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Effects of Maturity, Dipping Time and Drying Method on Selected Physical and Mechanical Properties of Dried Saba (*Musa acuminate x balbisiana*) Leaves as Packaging Material

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ABSTRACT

Banana leaves are currently used as packaging material for fresh fruits and vegetables. This study focused on the characterization of the physical and mechanical properties of dried banana leaves. This study evaluated the effect of maturity (young, mature and old leaves), dipping time and drying method on the color, tensile strength and puncture strength of dried banana leaves. The leaves were dipped in boiling water at varying time (2 to 3 s, 5 to 6 s and 8 to 9 s) and dried using different methods (air, sun and oven drying). After drying, the samples were subjected to color analysis, tensile and puncture testing. Browning index was computed using the L, a* and b* values measured. The combination of blanching and drying process will improve the properties of the leaves. The result showed that the browning index decreases with maturity while it increases with longer dipping time and higher drying temperature. Tensile strength was computed and showed that as the leaves mature, tensile strength decreases. Also, tensile strength decreases with longer dipping time. Puncture strength increases with maturity and decreases with longer dipping time. Overall, the combination of blanching followed by drying was proven to be effective in increasing the physical strength of the banana leaves. The study can be used in knowing the quality and finding the appropriate harvesting age of the leaves to be used as a packaging material.*

Keywords: banana leaves, dipping time, tensile strength, puncture strength, packaging material

INTRODUCTION

Banana is the number one fruit commodity in the Philippines both in production and land scale. The Philippines produced a total of 2.39 million metric tons of banana in the last quarter of 2019. The total banana production is distributed based on the requirements of the domestic and export market (PSA, 2019). Aside from its fruit, banana plants are also known for its leaves. After a banana plant yields its fruit, it dies and is replaced by a secondary stem called sucker (FAO, 2011). The main stem together with the leaves is considered waste as it was thrown away after fruit is harvested. Banana leaves should be utilized to prevent it from being treated as waste (PBworks, 2007).

Banana leaves are widely used as a plate and food packaging material. It does not only protect and conserve the foods original state but also maintains the moisture content and enhances its color, aroma, and taste. However, advances in technology and living standard decreased the use of traditional packaging. The demand for plastic packaging increased and traditional packaging have been overlooked. Using banana leaves as a packaging material is cost-efficient and environmentally friendly (Abdullah, Lah & Pakri, 2013). The use of these traditional packaging materials can be a substitute to plastic packaging as there had been bills and resolutions filed in the government to ban single-use plastics.

The concept of food packaging is based on how effective it is in preserving the freshness and quality of the food it contains. It allows the food to be transported safely through long distances, without damage, and still be acceptable for the consumer's standard at the time of consumption (IFT, 2007). The packaging provides a barrier against dirt, microorganisms, insects, oxidation, heat, moisture loss or absorption, gas exchange, light and other contaminants (Practical Action, 2008). It should also protect the food from shock, vibrations, compressive forces and other types of forces that may be encountered during distribution and storage (Robertson, 1998).

The packaging material is selected by considering the product and material characteristics such as physical, chemical, biochemical, and microbial. The selection also takes into consideration the processes needed in designing the packaging material. Food contamination, loss of package integrity or decrease in quality can happen if there is an occurrence of chemical changes in the food, packaging material or both (IFT, 2007).

Additional processing such as blanching or passing over flame is done to improve its strength and make it more pliable Compared to the other packaging material, banana leaves are more delicate. These processes also help in releasing the natural oils and fragrance of the leaves that aids in developing richer flavor of the food stored in it.

This study aimed to determine the effect of maturity, dipping time, and drying methods to color, tensile strength and puncture strength of dried banana leaves. These parameters will help in knowing the quality and finding the appropriate maturity of the leaves to be used as a packaging material. This knowledge may also be used in determining the appropriate storage conditions, handling, and transportation needs for the commodity.

MATERIALS AND METHODS

Banana Leaves Samples

Banana leaves samples were harvested from a grower in Bay, Laguna. Leaves at the top (youngest leaf), middle (fourth youngest leaf) and bottom (oldest leaf) were cut from the plant and the midrib part of the leaves was removed. The center portion (Figure 1) of the cut leaves were used in the experiment. The leaves were cut into 10cm by 20cm. Three replicates were made per treatment.

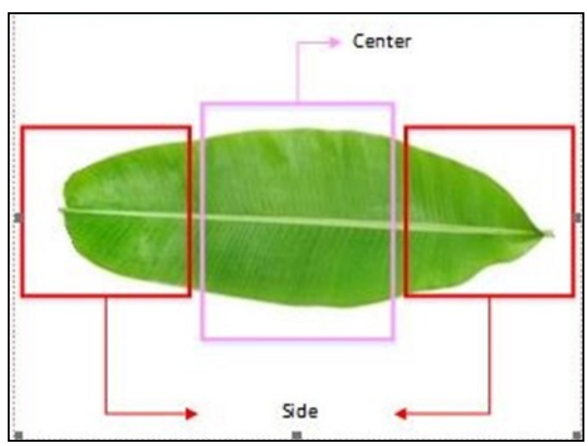

Figure 1. Segmented parts of banana leaves

Dipping Process

Three dipping time were used in this experiment, 2 to 3 seconds, 5 to 6 seconds and 8 to 9 seconds. The samples were dipped in the boiling water using a modified screen container to ensure that the samples were dipped uniformly. Figure 2 shows the set-up for the dipping process. The weights of the leaves were measured after the dipping process using an electronic beam balance.

Drying Process

The three drying methods used were sun drying (average temperature was 33°C), open-air drying (average temperature was 30°C) and oven drying at 35°C. In sun drying, the samples were dried in an open area where sunlight was available. A plastic straw was used to hang the samples. The samples were turned over at least once every 30 minutes to ensure an even drying. The same set-up, but without the sunlight exposure, was used for the air-drying method. Memmert Universal Oven UF260 was used for oven drying. The leaves were dried until the moisture content (wet basis) of the samples were equal to 70 to 75%. The final moisture content was based on the measured value of the commercially available banana leaves in the market.

Moisture Content

The moisture content of the samples was determined using oven drying method and Equation 1 was used to compute for the value.

$$\%MC_{wb} = \frac{W_i - W_f}{W_i} \times 100$$

Equation 1

where, W_i is the initial weight of the sample in g, W_f is the final weight of the sample after drying in g and % MC_{wb} is the initial moisture content wet basis in %.

Color Analysis

After drying, the samples were subjected to color analysis. A color meter (Konica Minolta Color Reader CR-10) which was calibrated using a white standard was used to measure color parameters. The

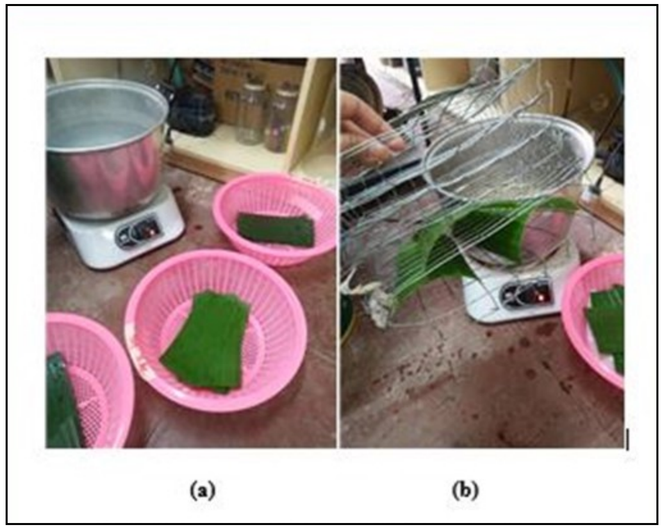

Figure 2. Dipping process set-up (a) and Screen Container (b)

Figure 3. Konica Minolta Color Reader CR-10

parameters L* (lightness or brightness), a* (color channel from green to red) and b* (color channel from blue to yellow) were measured at three random points in the sample. Figure 3 shows the color meter that was used.

The readings obtained was the color difference between the white standard and the sample. The color value reading of the samples were computed using Equation 2.

$$X_{Sample} = \Delta_X + X_{standard}$$

Equation 2

where, X_{sample} is the color value reading of the sample and Δ_X is the difference between the white standard and the sample and $X_{standard}$ is the color value reading of the white standard.

Using the L*, a* and b* values obtained, the Browning Index (BI) was computed (Equations 3 and 4).

$$\text{Browning Index (YI)} = 100 \times \frac{x - 0.31}{0.17}$$ **Equation 3**

$$X \text{ is } \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*}$$ **Equation 4**

where, a^* is the indication of red or green color, b^* is the indication of yellow or blue color, L^* is the indication of lightness of color and BI is the Yellowness Index.

Strength Test

Tensile Test

Universal testing machine (UTM) was used to measure the tensile and puncture strength of the samples. Figure 4 shows the set up for tensile strength test. The samples were cut lengthwise (dog bone shape) as shown in Figure 5.

The UTM's maximum load was set to 450 N, with speed at 1 mm/s. The elongation was recorded until the sample breaks. The UTM presented the maximum force and maximum strain of the sample. The maximum tensile strength was computed using Equation 5. The thickness of the samples was measured using a digital caliper.

$$P_T = \frac{F}{A}$$ **Equation 5**

where, F is the force of fracture in N, A is the cross-sectional area (thickness x minimum width of the sample) in mm^2 and P_T is the tensile strength in MPa.

Puncture Test

The other half of the sample with dimensions of 5cm by 20cm was subjected to puncture testing. The puncture test was done using the UTM as shown in Figure 6. The puncture test evaluated the fracture toughness of the leaves. In the sampling method, the thicker central vein of the leaves was avoided. Also, the parts closer to the blade edge were not included. The UTM was set to a maximum load of 450 N, speed at 1 mm/s and the initial load to zero. The diameter of the flathead puncher was 10 mm. The UTM presented the maximum force and maximum strain of the sample. The maximum puncture strength was computed using Equation 6 and Figure 6 shows the UTM set-up during the process.

Figure 4. Tensile test set-up

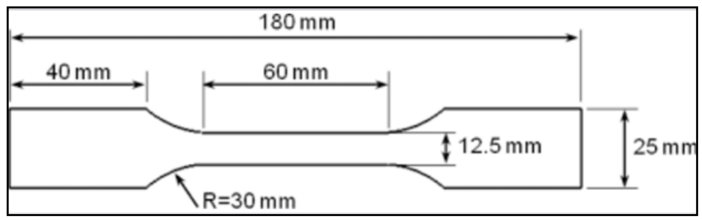

Figure 5. Dimensions of the dog bone

Figure 6. Puncture testing set-up

$$P_P = \frac{F}{A} \quad \text{Equation 6}$$

where, F is the force of fracture in N, A is the cross-sectional area (thickness x $2\pi r$) in mm^2 and P_P is the puncture strength in MPa.

Statistical Analysis

Analysis of variance (ANOVA) was used to compare the variation between the values obtained from the samples. Tukey's Honestly Significance Difference (HSD) test was used to analyze the significant difference. The software R studio was used to compute for the ANOVA and Tukey's Honestly Significance Difference (HSD).

RESULTS AND DISCUSSION

Moisture Content

The samples were dried from 79.32 ± 0.83% MC_{wb} (initial) to approximately 72.72% ± 2.28% MC_{wb} (commercially available banana leaves). The final MC_{wb} of the samples were 75.33 ± 0.57 % (oven drying), 73.92 ± 1.38 % (sun drying) and 74.93 ± 0.94 % (air drying).

Leaf Color

The L*, a* and b* values of the samples were measured. Figures 7 to Figure 9 shows the L, a* and b* values of the samples at different treatments, respectively.

The L* value of the young leaves ranges from 38 to 62, leaves at the middle ranges from 28 to 45 while the values from bottom are from 26 to 43. Since, top is the youngest leaf, its L* value is higher than the older leaf as the L* value indicates lightness. The a* values of the leaves located at the top ranges from 0.5 to -7.3. The mature leaves ranges from 0.5 to -7.5 and the old leaves ranges from -0.6 to -6.4. This means that younger leaves have less green color. The results of

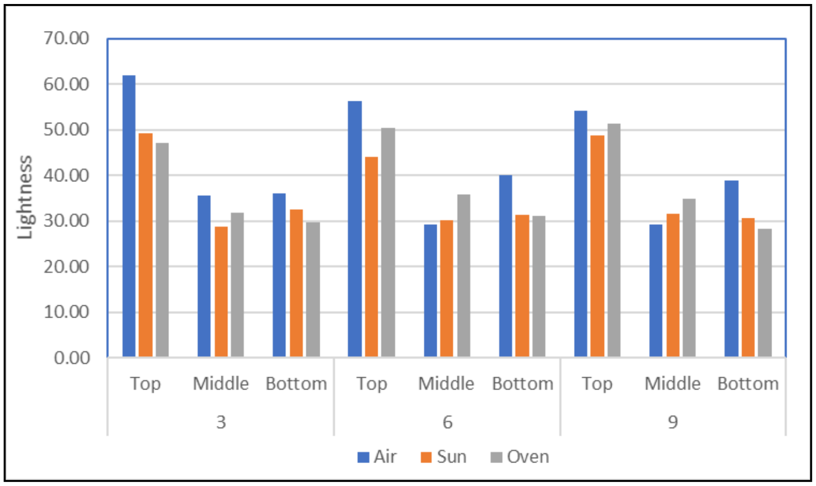

Figure 7. Lightness values of dried banana leaves

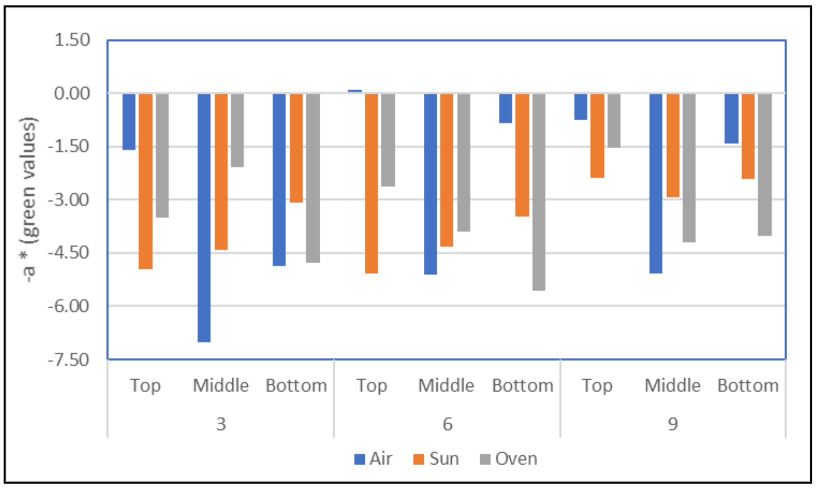

Figure 8. a* values of dried banana leaves

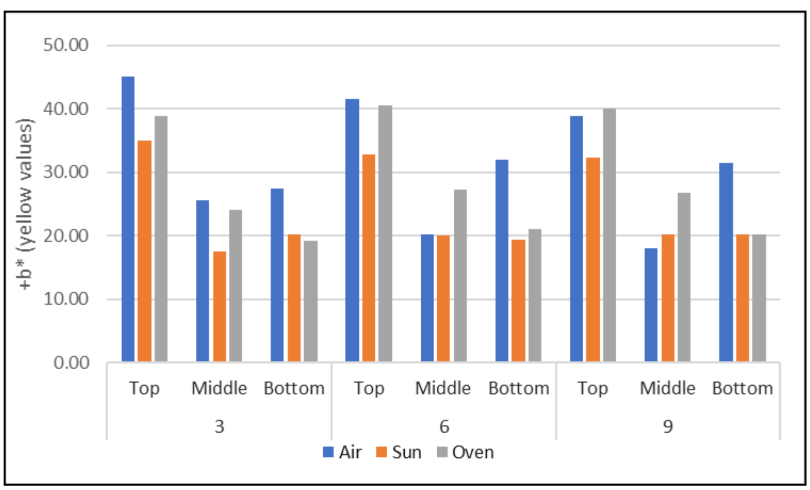

Figure 9. b* values of dried banana leaves

the b* also shows the same trend as the leaves from the top had the highest average b* value.

This indicates that of the three drying methods used, sun drying had the lowest average L* value at 36.3. Sun drying also had the highest green value (a*) and lowest b* value. Leaves that were dipped longer in hot water had low green value (a*) and had light yellow index based on the L* and b* value. According to Monsalve-Gonzales *et al*. (1993), increased in a* values is an indicator of browning. Low values of b* (Bernardo *et al*., 2011) and increase in L* value is also an indication of browning.

The Browning index (BI) value of the samples was computed using Equation 3. The BI value at different treatments are shown in Figure 10 and Table 1. Oven drying had the highest value of BI and sun drying had the lowest value. Analysis of variance showed significant effect of the maturity and drying method and dipping time. Post-hoc comparisons using Tukey HSD test indicated that the BI values at each maturity stage, maturity, dipping time, method of drying and their interaction is significant. This indicates that the browning index (BI) is affected by the choice of drying method, dipping time and maturity. This means that the youngest leaf which is the young leaves has a significant increase in the BI value and the BI value also increases as the temperature and dipping time increases. In general, the browning index decreases with maturity. The top had the highest browning index followed by the middle, then the bottom portion with the lowest

Table 1. Browning index (BI) of dried banana leaves.

Drying Method	Dipping Time (seconds)	Maturity	Browning Index Mean		SD	
Air	2-3	Young	114.36	±	2.90	abc
		Mature	82.77	±	43.08	cde
		Old	108.35	±	13.54	abcde
	5-6	Young	109.08	±	2.40	abcd
		Mature	84.51	±	15.72	cde
		Old	130.23	±	5.67	a
	8-9	Young	102.63	±	5.23	abcde
		Mature	74.96	±	1.71	de
		Old	131.96	±	1.51	a
Sun	2-3	Young	114.83	±	16.01	abc
		Mature	71.40	±	3.19	e
		Old	87.38	±	9.23	cde
	5-6	Young	112.34	±	5.54	abcd
		Mature	84.47	±	15.22	cde
		Old	87.73	±	12.49	cde
	8-9	Young	115.51	±	9.51	abc
		Mature	90.18	±	5.79	cde
		Old	92.76	±	3.84	bcde
Oven	2-3	Young	134.10	±	1.81	a
		Mature	110.61	±	6.33	abcd
		Old	85.94	±	13.76	cde
	5-6	Young	136.12	±	7.67	a
		Mature	118.95	±	5.22	abc
		Old	89.18	±	4.39	cde
	8-9	Young	127.86	±	5.31	ab
		Mature	115.95	±	7.71	abc
		Old	91.77	±	6.40	bcde

Means within group in a column followed by a common letter do not differ with at Tukey's Honest Significance Difference (HSD) at 5% level.

brown index. Browning index increases with longer dipping time and higher drying temperature.

Browning index is an indicator of chemical change or the color change due to oxidation of a freshly cut fruit or vegetable surface or during storage or drying. It symbolizes the purity of brown color. It is considered as a crucial parameter in drying processes where enzymatic and non-enzymatic browning occurs (Yun, Zzaman & Yang, 2015). The positive values indicate that after drying, browning occurred. According to Demirhan & Obek (2009), the browning index of basil increased with an increase in microwave drying time. Also, browning index increases as the temperature increases (Chutintrasri & Noomhorm, 2007). Measurement of browning index is used to select a suitable drying technique that will not cause high degradation of color quality (Opara & Pathare, 2013).

Table 2. Tensile strength values of the dried banana leaves samples.

Drying Method	Dipping Time (seconds)	Maturity	Tensile strength (MPa)			
			Mean		SD	
Air	2-3	Young	1.72	±	0.04	de
		Mature	1.91	±	0.10	bcde
		Old	1.32	±	0.36	de
	5-6	Young	1.10	±	0.29	e
		Mature	1.75	±	0.04	cde
		Old	1.86	±	0.08	bcde
	8-9	Young	1.41	±	0.13	de
		Mature	1.49	±	0.05	de
		Old	2.07	±	0.20	abcde
Sun	2-3	Young	2.02	±	0.14	bcde
		Mature	2.02	±	0.14	bcde
		Old	1.66	±	0.32	de
	5-6	Young	2.88	±	1.28	abc
		Mature	2.29	±	0.19	abcd
		Old	2.24	±	0.11	abcde
	8-9	Young	1.55	±	0.10	de
		Mature	1.92	±	0.10	bcde
		Old	3.21	±	0.34	a
Oven	2-3	Young	2.91	±	0.42	ab
		Mature	2.18	±	0.09	abcde
		Old	1.82	±	0.63	bcde
	5-6	Young	1.83	±	0.63	bcde
		Mature	1.90	±	0.32	bcde
		Old	1.18	±	0.31	de
	8-9	Young	1.77	±	0.10	bcde
		Mature	1.52	±	0.05	de
		Old	1.65	±	0.21	de

Means within group in a column followed by a common letter do not differ with at Tukey's Honest Significance Difference (HSD) at 5% level.

Leaf Strength

Tensile Strength

Tensile strength is basically the force needed to pull the material apart. For packaging materials, it is important to know the tensile strength since it is a basis of comparison. It is used to know whether a certain packaging material is appropriate to a specific commodity. The tensile strength of the samples was computed using Equation 5. Figure 11 and Table 2 shows the tensile strength banana leaves samples.

The tensile strength value of the samples subjected to sun (3.21 MPa) and oven drying (2.91MPa) with had the highest tensile strength. Analysis of variance showed that the interaction between drying method, leaf maturity and dipping time had a significant effect on the tensile strength. This suggested that the tensile strength values at maturity level, dipping time and method of drying and their interaction is significant. It also means that the tensile strength is affected by the choice of drying method, dipping time, maturity of the leaf in tree and part of the leaf. Results showed that the as drying temperature increased (air to oven drying), the tensile strength also increased. Tensile strength increased with leaf maturity. On the average, bottom had the lowest value followed by middle and then top. However, the tensile strength decreased when the leaves were dipped in the hot water for a longer period.

Leaf tensile strength increased with development (Balsamo & Orkwiszewski, 2008). Since bottom is the oldest leaf, it has weaker structure than the younger leaves. In a banana tree, the bottom leaves are in the process of deterioration or withering. The bottom leaf dries up after a new leaf sprouts. According to Kneebone (1960), leaf age is the most important factor that caused variation in leaf tensile properties.

The highest measured tensile strength was 3.63 MPa. Studies of mechanical properties of typical plant leaves found that *Nelumbo nucifera* or most commonly known as Indian lotus has a tensile strength of 3.4884 MPa (Yang, *et al*., 2010). During tensile test, lotus leaf was not ruptured easily but can be broken with low deformation during bending. This result suggest that it has a high elastic modulus, strong strength and low plasticity (Zhang, *et al*., 2012). This means that after the blanching and drying, banana leaves improved its tensile strength significantly.

Table 3. Puncture strength values of the dried banana leaves samples.

Drying Method	Dipping Time (seconds)	Maturity	Puncture strength (MPa) Mean		SD	
Air	2-3	Young	1.81	±	0.41	ab
		Mature	2.80	±	0.06	ab
		Old	2.40	±	0.35	ab
	5-6	Young	2.12	±	1.69	ab
		Mature	2.67	±	0.65	ab
		Old	2.20	±	0.43	ab
	8-9	Young	1.44	±	0.16	b
		Mature	1.98	±	0.30	ab
		Old	2.03	±	0.45	ab
Sun	2-3	Young	2.48	±	0.20	ab
		Mature	2.46	±	0.99	ab
		Old	2.44	±	0.35	ab
	5-6	Young	2.88	±	0.31	ab
		Mature	2.48	±	0.21	ab
		Old	2.28	±	0.42	ab
	8-9	Young	2.22	±	0.36	ab
		Mature	2.12	±	0.24	ab
		Old	2.81	±	0.18	ab
Oven	2-3	Young	2.77	±	0.38	ab
		Mature	3.51	±	0.88	a
		Old	3.49	±	0.55	a
	5-6	Young	2.55	±	0.04	ab
		Mature	3.55	±	1.52	a
		Old	2.49	±	0.43	ab
	8-9	Young	2.31	±	0.19	ab
		Mature	2.13	±	0.23	ab
		Old	3.01	±	0.31	ab

Means within group in a column followed by a common letter do not differ with at Tukey's Honest Significance Difference (HSD) at 5% level.

Puncture Strength

Puncture strength is basically the force needed to punch a hole in a material. Since, packaging materials are subjected to different stresses and vibrations, it is important to know the force needed until the material ruptures. Puncture strength, just like tensile strength, is one of the physical characteristics of a packaging material.

The puncture strength of the samples was computed using Equation 6. Figure 12 and Table 3 shows the puncture strength of the dried banana leaves.

It was observed that the puncture strength increased with maturity level since the average puncture strength of the top leaves (2.29MPa) was lower than that of the bottom leaves (2.57MPa). Since top was the youngest leaf, the force needed to create a hole on it was lesser. Analysis of variance showed that maturity, dipping time and drying method and the interaction between the three factors had a significant effect on the puncture strength of the dried leaves. This means that the puncture strength is affected by the choice of drying method, dipping time, leaf maturity. Results showed a decreasing puncture strength with longer dipping time. The lowest puncture strength was from 8 to 9 seconds followed by 5 to 6 seconds and the highest was at 2 to 3 seconds. As the drying air temperature increases (air to over drying), the puncture strength also increases.

The results indicated that the combination of blanching and drying improved the puncture strength of the samples. Lower maximum force to rupture as well as lower leaf toughness was apparent for the distal portion of the leaf (Labavitch *et al*., 2012).

SUMMARY AND CONCLUSION

Banana leaves were harvested, cleaned and sorted. Three parameters were used in this study namely, maturity level, dipping time and drying method. The samples were dipped in boiling water and the excess water were removed using paper towels. The moisture content wet basis of the samples used in the experiment and commercially available leaves was measured using the oven drying method. Three drying methods were used, open-air drying, sun drying and oven drying. The initial moisture content of the commercially available leaves was used

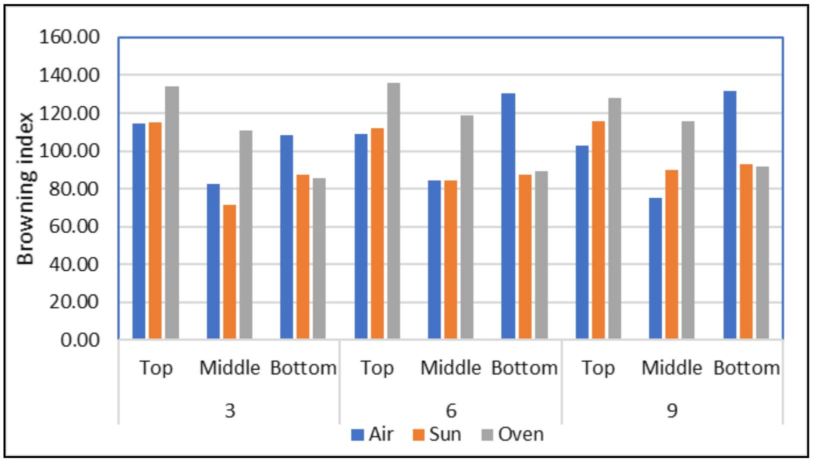

Figure 10. Browning index of the dried banana leaves

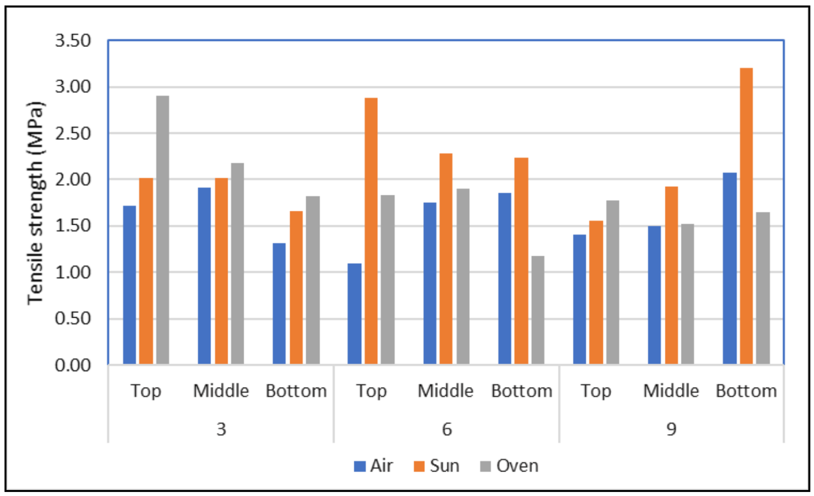

Figure 11. Tensile strength of the dried banana leaves

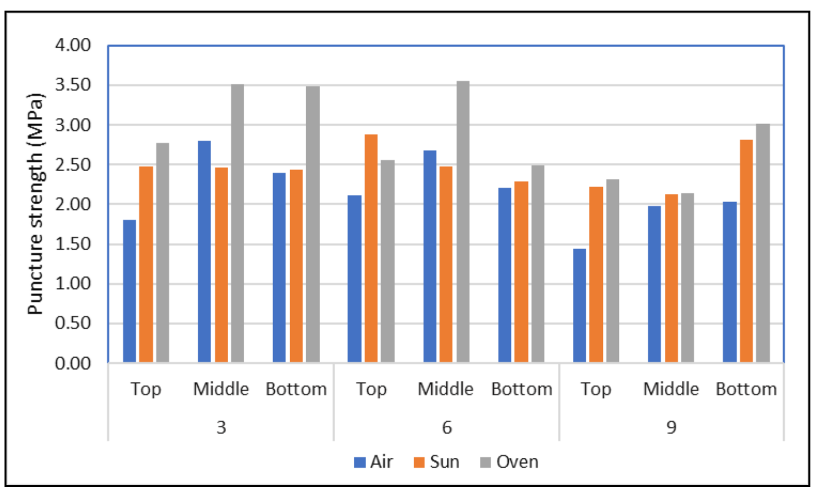

Figure 12. Puncture strength values of the dried banana leaves.

as the final moisture content after drying. The initial moisture content wet basis (MCwb %) of fresh banana leaves was 79.32 ± 0.83 % while the commercially available leaves was 72.72 ± 2.28 %.

After drying, the samples were subjected to color, tensile and puncture testing. The L*, a* and b* values were obtained using the colorimeter. BI was computed using the L*, a* and b* values. Results showed that BI decreases with maturity but it increases with longer dipping time and higher drying temperature.

Results showed that tensile strength decreases with maturity and longer dipping time but increases with drying temperature. Puncture strength increases with maturity but decreases with longer dipping time. Overall, the combination of blanching in hot water followed by drying was proven to be effective in increasing the physical strength of the banana leaves and the browning index.

RECOMMENDATIONS

Further studies on following are recommended (1) measurement of the gas transmission and water vapor transmission rate of the dried and fresh banana leaves, (2) determination of the shelf-life of the fresh and dried banana leaves, (3) measurement of the effect of drying method on the aroma of dried banana leaves and (4) determination of the chemical properties of the leaf before and after the treatments.

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