Assessing properties of solar-dried banana with white chocolate coating

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Abstract. Banana is one of the most prevalent tropical fruits, renowned for its nutritional and energetic value. Drying bananas prolongs their shelf life, reduces weight, conserves storage space, and controls enzymatic reactions that lead to banana degradation. Drying also enhances sensory attributes such as flavor and texture. Producing solar-dried banana coating with fancy flavors is an innovation in banana product processing, especially with white chocolate coating. However, the coating made from white chocolate mixed with various flavors has a problem with its viscosity, and this type of chocolate is considered not heat resistant enough, leading to melting in most tropical temperatures, such as those in Thailand. Therefore, four components were incorporated into the mixture of white chocolate coating to improve its quality. Palm Kernel Oil (PKO), Palmitic Acid (PA), Cocoa Butter (CB), and Soy Lecithin (SL) were added to enhance the coating's properties. The results showed that CB had the best viscosity at 9600 cP, a slightly lower melting point at 29.01°C, and a hardness measurement of 152 g. These modifications proved proper components to stabilize the coating under high temperatures, making it suitable for tropical climates. Further research is needed to produce a heat-resistant white chocolate coating, ensuring it maintains its integrity and desirable properties during storage and transportation in hot conditions. Additionally, consumer preferences and sensory evaluations must be considered to ensure that the modified white chocolate coating meets taste and texture expectations while providing the necessary heat resistance.

1 Introduction

Bananas are popularly consumed worldwide due to their pleasant taste and significant nutritional value, being rich in starch, sugar, vitamins A and C, calcium, potassium, sodium, and magnesium (1). However, their high water content poses challenges for storage and transportation, reducing their commercial viability in distant markets. Drying is a method capable of prolonging shelf life, reducing transportation weight, conserving storage

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space, and controlling the microbiological and enzymatic reactions responsible for banana degradation (2). Additionally, drying helps preserve the bananas and alters their flavor, texture, and taste to suit consumer preferences better, thereby significantly raising their market value.

One of the leading enterprises based in Chiang Mai, Thailand, has gained a reputation for producing various innovative solar-dried banana products. These products have become the most popular snacks produced by this company. Solar-dried bananas aim to retain their nutritional value, remove moisture, and extend shelf life while emphasizing sustainability by using only locally sourced produce. This approach supports local farmers and ensures that the products are fresh and environmentally friendly. The company produces solar-dried bananas dipped in various coffee and tea flavors, such as espresso, cappuccino, and matcha green tea. Additionally, they offer solar-dried bananas in original flavors, strawberry, chocolate, and pumpkin, catering to diverse consumer tastes.

The main ingredient used in producing these solar-dried bananas is white chocolate. However, the white chocolate coating poses several challenges during the coating process. The white chocolate mixture lacks sufficient viscosity (3), complicating the coating process and often results in uneven coatings. Additionally, the mixture lacks heat resistance and tends to melt quickly, especially in Thailand's hot climate, affecting the final product's overall quality and shelf life.

Continuous innovation is essential in improving the production process of flavor-coated solar-dried banana products. Enhancing the viscosity of the coating mixture is crucial, as it is the main component in the coating process. Mixtures that do not melt uniformly cause issues such as inconsistent appearance and may negatively impact the texture or mouthfeel of the final product, which can be detrimental to consumer satisfaction (4). Besides viscosity, the melting point temperature is also essential for enhancing the convenience and quality of the final product. Heat-resistant chocolate is typically developed for use in tropical and subtropical countries, preventing it from adhering to wrappers and ensuring it remains intact under higher temperatures.

This research aims to find a suitable additive from four different substances: Palm Kernel Oil (PKO), Palmitic Acid (PA), Cocoa Butter (CB), and Soy Lecithin (SLO). The goal is to identify the best combination of these additives to enhance the white chocolate coating's viscosity and heat resistance, ensuring its integrity and desirable properties during storage and transportation in hot conditions. By addressing these challenges, a superior solar-dried banana product can be produced to withstand tropical climates, meet consumer expectations for taste and texture, and expand its market reach.Methodology

This research was conducted at the factory located in Mae Taeng District, Chiang Mai, Thailand, and at Maejo University, San Sai District, Chiang Mai, Thailand. These three step in the research i.e. producing solar-dried banana, coating process, and properties analysis.

2 MATERIAL AND METHOD

2.1 Material

The material used in this research includes Ducasse banana, white chocolate, Palm Kernel Oil (PKO), Palmitic Acid (PA), cocoa butter (CB) dan Soy lecithin (SLO). The chemical used were potassium metabisulfite (KMS)

2.2 Method

This research was conducted at the factory located in Mae Taeng District, Chiang Mai, Thailand, and at Maejo University, San Sai District, Chiang Mai, Thailand. There were three steps in the research i.e. producing solar dried banana, coating process and properties analysis.

2.2.1 Solar Dried Banana Production

The Ducasse banana, a hybrid of Musa acuminata and Musa balbisiana, was meticulously chosen for production. Upon arrival at the facility, the bananas were carefully destemmed and cut into combs to facilitate uniform ripening. Adhering to the standard procedures, the selection process was executed with precision, ensuring that only the finest bananas were chosen. These bananas were then stored in a precisely controlled incubation room at 40°C. Ripening occurred over 3 to 4 days during the hot season and extended to 5 to 6 days during the cooler season.

Once ripened, approximately 80% of the bananas were selected for further processing. These bananas were carefully peeled, and any fibrous lines were meticulously removed. Each production grade within the same lot was recorded separately, ensuring traceability and consistency, and then subjected to rigorous quality control check.

To ensure the bananas were free from harmful bacteria, they were soaked in a carefully prepared solution containing 0.2 grams of potassium metabisulfite (KMS) and 2 g/L of salt in water for 15 minutes. This step was crucial for maintaining food safety standards. Following this, the bananas were placed in a solar-dome dryer, a key step in the process, where they were dried at a controlled temperature of 50°C for 24 hours. This drying process was carefully monitored to maintain a water activity level between 0.80 and 0.95 aw, essential for achieving the desired texture and shelf stability.

After drying, the bananas were spread in trays, covered with plastic bags, and rested for 12 hours to undergo syrup desugaring. This process significantly influenced their texture and color, enhancing the final product's quality. Finally, the bananas were machine-processed to achieve a uniform thickness of 0.5 to 0.7 cm, and a skewer was meticulously inserted at the end, preparing them for coating process.

2.2.2 Coating Process

When preparing bananas for orders, they undergo a specialized coating process. It begins with melting white chocolate for 2 minutes, followed by manual stirring. The melted chocolate is then transferred to a slow cooker and blended with espresso powder. During this stage, selected components—PKO (Palm Kernel Oil), PA (palm oil), CB (cocoa butter), and SLO (sunflower lecithin)—are incorporated into the mixture at 0.5% each. The bananas are dipped into this mixture, ensuring they are evenly coated. Once coated, they are hung on a drying rack for 15-20 minutes to allow the chocolate to set evenly. After drying, the bananas are packed using aluminum-coated packaging to protect them from heat and maintain quality. A process flow diagram illustrating this procedure is shown in Figure 1.

2.2.3 Properties Analysis

The coated-solar dried banana was meticulously executed by conducting detailed laboratory analyses. These analyses included viscosity, texture, and melting point assessments, each critical to ensuring the prototype's quality and performance. The viscosity analysis was performed using a Model DV2T Brookfield digital viscometer. This advanced instrument, paired with a spindle LV-04(64), operated at speeds ranging from 20 to 60 RPM. Samples were carefully incubated at 40°C in a water bath to ensure consistent and accurate readings. This step was crucial for understanding the prototype's fluid dynamics and flow characteristics.

Furthermore, the melting point of the product was determined using a highly precise Differential Scanning Calorimetry (DSC) 25 by TA Instruments. This instrument, renowned for its accuracy, measures the thermal properties of the material, identifying the exact temperature at which it transitions from solid to liquid. Understanding the melting point is essential for predicting the coated dried banana behavior under various thermal conditions. Each of these analytical techniques, carefully selected and executed, plays a crucial role in providing a comprehensive understanding of physical and chemical properties, ensuring it meets the required specifications and performance standards.

Texture analysis was conducted using a Brookfield Ametek Texture Analyzer CTX, equipped with a Type 39 Cylinder Probe. This sophisticated device measures the mechanical properties of the sample, providing value into its firmness, cohesiveness, and overall textural quality. Such analysis was vital for assessing the prototype's suitability for its intended application.

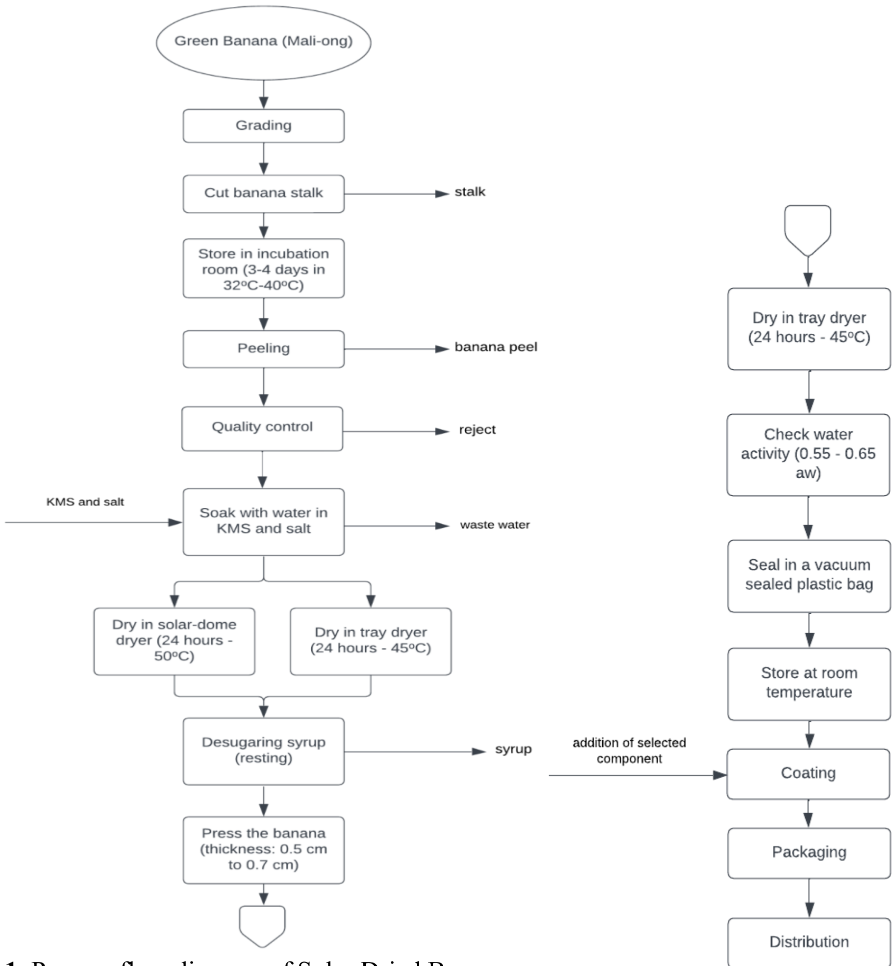

Fig. 1. Process flow diagram of Solar Dried Banana.

3 RESULTS AND DISCUSSION

Viscosity is the determining factor of coating properties. High viscosity chocolate mixture tends to be sticky and thick, which puts on a challenge to achieve desired smooth and even coating on the solar-dried bananas. The thick and sticky coating surface will also result in a heavy coating which causes the coating to be inconsistent. In terms of coating thickness, some parts will be too thick or too thin, and will not harden uniformly. Coating thickness depends on the viscosity of the chocolate, with decreasing viscosity, coating thickness decreases [5]. Longer setting time is also an issue when the coating process is faced with a high-viscosity mixture. It slows down the drying time which results in a prolonged setting process. The appearance of the final product may also be affected. A prolonged setting time may increase the risk of accidental damage during handling and impact the overall visual appearance, which may affect consumer perception.

3.1 Components Added into Coating Mixed

3.1.1 Palm Kernel Oil (PKO)

According to Ref. (6), the physical properties of Palm Kernel Oil (PKO) resemble particularly closely those of cocoa butter, and it is generally acknowledged that the best types of CBS are made from this fat. This is due to its versatility, cost-effectiveness, and nutritional benefits. In addition, PKO can aid in increasing the heat resistance of chocolate due to its high content of saturated fatty acids, particularly lauric acid, which has a relatively high melting point. The primary fatty acids in PKO are lauric acid (C12:0), approximately 48%; myristic acid (C14:0), approximately 16%; palmitic acid (C16:0), approximately 7-12%; and oleic acid (C18:0) approximately 15%. No other fatty acid is present at over 10% (7).
PKO can also help prevent fat bloom formation, caused by changes in the fat crystals within the chocolate. Its high content of lauric acid, which has a relatively high melting point, allows the fat crystals in the chocolate to remain stable and reduces the likelihood of fat migration or crystalline structure changes that lead to fat bloom. Additionally, PKO contains a relatively low amount of unsaturated fats compared to other vegetable oils. Unsaturated fats are more prone to oxidation, which can contribute to fat bloom development. The lower unsaturated fat content in PKO helps reduce the oxidation process and further prevents fat bloom. Texture-wise, PKO produces a firm and less creamy texture of the chocolate due to its low unsaturated fat content. It also has a neutral taste, which will not affect the final product's taste (8).

3.1.2 Palmitic Acid (PA)

Palmitic Acid (PA) plays a crucial role in forming stable cocoa butter crystals, essential for maintaining chocolate's smoothness and firmness. These stable crystals create a robust framework that enhances chocolate's overall texture and mouthfeel, contributing to its desirable snap and glossy appearance. By aiding in forming these stable crystals, PA helps to prevent the occurrence of fat bloom, a common defect in chocolate characterized by the migration of fat crystals to the surface, causing a dull and whitish appearance (5).
PA has a high melting point of around 62-64°C, which means it remains in a solid, crystalline form at room temperature (9). This property is beneficial for stabilizing fat crystals in chocolate, as it reduces their tendency to migrate to the surface, thereby maintaining the chocolate's aesthetic appeal and texture. The presence of PA in cocoa butter

enhances the thermal stability of chocolate, making it more resistant to temperature fluctuations that can cause bloom (10).
However, it is essential to note that while PA is beneficial for chocolate production, its high intake has been associated with increased health risks, particularly heart disease. As a saturated fat, excessive consumption of PA can contribute to the development of cardiovascular issues (11). Therefore, it is recommended that Palmitic Acid ideally constitute no more than 25-30% of the total fat content in chocolate.

3.1.3 Cocoa Butter (CB)

Cocoa Butter (CB) has quick melting properties in the mouth, releasing its maximum flavor due to its narrow melting range of 30–36°C (12). This feature enhances the sensory experience, providing a smooth, creamy texture and a burst of flavor as it melts almost immediately upon contact with the warmth of the mouth. CB also boasts a narrow plastic range, characterized by a high solid fat content of more than 70% at 10°C and dropping to 0% at 37°C (13). This distinguishing characteristic ensures that chocolate made with CB maintains an appealing solid state when held in hand but melts rapidly once consumed, creating a luxurious mouthfeel.
Additionally, including cocoa butter in chocolate significantly increases its overall fat content. Fats generally have higher melting points than other chocolate components, such as sugar or milk solids. Consequently, the addition of cocoa butter not only enhances the melting properties but also raises the melting point of the chocolate. This adjustment allows the chocolate to remain solid at room temperature and in warmer conditions while still providing the desirable quick melt-in-the-mouth, thus maintaining the balance between firmness and melt-in-your-mouth sensation.

3.1.4 Soy Lecithin (SLO)

Soy lecithin (SLO) is a highly effective emulsifier that significantly enhances the texture and consistency of chocolate products (14). By stabilizing the mixture, SLO prevents the separation of fat into crystalline and liquid forms on the chocolate's surface, thereby inhibiting the formation of bloom—a common defect that results in a dull, whitish appearance. This stabilization is crucial for maintaining the visual and textural appeal of chocolate.

Furthermore, SLO contributes to extending the shelf life of chocolate products by preventing the separation of various ingredients within the recipe. This stabilization reduces the risk of spoilage and ensures the product retains its quality over time, leading to a more consistent and enjoyable consumer experience.

In terms of heat resistance, SLO has a melting point of 30 to 40°C, which is beneficial for maintaining the structural integrity of chocolate under varying temperature conditions. This property is especially advantageous for enhancing the properties of white chocolate, which can be more susceptible to temperature fluctuations. However, when incorporating SLO into white chocolate, it is necessary to dilute it with Palm Kernel Oil (PKO) to achieve the desired consistency and performance. This combination ensures that the emulsifying properties of SLO are effectively utilized without compromising the texture or stability of the final productProduct Properties

3.1.5 Viscosity

When various additional components are mixed into chocolate, the viscosity of the resulting product can be significantly affected. Including ingredients such as emulsifiers, fats, and other additives can either increase or decrease the viscosity, depending on their properties and interactions with the primary components of chocolate (cocoa butter, sugar, and milk solids). The viscosity of the chocolate added with different additional component was shown in Tabel 1.

Table 1. The viscosity of The Coated Banana in Different Coating Components.

Properties	Component added			
	PKO	PA	CB	SLO
Viscosity (cp)	13610	10870	10240	9670
Speed (rpm)	40	50	60	60
Torque (%)	90.7	90.6	88.2	96.7

The presence of solid particles such as sugar, milk solids, and cocoa solids also affects the viscosity. Higher concentrations of these particles generally increase the viscosity due to the increased resistance to flow. The particle size distribution and the degree of particle dispersion are crucial factors; finer particles and better dispersion typically lead to lower viscosity (9). Palm Kernel Oil (PKO) has the highest viscosity among the tested components. The high viscosity indicates a thicker coating, which might provide a firmer texture and better stability but could also impact the sensory properties, making the coated banana harder to bite. The torque percentage indicates a relatively high resistance to flow, which correlates with the high viscosity.

Palmitic Acid (PA) shows a lower viscosity than PKO but remains significantly higher than Cocoa Butter (CB) and Soy Lecithin (SLO). The increased speed (50 rpm) used to measure PA suggests that it flows more readily than PKO, yet it still provides a substantial coating. The torque is almost similar to PKO, indicating a high resistance to flow but slightly less than PKO.

Cocoa Butter (CB) has a lower viscosity than PKO and PA. This lower viscosity suggests a smoother, more fluid coating, which might contribute to a better mouthfeel and a quicker melt-in-the-mouth experience. The higher speed (60 rpm) indicates better flow properties, and the lower torque compared to PKO and PA suggests less resistance to flow, aligning with its smoother texture.

Soy Lecithin (SLO) has the lowest viscosity among the tested components. It is suggested that the thinnest and most fluid coating can improve the mouthfeel and provide a more delicate texture. The speed is maintained at 60 rpm, similar to CB, indicating good flow properties. However, the torque percentage is the highest, suggesting that while SLO reduces viscosity significantly, it still interacts strongly with the mixture components to resist flow.

3.1.6 Melting temperature

The melting temperatures of the different components added to the chocolate coating has displayed in Table 2.

Table 2. Viscosity of The Coated Banana in Different Coating.

Properties	Component added			
	PKO	PA	CB	SLO
Enthalpy (J/g)	33,826	39,936	46,215	41,025
Melting Temperature (^{o}C)	30.05	29.25	28.83	29.01
Onset Temperature (^{o}C)	23.37	23.16	22.22	22.81

PKO exhibits a relatively low enthalpy, melting temperature, and onset temperature compared to other components. From the data, PKO melts at a lower temperature and has a narrower temperature range compared to PA, CB, and SLO. The low enthalpy indicates less energy required for the phase transition from solid to liquid state, which can influence the processing and stability of chocolate coatings (15). On the other hand PA shows a higher enthalpy and slightly lower melting and onset temperatures compared to PKO. The higher enthalpy suggests PA requires more energy for melting, contributing to its stability in chocolate coatings. The melting and onset temperatures are close to PKO, indicating similar thermal behavior but slightly different energy requirements for phase transition. .

CB exhibits the highest enthalpy among the components, indicating a significant amount of energy required for melting. Despite having a lower melting temperature than PKO and PA, CB's higher enthalpy suggests a more complex crystalline structure, contributing to chocolate's stability and desirable melting properties. The onset temperature is also lower, indicating CB starts to melt earlier than PKO and PA. Furthermore, SLO shows moderate enthalpy and melting temperatures, similar to PA but slightly higher than CB. The onset temperature is comparable to PA and CB, suggesting SLO starts melting at a similar temperature range. This thermal behavior makes SLO effective as an emulsifier and stabilizer in chocolate coatings, contributing to improved texture and shelf life (16)

3.1.7 Texture

The data in Fig. 2 provided reflects the hardness measurements of coated bananas using different coating components: Control, Palm Kernel Oil (PKO), Palmitic Acid (PA), Cocoa Butter (CB), and Soy Lecithin (SLO). The hardness values are given in grams-force (gf), a measure of the force required to compress the sample.

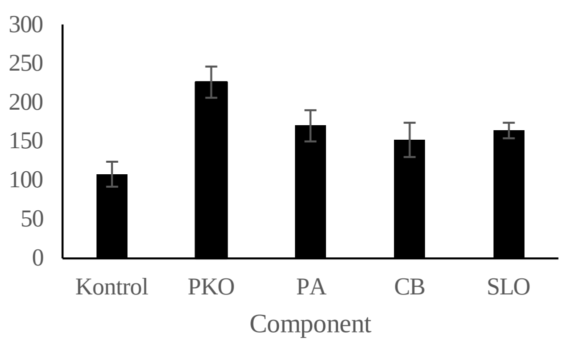

Fig. 2. Texture of coated banana in different coating components.

The control sample has the lowest hardness value at 108 g as a baseline for comparison against the samples coated with different components. The lower hardness indicates a softer texture, which might result in a less firm bite compared to the coated samples. On the other hand, the PKO-coated sample exhibits the highest hardness value at 226 g. PKO is known for its solid fat content at lower temperatures, contributing to a firmer and more brittle texture. This increased hardness indicates a significant improvement in the structural integrity and firmness of the coating, making it more resistant to deformation.

The PA and CB-coated samples show hardness values of 170 g and 152 g, respectively, which are higher than the control but lower than PKO. Palmitic Acid contributes to the formation of stable fat crystals, enhancing the texture and firmness of the coating.

Furthermore, cocoa butter is known for its desirable melting properties and smooth texture. The hardness is higher than the control but lower than PA and PKO. This value reflects the balanced properties of cocoa butter, providing a firm yet smooth texture that is pleasant to consume.

The SLO-coated sample has a hardness value of 164 g, similar to that of CB. Soy lecithin acts as an emulsifier and stabilizer, improving the texture and shelf life of the coating. The moderate hardness indicates that SLO enhances the structural integrity of the coating without making it overly hard, maintaining a good texture profile..

4 CONCLUSION

Based on the comprehensive measurements conducted, it is evident that the four components—Palm Kernel Oil (PKO), Palmitic Acid (PA), Cocoa Butter (CB), and Soy Lecithin (SLO)—substantially enhance the quality of the white chocolate coating. Each component contributes distinctively to the chocolate's overall properties, but Cocoa Butter (CB) emerges as the most promising additive. Cocoa Butter exhibits the best viscosity among the tested components, with a value of 9600 cP. This optimal viscosity is crucial for achieving a smooth and manageable coating consistency. Additionally, CB has a slightly lower melting point at 29.01°C. This characteristic ensures the chocolate melts smoothly in the mouth without becoming too runny at room temperature. In conclusion, adding Cocoa Butter to the white chocolate mixture is the best solution. CB improves viscosity, melting properties, and hardness and excels in organoleptic qualities, making it the ideal choice for enhancing the white chocolate coating.

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