Nephelium lappaceum* L.) en función de su temperatura de almacenaje y del material de envase.

Resumen – **Introducción**. El rambután (*Nephelium lappaceum* L.) es una especie tropical que presenta un gran valor económico en el comercio internacional. Sin embargo, después de su cosecha, los frutos de rambután tienen una duración de vida corta y se deterioran rápidamente por el oscurecimiento de sus espinas y por el deterioro de su pulpa. **Material y métodos**. Se cosecharon frutos de rambután (cv. 'Baoyan 5') en 2009 y 2010. Se estudiaron las modificaciones de ciertos compuestos químicos y los cambios fisiológicos de estos frutos en función de la temperatura de almacenaje (25 °C y 10 °C) y del material de envase empleado (polietileno estándar de baja densidad y bolsa de polietileno antihumedad). **Resultados y discusión**. El valor del índice de oscurecimiento y los contenidos de sólidos solubles totales, acidez valorable y vitamina C disminuyeron fuertemente en el curso del almacenaje a baja temperatura (10 °C); por otro lado, el almacenaje a baja temperatura (10 °C) permitió mantener un mejor nivel de actividad del superóxido dismutasa, así como unos contenidos bajos de malondialdehído y un menor índice de permeabilidad de la membrana celular. La naturaleza del envase tuvo efectos diferentes según las diferentes temperaturas de almacenaje sometidas a prueba. A 10 °C, la bolsa de polietileno antihumedad mostró efectos beneficiosos en la calidad de los frutos y en su fisiología. Sin embargo, a 25 °C, los frutos envasados con polietileno estándar de baja densidad resultaron ser de mejor calidad que aquéllos conservados en bolsa de polietileno antihumedad. **Conclusión**. Los resultados generales indican que las condiciones más apropiadas para mantener la calidad y para prolongar la duración del almacenaje de los rambutanes serían las de un envase en bolsa de polietileno antihumedad, almacenado a 10 °C.

China / *Nephelium lappaceum* / frutas / almacenamiento / temperatura / maquinaria de embalaje / composición quimica / fisiología postcosecha