Extraction of Wax from Banana Leaves as an Alternative Way of Utilizing Agricultural Residues

Takashi YANAGIDA, Naoto SHIMIZU and Toshinori KIMURA†

Graduate School of Life and Environmental Sciences, University of Tsukuba,
1-1-1 Tennodai, Tsukuba, Ibaraki 305-8572, Japan

Banana leaf wax was quantified and assessed to determine the feasibility of its utilization as agricultural residue. Banana leaf wax was extracted using hexane reflux. Musa liukiuensis yielded 0.58% wax, M. acuminata 1.05%, and M. chiliocarpa 1.41% (dry basis). The melting point of banana leaf wax was determined by differential scanning calorimetry, which indicated higher values than commercial natural waxes. Color evaluation revealed that M. acuminata leaf wax was whiter than commercial natural wax. The banana leaf wax had tolerance against organic solvent systems. Using thin-layer chromatography analysis, we identified the components of the M. chiliocarpa leaf wax as being similar to those of carnauba wax. The M. chiliocarpa leaf wax was analyzed after saponification using gas chromatography. The predominant acid was C22, and the major alcohols were C28 and C30. The results demonstrated that the banana leaf wax is a potential source of natural wax for industrial material and is expected to be used extensively.

Key words: agricultural residue, banana leaf, natural wax, tropical plantation, waste utilization

1. Introduction

Developing countries in the tropical region are faced with financial difficulties. Turning biomass resources into valuable global exports will likely overcome these difficulties. Banana, well known as an economically important tropical crop, is cultivated worldwide in 4.54 × 10⁶ ha yielding 6.93 × 10⁷ t annually [1]. This cultivation generates a large amount of residue since each plant produces only one bunch of bananas. After its harvesting, the pseudostems and leaves are cut and usually left in the field or incinerated [1,2]. Furthermore, the banana harvesting residues are regarded as waste and a recognized source of environmental pollution in Costa Rica [3]. Shah et al. reported each hectare of banana crop generates nearly 220 t of plant residual waste [4]. The putative amount of the annual global banana waste is 9.99 × 10⁸ t. This huge amount of the waste has some advantages, such as its potential use in its conversion into industrial products. Biomethanation [5] and the anaerobic digestion of banana waste [6] for biogas production have been reported; Krishna reported the production of bacterial cellulases by solid-state banana waste bio-processing [7]. In a study conducted by Savastano et al., banana waste fiber was used for cement-based composites as reinforcement [8]. Another study reported its use for pulping [2].

Banana is a perennial herbaceous crop. The surface of the banana leaf is covered with a natural wax. Natural waxes are used for a number of purposes, including automobile wax, food coating, confections, cosmetics, medicines and chemical bases. In 2003, Japan’s imported natural waxes were 3081 t of carnauba wax, 259 t of other natural plant waxes and 712 t of bees wax [9]. Carnauba wax, or Copernica cerifera, is extracted from palm tree leaves and is the most popular commercial wax because of its high melting point, hardness, toughness and luster [10]. If the properties of the banana leaf wax are similar to natural commercial wax such as carnauba, banana wax may become an alternative material. Using banana wax byproducts would greatly benefit tropical developing countries by creating a high value product from unutilized biomass resources of banana cultivation. Information on leaf surface waxes from several plants has been reported in the literature. However, there are few published studies on banana leaf wax. Wax derived from banana leaves would be a new alternative and important agricultural residue in those regions.

Thus, the objective of this report was to investigate banana leaf wax. The waxes were extracted from banana leaves and were compared with natural commercial waxes. Wax yield, thermal properties, color, solvent tolerance and chemical composition were investigated.

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Tel: +81-29-853-4650, Fax: +81-29-855-2200, E-mail: toshhibio@sakura.cc.tsukuba.ac.jp
2. Materials and Methods

2.1 Materials

The three varieties of banana leaf materials used in the experiment were *Musa acuminata*, *M. liukiuensis* and *M. chilicarpa*. All banana leaves were collected in the tropical green house of the Tsukuba Botanical Garden, National Science Museum, Ibaraki, Japan in August 2002.

The five natural wax samples were carnauba, candelilla, rice, Japan and bees wax and were provided by Cerarica Noda Co., Ltd., Kanagawa, Japan. These natural waxes were compared to banana leaf wax.

2.2 Extraction of wax from banana leaves

Banana wax was extracted using a reflux method as described for sorghum wax [11]. Sample weights (fresh leaf) were 240 g for *M. liukiuensis*, 405 g for *M. acuminata*, and 324 g for *M. chilicarpa*. Banana leaf materials were cut into small pieces and placed in a round bottom flask for each variety. Hexane (1 L) was added to the flask until the leaf material was covered. The banana leaf and solvent mixture were set in a water bath and maintained at 60°C for 10 minutes. A glass condenser was directly connected to the top of the flask. After refluxing, the solvent mixture was collected into the conical flask through the filter. The flask was allowed to cool at room temperature for two hours and placed in a freezer for six hours. The precipitated wax was collected using a filter paper. A pre-weighed filter paper was placed in the glass funnel and the solvent and wax mixture were poured into the funnel. The precipitated wax was retained on the surface of the filter paper. After drying, the filter paper was weighed to determine wax weight.

2.3 Differential scanning calorimetry measurement

The differential scanning calorimeter (DSC) was a DSC 6100 (Seiko Instruments Inc., Chiba, Japan) with an EXSTAR 6000 thermal analysis processor. The apparatus was continually flushed with nitrogen at a flow rate of 30 ml/min. The sample weighed 20.0 mg. Each sample was heated from 25 to 200°C at a rate of 10°C/min [12,13]. An empty aluminum pan was used for reference.

2.4 Solvent tolerance test

A solvent tolerance test was conducted on banana leaf wax (*M. chilicarpa*) and commercial natural waxes using an extract method (see Figure 1). 100 mg of each ground wax sample was fractionated sequentially with solvents (15 ml) of increasing polarity, i.e. hexane, hexane-diethyl ether (80:20), hexane-diethyl ether (40:60), diethyl ether-dichloromethane (95:5) and diethyl ether-acetic acid (95:5). The soluble fractions were then recovered after evaporation of the solvent and weighed.

2.5 Color value determination

Color values of waxes were measured with a Minolta CR-20 (Konica Minolta Holdings, Inc., Tokyo, Japan) color meter using the L* a* b* color scale: L* (lightness), a* (from green to red) and b* (from blue to yellow). The C* (chroma) parameter is calculated from the former. Wax (150 mg) was placed in a flat bottom glass bottle and fitted with the color meter for the determination. The results are means of 10 determinations. The instrument was calibrated against a standard white reference plate.

2.6 Thin-layer chromatography (TLC)

Sample wax components were compared using TLC [14,15]. Silicagel plates (60 F254; Merck Ltd., Tokyo, Japan) were used in this experiment. The wax samples were dissolved in warm chloroform and applied to the start lines on the plate. TLC development used two solvent systems. Solvent system I consisted of hexane-diethyl ether-acetic acid (90:15:1 v/v) for investigating non-polar components. Solvent system II consisted of hexane- diethyl ether-acetic acid (50:50:1 v/v) for investigating of polar components. After development, the plates were placed in I2 vapor or sprayed with 50% H2SO4 aqueous solution and
heated at 105°C until colored spots appeared.

2.7 Saponification and separation

Samples were saponified and separated by a procedure invented by Tonogai et al. [14]. Banana leaf wax (M. chillicarp, 20 mg) and 0.5N KOH/ethanol solution (30 ml) were mixed and stirred in a flask. A glass condenser was connected directly to the top of the flask. The sample was saponified for 2 h at 95°C. Distilled water (10 ml) was then added to the saponificated solution. The saponified mixture was extracted repeatedly with hexane (100 ml). The combined hexane extracts were washed with 0.1N KOH-ethanol (2:3) and dried over anhydrous Na₂SO₄. The water layer was combined and added to 1N H₂SO₄ (30 ml). The water layer was extracted repeatedly with diethyl ether (100 ml). The combined ether extracts were washed with distilled water and dried over anhydrous Na₂SO₄.

Fatty alcohols and fatty acids were recovered after evaporation of the solvent from the hexane extract and the ether extract, respectively.

2.8 Gas chromatography (GC)

Fatty acids as their methyl ester derivatives produced by diazomethane and fatty alcohols were analyzed using a Shimadzu GC–14B (Shimadzu Co., Kyoto, Japan) fitted with a URBN HR–52 capillary column (0.25 mm × 25 m). The operating temperatures were as follows: injector, 330°C; detector (flame ionization detector), 330°C; and initial oven temperature, 200°C with a ramp rate of 5°C/min. to 290°C, and maintained for 10 min. Helium was used as the carrier gas.

3. Results and Discussion

3.1 Wax yields

Two leaves each of Musa liukiuensis, M. acuminata and M. chillicarp were used for wax extraction. The moisture content of banana leaves ranged from 84.9 to 86.0%. Table 1 shows the yields of natural wax. Wax yields (dry basis (d.b.)) were 0.58% for Musa liukiuensis, 1.05% for M. acuminata, and 1.41% for M. chillicarp. The wax yield of M. chillicarp exhibited the highest percentage of the varieties. Air-dried banana straw contains 1.76% of wax and fat [16].

The wax yields of the banana leaf wax and the carnauba wax cannot be compared because there are few studies on carnauba wax yield. Warth [16] reported 5 g of carnauba wax was collected from a palm tree (Copernica cerifera) leaf.

Candelilla wax is found in scale form that completely covers a wild-growing reed-like plant (Euphorbia antisiphylitica). This plant grows wild and in great abundance on the rocky slopes and plains of northwestern Mexico and southern Texas. The yield is usually between 1.5 and 2.5% of the plant weight [17].

Rice wax is present at a level of less than 0.4% in rice bran [16].

Grain sorghum is found on the outer layer or epicarp of sorghum kernels at levels of 0.2 to 0.25% d.b. [18]. Wax recovery from sorghum is well documented as a relevant method for replacing carnauba wax using domestically produced vegetable waxes [11,19,20].

Therefore, banana leaf is a material of interest for wax production because of the high wax yield (0.58 to 1.41%). In addition, the banana plantation is efficiently maintained for transporting fruit to market. The collection of banana leaves and stems can use the same transportation system from plantation to wax extraction sites.

A simple, low-cost wax extraction process may be required in developing countries. In case of boiling water instead of organic solvents such as hexane is used in the extraction process of banana leaf wax, the process seems to be an environmentally friendly and cheaper treatment. The wax yield by the hot water (98°C) reflux extraction method was smaller than by the present study extraction method. The wax extraction cost is desired less than 400 yen/kg because of the price of natural plant waxes imported in Japan 2003 were 226 to 443 yen/kg [9].

3.2 Thermal analysis

The melting point represents one of the physical properties for wax. The structure of the long chain fatty acid in waxes has a crystalline form, and this form is expressed in various physical properties.

Thermal analysis of the waxes was carried out using DSC to determine the melting temperature. Figure 2 plots
the DSC curves of the natural waxes. Table 2 presents their thermal properties. The peak temperature is known as the melting point when the sample is completely melted [21]. The peak temperatures of banana leaf waxes were 88.8°C for *Musa liukiuensis*, 86.6°C for *M. acuminata*, and 89.1°C for *M. chilicarpa*. Their DSC curves exhibited sharp single peaks. While carnauba wax has the highest known melting temperature of commercial natural waxes, it had a peak temperature of 85.5°C.

The banana leaf wax thus had the highest melting point and heat resistance comparatively. Moreover, the sharp melting point distribution curve suggested that the banana leaf wax had a large crystalline form.

If the wax is in a solid state at the normal temperature and the temperature is raised, a crystal structure changes at a temperature below the melting point. This is known as a transition phenomenon. The phase transition was seen to some extent with carnauba wax and rice wax. However, this was not observed with banana leaf wax.

Due to its outstanding heat characteristics, carnauba wax is used in various fields, for such things as a toner and a mold release agent of a semiconductor tip. Carnauba wax is also used extensively to elevate the melting point of other waxes.

The banana leaf wax was expected to have extensive applications similar to those of carnauba wax.

### 3.3 Solvent tolerance test

Solvent tolerance test were conducted on wax samples using the extract method. Figure 3 shows the amounts of wax fraction obtained by extraction (see Fig.1). Fraction weights of *M. chilicarpa* wax were 1.6 mg for Fr. 1, 2.6 mg for Fr. 2, 0.9 mg for Fr. 3, 2.2 mg for Fr. 4 and 3.3 mg for Fr. 5. Total fraction weight of *M. chilicarpa* wax was 10.6 mg. Fraction weights of Japan wax were 72.2 mg for Fr. 1, 20.2 mg for Fr. 2, 2.5 mg for Fr. 3, 0.8 mg for Fr. 4 and 1.0 mg for Fr. 5. Total fraction weight of Japan wax was 96.7 mg. Solvent tolerance was evaluated by solubility of wax with solvents of increasing polarity. The solubility was calculated from the following equation.

\[
\text{Solubility (\%)} = \left( \frac{\text{initial wax weight} - \text{total solved wax weight}}{\text{initial wax weight}} \right) \times 100 \tag{1}
\]

The solubility of banana leaf wax was 10.6%, carnauba wax 13.2%, rice wax 18.1%, candelilla wax 76.8%, bees wax 80.9% and Japan wax 96.7% (w/w). With a solubility of 10.6%, banana leaf wax (*M. chilicarpa*) was the most stable against organic solvent systems ranging from non-polar to polar. In this test, banana leaf wax exhibited behavior similar to carnauba wax. Wax solubility in organic solvents was closely related to their melting points. The higher (lower) melting point wax exhibited the higher (lower) solvent tolerance.

Carnauba wax is commonly added to edible coatings of fruits and vegetables. Weller et al. studied sorghum wax as an edible coating for gelatin-based candies because they have characteristics similar to those of carnauba wax [19].
There were some similarities between banana wax and carnauba wax, including high melting points and solvent tolerance. Therefore, banana wax may be useful as a protective coating in restricting the melting of confectionery items and pharmaceutical tablets under storage conditions. In addition, banana wax could be applied as a polish, since carnauba wax is used as a polish for shoes, furniture, leather, automobiles, floors, fruit and vegetables.

3.4 Color

Color is also an important parameter for wax. Wax products like candles often must be dyed or colored in order to make them more attractive. However wax as a chemical base should be colorless.

Japan wax is prepared by bleaching raw wax extracted from haze-nuts (*Rhus succedanea*). Sumimoto and Tachibana investigated the changes in the fatty acid constituents during sunlight bleaching, and reported that the major coloring matters of raw wax were flavonoids such as apigenin [22].

Carnauba wax is classified into five types. High-quality carnauba wax is yellow, while low-grade wax is dark brownish-green. Resin pigments make the carnauba wax yellow.

Banana leaf waxes were white or light gray. Table 3 shows the color values of natural waxes. Banana wax lightness ranged from 72.23 to 86.08, higher than other natural waxes. The value of \( a^* \) of the banana leaf waxes ranged from –1.15 to –0.48. The banana leaf wax was light green and without red coloring. The \( b^* \) of the natural waxes were \( b^* \) values and were yellow. The \( b^* \) values of the banana leaf waxes ranged from +8.36 to +15.45. These \( b^* \) values were close to the Japan wax and bees wax values (+8.23 and +9.67). The \( b^* \) values of candelilla and carnauba wax were +41.27 and +32.65. These waxes had high \( b^* \) values because of their characteristic yellow color.

The *M. acuminata* banana leaf wax was the whitest wax among the natural waxes used in this experiment, meaning that it may not contain flavonoid pigments or color resin. Thus, the properties of the banana leaf wax are expected to produce advantages in the refining process.

3.5 Chemical analysis

*M. chilicarpa* leaf wax was chosen to investigate fatty acid and alcohol composition. It was chosen because the component profiles of *Musa chilicarpa* wax from TLC chromatogram were similar to those of carnauba wax (data not shown).

Fatty acids of 12.2 mg and alcohols of 5.0 mg were recovered from *M. chilicarpa* leaf wax of 20.0 mg after saponification. Fatty acids, such as methyl ester derivatives, and alcohols were quantified and identified by GC.

Table 4 shows fatty acid and alcohol compositions in the wax extracted from *M. chilicarpa* leaves. Fatty acids with carbon numbers ranging from C14 to C30 were detected in *M. chilicarpa* leaf wax after saponification. C22 fatty acid indicated 24.31% was most abundant in these fatty acids. *M. chilicarpa* leaf wax contains fatty acids ranging in carbon number from C16 to C30, and their predominant compounds are C28 (23.78%) and C30 (21.87%). There was some unidentified peak in the chromatograms.

TLC chromatograms indicated the component profiles of *Musa chilicarpa* were similar to those of carnauba wax; however, there were some differences in fatty acid and alcohol compositions between *M. chilicarpa* wax and carnauba wax. As reported by Japan Oil Chemists’ Society [23], carnauba wax contains fatty acids ranging in

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Color values of natural waxes.</th>
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<tbody>
<tr>
<td></td>
<td>( L^* ) (lightness)</td>
</tr>
<tr>
<td><em>Musa acuminata</em> wax</td>
<td>86.08</td>
</tr>
<tr>
<td><em>Musa liukiuensis</em> wax</td>
<td>79.70</td>
</tr>
<tr>
<td><em>Musa chilicarpa</em> wax</td>
<td>72.23</td>
</tr>
<tr>
<td>Candelilla wax</td>
<td>63.88</td>
</tr>
<tr>
<td>Rice wax</td>
<td>68.02</td>
</tr>
<tr>
<td>Bees wax</td>
<td>64.41</td>
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<tr>
<td>Japan wax</td>
<td>56.50</td>
</tr>
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<td></td>
<td>65.08</td>
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</table>

a. (Individual peak area / combined areas of all peaks except solvent peak) × 100.

b. Trace.

Table 4 Fatty acids and alcohols obtained by saponification of banana (*Musa chilicarpa*) leaf wax.

<table>
<thead>
<tr>
<th>Carbon number</th>
<th>Fatty acids (%)</th>
<th>Alcohols (%)</th>
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<tbody>
<tr>
<td>C14</td>
<td>0.25</td>
<td>Tr. b</td>
</tr>
<tr>
<td>C16</td>
<td>1.36</td>
<td>Tr. b</td>
</tr>
<tr>
<td>C17</td>
<td>Tr. h</td>
<td>1.16</td>
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<tr>
<td>C18</td>
<td>3.59</td>
<td>0.88</td>
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<tr>
<td>C20</td>
<td>3.97</td>
<td>Tr. b</td>
</tr>
<tr>
<td>C21</td>
<td>0.57</td>
<td>Tr. b</td>
</tr>
<tr>
<td>C22</td>
<td>24.31</td>
<td>1.26</td>
</tr>
<tr>
<td>C23</td>
<td>0.98</td>
<td>Tr. b</td>
</tr>
<tr>
<td>C24</td>
<td>15.48</td>
<td>2.11</td>
</tr>
<tr>
<td>C25</td>
<td>9.17</td>
<td>16.07</td>
</tr>
<tr>
<td>C26</td>
<td>7.03</td>
<td>7.96</td>
</tr>
<tr>
<td>C27</td>
<td>2.07</td>
<td>Tr. b</td>
</tr>
<tr>
<td>C28</td>
<td>9.51</td>
<td>23.78</td>
</tr>
<tr>
<td>C29</td>
<td>1.09</td>
<td>Tr. b</td>
</tr>
<tr>
<td>C30</td>
<td>7.36</td>
<td>21.87</td>
</tr>
</tbody>
</table>

a. (Individual peak area / combined areas of all peaks except solvent peak) × 100.

b. Trace.
carbon number from C16 to C34 (predominance of C24, 27.4%) and fatty alcohols ranging in carbon number from C22 to C34 (predominance of C32, 73.4%). The shorter-chain fatty acids and alcohols were more prevalent in *M. chilicocarpa* wax. With respect to their thermal properties (Table 2), *M. chilicocarpa* wax had a higher melting point than carnauba wax. Generally, the melting point reflects the carbon chain length of the straight molecules. However, some differences appear in our results, which could be due to the composition, type of structure and/or other components of the wax.

4. Conclusions

Banana cultivation generates an enormous amount of agricultural residues, such as pseudo-stems and leaves. These residues are regarded as an unutilized sustainable biomass resource. We proposed to utilize banana leaf residue as an alternative natural wax. The general properties of banana leaf wax were examined in this study. Results demonstrated that banana leaf wax had characteristics similar to those of carnauba wax, which is the most popular commercial natural wax and is extracted from palm leaves. Therefore, banana leaves can be used as a new source of natural wax. Therefore banana leaves can be used as a new source of natural wax. The characteristics of banana leaf wax, e.g., high melting point, stability, color, is suitable for using it as a coating agent.

Since food products such as most confections, meat and fish have been packaged, it has always been a desideratum to prepare a wrapping material to retain as long as possible the original moisture content of the food product. In order to maintain the proper conditions, a wrapping material has high resistance to the transmission of moisture is desired. The banana leaf wax will be used for this purpose effectively as a coating agent for wrapping materials.

In the rural of developing countries, it is difficult to maintain the food quality because of the lack of food wrapping materials. After wax recovery, the banana leaf material contents a rich fiber would be used for other process, such as pulp production for higher economic returns. Banana paper may be converted into waterproofing paper for food wrapping material, trays and paper cups. Historically, a fresh banana leaf has been used directly as a food tray in tropical regions. This conversion from the fresh banana residue to the food wrapping materials combination of natural wax and banana paper would create a new industry in developing countries. The utilization of the banana leaves may offer an economical benefit in the tropical developing countries by creating a natural wax from the agricultural residue of banana cultivation.

This study was only a cursory analysis of wax quality and quantity in small samples. Future research should be considered on larger models, extraction procedure and commercial applications.

Acknowledgments

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References

Wax extraction of banana leaves


URL cited

バナナ葉から抽出したワックスの基本特性
—プランテーション残渣の有効利用—

柳田高志，清水直人，木村俊範

筑波大学大学院生命環境科学研究科

バナナは熱帯プランテーションなどで大量に生産されている稲作植物である。現地では果実が収穫された後の葉や茎（偽茎）は、切り倒され土に返されるか、ゴミとして処理されており、その縦長は年間約10億トンに達する。バナナの主要生産国は開発途上にあり、これらプランテーション残渣はバイオマス資源とみなされ、有効に利用することは重要な課題となっている。

これまで、バナナの芽、葉からバイオガスやバブルを生産する目的で行われた報告はあるが、その他の利用に関する研究は少なく、われわれは、バナナ葉の表面にワックスが存在することを示し、バナナ葉ワックスとしての利用の可能性について検討した。

そこで本実験では、バナナ葉からワックスを抽出し、その収率を比較した。パラナ葉ワックスの用途を目指し、溶点、色、溶媒耐性、成分などの基本特性を明らかにした。

*Musa liukiuensis, M. acuminata, M. chiliocarpa*の葉を供試し、ヘキサングリッド流法でワックス抽出を行った。バナナの葉の含有率は84.9から86.0%であった。ワックスの収率は、乾燥重量に対して *M. liukiuensis*が0.58%, *M. acuminata*が1.0%, *M. chiliocarpa*が1.41%であった。市販の天然ワックスの収率は、キャンディラワックスが乾燥葉に対して1.5から2.5%, ライックスワックスが米ぬかに対して0.4%であり、バナナの葉はワックス生産を考慮した場合に大変興味深い素材であることが示された。

ワックスの特性を測定するために、示差走査熱量計（DSC）により天然ワックスの融点測定を行った。一般的にDSC曲線のピーク温度で融点として知られており、バナナ葉ワックス3種類 *M. liukiuensis, M. acuminata, M. chiliocarpa*は、それぞれピーク温度88.8, 86.6, 89.1℃と、そのDSC曲線がシャープな高いピークであった。カルナバワックスは、市販されている天然ワックスの中で最も融点の高いワックスとして知られるが、その値は85.5℃である。このことから、バナナ葉ワックスは高融点ワックスであり、耐熱性を有していることが明らかとなった。

ワックスの溶媒に対する耐性を5種類の溶媒系を用いて検証した。溶媒は、極性の低いものから高いものまで調整して、順次ワックスを懸濁し、その溶解度で評価した。バナナ葉ワックスは、市販の天然ワックスよりも溶媒に対して安定していることが明らかとなった。

L*a* b*色表示系でワックスの色を評価した。ロウソク等のワックス製品は、装飾性をより高めるために染色あるいは色づけされるが、工業原料としてのワックスの場合は、無色もしくは白色であることが好ましい。バナナ葉ワックスは、白色もしくはライトグレーであった。明度L*は72.23から86.08で、市販の天然ワックスの中で最も高い値を示した。バナナ葉ワックスの中で *M. acuminata*のワックスは色と関係がなく、モクロに含まれるアビゲモンのようなプラナノイドやカルナバワックスおよびキャンドリワックスに含まれる樹脂などの色が混ざっているように思われた。このためバナナ葉 *M. acuminata*ワックスは、生産の工程で脱色を必要としないため、他の天然ワックスと比較して製造段階に利益が生まれると思われた。

成分分析のために、バナナ葉ワックスを乾燥処理し、脂肪酸とアルコールに分離した後、ガスクロマトグラフィーで分析した。バナナ葉ワックスの構成脂肪酸の炭素鎖数はC14からC30の範囲にあり、C22（24.31％）が主要脂肪酸であった。一方、構成アルコールはC16からC30の範囲にあり、C28（23.78％）とC30（21.87％）が主要アルコールであった。

以上、バナナ葉からワックスを抽出し、その基本的な特性が明らかになった。高融点や安定性と優れた特性を有するバナナ葉ワックスは、コーティング剤などの工業原料としての可能性を示した。このことは、バナナ葉から天然ワックスを生産することが有効利用資源の有効利用技術のひとつとして示例できたと考える。

葉子類、肉、魚などの食品は、水分の蒸発などによる品質の低下を防ぐために包装されている。しかし、開発途上国では慢性的な資源不足から食品の品質保持が困難である。ワックスを採取した後のバナナ葉は、繊維が豊富であるため、バルブ生産などに再利用することもできる。バナナプランテーション残渣からワックスとバルブを回収し、食品包装素材やドライエクストラクト化することによって、現地での食品流通に効果が期待される。

開発途上国でのワックス抽出実用化に向けての抽出溶媒は、環境に対する配慮や入手のしやすさなどの観点からへキサソノールに代替した方法が望ましい。本研究で使用した加熱還元法で熱抽出ワックスを抽出した場合、液面で固化したワックスがバナナ葉に再吸着してしまいワックス収率が低下した。ワックスのバナナ葉に効率よく分離できる熱抽出方法の検討などが今後の課題である。また、日本に輸入されている天然ワックスは、カルバウワックスが226円/kg、その他の植物ワックスが443円/kgである。よって、バナナ葉ワックスの生産コストは、400円/kgに抑えることが望ましい。今後、食品、化粧品、医薬品など様々な分野への応用も検討していきたい。