

UNIVERSITI PUTRA MALAYSIA

POTENTIAL FOOD DEVELOPMENT FROM DIFFERENT PARTS OF SWEET POTATO PLANT

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FK 2019 20

POTENTIAL FOOD DEVELOPMENT FROM DIFFERENT PARTS OF SWEET POTATO PLANT

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182214

PROJECT REPORT SUBMITTED IN PARTIALLY FULFILLMENT OF THE REQUIREMENT FOR THE BACHELOR ENGINEERING (PROCESS AND FOOD)

DEPARTMENT OF PROCESS AND FOOD ENGINEERING

FACULTY OF ENGINEERING

UNIVERSITI PUTRA MALAYSIA

2019

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ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful. Alhamdulillah, first and foremost I would like to praise to Allah for His blessing to complete this thesis. Special thank you goes to my supervisor, Dr. Mohd Zuhair bin Mohd Nor for his supervision, guidance and support with constructive comments and suggestions throughout the experimental and thesis works. He motivates and triggers me to be on track until the finishing line. Besides, my sincere appreciation is given to my final year project coordinator, Dr. Intan Syafinaz binti Mohamed Amin Tawakkal. Her guidance enabled me as well as other final year students to complete our thesis successfully.

My appreciation also extends to master student, Nurfarhana binti Shaari that always give me motivation and guidance during running the experiment analysis. I would also like to express my gratitude to all technicians and office staff of the Department of Process and Food Engineering for their extensive co-operation. Sincere thanks and big applause to all my lovely course mates and others for their moral support during my journey toward this degree and we did it well guys. Thanks for the friendship and precious memories during these four years degree.

My acknowledgment would be incomplete without thanking the important persons in my life, my beloved parents, Mr. Zakaria bin Hashim and Mrs. Wan Chik binti Abdul Kadir and also to my family members for their endless care, love and prayers. This would not have been possible without their unwavering and unselfish love and also support given to me at all times.

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Last but not least, it would be inappropriate if I omit to express my gratitude to all people who indirectly contributed to this research and thesis works. All of your kindness really means a lot to me. Thank you so much.

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ABSTRACT

Sweet potato *(Ipomoea batatas (L.) Lam.),* a hardy, nutritious staple food crop that grown throughout the humid subtropical and tropical regions of the world. Different parts of sweet potato plant may offer various benefits, but there is a lack of understanding of the properties of its parts particularly to link to potential food development exploration. This study focused on establishing characteristic properties of the sweet potato plant parts including the leaves, stems, tuber and peels in a powder form as a potential source for animal feed production. The analyses were done using thermogravimetric analysis (TGA) to determine the cell wall structure which are hemicellulose, cellulose and lignin, as well as proximate analysis including the measurement of the dry matter, moisture content, crude fiber, crude protein, fat, ash and carbohydrate. Based on the determined characteristics properties, an effort has been done to investigate the potential of the sweet potato plant parts to be marketed as a technical-grade powder for the formulation of animal feed by performing a flowability analysis of the powder properties i.e. cohesion test, caking test, and powder flow speed dependency (PFSD) test. Besides, this study also has investigated the potential of producing animal feed pallet from the underutilized leaves and stems of sweet potato plant through a compaction process. The pallets were formulated at a ratio of 1:1 of leaves: stems at a different moisture content of 40%, 45%, 50%, 55%, 60%. The produced pallets were tested in terms of their friability, bulk density, true density, porosity and tensile strength. The findings showed that the sweet potato plant parts, particularly the leaves and stems, contained appreciable nutritional substances, particularly protein content and perishable amount of fat, which is suitable for animal feed production. The powders of sweet potato stem, leaves, tuber and skin can be classified as stable powders and free-flowing based on the findings in the flowability analysis. Based on the analysis of the produced pallets, difference physical characteristics have been exhibited by the pellets of different moisture content ranging from 40% to 60%. This study found

that the best moisture content formulation for the production of sweet potato leaves and stems pellets is at 60% since it exhibited the lowest friability (0.30%), the lowest bulk density (629.5 kg/m^3), the highest porosity (56.51%) and the highest work of compression (303.79 kg.s) as well as high tensile strength compared to other moisture contents formulation of the SPLS pellets.

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ABSTRAK

Ubi keledek atau nama saintifiknya *Ipomoea batatas (L.) Lam.* antara tanaman makanan ruji berkhasiat yang ditanam di seluruh kawasan subtropika dan tropika lembap di dunia. Bahagian pokok ubi keledek yang berbeza boleh menawarkan pelbagai manfaat, namun terdapat kurang permerhatian mengenai sifat-sifatnya terutamanya bagi menghasilkan potensi pembangunan makanan. Kajian ini tertumpu kepada mengenalpasti ciri-ciri bahagian tumbuhan ubi keledek termasuk daun, batang, ubi dan kulit dalam bentuk serbuk sebagai sumber berpotensi untuk pengeluaran makanan haiwan. Analisis telah dilakukan dengan menggunakan analisis Termogravimetri (TGA) untuk menentukan struktur dinding sel yang hemiselulosa, selulosa dan lignin, serta analisis proksimat termasuk pengukuran bahan kering, kandungan kelembapan, serat mentah, protein mentah, lemak, abu dan karbohidrat. Berdasarkan sifat-sifat ciri-ciri didapati, usaha telah dilakukan untuk menyiasat potensi bahagian tumbuhan ubi keledek untuk dipasarkan sebagai serbuk teknikal gred bagi penggubalan makanan haiwan dengan melakukan analisis kebolehaliran sifat serbuk iaitu ujian perpaduan, ujian 'caking', dan ujian kelajuan aliran serbuk pergantungan (PFSD). Di samping itu, kajian ini juga telah mengkaji potensi menghasilkan pelet makanan haiwan dari daun dan batang tumbuhan ubi keledek melalui proses pemadatan. Pelet telah dicampur pada nisbah 1: 1 daun : batang pada kandungan lembapan yang berbeza sebanyak 40%, 45%, 50%, 55%, 60%. Pelet yang dihasilkan telah diuji dari segi kerapuhan mereka, ketumpatan pukal, kepadatan sebenar, keliangan dan kekuatan tegangan. Dapatan kajian menunjukkan bahawa bahagian-bahagian tumbuhan ubi keledek, terutamanya daun dan batang, mempunyai kandungan bahan-bahan pemakanan yang ketara, terutama kandungan protein dan lemak yang sesuai untuk pengeluaran makanan haiwan. Serbuk ubi keledek iaitu batang, daun, ubi dan kulit boleh diklasifikasikan sebagai serbuk stabil dan bebas mengalir berdasarkan kajian dalam

analisis kebolehaliran. Berdasarkan analisis pelet yang dihasilkan, ciri-ciri perbezaan fizikal telah dipamerkan oleh pelet kandungan lembapan yang berbeza dari 40% kepada 60%. Kajian ini mendapati bahawa kandungan kelembapan terbaik untuk pengeluaran pelet daripada daun keledek dan batang adalah pada 60% kerana menunjukkan kerapuhan paling rendah (0.30%), ketumpatan paling rendah pukal (629.5 kg / m3), keliangan yang paling tinggi (56.51%) dan kadar kemampatan paling tinggi (303.79 kg.s) serta kekuatan tegangan yang tinggi berbanding kandungan kelembapan penggubalan pellet yang lain.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AOAC	Association of Analytical Chemists
DTG	Derivative Gravimetric
DW	Dry Weight
MARDI	Malaysian Agricultural Research and Development Institute
OPF	Oil Palm Frond
PFSD	Powder Flow Speed Dependency
PKC	Palm Kernel Cake
POME	Palm Oil Mill Effluent
SPLS	Sweet Potato Leaves and Stem
TGA	Thermal Gravimetric Analysis

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CHAPTER 1

INTRODUCTION

1.1 Overview of the Study

Sweet potato, *Ipomea batatas* is a staple food crop that contains nutritional value and hardy that grown throughout the humid condition in tropical and subtropical regions of the world. This perennial plant of *Convolvulaceae* family has long trailing vines and leaves that has different in shape form simple to deeply (Sullivan, Asher, & Blarney, 1997). Sweet potato is grown widely during warm temperature and tropics regions. It is becoming a very important crop in developing countries due to the value for sweet potato's short growing period of 90 to 120 days. In fact, it is one of the seven crops in the world that produced over 135 hundred million metric tons of edible food products annually (Mohd Hanim, Chin, & Yusof, 2014). According to Ellong, Billard, & Adenet (2014), sweet potato also plays a multitude of varied roles in human diets, being either supplemental and luxury food, apart from being a staple crop for some part of the world such as Papua New Guinea, Philippines, Tonga and Solomon Islands. Other than that, sweet potato is reported to have high technological potentials and it can be used for various products such as sugar production, biscuits, flour, pasta, alcohol, drinks like wine liquor and vinegar (Ellong, Billard, & Adenet, 2014). In Malaysia, sweet potato is ranked second among the tuber crops after cassava in term of production and has been cultivated on a small scale since the 17th century (Mohd Hanim et al., 2014). There are many varieties of sweet potato available in Malaysia, differentiate mostly due to their colours and shapes. Among the varieties, purple sweet potato has high nutritional values due to the presence of "anthocyanin" pigment derived from purple-coloured flesh variety of sweet potato. Moreover, peonidins and cyanidins in anthocyanin have anti-oxidant and anti-

inflammation properties that are very vital for good digestion (Yusoff, Abdullah, Ridzwan, & Halim, 2018).

1.1.1 Nutritional Value

As for meeting human nutritional needs, sweet potato is crucial for nutritional qualities such as high-quality protein, potassium, iron, fibers, vitamin A and C, and also carbohydrates (Mais and Brennan, 2008). Sweet potato can produce more edible energy per hectare per day than cereals as well as becoming an excellent source of energy which is 438 kJ/100g edible portion (Sanoussi et al., 2016). The other advantages of sweet potato are high yield, versatility, hardiness and wide ecological adaptability (Sanoussi et al., 2016).

Sweet potato tops can be harvested several times a year, their annual yield is much higher than many other green vegetables. Leaves of sweet potato are rich in, ß carotene, vitamin B, protein, calcium, zinc and iron (Islam, 2003). Besides, the crop is highly tolerant of disease, pests and high moisture than many other leafy vegetables grown in the tropics. The leaves of sweet potato are gaining recognition for its nutritional value as well as the understanding between health and diet increase with high nutritional value and also antioxidants that may become a good leafy vegetable (Islam, 2003).

Other than leaves, the root is also claimed to have usually higher protein content than other tubers and roots like yams and cassava (Sanoussi et al., 2016). The edible roots, usually referred to as tubers are formed by a secondary thickening of the upper part of some feeder (Sullivan et al., 1997). Tubers of sweet potato are rich in sugar, starch, iron, vitamin C, β-carotene and several

other minerals (Sanoussi et al., 2016). According to Eleazu & Eleazu (2012), sweet potato roots that are processed into flour is an initiative to minimize post-harvest losses and increase its utilization.

1.1.2 Economy and Processing Technology

According to Tan (2015), sweet potato is a sprawling or trailing vine which can be harvested as early as 3½- 4 months after planting in the tropics, or after 5-6 months in the temperate region during the summer. With this short crop cycle, this crop can be grown not only in the tropics but also in the temperate zone during the summer months. In a very broad altitudinal range from sea level to 2,500 meters in tropics, sweet potato can survive and grow (Tan, 2015). While sweet potato produces sexual seed, the crop is vegetatively propagated by the use of stem cuttings. Shoot cuttings are the preferred planting materials. As in other root crops, the economic part is the storage roots, formed by bulking of and starch deposition in the adventitious roots which form wherever the stem nodes make contact with the soil. Sweet potato has a great benefit to grow well on marginal soils such as tin-tailings, acid sulphate soils, bris and drained peat (Tan, 2015). All it needs is the adoption of certain recommended soil amendments which means that sweet potato will not compete with another crop for better soils and fertile. Marginal soils in Peninsular Malaysia alone cover some 1.67 million hectares, with 91, 000 ha of sand tailings, 110,000 ha of acid sulfate, 165,000 ha of the bris, 433,000 ha of idle paddy land, and 870,000 ha of peatland and muck soils (Tan, 2015).a

From a processing technology perspective, one of the potential processing related to sweet potato is pelletization focusing on the animal feed industry. Pelletization process consists of several types including compression, extrusion, globulation, balling and also freeze pelletization

(Supriya, Rajni, & A.C, 2012). In Malaysia, derivation of pellet commercialization is from oil-palm by-products, for example, an oil palm frond (OPF), palm kernel cake (PKC), and palm oil mill effluent (POME). They are usually used as the main components in the feeds formulation. The development of new approaches is introduced to improve the quality of the raw materials as well as finished products. Attempts have been introduced to produce higher value-added feeds to improve overall digestive system, health status, and growth performance of the herbivores, apart from locally consume available ingredients to reduce the cost of production (Zainuddin et al., 2014). Consumer preferences are related to one of the issues which are a continuous demand for "high quality-low cost" feeds, which is become a big challenge in feed manufacturing that uses agricultural-by products (Zainuddin, 2015).

1.2 Problem Statement

Sweet potato is considered as our "traditional crop" where it is adaptable to the wide ecological range, relatively short growing period and high yield potential even on infertile soil. The abundant nutrients in the crop have high potentials as they can help to prevent nutritional problems. Besides, this versatile crop can be applied in many industrial areas including for alcohol production, starch production, human food and also livestock feed. However, most of the previous researches were focusing on the usage of the tuber part of sweet potato for the mentioned applications, while the other parts of the plant such as the leaves, stems and skins of the crops were rarely discussed.

The potential of using these underutilized parts is huge by considering they also contain appreciable nutritional values. Besides, these parts were mostly discharged from the production line and were considered as "waste". Without proper management of these discharge, they might

affect the environment. Hence, the conversion of these parts to valuable by-products will give some more profits to the producer while preserving our environment.

In order to utilize different parts of the sweet potato plant, strategic identification and characterization investigation of their properties are required. Consequently, all the gathered information will lead us to discover the true potentials of these parts in any related industrial areas. One of the potential areas of exploration is the production of animal feed using the leaves, stems and skins of the sweet potato plant.

The significant effect of animal production over the world comes from the poor nutrition of animals (Bruinsma, 2003). As for so many reasons, the tropical world is basically confronted with the issue of an intense deficiency of feed resources. The feed shortage due to the extensive population of the animal to feed is become more crucial since there is a failure in managing the degraded and unmanaged pastures and also lack of green forage production. A suitable methodology and strategy for processing of feed must be applied to minimize the cost of production and to produce a consumable application of food (Zainuddin, 2015).

In Malaysia, overgrazing is a typical issue prompting to rapid degradation of the pastures. According to Chin (1998), an alternate basic issue is extreme uses of soil nutrients as well as there is improper management to beat the issue (Zainuddin, 2015). Therefore, there is a need to invent a new alternative to replace grazing forages and pastures for herbivores. Another component that contributes to low productivity of herbivores and animals in the tropics is improper or unsuitable management of feed. By doing this way, there is a critical need to enhance the uses of the limited feed resources, specifically for stems and leaves of sweet potato plant to feed livestock focusing on herbivores.

In the economic aspect, the livestock industry will improve the economy through this strategy by enhancing the feeding system. The higher income for farmers, as well as the improvement of nutrition for their animals, lead to expanded animal productivity and better animal performance. Thus, this improves the higher level income of the ranchers and upgrade their societal position in their community (Zainuddin, 2015).

In conclusion, different parts of sweet potato focusing on stems and leaves need to be utilized properly to identify the potential food application based on the characteristic properties of different parts of sweet potato and this food development can approach higher economical standard in the feed industry, reduce and manage waste as well as becoming environmentally friendly.

1.3 Objectives

i. To determine the physicochemical properties of different parts of sweet potato plant including stems, leaves, tubers and peels.

ii. To develop the pelletizing process of the stems and leaves of the sweet potato plant using a compaction process.

1.4 Hypothesis

If characteristic properties for different parts of sweet potato are identified, a proper pelletization process technology can be developed for animals feed application.

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1.5 Framework of the Thesis

This thesis is organized in five chapters which are introduction, literature review, methodology, results and discussion and conclusion.

In the introduction chapter, a general introduction about sweet potato and different parts of sweet potato are given including a discussion of the potential development to use as feed material. The chapter of literature review presents details of the focusing on characteristic properties of different parts of sweet potato that want to be applied as feed production especially for herbivores, and the background of the processing method is given. The physical and chemical properties of different parts of sweet potato, as well as the processing parameters affecting the pelleting process with different moisture content, is discussed. In the methodology chapter, the method of process and analyses are explained followed by the equipment used to determine the physical and chemical properties. In result and discussion chapter, the experimental results obtained for the physical and chemical composition of the samples are interpreted, presented and discussed. Lastly, the conclusions and recommendation which addresses issues that could be improved and considered or applied in future studied are concluded.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review addresses four major topics. First, it describes the overview of the study about the history of sweet potato plants and different parts of sweet potato such as leaves, stems, tuber and peels, sweet potato industry in Malaysia and also types of sweet potato in Malaysia. Second, it describes the processing technology of sweet potato focusing on a pelletization process involving compaction process with a different percentage moisture content of pre-treatment. Next, it discusses the physicochemical properties of sweet potato involving proximate composition for different parts of sweet potato in the literature. After that, it discusses the physical properties of sweet potato involving flowability analysis of sweet potato powders, friability, true density, bulk density and porosity. Therefore, this chapter includes all the information needed to carry out this study before moving to Chapter 3.

2.2 Overview of Sweet Potato Plant

2.2.1 History of Sweet Potato Plant

Sweet potatoes are vining plants with pink morning-glory type flowers, attractively lobed leaves and tuberous roots. They are so easily grown crop in warmer regions, high in nutrition and can be used in a big range of recipes. The vines are vigorous so that space is required. They are in the best condition that is frost-free for at least 5 months warm days and nights. In cooler regions wait for the beginning of warm weather to plant (Green Harvest Organic Gardening Supplies Pty Ltd, n.d.). Research published by the National Academy of Sciences has now demonstrated that Polynesians

journeyed to South America and brought home kumara, long before Europeans even reached the South Pacific (Green Harvest Organic Gardening Supplies Pty Ltd, n.d.). The soil that suitable for sweet potato must be fertile, rich, well-drained soil in full sun where the space plants must be 35 cm apart. In tropical and subtropical regions, sweet potato can be planted all year round (Green Harvest Organic Gardening Supplies Pty Ltd, n.d.). Figure 1 shows the morphological structure of the sweet potato plant.

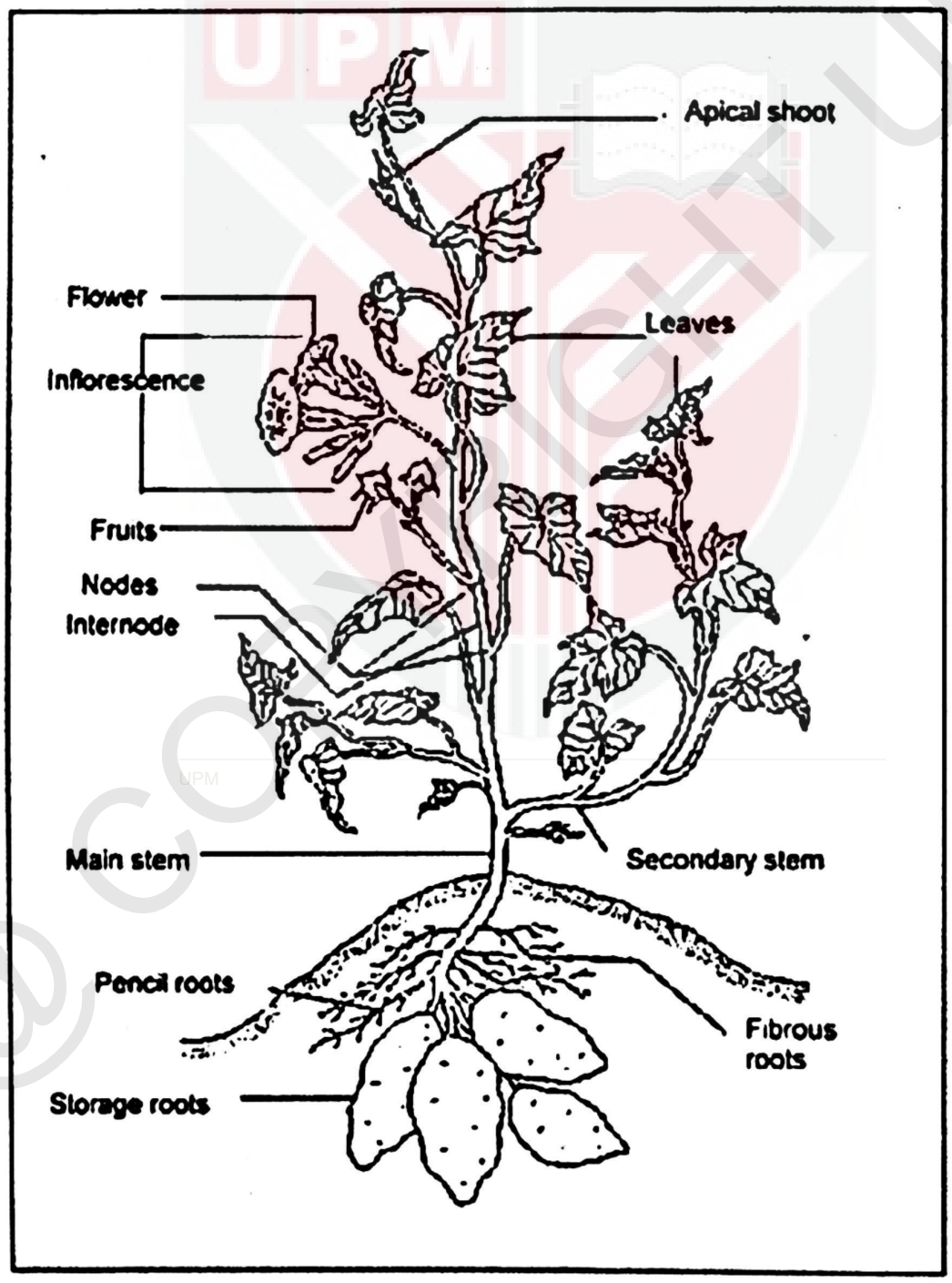


Figure 1: Structure of the Sweet Potato Plant (Ipomoea & Ed, 2007).

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2.2.1.1 Leaves of Sweet Potato Plant

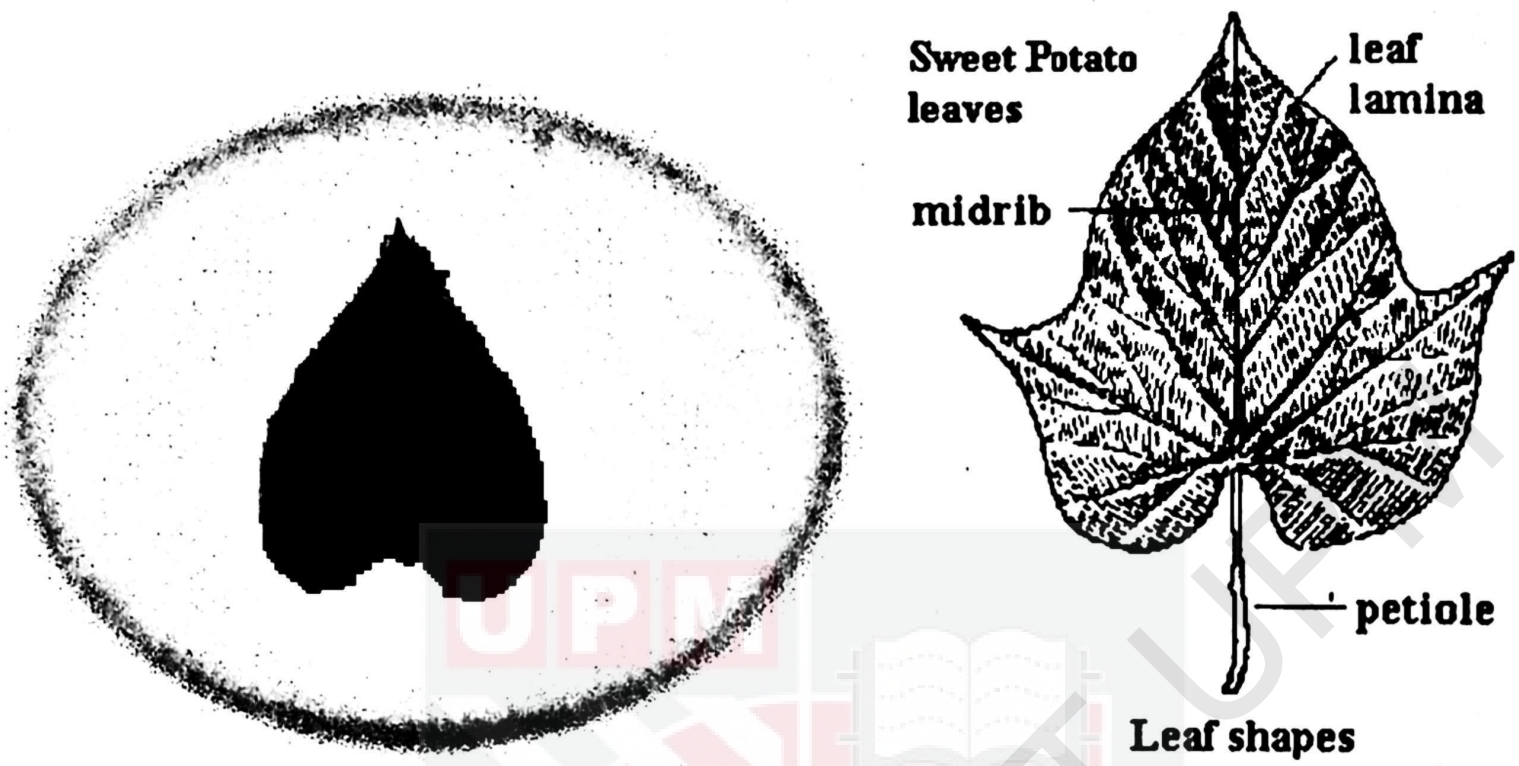


Figure 2: Structure of Sweet Potato Leaves (SPotProj, n.d.).

Figure 2 shows the structure of sweet potato leaves. The leaves are simple and alternately spirally arranged on the stem in a pattern known as 2/5 phyllotaxis which is five leaves spirally arranged in two circles around the stem for any two leaves be located in the same vertical plane of the stem. The edge of the leaves lamina can be entire, toothed or lobed depends on the cultivar. Generally, there are two lobes for the base of leaf lamina that can be almost straight and rounded. The shape of the general outline of sweet potato leaves can be rounded, kidney shape, heart-shape, triangular, trilobular and spear-shape with the two basal loves divergent, lobed and almost divided. Lobed leaves have a different degree of cut, range of superficial to deeply lobed. Generally, the number of lobes range from three to 7 and can be easily measured by counting the veins that go from the junction of the petiole up to the edge of the leaf lamina (Ipomoea & Ed, 2007). However, toothed leaves have minute lobes called teeth which could range from one to more than nine. Some variation in leaf shape is shown by some cultivars on the same plant (Ipomoea & Ed, 2007). Hue, Chandran and Boyce (2012) figured out that all the *Ipomoea batatas* varieties have entire margin

in their leaves with no presence of edge and lobes. Thus, it can be proved that this plant has a good cooling system that helps to transmit heat from the plant as well as the surface area of these leaves will also affect the transpiration rate in the plant.

2.2.1.2 Stem of Sweet Potato Plant

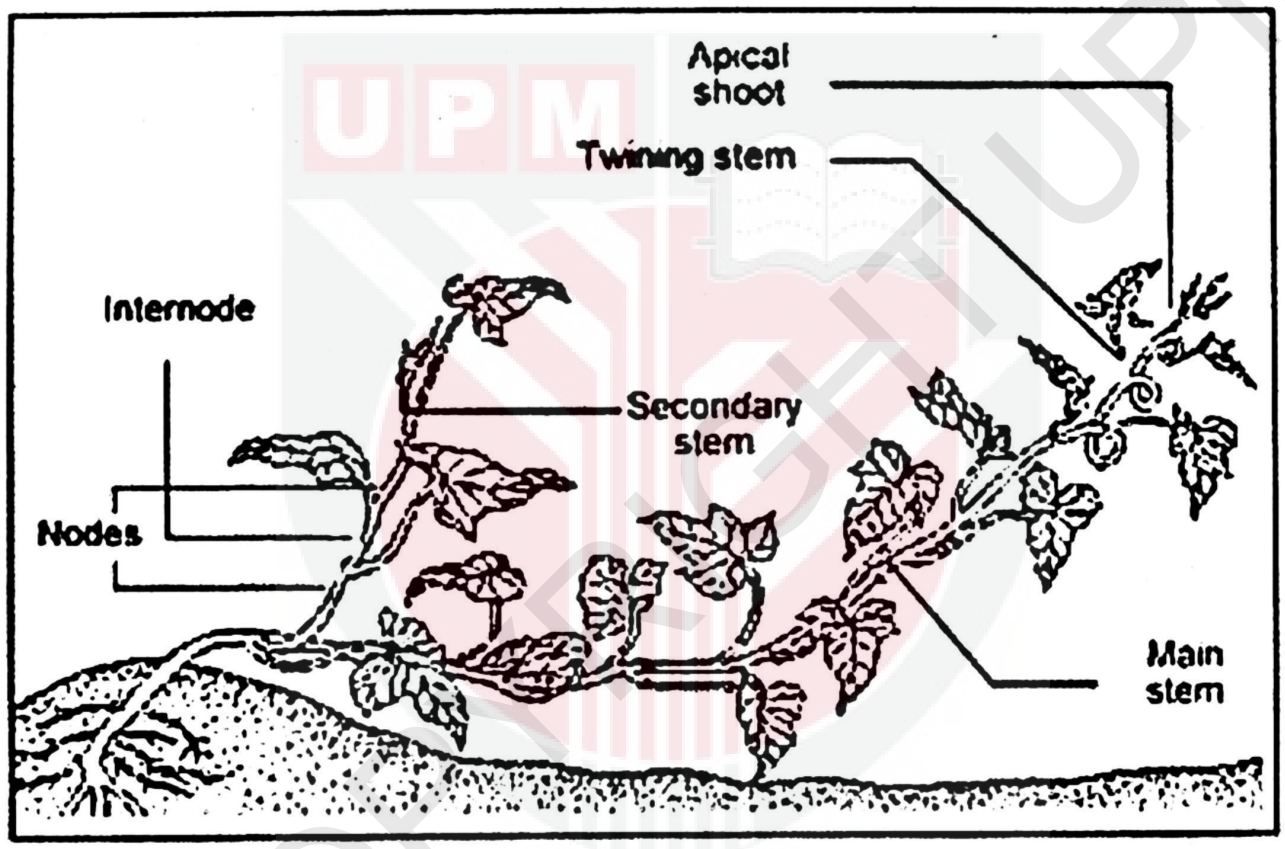


Figure 3: Structure of Sweet Potato's Stem (Ipomoea & Ed, 2007).

Figure 3 shows the structure of the sweet potato's stem. A sweet potato stem is cylindrical and its length, like that of internodes, depends on the availability of water in the soil and the growth habit of the cultivar. The erect cultivars are approximately one meter long, while the very spreading one can reach more than five meters long. Some of the cultivars have stems with twining characteristics. The internode length can change from short to very long by according to stem diameter that can be thin or very thick. The stem colour varies from green to totally pigment with anthocyanins red-purple colour depend on the sweet potato cultivar (Ipomoea & Ed, 2007). The

hairiness in apical shoots and in some cultivars also in the stems, various from glabrous which is without hair to very pubescent (Ipomoea & Ed, 2007).

2.2.1.3 Tuber of Sweet Potato Plant

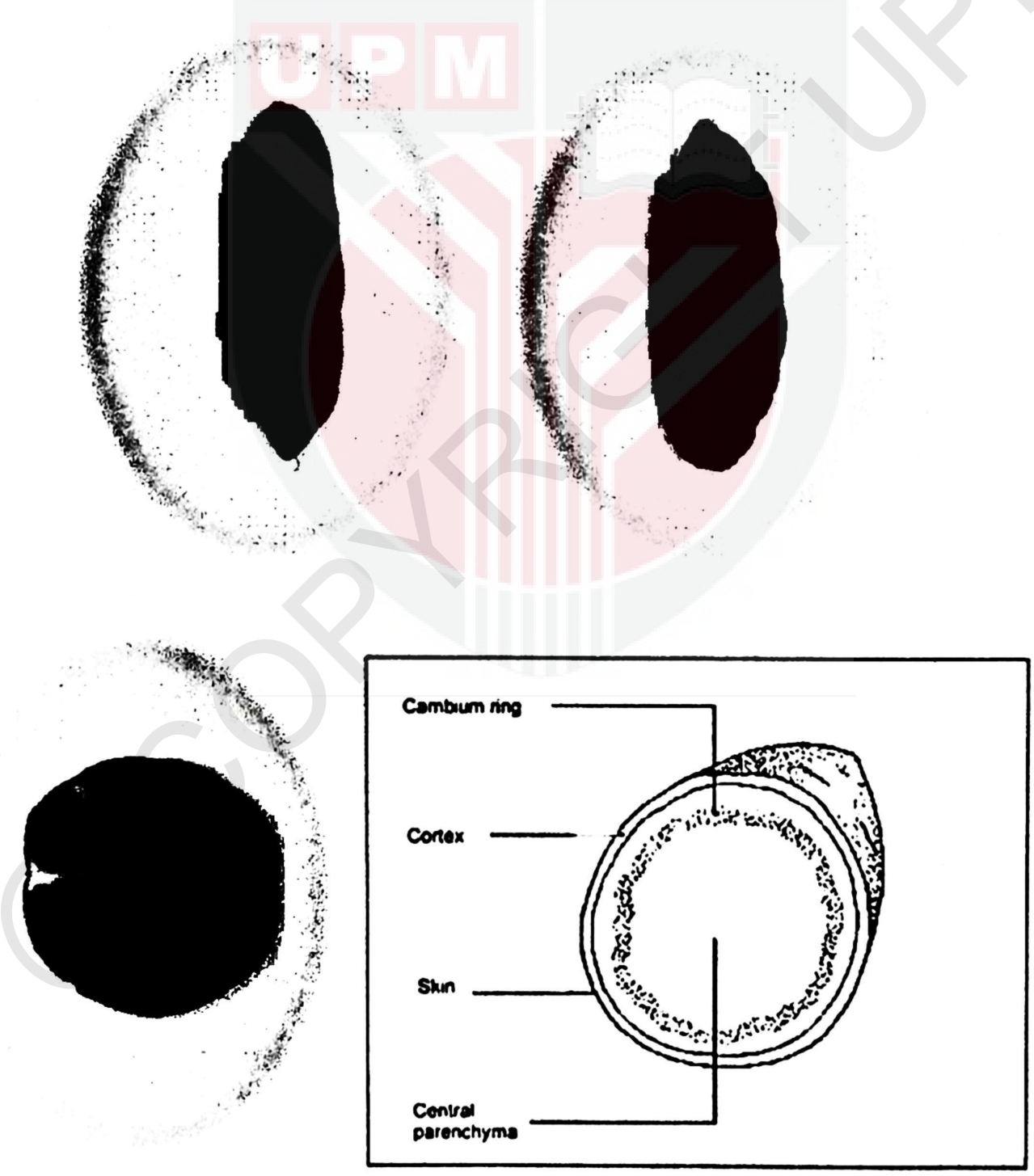


Figure 4: Structure of Sweet Potato's Storage Root known as Tuber (Ipomoea & Ed, 2007).

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As shown in Figure 4, the structure of sweet potato's storage root that is also known as a tuber is the commercial part of the sweet potato plant. Most cultivars develop storage roots at the nodes of the mother stem, cuttings that are underground (Ipomoea & Ed, 2007). However, the very spreading cultivars produce storage roots at some of the nodes that come into contact with the soil (Ipomoea & Ed, 2007). The storage roots part are the proximal end that joins to the stem, through a root stalk and many adventitious buds are found from which the sprouts are originated, a central part that is more expanded and the distal end is opposite to the root stalk (Ipomoea & Ed, 2007). The adventitious buds that are located in the distal and central part usually sprout later than those located in the proximal end (Ipomoea & Ed, 2007).

2.2.2 Sweet Potato Industry in Malaysia

Data for the sweet potato industry in Malaysia from 2014 to 2016 is shown in Table 1 based on Food Innovation Online Corp [CA] (n.d.),

Table 1: Data for Malaysian Sweet Potato Industry in 2014-2016

Sweet Potato Yield in **2016**:	166,713.00	hg/ha
Sweet Potato Production in **2016**:	43,212.00	tonnes
Sweet Potato Area Harvested in **2016**:	2,592.00	ha
Sweet Potato Yield in **2015**:	158,892.00	hg/ha
Sweet Potato Production in **2015**:	50,607.00	tonnes
Sweet Potato Area Harvested in **2015**:	3,185.00	ha
Sweet Potato Yield in **2014**:	170,846.00	hg/ha

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According to the Department of Agriculture (2013), there are many regions in Perak, Terengganu and Kelantan states in Malaysia that are involved in sweet potato production. The planted area with sweet potato in Malaysia was 2229 ha in 2011 with the production reaching 26,582 tonnes and increased to 2505 ha with the production of 26,688 tonnes in 2013. However, the yield was decreased in 2012 with 25,417 tonnes from 2386 ha planted region. Based on PotatoPro (2019), in 2017 the sweet potato yield in Malaysia was increased to 168955 hg/ha with the production of 41245 tonnes.

According to Tan (2015), sweet potato is a great health food. In Malaysia, sweet potato currently associated with making desserts and snacks even there is in fact potential for it to be a supplementary staple to rice. Sweet potato is traditionally eaten more as a supplementary food rather than as a main staple. In Malaysia, it is boiled, fried in batter, steamed and also used for making traditional Malays and Nyonya cakes, such as kuih koci, onde-onde and keria. There are also small cottage industries making traditional snacks such as cakar ayam and crisps. All these traditional forms of food products have a limited market, but there are far prospects in another form of utilization.

As a carbohydrate-rich food, grain maize which has the gold standard for energy-rich feedstuffs can be replaced by sweet potato up to 30% especially in pig and poultry feeds (Ipomoea & Ed, 2007). The replacement level rises to 50% to 100% of grain maize in broiler feeds if dry roasted sweet potato meal is used. Cooking probably improves sweet potato starch digestibility as well as eliminating anti-trypsin activity associated with the raw storage roots. There is ample scope for replacing at least partially the imported grain by local production of this root crop.

Moreover, the high starch content of sweet potato can be processed into flour and then can be used to produce pasta or bakery products (Ipomoea & Ed, 2007). This flour can be used to

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prepare biscuits (50%), muffins (60%) and cakes (100% substitution) at varies leaves of wheat flour substitution (Ipomoea & Ed, 2007). The flour can also be used to prepare extruded snacks and breakfast cereal or rice crisps served with milk. The sweet bun can also be made directly from sweet potato by replacing 50% of wheat flour in the original recipe, without the need to process the roots into flour first. Other than that, nuggets and breaded sweet potato are also products that made directly from sweet potato.

Sweet potato offers an opportunity to tap on a range of foods targeted for people suffering from coeliac disease, who are allergic to wheat gluten (Ipomoea & Ed, 2007). Besides, fries are also traditionally prepared from imported 'Irish' potato that can be made from sweet potato (Ipomoea & Ed, 2007). Fries are sold as frozen fries in the supermarket for home consumption and in fast-food restaurants become a favourite among Malaysian especially youth (Ipomoea & Ed, 2007). The estimation is about half of the imported 'Irish' potato valued at RM299 million per year are made into fries (Ipomoea & Ed, 2007). Other ways to replace 'Irish' potato with sweet potato are cheese bakes and meat or vegetable pies (Ipomoea & Ed, 2007).

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2.2.3 Varieties of Sweet Potato Plant in Malaysia



Figure 5: Different varieties of sweet potato (Anon, 2019).

In Malaysia, sweet potato plant is a second rank among the tuber crops, after cassava. (Mohd Hanim et al., 2014). The total sweet potato area in Malaysia was about 2000 ha per year (Yusoff et al., 2018). The largest sweet potato producer is China, with an annual production of 100 million tonnes followed by Indonesia (Uwah, Undie, John, & Ukoha, 2013). The varieties of sweet potato may vary according to its flesh colour, storage root's skin colour and some by origin. Its flesh ranges in colour from beige to white, purple, red, pink, violet, yellow and orange. Sweet potato varieties with pale yellow or white flesh are not as sweet and moist as those with purple, red, pink or orange flesh (Hue et al., 2012).

In Cameron Highlands, Pahang, there are five types of sweet potato which are Purple sweet potato, Hannah sweet potato, Jewel sweet potato, Japanese sweet potato and Garnel sweet potato (Lou, 2019). Cameron Highlands has cool weather makes the sweet potato planting period longer, which is 10 months from start planting, growing until harvest. For hot weather like Ipoh or Kelantan sweet potatoes only need 3-5 months to grow (Lou, 2019).

Many researchers claimed that VitAto, Gendut and Jalomas are the popular varieties developed by the Malaysian Agricultural Research and Development Institute (MARDI) in Malaysia, besides other high-yielding varieties such as Madu, Telong, Pontian, Bukit Naga, Serdang, Rhu Tapai dan Kuala Linggi (Yusoff et al., 2018). Other local varieties such as Biru Putih, Oren, Indon and Batu Kelantan are also planted in Malaysia (Hue et al., 2012). Research on sweet potato by organizations such as MARDI and University Putra Malaysia (UPM) such as MARDI and Universiti Putra Malaysia (UPM) focus on developing specific sweet potato variety with high yield and quality (Yusoff et al., 2018).

2.2.3.1 Purple Sweet Potato Plant

In MARDI, the researchers have done the full research about three varieties of purple sweet potato that contain high food nutritional values which is anthocyanin. This can give benefits to health such as reduce the risk of cancer and cardiovascular attacks and also can produce a high yield. These three varieties of purple sweet potato were launched on 24th September 2017 and named as Anggun 1, Anggun 2, and Anggun 3. The yield of the production for these varieties are high in the range of 20 to 30 tonnes/ha. The price market for these sweet potato varieties is about RM2.50 per kg which is to be used as a nutritious food rich in nutrients. MARDI claimed that the farmers are able to obtain gross sales value up to RM60,000 for the planting season with issued capital amounted to RM40.00 per hectare. If dived by 43 to 4 months cultivation period means that farmers are able to earn an average of RM12,500 per month. The anthocyanin content is also high which range 185 to 316 mg/L. Besides, these varieties are easy to survive even in poor soil, drought tolerance, diseases and pests tolerance compare to other vegetable crops. In order to get a good quality yield of Anggun, the plantation area must have good water irrigation system, loose soil (not pack/hard) and have measuring pH soil ranges 5.5 to 6.5 which is acidic (Abd. Ghani et al., 2017).

2.2.3.1.1 Morphological Characteristic of Anggun 1, Anggun 2 and Anggun 3

There are differences in term of agronomical characteristics between these purple sweet potato Anggun 1, Anggun 2, and Anggun 3 which are shown in table and figures below.

Table 2: Agronomical characteristics of varieties Anggun 1, Anggun 2 and Anggun 3 (Abd. Ghani et al., 2017)

Variety	Leaves		Tuber		
	Shape	Colour	Shape	Colour of peel	Flesh
Anggun 1	Semi-elliptical	Green	Long elliptical	Dark purple	Purple
Anggun 2	Dentate	Green	Medium elliptical	Dark purple	Purple
Anggun 3	Triangular	Green	Circle elliptical	Dark purple	Purple

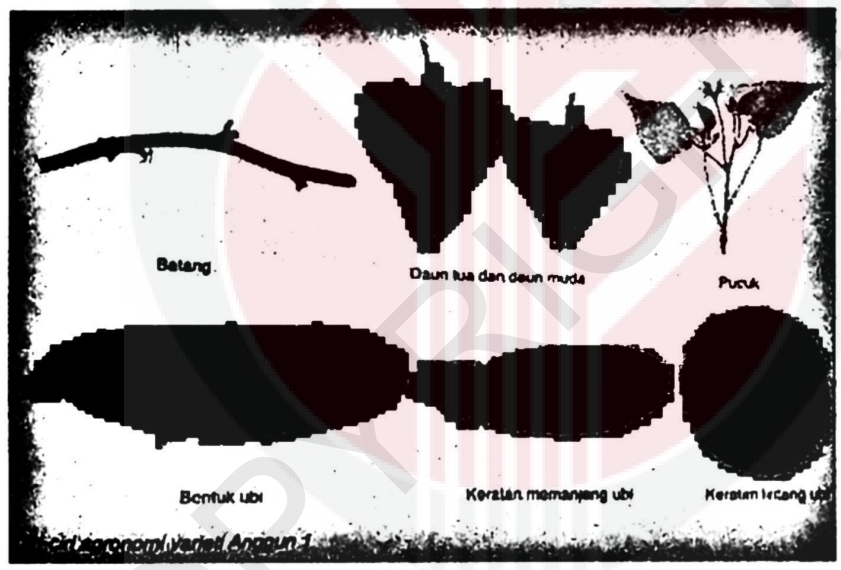


Figure 6: Agronomical characteristics of Anggun 1 (Abd. Ghani et al., 2017).

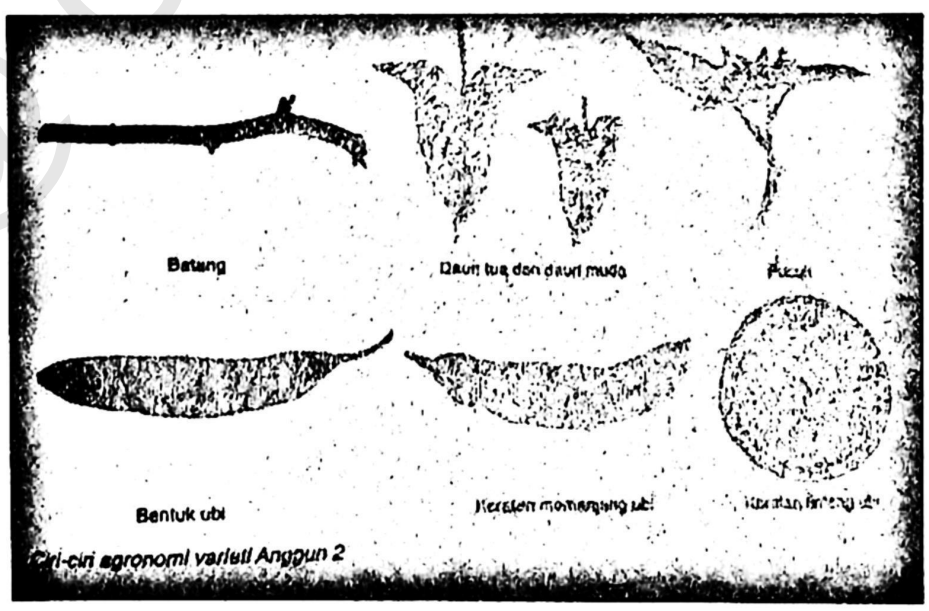


Figure 7 Agronomical characteristics of Anggun 2 (Abd. Ghani et al., 2017).

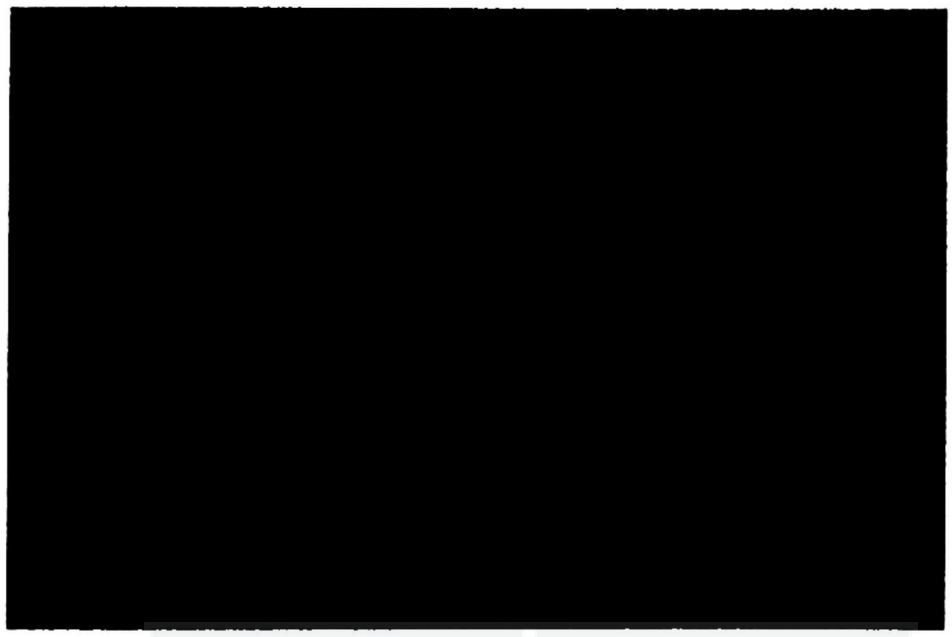


Figure 8: Agronomical characteristics of Anggun 3 (Abd. Ghani et al., 2017).

2.2.3.1.2 Application of Purple Sweet Potato Plant

These new varieties of purple sweet potato are very suitable to be introduced for school meals program, baby food, and food to the athletes as well as a great opportunity for the industry to increase the income of farmers and entrepreneurs through a variety of downstream products (BARU and Anem, 2019).

In MARDI, they try to develop processing technology from a variety of purple sweet potato. This product development of purple sweet potato is to create various food products as well as increase the nutritional value for the consumers. So, the products that MARDI has successfully develop are puree, drinks, preparative flour, ice cream, sauce, crisps and many more (Abd. Ghani et al., 2017). These products basically for human consumptions. Thus, this study is done to develop more potential food development from purple sweet potato plant especially on Anggun 1 not only for human uses but also for animal consumptions.

2.3 Processing Technology

One of the main issues is underutilized of sweet potato especially leaves, stems, tubers, and peels in term of the animal feed industry. There is a critical need to enhance the uses of the limited feed resources, specifically for stems and leaves of sweet potato plant to feed livestock focusing on herbivores. Thus, one of the processing technology demanded is pelletization.

Pelletization process consists of several types including compression or compaction, extrusion, globulation, balling and also freeze pelletization (Supriya et al., 2012). Type of process parameters and feedstock that mostly function is the quality of the pellet. By focusing on the effect of the different moisture content on sweet potato in term of physical properties, different technique of pellet processing is used. Moisture is one of the key parameters in the densification process. From the investigation of the pelletization process, strong physical properties and high nutritional value can produce the best pellet for herbivore consumption. Efficiency in animal feed can be improved by converting the material into pellet because of the heating process that reduces pathogens and becomes more digestible for the animals (Zainuddin et al., 2014). Moreover, there are several advantages of pellets which are reduction in segregation, reduction in waste, improvement of palatability and allow larger meals to be eaten in lesser time by the animals (Zainuddin, 2015). According to Kaliyan & Morey (2009), Pelleting of animal feed has shown several advantages :

- Increased bulk density
- Improved ease of handling
- Better flow properties than the ground feed
- Reduced ingredient segregation
- Less feed wastage

- Improved animal performance in terms of higher feed intake, feed conversion and daily weight gain
- Lower energy expenditure while eating
- Reduced microbial load
- Improved palatability

Compaction is one of the processes in pellets manufacturing. Size and shape of pellets are produced by compacting mixtures under certain pressure and certain moisture content of the mixtures. According to the Bureau of Rice Research and Development (2012), standards for pelleting biomass, first class pellets must have a size diameter less than 8.0mm and length less than 3.2 cm.

2.4 Physicochemical Properties of Sweet Potato Plant

2.4.1 Cellulose, Hemicellulose, and Lignin Content

In the previous study found that Lignocellulose biomass material is composed of three main compounds; cellulose (35-50%), hemicellulose (20-35%) and lignin (10-25%) (Zainuddin, 2015). There is a significant difference of hemicellulose, cellulose and lignin depend on whether it comes from hardwood, softwood or grass. Hemicellulose content shows the highest in leaves and lignin shows the highest in nut shells (Zainuddin, 2015).

Generally, cellulose is a hygroscopic material retaining 8-14% water under normal air conditions which is 20°C and 60% relative stickiness. However, it swells and insoluble in water as well as insoluble in dilute acids at low temperature (Zainuddin, 2015). At higher temperature, it becomes dissolvable as the energy supplied is enough to break the hydrogen bond that holds the

molecules of crystal structure together (Zainuddin, 2015). According to Thermowood Handbook (2003), the disintegration of cellulose will start at a temperature of 180°C.

Hemicellulose represents a group of polysaccharides such as gluco-manners, arabino-xylans, galactans and others that usually found in the plant cell wall. It has diverse structure and its structure is depending on their source and the extraction method. Hemicellulose is insoluble in water at low temperature. The vicinity of acid profoundly enhances the solubility of hemicellulose in water (Thermowood Handbook, 2003).

The last fundamental constituent of lignocellulose is lignin, the most complex natural polymer which is consists of three-dimensional polymer with phenylpropane units as the dominating building blocks. The most crucial function of lignin in plants becomes a structural component to give strength and rigidity to cell wall as well as limiting water loss by reducing the permeability of the cell wall and serves as a physical and biochemical barrier from disease organisms (Dean, 2014).

2.4.2 Proximate Composition of Different Parts of Sweet Potato Plant

Determination of nutritional content of materials is usually done by proximate analysis. Basically, proximate analysis is a way to determine moisture content, dry matter content, protein content, fiber content, fat content, ash content and also carbohydrate content by following AOAC method.

There is the previous study about the proximate composition of leaves of 40 of sweet potato cultivars. Sun, Mu, Xi, Zhang, & Chen (2014) claimed that the maturity of sweet potato leaves could have an influence on the moisture content. There were significant differences in proximate analysis among the sweet potato cultivars. The highest crude protein content of leaves among the

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sweet potato cultivars is 31.08 g/100g DW, while the lowest crude protein is 16.69 g/100g DW. The highest crude fiber content is among the cultivars is 14.26 g/100g DW as well as crude fat content which is 5.28 g/100g DW. This previous study shows that the leaves contain high protein content among the other compositions.

As for stem, there is a study about two varieties of sweet potato by Ishida, Suzuno, Sugiyama, & Innami (2000) stated that sugar content in stalks is lower than tubers but the dietary fiber is more in stems compared to leaves. The ranges of ash content are 1.3 g and 0.8 g. Further study is needed about the stem of sweet potato for the other nutritional content in order to prove the high value of all parts of sweet potato including stems.

As for tuber of sweet potato, it has high moisture content and low dry matter content around 30 % compared to other tubers but varies widely depending on variety, geographic area, soil, climate, amount of light and cultivation practices (Potato & Grown, 2016). From this previous study about the orange-fleshed sweet potato that has same Family *Convolvulaceae* with purple sweet potato, the protein content of the sweet potato ranged from 1.91% to 5.83%. Sweet potato also known as low-fat content crops. Many researchers found out the fat content for the sweet potato to be in ranges of 0.2% to 0.33%. Potato and Grown (2016) in their study found that the carbohydrate content was ranged 21% to 25% in fresh samples of sweet potato. The other studies also found out 27% and 28% of carbohydrate content. There should be some factors that affect the difference of carbohydrate content like varieties and also stages of maturity of the tubers. Besides, other researchers found out about the crude fiber content of 49 sweet potato varieties ranged 3.45% to 6.36% and also between 2.1% to 13.6% in various countries. For ash content, it can be

influenced by the use of fertilizer, soil and climatic condition that can affect the sweet potato. In Potato and Grown study, the ash content of the tubers ranged from 1.17% tol.31%.

From the previous study also found out the research about sweet potato peels as replacement and utilization of feed for fish authored by Solomon and Okomoda (2016) and also Omoregie, Igoche and Ojobe (2009). The proximate composition of sweet potato peels from both studies was revealed based on the table below.

Table 3: Proximate composition of sweet potato peels from Solomon and Okomoda (2016) and also Omoregie, Igoche and Ojobe (2009).

Nutrient content	Composition % (Solomon and Okomoda, 2016)	Composition % (Omoregie, Igoche and Ojobe, 2009)
Moisture	8.91	8.24
Crude protein	5.91	4.64
Crude fat	4.71	-
Crude fiber	3.56	3.80
Ash	6.02	4.56

2.5 Physical Properties

Sweet potato mostly will be processed into powder or flour because it is the most satisfactory method to create a product that is not functionally enough and also stable for long shelf period without spoilage. For flowability, its measurement is important because it can affect the behavior during handling, processing and storage. The flowability of powder and flow behaviour under temperature, pressure and humidity are crucial in processing and handling operation for example,

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storage in silos and hoppers, transportation, formulation and mixing, compression and packaging In the previous study, the VitAto was examined to gain more information on its physicochemical characteristics and also flowability in a trial to extend its usage in food industry (Mohd Hanim et al., 2014). Powder with smaller particle size is more cohesive and their flowability is more difficult. Flow stability index value close to 1 is that the powder has not much changed during the test means the powder is stable A decrease in compaction coefficient, as well as the increase of speed, indicates that the powder becomes freer flowing. Caking strength is depending on packing efficiency, moisture content and particle to particle interactions (Mohd Hanim et al., 2014).

In terms of physical properties of pellets, there are two quality parameters that are important for pellet which is friability and strength. Friability is the percentage of friable from the pellets while strength is a measure of compressive resistance and impact. According to Bathool, Gowda, and Khan (2012), the friability test is determined to make sure the mechanical strength of the pellets. It is the ability of compressed pellets to prevent breaking apart or fracture during handling and transportation. Other than that, low friability indicated that the pellets are able to withstand the shear forces if the pellets are subjected to mechanical shock or attrition (Zainuddin et al., 2014). In M.F. Zainuddin et al., (2014) research also resulted in friability of pineapple plant residue pellets that required higher moisture content to produce optimum condition for friability.

Physical properties of pellets determine its quality. Generally, physical properties used to establish the integrity of the pellets are durability, bulk density and porosity (Igathinathane et al., 2010). Porosity has an influence on bulk density. Zainuddin et al., (2014) study stated that higher bulk density could lead to reduce transportation cost and enable easier handling with proper storage equipment. Besides, true density is a fundamental material property to obtain an accurate characterization of mechanical properties of powder that measures the average density of the large

volume of powder in a specific volume. Whereby, the true density decreased as the moisture content increased. Moreover, porosity is also important for transportation and storage of the pellets. In Zainuddin et al., (2014) research also stated that as the moisture content increases, the porosity decreased.

For tensile strength, in Kaliyan & Morey (2009) study stated that the compressive or hardness is the maximum crushing load that a pellet can withstand before starting to crack or fracture. The tensile strength can be determined using the diametrical compression test. In their study observed the increase of pressure above 100MPa, tensile strength of the pellets started to decrease and lived off at 1.5 to 2.0 MPa. The basis of choosing tensile strength is to study the relationship of moisture during pelleting with the keeping pellets quality (Zainuddin et al., 2014).

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will cover the methodology from the first phase to the second phase. The first phase of investigation involved the determination of physicochemical properties of different parts of sweet potato including stem, leaves, skin and tuber. For analysis, a lignocellulosic analysis which consisted of hemicellulose, cellulose and lignin content by using Thermogravimetric Analysis (TGA). Then, further analysis was made for proximate analysis (crude protein, crude fiber, moisture, dry matter, ash, carbohydrate). In the second phase, identification of technical grade powder flow properties of the samples powder by conducting flowability analysis by using a texture analyzer instrument, and then proceed with the identification of physical properties of pellets produced from different formulations of leaves and stems of sweet potato based on the experimental analysis that has been done. A pelletization process which involved the compaction process was carried out in this study using moisture of 40-60 % using manual noodle maker. Then, physical tests were performed on the pellets to investigate their strength and ability. The summary of the whole process with a flow chart is shown in Figure 9 and Figure 10.

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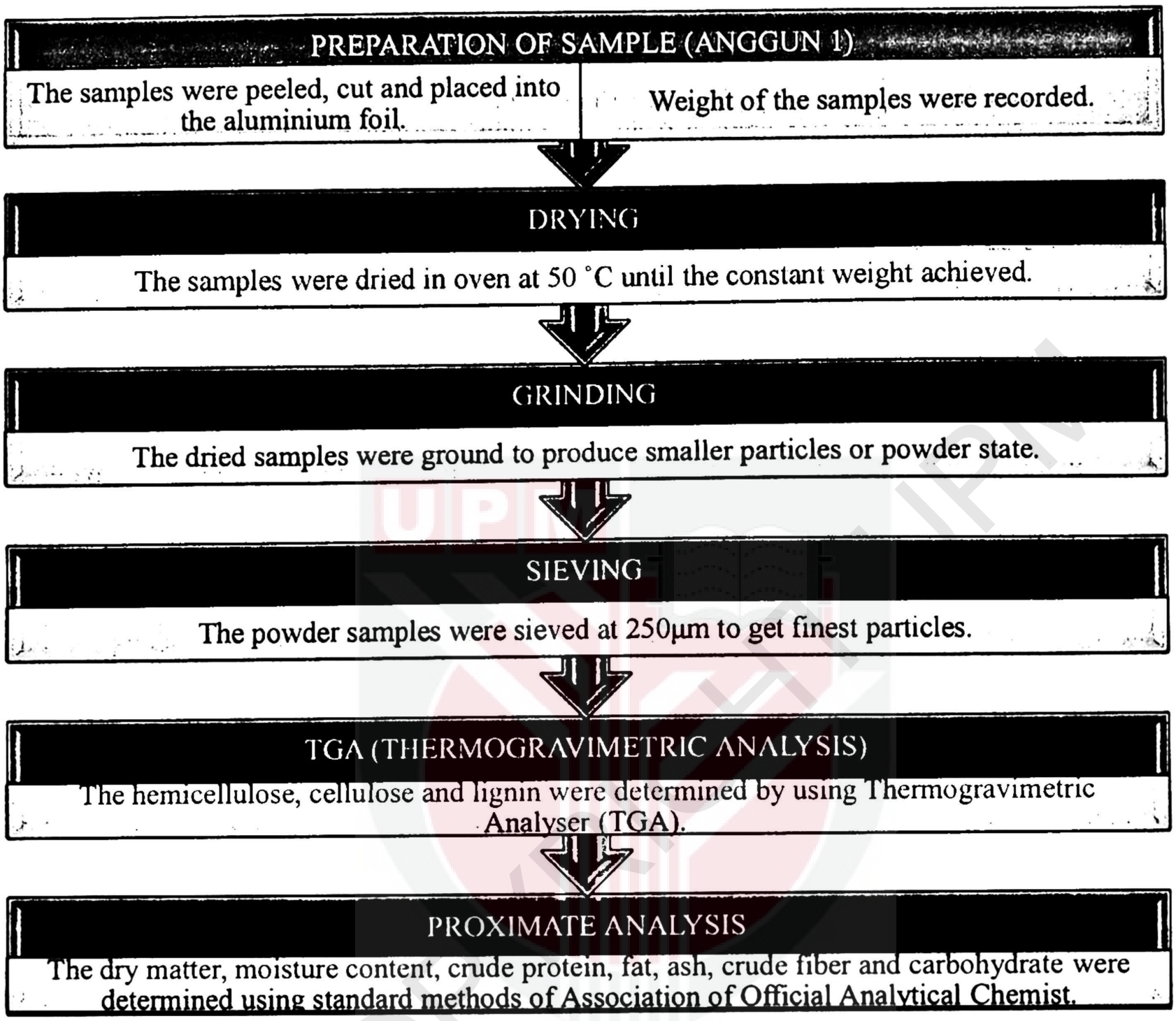


Figure 9: (PHASE 1) to determine the physicochemical properties of different parts of sweet potato plant including stem, leaves, peels and tuber.

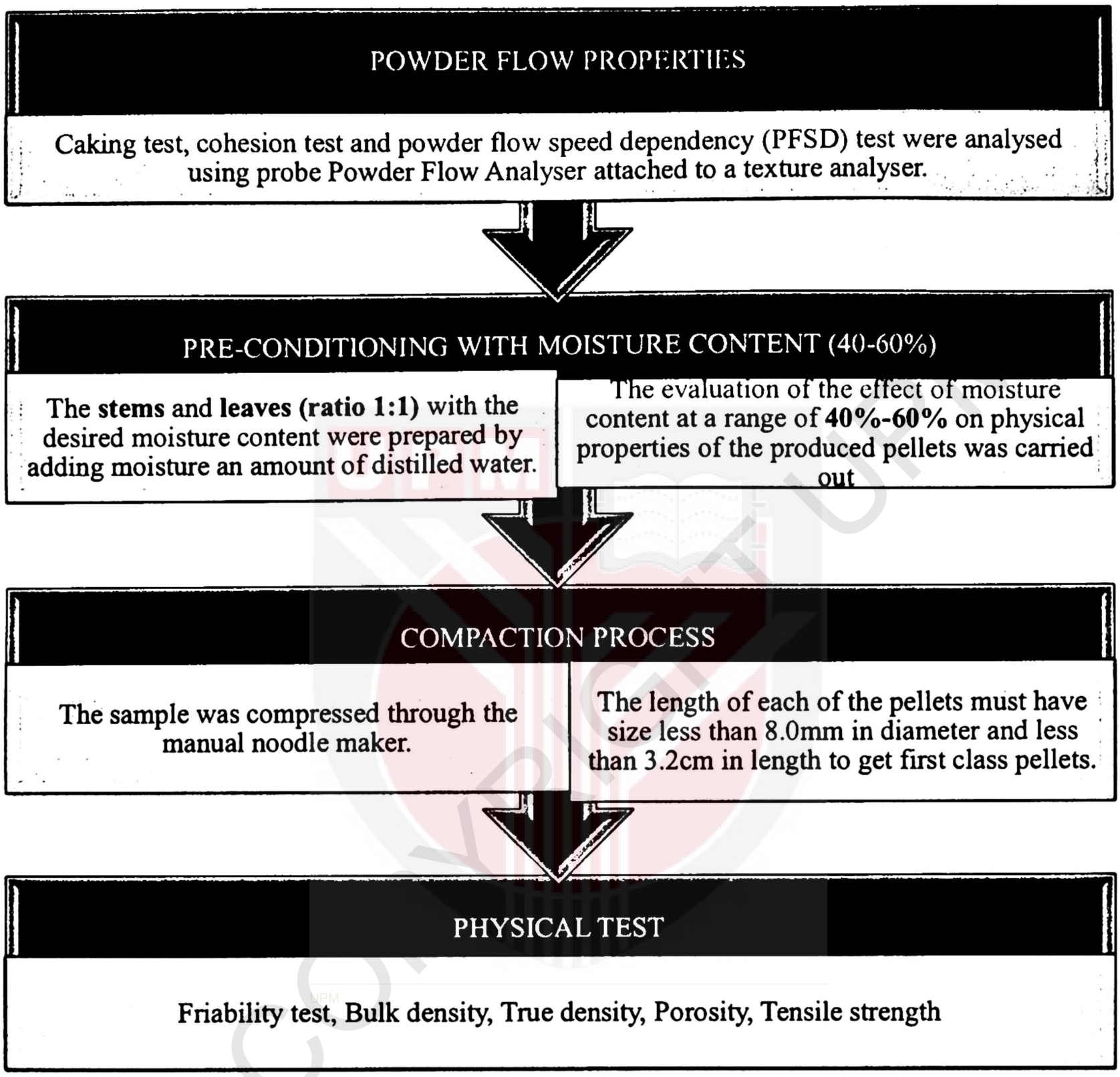


Figure 10: (PHASE 2) to develop the pelletising process of the stems and leaves of sweet potato plant using a compaction process.

3.2 Materials

In the experiment, the materials used was the purple sweet potato plants Impomea batatas species from variety Anggun 1. Anggun 1 was collected from Sweet Potato Plantation in Kawasan Perindustrian Bandar Rinching Seksyen 6, 43500 Semenyih, Selangor. Then, the sweet potato including leaves, stems and tubers were stored in a chiller at temperature 12°C.



Figure 11: Sweet potato plantation in Semenyih, Selangor.

3.3 Sample Preparation

3.3.1 Production of Powders from Leaves, Stems, Tuber and Peels of Sweet Potato Plant

The leaves and stem were separated and cut down to 2 to 3 cm to become small pieces and then placed into the aluminium foil. The tubers were peeled and cut into small pieces and then were separated into the aluminum foil. All the samples were dried in the oven (OF-G22W, Jejo Tech, Kore) at 50 °C to preserve the nutritional content of the materials. The drying process took about 72 hours. The samples were ground and sieved at 250μm using a Mill Grinder (Retsch, SM200 Rostfrei, Germany). Feeds without large (>1mm) particles are most rapidly digested after being

chewed by animals (Al-Rabadi, Torley, Williams, Bryden, & Gidley, 2011). The dried samples were kept in a chiller for further analysis.

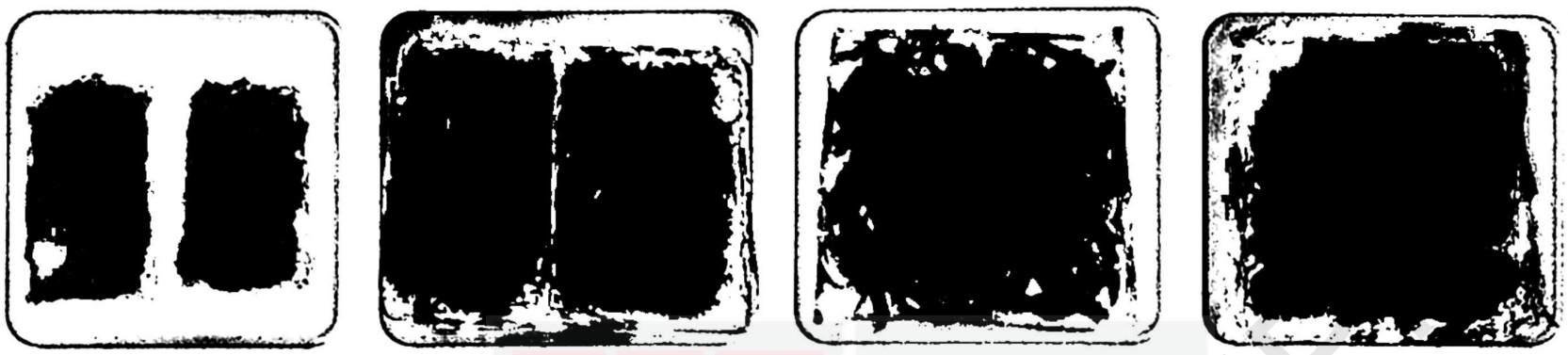


Figure 12: Samples before drying.

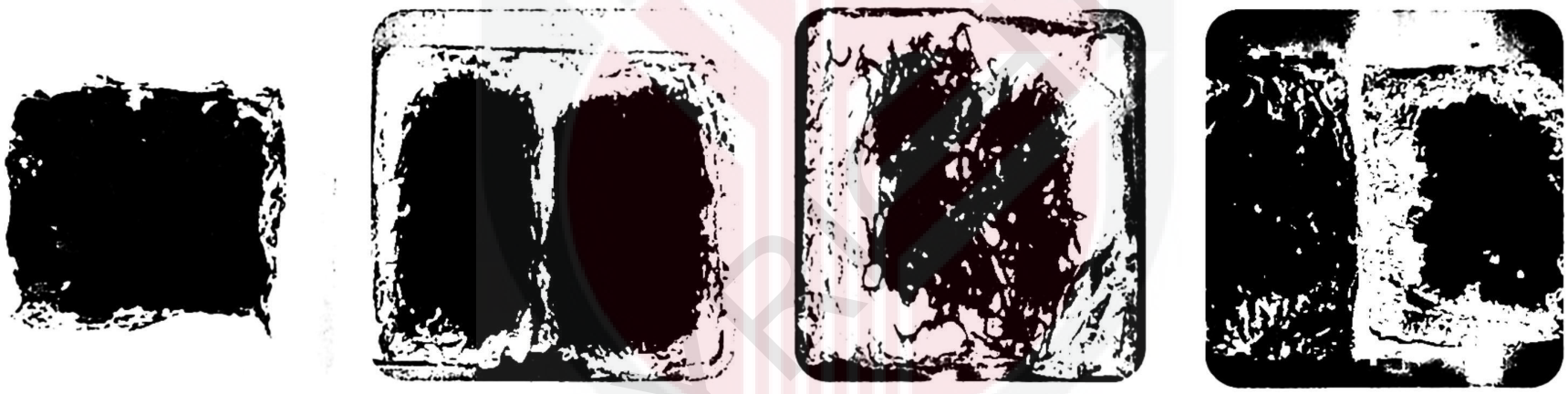


Figure 13: Dried samples

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Figure 14: Sieved sweet potato peels, tuber leaves and stems.

3.3.2 Pallets Production from Stem and Leaves Powders of Sweet Potato Plant through Compaction Process

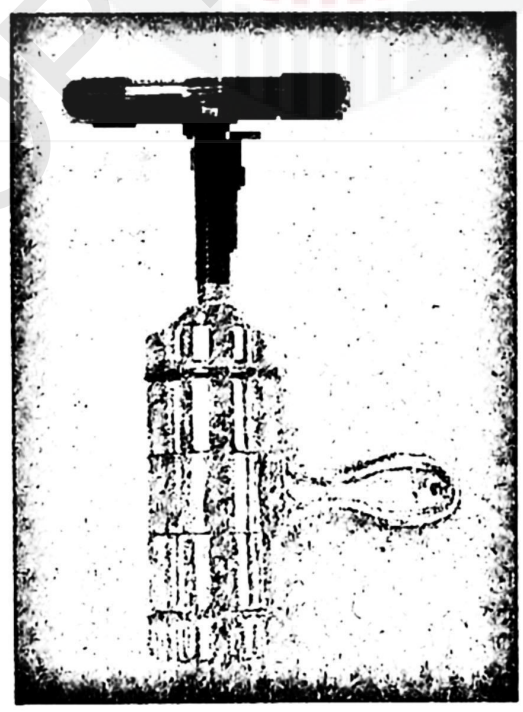


Figure 15: Manual noodle maker used for compaction process.

For compaction process, all the powder samples of leaves and stems were mixed together at a ratio of 1:1. The sample was then moisturized with water with different moisture levels (40%, 45%, 50%, 55% and 60%). The moisture can affect the physicochemical and stability of the pellets (Mahapatra et al., 2010). The chosen range of moisture content (40%-60%) used was because of the equipment used which was manual noodle maker only operated well for the sample that exceeds 40% moisture content. The moisture content of the sample was measured based on a wet basis. The samples with the desired moisture content area were prepared by adding an amount of distilled water as calculated below (Coşkun, Yalçin, & Özarslan, 2006):

$$Q = Wi\ (Mf - Mi) / (100 - Mf)$$

Where;

Q: Mass of distilled water added in kg

Wi: Initial mass of the sample in g

Mi: Initial moisture content mass of the sample in %

Mf: Final moisture content of the sample in %

After the compaction process, the pellets were obtained with different moisture content. The length of each of the pellets was 1.4 to 3 cm. Based on the Bureau Research and Development (2012) who has developed standards for pelleting biomass that stated by Zainuddin et al., (2014), first class pellets must have a size less than 8.0mm in diameter and less than 3.2 cm in length. The mixture of stems and leaves of sweet potato in pellets form with different moisture content were shown in Figure 16.

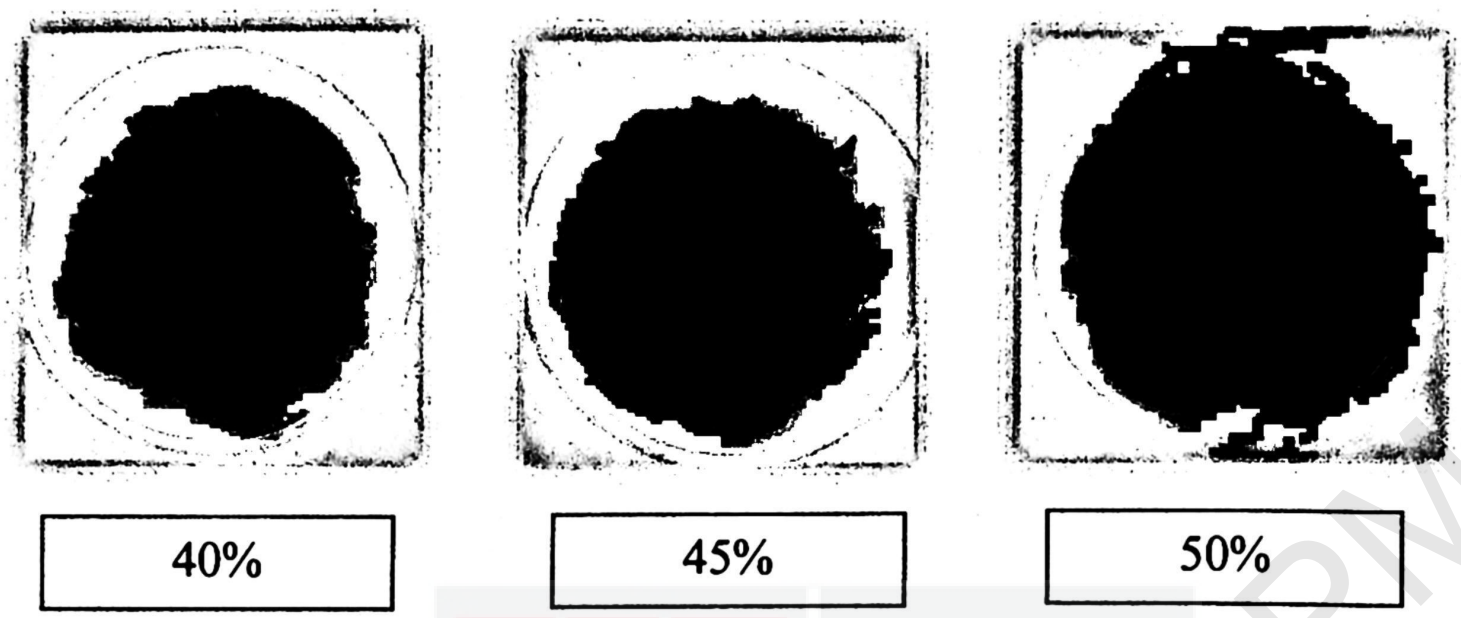


Figure 16: Mixture of stems and leaves of the sweet potato plant in pellets form with different moisture content.

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3.4 Sweet Potato Plant Powders Analyses

3.4.1 Cellulose, Hemicellulose, and Lignin Content



Figure 17: Thermogravimetric Analyser (TGA).

The hemicellulose, cellulose and lignin content were determined by using Thermogravimetric Analyser (TGA) (Metler Toledo, TGA/SDTA851e, USA) shown in Figure 17. Approximately 10 mg of oven-dried sample was placed in an alumina ceramic crucible and weighed. The TGA was programmed starting at 30 to 600°C at a rate of 10°C/min under 10Ml/min N^2 purging. After that, the temperature was further increased to 900°C at the same rate but purged with 10 mL/min air (Omar, Idris, Yunus, Khalid, & Aida Isma, 2011). All data analysis was collected from the graph.

3.4.2 Proximate Analysis

3.4.2.1 Dry Matter Content

Dry matter is everything contained in the sample except for water, which included protein, fiber, fat, and other minerals. In a practical way, it is the total weight of the sample subtracted by the weight of water, expressed as a percentage. In this study, it was determined by drying the sample

in the oven (OF-G22W, Jjejo Tech, Korea) until the sample reached a stable weight. The clean crucible was dried in the oven at 105°C for 30 min and then were cooled and dried in the desiccator. The sample was weighed and about 1g was placed in a dry crucible. The crucible and sample were dried for 24 h. After that, the crucible and sample were let to be cooled in a desiccator and then weighed. The percentage of dry matter was calculated and recorded.

W1/W2 ×100 %

Where;

W1: Dry weight (g) and W2: Total Weight (g)

3.4.2.2 Moisture Content

Moisture content was determined using Standard Official Methods of Analysis of the AOAC (1990), involved the drying process until constant weight at 105°C achieved and calculating moisture as the loss weight of dried samples. The clean crucible was dried in the oven at 105°C for 30 min and then was dried and cooled in the desiccator. After that, the samples were weighed using a weighing balance and recorded as W1. 1.0 g of samples were placed into the crucible and weighed to get W2. Then, the sample and crucible were placed inside the oven at 100°C for 4 hours. Next, the dried sample with the crucible was cooled in a desiccator for 30 min and weighed to get W3.

$[(W2)-(W3)/(W2)-(W1)]\times 100\%$

Where;

W1: Initial weight of empty crucible (g)

W2: Initial weight of filled crucible (g)

W3: Final weight of filled crucible (g)

3.4.2.3 Crude Protein



Figure 18: Kjeltec Analysis.

The crude protein content of the samples was determined using the Kjeldahl method of AOAC (1990) involving protein digestion and distillation. As for protein digestion, about 1.0 g of the sample was weighed into Kjeldahl flask, and one tablet of Kjeldahl Catalyst was added. Then, 12 mL of concentrated sulphuric acid was added. The whole mixture was subjected to heat in the fume cupboard. The heating was done at first then increased with occasional shaking until a green colour of the solution. The temperature of digester remained above 420°C about 30 min. The solution was cooled and then re-heated until the green colour disappeared. After that, it was allowed to cool down. For protein distillation, 100 mL conical flask containing 5 mL of the boric acid/indicator was placed under the condenser to make sure that the condenser tip was under the liquid. Then, the Kjeltec distillation apparatus (KjeltecTM 2300, Foss Analytical, Denmark) was steamed for 15 min. About 5.0 mL of the digest was pipetted into the body of the apparatus by a small funnel aperture and was washed down with distilled water. Then 50 mL of NaOH solution

was added and the digest in the condenser was steamed for 1 to 5 min after sufficient ammonium sulfate was collected. The receiving flask was removed and the tips of the condenser were washed down into flask after the condensed water was removed. The solution in the receiving flask was treated with 0.01 M hydrochloric acid. Besides, a blank also needs to be run along with the sample. The data was collected and recorded.

3.4.2.4 Crude Fiber Content

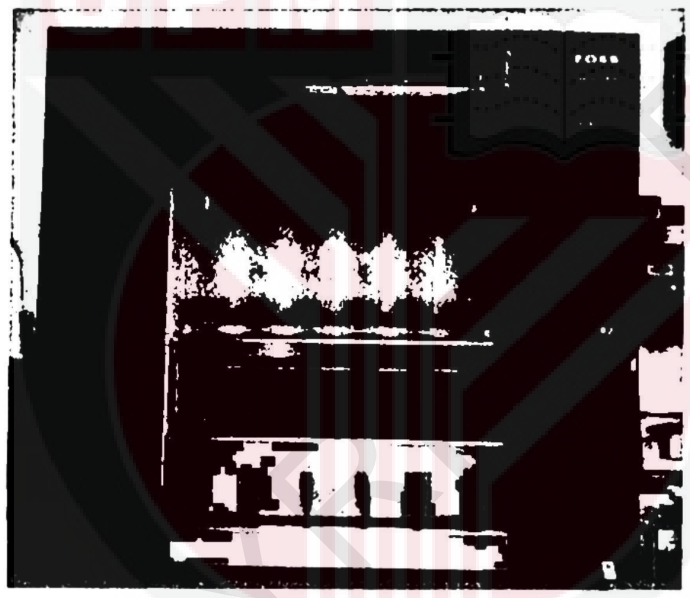


Figure 19: Fibertec Analysis

Crude fiber content was determined by using the method in AOAC (1990). The clean crucible was dried in the oven at 105°C for 1 hour and then was cooled and dried in the desiccator for 30 min and then weighed. About 1.0 g of the samples and 1.0 g of Celite 545 diatomaceous as filter agent (Sigma Aldrich, Germany) was dissolved in 200 mL of boiling 0.25N sulphuric acid using fibertec analysis. (Fibertec TM 2010, Foss Analytical; Denmark) and then boiled for 30 min. The hydrolyzed mixture was filtered through the crucible and the residue was rinsed with boiled water to remove the acid from the filtrate inside the crucible. Then, 200 mL of boiled 0.313 N sodium hydroxide (NaOH) was added to the crucible and boiled for 30 min. The hydrolyzed mixture was

filtered again and rinsed again with distilled water until the crucible was free of alkaline. The residue was rinsed again with small amount was rinsed again using a small amount of acetone, 2 to 3 droplets and then drained. After that, the residue in the crucible was dried in an oven at 105°C until a constant weight was achieved. Lastly, the crucible with the residue was placed in the furnace at 550°C and burnt completely. The crucible was cooled in a desiccator and weighed until a constant weight was achieved and calculated as:

$W1/W2 \times 100\%$

Where;

W1: Weight of residue without ash (g)

W2: Weight sample (g)

3.4.2.5 Crude Fat Content

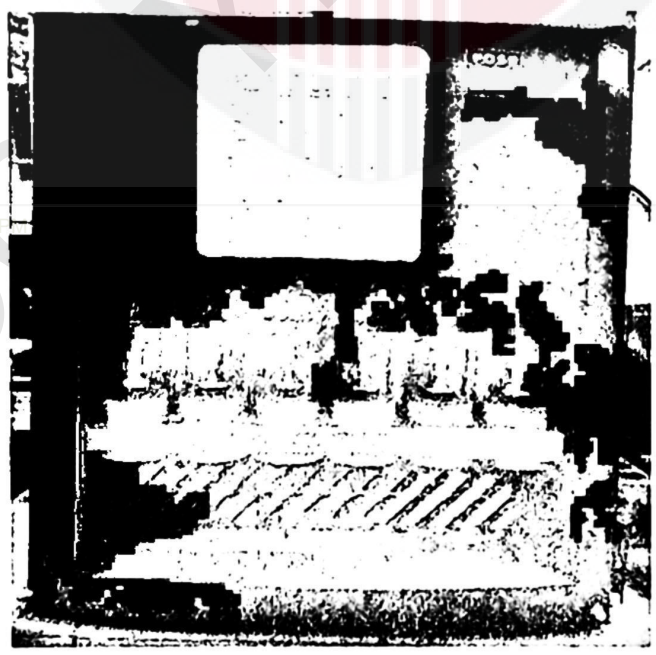


Figure 20: Soxtec Extraction.

Determination of fat in the sample is according to the Soxhlet extraction method by using Soxtec Extraction (SoxtecTM 2050, Foss Analytical, Denmark). At first, 250 ml of the aluminum cup was

dried in the oven at 105 °C for about 30 min and cooled in a desiccator. About 1.0 g of sample was weighed and placed into thimbles. The extraction thimbles were covered with cotton wool. The aluminum cup was weighed and filled with 80 mL of petroleum ether. Then, the Soxtec apparatus was assembled and allowed to reflux for 75 min. After finished the extraction, the thimbles were removed with care. After that, the aluminum cup was dried at 105 for 1 h, when it was almost free of petroleum ether. After that, it was cooled in a desiccator and weighed (Pearson 1976). The fat percentage of the samples can be calculated by the equation below:

$W1/W2 \times 100\%$

Where;

W1: Weight of fat (g)

W2: Weight of sample (g)

3.4.2.6 Ash Content

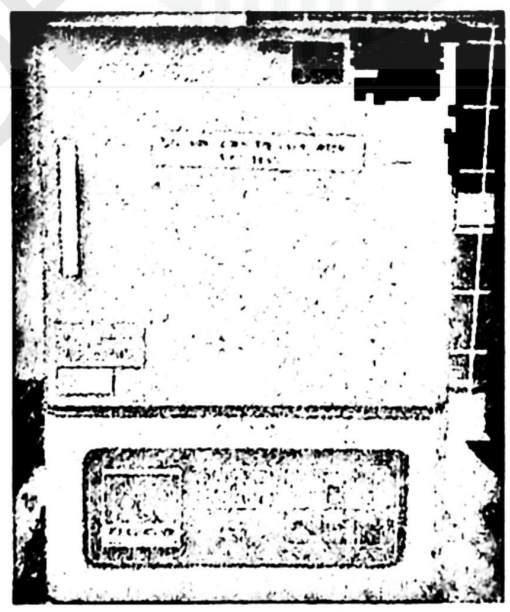


Figure 21: Furnace.

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Determination of the total ash content was determined using furnace incineration as described in AOAC (1990) based on the vaporization of water and volatiles by burning organic substances in the presence of oxygen in the air to carbon dioxide at a temperature of 550°C. About 1.0 g of dried sample was placed in a crucible and incinerated at 550°C for 6 h in a furnace (KSL-1700X, MTI Corporation; USA) until ash was obtained. The ash with the crucible was cooled in a desiccator and weighed. The percentage of ash content in the samples was calculated.

$W1/W2 \times 100\%$

Where;

W1: Weight of ash (g)

W2: Weight of original (g)

3.4.2.7 Carbohydrate Content

The total percentage of the carbohydrate content in the samples can be measured by using the difference method (Eugene N., Onyeike, Tamunosiki, Olungwe, Augustine A., 1995). One of the methods that have been used for this study was by adding the total values of moisture, crude protein, fiber, fat and ash constituents of the sample and subtracting it from 100. The value obtained was the percentage of carbohydrate constituent of the sample.

100 – (% moisture + % crude fiber + % crude protein + %fat + % ash) = % carbohydrate

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3.4.3 Flowability Analysis



Figure 22: Powder Flow Analyser attached to a texture analyzer.

The flow properties of different parts of sweet potato powder were analyzed using probe Powder Flow Analyser attached to a texture analyzer (TA-XT plus, Stable Micro Systems, Surrey, UK) (Benkovic and Bauman, 2009). The caking test, cohesion test and powder flow speed dependency test (PFSD test) were performed. All samples were fixed at 70 mL volume for each experiment. The caking test, cohesion test, and PFSD test were run and triplicated except for caking test. A conditioning cycle was performed at the beginning of the test to remove user loading variation by moving the blade downward and upward through the powder column at a tip speed of 50 $mm.s^{-1}$.

3.5 Sweet Potato Leaves and Stems (SPLS) Pellets Analyses

3.5.1 Friability



Figure 23: Friabilitor

20 pellets were randomly selected and then weighed using electronic balance (ER-120A, A&D, Japan). Next, by using the electronic friabilitor (DF-3, Distek, USA) shown in Figure 23, the pellet was rotated at 25 rpm and let the pellets to roll and fall for 20 times by means of drum rotation and removal of any loose dust generated from the pellets during the test. Then, the pellets were dedusted and weighed. The percentage of weight loss was calculated using the formula below. (Deveswaran et al., 2009):

$$\% \text{ Friability} = (W1-W2)/W1 \times 100\%$$

Where;

W1: Initial weight (g)

W2: Final weight (g)

3.5.2 True Density



Figure 24: Helium gas pycnometer.

True density measures the weight per unit volume of powder material, excluding the voids (Zainuddin et al., 2014). The true density of single-components and binary mixtures were measured using a helium gas pycnometer (AccuPyc II 1340) Pycnometer Micromimetics, U.S.A.). The pressure difference between the known reference volume and total cell sample was taken as the measurement (M.F. Zainuddin et al., 2014). The test was carried out by measuring 1.0 g for each sample. The results of the true densities of the pellets were reported in triplicate.

3.5.3 Bulk Density

Bulk density was measured by filling a 25 ml measuring cylinder with a sample from a set height, then, tapping twice in order to get uniform packing and minimize wall effect. Next, the contents were weighed by using the digital balance. The bulk density was calculated as the ratio of the sample mass to the measuring cylinder volume (Liu et al., 2013):

$\rho b = mb/Vb$

Where;

ρb: Bulk density (kg/m^3)

mb: Total mass of pellets (kg)

Vb: Volume of the cylinder (m^3)

3.5.4 Porosity

The porosity was calculated by the true density and bulk density (Stelte et al., 2011). Porosity or void fraction measurement of the void spaces in a material. It was a fraction of the volume of voids over total volume lies between 0 - 1.

$$\text{Porosity} = 1 - (\rho b/\rho t) \times 100\%$$

Where;

ρb: Bulk density (kg/m^3)

ρt: True density (kg/m^3)

3.5.5 Tensile Strength

The tensile strength of pellets was measured by using texture analyzer (TA-XT plus, Stable Micro Systems, Surrey, UK) to test the hardness that the samples can endure before started to fracture. Two selected pellets with length about 1.4 cm and diameter about 0.3 meters. The length and diameter were chosen based on the probe used which was 35 mm Cylinder Probe using 5 kg load. Then, the two pellets were positioned centrally under the probe, and the compression test was commenced. The results were recorded for analysis of data.

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3.6 Statistical Analysis

Analysis of variance was applied in the determination of statistically significant differences between the means of triplicate raw data of samples by using one-way ANOVA. Significance was accepted at $P < 0.05$ using IBM SPSS Statistic Software Version 25.

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physicochemical Properties of Sweet Potato Plant Powders

4.1.1 Cellulose, Hemicellulose and Lignin Content

Thermogravimetry (TG) is a branch of thermal analysis which examines the change of mass of a sample as a function of temperature in the scanning mode or as a function of time in the isothermal mode. TG functions to characterize the decomposition and thermal stability of materials under a variety of conditions (Zainuddin, 2015). According to Brown (2004), thermogravimetric curves are characteristic for a given polymer or compound because of the unique sequence of the physicochemical reaction that occurs over specific temperature ranges and heating rates, and also become the function of the molecular structure. The thermal degradation of lignocellulose in samples happens in three stages (Yunos et al., 2012). The first stage is the moisture removal from samples, the second stage is hemicelluloses decomposition and the last one, the third stage is the degradation of cellulose and lignin. Figure 25 shows the TGA curves of all powders of sweet potato parts. Figure 26 shows the Derivative Thermogravimetric (DTG) curves of all powders of sweet potato parts. In this study, all stages occurred at a particular temperature range, minimum 0°C and maximum 900°C (Zainuddin, 2015). As for the result for this study which is similar to Zainuddin (2015) study where the degradation of cellulose and hemicellulose occurred in the range of 220°C to 315°C and 315°C to 400°C respectively. For lignin degradation, it occurred in within a higher range 160°C to 900°C as shown in the result of TGA and DTG curves. Weight loss (%) at selected temperatures indicates the percentage of hemicellulose, cellulose and lignin in the fiber.

Basically, hemicellulose decomposes first, then followed by cellulose and lignin (Yang et al., 2007). Hemicellulose in plant fiber generally consists of mannose, arabinose, galactose, xylose and glucose. It is also become a filler between cellulose and lignin as well as give a little contribution to stiffness and strength of fibers or individual cells (Thompson, 1993). As for the plant fiber, hemicellulose started to decompose at temperatures as low as 150°C for leaves, and for stems, decomposed at the highest temperature of 304°C. Hemicellulose is a cell wall polymer with the highest moisture sorption (Madsen, 2004) and this might help the absorption of the formulation of pellet production in the controlled condition in term of amount of water, process, handling, storage and transportation.

Cellulose is the main structural component that provides strength and stability for the plant cell walls and fiber (Paster et al., 2003). The amount of cellulose in the fiber might influence its properties, the economics of fiber production, and the utilization of fiber in various application including animal feed application. Higher cellulose content might be preferable for paper, textile and other fibrous applications. Traditionally, human has employed cellulosic biomass for uses like construction, soil stabilization, paper manufacture and also animal feed (Zainuddin, 2015).

Lignin consists of an amorphous structure that provides individual fibers and plant tissue with compressive strength and helps strengthen the cell wall of fibers to protect carbohydrates from chemical and physical damage (Saheb and Jog, 1999). Lignin contains structural units that could serve as a source of fuels and could be of high-value for chemical production (Mendu et al., 2011).

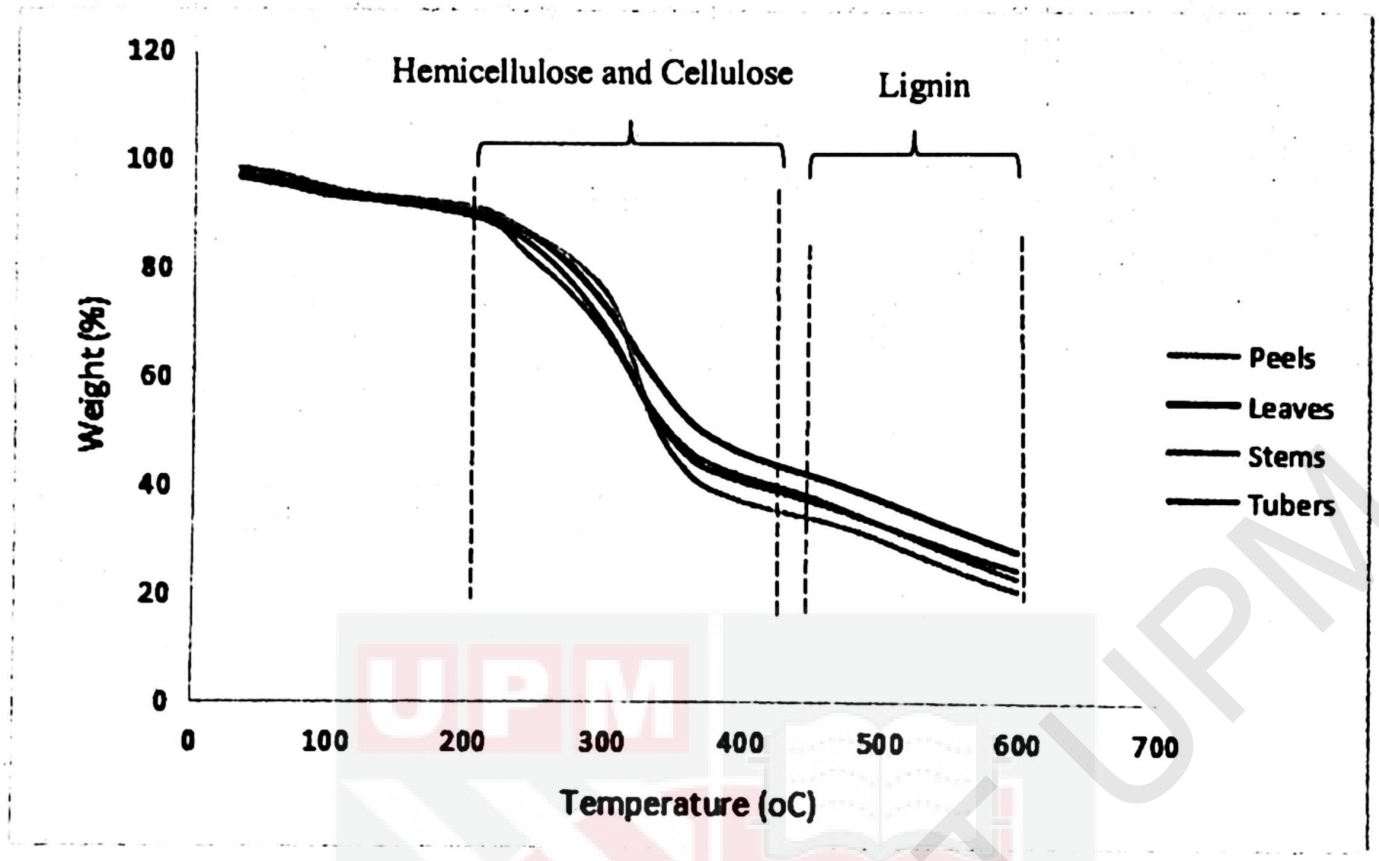


Figure 25: Thermogravimetric analysis (TGA) curves for sweet potato leaves, stems, tubers and peels in powder form.

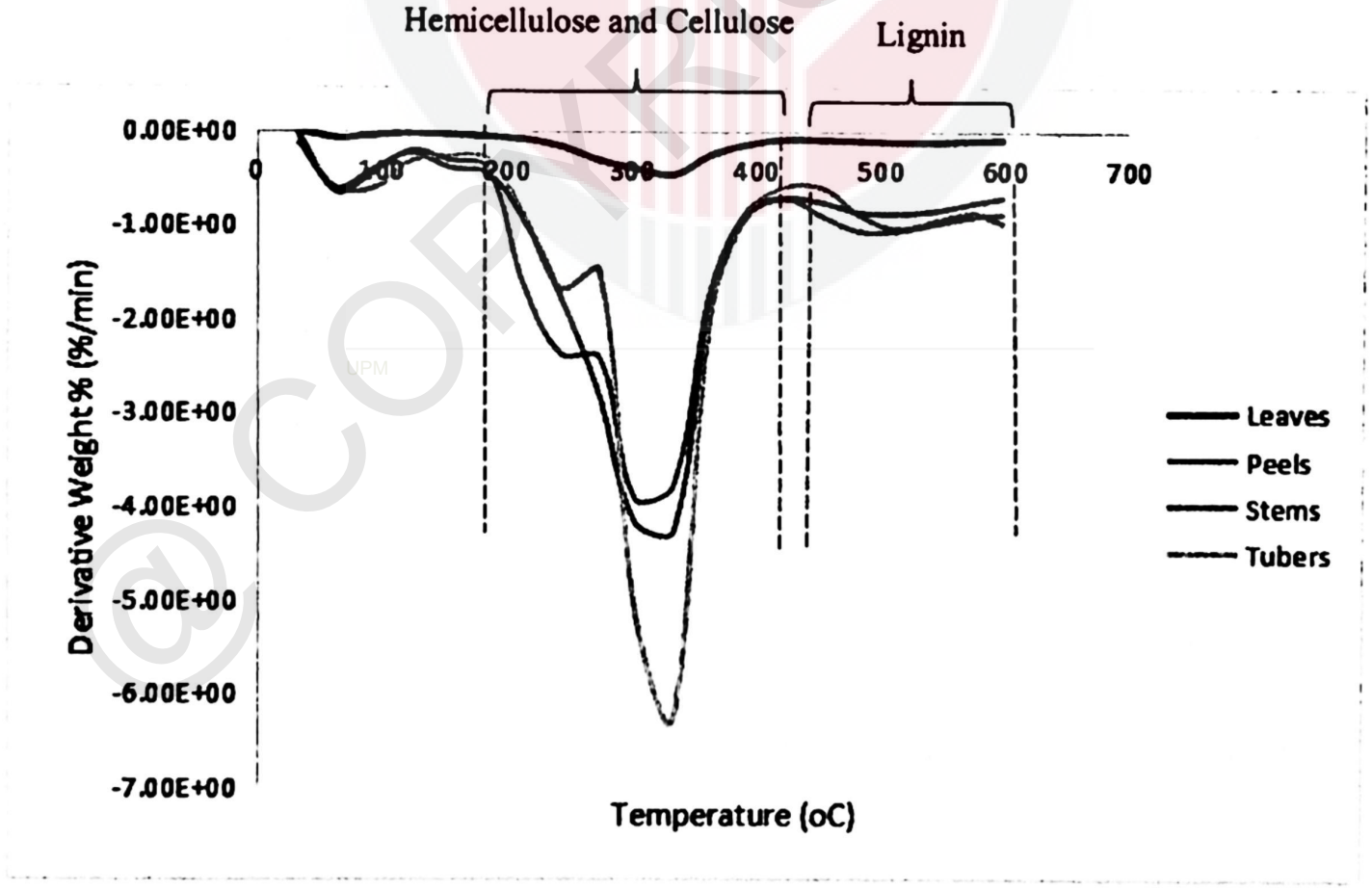


Figure 26: Derivative Thermogravimetric (DTG) curves for sweet potato leaves, stems, tubers and peels in powder form.

4.1.2 Proximate Analysis

The proximate analysis was focused on the evaluation of the dry matter, moisture, protein, fat, fiber, ash and carbohydrate content of powder form of the leaves, stems, tuber and peels of sweet potato. The results obtained from the proximate analysis of purple sweet potato plant (Anggun 1) including leaves, stems, tubers and peels based on the dry basis in Table 4 shows the presence of protein in great quantity, especially in leaves. The fibers and carbohydrates content also high among the different parts of sweet potato. A brief discussion of proximate analysis is given below.

Table 4: Proximate composition of powders of the leaves, stems, tubers and peels of sweet potato.

Constituents	Proximate Analysis (%)			
	Sweet Potato Powder			
	Leaves	Stems	Tubers	Peels
Dry Matter	92.62 ± 0.20^{b}	91.96 ± 0.19^{c}	93.14 ± 0.13^{a}	91.75 ± 0.19^{c}
Moisture Content	7.18 ± 0.57^{b}	7.70 ± 0.41^{b}	7.12 ± 0.24^{b}	8.83 ± 0.18^{a}
Crude Protein	29.76 ± 0.05^{a}	5.08 ± 1.91^{c}	7.40 ± 0.03^{b}	6.52 ± 0.03^{bc}
Fat	4.41 ± 0.20^{a}	4.58 ± 0.57^{a}	0.69 ± 0.11^{c}	1.40 ± 0.32^{b}
Crude Fiber	14.53 ± 0.59^{b}	10.92 ± 1.46^{c}	8.33 ± 0.17^{d}	16.34 ± 0.58^{a}
Ash	9.93 ± 0.01^{c}	11.80 ± 0.02^{a}	4.02 ± 0.02^{d}	11.67 ± 0.04^{b}
Carbohydrate	34.18 ± 1.39^{d}	59.92 ± 1.20^{b}	72.43 ± 0.50^{a}	55.24 ± 1.07^{c}

*Means (± SD) with the same letter are not significantly different at $p > 0.05$ for each row

4.1.2.1 Dry Matter Content

The dry matter content of leaves, stems, tubers and peels ranged from 91.75% to 93.14 % as shown in Table 4. Tubers have the highest dry matter of 93.14% followed by leaves with 92.62 %. For stems and peels, there were not significantly different at $p > 0.05$ and have lower dry matter content compared to both leaves and tubers. According to Sanoussi et al. (2016) from their study on orange-fleshed sweet potato fresh sample with different cultivars, lower dry matter content might

present higher carotenoids content. Chinedum Ogbonnaya Eleazu (2015) dry matter content can be related to good cooking qualities and extended storage lives.

4.1.2.2 Moisture Content

According to Doymaz (2012), the moisture content and drying rate decrease continuously with drying time and this shows the diffusion in dominant physical mechanism governing moisture movement in the samples. Based on Table 4, tuber powder has the lowest moisture content (7.12%) and show no significant difference ($p < 0.05$) with leaves (7.18%) and stems (7.70%). As for peels, it has a slightly higher moisture content of 8.83% (significant at $p < 0.05$) to the other parts of sweet potato. The variation of the moisture content of the powders in this study is might due to the differences sample preparation (e.g. thickness of the sample during the drying process) as all the and the drying parameters (temperature, duration, etc.) were fixed for all the samples. Agbeven (2012) reported the moisture content of dried sweet potato tubers in chips form range from 8.50% to 9.88%. The report also mentioned that the products of sweet potato with the lowest moisture content had the highest percentage of protein and fiber content and also lower ash content.

4.1.2.3 Crude Protein Content

Crude protein is a measurement to determine the amount of protein in a material. Based on the findings in Table 4, the crude protein content of leaves, stems, tubers and peels were varied from 5.08% to 29.76%. The lowest value was found in stems (5.08%) and the highest value was found in leaves (29.76%). This result shows that the leaves are highly significant at $p < 0.05$ from the other parts of sweet potato. Besides, there are also have significant difference among tubers (7.40%) and peels (6.52%). According to Zainuddin (2015), crude protein is very different across the feed,

a higher level is usually associated with higher quality. The high crude protein content in the leaves in this study in agreement with other studies including Sun et al. (2014). They reported crude protein in leaves of sweet potato ranging from 16 to 31 g per 100 g of dried weight. Hence, the potential of using the leaves part of sweet potato for food application such as dishes or animal feed is really wide by considering its high protein content. The importance of appropriate available energy supply in a balanced diet for efficient protein use by livestock was stressed, high energy to protein ratio being needed to optimize the use of the protein (Fao.org, 2019). Different protein requirements for different species and the effects of age and growth stage of animals (Fao.org, 2019). Usually, young growing animals have greater requirements for protein than older animals. So, more energy is needed for the maintenance of the bigger body and also to support an increasing proportion of fat deposition in the body (Fao.org, 2019). As for growing cattle, increase in protein retention can also be observed with the increase in live weight from 176 up to 275 to 325 kg and then protein retention decreases corresponds to the maximum daily protein retention approximately about 200g/day (Centre & Zootechniques, 1984). Ellenberger et al. (1950) have analyzed chemically the ingesta-free bodies of different ages and weights of Holstein's calves and concluded that the percentage of protein in the body remains relatively constant from birth to maturity approximately 19% protein at birth and 18% protein at maturity. The significance of protein influences on the immune system, as antigenic factors and anti-nutrition agents, was also stressed, in addition to animal nutrition effects (Fao.org, 2019). According to Willis (2003), soybean meal was universally accepted as the most important protein ingredient in animal diets with the amount of 48% crude protein. Leaves of sweet potato plant have potential to be the replacer for soybean due to the highest amount of crude protein based on the result obtained and sweet potato plant especially leaves were locally available and considered as cheap. Besides, sweet potato leaves were also considered as waste and were discarded during the processing. Converting

this underutilized part to produce by-product will give some economic benefits to the sweet potato producer while at the same time avoiding some environmental issue.

4.1.2.4 Crude Fat Content

Crude fat is an estimate of the total fat content of feed and includes triglycerides as well as waxes, terpenes, steroids, pigments, alcohols, esters, aldehydes and other lipids (Zainuddin, 2015). From Table 4, the fat contents for leaves, stems, tubers and peels varied from 0.69 % to 4.58 %. The highest fat content was found in the sweet potato stems (4.58%) followed by leaves (4.41%). However, the result shows no significant different ($p < 0.05$) between both of them compare to the tubers and peels. The fat content in the tubers is the lowest (0.69%) while peels have 1.40% fat content. According to Ishida et al. (2000), the average crude fat content of leaves (3.69 g/100 g DW; 0.46 g/100 g FW) was higher than sweet potato tubers (0.33 g/100 g FW) and sweet potato stems (0.53 g/100 g FW). Fat is related in the insulation of body organs and in the maintenance of body temperature and cell function. Moreover, fats are sources of omega-3 and omega-6 fatty acids as well as the requirement for digestion, absorption and vitamin A, D, E, K transportation medium (Sun et al., 2014). With these benefits, the fat content in the sweet potato plant can be utilized to develop food production including animal feed.

4.1.2.5 Crude Fiber Content

Crude fiber is carbohydrates that are not digestible by mammalian enzymes but that can be digested by rumen microorganisms. In Table 4, the result obtained for crude fiber in leaves, stems, tubers and peels varied from 8.33% to 16.34%. Each of different parts of sweet potato showed a

significant difference ($p < 0.05$), whereas the peels (16.34%) were highly significant to leaves (14.53%) followed by stems (10.92%) and then tubers (8.33%). However, in another study by Sun et al. (2014) showed that the fiber content varied among the sweet potato cultivars (9.15 to 14.26 g/100 g DW) which is slightly different but almost in the range. According to Sun et al. (2014) also, there are several factors contribute to varies in crude fiber content including genotype, maturity and nutritional composition. The demands for fiber content in the feed are growing. For monogastric animals such as pig, a proper proportioning of fiber fractions increases the utilization of the compounded feed. Meanwhile, for ruminants, fiber is an important part of the metabolism in the rumen. Fiber is a determining factor for the hydrolysis of all nutritional ingredients in the feed. Very high fiber levels would slow down the rate of digestion and limit dry matter intake, however, a certain amount of fiber is needed in order to stimulate rumen activity (Van Soest et al., 1991).

4.1.2.6 Ash Content

Ash is a residue that contains the inorganic mineral element of a feed sample and is determined in a laboratory by burning the sample at a high temperature to remove the organic matter and then weigh the residue. From Table 4, the ash content for leaves, stems, tubers and peels varied from 4.02 ± 0.02% to 11.80 ± 0.02%. Each of different parts of sweet potato showed a significant difference ($p < 0.05$), whereas the stems (11.80 ± 0.02%) were highly significant to peels (11.67 ± 0.04%) followed by leaves (9.93 ± 0.01%) and then tubers (4.02 ± 0.02%). Based on the finding from Abubakar et al. (2010), the leaves of sweet potato has higher ash content compared to other food samples such as mashed, porridge, boiled and fried sweet potato ranged from 1.13 to 8.83g% which is near the value of ash content in leaves for this study. (Ukom & Ojimelukwe, 2009)

reported that high ash content indicates that the cultivars are rich in some mineral salt. The analysis of ash content in foods is simply the burning away of organic content and also leaving inorganic minerals which help to determine the amount and type of minerals in food (Animals.mom.me, 2019). This is important because the amount of minerals can determine the physiochemical properties of foods, as well as retard the growth of microorganisms (Animals.mom.me, 2019). Thus, for food production, low ash content is suggested but the certain amount of ash is still needed especially for animals because ash helps in controlling urinary tract problems in a cat (Animals.mom.me, 2019).

4.1.2.7 Carbohydrate Content

Carbohydrate content is referred to the subtraction of hundred percent of content subtracted with the other proximate composition including moisture content, crude protein, crude fiber, crude fat and ash. Plant carbohydrates might be conveniently classified as structural or cell wall carbohydrates and also non-structural or cell contents carbohydrates. The structural carbohydrates are dominated by hemicellulose, cellulose and these polymers form the basis of fiber in all plant tissue (Zainuddin, 2015). From Table 4, the result of carbohydrate content obtained was varied from 34.18% to 72.43%. The tubers (72.43%) showed the highest significant difference at $p < 0.05$ followed by stems (59.92%), peels (55.24%) and the lowest carbohydrate was leaves (34.18%). From a study by Sanoussi et al.c (2016), carbohydrate represented in higher quantities (14.86% to 38.92%) for the ten selected sweet potato cultivars indicating that they are a good source of energy. Sc et al. (1981) stated in their study, food with carbohydrates that break down quickly during digestion and release glucose into the bloodstream tend to have a high glycemic index and foods with carbohydrates that break down more slowly, releasing glucose more gradually into the

bloodstream, tend to have a low glycemic index. Thus, it was clear that high carbohydrate content in tuber is very good for food production especially flour. However, carbohydrate content in stems and leaves also were in appreciable amounts, hence they can be a supplement energy source in animal feed.

4.2 Flowability Analysis of Potential Technical-grade Powders of Sweet Potato Plant

Based on the findings in Section 4.1, the sweet potato plant parts have been proven to have high potential to be applied as animal feed. The parts can be commercialized either as animal feed in a palate shape as they are or marketed as technical grade powder to be mixed with other ingredients in the animal feed formulation. In order to explore the potential of marketing the sweet potato plant parts powder as technical grade animal feed powder, some investigation on the powder flowability properties have been performed and presented in this section. Flowability of powders is an important property because it will affect the behavior of the powders during processing, handling and storage. The caking test, cohesion test and powder flow speed dependency test (PFSD test) are presented in this section as an option or guidance to be used for pellet production and also for other food applications.

Table 5: Flow characteristic properties of different parts of sweet potato powders.

Parameter	Leaves	Stems	Tubers	Peels
Cohesion index	2.9 ± 0.07^{b}	1.63 ± 0.03^{d}	3.01 ± 0.05^{a}	2.1 ± 0.07^{c}
Flow stability	0.92 ± 0.01^{ab}	0.95 ± 0.01^{a}	1.01 ± 0.06^{ab}	0.86 ± 0.10^{b}
Cohesion coefficient 50 mm/s	488.09 ± 23.56^{b}	495.34 ± 4.96^{b}	717.08 ± 69.52^{a}	204.36 ± 6.71^{a}
Cake strength (g.mm)	8275.04	2272.25	21336.52	9336.97
Mean cake strength (g)	344.82	307.25	853.85	577.27

*Means (± SD) with the different letters are significantly different at $p > 0.05$ for each row

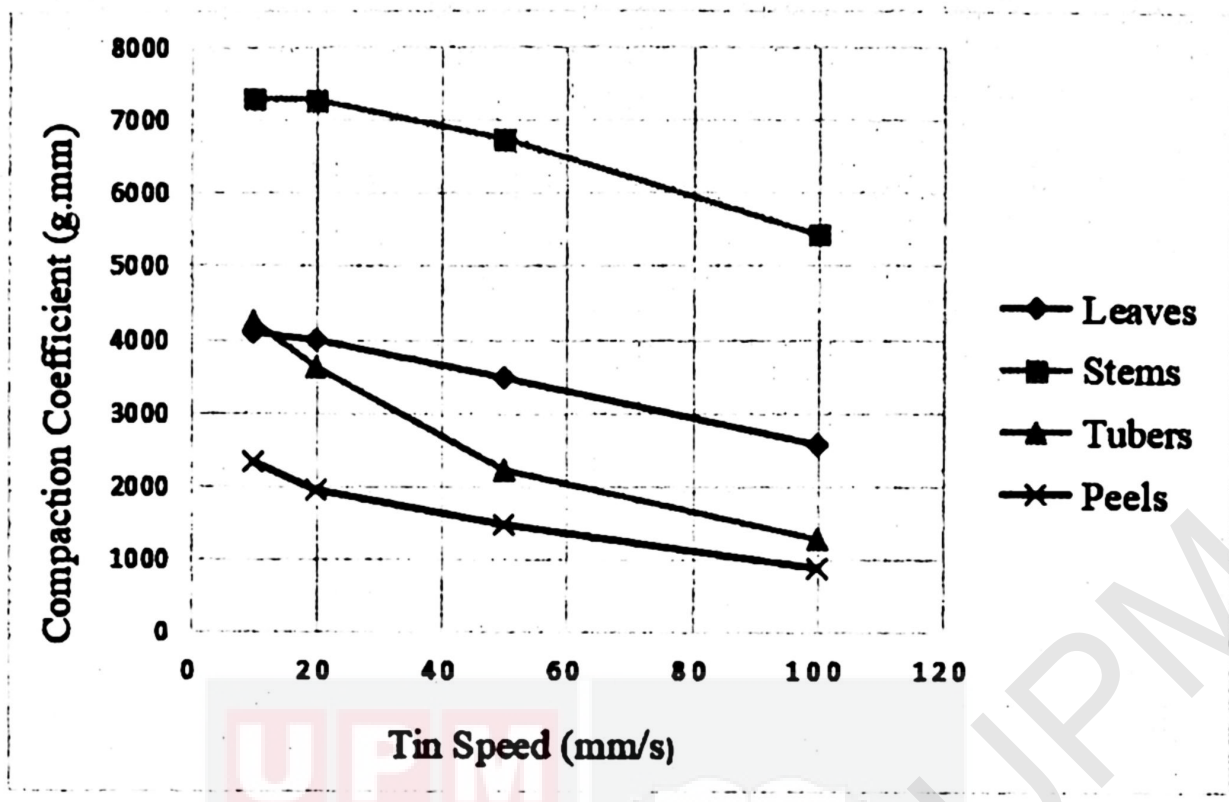


Figure 27: Tin Speed versus compaction coefficient of different parts of sweet potato powders.

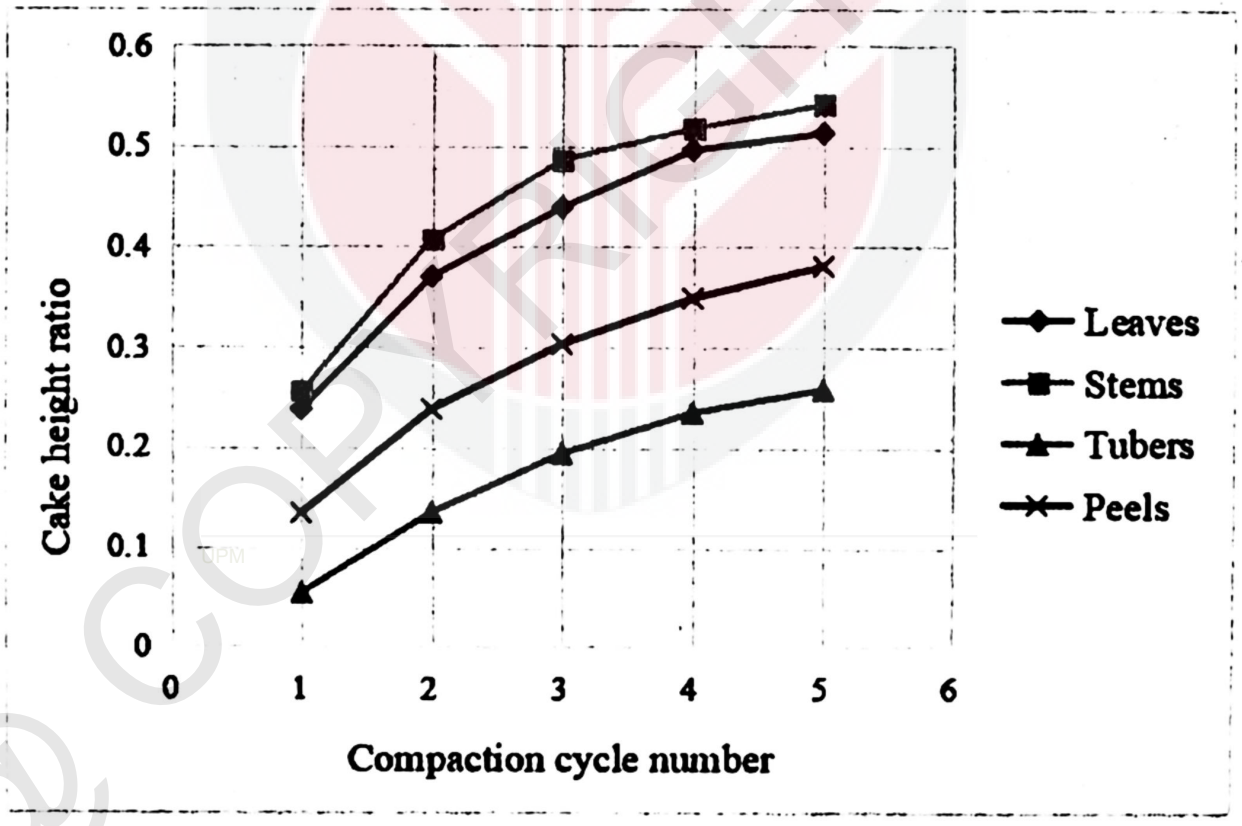


Figure 28: Caking height ratio versus compaction cycle number of different parts of sweet potato powders.

Table 5 shows the tabulation data for the flow characteristics of powders from different parts of the sweet potato plant. Based on the finding, the cohesion index for leaves, stems, tubers and peels powders were significantly different ranged 1.63 to 3.01. Tubers powders have the

highest cohesion index of 3.01, followed by leaves, peels and stems respectively. However, all samples were categorized as free-flowing powders with cohesion index below 11. This may be due to the small particle size of the powders that have been sieved at 250 μm during the sample preparation stage. The smaller the particle size of the powder, the more cohesive it is and the ability to flow is becoming more difficult. The flowability reduction for smaller particle sizes is due to the increase of surface area per unit mass of the powders. More surface area or surface contacts lead to high resist flow resistance. Meanwhile, all the samples were considered as stable powders since the flow stability values were closed to 1. Flow stability index near to 1 indicates that the powders will not easily change. Figure 27 shows tin speed versus compaction coefficient of different parts of sweet potato powders. Stem powder has the highest compaction coefficient followed by leaves, tuber and peels powder respectively. Based on the finding, the compaction coefficient of all samples decreased at high tin speed. This analyses that as the flow speed increases, the powders become freer to flow. The smaller the particles, the freer the powder to flow. Another analysis is caking. Caking is a phenomenon where the powders of food are transformed into a sticky unwanted material that can cause deterioration in powders quality and functionality. Cake strength can be affected by some factors such as particle to particle interactions, moisture content and packing efficiency (Benkovic and Bauman, 2009). The tuber powder had the highest cake strength of 21336.52 g.mm and mean cake strength of 853.85 g compared to leaves, stem and skin powder as shown in Table 5. Figure 28 illustrates the cake height ratio of all the powders. From the finding, the cake height ratio increased as the number of compaction cycle increased. High cake ratio describes a higher tendency for the powders to cake, which related to having high mean cake strength and high cake. Hence, the result indicates that all the samples have a high tendency to cake. This finding is important especially for food production where the results

might be applied as technical grading of powders to be standardized as food formulation or ingredients for living consumption or used this formulation to produce animal feed pellets.

4.3 Physical Properties Analyses of Sweet Potato Leaves and Stems (SPLS) Pellets

This section further explores the potentials of producing animal feed pallets using parts from a sweet potato plant. Based on the results in Section 4.1 on the physicochemical properties, it can be observed that the stems and leaves have high protein and fat content, hence, these parts were further used for the investigation of the pallet production. In addition, both parts were considered as waste in the sweet potato processing lines, hence the utilization of both parts for the pallet production will offer some economic advantages. By considering these parts were mixed up together during the real processing lines, not in separate portions, the pallets produced in this study were formulated from a same ratio of the stems and leaves, as to represent the real waste source available in the industry. Compaction process was chosen for the pallet production at different moisture contents (40-60%) and all the produced pallets were labeled as the Sweet Potato Leaves and Stems (SPLS) pellets. Physical properties of the SPLS pallets such as friability, bulk density, true density, porosity and tensile strength are presented and discussed in this section.

4.3.1 Friability of Sweet Potato Leaves and Stems (SPLS) Pellets

From Figure 29, the effect of moisture content on the friability of SPLS pellets produced by the compaction process varied from 0.30 % to 2.31%. Friability can be defined as the tendency of the pellets to form dust or to break off when subjected to destructive forces. It is a measure of how resistant the pellets to breakage and abrasion (Rosentrater, 2007). The ability of compressed pellets

is measured to avoid fracture and breaking apart during handling and transportation (Zainuddin, 2015).

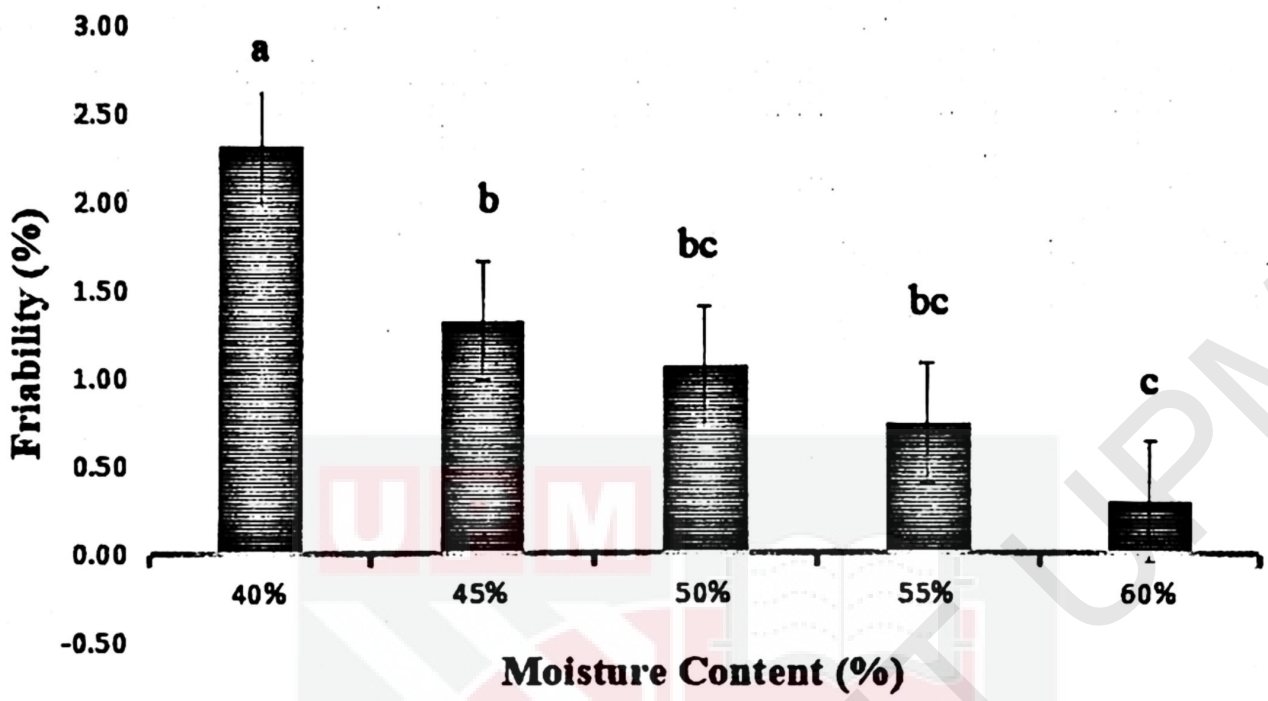


Figure 29: Effect of moisture content on the friability of pellets (%).

Based on the values, all pellets that have different moisture content showed an acceptable level of friability value, which below 5% of fines. The previous study by Karunanithy et al. (2012), suggested that fines up to 5% by weight would be an acceptable level, but greater than 5% would reduce storage capacity and create problems in flow characteristics. The low friability from compaction process indicates that the pellets were able to withstand the shear forces when subjected to mechanical attrition or shock (Zainuddin, 2015). Based on Figure 29, it can be observed that the lowest friability was 60% moisture content, followed by 55%, 50%, 45% and the highest friability, 40% respectively. Friability is depending on various factors such as moisture content, pressure and heating temperature (Zainuddin, 2015). The results can be analyzed that there is significant value ($p > 0.05$) increase in the friability percentage from the increase of moisture content 40% to 60%. Thus, the pellets from compaction process with 60% of moisture content

were found to have the optimum condition to produce pellets since the friability test resulted that the friability percentage was the lowest compared to the others.

4.3.2 True Density of Sweet Potato Leaves and Stems (SPLS) Pellets

True density is a crucial material property in order to get an accurate characterization of the mechanical properties of the powder and it also measures the average density of a volume of the powder in a specific medium usually air. From Figure 30, the true density of the pellets for moisture content 40% to 60% ranged between 1447.10 kg/m^3 to 1481.83 kg/m^3. From Figure 30 also showed the effect of moisture content on the true density, observed that there is decreasing of true density with increasing of moisture content except at 60% moisture content, maybe due to different mass used during the experiment but overall, the decreasing pattern of the chart was obtained. The results of this experiment exhibited the same trend as obtained by Zainuddin (2015), stated that the true density of compacted pellet and also extruded pellet shows a significant decrease at $p < 0.05$ with increasing moisture content. Same goes to Barnwal et al. (2011), found out that the true density of maize powder decreased with increasing moisture content. The density depended on the type of feedstock, process variables and also machines (Kaliyan and Morey, 2009). Thus, the result showed the decreased of true density as the moisture content increased and also these true density values can be used to determine the percentage of porosity.

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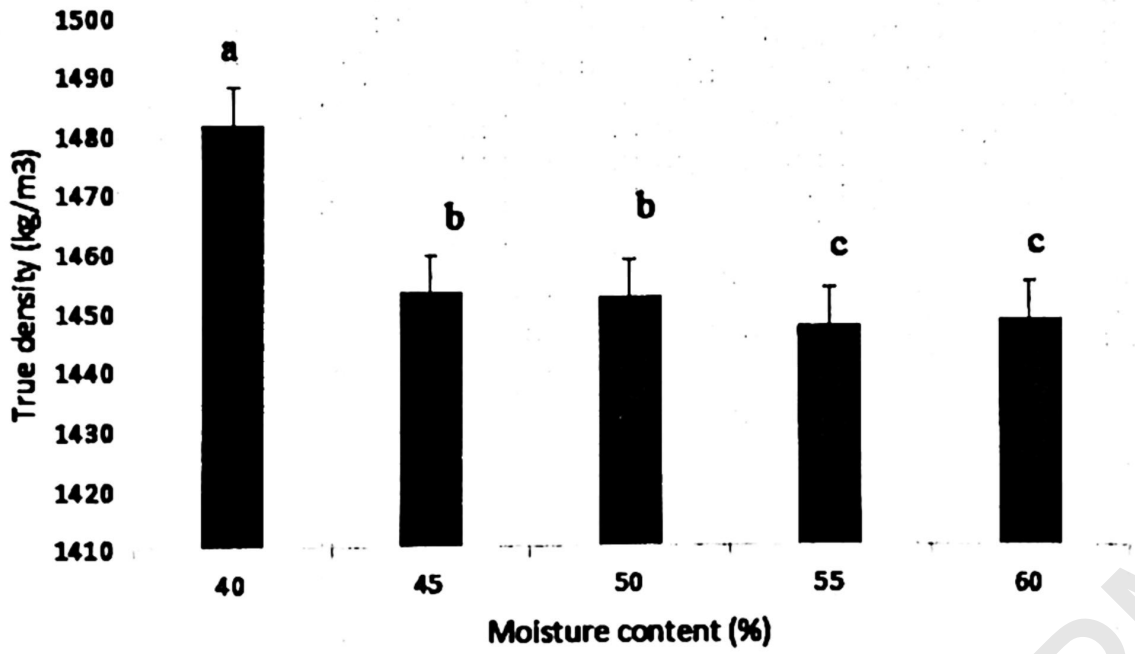


Figure 30: Effect of moisture content on the true density.

4.3.3 Bulk Density of Sweet Potato Leaves and Stems (SPLS) Pellets

Bulk density can be one of the fundamental factors in the design and operation of loading vessels, such as tanks, bins, road tankers and also railway goods wagons (Rosentrater, 2006). Bulk density plays an important role in transport and storage efficiency as well as provide a strong influence in the form of transport equipment, storage and conversion process (Karunanithy et al., 2012). Figure 31 showed the result for the effect of moisture content on bulk density. The bulk density of the pellets for 40% to 60% moisture content were 674.5 kg/m^3, 750 kg/m^3, 699.75 kg/m^3, 766 kg/m^3 and 629.5 kg/m^3 respectively. The lowest bulk density resulted from 60% moisture content and the highest value of bulk density was in 55% moisture content. From Figure 31, it can be seen generally that that bulk density was decreased with increased moisture content. However, it was different from Zainuddin (2015) study, where the bulk density for compacted pellets have a significant difference with the increased of bulk density while for the bulk density of the extruded pellets was found to be same as this study, which agreed that the bulk density decreased with the increase of moisture content. Generally, the bulk density of the pellets increased 2 to 13 times

depending upon the feedstock, densification equipment, and process conditions (Karuranithy et al., 2012). Thus, the pellets from sweet potato stems and leaves show a higher bulk density compared to the others such as corn stover (131-158 kg/m^3) and switch grass (115-182 kg/m^3) pellets as studied by Mani et al. (2015). These higher bulk density can lead to reducing transportation costs and easier handling with proper storage management.

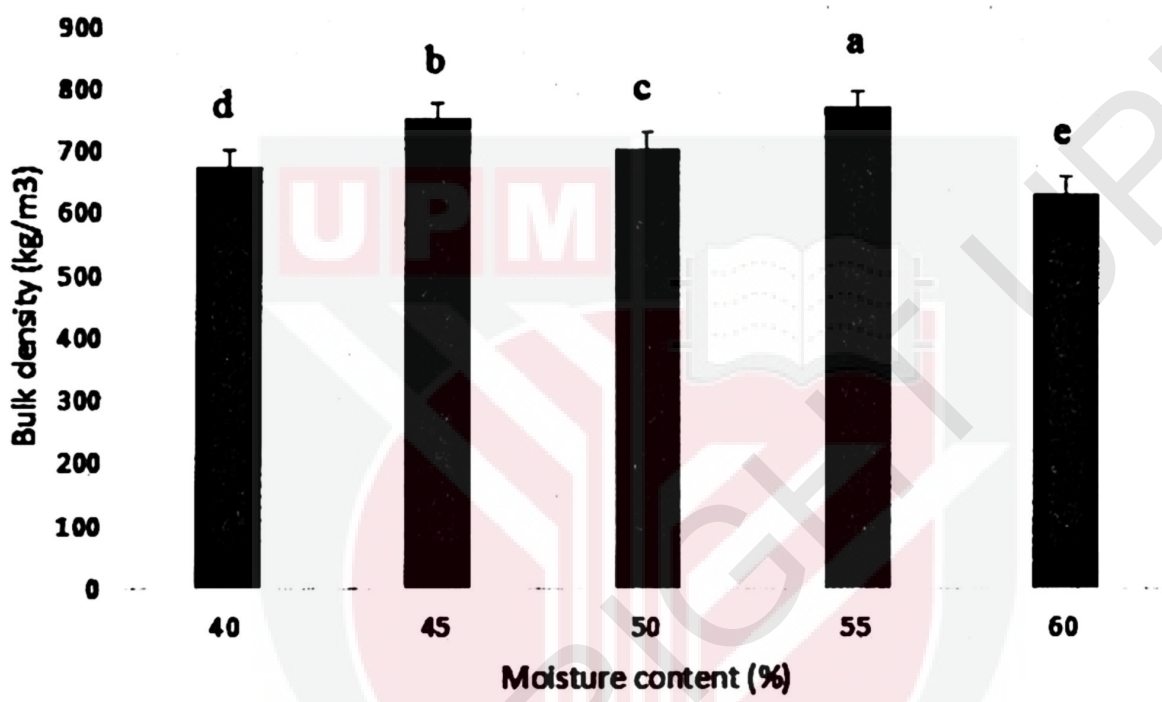


Figure 31: Effect of moisture content on the bulk density.

4.3.4 Porosity of Sweet Potato Leaves and Stems (SPLS) Pellets

Porosity can be defined as the fraction of volume of voids over the total volume and void spaces in a material, generally lies between 0-1. According to the British Standard Institute (IBS), porosity is the ratio of open pores and the voids to the envelope volume. Meanwhile, according to American Society for Testing and Materials (ASTM), porosity is a ratio usually described as a percentage of the total volume of voids of a given porous medium to the total volume of the porous medium (Webb, 2001). Based on Figure 32, pellet with a moisture content of 60% yielded the highest

porosity value which is 56.51%, and the lowest porosity was exhibited by a pellet of 55% moisture content at value 47.07%. However, the result of this study was different from Zainuddin (2015) study stated that the porosity decreased with the increased in moisture content. From the result shown in Figure 32, the low porosity of the feedstock at 55% moisture content indicated that the void space was less and the feedstock within the given volume would result in low compressibility. Other than that, the high porosity of the feedstock at moisture content 60% indicated that the sample was compacted, thus resulting in higher compressibility. This result was similar to Mahapatra et al. (2010) study that obtained the increased of porosity with an increase in the moisture content. Kaliyan and Morey (2009b) claimed that the increasing of porosity as well as moisture content because of the different types of feedstock, process variables and machines used. Thus, 60% of moisture content was considered as the optimum condition for the pellets from stem and leaves of sweet potato due to the higher percentage of porosity and lower compaction needed compared to other percentages.

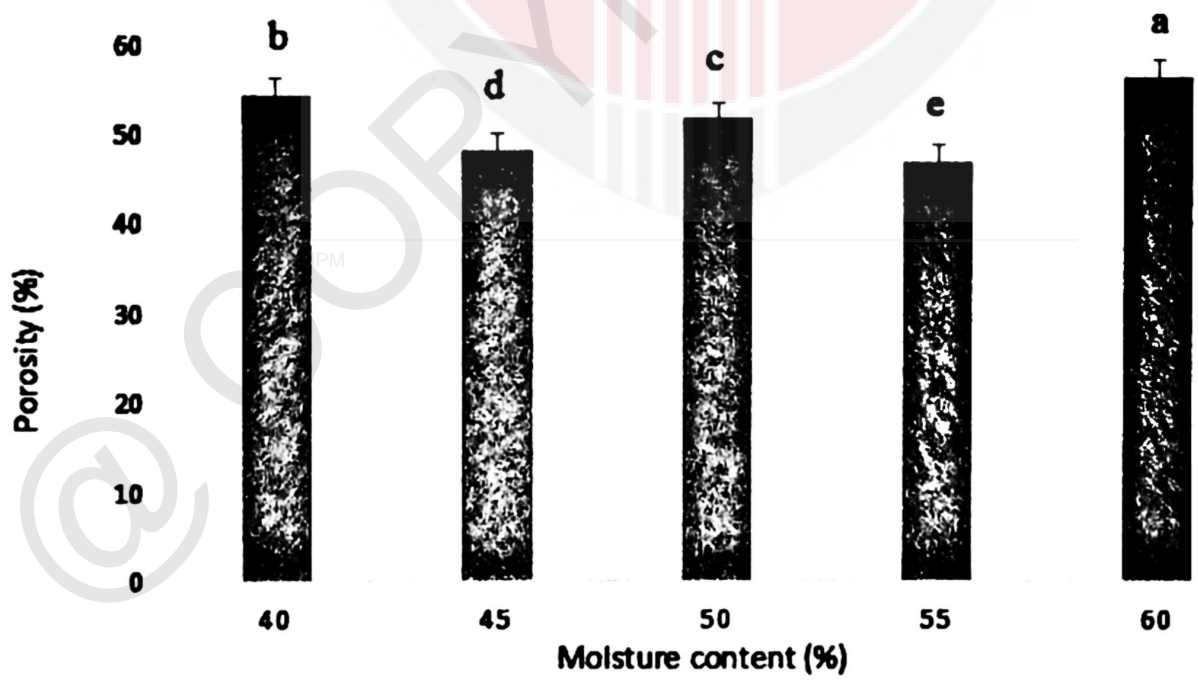


Figure 32: Effect of moisture content on the porosity.

4.3.5 Tensile Strength of Sweet Potato Leaves and Stems (SPLS) Pellets

Compressive forces can be obtained by the tensile strength of the pellets. The aim of doing tensile strength is to investigate the relationship between the moisture content during pelletizing while keeping the quality of the pellets (Zainuddin, 2015). According to Zainuddin (2015) also, a higher level of moisture can increase the tensile strength of the pellets. Compressive resistance is the maximum crushing load a pellet can endure before it started to crack of fracture. When the increasing load is applied to a pellet at a continuously constant rate, it tends to crack or break or considered as fail. All the compression work values increased significantly at $p > 0.05$ for the increased moisture content (40%-60%). The moisture content at 60% exhibited the highest work of compression which is 303.79 kg.s, while the lowest work of compression goes to 40% moisture content which is 91.29 kg.s as shown in Figure 33. It can be observed that as the moisture content increased, the work of compression also increased. The highest work of compression was strong and did not easily tend to crack or break. Meanwhile, the lowest work of compression showed that it was easy to fracture and maybe has lower tensile strength compared to the others.

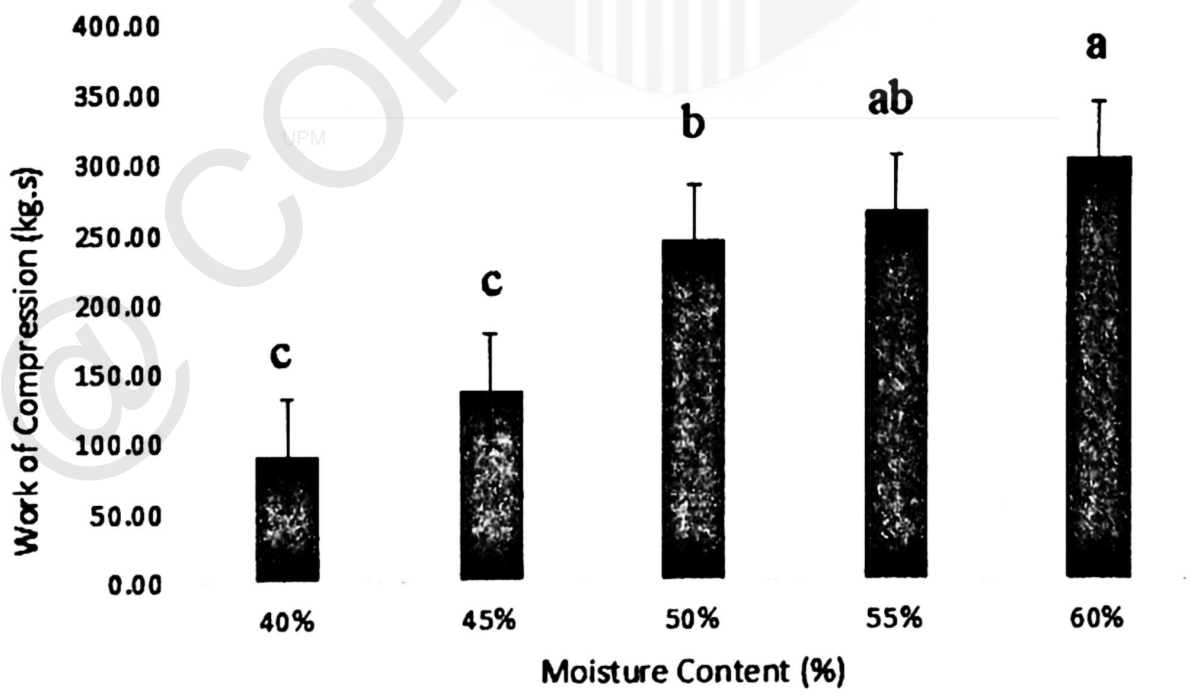


Figure 33: Effect of moisture content on the work of compression.

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Few studies have shown that the strength of the compacted products increases with increasing moisture content until optimum strength is obtained. As for example, the nearest research that similar to this study, which is by Zainuddin (2015) stated that all the tensile strength values increased significantly for both extruded and compacted pellets processed from pineapple waste (leaves and stems). Besides, high moisture content basically 19% to 23% wet basis has been found can reduce the resilience and flexibility characteristics of fibrous biomass materials such as sawdust, bark and hay (Mohsenin and Zaske, 1976) since sweet potato leaves and stems also contain fibers in a high certain amount. Thus, in this experiment, 60% of moisture content was found to be the optimum condition to produce strong and densified pellets. While the other moisture content 40% to 55% were considered as low tensile strength and low work of compression due to the high fibers that are unable to absorb moisture properly. This condition causes the forming of a "Chrismas tree" shape of pellets that reduces the pellet durability and strength same case as stated by Winowiski (1995) where this condition causes the center of the pellet to extrude faster than the exterior thus forming that undesired shape.

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4.4 Summary

This chapter shows the results of the experiments that have been described in the previous chapter. The result of the physicochemical properties of leaves, stems, tubers and peels powders which are TGA and proximate analysis were presented followed by the discussion in Section 4.1. Based on the findings, this study explores the potential of commercializing the sweet potato plant parts as an animal feed via 2 options; 1) as technical-grade powder marketed to the animal feed producer; or 2) as animal feed pallets formulated solely from sweet potato plant. Section 4.2 discussed the flowability analysis of potentially technical-grade powders of the sweet potato plant. While Section 4.3 explored the physical properties of SPLS pallets at different moisture content.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The first objective of the study was to determine physicochemical properties of different parts of sweet potato plant including stems, leaves, tubers and peels focus on Anggun 1 variety. The lignocellulose content (cellulose, hemicellulose and lignin) and proximate analysis (dry matter, moisture content, protein, fiber, fat, ash, and carbohydrate) of leaves, stems, tubers and peels powders were studied. Based on the results obtained, it can be concluded that stem and leaves of sweet potato contain lower cellulose, hemicellulose and lignin than tubers and peels. Meanwhile, the results from proximate analysis indicated that leaves contained the highest crude protein content while stems contained the highest fat and an appreciable amount of ash and crude fiber content and also other nutrients for both parts of the sweet potato plant. Thus, the conversion into animal feed can be suggested so that the animals can obtain all the required essential nutrients from the sweet potato leaves and stems.

The second objective was to develop the pelleting process of the stems and leaves of sweet potato using the compaction process. The physical properties of the powders of leaves, stems, tubers and peels of sweet potato plant and also in pellets form of stem and leaves (ratio 1:1) were examined with regard to the parameters of different moisture content (40%, 45%, 50%, 55%, 60%). As for the flowability, the powder of sweet potato stem, leaves, tuber and skin are classified as stable powders and free-flowing. They were also becoming more likely to caking. The results of the flowability analysis can be as an option or guidance to be used for pellet production and also for other food applications. Next, the properties of different moisture content level, including

friability, true density, bulk density, and porosity were determined. It can be concluded from the analysis that a moisture content range of 40% to 60% showed significant difference effect on the physical characteristics of the pellets. Based on the findings, the best moisture content formulation for the production of pellets in this study is at 60% moisture content since it exhibited the lowest friability (0.30 ± 0.16%), the lowest bulk density (629.5 kg/m^3), the highest porosity (56.51%) and the highest work of compression (303.79 ± 24.78 kg.s) as well as tensile strength compared to other moisture contents formulation of the SPLS pellets. Pelleting of sweet potato stems and leaves could enhance the potential utilization for the natural protein and fiber source for animals especially herbivores. Besides, pelleting also gives benefits of increasing the flexibility for feeding. Thus, the compaction process of different parts of sweet potato plant especially stems and leaves into pellets could reduce costs, increase incomes as well as reduce problems with handling, transportation and also storage.

Finally, it can be concluded that the pellets produced through the compaction process can be commercially produced and used as potential food development especially for animal feed production.

5.2 Recommendations

As for recommendations and for future research, the analysis for the determination of mineral element content can be done to determine more benefits of sweet potato plants that can be developed for many food applications. As for flowability analysis, it can be suggested to perform more research to determine the technical grades especially for different parts of sweet potato powder for another application or potential food development as living consumptions. Advanced technologies are needed in terms of equipment to enable a high level of quality and also

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commercialization for pellet production such as palletizing using extruder, testing of the pallet on a real animal model, etc. Other processing parameters such as chemical properties of pellets could be considered for the production of quality pellets. Thus, future studies are needed for the improvement of potential food development for different parts of sweet potato including leaves, stems, tubers and peels.

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APPENDICES

Table 6: Tabulation result for the effect of moisture content on the friability of pellets (%).

Moisture Content (%)	Friability (%)
40%	2.31 ± 0.75^{a}
45%	1.32 ± 0.76^{b}
50%	1.06 ± 0.24^{bc}
55%	0.73 ± 0.30^{bc}
60%	0.30 ± 0.16^{c}

Table 7: Tabulation result for the effect of moisture content on true density.

Moisture Content (%)	True Density (kg/m^3)
40	1481.83 ± 0.56^{a}
45	1453.23 ± 0.74^{b}
50	1452.35 ± 0.37^{b}
55	1447.10 ± 0.39^{c}
60	1447.68 ± 6.46^{c}

Table 8: Tabulation result for the effect of moisture content on bulk density.

Moisture Content (%)	Bulk Density (kg/m^3)
40	674.50 ± 6.40^{d}
45	750.00 ± 8.16^{b}
50	699.75 ± 8.18^{c}
55	766.00 ± 13.56^{a}
60	629.50 ± 8.23^{e}

Table 9: Tabulation result for the effect of moisture content on porosity.

Moisture Content (%)	Porosity (%)
40	54.48 ± 0.44^{b}
45	48.39 ± 0.59^{d}
50	51.82 ± 0.57^{c}
55	47.07 ± 0.92^{e}
60	56.51 ± 0.69^{a}

Table 10: Tabulation result for the effect of moisture content on the work of compression.

Moisture Content (%)	Compression work (kg.s)
40	91.29 ± 20.70^{c}
45	138.03 ± 21.78^{c}
50	245.05 ± 41.55^{b}
55	266.85 ± 8.92^{ab}
60	303.79 ± 24.78^{a}

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