UNIVERSITI PUTRA MALAYSIA

***THE PRODUCTION OF BANANA PUREE POWDER BY FOAM MAT DRYING METHOD***

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## ABSTRACT

Banana fruit is one of the world's most important crops and plays a key role in food security especially in the developing countries. Regrettably, almost one quarter of the annual banana production is rejected due to not meeting the required dimensions for retail sale. Fortunately, the rejected bananas can be used as a food ingredient for various applications, including as banana puree. Banana puree is the main commercial processed banana product worldwide; however, it is generally deteriorating rapidly. Thus, this study focuses on the dehydration of banana puree through foam mat drying (FMD) technique to prolong its shelf life. It involves whipping the banana puree to form the foams with the existence of whey protein concentrate (WPC) and carboxymethyl cellulose (CMC) as the foaming agent and foam stabilizer, respectively. The study was divided into 3 stages in order to 1) evaluate the effect of different foaming agent percentages (5, 7.5, 10, 12.5 and 15%); and 2) determine the effect of drying temperatures (80, 70, 60 and 50°C) on the production of FMD banana puree powder; while 3) comparison of the drying curve between FMD and control sample. The oven dried sample was used as the sample control. The banana puree powders produced were analyzed in terms of the foam density, moisture content, solubility, color (browning index) and flow ability (caking strength). Based on the obtained findings in both stages, the foam mat drying technique has proven to produce good quality banana puree powder in terms of the powder properties in comparisom with the control sample. In addition, by using the FMD technique, the drying time of the banana puree can be reduced by 2-3 times. Due to acceptable characteristics of the produced powder, this study has recommended the production of the –FMD banana puree powder by using 10% of foaming agent and at 80 °C drying temperature.

## ABSTRAK

Buah pisang adalah salah satu tanaman yang paling penting di dunia dan memainkan peranan penting dalam keselamatan makanan terutamanya di negara-negara membangun. Malangnya, hampir satu perempat daripada pengeluaran pisang tahunan ditolak kerana tidak memenuhi dimensi yang diperlukan untuk jualan runcit. Namun, pisang rosak boleh digunakan sebagai bahan makanan untuk pelbagai aplikasi, termasuk pisang puri. Pisang puri adalah hasil pisang pemprosesan utama komersial di seluruh dunia; Walau bagaimanapun, ia biasanya merosot dengan cepat. Oleh itu, kajian ini fokus kepada dehidrasi pisang puri melalui buih teknik mat pengeringan untuk memanjangkan jangka hayat mereka. Ia melibatkan proses memutar puri pisang untuk membentuk buih dengan penggunaan ejen berbuih dan buih penstabil tertentu. Kajian ini dibahagikan kepada 3 peringkat untuk 1) menilai kesan perbezaan peratusan agen berbuih (5, 7.5, 10, 12.5 dan 15%); dan 2) mengkaji kesan suhu pengeringan (80, 70, 60 dan 50 ° C) pada penghasilan serbuk pisang mengunakan kaedah FMD; manakala 3) perbandingan lengkung pengeringan antara FMD dan sampel kawalan. Sampel pengeringan oven secara terus telah digunakan sebagai kawalan sampel. Serbuk yang dihasilkan akan dianalisis dengan ketumpatan buih, kandungan kelembapan, kelarutan, warna (indeks pemerangan) dan aliran keupayaan (caking kekuatan). Berdasarkan penemuan yang diperolehi dalam kedua-dua peringkat, teknik pengeringan buih mat telah terbukti menghasilkan serbuk pisang berkualiti baik dari segi sifat serbuk dalam perbandingan dengan sampel kawalan. Di samping itu, dengan menggunakan teknik

FMD, masa pengeringan pisang puri dapat dikurangkan sebanyak 2-3 kali. Disebabkan oleh ciri-ciri yang boleh diterima daripada serbuk yang dihasilkan, kajian ini telah mencadangkan penghasilan serbuk pisang-FMD dengan menggunakan 10% agen berbuih dan pada suhu pengeringan 80 °C.

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| FMD | - | Foam mat drying |
| FAO | - | Food and Agriculture Organization |
| UTAR | - | Agriculture Science Journal |
| USDA | - | United State Department of Agriculture |
| CMC | - | carboxymethyl cellulose |
| L* | - | lightness of sample |
| a* | - | redness of sample |
| b* | - | yellowness of sample |
| WPC | - | whey protein concentrated |
| rpm | - | revolution per minute |
| MC | - | moisture content |
| PE | - | polyethylene |
| BI | - | browning index |
| Temp | - | temperature |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Banana, a major global food primary, is the fourth most important nutrient, after rice, straw, and corn. There are 12.7 million tons of bananas in world trade, worth US$4, 306 million. Even so, this represents only 13% of the bananas grown worldwide. The remainder is produced in the household garden for family consumption and local trade (Daniells, 2003). The production, distribution details were presented by pie chart in figure 1.1.

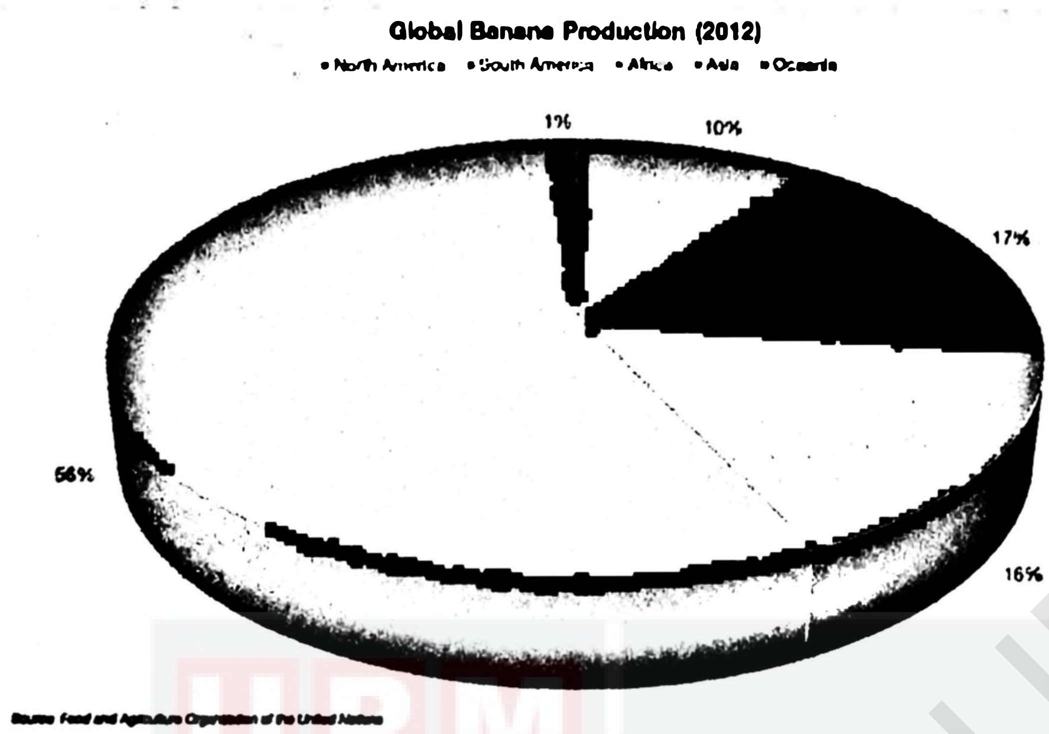



**Figure 1-1:** World banana production average of 2012 ("EST: Banana facts,")

In Malaysia, '*Pisang*' is the local name for banana or banane. Malaysia is rich in varieties of banana, from large size '*Pisang Tanduk*' to small size '*Pisang Emas*'. There are more than 20 types of bananas planted locally. The most common bananas among Malaysian are: '*Pisang Embun*', '*Pisang Emas*', '*Pisang Rastali*', '*Pisang Berangan*' and '*Pisang Tanduk*'(Mahmood, 2001). Bananas offer a quick boost of vitality and are a good source of vitamins C and B6. In fact, vitamin C has been shown to help prevent cancer while vitamin B6 can help in the formation of red blood cells. Besides that, Bananas contain high potassium which helps prevent high blood pressure (Debjit Bhowmik et al, 2012)

Despite the fact that most of banana fruits are consumed fresh, an increasing number of processed products have emerged, such as banana chips, banana juice and banana puree. Banana puree, as one of the main product from banana is the basis for bakery and beverages. Besides, another application for banana puree is in confection, sauce, fruit snack and bars, ice cream and yogurt, smoothies, sorbet and granites. Unfortunately, banana puree is very sensitive, easily spoiled and has a short shelf life. Therefore, the way to solve this issue is by the dehydration process of banana puree.

The dehydration or drying process takes place when water vapor is taken away from its surface into the surrounding space, resulting in a dried material with an extended shelf life and reduced water activity of food products (wilhelm et al., 2004). During drying, the moisture content can be brought down to a level ranging from 1 to 5%, which avoids microbial spoilage and undesirable enzymatic reactions (Fumagalli & Silveira, 2005). By this process, the banana puree can be converted into powder form for commercialization purpose. Powder production is also beneficial for size reduction, easy for storage and an effective method of prolonging the shelf-life. In addition, banana puree powder is more convenient in terms of in handling compared to the fresh puree. Furthermore, banana puree powder offer more flexibility to be used in varieties of banana based products.

There are several the dehydration methods in order to produce banana powder such as hot air drying, vacuum drying, microwave and freeze-drying and foam mat drying techniques. Among the mentioned drying techniques, foam mat drying (FMD) is relatively simple, low cost and practical to be applied for the removal of water from banana puree. This method is suitable for the dehydration of heat-sensitive, high sugar content and viscous foods, which are difficult-to-dry and sticky under relatively mild conditions without change in quality (Sangamithra et al., 2014). This process can be used for large scale production of fruit powders because of its suitability for all types of juices, rapid drying at lower temperature, retention of nutritional quality, easy reconstitution and cost-effective for producing easily reconstitute table juice powders. Banana puree powder obtained through this process has high economic potentials over their liquid counterparts such as reduced volume or weight, reduced storage space, simpler handling and transportation, and much longer shelf life (Sangamithra, Sivakumar, Kannan, & John, 2015).

**1.2 Problem Statement**

In Malaysia banana usually is freshly consumed. Apart from that, banana chip and banana dessert are quite popular, but not the banana puree powder. This indicates potentials for developing of such product for local and international. As banana puree is widely used in many of food product, the production of banana puree powder might open up for a new market area. The banana powder can be used as a multipurpose raw material for making coolies, dessert or beverages.

Banana puree is normally derived from overripe banana which demand to have lesser commercial value. In its original form, banana puree has short shelf life, thus, converting it into the powder form through drying process will increase its commercial value. The dehydration method in producing banana puree powder can be of several types of technique such as conventional oven drying, spray drying, or freeze drying.

However, there are some limitations in using the meantioned drying techniques to produce banana powder due to the a sticky attribute which will create problems during the drying process. The stickiness properties in the banana puree are related to the high content of low molecular weight sugar, such as fructose, glucose, and sucrose in the fruit puree.

The problem of powder stickiness is mainly due to the low glass transition temperature of low molecular weight sugar content in the fruit puree. The produced powders may turn to be very hygroscopic which is it easily absorbing moisture from environment that makes them very susceptible to the functional property of stickiness and forming high agglomerates. The agglomeration problem is then will cause a caking problem, especially during the storage of the bulk powder.

Moreover, the flow behavior of the bulk powder under various conditions is very important the especially in handling operations such as for the storage of the powder in silos or bins and transportation. According on Johanson (1978), physical properties of the powder are highly dependent on the moisture content. When powders contain high moisture content, the powder will adhere strongly to the bin and would cause several flow ability problems.

The application of foam mat drying (FMD) method can solve the problem of stickiness during the drying process. This method allows the dehydration of heat sensitive, high sugar content and viscous foods, which difficult to dry and sticky under relatively mild conditions without change in quality (Sangamithra et al., 2014). The foam mat drying is suitable for drying of sticky, viscous and heat sensitive products, which cannot be dried by spray drying. Banana powder using a foam mat drying is a new and not commercialized yet product.

## 1.3 Objective

This research is an experimental study of banana powder using a foam mat drying method using over ripe banana fruits, foaming agent and foam stabilizer. The objective of this study are:

- To determine the effect of different percentage of foaming agent on the properties of the banana puree powder produced by a foam mat drying method
- To evaluate the effect of different drying temperature on the properties of the banana puree powder produced by a foam mat drying method.
- To compare the drying rate of the foam mat and oven dried samples.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter contains all relevant information about banana and foam mat drying method. The information in this chapter were based from sources related to the banana powder processing such as journal, book, website and brochures. This chapter inclusive information about banana including backgrounds, usage, nutrition contents, and benefits to human on the quality parameter for powder produced.

## 2.2 Banana

The banana belongs to the genus *Musa* of the family *Musaceae* which wild and cultivated banana. The genus *Musa* is divided into two sections which are *Musa* and *Callimusa*. *Musa* is the largest and most widespread geographically and contain all the major edible species of banana (Häkkinen, 2013). The most important distinction for *Callimusa* is the shape of the seeds (Vezina, 2018.).

Banana is one of the most important fruits in the developing countries of Asian, Latin American and Africa. Besides, it also a major global food staple, is the fourth most import food in the world after rice, wheat and maize. India is the largest banana world producer with 27,575,000 tons production. There are many varieties of bananas grown in India such as Robusta, Dwarf Cavendish, Poovan, and Nendran. The type of soil, volcanic and alluvial soil and temperature, above 24 degree calcius in India that produces high yield of bananas. China is the second largest world banana producer with 12,075,238 tons. China has five major provinces for banana production namely Guangdong, Guangxi, Yunnan, the island of Hainan and Fujian. Then, the Philippines stand on the third rank with 8,645,749 tons of production. Table 2.1 shows the top banana producing countries in the world based on wordatlas analysis ("Top Banana Producing Countries In The World - WorldAtlas.com,")

**Table 2-1:** Banana producing countries in the world ("Top Banana Producing Countries In The World - WorldAtlas.com,")

| Rank | Country | Production (in tonnes) |
|---|---|---|
| 1 | India | 27,575,000 |
| 2 | China (mainland) | 12,075,238 |
| 3 | Philippines | 8,645,749 |
| 4 | Brazil | 6,892,622 |
| 5 | Ecuador | 5,995,527 |

### 2.2.2 Banana in Malaysia

In Malaysia, '*pisang*' is the local name for banana. The word "banana" is a general term embracing a number of species or hybrids in the genus *Musa* of the family *Musaceae*. Banana is the second most widely cultivated fruit after durian in Malaysia. According to report by FAO( 2016), the total production of banana in Malaysia was 309,9508 tones. Besides, bananas were exported from Malaysia mainly to three major countries, Brunei, Indonesia and Singapore with 18814 tones capacity in 2013 (FAO, 2013).

Malaysia is rich in varieties of banana from large size '*Pisang Tanduk*' to small size '*Pisang Mas*'. There are more than 20 types of bananas planted locally (Milsum, 1919). Most common and popular bananas among Malaysians are *Mas* and *Berangan*, *Awak Nangka* and *Raja* (acuminata et al., 2012). According to Milsum, (1919), there have describes a few types of bananas in Malaysia.

**Table 2-2:** Description Types of Banana

| NO | TYPES OF BANANA | DESCRIPTION |
|---|---|---|
| 1 | *Pisang Mas* | a great favourite and extensively grown for sale in the local markets. Its have 2 to 3 inches long and 1.5 inches broad. It also has thin, often sticking to flesh and golden-yellow. The tasted is flesh soft and sweet. |

| | | |
|---|---|---|
| 2 | *Cavendish* | it is the commercial variety that is always available in local supermarket. This type has 6 to 9 inches long. Besides, its have white flesh, soft with sweet sour flavor. |
| 3 | *Pisang berangan* | The chestnut banana that have yellow skin with numerous black spot when ripe. It has about 4 inches long and flesh reddish, soft, sweet and fragrant. A similar types to 'Pisang Raja'. |
| 4 | *Pisang awak* | some districts have call 'Pisang Siam' that has skin dark yellow and turning red when bruised. It has 4 inches long and 1.5 inches in diameter. Its flesh sometimes containing a number of seeds. |
| 5 | *Pisang nangka* | this type has skin green color with 5 or more ridges not sharply defined. It's have 8 inches and 1.5 inches broad. It also has flesh light yellow, stiff and rather sour tastes. |

### 2.2.3 Benefits of banana

Bananas are indeed a great source of essential vitamins and minerals such as potassium, magnesium, vitamin B6, vitamin C and calcium. Besides, bananas have been reported as one of the antioxidative foods where have strong ability to protect themselves from the oxidative stress caused by the intense sunshine and high temperature (Shian, Abdullah, Musa, Maskat, & Ghani, 2012). Antioxidants help in decreases incidence of degenerative disease such as cancer, arthritis, arteriosclerosis, heart disease, inflammation, and brain dysfuntion (Cannioto et al., 2018). Furthermore, antioxidants also can delay oxidative damage of lipids, proteins and nucleic acids by reactive oxygen species, which include reactive free radicals. However, banana is not as a primary antioxidant but it is a great secondary antioxidant (Lim, Lim, & Tee, 2007).

In other hand, bananas are one of the richest sources of potassium in the world (Debjit Bhowmik et al., 2012). Potassium is the richest intracellular cationic electrolyte which is important for normal cellular function. Besides, it also participates in protein synthesis and carbohydrate metabolism (Lubin & Ennis, 1964). Potassium is useful in preventing cardiovascular, nutritional, and kidney consideration associated with both hypo and hyperkalemia (Kovesdy et al., 2017). Additionally, increasing potassium intake will decrease odds for having metabolic syndrome (Shin, Joh, Kim, & Park, 2013). Vitamin B6 is the one of nutrition contents in bananas which is can help improves visual acuity and optical coherence (Michaelides, 2018). Plus, it also can help in the formation of red blood cells. Table 2.2 shows the nutrient content of banana based on USDA analysis ("Food Composition Databases Show Foods -- Bananas, raw," 2018).

**Table 2-3:** Fresh common banana nutritive value per 100g ("Food Composition Databases Show Foods -- Bananas, raw,")

| PRINCPLE | NUTRIENT VALUE |
|---|---|
| Water | 74.91 g |
| energy | 89 kcal |
| protein | 1.09 g |
| Total lipid (fat) | 0.33 g |
| carbohydrate | 22.84 g |
| sugar | 12.23 g |
| MINERALS | |
| potassium | 358 mg |
| Calcium, Ca | 5 mg |
| Magnesium, Mg | 27 mg |
| VITAMINS | |
| Vitamin C | 8.7 mg |
| Vitamin B6 | 0.367 |



### 2.2.4 Banana-based product

Bananas are tropical fruits that have soft flesh, sweet taste and very nutritious for human health. In Malaysia, it is commonly eaten as fresh peeled banana. However, recently, there are many innovations of the banana fresh fruits to the other product that have been diversifying the banana based product in the market. Nowadays, in Malaysia we can see varieties of banana-based product such as banana juice drink concentrates, banana jams and banana fillings ("Welcome to Madam Sun," 2018). Besides, banana also used as products in chip shape in small and medium industry (Hamir, Khairol, & Ariff, 2006).

However, despite some of our local bananas are either being consumed fresh or utilized the banana for juice, chip and puree production, some of the banana in the industry will be discarded because of over ripe and rotten issue. Thus, this discarded banana can be used for the production of banana puree. Banana puree is the main ingredient in many traditional and modern dessert, snack and beverages. Despite its potential, banana puree is very sensitive, easily spoiled and has a short shelf life (Xu, Wang, Ren, Ni, & Liao, 2016). In order to tackle this issue, one of the possible alternatives is to convert the fresh banana puree into powder form.

**2.2.5 Banana powder**

An improvement method by dehydration could make banana as a commercial processed product from banana puree become powder. The banana powder is also could be used as a multipurpose raw material as a flour to make cookies or traditional food in Malaysia or used as an instant powder product which will be used to flavor iced cream, confection, formulated drinks and commercialized the powder to banana based product manufacturers. (Chauhan & Jethva, 2016). Besides, banana powder is also long in shelf life since the water content has been reduced, hence resulting a more convenient transporting, handling and storage of this product. (Haider, Niederreiter, Palzer, Hounslow, & Salman, 2018).

Banana powder product market is considered limited in Malaysia, however there is a huge commercial potential of this product. There is no existing banana powder processing plant in Malaysia. Nowadays, consumer pays a lot of attention in food safety and nutrition, so by applying consumer centric strategy, which banana powder is very nutritious, it will be a good way to introduce the banana powder to the local market ("SELF Nutrition Data | Food Facts, Information & Calorie Calculator," 2018). In order to produce the banana puree powder, this product must be undergone the drying process first.

## 2.3 Drying

Drying is a dehydration method of heat application under control condition to remove the moisture of water content by evaporation which involving simultaneous heat and mass transfer. Heat is transferred to the product and cause moisture removal by evaporating to an unsaturated gas (wilhelm et al., 2004).

Drying of fruits purposely is used to preserve the fruits from their fresh form to become dried nform for it durability. Drying removes the moisture from the fruit, reduce its water activity so that the bacteria or molds cannot grow and damage the fruits. Preserving fruit by drying can avoid the wastage of over-supplied fresh fruits. Moreover, it also can increase banana based product varieties and can be commercialized. There are three basic systems of dehydration, which is sun drying, hot air dehydration, and freeze drying (R. Mark, n.d.). Sun drying is a traditional method for reducing the moisture content from food preservation by exposing the food product with sun ray. The sun heats up the food and the surrounding air and cause the water to evaporate from food production. Sun drying is cheaper than mechanical drying and friendly to the environment. However, there are some limitation on sun drying, which are not possible during rainy season and at night, and delay leads to excess respiration and fungal growth will cause losses and temperature controls is difficult ("Drying Food,"1975).

Freeze drying is a drying involves the removal of water or other solvent from a frozen product by a process called sublimation. Sublimation occurs when a frozen liquid goes directly to the gaseous state without passing through the liquid phase. The advantages of freeze dried products can be stored at room temperature without spoilage (Ratti, 2013). However the cost of the specialized equipment required for freeze drying can be substantial, this drying process may to be an expensive (Pan, Shih, Mchugh, & Hirschberg,2008).

Hot air dehydration is a dehydration processing in a condition of air flow drying. It is a mechanical air dehydration that has many advantages over sun drying that the drying parameter can be accurately set, controlled and changed over the entire processing time. Thus, more consistently uniform product can be achieved with less quality degradation (Antal, 2015). The example of hot air drying is a spray drying.

Spray drying is a technique of transforming a feed from a fluid or slurry phase into dried particulate by spraying the feed with hot dry gas. The basic idea of spray drying is the production of highly dispersed powder from a feed by evaporating the water content of the droplets. The process is by the mixing if the heated gas with atomized droplets within the drying chamber and causing the water in the droplet to evaporate uniformly and quickly through direct contact (Kuriakose &

Anandharamakrishnan, 2010). However, the spray drying have problem with high sugar content of food likes banana fruit whereby the powder start sticking in the wall of drying chamber and coating (Fitzpatrick & Ahrné, 2005). Thus, this can reduce the production yield quality of banana powder.

Beside the mentioned drying techniques, there are many other drying methods available that offer different advantages. One of them is the foam mat drying (FMD) which requires the food sample to be in a foamy structure prior to drying. This method is suitable for viscous and high sugar products.

### 2.4 Foam mat drying

According to the USDA analysis of banana in Table 2.2, banana have high sugar content that can give problem to drying process. Besides, banana also has a dense tissue structure of banana that can cause long drying time. Thus, it leads to low quality of banana powder and increasing cost because it required a large amount of energy (Thuwapanichayanan, Prachayawarakorn, & Soponronnarit, 2012a)

By creating a porous structure of banana puree, the mentioned problems be overcomed. The porous structure of banana mixture will resulted more surface areas available for the removal of moisture from the sample during the drying process. There are several techniques that can be used to create the porous structure of banana puree including foam mat drying method (Franco, Perussello, Ellendersen, & Masson, 2015).

Foam mat drying (FMD) method is a combination of foam formation and drying. The formation of the foam structure in this method requires the existence of foaming agent and foam stabilizer, which will be discussed later in this chapter. Foam is a colloidal dispersion in which gas is dispersed in a continuous liquid phase. The dispersion phase is the internal phase while continuous phase is external phase. The dispersion phase is larger than continuous phase (Xiong et al., 2018). Thus, it can increase the volume of banana powder. Besides, the foams have flat, thin and have lamellae between bubbles or liquid film (figure 2.1). The gaseous phase is absorb in the form of uniformly distributed tiny bubbles and then the texture and appearance will change. Additionally, foam making by high sugar content of liquid can produce more stable foams due to the increases elasticity of the lamella or liquid film (Sangamithra et al., 2014).

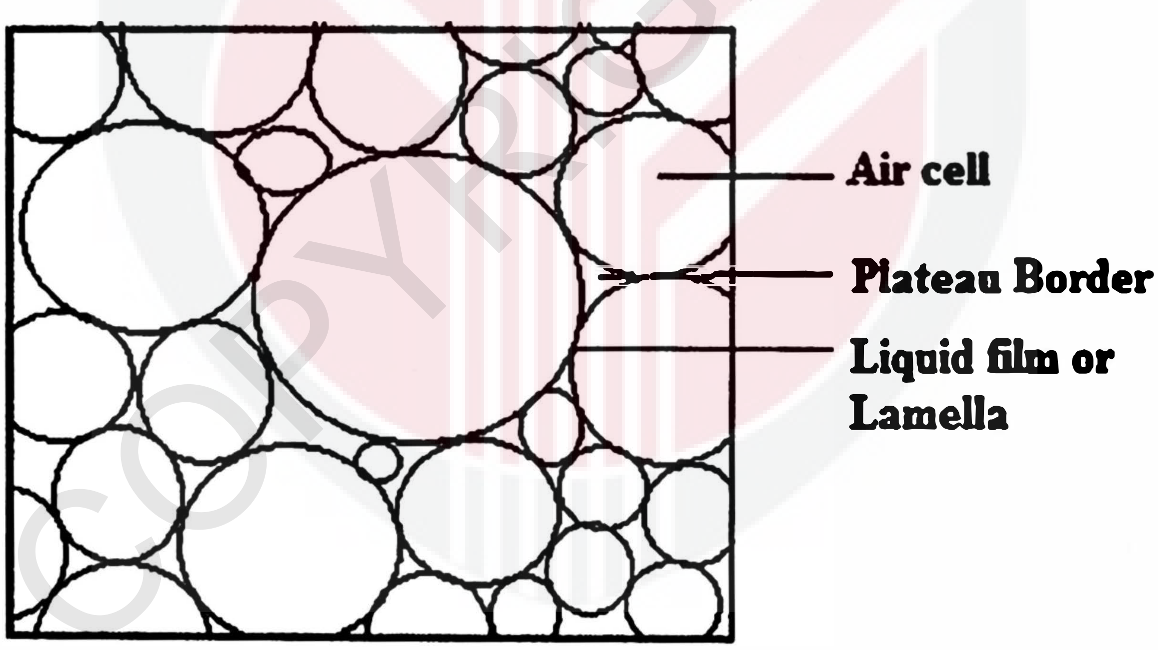



**Figure 2-1:**Schematic structure of foam (Sangamithra et al., 2014)

In other hand, this method is a process in liquid or puree are whipped into stable foams and then air dried. During drying process it is desirable that the foams remain stable and retain their typical open structure to facilitate rapid drying. Thus, the primary condition for successful foam mat drying is stable gas-liquid form. Mixtures of banana puree and agents are whipped to form stable forms using specially designed device such as a blender or kitchen mixer. Then, the foam is then spread as a thin sheet or mat and exposed to stream of hot air until it dried.

### 2.4.2 Advantages of foam mat drying

The FMD is the most suitable drying method to produce the banana powder by considering several advantages. Firstly, the foam mat drying method can be used on heat sensitive, viscous and high sugar content of food likes banana puree. Foam formation in this method can increase the surface area exposed to the drying air due to porous structure. Thus, leading to a shorter period of dehydration because of increasing the mass transfer rates. Plus, foam mat drying will increase the quality of final product (Franco et al., 2015).

Furthermore, foam mat drying is an economical alternative than spray and freeze drying method. The foam mat drying process can be used for large scale production because banana powder because of rapid drying at lower temperature, retention of nutritional quality, easy reconstitution and cost effective for producing easily stable banana powder. Additionally, this method is relatively simple and alternative method which facilitates the removal of water from banana puree compared to other method (Sangamithra et al., 2014).

However, the foams formation in this this method should remain mechanically and thermodynamically stable in order to maintain the efficiency of the water removal and the quality of the product (Franco et al., 2015). The undesirable feature increases the drying rate, if foams collapse during drying process. Therefore, necessary to add foaming agents and stabilizers to induce foaming and to impart proper in oven stability (Sankat & Castaigne, 2004).

**2.4.3 Foaming agents**

One of the most difficult problems in the processing of foamed materials is the instability of the foam which is can occur during the foaming and drying steps (Thuwapanichayanan et al., 2012). If the foam is unstable, the collapse of porous structure occurs, resulting in deteriorated foamed quality. Thus, the suitability of foaming agents is very important for foam mat drying method. A foaming agent is a surfactant material that reduces the surface tension between two liquids which is between a liquid and a solid and also facilitates to foam formation. Ability to adsorb readily at the air water interface which reduce interface is a good foaming agent. Besides, the features of good foaming agent also able to interact mutually, form a strong cohesive and viscoelastic film that can withstand thermal and mechanical agitation (Sangamithra et al., 2014).

Protein gives a good foamability and high foam stability through their hydrophobicity. Besides, it also allow rapid adsorption at the air-water interface leading to the formation of a coherent elastic adsorbed layer (Dickinson, 1998). According to

(Sangamithra et al., 2014), the most widely used foaming agents are albumin, soy protein isolate and whey protein concentrated.

Albumin or know as egg white is the main protein in eggs. Whipping the albumin in room temperature to produce a larger volume of foam than whipping in refrigerated temperature (Henry & Barbour, 1933). According to Townsend and Nakai (1983) the egg white could be more rapidly adsorbed at the air-liquid interface which have shorter time for whipping than other type of foaming agent. However, its easy to collapse after 20 minutes of whipping process and unstable during drying process (Falade & Okocha, 2012).

In other hand, soy protein isolate is made from soybean meal that has been dehulled and defatted. The features of soy protein isolate is emulsification, viscosity, water binding, dispersability and foaming (Sangamithra et al., 2014). However, the compact tertiary structure of the soy protein isolate are made its instability of foams over time and produce poor foaming properties such as foam formation and foam drainage (Martínez, Carrera Sánchez, Rodríguez Patino, & Pilosof, 2009). Plus, according to Thuwapanichayanan et al. (2012) where the elongation of microstructure of soy protein isolate banana forms shown the instability of foam because of bubble collapse and extensive shrinkage.

Furthermore, whey protein is a by-product of the cheese making process and potential source as emulsifier, stabilizer, whitening agent and foaming agent (Kinsella and whitehead 1989). The banana foam using whey protein concentrated (figure 2-2) was the most stable during whipping process than egg albumin and soy protein isolate even though its took longer time in whipping process than other foaming agent (Thuwapanichayanan et al., 2012). The author also reports that whey protein concentrated had the least shrinkage, highest void area fraction and highest value of the effective moisture diffusivity than egg albumin.

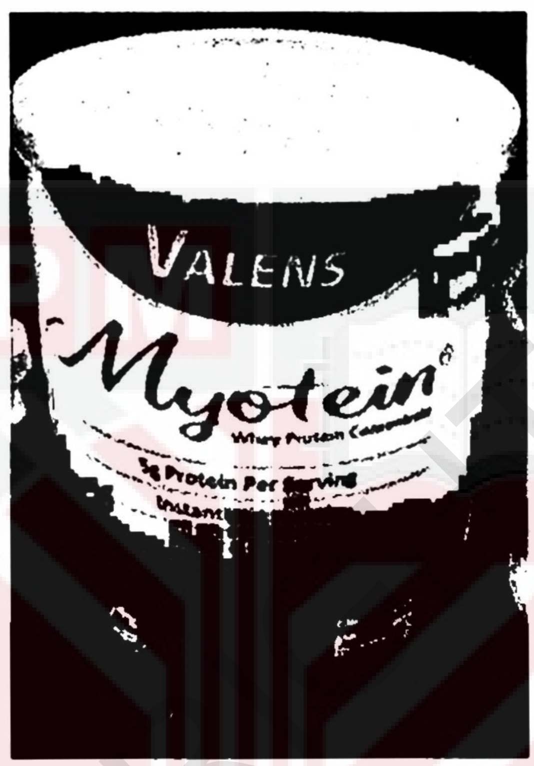



**Figure 2-2:** Whey protein concentrated

### 2.4.4 Foam stabilizers

Foam stabilizers are ingredients that increase the stability of banana foams. According to Muller (2002), the foam stabilizers can enhance the stability of foam by a thickening and gelling effect of the liquid solution. Besides, it also do not adsorb at the interface (Sangamithra et al., 2014). The xanthan gum, Arabic gum, starches, pectins and gelatin is an examples of foam stablizers where increasing the viscosity of the continuous phase. Plus, these agents also forming a three dimensional network that retards the movement of component within the foam (Walsh, Russell, & Fitzgerald, 2008). The effect of foam stabilizers on foaming properties of food proteins like whey protein concentrated shown that stability is strongly increased and lowering the surface tension (Sangamithra et al., 2014).

However, the cellulose gum or know as CMC is the most common stabilizer used by many of the researchers. CMC is used as sodium salt, stabilizer to stabilize emulsions and as thickener or viscosity modifier. Additionally, CMC can be successfully dried using foam mat drying method due to it can produce mechanically and thermodynamically stable foam (Sangamithra et al., 2014).

### 2.4.5 Foam density

The drying rate of any foamed materials depends on foam density characteristic. The lower of the foam density, the more air trapped in foam during whipping process. Then, the more air present in the foam, the higher the whip ability (Falade & Okocha, 2012). While, the more mechanical deformation and more bubble wall rupture during extended whipping when the foam density increasing (Dickinson, 1998). Thermal degradation lead to inferior product quality caused by higher foam density (Sangamithra et al., 2014). Thus, the foam density can be calculated by measuring the mass of a fixed volume of the foam (Thuwapanichayanan et al., 2012).

## 2.5 Fruits powder properties

The characteristic of the banana powder after drying process should be determined in terms of its physiochemical characteristic, to identify the quality of the powder and to ensure the product produced is good enough to be consumed by the customers. Physical properties of the powder such as moisture content, solubility, color and flow ability also play a significant role in their resulting storage and flow behavior.

### 2.5.1 Moisture content

Moisture content of dried powder is a percentage of water contained in the materials by its mass of the dry solid in the sample. Moisture content is important in the quality control of the powder produce because moisture content will affect their susceptibility to spoilage and also can create a problem during the storage and transportation of the powder regarding to the caking problem. The same product from different country will have different humidity to different weather.

According to industry report of NBHC (2015), the powder that has been over exposed to the environment moisture or excessive of humidity during the storage until the moisture content above 15 percentages can sustain the microbial growth and should not be used. Besides, to determine the storage life need to determine of moisture content of powder. Plus, spoilage of the product can increase when hygroscopic product exposure to the moisture (Naviglio, Conti, Ferrara, & Santini, 2010).

### 2.5.2 Solubility

The solubility is a chemical property based on the ability for the solute to dissolve in a solvent. Besides, solubility also defines as how well the powders dissolve and create a stable suspension. Clogging of filters is a of problems if the powder not completely solubilized (Tan, 2016). Additionally, the solubility is the most important property of the rehydration process as it is final stage (Fang, Selomulya, & Chen, 2007).

The factors that effect the result of results for solubility is particle size and temperature (Sikand, Tong, Vink, & Walker, 2012).

There are several methods for solubility measurement such as using mechanical stirred, magnetic stirred and Pharma Test dissolution tester. The Pharma Test dissolution allows the prediction of the time for powder complete soluble in water ("Dissolution Testing Archive - Pharma Test," 2018).

### 2.5.3 Color

In determining of quality the banana powder, the color powder is the one of powder properties that also can be analyzed since the first judgment made by a consumer on a food is its visual appearance. The color of the powder will effect due to enzymatic browning where the brown color is developed when the presence of oxygen (Chaisakdanugull, Theerakulkait, & Wrolstad, 2007). Besides, the brown color appearance because of the Maillard reaction where chemical reaction happened between amino acids and reducing sugars. This reaction occurs in the process of roasting of coffee, baking of bread, toasting of cereals and drying process (Martins, Martins, & Jongen, 2001). The authors also report that Maillard reaction not only influences color of food, but also influence into flavor and nutritional value.

The intense brown color of the powder is determined by calculating the browning index using the formula combining the L*a*b* (Nasser, Moreau, Jeantet, Hédoux, & Delaplace, 2017).

$$BI = \frac{[100\ (x - 0.31)]}{0.17} \quad \textbf{Equation 2-1}$$

$$\text{With } x = \frac{(a* + 1.750\ x\ L*)}{(5.645 \times L* + a* - 3.012 \times b*)} \quad \textbf{Equation 2-2}$$

Where L is lightness, a is redness and b is yellowness. The portable spectrophotometer is used to measure the L*a*b* of the banana powder samples.

### 2.5.5 Flow ability

The flow ability of the powder is the ability of granular solid to flow. Flow ability is a combination of the physical properties that will influence of material flow, environmental condition, storage, equipment used during handling and the processing method of producing the material (Prescott 2000). Factors that affecting the flow ability of powder include the moisture content, particle size and flow agent. Thus, the powder need to sieve before flow ability test.

There are several method for powder flow measurement such as angle of repose which is the angle formed by the horizontal base surface and the edge of a cone like pile of granules, by bulk density and tapped density, compressibility index, which is using tapped and bulk density and powder rheometer from texture analyze which is performed with powder flow analyzer attachment. In powder flow measurement by flow analyzer can be done by doing caking test. Caking test by flow analyzer was involving rotor spinning with a force purposely for compaction of the powder. At the end, the rotor slices through the compacted cake recording hardness of the cake where the force required to get the compacted powder flowing freely (Shah, Tawakkul, & Khan, 2008) .

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

In this chapter the sample preparation, experimental work, foam mat drying of banana and analyse involved will be explained in detail. All of these will be carried out by referring to the previous studies in the literature.

## 3.2 Experimental work

The experimental work was involved the banana foam preparation from banana puree until the foam mat drying of banana foam. This study was divided into 3 stages namely 1) the production of FMD banana puree powder at different foaming agent 2) the production of FMD banana puree powder at different drying temperatures, and 3) the comparison on drying curve between FMD and oven-dried samples.

### 3.2.1 Sample preparation

The banana fruit of the Cavendish variety was bought from convenient stores (Sri Serdang, Selangor, Malaysia). The aim of this project to overcome the problem over ripe and rotten banana that thrown away. However, in the market, only freshly consume banana is selected from stage 5 and 6 bananas (figure 3.1). Thus, the banana was left at room temperature for 3 days to speed up the ripening process. Many dark spots will be form in stage 7 because of browning process. The peel was separated and only the flesh was used as the main ingredient. The Whey Protein Concentrate (WPC) was used as a foaming agent where have 80 g protein per 100 g dry solids and Carboxymethyl Cellulose (CMC) as foam stabilizer. WPC and CMC ware also acquired from the local convenient stores.


**Figure 3-1:** The banana ripeness grading pictorial scales (Yap, Fernando, Brennan, Jayasena, & Coorey, 2017)

The overripe bananas flesh were blanched by placing them in boiling water for 1 min to inactivate the polyphenoloxidase which triggers the generation of dark pigment (Yap et al., 2017). The flesh of the banana was mash to form banana puree before weighed to 100 g by using a weighing balance. Then, whey protein concentrated (WPC), Carboxymethyl Cellulose (CMC) and distilled water was also weighed based on modified formula from Thuwapanichayanan, Prachayawarakorn, & Soponronnarit (2012) and Abbasi & Azizpour (2016) below:

| | | |
|---|---|---|
| i. | Banana puree | : 100 g |
| ii. | Whey protein concentrated (WPC) | : 5 g / 100 g (5%) |
| iii. | Carboxymethyl Cellulose (CMC) | : 8 g / 100 g (8%) |
| iv. | distilled water | : 85 g / 100 g (85%) |

The mixture of WPC, CMC and distilled water were being whipping using a kitchen mixer with maximum speed was 1150 rpm for 50 minutes. Then, the banana puree added to the mixture and mixing for 5 minutes at the same speed. Next the foamed samples removed from the foaming device and analyzed for foam density.

**Figure 3-2:** The foam banana after wiping process

### 3.2.2 Foam mat drying of the banana

The produced foam spread uniformly on a tray that covered with parchment baking paper with the thickness of 3.0 ± 0.02 mm (figure 3.3) and then put into the cabinet dryer. The foam banana was dried for 7 hours. The dried mat removed from dryer plate and then the dried foam will be ground by kitchen grinder. The banana powder was sieved by 100 μm screen mesh using woven wire sieves before evaluation of powder quality. Finally, the banana powder packaged for evaluation of powder quality.

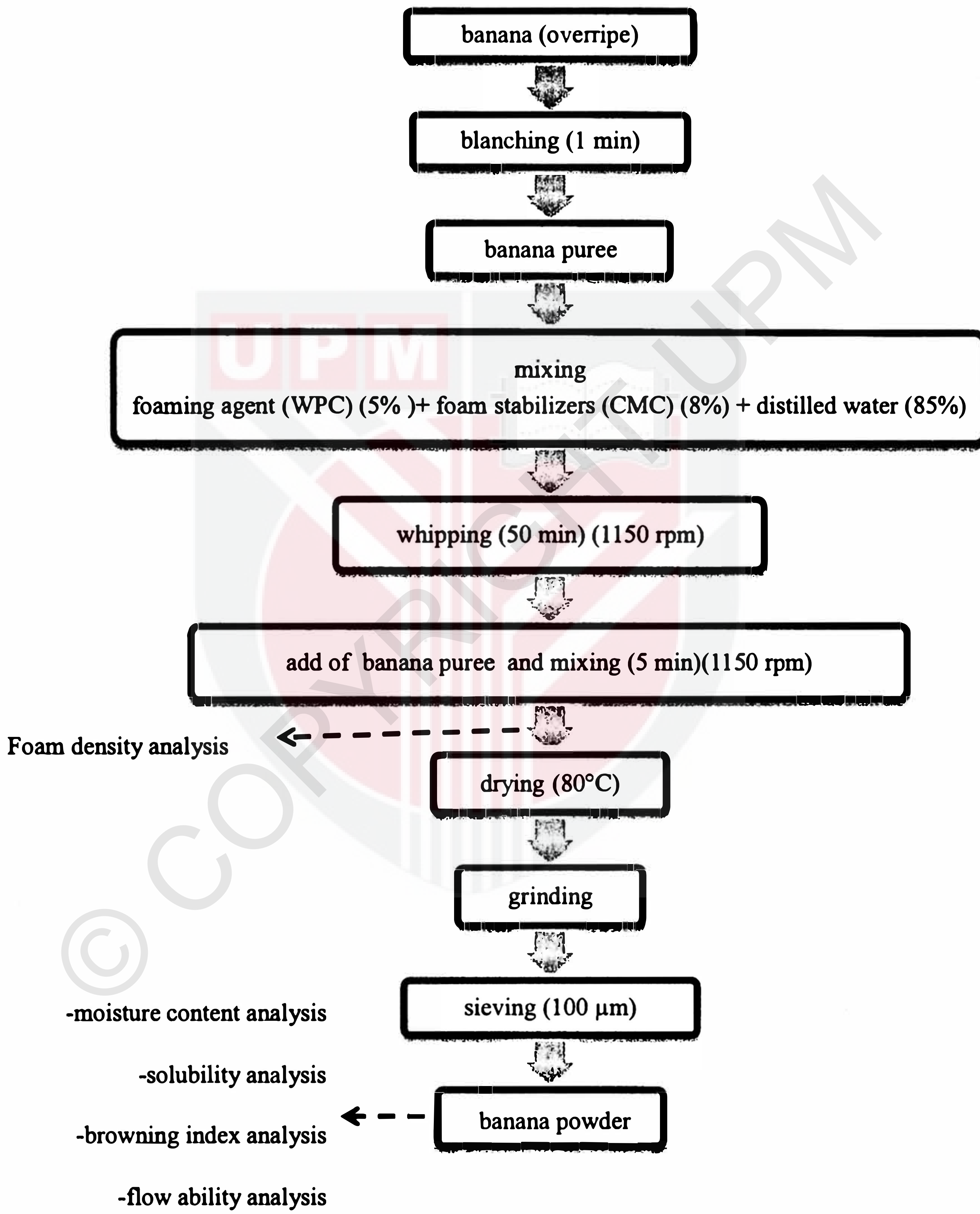
**Figure 3-3:** The foam spread uniformly on tray

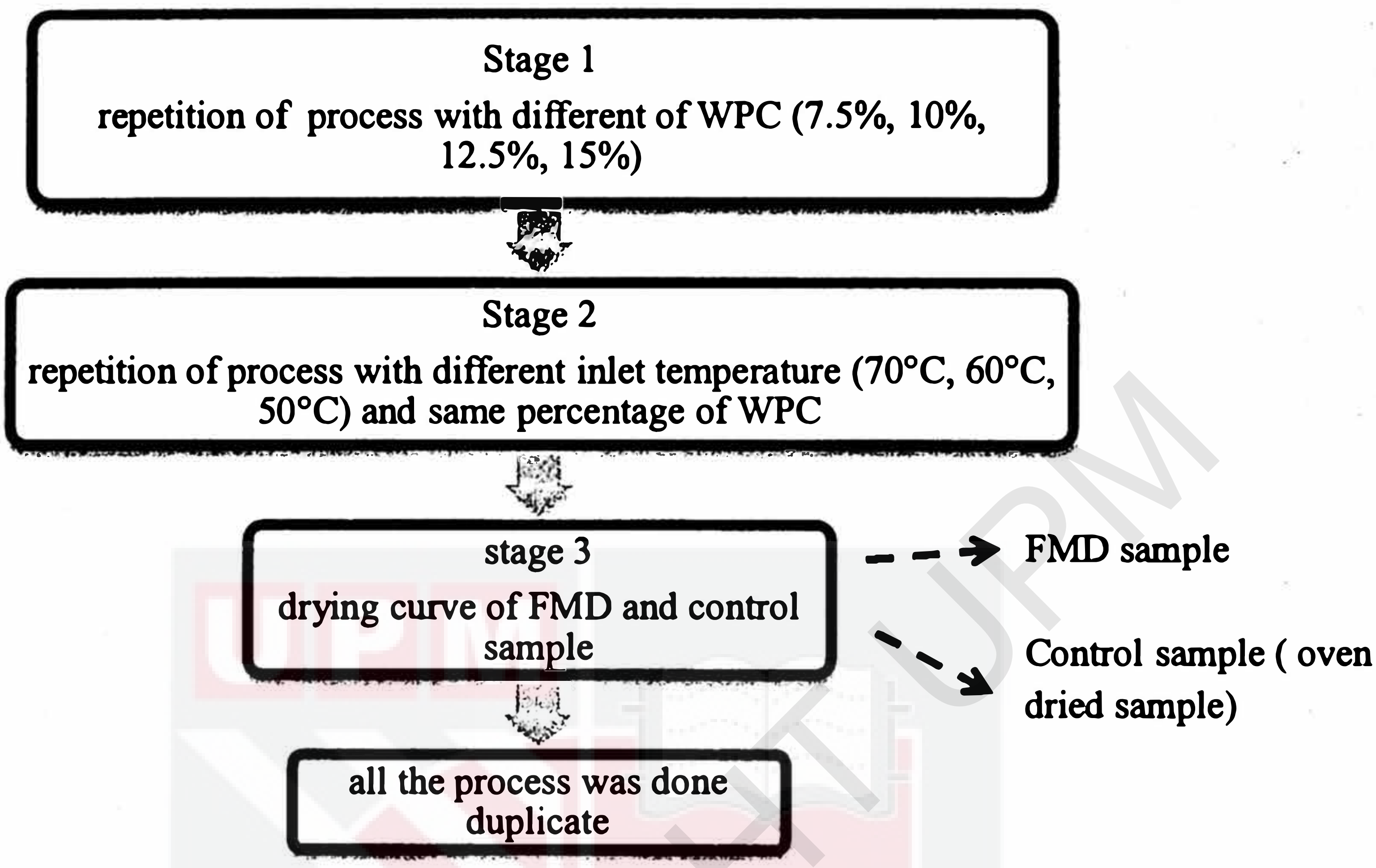
In Stage 1 of this study, the controlled parameter was the percentages of <u>foaming</u> agent (WPC), with contant drying temperature of 80 °C and drying time of 7 hours. The percentages of WPC varied to 5, 7.5, 10, 12.5 and 15 % (5g/100g, 7.5g/100g, 10g/100g, 12.5g/100g and 15g/100g). Then, the produced banana powders were evaluated the find the best WPC percentage for the mixture.

The Stage 2 of the experiment, the controlled parameters was the drying temperature at a fixed percentages of foaming agent (chosen in the Stage 1). The drying temperature of oven varied from 80, 70, 60 and 50°C. Then, the banana powders were evaluated of powder quality to find the best drying temperature.

The final part in this study (Stage 3), observation on the drying curve of FMD and control samples was done. This stage is to see the moisture content removal between two different samples. The FMD sample was prepared based on the suggestion in Stage 1 and 2 in this study. While, the control sample was the fresh banana puree that directly oven dried. The samples were weighed hourly using weighing balance until the samples achieve a constant moisture content (MC).

## 3.3 Overall process flow






### 3.4 Analysis involved

The banana foam and banana powder produced was determined on their foam density, moisture content, solubility, color and flow ability.

#### 3.4.1 Determination of foam density

The foam density is important indicator of foam performance to improve the combustion resistance properties of the foam (Polyurethane Foam Association, 1991). The foam density was determined according to Bag, Srivastav, & Mishra (2011) where 50 ml of the foam poured into a 50 ml graduated cylinder at a controlled ambient temperature (22-25 °C). The samples weighed and foam density calculated according to the following equation:

$$\text{Foam density} = \frac{weight\ of\ foam\ (g)}{volume\ of\ foam\ (cm^3)} \qquad \textbf{Equation 3-1}$$

### 3.4.2 Determination of moisture content

Determination of moisture content of banana powder can be done most commonly either using the oven method which needs longer time or using moisture analyzer which is less time consuming. Moisture determination by using moisture analyzer is more preferable because it is does not large amount of effort involve and do not need long measurement time in the region of hours. Besides, the result obtains between the two methods is did not have much different.

The moisture content of banana powder was determined by using moisture analyzer (MX-50 Moisture analyzer, Japan) right after foam mat banana powder produced. A sample of 3 g of banana powder was then put in provided plate, close the moisture analyzer and run the analysis.

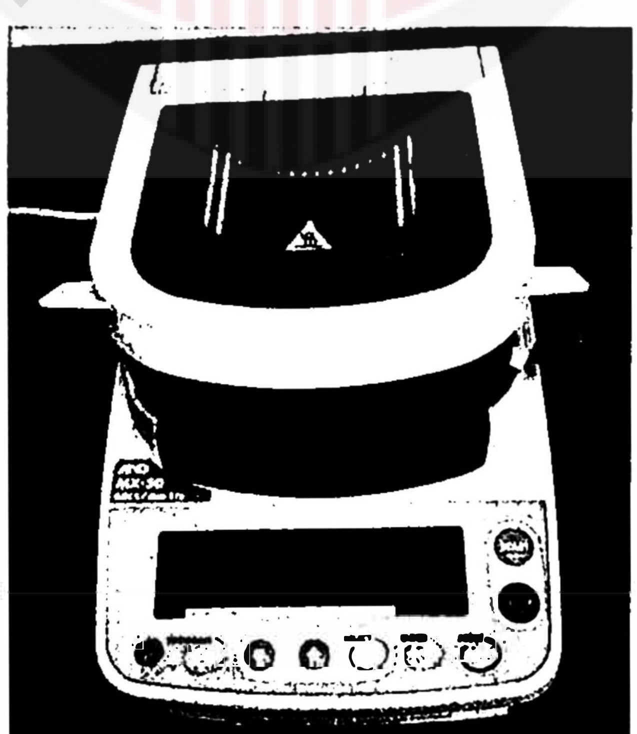


**Figure 3-4:** Moisture analyzer

### 3.4.3 Determination of solubility

Solubility is the dissolving rate of particle in a solution. The time in min was used to evaluate the solubility of banana powders. The solubility of banana powder was determined by Pharma Test dissolution tester (D-63512, Germany). The samples of 2.5 g of banana powder were then put in a vessel filled with 250 ml distilled water inside the bath. The speed of stirrers and temperature of water bath was set to 250 rpm and 45 °C. The Pharma Test dissolution tester was closed and the sample was run by turned on the stirrer button. The time was taken when the sample was dissolved in warm distilled water. All the samples every stage were run simultaneously to observe the faster and slower samples were dissolved in warm distilled water.

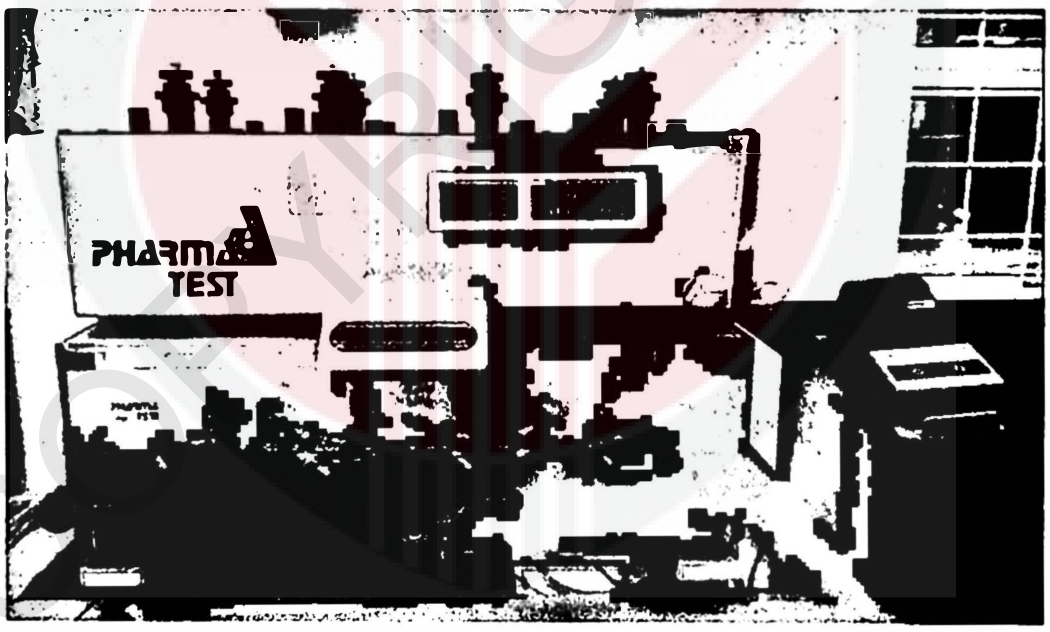



**Figure 3-5:** Pharma test dissolution tester

### 3.4.4 Determination of color

The visual color deterioration can describe by portable spectrophotometer (Konica Minolta CR-10, Japan). Besides, it also provides useful information (L*a*b*) for quality control of water, which for calculating the browning index (Oliveira, Sousa-Gallagher, Mahajan, & Teixeira, 2012). To measure color, 10 g of banana powder was placed in a polyethylene (PE) bag. It was ensured that all of the air inside PE bag has been drawn out before sealing up the bag. Before the test the sample, white and black calibration plate was used as standardized. Then, PE bag was placed at the port on the sensor of the portable spectrophotometer. The measurement simply measures the target. After one second the color difference is expressed as L*a*b*. Luminosity (L*), greenness (a*) and yellowness (b*) values were recorded. The browning index (BI), used to assess the intensity of the brown color of the samples, and was calculated from formula combining the L*a*b* in **Equation 2-1** and **Equation 2-2** (Nasser et al., 2017).

**Figure 3-6:** Portable spectrophotometer

### 3.4.5 Determination of flow ability

The banana powders were analyzed for their flow ability. Flow ability of the powder is a powder's resistance to flow, which also altering by the moisture content, particle size and also carrier agent to the powder produced. Knowing the flow ability properties of powder is important, especially for storage purpose and gravitational flow through pipe during transfer the powder for example during filling process or transferring powders from or to silos.

Flow ability of powders can be measured by using Powder Flow Ability Analyzer (TTC company, North America) as proposed by Shah et al., (2008). The flow ability of the powder was determined by running the caking test. The bulk powder of banana powder was fed into the glass vessel and lock on the stage of the analyzer.

The used of compaction method used as analysis for the caking potential. The rotor will spin down through the powder in the vessel with minimum disturbance and will be spinning back up. Measuring the cohesion between powder which cause caking and so can analyze how well the powder flow ability especially in silo storage application.



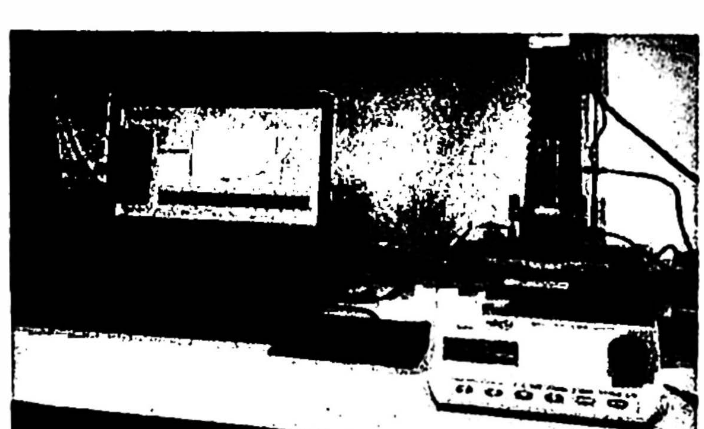


**Figure 3-7:** Powder flow ability analyzer

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 Introduction

This chapter presents the results and the discussions about the findings obtained from the experiments. These results include all the parameters of the FMD powder that need to be studied as stated in Chapter 3. The parameters are moisture content, solubility, color, flow ability. This chapter will also discuss about the relation between all the parameter with each other and their relation with the produced foam mat banana powder. Besides, comparison on the drying curve between FMD sample and normal oven dried sample was also being discussed in the last part of this chapter.

## 4.2 Stage 1: Effect of different percentages of foaming agent

During the Stage 1 of this study, different percentages of the foaming agent (WPC) was being added to the banana puree misture to observe its effect on the produced powder. The main purpose of the addition of WPC is to facilitate the banana powder production by reducing the hygroscopic properties of banana puree where change the form from a viscous liquid to a amorphous solids (Dehghannya, Pourahmad, Ghanbarzadeh, & Ghaffari, 2018). It also can affect the properties of the produced foam and powder which include the foam density, the moisture content, the solubility, the colour and flow ability of powder. As for comparison, control sample which was prepared without any WPC content by using oven drying method, was also included in some of the analyses.

### 4.2.1 Foam density of FMD moisture

Density is determined in order to evaluate the whipping properties. The change of density depends on the trapping of air during mixing (Falade, Adeyanju, & Uzo-Peters, 2003). Figure 4-1 shows the foam density of the banana puree mixture at different percentage of foaming agent. There were five different percentages of foaming agent (WPC) used during the study in Stage 1 i.e. 5, 7.5, 10, 12.5 and 15%.

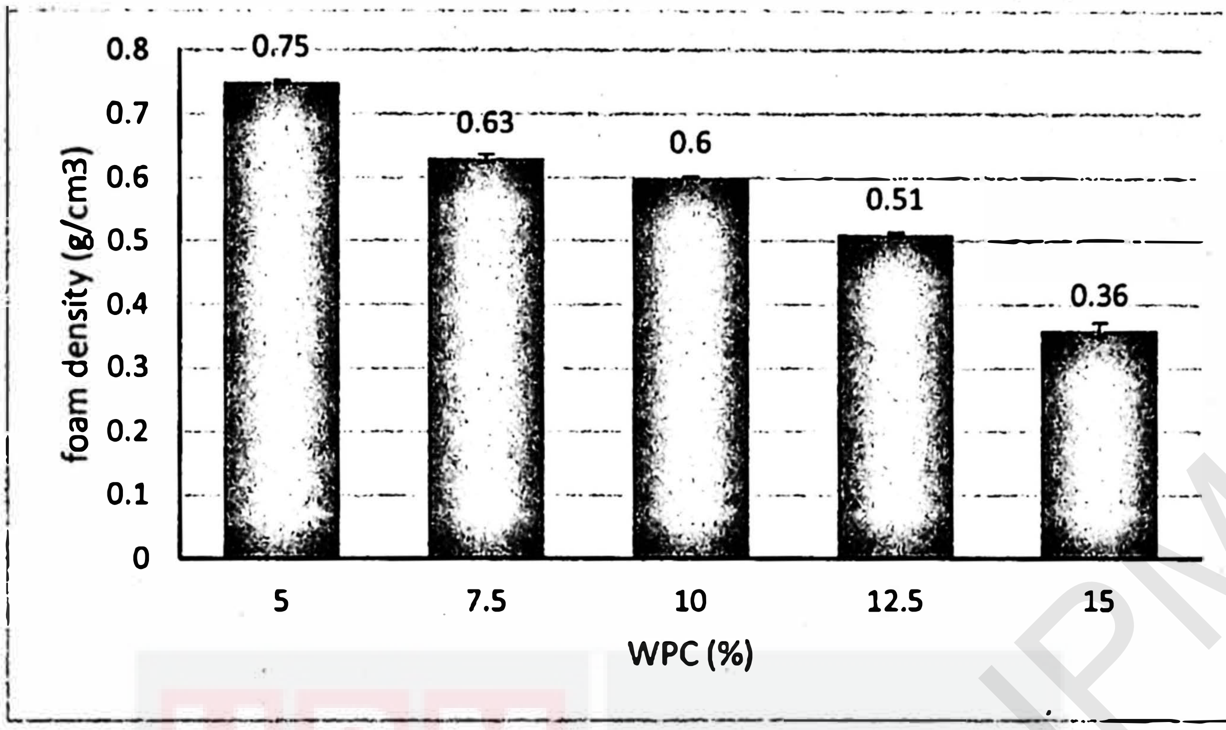



**Figure 4-1:** Foam density of FMD powders of different percentages of foaming agent

Based on figure 4-1, the density of the foam decreases significantly with increment of the concentration of WPC. This clear trend is due to reduce the interfacial tension at air or liquid interface with the increment of WPC concentration and subsequently reduces the surface tension of the structure. Higher WPC content leads to an increment in foaming ability and a reduction in the mixture density (Karim & Wai, 1999). It also resulted a reduction in surface tension which leads to increases in the entry of air into a foam structure and causes the density to reduce. Besides, the expansion in foam volume at higher foaming agent percentages has resulted the decrement of the foam density.

### 4.2.2 Moisture content

In powder production, high moisture content can cause the powder to be easily agglomerate and produce caking problem. Besides, high moisture content powder may prone to microbial activities and spoil easily. The powder should be as less as possible in contact with surrounding after drying process because it can cause exact reading of the moisture content. Additionally, spoilage of the product can increase when hygroscopic product exposure to the moisture (Naviglio et al., 2010). Figure 4-2 exhibit the moisture content of the banana powder produced at different percentage of foaming agent and a control sample with no WPC added.

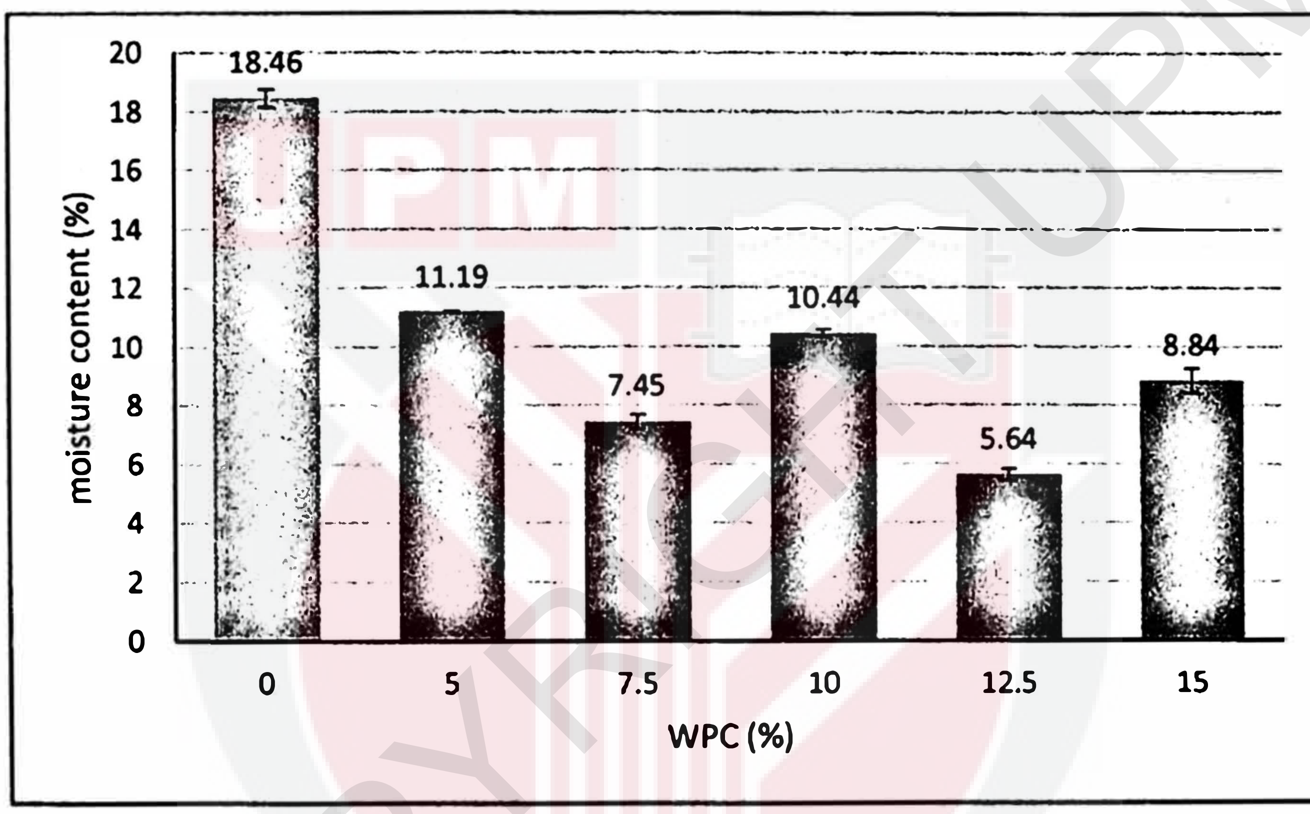



**Figure 4-2:** Moisture content of FMD powders of different percentages of foaming agent and a control sample

As shown in Figure 4-2, the moisture content of the sample is ranging from 5.64 to 11.19% for FMD samples which is significantly lower than the control sample (18.46%). This finding might be because the increasing foaming agent concentration may reduce the hygroscopicity of the powder (Seeranguravar, Manickavasagan, Al-Ismaili, & Al-Mulla, 2017). Besides, FDM sample have the large void area fraction due to increase the surface area of mixture during foaming developing process which facilitated moisture movement from inside to the sample surface. Thus, resulted more moisture removal during the drying process (Thuwapanichayanan et al., 2012a).

However, the Figure 4-2 also shown that there were no obvious trend among different of concentration of foaming agent between all the FMD samples which might be due to the handling error. Thus, the moisture content of the sample does not affected by the percentage of foaming agent (WPC).

### 4.2.3 Powder solubility rate

The solubility analysis is to determine the time taken for the banana powder to dissolve in distilled water. Figure 4-3 shows the solubility duration of the banana powder at different percentages of foaming agent and a control sample.

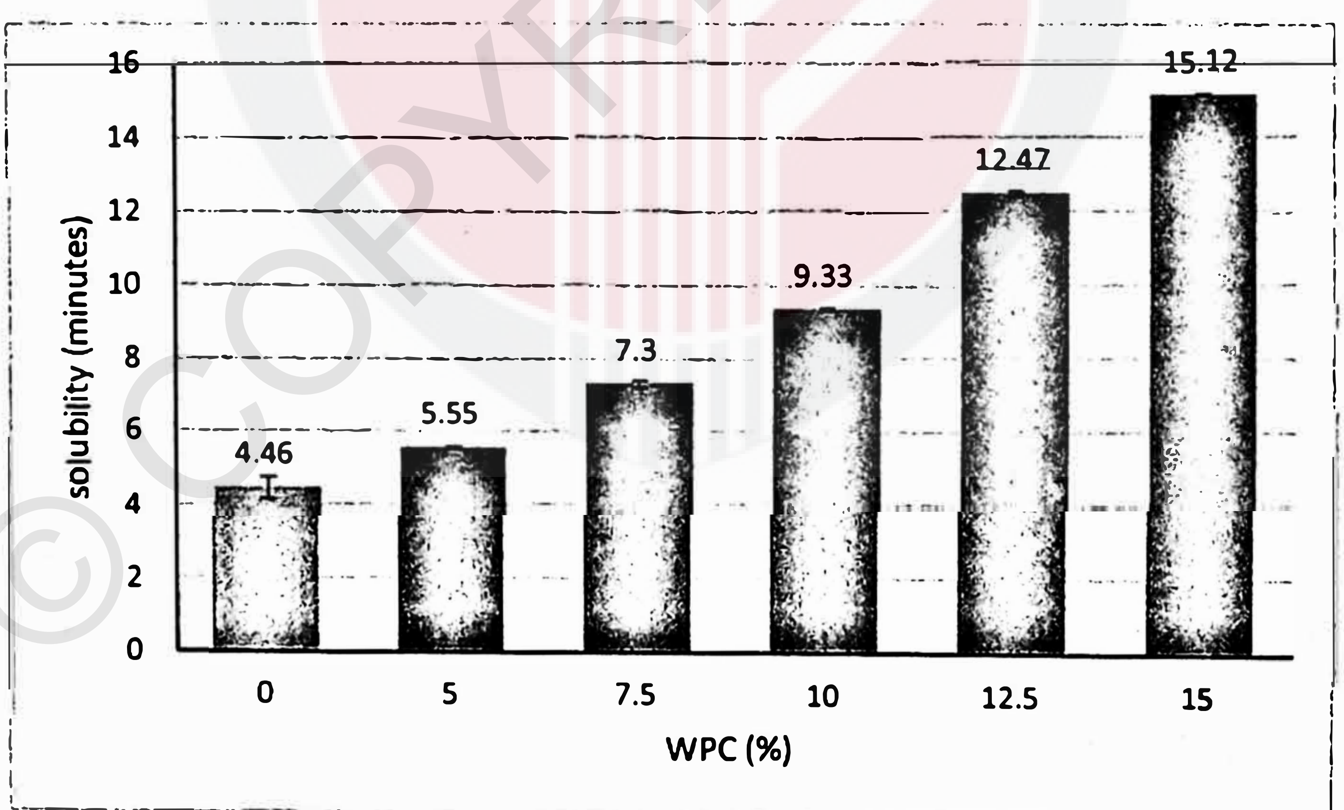



**Figure 4-3:** Solubility duration of FMD powders of different percentages of foaming agent and a control sample.

The time to solubilize the powdrs increased significantly with the rise of the concentration of WPC. Hence reflecting the fact that high WPC content in the FMD powder will result the powder with a low solubility rate. The clear trend is due to change in the microstructure of the FMD mixture (Cano-Chauca, Stringheta, Ramos, & Cal-Vidal, 2005) where reducing the hygroscopic behavior. Hygroscopic is the property of absorbing the water. According to Cano-Chauca et al., (2005)the low of hygroscopic character on the amorphous state of the powder. Since the increasing of WPC will increases the amorphous behavior of banana puree powder (Sangamithra et al., 2014), reducing the hygroscopic character. Thus, the solubility rate of the banana puree powder will increases when increment of the concentration of WPC.

### 4.2.4 Color properties

The first judgment made by consumers towards a food is its visual appearance. Besides, other quality parameters such as taste, aroma and texture also can also influence the judgment of the consumers. These quality parameters may be destroyed/deteriorated during drying process. The color of the banana purere powder will be effected due to enzymatic browning where the brown color is developed with the presence of oxygen during drying process (Chaisakdanugull et al., 2007). Colour is the single most important sensory cue when it comes to setting consumer expectations regarding the lokely taste and flavor of food. Most of cunsomer more prefer the light color of food than the dark color (Spence, 2015). Thus, the browning index (BI) will give effect to color of banana puree powder and acceptance of consumer. Figure 4-4 displays the browning index (BI) of the banana puree powder at different percentages of foaming agent and a control sample.

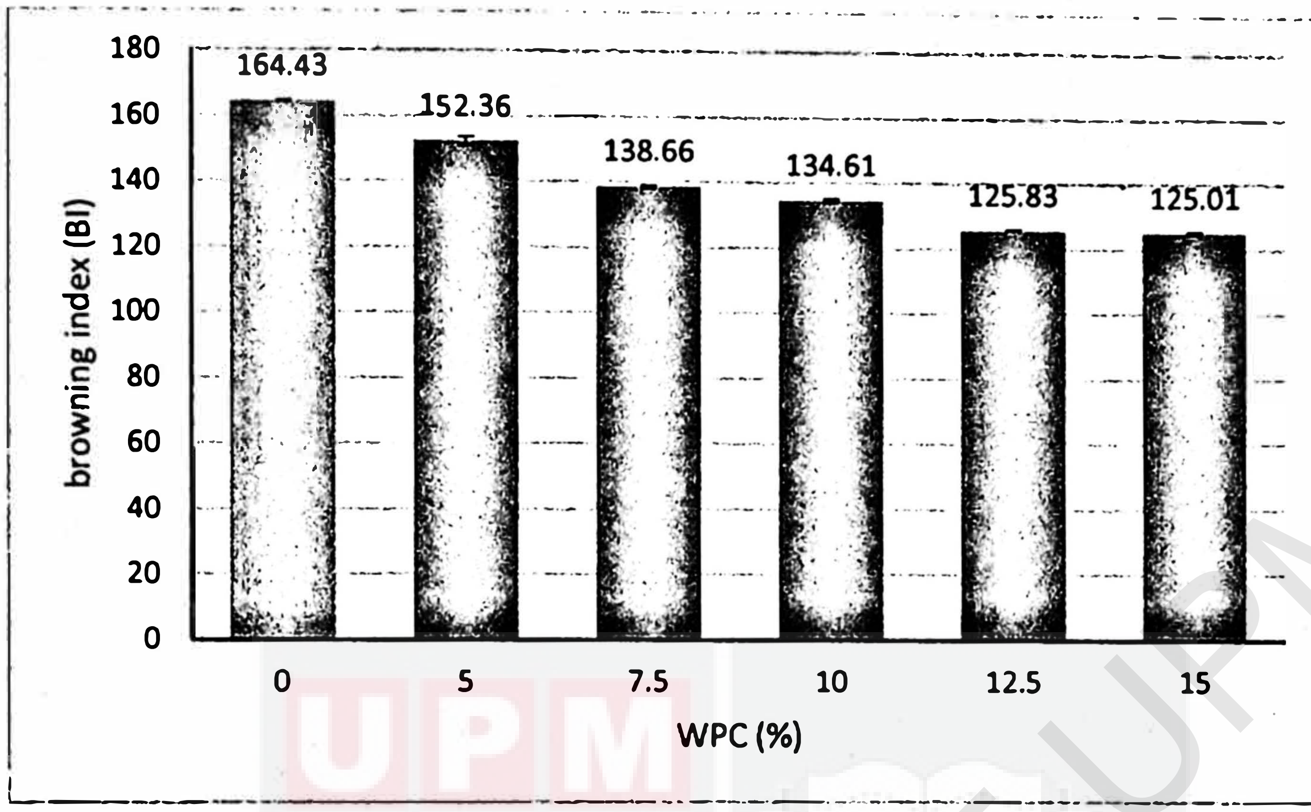



**Figure 4-4:** Browning index of FMD powders of different percentages of foaming agent and a control sample

As shown in the figure 4-4, by increasing the percentage of WPC, BI was reduced. The effect of WPC on the browning index showed a decreasing trend. The structure of WPC is made of protein, so by increasing the amount of WPC in the process, the amino acids existing in its chemical composition start to reducing sugar of the system (Wilson, Kadam, Chadha, Grewal, & Sharma, 2014), which lead to reducing the browning.

In comparison with the control sample, FMD samples have lower BI values. This might be due to the existence of CMC in the mixture. The CMC act as a foam stabilizer also gives effect to BI when CMC has a hydrophilic structure which bonds surrounding free-water. Furthermore, the first step of Maillard reaction performs better at lower amounts of water. This effect of CMC can contribute to the reduction of humidity that turns into precipitation in the first stage of Maillard reaction and consequently decrease the BI (Abbasi & Azizpour, 2016).

### 4.2.5 Flow ability

Flow ability of the banana powder was determined based on its caking strength of the powders using texture analyzer. Caking strength is a measurement to evaluate the potential of the particular powder to form cake based on the force required to cut through the cake formed after the compaction which would determine the strength of the cake (Shah et al., 2008). The greater the strength, the higher the tendency of the powder to form hard cake which is not easy to disperse. Thus, the tendency of the powder become caking is high.

Caking problem can happen during handling, storage, processing and distribution since the powder may experience different temperature and surrounding humidity. For example, excessive exposure of fruits powder to the humidity can cause the caking and can cause difficulties in discharging the powder from its container or silo. Figure 4-5 shows the flow ability of the banana powder in different percentage of foaming agent and a control sample.

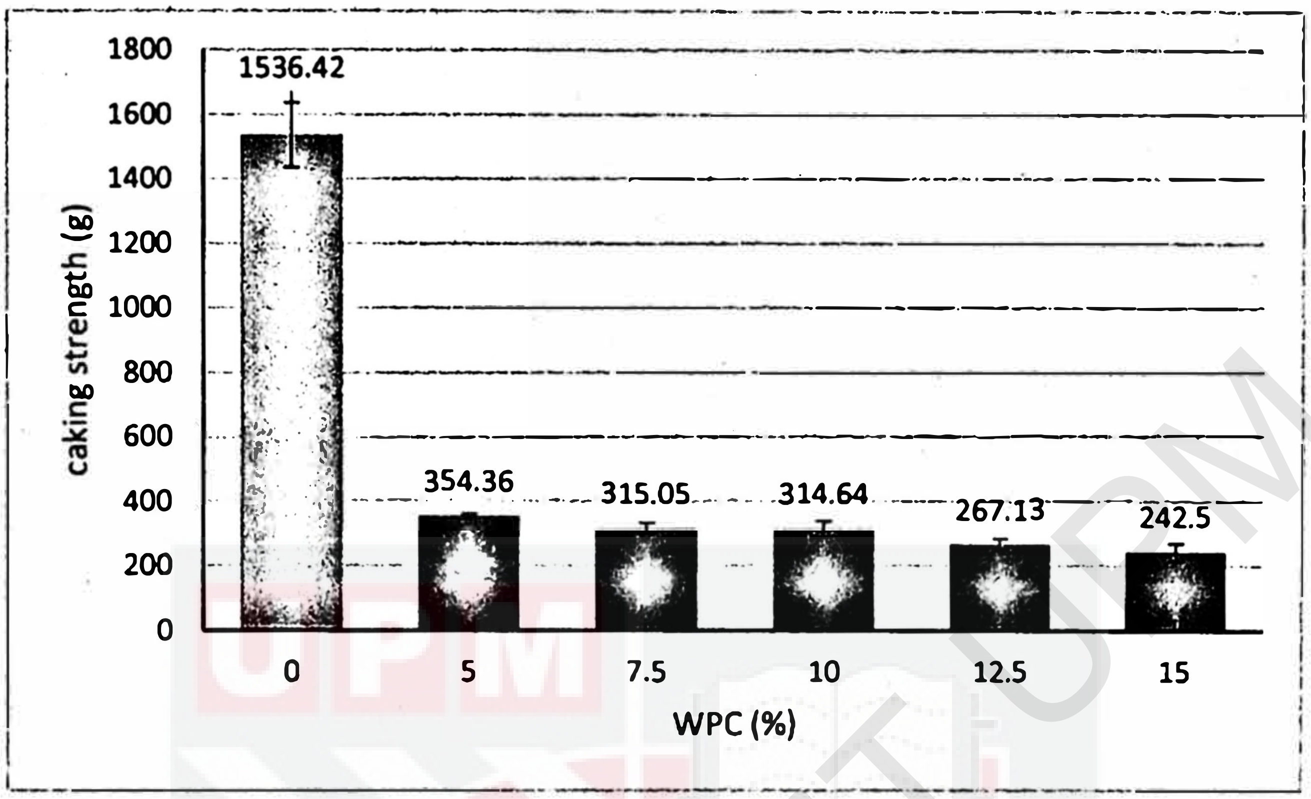



**Figure 4-5:** Caking strength of FMD powders of different percentages of foaming agent and a control sample

Based on the result obtain in figure 4-5, the control powder has a significantly stronger caking strength than any of the FMD powders. The figure also exhibits that the caking strength of the banana puree powder is decreasing as the concentration of WPC increasing. This finding has proven that the existence of the foaming agent and its concentration level have a significant effect on the lowering the caking problem of the banana powder. This is might be due to the existence of foaming agent may reduce the hygroscopicity of the powder (Seerangurayar et al., 2017). The hygroscopicity characteristic will produce sticky powder. The stickiness can lead in the rise of the cohesiveness, powder caking and increase the adhesion to surface of the powder. Thus, low of hygroscopicity behavior lead to decrease the caking strength and increase the flow ability.

### 4.2.6 Selection of the best foaming agent percentage in the FMD mixture

The powder produced by the best WPC percentage formulation should exhibit high foam density during mixing, acceptable moisture content, high solubility rate, low browning index and low caking strength. Based on the findings in Stage 1, this study has decided to choose FMD formulation with 10% WPC for the subsequent analyses. This is because, since at this percentage, some of the quality criteria listed above were fulfilled compared to the rest.

## 4.3 Stage 2: Effect of different drying temperatures

The best foaming agent (WPC) percentage concluded at Stage 1 was at 10%, hence this formulation was used in Stage 2 study. In Stage 2, drying temperature was varied at 80℃, 70 ℃, 60℃ and 50℃ to evaluate the effect of this factor on the characteristics of the FMD powder produced.

### 4.3.1 Moisture content

Based on the result obtain as in figure 4-6, as expected, the lowest drying temperature of 50℃ produced powder with the highest moisture content. This is due to increasing the relative humidty air in oven as the decrease of the temperature. Thus, it will cause the higher of the moisture content of the powder produced. However, this study also found an unexpected result where powder dried at 80℃ contained higher moisture compared to banana powders dried at 70℃ and 60℃. This might be due to error in sample preparation and handling process when measuring the moisture content since banana powder is very sensitive moisture and requires high precision in terms of time interval and storage system.

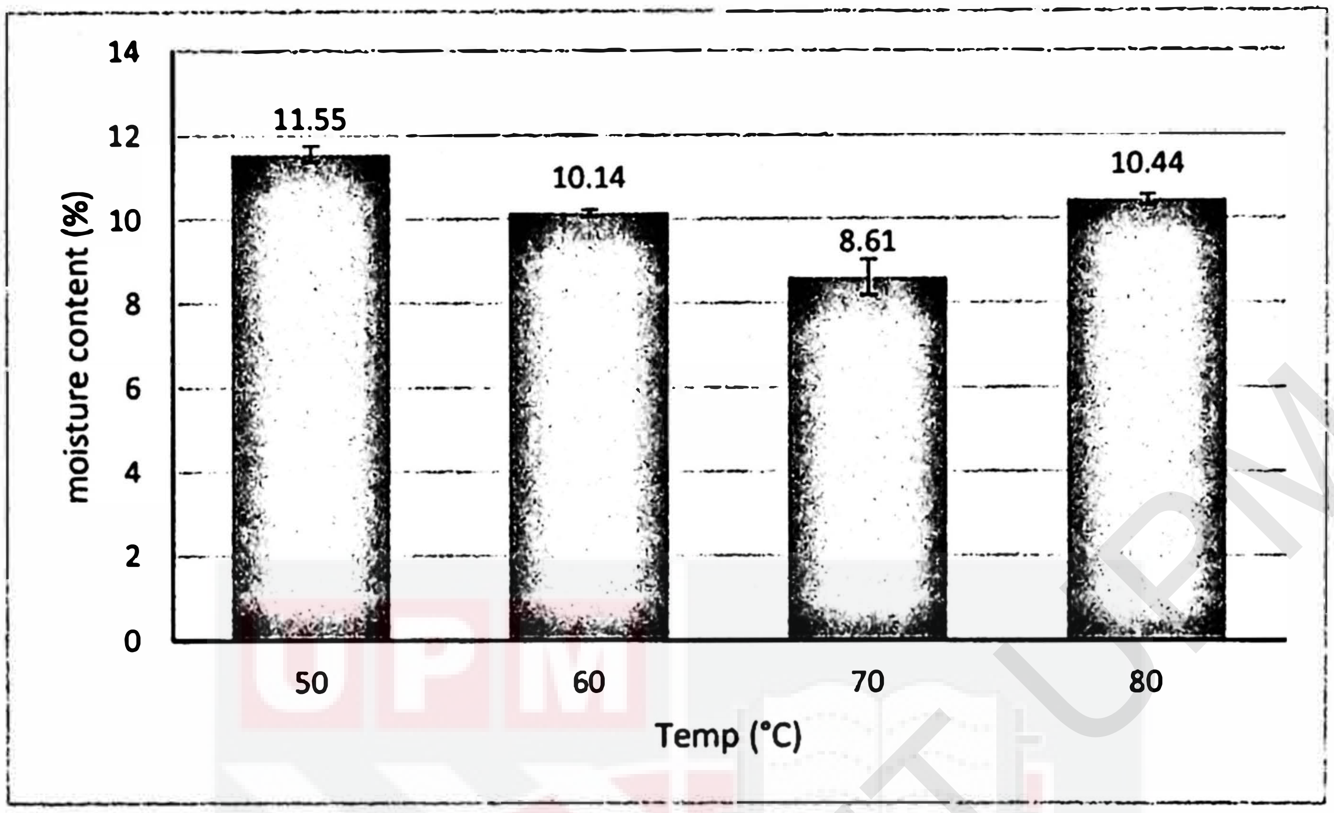



**Figure 4-6:** Moisture content of FMD powders dried at various drying temperatures

### 4.3.2 Solubility

Based on figure 4-7, the solubility increased as the drying temperature increased. This is due to increases the denaturation of protein where the increased the unfolded form of protein structure where the foaming agent was used in this study was protein group (Pauling L. and Miraky A., 1936). Besides, the decreasing the solubility is due to the increment of moisture content. Since the higher the moisture content, the higher the stickness of the banana puree powder which has less surface area available for contact with hydration water (Franco, Perussello, Ellendersen, & Masson, 2016)

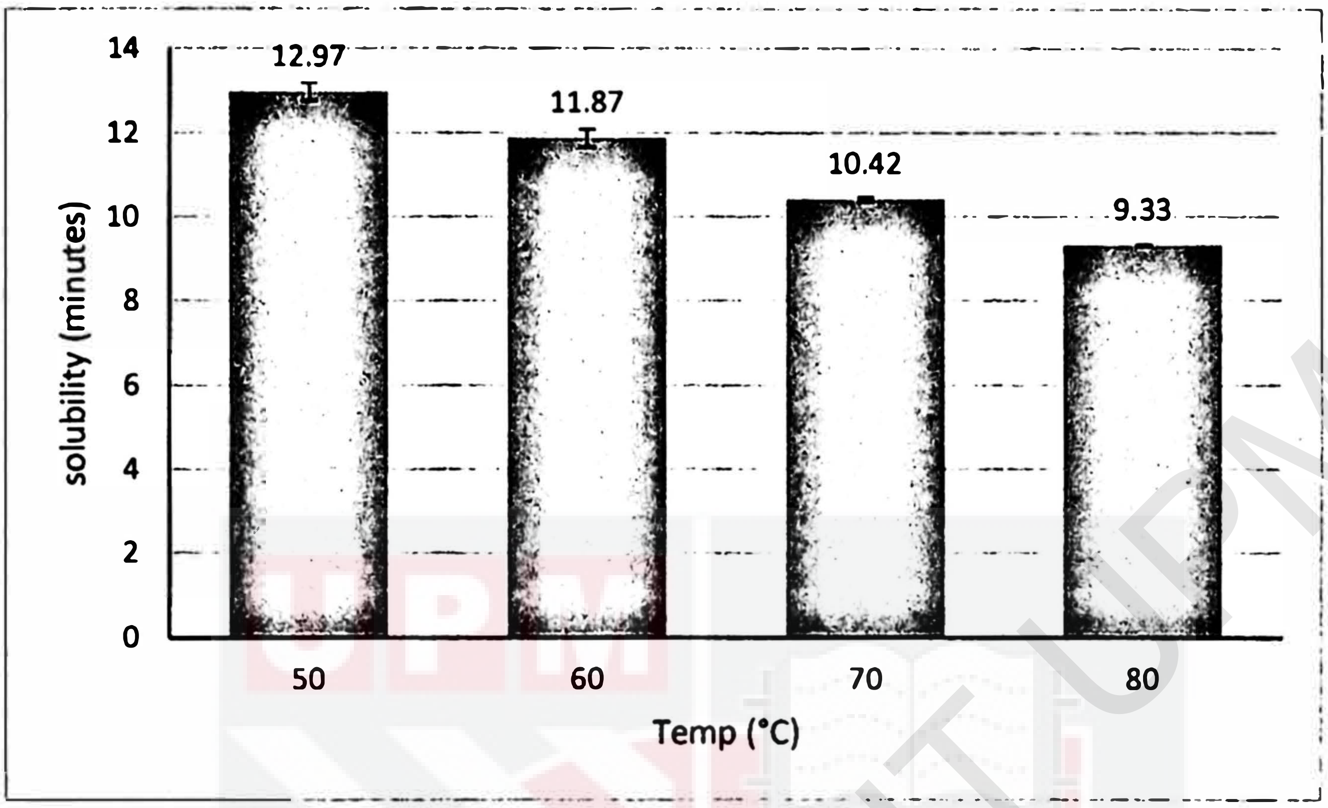



**Figure 4-7:** Solubility duration of FMD powders dried at various drying temperature

### 4.3.3 Color properties

Figure 4-8 exhibit that by increasing the drying temperature, the browning index (BI) increases. This is due to increasing the Maillard reaction where the first step of Maillard reaction performs better at lower amounts of water. The Maillard reaction is chemical reaction happened between amino acids and reducing sugars where the foaming agent that occurs in banana powder and lower amount of water in powder produce high browning index (BI).

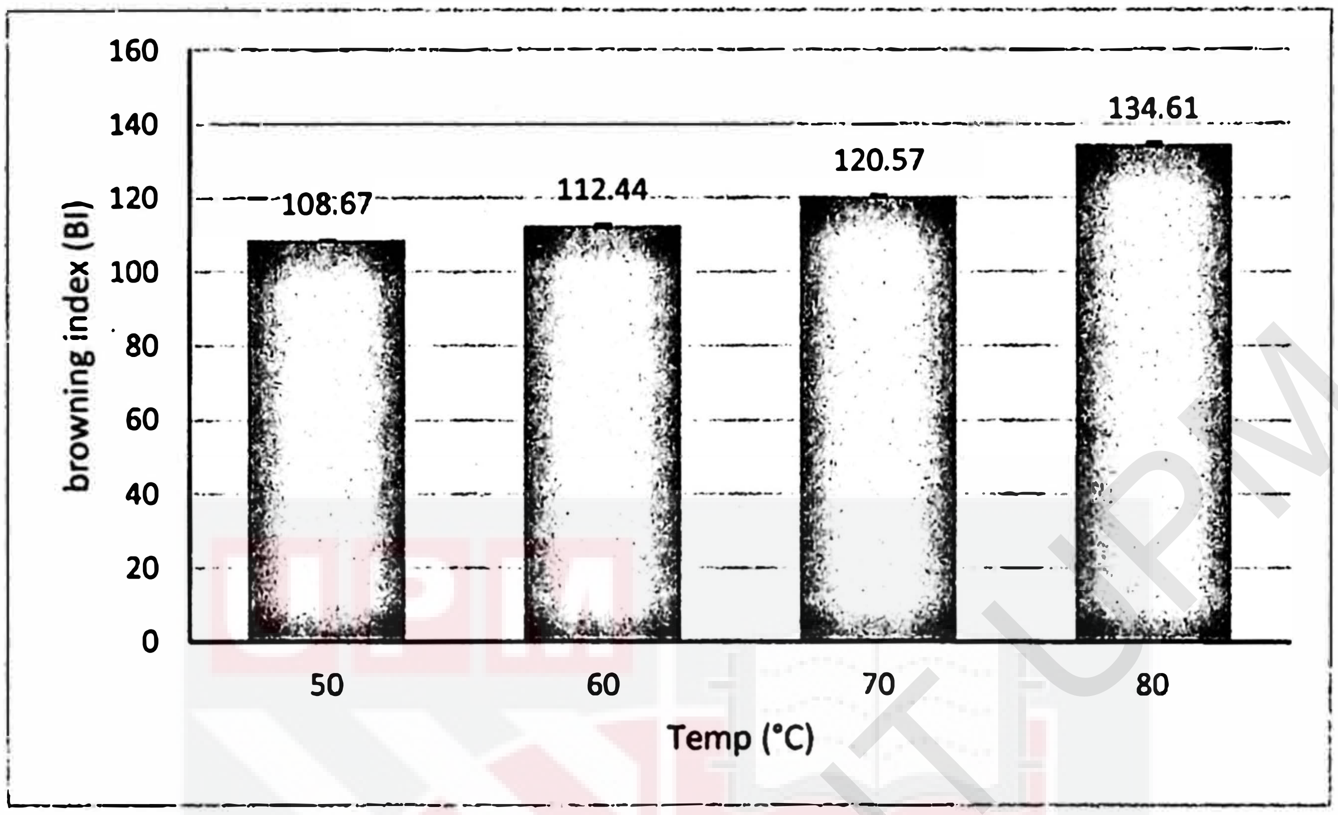



**Figure 4-8**:Browning index of FMD powders dried at various drying temperatures

### 4.3.4 Flow ability

Based on figure 4-9, the caking behavior can be related on the moisture content of banana powder. From the previous result on analysis of moisture content, as the drying temperature increase, the moisture content was decreases. Thus, when the moisture content lower the tendency of powder to form crystalline bond caking was also low. The crystalline bonds is the form between particles when the materials is soluble and high of water source (Johanson, 2014). The increasing temperature, the water in powder decreases. Then, the tendency of water migrates to particles and dissolving particle to form caking was dercrease.

However, at the end of experiment the caking strength at temperature 80°C shown unexpected result where it had a significantly higher of than the caking strength at temperature 70℃. This is due to the previous result of moisture content where at the temperature 80℃ the moisture content higher than at the temperature 70°C. Error during sample preparation and handling process when measured the moisture content is factor the moisture content high since banana powder has very sensitive to time interval and storage system.

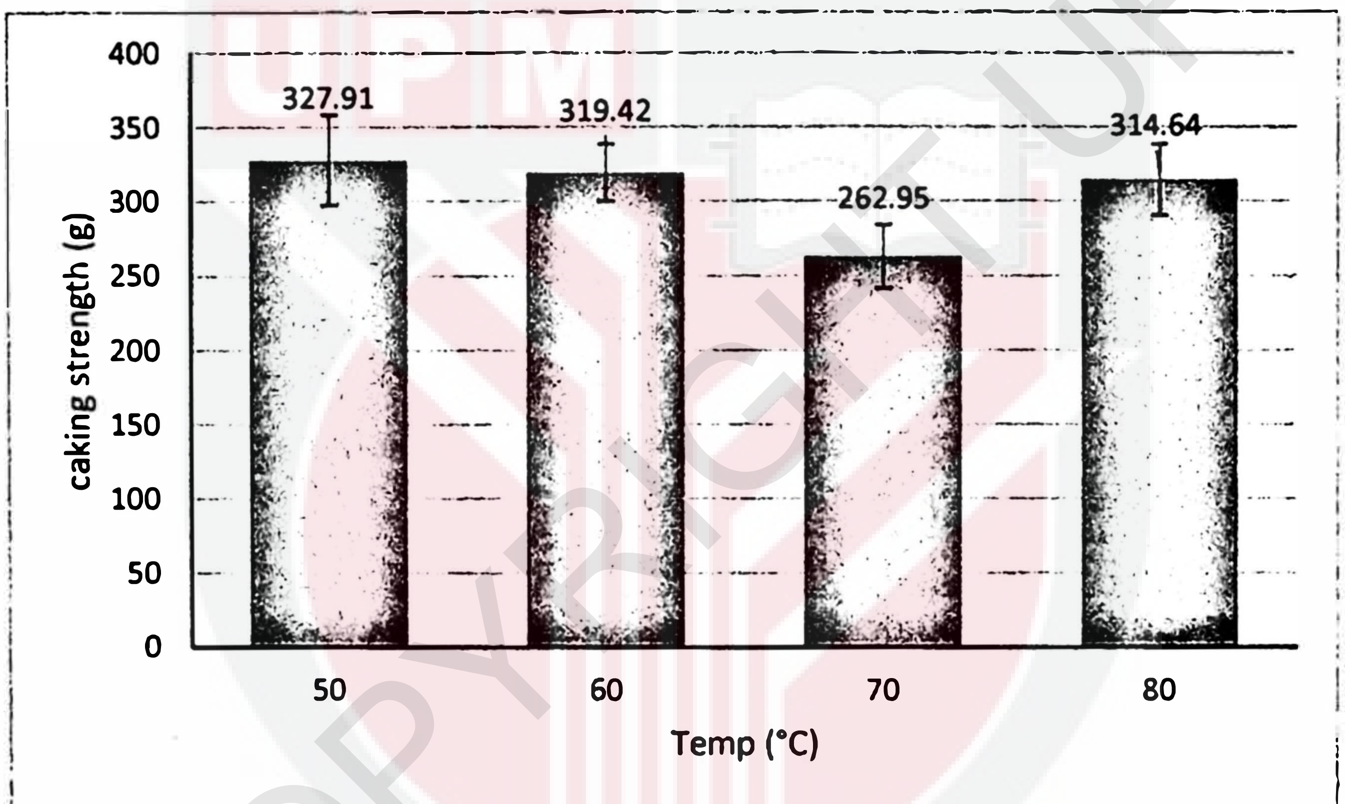



**Figure 4-9**:Caking strength of FMD powders dried at various drying temperatures

### 4.3.5 Selection of the best drying temperature of FMD of banana puree

Based on the findings in Section 2, this study suggested the FMD of banana puree to be performed at 80℃. This is because, at this temperature, the powder produced has high solubility rate with acceptable moisture content, browning index and flow ability.

### 4.4 Stage 3: Comparison of Drying curve of FMD and control samples

The FMD sample was prepsred with 10% of WPC and the drying temperature was fixed at 80°C, as per suggested in Section 1 and 2 of this study. Plain banana puree was used as a control sample, and was also dried at 80°C. the moisture removal of both samples was observed at a certain time interval (every 1 hour) based on the weigth loss of each sample until they reach constant weight. The figure 4-10 show the drying curve of the FMD and a control samples..

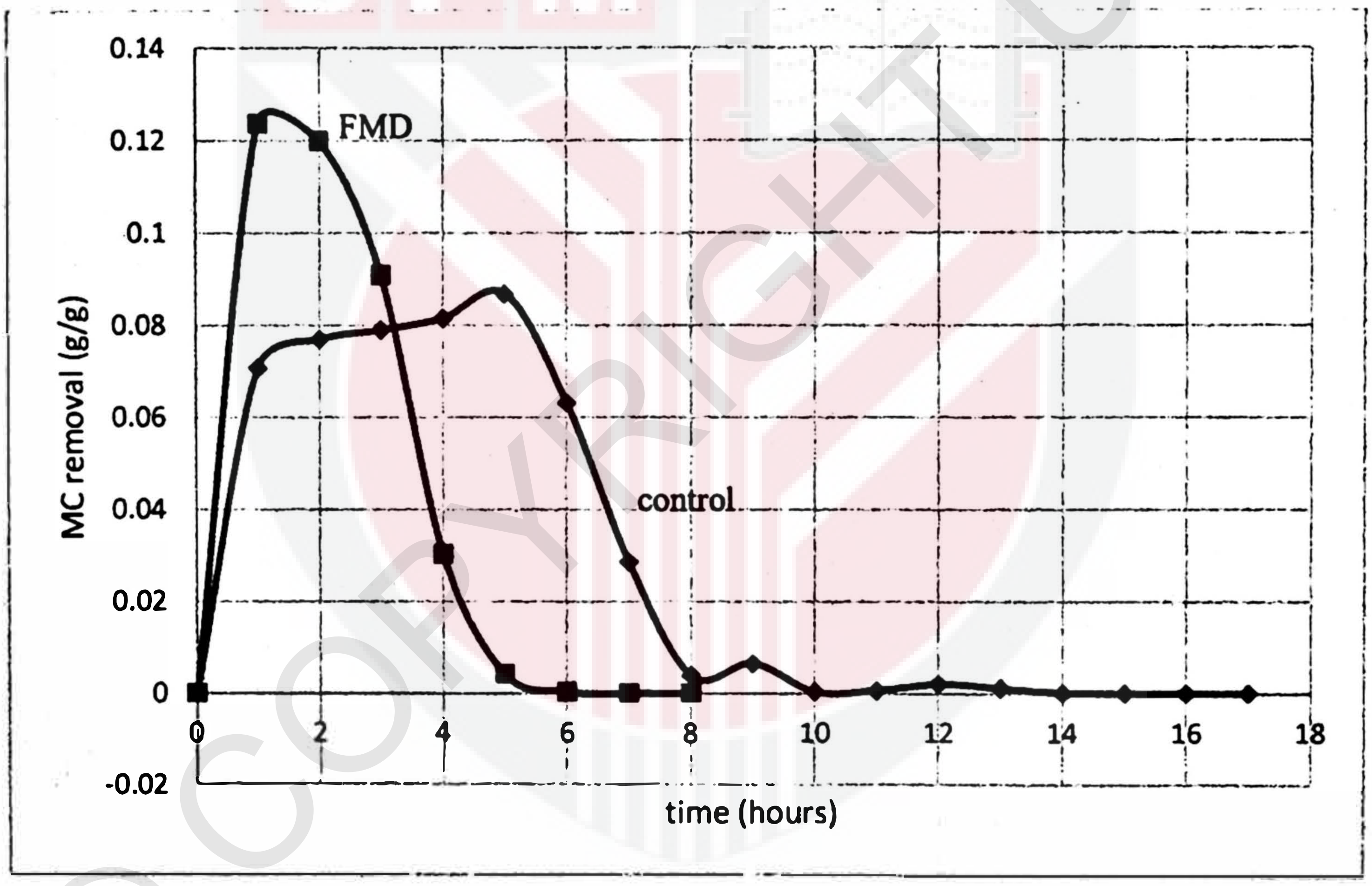



**Figure 4-10:** Moisture removal of FMD and control samples at 80°C drying temperature

Based on figure 4-10, the FMD sample exhibited a drying curve bend abruptly and sharply as the moisture content levels then it approaching to zero where equilibrium value at 5-6 hours. While, the drying curve for untreated sample which was ovendried banana puree sample shown that gradually approach to equilibrium at almost 14-16 hours. This is due to the physical structures of banana foam and banana puree. The FMD sample is more of a porous structure which help in increasing the moisture movement. Besides, the drying of FMD sample also easily persuaded to its inners most layer. Otherwise, the physical structure of plain banana puree (control sample) was denser, stickness and hardened surface that do not facilitate the moisture diffusion (Sankat & Castaigne, 2004).

This result showed the FMD technique was superior in reducing the drying duration of the banana puree. The drying time of FMD sample was approximately 2-3 times shorter compared to the control sample. Thus, it shown how the FMD is a promising technique that can be further develop for the production of banana puree powder.

# CHAPTER 5

# CONCLUSION

## 5.1 Conclusion

In the present study, banana powder produced by foam mat drying method. The reasons for using this method to reduce the drying time and solve problems of stickiness during the drying process. The WPC and CMC were used as a foaming agent and foam stabilizer, respectively. Moreover, observation showed that using a foam mat drying method can reduce around triple time of drying process than using direct drying method (sample control). This study demonstrated that the banana puree can be successfully foamed using whey protein concentrate and dried in a oven at fixed temperature to produce a dehydrated and porous mat, which can then be ground into a powder. This powder can be used in many food products such as beverages, yogurt and bakery.

The effect of additional of foaming agent in the puree at different drying temperature, it was found that:

i. The density of the foam decreases significantly with increases in the concentration of foaming agent.

ii. The moisture content of banana powder will reducing as the amount of foaming agent and drying temperature increase.

iii. The solubility of banana powder will decreases as increase of the concentration foaming agent but will increases as the drying temperature increases.

iv. The browning index of banana powder will reduced as increase of the concentration foaming agent but will increases as the drying temperature increases.

v. The caking strength of banana powder will reducing as the amount of foaming agent and drying temperature increase.

Based from the result obtained, the addition of foaming agent at 10% on the 80°C drying temperature of oven will produce better properties of powder since it contain lower foam density, less moisture content, better of solubility and browning index, and has low caking strength which is not easy to form caking.

## 5.2 Recommendation

Based from the result obtained, there is some improvement can be applied in order to improve the effectiveness of the experimental work and result obtained. Another method can be done while analyzing the powder produce properties in order to improve the effectiveness and to get better results. For example, the vacuum oven can be used to measure moisture content because determining of moisture content by using an oven drying is more accurate. Besides, other physical and nutritional properties of powder can be measured to get more information about the effect before and after the powder production for fruit powder quality sustainable.

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# APPENDICES

| WPC (%) | foam density (g/cm3) | moisture content (%) | solubility (minutes) | browning index (BI) | Caking strength (g) |
|---|---|---|---|---|---|
| 0 | 0.99 ± 0.006 | 18.46 ± 0.515 | 4.46 ± 0.430 | 164.43 ± 0.141 | 1536.42 |
| 5 | 0.75 ± 0.005 | 11.19 ± 0.040 | 5.55 ± 0.035 | 152.36 ± 2.437 | 354.36 |
| 7.5 | 0.63 ± 0.010 | 7.45 ± 0.399 | 7.30 ± 0.167 | 138.66 ± 0.779 | 315.05 |
| 10 | 0.60 ± 0.002 | 10.44 ± 0.207 | 9.33 ± 0.058 | 134.61 ± 0.967 | 314.64 |
| 12.5 | 0.51 ± 0.006 | 5.64 ± 0.351 | 12.47 ± 0.110 | 125.83 ± 0.395 | 267.13 |
| 15 | 0.36 ± 0.019 | 8.84 ± 0.723 | 15.12 ± 0.023 | 125.01 ± 0.463 | 242.5 |

**Appendices I:** Overall data effect on different percentages of foaming agent (stage 1) (Temp,80ºC) (time,7h)

| Temp (°C) | foam density (g/cm3) | moisture content (%) | solubility (minutes) | browning index (BI) | Caking strength (g) |
|---|---|---|---|---|---|
| 80 | 0.60 ± 0.002 | 10.44 ± 0.207 | 9.33 ± 0.057 | 134.61 ± 0.968 | 314.64 |
| 70 | 0.59 ± 0.038 | 8.61 ± 0.748 | 10.42 ± 0.108 | 120.57 ± 0.521 | 262.95 |
| 60 | 0.63 ± 0.012 | 10.14 ± 0.140 | 11.87 ± 0.367 | 112.44 ± 0.604 | 319.42 |
| 50 | 0.62 ± 0.001 | 11.55 ± 0.320 | 12.97 ± 0.356 | 108.67 ± 0.270 | 327.91 |

**Appendices II:** Overall data effect on different drying temperature (stage2) (WPC, 10%) (time,7h)

| time (hours) | weight (g) | MC removal (g/g) |
|---|---|---|
| 0 | 314.26 | 0 |
| 1 | 292.05 | 0.070673964 |
| 2 | 269.59 | 0.07690464 |
| 3 | 248.29 | 0.079008865 |
| 4 | 228.05 | 0.08151758 |
| 5 | 208.26 | 0.086779215 |
| 6 | 195.08 | 0.063286277 |
| 7 | 189.51 | 0.028552389 |
| 8 | 188.78 | 0.003852039 |
| 9 | 187.57 | 0.006409577 |
| 10 | 187.5 | 0.000373194 |
| 11 | 187.39 | 0.000586667 |
| 12 | 187.02 | 0.001974492 |
| 13 | 186.82 | 0.001069404 |
| 14 | 186.81 | 0.00 |
| 15 | 186.81 | 0 |

**Appendices III:** drying curve data of the oven dried sample (WPC,0%) (Temp, 80°C)

| time (hours) | weight (g) | MC removal (g/g) |
|---|---|---|
| 0 | 181.51 | 0 |
| 1 | 159.04 | 0.123794832 |
| 2 | 139.96 | 0.119969819 |
| 3 | 127.24 | 0.090883109 |
| 4 | 123.38 | 0.030336372 |
| 5 | 122.85 | 0.004295672 |
| 6 | 122.81 | 0.0003256 |
| 7 | 122.81 | 0 |
| 8 | 122.81 | 0 |

**Appendices IV:** drying curve data of foam mat sample (WPC,10%) (Temp, 80°C)