HEALTHCARE PACKAGING CONSORTIUM

Cloud Publications
International Journal of Advanced Packaging Technology
2014, Volume 2, Issue 1, pp. 84-95, Article ID Tech-246
ISSN 2349 – 6665, doi 10.23953/cloud.ijapt.10

Cloud Publications

Research Article **Open Access**

Evaluating the Performance of Coconut Fiber and Wood Straw as Cushioning Materials to Reduce Injuries of Papaya and Mango during Transportation

Clívia Danúbia Pinho da Costa Castro[1], José de Assis Fonseca Faria[1] and Tiago Bassani Hellmeister Dantas[2]

[1]University of Campinas, Faculty of Food Engineering, Department of Food Technology, Rua Monteiro Lobato, Campinas, SP, Brazil
[2]Packaging Technology Center – CETEA/ITAL, Av. Brasil, Campinas, SP, Brazil

Correspondence should be addressed to José de Assis Fonseca Faria, assis@fea.unicamp.br

Publication Date: 30 April 2014

DOI: https://doi.org/10.23953/cloud.ijapt.10

Abstract For the purpose to explore more ecologically sound alternatives as cushioning materials to protect fruits against injury during transport, the objective of the research was to evaluate the performance of coconut fiber and wood straw during the simulated transport of papayas and mangoes. Tests were carried out to simulate the transport of fruits in corrugated paperboard boxes in three different packaging systems: (1) with no cushioning, (2) with coconut fiber and (3) with wood straw. Physical and physiological behaviors of papaya and mango throughout transport and storage period were studied, and the rate of injuries, weight loss, skin color and respiration rate were quantified. The results showed that the coconut fiber was more efficient than wood straw in the prevention of pulp injuries, but not in prevention of abrasions on papaya surface. In mangoes, no significant differences were found between the two cushioning materials.
Keywords *Natural Fiber; Cushioning; Transport Packaging; Fruit Injuries*

1. Introduction

Economical and environmental concerns over natural resources are intensifying, which becomes evident through practices like waste utilization, alternative material development and, in some cases, substitution of fossil material by renewable material.

Of the natural fibers available, coconut fiber is becoming one of the most used in the development of environmentally friendly products, probably due to its characteristic of being an agricultural waste. In this area we find the traditional manufacturing of rope, brush and tapestry, and, more recently, automotive parts and gardening products. In general, coconut fiber presents good properties in reinforcing composite, acoustic and thermal insulation materials [1, 2, 3]. Other uses were found in absorbing material for petroleum and heavy metals [4, 5]. Some studies have mentioned the possibility of using the coconut fiber as a means of protection in packaging systems [6, 7], but the present authors found no research on the behavior of this material in the fruit industry.

Tissue paper, wood straw, molded pulp trays and expanded polyethylene nets are components commonly found in use to protect fruits and vegetables during transportation [8, 9]. Cellulosic materials have been in use for some time, but plastic materials are now more widely used, mostly for their effective performance with limited amount [10, 11]. However, ecological requirements have led to a reduction in the amount of plastic used in the manufacture of packaging [12], and more alternative materials and technologies are being studied and developed.

In the agriculture sector, horticultural products require a special attention regarding transport packaging system improvements, since in most cases such products have no primary packaging and are very susceptible to mechanical damages. Such injuries cause post-harvest loss and interfere in the classification and consumer purchase decision. Among the tropical fruits, papaya and mango present a rapid world production and commercialization [13]. These fruits are also susceptible to losses by mechanical damage, since the papaya epidermis is very thin, subjecting the microorganism penetration easily through ruptures and abrasions caused by mechanical forces during transportation [14, 15], while mango, with a thicker epidermis, develops internal damages that are not so easy to detect.

Thus, the main objective of this study is to evaluate the performance of coconut fiber as an alternative cushioning material for the transport of papaya and mango, and compare its performance to that of wood straw.

2. Materials and Methods

The raw material used for coconut fiber was the green coconut shell resulting from post-consumer disposal after coconut juice consumption. The material was obtained from kiosks and leisure facilities in Campinas, SP, and then the coconut husks were then mechanically processed into fiber. The wood straw was obtained directly from the FAPEM Ltd., a straw factory - in Campinas, SP.

A transport simulation test was conducted in order to evaluate the coconut fiber performance as a cushioning material. Two tropical fruits were selected: papaya, a fruit with a delicate structure; and the mango, that has a thicker epidermis. Papayas, variety Sunrise, and mangoes, variety Palmer, were purchased from the distributor - Campinas Central Supply Center, Campinas, SP, Brazil (CEASA Campinas). The fruits were purchased in corrugated boxes of the pre-assembled type and subsequently used in the transport simulation test. In order to standardize the experiments, fruits were selected according to the technical regulation of the Brazilian Ministry of Agriculture [16, 17]. Such requirements were used to guarantee uniformity in size, coloration and quality standard. Thus, papayas were selected from 430 to 500 grams, 15% to 25% of yellow epidermis and fruit surface with maximum limit of 5% of damage, while mangoes were selected from 400 to 500 grams, epidermis coloration from rose to red, pulp color predominantly yellow around the seed and fruit surface with maximum limit of 1% of severe damage, 5% of light damage and 5% of spots.

2.1. Transport Simulation Test

The selected fruits were physically analyzed for possible defects and packaged in three different packaging systems: (1) corrugated box with no cushioning (system 1 or control system), (2) corrugated box with coconut fiber (system 2) and (3) corrugated box with wood straw (system 3). There were fifteen fruits packed, in one layer, inside each box.

The completely randomized experimental design was used for the transport simulation, according to the 2 x 3 factorial scheme (two types of fruits and three packaging systems), adding up six treatments (Table 1 and Figure 1) with two repetitions for each treatment.

Table 1: *Transport Simulation Test Treatments and the Respective Packaging Systems for Papaya and Mango*

Treatment	Packaging System
A	Papaya; system 1
B	Papaya; system 2
C	Papaya; system 3
D	Mango; system 1
E	Mango; system 2
F	Mango; system 3

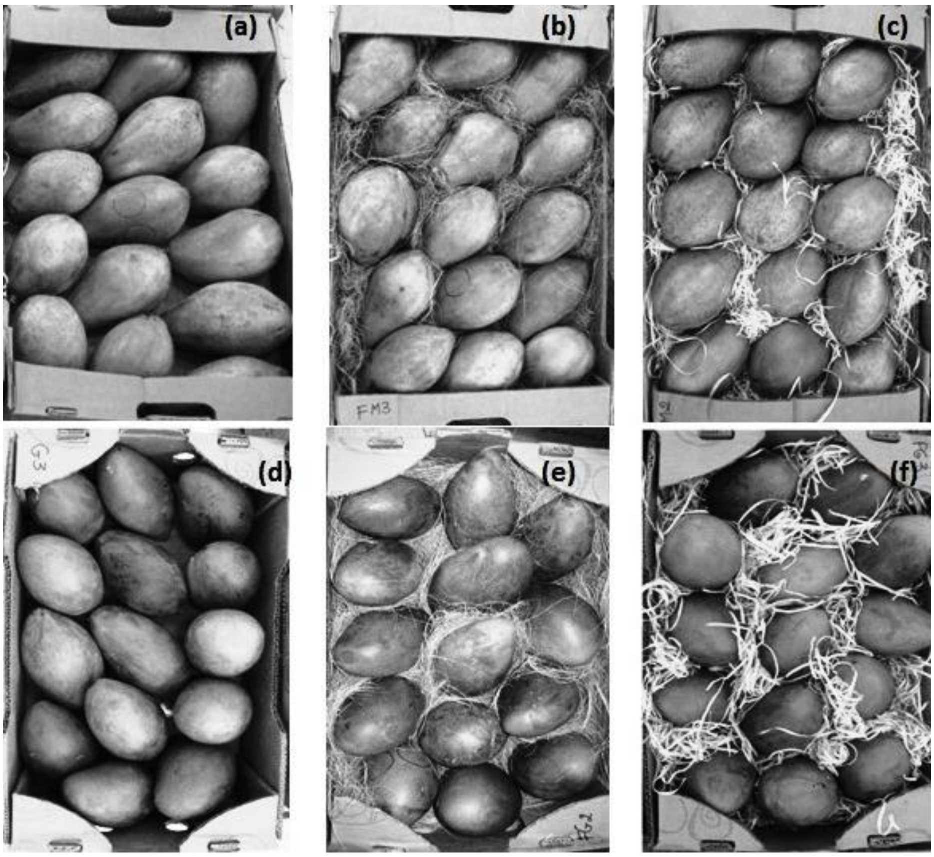

Figure 1: *Packaging Systems Used for Papaya and Mango Transport Simulation Test: (a) Treatment A, (b) Treatment B (c) Treatment C, (d) Treatment D, (e) Treatment E and (f) Treatment F*

In order to compare the performance of coconut fiber with that of wood straw, 1.9 kg/m^2 of each material type was used inside every corrugated box. This value was based on the cushioning curves

[18] and the volumetric capacity of the boxes. For papaya, box dimensions were 0.43m x 0.27m x 0.13m and for mango were 0.54m x 0.34m x 0.13m.

The truck transport simulation test was carried out according to the ASTM D4728 (2006) procedure, using the PSD (Power Spectrum Density) for truck transportation, assurance level II with an overall g rms of 0.52, for 1 h at 23 ± 1ºC and 55 ± 1% R.H.

The fruit packages were placed directly on the MTS model 891 vibration table controlled by MTS model 407 Controller, and SignalCalc 550 Vibration Controller (Figure 2).

Figure 2: *Disposal of Packaging on a Vibration Table*

2.2. Evaluation of the Package Cushioning Systems

After the simulation test, ten papayas and ten mangoes were randomly selected from each packaging system to evaluate the performances of the cushioning materials.

The papayas were evaluated the day before simulation test (zero time) and during the six days of storage, while the mangoes were stored for eight days in a conditioned room at 24.5 ± 2ºC and 60 ± 5% R.H. During this period the fruits were classified according to their mechanical injuries, weight loss, instrumental color and respiration rate.

With respect to the injuries, the epidermis of each fruit was classified with respect to the absence or presence of *serious damages* and/or *slight damages* [16, 17]. The following were considered as *serious damages*: rupture of the epidermis covering an area greater than 5% of the fruit surface; rupture of the epidermis reaching the fruit pulp, and injury of the pulp without rupturing the epidermis; the following as *slight damages*: rupture of the epidermis covering an area less than 5% of the fruit surface.

To evaluate instrumental color, a direct reading of the external fruit surface was made using the CIELab color system. Initially green areas were selected in a random distribution such that the readings, carried out in triplicate, were analyzed from the same areas throughout the storage period.

The respiration rate was evaluated in a closed system by measuring the production of carbon dioxide by the fruit during one hour. To avoid problems due to interference caused by the accumulation of gases in the fruit tissues in this measurement; preliminary tests were carried out to guarantee that during the storage period, the CO_2 measurement was greater than 0.2% [19]. CO_2 reading was accomplished with a MOCON Pac Check TM 650 carbon dioxide and oxygen analyzer. Respiration rate is expressed in [mg of $CO_2.kg^{-1}.h^{-1}$], considering dessicator volume, fruit volume and mass, and time dessicators remained closed.

The results were analyzed statistically using the analysis of variance (ANOVA), and the means of each treatment were tested for significance and compared with each other by the Tukey test ($p < 0.05$), except for the injury incidence analysis which was done by human visual inspection.

3. Results and Discussions

3.1. Papaya

For the papaya, the *appearance of injuries* was observed twenty four hours after simulation test (Figure 3). As for the comparison, none of the packaging systems evaluated was found to be effective in preventing mechanical injuries under the conditions imposed in the simulation test, since all the fruits already showed some damage on the first day of analysis.

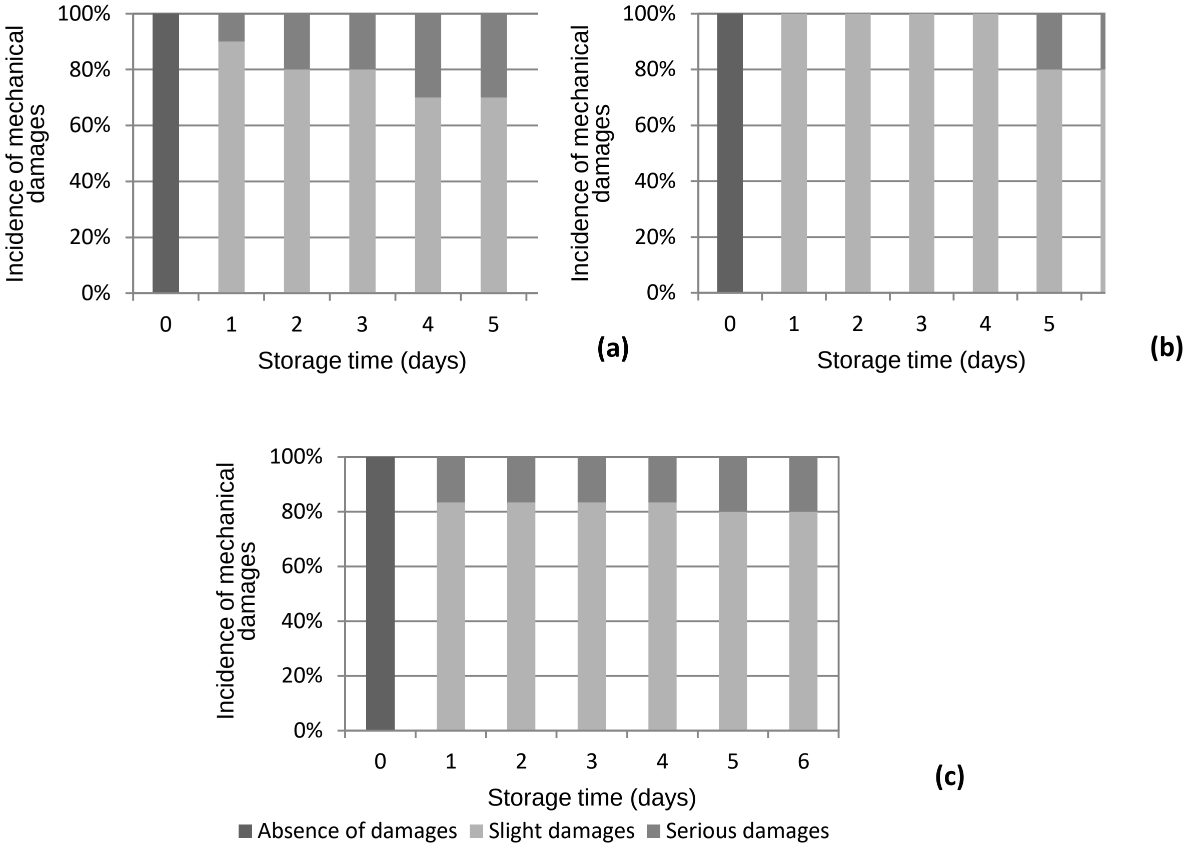

***Figure 3**: Incidence and Classification of Mechanical Damages in Papaya: a) No Cushioning; b) With Coconut Fiber; c) With Wooden Straw, Along the Storage Period*

During the evaluation of *slight damage*, epidermis injuries were observed in the system with no cushioning, highlighting the damage caused by the structure of the corrugated box. In the system with coconut fiber, the formation of deeper injuries was observed, probably due to the rotary movement of the fruit on its own axis, during the transport simulation test. In the system with wood straw, *abrasions* were found over the whole surface of contact with the straw, causing a corrugated appearance, particularly at the end of the storage period. Abrasions were also observed in the system with coconut fiber, but the wood straw was shown to cause worse injuries on the epidermis of the fruit, as it had a thicker and coarser structure than the coconut fiber.

As for *serious damage*, the packaging system with coconut fiber was more efficient in preventing injury to the pulp than the other systems, considering that such injuries were only observed on the fifth day of storage in the papaya fruits protected by fiber. Figure 4 shows an example of serious damage to the epidermis of a papaya fruit (with no cushioning), where a well-defined dark spot can be observed located in the contact area of the fruit with the corrugated box. In this case, most of the impact energy was absorbed by the fruit and little energy was absorbed by the corrugated box, as also observed in a study with apples [20].

Figure 4: *Papaya with Serious Damage – System with No Cushioning*

Regarding *weight loss*, there was no significant difference ($p \geq 0.05$) among the treatments during the storage period. Considering that weight losses below 5% may be sufficient to reduce the value of papaya fruits [21], even papayas from the system with no cushioning remained within this loss limit up to the third day of storage. In treatment B and C such behavior was attributed to abrasions caused by the cushioning, evident from the fruit epidermis.

With respect to the *instrumental color* of the studied areas, the abrasions on the fruit surfaces were not sufficiently aggressive to cause enzymatic browning; there was an increase in luminosity during the whole storage period. In a study with Formosa papayas [22], this behavior was related to mechanical injuries, which can accelerate the metabolism of the fruit and promote a change in skin color.

As for the luminosity of the fruit skin, there was no significant difference between the treatments ($p \geq 0.05$). However, only treatments A and B remained constant during storage; results showed that fruits of treatment C had a lower luminosity at the beginning, only matching the other treatments after the fourth day of storage (Figure 5).

The results for the hue angle revealed that all systems showed a significant decrease in the values of this parameter with time (Figure 5) and there was no significant difference ($p \geq 0.05$) between them. The development of the yellow color was similar in all treatments. The average results ranged from green (111º) to yellow, tending to orange (72º).

About color intensity, the same change in chromaticity was observed for all treatments ($p \geq 0.05$). As illustrated in Figure 5, during storage, only the fruits from treatment C showed a significant difference from the second day of storage, when the hue angle defined the color of the epidermis as being between yellow and orange quadrants.

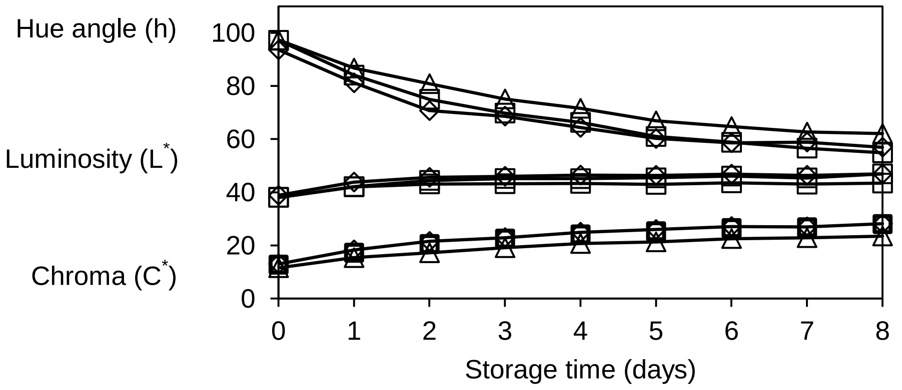

Figure 5: *Luminosity, Changes during Storage in Hue Angle and Chroma of the Epidermis of Papaya Fruits Submitted to Transport in the Following Packaging Systems: (Δ) No Cushioning, (□) with Coconut Fiber and (◊) with Wood Straw*

With respect to respiratory activity, Figure 6 shows the rate of carbon dioxide production by the papaya fruits during storage. Regarding the treatments, the wood straw system differed from the other treatments ($p < 0.05$) due to a greater production of CO_2.

Considering that an increase in *respiration rate* is generally proportional to the severity of the injuries [23], this result matches with the incidence of serious injuries observed in the pulp of papaya fruits protected by wood straw (Figure 6). Furthermore, a higher respiration rate is usually associated with a reduction in the fruit shelf life and quality loss [24].

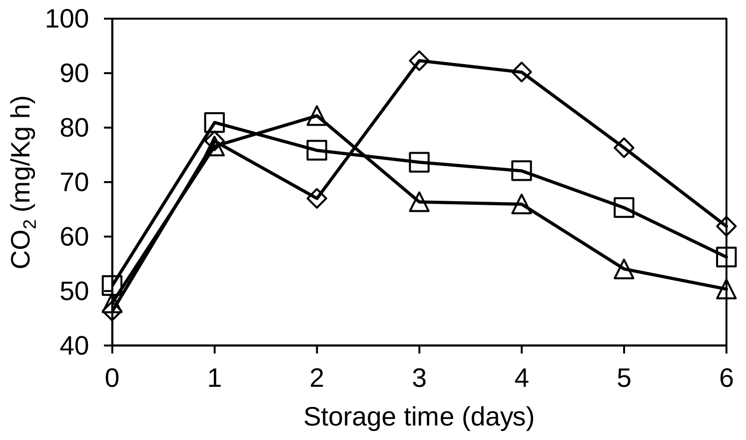

Figure 6: *Comparison of Carbon Dioxide Production during Storage by Papaya Fruits Submitted to Transport in the Following Packaging Systems: (Δ) No Cushioning, (□) with Coconut Fiber and (◊) with Wood Straw*

Thus for moderate intensity transport and distribution, coconut fiber was effective in preventing injuries from impact, but did not prevent the occurrence of injuries due to abrasion since the delicate epidermis of the Sunrise papaya requires a cushioning material made up of much thinner fibers, similar to tissue paper.

3.2. Mango

In the packaging system with coconut fiber the majority of *injuries* to mangoes were considered to be light and only found from the third day of storage (Figure 7). The cushioning systems were shown to be efficient in protecting the mangoes under the conditions imposed during the simulation test, considering that the appearance of the fruit was not compromised during storage. On the other hand, anthracnoses became evident in the epidermis of some fruits on the fifth day of storage.

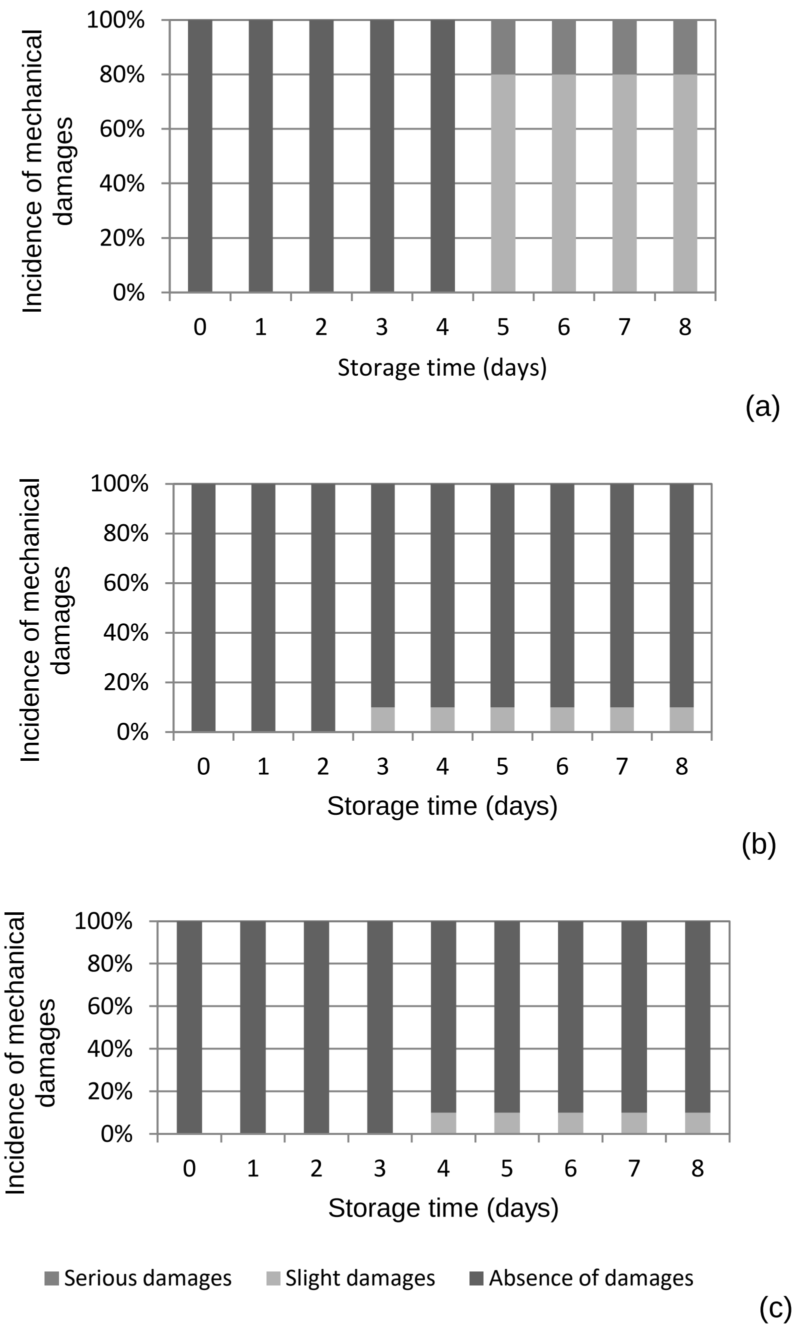

Figure 7*: Incidence and Classification of Mechanical Damages in Mangoes: a) No Cushioning; b) with Coconut Fiber; c) with Wooden Straw, Along the Storage Period*

The results for *weight loss* during the last eight days of storage clearly showed there was no significant difference between the packaging systems evaluated ($p \geq 0.05$). The absence of *abrasions* contributed to the uniform loss in weight between the systems. Regarding weight loss, it is interesting to highlight the fact that the cellulose-based cushioning materials maintained the optimum conditions of humidity and temperature by absorbing the moisture lost from the fruit [26] thus avoiding the proliferation of fungi in high humidity environments.

The changes in skin *color* of the fruits were also highly similar between all the treatments evaluated and presented no significant difference with respect to storage time ($p \geq 0.05$). With respect to luminosity, on average the mangoes packed in fiber or straw presented a higher mean for luminosity throughout storage as compared to that of the control without cushioning, with a significant difference considering the mean values. The results for luminosity (Figure 8) are in agreement with the appearance of a greater number of injuries in the fruits without cushioning. Surface injuries of the fruits caused darkening due to enzymatic oxidation, in addition to causing metabolic changes that accelerated the senescence of the fruits [25].

The results for hue (Figure 8) showed similar behavior for all treatments, with a gradual change in yellow color towards an orange color. Such behavior is evidence of the disappearance of chlorophyll and increases in anthocyanin, total carotenoids and beta-carotene pigments in the fruit epidermis [26]. Such modifications result in greater color intensity throughout storage, principally for the color orange, as shown in the results for chroma in Figure 8.

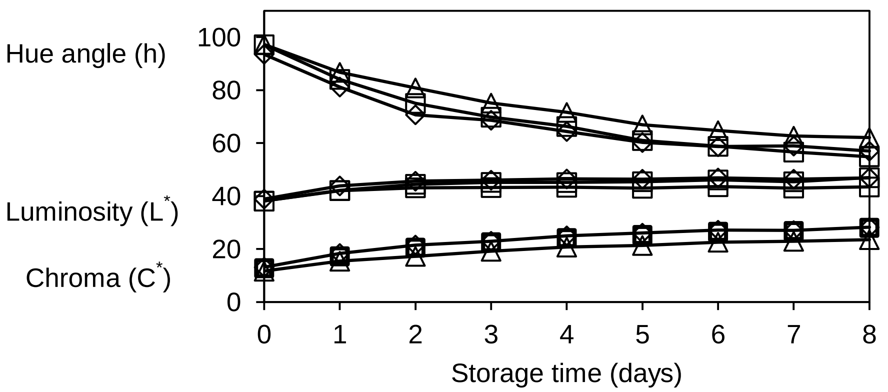

Figure 8: *Changes in Luminosity in the Color, Values for Hue of the Skins of Mangoes, Values for Chroma Submitted to Transport in the Following Packaging Systems: (Δ) control, (□) fiber (◊) straw, During the Storage Period*

With respect to *respiratory activity*, Figure 9 shows the results for the production of carbon dioxide. The mangoes protected by coconut fiber presented similar behavior to those of the control system. On comparing the mean values obtained for the treatments, the production of CO_2 by the system with fiber was significantly lower than that for the mangoes protected by wood straw. However, with time there was no significant difference in the production of CO_2, indicating that the degree of injury caused to the mangoes was not very intense.

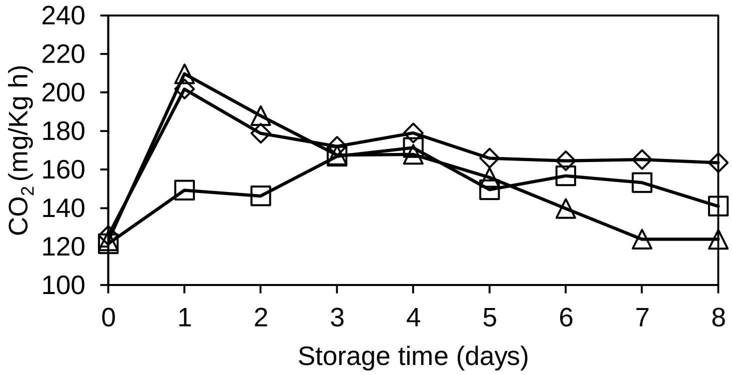

Figure 9*: Comparison of the Production of Carbon Dioxide by Palmer Mangoes Stored at 23±2ºC as a Function of the Packaging System: (Δ) Control, (□) Fiber (◊) Straw*

4. Conclusions

Coconut fiber reduced the more serious injuries in the papaya fruits, such as those that affect the pulp, but did not prevent the incidence of abrasions during ripening. In fruits with a thicker epidermis, the number of abrasions caused by the fiber would probably be smaller.

Compared to wood straw, coconut fiber produced less damage on fruit epidermis, since the straw has a rough, more rigid surface than the fiber, and is therefore far more aggressive for delicate fruits such as the papaya. For the mangoes, it was difficult to determine bruising due to their thick epidermal, suggesting that in such case is necessary to cut the fruit open to investigate bruising effect that was not apparent from the outside of the fruit.

In general the injuries caused to the mangoes during the simulation test were not so drastic with respect to the fruit quality after transport, that is, there was little change in the natural metabolism of the fruits. No significant difference was observed between the use of coconut fiber and wood straw; both materials presented cushioning characteristics against serious injuries as compared to the treatment with no cushioning (control).

Acknowledgements

The authors are grateful to the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for their financial support and to the Brazilian Scientific Research Council (CNPq) for the research grant.

References

[1] Foluladi, M.H., Ayud, Md., and Mohd Nor, M.J. *Analysis of Coir Fiber Acoustical Characteristics*. Applied Acoustics. 2011. 72 (1) 35-42.

[2] Satyanarayana, K.G., Guimarães, J.L., and Wypych, F. *Studies on Lignocellulosic Fibers of Brazil. Part I: Source, Production, Morphology, Properties and Applications.* Composites Part A: Applied Science and Manufacturing. 2007. 38 (7) 1694-1709.

[3] Silva, G.G., Souza, D.A., De, Machado, J.C., and Hourston, D.J. *Mechanical and Thermal Characterization of Native Brazilian Coir Fiber*. Journal of Applied Polymer Science. 2000. 76 (7) 1197-1206.

[4] Annunciado, T.R., Sydenstricker, T.H.D., and Amico, S.C. *Experimental Investigation of Various Vegetable Fibers as Sorbent Materials for Oil Spills*. Marine Pollution Bulletin. 2005. 50 (11) 1340-1346.

[5] Igwe, J.C., Abia, A.A., and Ibed, C.A. *Adsorption Kinetics and Intraparticulate Diffusivities of Hg, As and Pb ions on Unmodified and Thiolated Coconut Fiber*. International Journal of Environment Science Technology. 2008. 5 (1) 83-92.

[6] Grimwood, B.E., 1975: *Coconut Palm Products: Their Processing in Developing Countries*. Food and Agriculture Organization of the United Nations, Roma.

[7] Osborn, D.B., 1967: *Package Cushioning Systems*. Packaging Materials and Containers, Blackie e Son Limited, London.

[8] Chonhenchob, V., and Singh, P. *Packaging Performance Comparison for Distribution and Export of Papaya Fruit*. Packaging Technology and Science. 2005. 18 (3) 125-131.

[9] Luengo, R. de F.A., and Calbo, A.G., 2006: Embalagens para comercialização de hortaliças e frutas. Circular Tecnica, Brasília, DF Dezembro.

[10] Mckinlay, A.H., 2004: *Cushioning Systems: Interior Packaging for Shock and Vibration Protection*. Transport Packaging, New York. 109-123.

[11] Ramsland, T., 1989: *Cushioning Materials*. Handbook on Procurement of Packaging, PRODEC, Finland.

[12] Gonzalez, P.M., and Zepka M.M., 2008: Embalagens e materiais de acolchoamento e o meio ambiente. Portal de Embalagens.

[13] FAO (Food and Agriculture Organization of the United Nations), 2010: Fibre. http://faostat.fao.org.

[14] Bollen, A.F., Nguyen, H.X., and Dela Rue, B.T. *Comparison of Methods for Estimating the Bruise Volume of Apples*. Journal of Agricultural Engineering Research. 1999. 74 (4) 325-330.

[15] Timm, E.J., and Brown, G.K. *Impacts Recorded on Avocado, Papaya, and Pineapple Packing Lines*. Applied Engineering in Agriculture. 1991. 7; 418-422.

[16] Brasil, Portaria nº249, de 29 de julho de 2009. Anexos do regulamento técnico do mamão.

[17] Brasil, Portaria nº689, de 21 de novembro de 2002. Regulamento técnico de identidade e de qualidade da manga.

[18] Castro, C.D.P.C., Faria J.A.F., and Dantas, T.B.H. *Testing the Use of Coconut Fiber as a Cushioning Material for Transport Packaging*. Materials Science and Applications. 2012. 3 (3) 151-156.

[19] Kader, A.A., and Saltveit, M.E., 2003: *Respiration and Gás Exchance*. Postharvest Physiology and Pathology of Vegetables, Marcel Dekker, New York.

[20] Jarimopas, B., Singh, S.P., and Sayasoonthorn, S. *Test Method to Evaluate Bruising During Impacts to Apples and Compare Cushioning Materials*. Journal of Testing and Evaluation. 2007. 35. 1-6.

[21] Cenci, S.A., 2002: *Procedimentos pós-colheita. Mamão: pós-colheita. Brasília*. Embrapa Informação Tecnológica.

[22] Santos, C.E.M., Couto D'Araújo, F.A., Salomão, L.C.C., Cecon, P.R., Júnior, A.W., and Bruckner, C.H. *Comportamento pós-colheita de mamões Formosa 'Tainung 01' acondicionados em diferentes embalagens para o transporte*. Revista Brasileira de Fruticultura. 2008. 30. 315-321.

[23] Kader, A.A., 1987: *Respiration and Gas Exchange of Vegetables*. Postharvest Physiology of Vegetables, Marcel Dekker, New York.

[24] Phan, C.T., 1975: *Respiration and Respiratory Climacteric*. Postharvest Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables.

[25] Mohsenin, N.N., 1986: *Physical Properties of Plant and Animal Materials: Structure, Physical Characteristics and Mechanical Properties*. Gordon and Breach, New York.

[26] Lakshminarayana, S., 1980: *Mango.* Tropical and Subtropical Fruits: Composition, Properties and Uses. AVI Publishing, Westport.