INDONESIAN KONJAC:
ITS BENEFITS IN INDUSTRY AND FOOD SECURITY

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FOREWORD

Indonesian Konjak (*Amorphophallus muelleri* Blume) is originally a West African wild plant. Since WWII, it also grows in Asia such as (in alphabetical order) Japan, Korea, Thailand, and Southeast Asia region. Since the era of Japan occupation, Indonesian people become familiar with this plant. It is a potential raw material in cosmetics industry and food industry. Its compound called glucomannan is of high economic value.

This book is very important not only for academicians and researchers but also for industries. It describes the morphological characteristics of IK as well as cultivation techniques, post-harvest handling, glucomannan content in the IK tuber, and water sorption isotherm (WSI) in IK chips and flour. In practice, WSI is usually used as an indicator to make sure that the chips and flour are safety to be stored.

To improve the quality if IK chips, in this book the readers will find a proposed drying method and a soaking method before drying process. Drying process is applied at certain salt by desorption process while soaking process is in natrium metabisulphite salt. Besides that, the readers can also find how WSI can be used to determinate the drying limit. And, to get the final product from IK, the technique used by the authors is by studying and calculating the WSI that connects the water content of the material through oven drying and desorption process using certain salts. With this technique a mathematical relationship can be found between oven drying and WSI to see Primarily Bound Water, Secondary Bound Water, and Tertiary Bound Water. Furthermore, to produce a product that is completely safe and free from microorganism attack, the authors use a particular humidity and storage room temperature determined based on a mathematical relation between drying and WSI. The final product form of IK is a durable chips or powder. To have such products, certain environmental conditions (pH and storage room temperature) are needed. These conditions are determined in accordance with the mathematical formula that has been resulted of previous IK studies.

In this book the readers will be guided step-by-step to master the techniques presented therein. Once the steps have been followed properly and correctly, the readers will get the desired product as expected. It is recommended that the readers understand the following statistical analyses; correlation analysis, regression analysis, and statistical descriptive analysis such as mean, variance, numerical summary, scatter plot, etc. The novelty of this book lies in the process which transforms IK the wild plant that of no use into industrial stuff of higher quality. It describes the quality improvement technique of chips using (i) soaking process in natrium metabisulphite, (ii) drying technique via desorption by certain salt in WSI process, and (iii) determining technique of water content in chip and flour using mathematical relation between drying rate and water fraction. It is hoped that this book can guide the readers who want to take advantage of IK that has many benefits and high economic value.

This book is indeed a useful literature for academicians and professionals as well as researchers, students and people who appreciate ornamental plants. The IK beautiful flower has artistic value and unique so that it can attract international tourists to see it in Indonesia (e.g., Bogor Botanical Garden). The authors' contribution in bringing to light a special aspect of IK is indeed laudable.

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PREFACE

Indonesian Konjac (*Amorphophallus muelleri* Blume), or IK in brief, is an herbaceous member of araceae family in monaceous class. In Indonesia it can grow in the house yard, plantation area and forest under the stands of teak, bamboo, and some other trees. This plant originating from West Africa had spread eastward through the Andaman islands of India, to Asia. In Southeast Asia it can be found in Cambodia, China, Indonesia, Japan, Korea, Laos, and Thailand. In Indonesia this plant grows in several islands such as Sumatra, Java, Bali, Kalimantan, Sulawesi, Madura, West Nusatenggara, and East Nusatenggara. It is a shade crop with 60% of sunlight and thus its habitat is characterized by loose soil at altitude between 100 to 1000 meters above sea level (masl) with pH between 6 and 7.

Morphologically, this plant has a single leaf, resembling hand fingers, with saplings forming a branching. At the base of the branching leaves, bulbils or tuber leaves grow bigger and bigger following the size of the plant. It has smooth green stems with white patches and produces underground round tubers of diameter between 25 to 30 cm. Generally, the color of the tubers is blackish-brown but depends on the type of soil where it grows.

The growth of IK has two types, namely vegetative growth and generative growth which alternate every year. In the rainy season IK experiences either vegetative growth which produces stems and leaves or generative growth which produces flowers, fruits, and seeds as plant propagation material. In the dry season the plant experiences dormancy period followed by the death of plant organs such as stems and leaves. However, during that period, the tuber organs still alive and survive in the beneath of soil. For its growth, IK requires environment condition such as loose soil and water flow or sanitation. And, since this plant cannot stand direct sunlight, it requires shade plants. Moreover, during growth period, the weeds around the base of the plant should be removed and, if it is planted during dry season, watering is recommended.

In order to produce high yield (17-20%), tubers harvesting should be done in the dry season around June – August. It is not recommended to harvest the tubers before June because it will produce low-yield (< 17%) and easily be damaged by microorganisms. After harvesting, the tubers should be handled carefully and, in general, post-harvest handling must be carried out. For example, once they were harvested, the tubers should immediately be dried in the sun to remove the soil.

IK has become a valuable economic commodity because it can be used in world food security program to substitute the traditional food. Besides that, its glucomannan content is widely used in various industries such as cosmetics and food industries. This compound belongs to a group of carbohydrates, composed of glucose and manosa compounds. It is a hydrocolloid polysaccharide compound composed of monosaccharide units of manosa and glucose with a molar ratio of 3:2. Its content in IK tubers is high about 40-70% and thus it is a very good stuff as an ingredient in food industry as well as medicine, cosmetics, and as microbial media.

As a wild plant, IK can be cultivated in tropical countries similar to Indonesia. It is not only economically valuable as an industrial material but it can also be used to substitute the traditional food in the framework of global food security. In addition, in terms of

glucomannan-based industry, to extract this compound from IK tubers, the process is quite simple; we can use wet extraction with the help of ethanol 96% and alpha amylase or dry extraction by blowing IK flour at certain mesh sizes (60 and 80 mesh). All techniques to lift up the value of IK are described in the book.

Have a nice journey!

Jakarta, November 10, 2019
The Authors,

Kisroh Dwiyono
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CHAPTER I. INTRODUCTION

1.1. Overview

Indonesian Konjak (*Amorphophallus muelleri* Blume), or IK in brief, is one of tuber plants belongs to Family Araceae, Class Monocotyledoneae which can grow well in tropical countries such as Japan, China, Thailand, Vietnam, Cambodia and Indonesia (Jansen et al., 1996; An et al., 2010). Under certain agroindustry processes, IK tubers will produce glucomannan; a hidrocolloid polysaccharides compound which has high economic value as it has many benefits. It can be used as the source to produce foods such as *konyaku* and *shirataki*. It is also to reduce obesity, anti-diabetes mellitus, reduce blood cholesterol, to form gel, thicken dirt or waste, emulsifier, solution stabilizer, to make crystal structure, anti-human immunodeficiency virus (anti-HIV) compound, and anti-blood clotting (Chua et al., 2012; Bo et al., 2013).

IK is widely planted on Indonesian forest gerenal company Ltd., (*Perhutani*-in Indonesia)-owned land under teak, mahogany and oak-like tree **(*sonobrits*)** stands. In order to get optimum growth, the plants require shade trees which can inhibit 50-60% of sunlight. IK can grow well at altitude up to 1000 masl, temperature between 25-35^{o}C and rainfall rate between 300-400 mm per month (Jansen et al., 1996). IK tubers are harvested at age of 2 years or more. The harvesting process is done during dry season between May to August. At this time the plants are entering dormancy period (Ohtsuki 1968). The cultivation of IK in Klangon Village (East Java) has been started since 1986 but the large-scale cultivation has being started in 2003 when the Joint-Community Forest Management Program. In Indonesia was officially taken place and farmers who cultivate the lands were organized into the so-called Forest Village Community Institutions under authority of Indonesian Forest Management Unit of Klangon Village is named with "*Pandan Asri*" belongs to authority of Sub-district of Saradan, Madiun which is one of 13 located in East Java (Santosa, 2003)

IK is one of the popular wild among Indonesian people since Japanese occupation during WWII. However, up to present, is is not yet cultivated intensively. This plant is a member of Araceae family in monocotyledonous class which produces glucomannan; a compound of high economic value. If it is produced in mass, it can increase non-oil-and-gas export as well as the strength of IDR in foreign exchange market, people's welfare, and the creation of employment.

The plant is originated from tropical West Africa. It then spreads out eastward through Andaman island in India to China, Indonesia, Japan, Myanmar, and Thailand. In Indonesia, it grows in Sumatera, Java, Madura, Bali and West Nusa Tenggara (Jansen et al., 1996). In this region, IK has several distinct local names such as *porang* and *ponang* (Java), *kruwu*, *lorkong*, *labing*, *subeg leres*, *subeg bali* (Madura), *acung*, *cocoan oray* (Sunda), and *badur* (West Nusa Tenggara). During its growth, IK undergoes two phases namely vegetative phase and generative phase. The vegetative phase starts when root and stem-and-leaves grow while the generative phase is the time period when the plant produces flowers, fruits and thus seeds.

During dry season, the plant dries out or dies except its tuber hidden beneath the soil. It is the time where the plant is entering the dormant period which last 5-6 months. Entering the rainy season, the plant grows again as vegetative phase or generative phases depending on the weight and age of the tuber. When IK tuber weight reaches 500-600 grams or more, and has reached two years old, then the growth will experience vegetative and generative phases. These two phases alternate each year.

In 1973, Kay (1973) has reported that the total number of *Amorphopallus* Sp species that still exist in the world was 90. Meanwhile, according to Hay et al. (1995), in 1995 there were 161 species. One year later, Jansen et al. (1996) estimated that total number is 170 species or more. In Indonesia, IK types that are commonly found are,

1. *A campanulatus* (*suweg*) sin.
2. *A. paeonifolius*,
3. *A. muelleri* blume (IK) sin.
4. *A. Blumei* (Scott) Engl. sin.
5. *A. oncophyllus* Prain, and
6. *A. variabilis* Bl (*walur*).

In Japan, there is one type that cannot be found in Indonesia and has been cultivated massively, i.e., *A. konjac* Koch or synonimously *A. rivieri* Dur.

Backer and van den Brink (1968) stated that the Herbarium Bogoriensis in Bogor, West Java, Indonesia, collected around 20 types of *Amorphophallus* spp from all over Indonesia, but only 8 types grow in Java Island. The Bogor Botanical Garden has successfully grown, as a living collection, 6 types of all the types found in Indonesian, including a type of corpse flower (*A. titanium*).

IK tubers contain glucomannan that have many benefits for human as they can be used as various basic materials for industries such as food, beverage, medication or pharmacy, cosmetics, paper, textile, film/celluloid, mining, microbiology, glue or adhesive,

and rubber. In food industry, Japanese people use glucomannan to make *konnyako* and *shirataki*; popular and highly favored dishes by the Japanese people. Meanwhile, in the Philippines, it is used for making beer or alcoholic drinks. A more interesting benefit of glucomannan is showed by pharmaceutical industry, cosmetics industry and paper industry. In the former, glucomannan is used as the material for binding tablets and medication for cholesterol and diabetes mellitus diseases. Meanwhile, in the cosmetics industry, glucomannan is used as the thickening agent for cream. In paper industry, it is used as the material for mixing pulp and settling water to produce a more flexible and solid paper. It can also be used as a substitute for starch powder to polish and strengthen celluloid materials in synthetic rubber industry.

In the present day, glucomannan has been exported in large quantity to various countries such as China, Hongkong, Japan, Myanmar, Singapore, South Korea, Taiwan, Thailand, the United States, and Europe. In what follows the IK botany, benefits, and cultivation methods will be discussed.

1.2. Systematics and morphological characteristics

The systematics of IK has been long studied by many scientists such as Lawrence (1955), Benson (1957), Jansen, et al. (1996) and many more. From the literature, we learn that in terms of systematics, IK has the following characteristics.

Division	: Spermatophyte
Subdivision	: Angiospermae
Class	: Monocotyledoneae
Order	: Arecales (Sphathiflorae)
Family	: Araceae
Subfamily	: Aroideae
Genus	: Amorphophallus
Species	: *Amorphophallus muelleri* Blume

Meanwhile, in terms of morphological characteristics, see Dwiyono (2004). IK has a petiole and leaves**.** The petiole is a pseudo stem round in shape, soft surface, green color (light green, green or dark green), and has greenish white spots. The shoot of IK grows from the tuber underground. The diameter of the stem (as measured 10 cm above

the ground) are respectively 5-10 mm (in the first growth period), 15-25 mm (second), and 25-50 mm (third). The leaves are light green to dark green in color with greenish white spots, elliptical or round in shape with veins, have 3-5 leaflets or leaf branch when young and up to 6 when adult.

The diameter of the leave is respectively 25-50 cm (in the first growth period), 40-75 cm (second), and 50-150 cm (third). On the upper axil grows a bulbil which is the place for storing food and the medium for reproduction, blackish brown in color, and round or oval in shape. Bulbil can also be found on the stem of each branch but relatively small in size. The size of bulbils is not the same depending on the age and size of the plant. A big bulbil may weigh 50 gram or more. The upper surface of the leaf is smooth and wavy, and the edge color is light purple to yellowish green while the midpart is whitish green depending on the shade level of the plant overhead. When they grow old approaching the dormant period the leaf color turns yellowish and dry.

1.3. Tuber

IK tuber (Figure 1.1) is classified under tuber cauligenum which is in general round in shape, and reddish yellow inside. IK tubers contain calcium oxalate gum that may cause itchy on human skin.

On the outer surface of the leaf (Figure 1.2) grow fiber roots and shoots. Each tuber has varied weight depending on the age and size of plant. On average, each tuber has a weight of 50-200 grams (in the first growth period), 200-1,350 grams (second), and 1,350-3,350 grams (third). If IK tubers are not harvested in the third period, in the fourth period they can reach the weight of 5-6 kg and have the decimeter of up to 30 cm. Each 100 gram of wet IK tubers contains the following compounds; water (80 g), protein (6.3 g), fat (0.2 g), carbohydrate (3.6 g), crude fiber (4 g), ash (4.3 g), calcium (50 mg), phosphor (21 mg), iron (0.7 mg), natrium (4.7 mg), potassium (100 mg), thiamine (0.05 mg), riboflavin (0.02 mg), niacin (1.6 mg), and vitamin C (6 mg).

Figure 1.1. IK tubers

Figure 1.2. IK three and leaf

1.4. Flower, fruit, and seed

IK flower, see Figure 1.3, is classified as inflorescence with spadix shape. It is hermaphrodite because the male and female flowers are in one plant and one stem. The IK flower structure consists of respectively from up to down appendage, stamen, pistil, brachtea, and pedicel (in the form of pseudo stem). Before blossoming, they physically resemble a trumpet, pink to purple in color and white spots throughout. The flowers

grow at the beginning of rainy season and reach maturity when dry season comes. The part of flower visible from outside is actually brachtea which resembles skin, relatively thick, and its lower surface is purplish green in color and white spots throughout. The upper surface is orange color with irregular white spots throughout.

(A) (B) (C)

Figure 1.3. IK flower at (A) Stadium 1 (bud), (B) Stadium 2 (blooming), (C) Fruits (unripe)

IK flowers are classified as inflorescence which forms an oval spadix. It is important to note that the spadix may produce different total fruits, see Figure 1.4, depending on the size of tuber planted and the size of flower produced. When the flowers are maturing or ripen, the brachtea will dry up and fall to the ground as seeds (Figure 1.5). It is also worth noting that IK flower entering the anthesis or blossoming period smell bad for 2 hours in the afternoon.

(A) (B) (C)

Figure 1.4. IK fruit (A) halfripe fruits, (B) ripe fruits, (C) loosen fruits

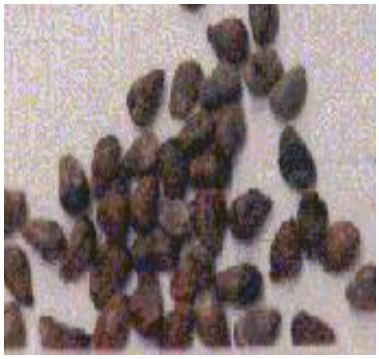

Figure 1.5. IK seeds

New fruits are blackish brown, then turn green, yellow and finally dark read. The number of fruits determines the total number of seeds. The more fruits created the more seeds produced. The fruit spadix produces between 100 to 450 fruits and each fruit contains 2-4 seeds. It needs 8-9 months for waiting the riped fruit from the time of the creation of young fruit.

1.5. Growing condition.

IK needs the following conditions for it to grow optimally; (i) loose soil containing humus with pH 6 - 7.5, (ii) shade plant that gives the light intensity of 50-60%, (iii) low up to highland at the height of 1,000 masl, (iv) rainfall of 1,000-1,500 mm per year, (v) air temperature of 26-30° C, and (vi) humidity of 60-80% .

1.6. Cultivation

The stages that must be taken into consideration in cultivating process are as follows.

1) Planting materials

The planting materials used in the cultivation of IK are small tubers or extracted seeds, bulbil or tubers growing in the leaf organ, and seeds. If extracted seeds and bulbil are used, it would be better to wait until the tubers grow shoots before planting. If it is in the form of seeds, it should be first nursed.

2) Soil preparation.

The soil for planting must be free from weed. And, the land or drainage, the shade plants and the holes for planting must be well prepared. The planting holes are prepared at varied distances depending on the size and age of the seeds. When small nursed seeds are used the planting holes distance should be 30 x 40 cm. Meanwhile, it should be 40 x 75 cm when nursery is applied to bulbil, and 50 x 75 or 50 x 100 cm or 100 x 100 cm when we use extracted seeds.

3) Calcification

The purpose of calcification is to increase the soil pH and reach the limit for the condition of IK growth, i.e., 6 - 7.5. This process should be followed by adding organic fertilizer or compost to improve the soil property in terms of physical as well as chemical and biological properties of the soil. These three properties interact one to another and then come up with best condition of soil (Sanchez, 1976). The total amount of calcium given is around 2 - 4 tons per hectare depending on the acidity level of the soil.

4) Planting

Planting should be done once the rainy season has been started when the solid has been damped and the planting holes distances have been prepared. This planting technique will ensure optimal production of Gibberellic acid (GA_3); a plant hormone which is widely used to stimulate seed germination by activating enzymes especially alpha-amylase. It hydrolyzes starch to sucrose and glucose in producing energy during seed germination (Dwiyono et al. 2019).

5) Maintenance and fertilizing

Maintenance is meant weeding and making sure that the shade plants are not too shady. Thus, it must be taken place at anytime. Meanwhile, fertilization must be carried out after the plant is 1 month old when the leaves and roots have perfectly developed.

There are two kinds of fertilizers that can be used namely inorganic fertilizer in the form N, P and K fertilizers, and organic fertilizer in the form of animal dung, humus and compost. IK growth needs fertilizer 40 kg N, 40 kg P, and 80 kg for each hectare.

Harvesting

Harvesting is performed when dry season comes and the plant has been dormant. Based on field experience, to get the highest yield, the plants should be harvested in the period of July – August during which the plants have reached their maximum age and entered the dormant period.

CHAPTER II. POSTHARVEST HANDLING

At farmer level, IK tuber postharvest handling begins with sorting the tubers based on size and defective or non-defective tubers. Then, it is followed by tubers cleaning through drying process to remove the peels using bamboo knife to clean up the tubers surface. This is normally done during dry season as it is difficult to get water. After that, chopping is done manually by using tubers chopper made from wood where the knife is placed horizontally as shown in Figure 2.1(B).

(A) (B)

Figure 2.1. Chopping the IK tubers manually (A) and using machine (B)

To reduce the water content of the chips, drying process is done under direct sun light by placing the chips on bamboo racks of dimension 60 x 12 cm^2 specially made for this purpose. The rack can hold up to ±7 kg of fresh tubers slice. The drying process is continued on the concrete floor for 2-3 days to obtain dried-chips. The sun drying process will be stopped when the dried-chips are easily broken by fingers and the whole surface becomes white. The final step is dried-chips sortation. It is aimed to separate foreign materials and/or unhealthy chips indicated by black spots due to mold spores. See Figure 6 for the traditional process to produce dry chips (Dwiyono et al., 2014).

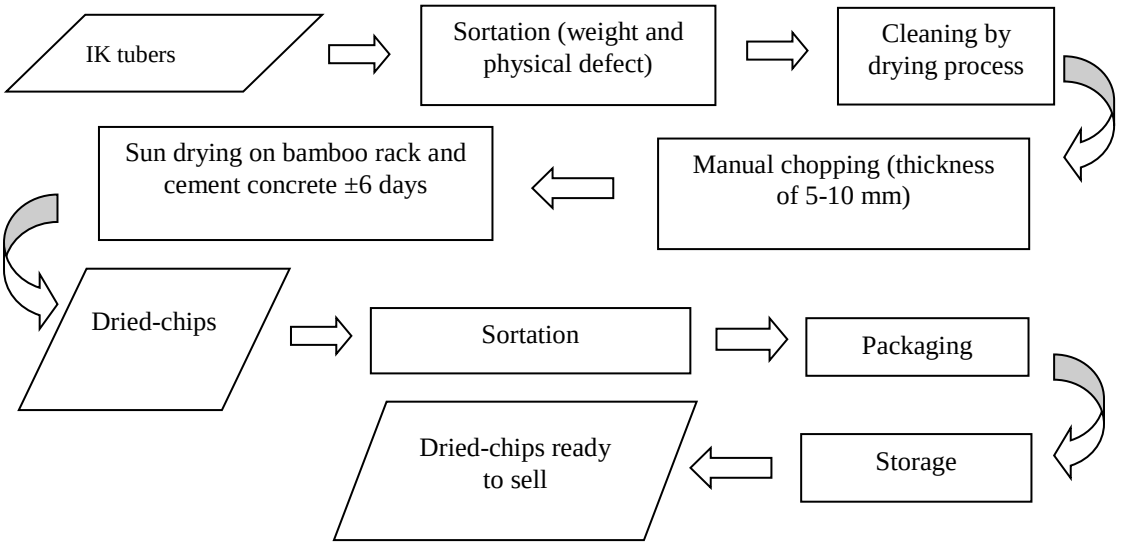

Figure 2.2. Traditional processing to produce dried-chips

On the other hand, at laboratory level, IK tubers postharvest handling is different from that traditional processing at farmer level. The difference lies in the process of washing, chopping and drying. Tuber washing in laboratory and industry is conducted using wet washing. In other words it uses water and washing machine. Meanwhile, tuber chopping in the laboratory is done by a particular machine that produces uniform 6 mm of thickness. And finally, drying process in laboratory is by using oven at temperature of 50 ℃ during 36 hours. These processes are diagrammatically shown in Figure 2.3.

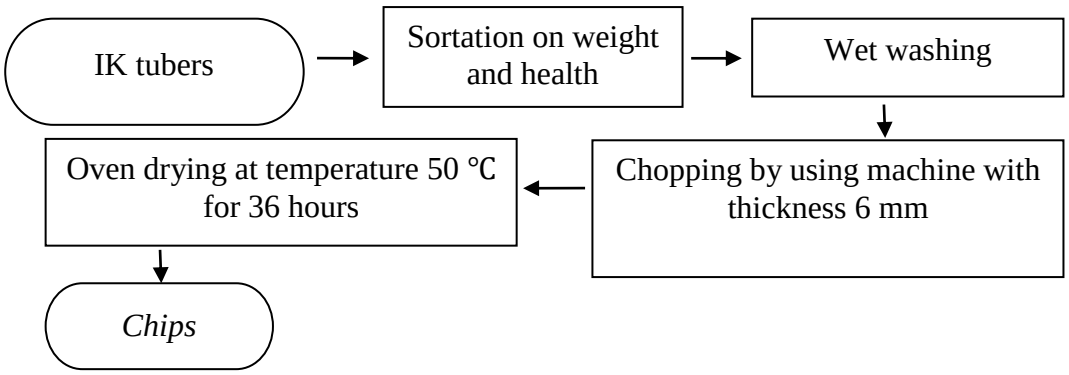

Figure 2.3. IK tubers processing stage done in laboratory

In what follows we focus our discussion on harvesting and drying processes, the important quality characteristics of chips, how to improve that quality, chemical composition

of IK flour, and last but not least flour packaging.

2.1. Harvesting and drying processes

IK can be harvested after entering the dormancy period (April to August). If the tuber is harvested in February to April the yield is still low (between 13-14%) but if harvested in July to August the yield can reach 17 - 18%. Harvesting process is done by using a trowel to avoid injury or damage of the tubers. A stake is needed to be taken in place to mark the location of the tubers. And, to produce a good-quality of chips, reduce weight loss, reduce bulk, and extend the shelf life, a proper and immediate postharvest handling of tubers is strongly recommended.

Postharvest handling carried out by people in Klangon Village, East Java, is still conventional and therefore the quality of their dry chips is poor. Thus, research to investigate the postharvest handling and to analyze the quality parameters of dry chips are needed to be done. For Klangon Village's community IK tuber is very important to support their life needs. On the other hand, dry chips are important for agroindustry to produce glucomannan which has many benefits with good economic value.

IK tubers are harvested by digging the surface soil using shovel or hoe carefully to avoid the damage of the tubers. Fresh tubers are easily attacked by fungus because it has high moisture content; between 80-85% (Ohtsuki, 1968). Immediate postharvest handling of IK tubers right after the harvest and with proper method can produce better quality of chips, can reduce weight loss, reduce bulk and extend shelf life.

Drying process is one of postharvest handling processes. It aims to reduce moisture content of the tubers by transferring it into atmosphere and then followed by physical and chemical treatments. Food drying often causes shrinkage, which is a reduction in volume followed by changes in shape, porosity, and increases hardness. This phenomenon is often followed by surface cracking and reduced rehydration ability of the material. During drying process, shrinkage must be avoided because of the changes in physical properties can reduce the quality of dried products that cannot be accepted by consumers (Jayaraman and Gupta, 1990; Senadeera et al. 2000).

Drying is a general process that can be used to improve food stability, decrease microorganism activity and enzymatic reactions, and avoid physical and chemical reactions during fresh storage (Russo et al. 2013). In practice, IK tubers can be dried under sun drying or by using artificial drying tools such as oven. When sun drying is applied, the temperature is about 35-48^{o}C. It is lower compared to artificial drying process which can work at ±50°C.

In both cases, according to Meisami et al. (2010) for the case of apple spread, drying time increases at constant drying temperature if the chips' thickness increases.

2.2. Chips quality characteristics

There are eleven parameters that characterized the quality of dried-chips. One of them is glucomannan content already discussed in the previous chapter. The other ten characteristics are moisture content, calcium oxalate, whiteness degree, ash content, crude fiber, fat, protein and starch, SO_2 residue, and Total Plate Colony (TPC). The maximum moisture content in dry chips as required by industry is 10 - 12%. In SNI 01-1680-1989 it is regulated as 12%. Meanwhile, based on interview with farmers, the moisture content of their dry chips is 11.89%. Thus, the chips that they produce are already met the standard of SNI.

The third one, calcium oxalate, is used because it can endanger human health; it can trigger the skin irritation and kidney stone disease at high intakes (Libert and Francschi, 1987; Thanasekaran et al., 2012). Calcium oxalate levels in dry chips produced by farmers and laboratories are relatively the same (Table 2.1). The form of calcium oxalate of is needle crystal, star and X which is not identified yet. The amount of calcium oxalate crystal is influenced by age, growth phase, season, nutrients and the land where it is cultivated. On the other hand, there is an indirect correlation between the diameter and the amount as well as the density of calcium oxalate in the tubers (East et al., 2013).

The fourth parameter used to determine the quality of dried-chips is the whiteness degree. This parameter is influenced by the Maillard reaction and the presence or absence of mold growth on the surface of the chips. Zhu et al. (2009) has mentioned that color parameter is an important assessment factor related to moisture content, age, and safety of wheat flour products to enzymatic reactions.

Others parameters are ash content, crude fiber, fat, protein and starch. Crude fiber, fat content, and protein are macromolecules that are directly related to the content of dietary fiber, hydrophobic properties, and the shape of the amino acid polymer (Pomeranz, 1991; Hii and Law, 2010). Meanwhile, starch consists of amylose and amylopectin which determine the gelatinization properties (Hii and Law, 2010). Information on the contents of IK dry chips taken from Klangon sample both in the form of dry chips and tubers as well as the quality requirements of IK in SNI number 01-1680-1989 are shown in Table 2.1 (Dwiyono *et al*., 2014) except SO_2 residue, and TPC.

Table 2.1. Quality parameters of IK flour

Parameter (in %)	Chips sample from farmers	Chips sample from laboratory	Quality of IK SNI 01-1680-1989	
			Grade I	Grade II
Moisture content	11,89 ± 0,46	11,85 ± 0,46	12	12
Glucomannan	35,77 ± 0,18	36,07 ± 0,05	min. 35	min.15
Calcium oxalate	0,84 ± 0,05	0,81± 0,05	-	-
Whiteness degree	53,36 ± 0,20	61,12 ± 0,09	-	-
Ash	4,46 ± 0,63	4,45 ± 0,80	-	-
Crude fiber	9,13 ± 0,10	9,06 ± 0,52	-	-
Fat	0,52 ± 0,00	0,54 ± 0,09	-	-
Protein	6,09 ± 0,20	6,22 ± 0,04	-	-
Starch	31,13 ± 1,86	31,36 ± 4,3	-	-

Davies et al. (2008) and Udoh (2009) have underlined that the use of machines, storage facilities and postharvest equipments consisting of different dryers, grinders and peelers influence the productivity of agricultural products. The use of technology and good management including the supply chain of tubers in the postharvest process can increase the productivity of agricultural products compared to the use of conventional household appliances (Davies et al. 2008; Udoh 2009).

2.3. Improving chips quality

New methods to improve the quality of IK chips consist of (i) slicing or chipping process to ensure homogenous thickness of chips, (ii) soaking treatment in pre-drying process, and (iii) drying process. Our experiment shows that soaking-oven-drying (SOD) method at drying temperature of 50°C during 36 hours gives the best results. The second best is given by soaking-sun-drying (SSD) method. This shows that soaking treatment improves the quality of IK chips. More specifically, soaking in sodium metabisulphite solution at a concentration of 1500 ppm for 15 minutes could improve the quality of dried-chips in terms of all eleven quality parameters except fiber, fat and protein. For these tree last parameters, oven drying (OD) and sun drying (SD) have no significant difference (Dwiyono and Djauhari, 2019).

To produce IK flour, IK tubers are cleanly peeled and then sliced with size of 5-10 mesh, dried by using oven at temperature of 50°C for 36 hours to achieve moisture content by maximum 12%. Then, they are milled with hammer mill and disc mill at size of 60-80 mesh and finally stored in air-tight packages. These packages are then placed in storage house at room temperature about 37°C. The flour can be stored for 2 or 3 years prior to shipment or further processed as raw material for food or other industries.

The harvesting age of tubers which planted from bulbils takes longer than those which planted from small tubers. The tubers production is significantly influenced by planting age or harvesting time. Older tuber will produce larger size of tuber. Figure 2.4 shows an example of harvested IK tubers in production center in Klangon Village.

Figure 2.4. Harvested IK tubers in Klangon Village

Besides the tuber size, harvesting time also influences the yield of dry chips and glucomannan content. And, regarding glucomannan content, Ohtsuki (1968) has remarked that it is influenced by several factors such as variety and harvesting age, and duration between harvesting and processing. The best results will be obtained during dry season on June and July, and even on August where it is the peak season during dry season in Madiun Regency which covers Klangon Village and its surrounding area. IK plants harvested in dry season can produce the highest yield of dry chips at ±18%. Furthermore, to obtain these results, after the tubers have immediately been dried, good and appropriate postharvest handling processes are required.

2.4. Chemical composition

Chemical composition of IK flour that has passed through the consecutive sieve with size 40, 60, 80, and 100 mesh consists of glucomannan, starch, fiber, moisture, whiteness, bulk density, viscosity, pH, and wight. These components and particle size are presented in Table 2.2. From this table we learn that particle size significantly influences the chemical component content of IK flour (Dwiyono, 2014).

Table 2.2. Chemical composition of IK flour*

Component	Particle size that passed the sieve (mesh)				
	<40	40	60	80	100
Glucomannan (%)	12.45^{ab}	19.38^{a}	12.17^{a}	8.82^{a}	6.06^{a}
Starch (%)	25.43^{a}	25.26^{a}	38.36^{a}	39.63^{a}	34.16^{a}
Fiber (%)	8.42^{ab}	5.71^{b}	5.71^{b}	9.15^{ab}	14.57^{a}
Moisture content (%)	11.19^{ab}	11.40^{a}	10.83^{bc}	10.54^{c}	8.72^{d}
Whiteness degree (%)	798.40^{a}	779.45^{b}	555.50^{c}	420.75^{d}	347.25^{e}
Bulk density (kg/m^3)	798.40^{a}	779.45^{b}	555.50^{c}	420.75^{d}	347.25^{e}
Viscosity (cPs)	$59x10^{4a}$	$4.85x10^{4a}$	$1.69x10^{4ab}$	$0.18x10^{4b}$	$0.0004x10^{4b}$
Ph	5.96^{c}	6.01^{bc}	6.02^{c}	6.08^{ab}	6.13^{a}
Weight percentage (%)	2.54^{c}	70.38^{a}	14.06^{b}	3.01^{c}	1.09^{c}

* *In this table a, b and c represent* average difference test conclusion symbol
.

In the rest of this section, each component in this table will be described one after another.

1. Glucomannan

The chemical component of IK flour treated with different sieve size showed that bigger sieve size (smaller particle size) produced less amount of glucomannan (Table 2.2). IK flour fraction that passed 40 mesh and doesn't pass 60 mesh has the highest glucomannan content compared to other particle size. IK flour which doesn't pass 40 mesh has less glucomannan content compared to IK flour which passes 40 mesh and doesn't pass 60 mesh. This illustrates that IK flour which has a larger particle size except of ≤ 40 mesh produces higher glucomannan yield. Wahjuningsih and Kunarto (2011) stated that smaller mesh size (larger particle size) indicates more glucomannan content. The decrease in glucomannan levels is as payoff with an increase in starch content, fiber content, and white degree (Faridah et al. (2012). Glucomannan level is a payoff of a decrease in non-glucomannan components

such as oxalate levels, protein content, fat content, ash content and starch content. Each glucomannan particle has different size variation, ranging from 0.812-1.86 µm or 20-200000 Da. An ANOVA with a 95% significance level shows that there is no significant effect of differences of IK flour particle size on the glucomannan content in the IK flour (Afriyani et al. (2013).

As much as ±1 gram sample is added with 30 ml of distilled water while stirring until forming homogeneous solution. Then, it is extracted in a shaker tool at a temperature of 45°C during 2 hours. After that, we centrifuge it at 4000 rpm for 20 minutes to separate the glucomannan, maltodextrin and flour dregs. Glucomannan fraction is separated from maltodextrin and flour dregs, then put in a beaker (glassware) and kept in refrigerator for one hour. We add 96% of alcohol as much as 13 ml into glucomannan in a same beaker while continuing stirring until a glucomannan precipitate is formed. The mixture of glucomannan and alcohol that has formed glucomannan precipitate is then filtered with Wahtman filter paper size 41. Then, glucomannan is put in an oven at a temperature of 35-40°C until constant glucomannan weight is reached. Finally, dried glucomannan is weighed and its glucomannan level is calculated using the following formula,

$$\text{Glucomannan content (\%)} = \frac{weight\ of\ precipitate\ (a)}{weight\ of\ sample\ (b)} \text{ x } 100\%$$

Due to the economic value of glucomannan, in the next paragraphs we present some important properties such as IK flour yield from glucomannan, the shape of glucomannan, and water absorption.

1.1. *IK flour yield*

Glucomannan yield is the amount of glucomannan flour contains in IK tuber flour after going through a multi-level or mechanical sifting process. It is chemically extracted with 96% ethanol solution and water alternately and repeatedly. The yield is calculated based on the comparison of the glucomannan flour from chemical extraction with 96% ethanol toward glucomannan flour from the sieve. The increasing yield indicates that the treatment is more efficient.

1.2. *The shape of glucomannan*

The shape of glucomannan granule is analyzed using a polarized light microscope at a magnification of 50 times. The magnification used is the minimum. This is because it produces the most obvious shape of granules.

1.3. *Water absorption*

Glucomannan samples are carefully weighed as much as 1 g, then mixed with 10 mL of distilled water for 10 seconds and left at room temperature for 30 minutes. Then, we centrifuge at a speed of 5000 rpm for 30 minutes. The filtrate obtained is weighed and water absorption is calculated by the following formula (assumed water density = 1 g/mL),

$$\text{Water absorption (\%)} = \frac{Vo - Vx}{Sample\ weight} \text{ X } 100\%.$$

where : *Vo* = initial weight of water

Vx = weight of supernatant water

2. Starch

The analysis result of starch content in IK flour treated with different mesh size shows higher starch content (Table 2.2). This is due to starch has lighter molecular weight than IK thus IK flour which has small size will produce higher content of starch. This indicates that the size of starch granule is smaller compared to the less amount of glucomannan in smaller particle. An ANOVA with a confidence level of 95% shows that there is a significant effect of difference size of IK flour particle towards starch content.

Sample with approximately one gram is hydrolyzed with 100 ml of 3% HCl in an autoclave for 15 minutes at 115°C. Then, it is neutralized with the addition of 4N NaOH and diluted with distilled water to reach a volume of 250 ml at pH 7 and filtered. The 10 ml filtrate is pipetted and put into an Erlenmeyer filled with 25 ml of Luff Schrool solution. Heat up it with an autoclave or reverse cooler for 10 minutes to boil. It is cooled with flowing water and added slowly with 20 ml of 20% KI and 25 ml of 25% H_2SO_4. After that, the mixture is titrated with 0.1 N of $Na_2S_2O_3$ until a pale yellow solution is formed then added 1% starch indicator (a blue solution is formed). Then, it is titrated again until the blue color disappears (a ml). This step is also carried out for blanco solution (b ml). Finally, starch content is calculated by the following formula,

$$\text{Starch content} = \frac{a \text{ x } P \text{ x } 0{,}95}{mg\ sample} \text{ x } 100\%$$

where: $P = 25$.

3. Fiber

An analysis of fiber content in IK flour treated with different particle size has been conducted. The results show that small particle size produces higher fiber content (Table 2.2). This is not in-line with the finding of Wahjuningsih and Kunarto (2011) who reported that higher fiber content is produced from large particle size. An ANOVA with significance level

of 95% shows that different particle size of IK flour significantly influences the fiber content.

It is then worth noting the way to measure the crude fiber content. First, as much as ± 1 gram sample is put into 250 ml size of Erlenmeyer flask and add with 100 ml of 0.325 N H_2SO_4 (1,25%) for hydrolysis. Second, we put it an oven at 105°C for 15 minutes. After temperature decreasing, we add 50 ml of NaOH then place into the autoclave again at the same temperature and time i.e. 105°C for 15 minutes. After that, we remove it and wait till cool and filter the cold solution using Whatman filter paper size No. 41 while rinsing successively with hot water, 0,325 N of H_2SO_4, hot water, and ethanol.

The filter paper containing the fibers is dried and then we put it into an oven at 105°C for about 2 hours. The dry filter paper is cooled in a desiccator and then weighed. Then, the crude fiber content is calculated using the following formula,

$$\text{Crude fiber content} = \frac{W2-W1}{W}\ x\ 100\%$$

where: W is the sample weight,

W_1 is the weight of empty filter paper, and

W_2 is the weight of filter paper and crude fiber.

4. Moisture Content

Moisture content is water molecule that significantly affects the quality of IK flour because water can be used as a medium for mold growth. High water content causes microorganism to grow well so the quality of the material can decrease. The growth of these microorganisms can affect the macromolecular component contained in material, such as carbohydrate, protein and lipid (Isengard 2001). Enzymatic reaction carried out by microorganism that contaminates the material can affect the content of macromolecule, such as browning and carbohydrate fermentation so that the quality of chips decreases (Isengard 2001).

Based on the moisture content analysis result of IK flour treated with different particle size shows that small particle size produces less moisture content (Table 2.2). This is because flour which has smaller size has wider surface area so that it can cause increasing evaporation that will reduce moisture content of the material. Soekarto (1981) stated that bound water to food is divided into three namely primary, secondary and tertiary bound water fraction. Volatile water is found on the surface of a material called free water. An ANOVA with a confidence level of 95% shows that particle size of IK flour significantly influences the moisture content.

The aluminum dish is dried at 105°C for 3-5 hours, then cooled in a desiccator and weighed. Weighed the sample as much as 2 g (W_1) and then put it in an aluminum cup which weight has already known before and dried it in the oven at 105°C for 1-2 hours. After that, place into desiccator and then measure the weight. Repeat heating the sample until reach a constant weight (W_2). The remaining samples are calculated as total solid and water as moisture content,

$$\text{Moisture content (\%)} = \frac{W1-W2}{W1} \text{ x } 100\%.$$

5. Whiteness Degree

Whiteness degree analysis on IK flour treated with different particle size shows that small particle size has higher moisture content (Table 2.2). This is because smaller particle has a greater ability to absorb color compound. Whiteness degree is also influenced by the occurrence of Maillard reaction and the presence or absence of mold growth on the surface of IK flour. Zhu et al. (2009) stated that the formation of brown or black pigment in flour is caused by a reaction which commonly referred to as Maillard reaction and enzymatic reaction of lipid and protein oxidation. An ANOVA with 95% confidence level shows that different particle size of IK flour significantly influences the whiteness degree result.

The whiteness degree of glucomannan flour issued from Natrium-metabisulphite immersion and without immersion has different value. Measurement of whiteness degree of *A. muelleri* (*porang*-local name) flour is conducted by using fotovolt. This instrument measures the value of brightness degree (L), score (a) that indicates red color if (+) and green if (-), and score (b) that indicates yellow color if (+) and blue if (-) of the flour. The whiteness degree is calculated by using this following formula,

$$W = 100 - (100\text{-}L)^2 + (a^2 + b^2)^{0,5}$$

where: W = Whiteness degree, with assumption that 100 is perfect white,

6. Bulk Density

A bulk density analysis on IK flour treated with different particle size shows that small particle size produces smaller bulk density. Density is used in planning the storage warehouse, volume of processing equipment and transportation facilities. The bulk density value is influenced by moisture content, particle size and surface roughness of a particle. Increasing moisture content of IK flour will increase bulk density (Table 2.2). An ANOVA with 95% confidence level shows that different particle size of IK flour significantly

influences the bulk density result.

Bulk density is calculated by adding a certain amount of glucomannan flour into a measuring cup whose weight has been determined before to reach a volume of 200 ml. Then, the measuring cup containing the flour is weighed. Bulk density is calculated by dividing the weight of flour with the volume of flour,

$$\text{Bulk density} = \frac{\boldsymbol{flour\ weight(g)}}{\boldsymbol{Flour\ volume\ (ml)}}.$$

7. Viscosity

Based on the viscosity analysis result of IK flour treated with different particle size shows that less particle size produce less viscosity. This is because flour which has small particle size contains less glucomannan thereby reducing gelatinization from glucomannan found in IK flour (Table 2.2). Viscosity value is related to the glucomannan contained in IK flour. Glucomannan level plays an important role in increasing the viscosity of IK flour because glucomannan can thicken, this shows that the higher the glucomannan content in IK flour the higher the viscosity. The level of glucomannan in IK dry chips is influenced by the glucomannan content found in tubers as well as the processing treatment. Flouring process will increase the level of glucomannan contained in IK flour. An ANOVA with a confidence level of 95% shows that different particle size of IK flour doesn't significantly influence the bulk density result (Faridah et al., 2012) .

Viscosity is determined by using viscometer Brookfield. Viscosity value is expressed in centipoises unit which generated by multiplying a factor of 10 ml of distilled water and stirring, then adding with 90 ml of boiling water and cool until the temperature reaches room temperature. The spindle used is spindle No. 4 with a speed of 6 rpm and the correction factor 1000.

8. pH

pH measurement is done by using pH meter. A sample of 3 g is dissolved in 100 ml of distilled water to form a paste. Then, pH is measured by inserting a device or needle into the paste. Measurement is made many times and the results read on the device are then averaged.

9. Weight percentage

Weight percentage is the ratio between the weight of flour in a certain mesh size with the overall flour weight of various mesh sizes multiplied by 100 percent

2.5. Packaging

To close this chapter, it is worth noting the important role of packaging. IK dried-chips packaging is also an important matter to ensure the quality of dried-chips and thus the flour. Its material must be the first to be determined. In this regards, material made from polypropylene plastic bag (PP) is recommended. Since IK chips temporary storage warehouse is a permanent building with brick walls and a tile roof, according to Jacobsson et al. (2004), PP is best used to regulate the stability of CO_2 and O_2 during storage of fresh broccoli with a modified atmosphere packaging (MAP) system. It is better than polyvinyl chloride (PVC) and low-density polyethylene (LDPE). Moreover, PP is easily available, relatively inexpensive, air-tight, and waterproof.

CHAPTER III. GLUCOMANNAN

Due to its important role of glucomannan in many industries, in this chapter its properties will be presented and discussed in more details. We start with its chemical structure followed by the role of glucomannan in health industry, the characteristics of commercial glucomannan, how to make glucomannan from IK tuber, and chemical analysis. This chapter ends with a list of the properties of glucomannan.

3.1. Chemical structure

Glucomannan is a form of polysaccharide powder comprising monosaccharide mannose and glucose with the molar ratio of 3:2 (Tye, 1991). It is a polysaccharide compound comprising one D-glucose and two D-mannose, each of 33% and 67%. It has linear chain molecule of ß 1-4 of its forming sugar unit and the molecule mass of greater than 300 kD (Tye, 1991). Another property of glucomannan is discussed in Goodwin and Mercer (1983). These authors have remarked that glucomannan has the property of serving as reserved polysaccharide which can be used during the growth of shoot. According to Ohtsuki (1968), the glucomannan content in IK is varied between 15 to 65 percent depending on the species, type, age of the plant, and timeliness of harvest time.

Meier (1967) underlined that only polymer with low molecule mass can procure co-polymerization to form a crystal, while polymer with high molekul mass cannot form crystal but may produce fine fibers (microfibrils). Frei and Peston (1967) argued that galactomanan may only form microfibrils. Glucomannan apparently have, among other cellulose with galactomanan, the ability to crystal and to form structures of fine fibers. Actually, since glucomannan solution may form transparent thin layer, it has broader benefits than cellulose and galactomanan (Budiman, 1970)

The structure of glucomannan series, its mass, type and chemical properties, can be identified based on radiation using X-ray. And, the structure of glucomannan molecule series is as in the following figure In this figure, M stands for mannose while G for glucose (Syaefullah, 1990)

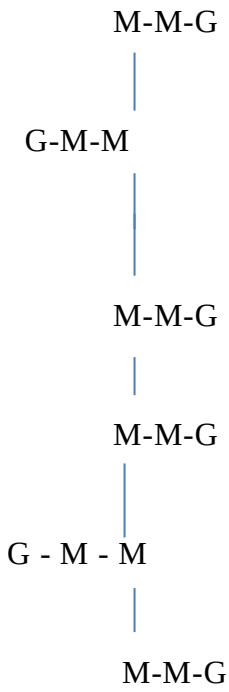

Figure 3.1. The structure of glucomannan

3.2. Glucomannan in industry

Glucomannan may dissolve in cold water by forming a thick mass. If the thick mass is heated to become gel, it cannot re-dissolve in water. Glucomannan solution in water has adhesive property, but if it is added with acetate acid or acid in general, the adhesiveness property will completely disappear. Glucomannan solution can be settled through recrystalization by ethanol and the crystal can be re-dissolved with chloride acid. This crystal is the same in shape as the glucomannan crystal in the tuber. If the glucomannan is mixed with alkaline solution (particularly Na, K, and Ca), a new crystal will be immediately formed and produce a gel mass. The new crystal cannot dissolve in water (although up to the temperature of 100° C) or liquid solution. The same is true for lead 110 acetate (cupriettilendiamin) in which the glucomannan solution will form stable white deposit. In addition to sedimentable, glucomannan can also be regenerated to become mannose and glucose by way of methylation or acetylation hydrolysis. In water at ambient temperature, glucomannan will have strong viscosity. Glucomannan can be extracted by using KOH solution and borate to form a complex compound with the hydrobit of 2.3-cis. It can also be separated with precipitation as barium or complex

copper. The content of glucomannan powder in IK tuber varies between 15-65% depending on the plant age and the timelines of the harvesting time (Ohtsuki, 1968).

The content level of glucomannan is influenced by several factors such as the type and age of plant, and initial treatment in the post-harvesting time before drying. Glucomannan level of IK ranges from 54.3 to 58.3 %. Meanwhile, glucomannan level in *A. muelleri* is higher than *A. varriabilis* (Jansen et al., 1996). Interestingly, when IK flour has been produced by traditional process, it contains the glucomannan level of less than 30% on average. Thus, the traditional process has significantly reduced glucomannan level (Ohtsuki, 1968).

In whatsoever process, whether traditional or laboratory, the quality of powder is indicated by the color of powder produced. The quality of the powder is high if the whiteness degree is high. It is natural that the color of glucomannan powder is usually brownish yellow. This browning process is caused by the reaction between phenolase enzyme and okxidation and forming carboxylic group in reduction sugar with the amine group in amino acid. It is important to note that the whiteness level of glucomannan powder is influenced by the amilum level, calcium oxalate, and temperature. Thus, since the chip yield is influenced by the plant's age and initial treatment. The timeliness of harvest time and the initial postharvest handling must be carefully conducted.

Glucomannan also has the ability to absorb water up to 138-200% and occurs quickly. Two percent glucomannan solution in water can form lender with the same viscosity as that given by 4 % gum Arabic solution. If it is made as adhesive, it has a distinctive property that is disliked by insects. Very liquid glucomannan solution (0.0025 %) may clot a colloid suspension. Glucomannan solution sprayed on a glass sheet and dried up will form a thin layer (film) that can be detached from the glass sheet. This film is transparent, elastic, strong and dissolvable in water. If the glucomannan solution is mixed with glycine and then dried up, the formed thin layer cannot dissolve in water.

Glucomannan is a polysaccharide deriving from *A. konjac* tubers which consists of glucose and mannose in a molecule ratio of 1:1.6 while galactomanan consists of galactose and mannose with the ratio of 1:2. Glucomannan as well as galactomannan, guar, pectin, and mucilago are easily dissolvable fibers and very hydrophilic and can form gel. These fibers are able to cover the content of food tract in the stomach and hence slowing down absorption process. They will increase the viscosity of the food tract and form a barrier on the outer part of the food. This is the reason why they will slow down the absorption process. Hence diet with such fibers may lower the curve of blood sugar in the postprandial time. When

compared to galactomanan (guar), the viscosity of glucomanan is higher and therefore glucomannan is more effective in suppressing transportation of postprandial blood sugar (Sutjahjo, 1986).

Fiber diet may also bind organic substances such as bile salt which will be bounded by lignine and other fibers. If the number of fibers in the diet increases, disposal of bile salt through feces will also increase. This will consequently reduce the blood cholesterol level. Glucomannan given with the dosage of 3 times 1.3 gram/day for 2 weeks is effective in reducing significantly the blood sugar 2 hours after meal for patients of diabetes mellitus who were given diet. This diet consists of 60% carbohydrate, 20% fat, and 20% protein given in the form of 3 times main meals and 3 times light meals. It is also effective during fasting (Sutjahjo, 1986).

3.3. Characteristics of commercial glucomannan

The physical-chemical characteristics of commercial glucomannan powder based on analysis are as follows: yield (58.20%), water content (7.15 %), glucomannan content (35%), Residue $S0_2$ (0.006 %), whiteness level (73.31 of $BaS0_4$ standard figure), viscosity (20630 cP), pH (6.2), bulk density (849 kg/m^3), angle of repose (28.25°). After separated from other compounds, Glucomannan need to be properly stored to maintain its quality. For that purpose, it is necessary to observe the bulk density and angle of respose of the glucomannan (Syaefullah, 1990)

3.4. Making Glucomannan from IK Tuber

In general, the process to produce glucomannan from IK tubers consists of the following four steps.

1. Mill the dry IK tubers dried under the sun or artificial dryer machine (hot-air dryer of the steam type) using a milling machine. In this step, IK flour will be produced.
2. Put the IK flour into a polishing machine (fin mill) with the sieve holes of 0.5 mm or 35 mesh. Then, brush the walls of cell and parts of cells around the glucomannan using blower. As the size of glucommanan particles is greater and the weight is heavier than the IK flour, in this step glucomannan will be left on the sieve while the IK flour passes the sieve. Parts of particles that are fine and light

from this blower machine will be sucked and parts of glucomannan particles will fall (not passing the sieve).

3. To get good quality, glucomannan is separated using rotap shaker with the mesh size of respectively 60, 80, dan 100. The coarse parts of glucomannan held at the 60 mesh size are put again into the polishing machine and sift again to get really fine particles.

4. The produced glucomannan powder is immediately packaged into air-tight plastic containers. The production process from IK tubers to glucomannan is presented in Figure 3.2.

3.5. Chemical Analysis

Chemical analysis is performed on fresh tuber and glucomannan powder. The analysis includes the water content, glucomannan level, carbohydrate content (amilum), protein content, fat content, rough fiber content, calcium oxalate content, ash content and heavy metal content (cu). In what follows, three components will be analyzed, namely, bulk density, angle of repose, and glucomannan powder particles.

1) Bulk density

The bulk density is calculated by pouring some glucomannan powder into a 200 ml beaker glass and/or the volume reaches 200 ml and thenit is weighed. The net weight of the glucomannan powder (in gram) is obtained by reducing the weight of the beaker glass when empty that has been weighed beforehand. After that, the bulk density is determined from the weight of glucomannan powder against the volume of the flour.

2) Angle of repose

The angle of repose is calculated by pouring some glucomannan powder into a 200 ml beaker glass until the volume is correct. Pour the glucomannan powder quickly on a flat surface and measure the angle of repose formed using vernier caliper by measuring the height and diameter of the bulk foundation. The projection of the bulk is deemed to form an isosceles triangle.

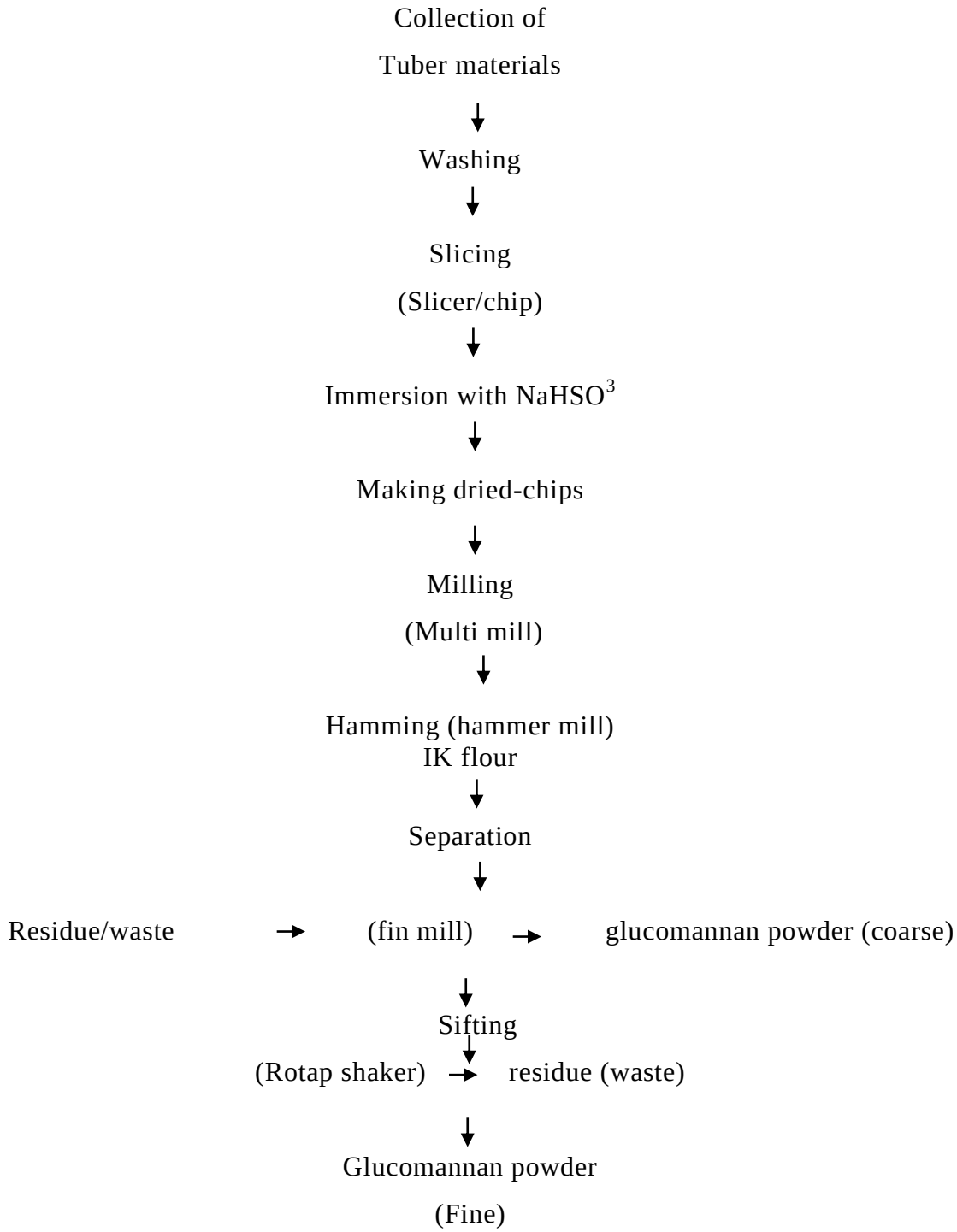

Figure 3.2. Production process from IK tubers to glucomannan

3) Glucomannan powder particles

The particles' shapes and sizes of glucomannan powder can be viewed by using a "polarization microscope".

3.6. Properties of glucomannan

In this section, some important properties of glucomannan will be presented and discussed. They are water content, yield of glucomannan powder, glucomannan level, glucomannan extraction, $S0_2$ residue, whiteness level, viscosity and pH.

1) Water content

Water content is measured using the method suggested in AOAC (1975). Two grams of flour as sample is heated in the oven at a temperature of 104° C during 3-4 hours. Then, it is cooled in the desiccator and weighed. The content of water sample (bb) is obtained using the following formula,

$$\text{Water content (lower base)} = \frac{a-b}{a} \times 100\%$$

Here, a = sample's initial weight (g) and b = sample's final weight (g).

2) Yield of glucomannan powder

The yield of glucomannan powder is calculated based on the weight of IK fluor. The yield of glucomannan powder can be calculated using the following formula,

$$\text{Yield} = \frac{a}{b} \times 100\ \%$$

where a = weight of glucomannan powder (g) and b = weight of IK flour (g).

3) Glucomannan level

The level of glucomannan powder is measured based on the extraction method using ethanol. Isolation of glucomannan powder from IK flour using alcohol 96 % (ethanol) through recrystalization is as follows. One gram of IK flour is added into 30 ml of distilled water and then extracted at a temperature of 45° C for two hours with continual stirring speed. Upon extraction, the solution is separated from the IK residue or waste with sentrimge. This solution is filtered using Erlenmeyer and then added with 13 ml alcohol 96% (ethanol) by pouring it little by little while stirring until glucomannan settles. After glucomannan sedimentation is formed, leave the sedimentation in the mixture until the layers between glucomannan and the solution are separated. The glucomannan sedimentation is separated and then washed using alcohol 96 %. The produced glucomannan is dried up in the oven at a temperature of 35-40° C

until the weight is constant. Dried glucomannan in the form of brownish grey powder is weighed and glucomannan level is calculated as follows,

$$\text{Glucomannan level} = \frac{a}{b} \times 100\ \%$$

Here, a = sediment weight (g) and b = sample weight (g).

Glucomannan is a hydrocolloid polysaccharide compound composed of linear bonds of β-1.4-D-glucose and D-mannose at molar ratio of 1: 1.6 and 1: 1.4. It is a branch of β-1.6-glucosyl groups. The branch is located at the C-3 atom in every 32 glucose molecules (Huang et al., 2002; Chua et al., 2012). Glucomannan has many benefits in various industries such as food industry (shirataki and konyaku), health industry (drug for diabetes mellitus, lowering blood cholesterol, weight loss, anti-HIV, anti-inflammatory), textiles, paper, cosmetics, oil industries, and mining waste purifiers (Chua et al., 2012; Zhang et al., 2010; Huang et al., 2002; Bo et al., 2013; Yao Ling et al., 2013).

Glucomannan is a hydrocolloid polysaccharide compound found in the IK tubers, composed of monosaccharide units of mannose and glucose at a molar ratio of 3: 2 (Tye 1991). Glucomannan content in IK tubers is around 8.03-12.43%, the shape of flour is 51.3-71.6% (Fang and Wu 2004). Sumarwoto (2004) stated that the harvest age of IK influences the moisture content, starch and glucomannan. Tuber age of 6, 17, and 24 months resulted in tubers moisture content of 78.32, 78.97 and 80.67%, starch content of 26.31, 16.25 and 13.75%, and glucomannan content of 37.99, 47.34 and 48.54%. The shape of the crystals is similar to the shape of glucomannan crystals in the tubers, but when glucomannan is mixed with an alkaline solution such as Na, K, and Ca, a new crystal will soon form and form a gel mass. Based on the results of the methylation analysis, glucomannan consists of D-glucopyranose and D-mannopyranose with β-1,4-glycosidic bonds.

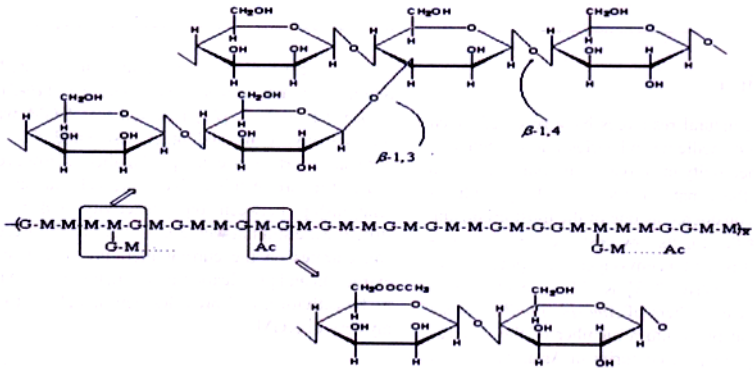

Figure 3.3. Chemical structure of glucomannan **(Li e*t al.* 2013)**

These are elevent properties of mannan cells (Tye 1991):

(1) Idioblast cells (mannan) like fibers,

(2) Cell size is 5-2 mm (1-2 times larger from starch cells or amylum),

(3) Colorless when tested for color with iodine,

(4) Cells are surrounded by thin-wall parenchyma cells containing of starch granules,

(5) Yellow granules,

(6) Glucomannan polymers have properties between cellulose and galactomannan, so they are able to undergo crystallization and can form the structure of fine fibers,

(7) The development of the volume of glucomannan in water can reach 138-200% and occurs rapidly while starch is only 25% bigger than the original,

(8) Glucomannan molecule consists of D-glucose polysaccharide (33%) and D-mannose (67%),

(9) Glucomannan is a form of polysaccharide composed of one monosaccharide mannose and glucose at a ratio of 1.6 - 4: 1

(10) Glucomannan has linear chain ß (1-4) units of sugar's constituents,

(11) Size of molecular weights is greater than 3 KD.

Glucomannan can be separated from IK flour by using a sieve of 0.18 mm or 80 mesh size. Part of the flour that is retained by the sifter is glucomannan because it has larger molecules than starch and fiber particles. The part that passes the sieve weight is a fraction of starch and fibers. In addition, glucomannan separation and purification can also be done by

enzymatic hydrolysis and 96% ethanol solution. Browning on tubers slices is prevented by soaking in sodium metabisulphite (Dwiyono and Maman, 2019). Glucomannan can also be obtained by wet extraction method using ethanol but the processing cost is higher. Glucomannan is an emulsifying agent in the food, paper and cosmetic industries because this material in liquid will form a gel that has high viscosity. Given the importance of glucomannan application in various fields, glucomannan has a molecular weight of 9.0 x 10^5gmol-1 or 2.7 x 10^5-1.1x10^6 Da (Yeh, 2010 and Li, 2013).

4) Glocomannan extraction

Glucomannan extraction is the process of separating glucomannan from IK flour. Glucomannan extraction can be done in several ways, namely mechanical and chemical methods. Method to extract glucomannan from IK flour can be done mechanically through blowing, sifting, and polishing IK flour, whereas chemically through the separation of glucomannan with 95% ethanol. Glucomannan extraction could be carried out mechanically by a combination of blowing and sifting, whereas chemical methods were carried out with acetate, aluminum sulfate compounds, and ethanol. Extraction with acetate and sulfate compounds produce glucomannan which cannot be used for food (Chua et al., 2012).

Glucomannan content of tubers is not only influenced varieties, age of plants, and the time span from harvesting to processing but also parts of plants treated and tools for processing dry chips. Glucomannan produced from konjac plant (*A. konjac)* and that from IK *(A. muelleri*) have different characteristics due to the differences in viscosity and the ratio of its monosaccharides constituent namely mannose and glucose These authors stated that the ratio of mannose and glucose of *A. muelleri* is 7.7: 1 and *A. konjac* is 1.6: 1. In terms of viscosity, glucomannan of *A. muelleri* is higher (47500 mPa.s) compared to that of *A. konjac* (32200 mPa.s). Further analysis shows that glucomannan from *A. muelleri* has higher level (72 ± 3.4%) than that from *A. konjac* (62 ± 3.3%) (An et al., 2010; Bo et al., 2013; Chua et al., 2012; Zhang et al., 2010).

The production process of glucomannan from fresh IK tubers through cleaning process until extraction process is illustrated in Figure 3.4.

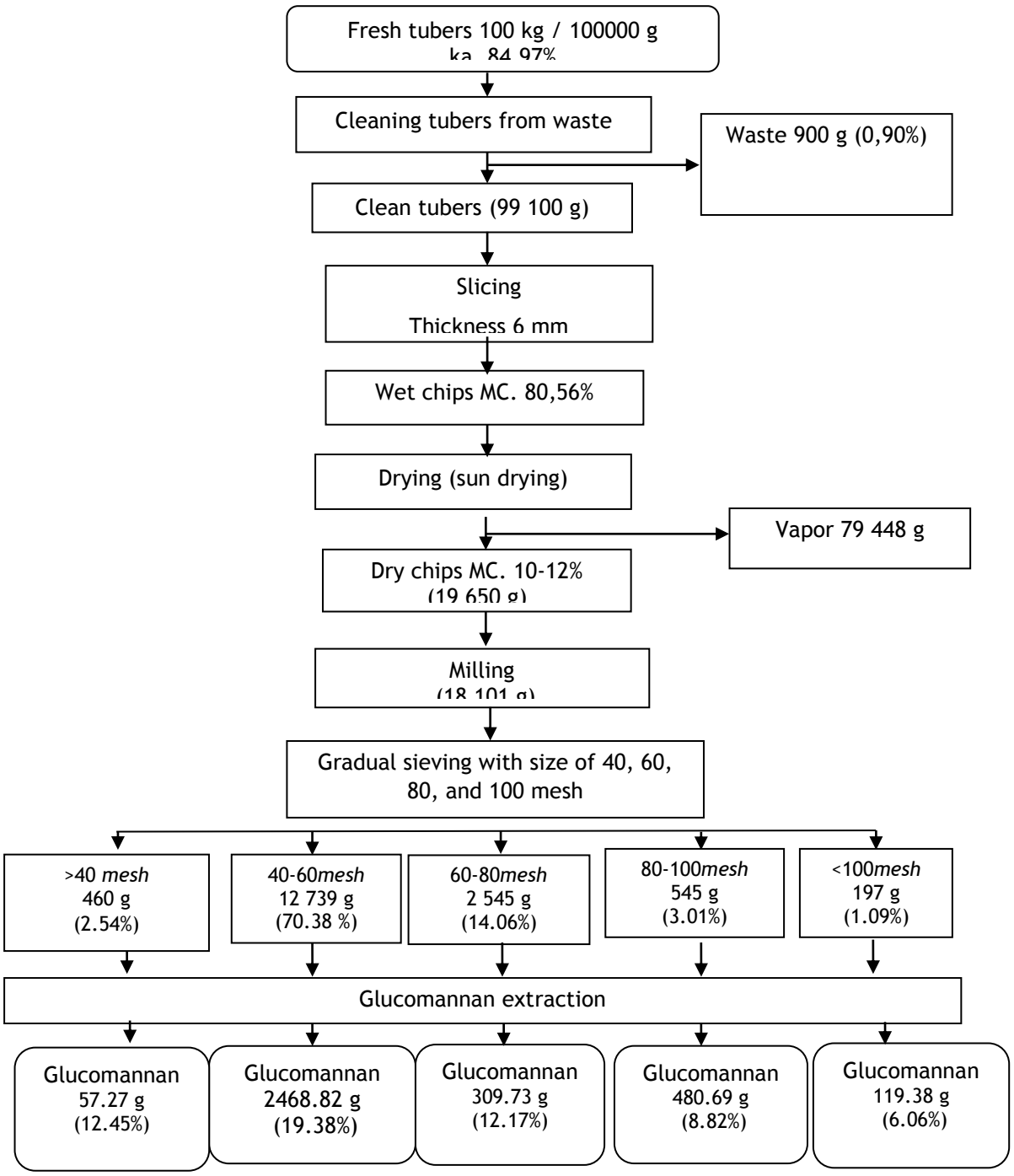

Figure 3.4. Glucomannan production process from fresh IK tubers

5) $S0_2$ residue

$S0_2$ residue from glucomannan powder is measured using iodometric titration. Ten grams of glucomannan powder is put in a boiling flask and added with 150 ml of distilled water and 25 ml of asamphosphate 6 N. Then, it is boiled and distilled for 15 minutes. The result of distillation is accommodated in an Erlenmeyer flask containing 1 ml starch solution. After that, it is added with 0.005 N iod solution for several drops until its color changes to blue. If the blue color disappears, the $S0_2$ is positive. To calculate the residu of $S0_2$, this formula can be used,

$$\text{Percent of } H_2S0_3 = \frac{\text{ml x N x bst x100 X percent}}{\text{sample weight}}$$

$$S0_2 \text{ Residue} = \frac{SO_2}{H_2SO_3} \text{ X percent} = \text{Y percent}$$

mL = milliliter

N= normality of H_2SO_4

100 X percent = 100 x %

Bst = sample weight used

6) Whiteness level

The whiteness level of glucomannan powder is measured using photovolt reflection and gloss meter model 575. The working method of this tool is as follows, → ADA 6 BUTTONS YANG DISEBUT. APA MAKSUDNYA? APA ADA GAMBAR ALAT ITU?

(1) Turn on the instrument, leave it for 30 minutes for stabilization

(2) After 30 minutes turn to the left or to the right until the Lo lamp or Hi lamp is on, turn the button in a clockwise direction, if the Hi is on turn the reverse direction.

(3) Take the black standard, place it under the sensor, turn in a clockwise direction full and in the middle.

(4) Turn until the display indicates 0.00 (% reflection)

(5) Take a suitable standard (for glucomannan powder take the white standard deriving from the $BaS0_4$ material).

(6) Record the standard value in accordance with the filter amber (red), green, blue

(7) Place the standard under the sensor (the sensor still contains green filter)

(8) Turn until the display indicates the figure in accordance with the standard data for green.

(9) If necessary turn .

(10) Change the standard with sample. Read the figure on the display... for example 60

(11) Change the filter with amber (red)

(12) Repeat steps (7), (8), and (9). Read the amber data on the display for example 75

(13) Change the filter with blue

(14) Repeat steps (7), (8), and (9). Read the blue data on the display.... For example 73

$$X = \frac{0{,}8\,(A) + 0.18(B)\,100}{100}$$

$$Y = \frac{1{,}18\,(B)}{100}\ 100$$

where A = amber/red, G = green and B = blue (colour of sign intrument). Afterward, we calculate,

$$L = 100(Y^{1/2})$$

$$a = \frac{175\,(1.02\,X - Y)}{Y^{1/2}}$$

$$b = \frac{70\,(Y - 0.847\,Z}{Y^{1/2}}$$

Here,

L = the value indicating the clarity

a = the value indicating red if the sign is positive and green if the sign is negative

b = the value indicating yellow if the sign is positive and blue if the sign is negative.

Then, whiteness level is given by this formula,

$$W = 100 - [(100 - \boldsymbol{L})^{2} + (a^2 + b^2)]^{1/2}$$

7) Viscosity

The viscosity of glucomannan powder is measured using the method advised by Brautlect (1953); 3 g of sample is dissolved into 100 ml air of distilled water and stirred

until evenly dissolved while heating it at a temperature of 60° C. Then, leave it at the ambient temperature. The viscosity is measured using a viscometer and during the measurement the ambient temperature indicates 25° C. As a blank, use solution glyserol 75 %. This is the formula to find the viscosity,

$$\text{Viscosity} = \frac{t_1}{t_2} \times \text{X cP}$$

where,

t_1 = the time needed to make 100 spins with the weight of 130 g by the solution of analyzed material
t_2 = the time needed at the condition and temperature the same as t, by glycerol
X = the standard figure at a temperature of 25° C (ambient temperature at the time of measurement) indicated in the Tabel attachment 19, namely 27,73 cP

8) pH

The pH of glucomannan powder is measured using pH meter.For this purpose, 3 g of sample is dissolved into 100 ml of distilled water so as to form paste. Then measure the pH by injecting the tool/needle into the paste several times. The result will then be averaged.

CHAPTER IV. WATER SORPTION ISOTHERMIS

Adsoprtion, desorption, correlation between drying rate and water soprtion isotherm (WSI), equilibrium moisture content, and bound water of *Iles-iles* flour and chips which consists of primary bound water (PBW), secondary bound water (SBW), and tertiary bound water (TBW).

4.1. Adsoprtion

To find out the environment's boundaries having certain relative humidity against IK's equilibrium moisture content, a water sorption isotherm (WSI) test can be done. WSI of *Iles-iles* can be done through adsorption and desorption. Adsoprtion is a process of capturing water molecule where the material is placed on the environment with higher water activity (a_w). Adsorption is a process where sample captures vapor from atmosphere which has higher relative humidity (RH) (Moreira et al., 2010). In other words, the ambient has higher a_w than the material. Adsorption can be used to analyze the storage requirement of a material in order to prolong the shelf life. In fact, adsorption can be used to predict the material's shelf life at a certain condition such as at specific equilibrium moisture content and RH. On the contrary, if the material is stored at non-equilibrium moisture content or a_w is higher or lower than the environment, then the material will be very susceptible to microorganism or mold which will fasten the deterioration. The equilibrium moisture content (M_e) based on adsorption and desorption with various saturated salt is shown in Table 4.1.

Table 4.1. The equilibrium moisture content (M_e) based on adsorption and desorption

Salt	a_w	M_e (% bb)	
		Adsorption	Desorption
$LiCl_2$	0.11	5.03	3.28
CH_3COOK	0.22	6.15	8.94
$MgCl_2$	0.32	7.90	11.50
K_2CO_3	0.44	10.24	13.77
NaBr	0.56	13.52	15.54
$NaNO_2$	0.64	15.53	18.15
NaCl	0.75	18.62	26.67
KCl	0.84	24.34	39.54
K_2SO_4	0.97	37.56	62.45

If data on this table is used to construct the adsorption curve of IK flour, we find a quadratic regression model between (M_e) as horizontal axis and (a_w) as vertical axis (Figure 4.1),

$$(M_e) = 0.703(a_w)^2 - 3.44(a_w) + 8.90$$

with R-squared 0.97. Since R-squared is high, for a given value of a_w we can predict the value of moisture equilibrium content (M_e) with high degree of accurateness. Therefore, this equation can be used to design the storage process.

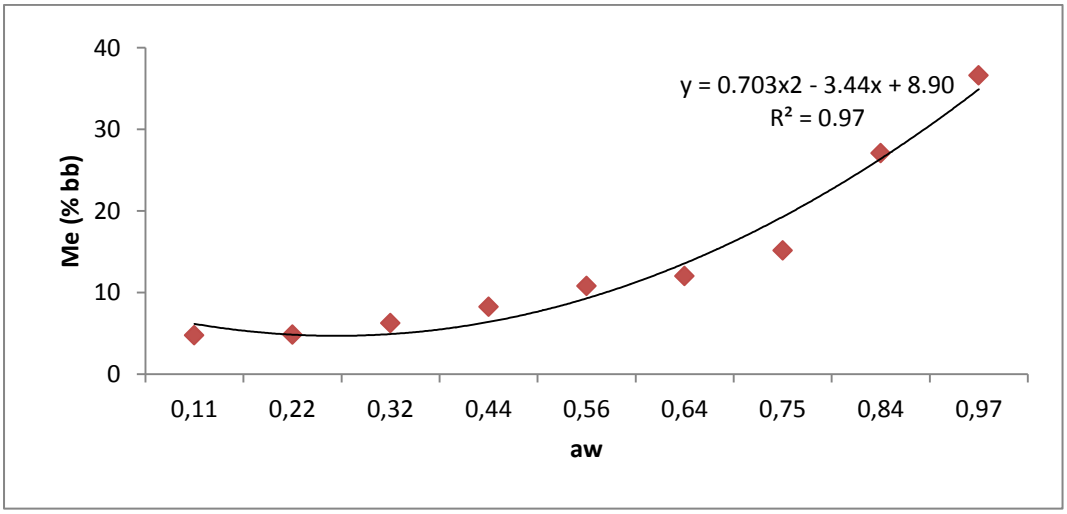

Figure 4.1. Interaction between (a_w) and (M_e)

According to Limousin et al. (2007), there are 4 main types of WSI commonly used in scientific investigation namely Type C, Type L, Type H and Type S. It is called Type C when the ratio between the solution and saturated salt is the same at any concentration. This type is used to investigate polutant solution having very low concentration and generates less-accurate value. On the other hand, we call Type L when the ratio between the volume of solution and that of solids decreases. Type H is similar to Type L; only in a particular case where the initial slope is very high. Type S is sigmoidal curve. This type of isothermic curve occurs in most agricultural products including IK.

4.2. Desorption

Desorption is a phenomenon where a substance or solid releases their molecules or vapor to the atmosphere having lower RH (Moreira et al. 2010). WSI of IK S-type isotherm

forms a sigmoid curve consisting of three parts. It is a typical curve of foods products. Gao et al. 2013 divides WSI curve into three water fraction zones inside material namely main fraction or primary bound water (monolayer), secondary bound water fraction (multilayer) and tertiary bound water (water solvent, plastilizer and soften products). Desorption can be used to design material drying process. If the material has high moisture content and then placed in lower RH environment, it will cause the water contained in the material vaporizes into the atmosphere. This is merely called as drying process. The water fraction inside the material can be used to determine safe moisture content during drying process. This WSI method can be applied at industrial scale and over wide-ranges of researches because of its simplicity and easiness in determining critical moisture content compared with other methods (Isengard, 2001; Staudt et al., 2013). Desorption curve which has been generated includes a_w and equilibrium moisture content (Me) as shown in Figure 22.

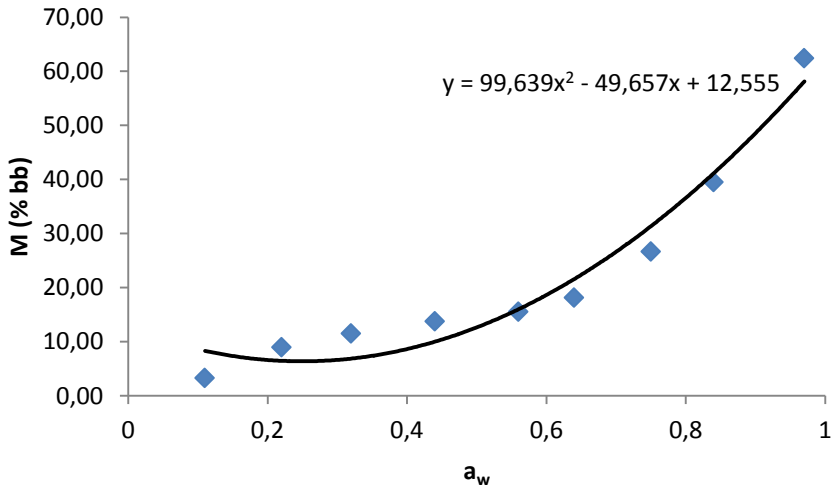

Figure 4.2. Interaction between (a_w) and desorption-equilibrium moisture content (M_e)

4.3. Correlation between Drying Rate and Water Soprtion Isotherm

Drying process using oven is influenced by several factors such as RH and initial temperature inside oven which tends to be less stable at the beginning stage of drying. This is because of some adjustment of temperature and pressure inside oven occur at the beginning stage of drying which indirectly decrease the moisture content of the material. The advantage of using oven for drying is that oven can produce faster decreases of moisture content. As temperature and pressure can be adjusted and controlled, constant drying rate can maintain the quality of the product (Mujumdar 2000).

According to Brooker et al. (1982), there are several factors that influence drying

process namely ambient temperature, air velocity, relative humidity, structure and surface area of the component. Drying process is not only to decrease moisture content, it is often followed by shrinkage in size and volume, changes in shape and structure of cellular component such as color, aroma and hardness level (Russo et al., 2013). Drying is done at 50°C so it neither increases the hardness nor changes the color of chip (Kone et al., 2013; Russo et al., 2013). When IK tuber with intial moisture content of 84.74% is dried using oven at 50 ℃ for 36 hours, the produced chips has moisture content of 3.14% (Table 4.2).

Table 4.2. Moisture content (M) during drying using oven at 50 ^{0}C

Time (hours)	M (%)
0	84,97
1	71,98
2	59,72
3	48,24
4	38,54
5	30,86
6	24,02
8	11,17
10	5,82
12	4,25
16	3,65
20	3,35
24	3,28
28	3,2
32	3,15
36	3,14

By using data on this table, the interaction curve between drying time length and moisture content of IK chips is shown in Figure 4.3. As we can see in this figure, at the beginning the moisture content of *Iles-iles* chips decreases very fast (Phase I), then decreases slowly (Phase II) and finally reaches the equilibrium state at the end of drying (Phase III). Drying process of IK generates asimptotic line where the end-point of the line never reaches or never crosses the horizontal axis. This illustrates that water in inner layer or PBW is difficult to evaporate.

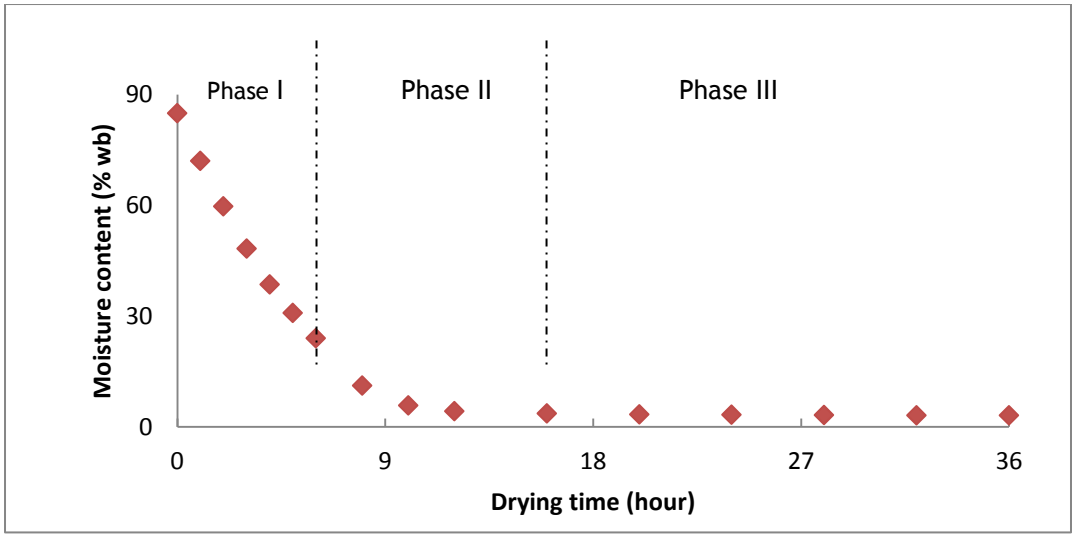

Figure 4.3. Interaction between moisture content and drying time at temperature 50℃

Based on logical analysis, it can be generated semilogarithmic equation as follow,

$$\text{Log } (M_o\text{-}M) = a + bt \quad (1)$$

where a = interception with vertical axis, b = drying rate/slope, t = drying time (hour), M_0 = initial moisture content (% wb), and M = moisture content at t-hour (% wb)

Based on Figure 4.3, the curve shows that moisture content decreases very fast until certain level especially for the first 16 hours then reaches the equilibrium moisture content. As we have mentioned earlier, the drying stage of *Iles-iles* can be divided into three phases. Phase I or quick phase which occurs during the initial stage of drying observed every one hour for the first six hours or the first-six observations point. Secondly, the Phase II or moderate slow occurs during eight hours (observed every two hours) or the second-four observation points. The third phase or the slowest phase occurs every four hours for the last 16 hours or the last-five observation points.

Drying at 50^{o}C doesn't change texture and color of tubers (Kone et al., 2013; Russo et al., 2013). After exposing a long drying duration, material will reach equilibrium moisture content. This is the condition of where the pressure of inside and outside of the material is similar. Thus, moisture content will never change. Bajpai and Tiwari (2013) stated that when a material reaches constant moisture content at the final duration of drying, then we call that the material already obtains the equilibrium moisture content. At this stage, material can't release water anymore. The decreasing moisture content curve of an agricultural product normally forms a sigmoid type which follows the first order of drying process (Mathlouthi and Roge 2003).

4.4. Equilibrium Moisture Content

After long duration of drying, material will reach to the equilibrium moisture content. The equilibrium moisture content is a state of moisture content inside material which can't change anymore because the pressure between inside and outside material is similar. Bajpai and Tiwari (2013) stated that the final moisture content of a material is called as equilibrium moisture content (Me). It is reached when the material can't release water anymore. The curve of decreasing moisture content during drying of agricultural products normally forms a sigmoid type following the first order of drying (Mathlouthi and Roge, 2003).

An equation obtained from the regression model of drying rate can be used to determine the moisture content and drying time by referring to drying phase transition point. The calculation results are showed in Table 4.3.

Table 4.3. Drying of IK chips using oven at temperature 50^{o}C

Drying time (hour)	Mo (%)	M (%)	M-Mo (%)
0	3.14	84,97	81,83
1	3.14	71,98	68,84
2	3.14	59,72	56,58
3	3.14	48,24	45,10
4	3.14	38,54	35,40
5	3.14	30,86	27,72
6	3.14	24,02	20,88
8	3.14	11,17	8,03
10	3.14	5,82	2,68
12	3.14	4,25	1,11
16	3.14	3,65	0,51
20	3.14	3,35	0,21
24	3.14	3,28	0,14
28	3.14	3,20	0,06
32	3.14	3,15	0,01
36	3.14	3,14	0

In this table, M_o = moisture content at the final stage under consideration that the final moisture content is equilibrium moisture content (%wb) and M = moisture content at any observation time.

Based on Figure 4.3, a linear regression analysis for each phase is conducted and by using semi-logarithmic model in Equation (1), we obtain that,

Regression in the first phase : $Y_1 = 1.93\text{-}0.1\ X$ ($R^2 = 0.99$) (2)

Regression in the second phase : $Y_2 = 2.51\text{-}0.21\ X$ ($R^2 = 0.99$) (3)

Regression in the third phase : $Y_3 = 0.95\text{-}0.08\ X$ ($R^2 = 0.98$) (4)

Here, Y_1, Y_2 and Y_3 represent dependent variable and X is free variable .

The interception of Equations (2) and (3) gives M = 28.26% wb and t = 5.3 hours. This indicates a transition phase between Phase I and Phase II. Meanwhile, the interception of Equations (3) and (4) gives M = 4.12% wb and t = 12 hours which occurs in the transition phase between Phase II and Phase III. The first phase shows the highest drying rate, the second phase is slower and the third phase is the lowest. Drying process using oven is merely influenced by several factors such as RH and temperature inside oven which relatively not stable during the initial stage of drying.

At the initial stage of drying, there is a phenomenon where the temperature and pressure inside the oven will cause moisture content doesn't directly change immediately. The advantage of drying using oven is that the moisture content will decrease faster because temperature and pressure are controllable and the process is continuous, i.e., not contaminated by outer environment and can maintain the quality of the product (Mujumdar 20004). In this regards, Brooker et al. (1982) stated that several factors which influence the drying process are ambient temperature, air velocity, relative humidity, component structure and surface area of the material. Besides that, see Russo et al. (2013) and Mayor and Sereno (2004), drying process is often followed by shrinkage of size and volume, changes in shape as well as in certain cellular structure such as color, aroma and hardness level.

The concept of equilibrium moisture content is very important to determine the boundaries of drying rate at each phase (Brooker et al., 1982). It is the amount of moisture content at water vapor pressure which equal to the environment (Jangam and Mujumdar 2010). The regression quations of drying rate can be used to determine moisture content and drying time, i.e., by using the interception point of the drying phases. The result of linear regression analysis is shown in Figure 4.4 where M_1 and M_2 represent limit of water content between phase I and II and the limit of water content between phase II and III.

Gao et al. (2013) stated that WSI curve is divided into three water fraction zones namely primary bound water (monolayer), secondary bound water (multilayer) and tertiary bound water (solvent, plasticize and soften products). Analysis of the fractions gives the

boundaries zone of those water fractions and also the cricital points of the material.

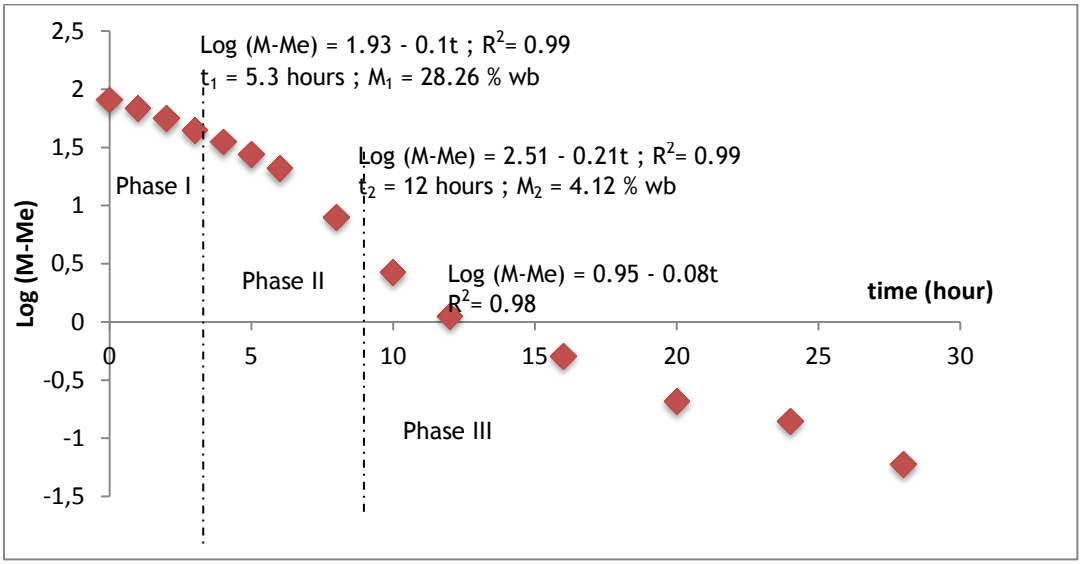

Figure 4.4. Interaction between drying rate and time during the drying process at 50 °C and transition of moisture content boundary (M_1 and M_2)

The above condition is caused by water immigration that tends to be more active during drying. Thus, water contained inside IK tubers moves to the environment or atmosphere (Vega-Galvez et al., 2011; Ramirez et al., 2011). The molecule movement which occurs during endothermist reaction also occurs in IK tubers. The occurrence of endothermist reaction in IK tubers is caused by calor movement process or heating during drying (Mathlouthi dan Roge, 2003). Calor movement inside IK tubers occurs for a certain period of time and it can reach equilibrium state after passing through molecule diffusion process, capiler flow and hydrodynamic flow (Ramirez et al., 2011).

During drying process, free water is easier and faster to evaporate while secondary bound water evaporates slower, and primary bound water is the most difficult water to evaporate. This indicates that drying occurs sequentially based on the position and the strength of water bond (Veneer and Maltini, 2013). Water which located in the surface of the material is faster to evaporate and followed by water evaporation in the inner surface in fewer amount. This is caused by bigger water bond (Sinija and Mishra, 2008; Veneer and Maltini 2013).

An understanding about equilibrium moisture content gives information about safe drying process. Thus, it can produce IK chips which meet the pre-determined quality standard and cannot be attacked by microorganism or mold. This is very important to prevent chips

deterioration during postharvest handling process of *Iles-iles* products. Evin (2012) and Moraga et al. (2006) stated that too short drying at 50^{o}C will decrease a little amount of moisture content which still can trigger the growth of microorganism. Meanwhile, too long drying at 50^{o}C can generate shrinkage and substance degradation inside material due to oxidatation and enzymatic reaction. Based on regression equation for the first, second and third phases (see Table 4.4) we can determine the drying rate limit between the first and second phases and that between the second and third phases. These equations generate the first and second critical moisture content.

Table 4.4. Regression model of drying for the first, second and third phases

Phase	T (hour)	Me	M	M-Me	Log (M-Me)	Regression
I	0	3.14	84.97	81.83	1.91	Y = 1.93 - 0.1X R^2 =0. 99
	1	3.14	71.98	68.84	1.84	
	2	3.14	59.72	56.58	1.75	
	3	3.14	48.24	45.1	1.65	
	4	3.14	38.54	35.4	1.55	
	5	3.14	30.86	27.72	1.44	
II	5	3.14	30.86	27.72	1.44	Y= 2.51 - 0.21X R^2 = 99
	6	3.14	24.02	20.88	1.32	
	8	3.14	11.17	8.03	0.9	
	10	3.14	5.82	2.68	0.43	
	12	3.14	4.25	1.11	0.05	
III	12	3.14	4.25	1.11	-0.05	Y= 0.95-0.08X R^2 = 98.5
	16	3.14	3.65	0.51	-0.29	
	20	3.14	3.35	0.21	-0.68	
	24	3.14	3.28	0.14	-0.85	
	28	3.14	3.2	0.06	-1.22	

4.5. Bound Water in *Iles-iles* Flour and Chips

Generally, water contained inside foods material is free water and bound water. As we have mentioned earlier, bound water inside IK consists of three fractions, i.e., PBW, SBW and TBW. Those water fractions determine the drying process and drying rate of IK. PBW, commonly called as monolayer moisture content, is the water strongly attached into material as a joint of hydrogen bond, interaction between ion dipole and other chemical bonds with relativey low RH (Seid and Hensel 2012, Venir and Maltini 2013). Meanwhile, SBW is located in outer layer of PBW with higher RH. In other side, TBW is located in the surface of IK chips with higher RH and weaker bond compared with SBW; usually only interacts with

hydrogen bond (Seid and Hensel 2012).

During drying process, TBW is easier to move or evaporate compared with SBW or PBW. Bond energy in PBW is higher compared with SBW or TBW. This causes PBW needs higher energy during drying. Thus, the value of PBW closes to the value of equilibrium moisture content obtained after drying process for a certain length of time.

Drying length time also determines the process of the transfer of free water into PBW, SBW and TBW. During drying process, free water moves from the material surface then followed by TBW together with SBW. PBW is difficult to evaporate because it is strongly attached to the component of material composition. The movement of TBW, SBW and PBW occurs to reach an equilibrium state. Thus, the water vapor pressure in the air and inside material is the same or constant and changing in temperature influences the pressure amount of water vapor and material (Bajpai and Tiwari 2013).

1) Primary Bound Water

Primary Bound Water (PBW) is the moisture content of a material, very strongly bound to a very deep layer of material, and is a monolayer. The moisture content in this layer is very difficult to dry; it is not easily released into the air or atmosphere. Thus, it is called as the equilibrium moisture content. One equation that can be used to determine the PBW fraction is Brunauer-Emmett-Teller (BET) equation. **According to Adawiyah and Soekarto (2010) the reason for using BET to get the PBW or monolayer fraction is that the solid surface is inert and uniform.** Observation of PBW fraction in the form of flour or chips using six observation points at a_w = 0.11 to 0.64 is shown in Figure 4.5. The BET equation can only be used at low a_w which is between 0.22-0.64 (Labuza, 1984).

General equation of BET to obtain M_p **(Primier moisture content**) is as follow,

$$\frac{\alpha_\omega}{(1-\ \alpha_\omega\ )M} = \frac{1}{M_P C} + \frac{(C-1)}{M_P C}\alpha_\omega$$

where,

M = equilibrium moisture content (% wb)
M_pC = PBW moisture content (monolayer)
α_ω = water activity
C = adsorption energy in PBW layer (monolayer)
M_p **= Primier moisture content**
That equation can be written in the form,

$$Y = a + bX$$

Y = ordinat

X = absis

$a = \frac{1}{MpC}$

$b = \frac{(C-1)}{MpC}$

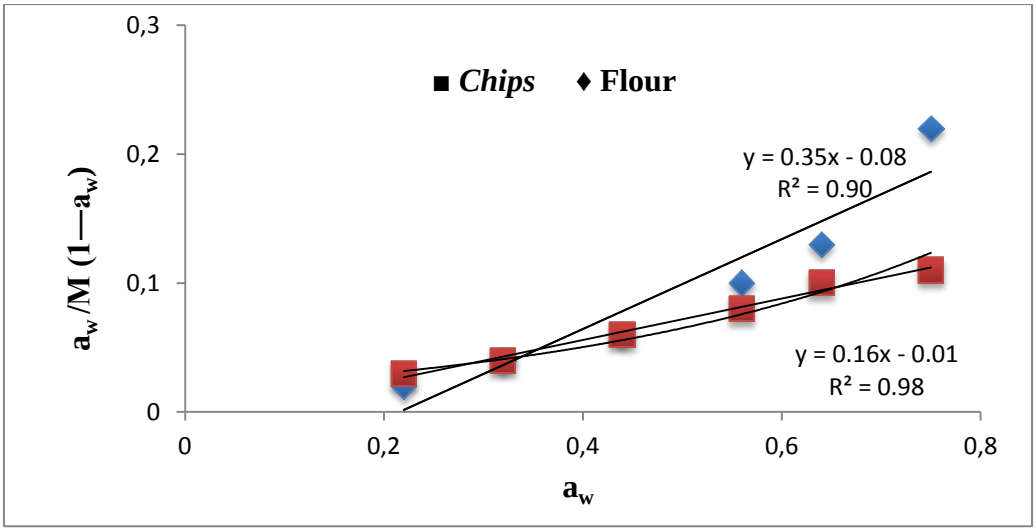

Figure 4.5. BET regression on the desorption of IK flour and chips

The regression equation of flour is given in (5) while that of chips in (6):

$$Y = -0.08 + 0.35\ X \qquad (R^2=0.90) \qquad (5)$$

$$Y = 0.01 + 0.16\ X \qquad (R^2=0.99) \qquad (6)$$

Each of these equations can produce M_p of flour = 3.70% wb and M_p of chips = 5.88% wb. The difference in PBW value in IK four and chips is due to the fact that IK chips have not reached the equilibrium moisture content yet because the surface area of chips is greater than the flour. This is slowing the equilibrium state and increasing the PBW value of the IK chips.

If we compare the PBW content in IK and that in Potatoe, Chirife and Iglesias (1978) and Yanniotis (1994) have remarked that the PBW content in potatoes is 6.86% wb. Meanwhile, according to Wang and Brennan (1991), at drying temperature 40-70 ℃ PBW value is 2.83-5.67% wb. However, Iguedjtal et al. (2008) stated that PBW in potatoes is 0.1% wb. These findings show that research on PBW value is very attractive.

2) Secondary Bound Water

SBW is the amount of water in the material that is located above the PBW layer. It forms a multilayer but weaker than PBW. Above the SBW layer is TBW. Figure 4.6 shows the interaction between moisture content and the semilogarithmic axis in IK flour and chips. SBW refers to the intersection between the first and second semilogarithmic regression equations. It is also critical point (M_s). It is the safe limit of drying from desorption of flour and IK chips. These two semilogarithmic regression equations are,

$$-\log (1-a_w) = Y_1 = -0.09 + 0.03\ X_1 \qquad (R^2=0.91) \tag{7}$$

and

$$-\log (1-a_w) = Y_2 = 0.14 + 0.02\ X_2 \qquad (R^2=0.99) \tag{8}$$

The intersection of these two equations gives M_s of flour equals to 23.00% wb.

On the other hand, the value of M_s for chips is given by these regression equations,

$$-\log (1-a_w) = Y_1 = -3.22 + 0.28\ X_1 \qquad (R^2=0.93) \tag{9}$$

and

$$-\log (1-a_w) = Y_2 = -0.64 + 0.07\ X_2 \qquad (R^2=0.69) \tag{10}$$

Their intersection gives M_s chips = 12.17% wb.

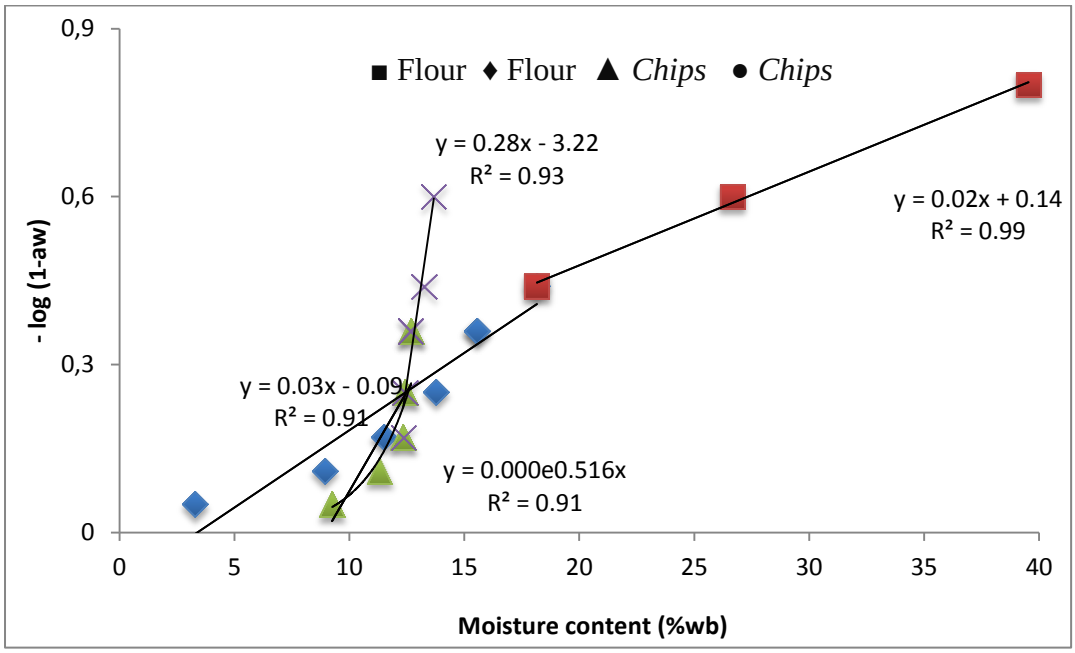

Figure 4.6. Semilogarithmic regression in IK flour and chips

Both bound water content (M_s) values must be achieved in the drying process to

confirm the safety of the dried product. When the drying process does not reach the value of M_s, then the growth of microorganism still occurs in the product. On the other hand, when the drying process passes the M_s value, it will cause physical damage to the product.

The merging of the semilogarithmic regression equations in Figure 4.6 second intersection point which is the limit of the second and third water fraction (secondary and tertiary) and that intersection value is the second critical moisture content (M_s).

Water activity is very important. It is related to the stability or deterioration of dry products. If a chemical reaction occurs in the TBW fraction, then it will cause deterioration to the dry products by the growth of microorganisms which occurs in the area of water fraction. This water activity can give an indication of the lowest limit for the growth of microorganism. In general, food derived from agricultural products can be attacked by microorganism until the limit of tertiary bound water (Aktas and Gurses 2005).

3) Tertiary Bound Water

TBW is a fraction of water which is mechanically bound water in a material network. So, its properties are almost same as free water (van den Berg and Bruin, 1981). TBW has water activity (a_w) equal to one, at a condition of room RH equals to 100%, where the material is in water-saturated condition. The formula to obtain TBW

$$\frac{\alpha_\omega}{M}\ \frac{1}{C_k\ M_\omega} + \frac{C_k - 2_k}{C_k\ M_\omega}\ a_\omega + \frac{C^2 - Ck^2}{C_k\ M_\omega} a^2\omega \qquad (11)$$

$$Y = a + bx + X^2$$

$$Y = a_\omega / M$$

$$X = a_\omega$$

The corresponding quadratic polynomial regression for IK flour is,

$$Y = 231.2\ X^2 - 237.05\ X + 74.99 \qquad (R^2 = 0.99) \qquad (12)$$

By doing visual extrapolation of Figure 4.7, when X = 1, then the tertiary bound fraction (M_t) flour = 69.14. The meaning of M_t value of flour shows the limit of tertiary bound fraction is 69.14% wb. Greater than that value of moisture content means it performs as free water fraction on the surface which is the most volatile material during drying. On the

other hand, lower value than that, means it performs as SBW fraction which is more difficult to evaporate and belongs to multilayer of the material. The value of R^2 = 0.99 indicates the suitability of the model for quadratic polynomial regression of IK (Foster et al., 2005).

Regarding the quadratic polynomial regression equation for IK chips, it isgiven by,

$$Y = 103.25\ X^2 + 130.34\ X + 54.14 \quad (R^2=0.99) \qquad (13)$$

By substituting X = 1, then M_t for chips = 27.5% wb. This value has the same meaning with the value of IK flour. The determination of free water content is done by finding the value of Y in quadratic polynomial regression equations at a_w in the interval 0.6-0.97. Water activity in the free water fraction is considered to be one because water activity value of one indicates maximum water activity. The moisture content produced in TBW fraction shows the limit of free water that can be bound by IK flour and chips. The boundary values of primary, secondary, tertiary, and free water content fractions for flour and IK chips are shown in Table 4.5. In this table, M_p = primary moisture content, M_s = secondary moisture content, M_t = tertiary moisture content, and M_f = free moisture content.

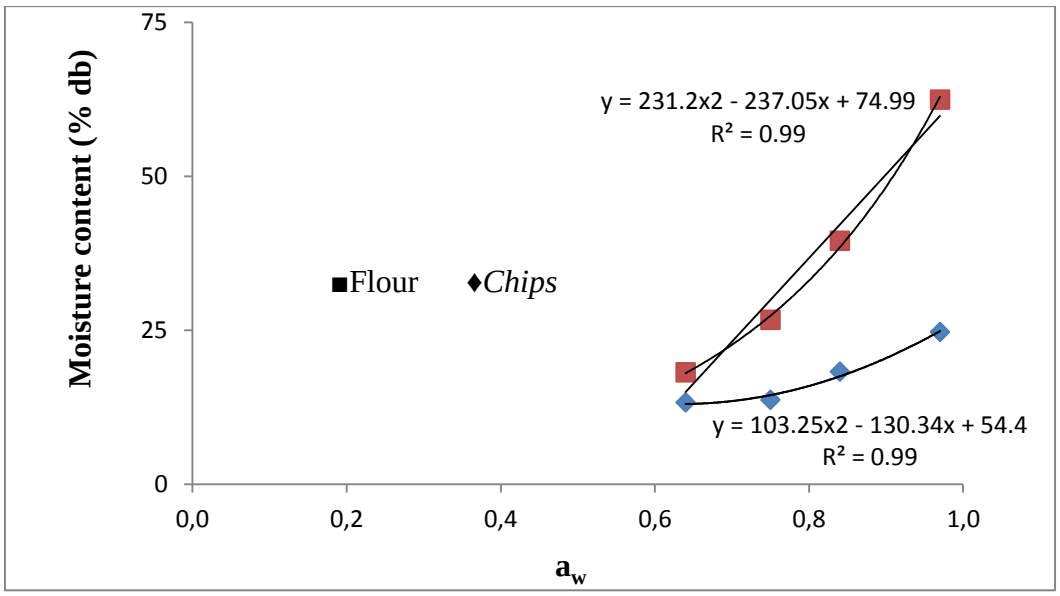

Figure 4.7. Quadratic polinomial regression of IK flour and chips

Table 4.5. The moisture content limit value of IK flour and chips

Moisture content	Value (% wb)	
	Flour	*Chips*
M_p	2.86	6.67
M_s	23.00	12.17
M_t	69.14	27.50
M_f	$\geq$ 69.14	$\geq$ 27.50

The correlation between phase boundaries of drying rate with bound water fractions is shown in Table 4.6. This table is the result of a linear regression analysis between time and moisture content at drying rate limit and sorption-desorption boundaries which produce bound water fraction to IK. The area between Phases I and II is M_1 which means the drying rate limit at the transition of the two phases. M_2 is II and III phases rate limit which is the secondary bound water and tertiary bound water fraction and above phase three is the free water fraction (M_f) which is the water fraction on the surface of the material.

Relationship between regions one and two drying rate tends to close to PBW. Meanwhile, that between regions three and four tends to close to SBW and TBW fraction values. However, the phase limit of the drying rate and the SBW and TBW fraction indicates further values. This is because the frequency of observation is less detailed or the time interval between observations is long. Observation at short time interval can be considered to obtain more precise observation in analyzing the phase limits of the drying rate.

Related to postharvest handling, an analysis of drying and absorption of water in food can be used in industrial fields. This includes drying, storage, and packaging agricultural products. The results will certainly be useful for designing drying process, storage process and packaging models (Bajpai and Tiwari 2013; Peng et al., 2007; Sinija and Mishra 2008).

Table 4.6. Correlation between drying rate limit and bound water fraction of IK

Correlation	Drying rate limit	Bound water fraction	
		Flour	*Chips*
Region 1 and 2	M_1 = 4.12	M_p=2.86	M_p=6.67
Region 2 and 3	M = 4.12-28.26	M_s=23.00	M_s=12.17
Region 3 and 4	M_2 = 28.26	M_t=69.14	M_t=27.50
Region 4 (free water)	M $\geq$ 28.26	$M_f \geq$69.14	$M_f \geq$27.50

CHAPTER V. RECOMMENDATION

Indonesian Konjac (*Amorphophallus muelleri* Blume), or IK in brief, plant produces tubers beneath the soil and it is in these tubers where glucomannan contained. Due to glucomannan content, among others, this wild plant has many industrial benefits with high economic value. This compound is not only used in cosmetics, food and beverages, health, paper, rubber, and textile industries but also useful in producing adhesive glue, producing film, in mining, and as microbial growth media. Other than that, it can also be used as the principal ingredient for producing artificial rice. This is an alternative food to substitute natural rice. Therefore, this food product can take an important role in global food security and thus in fighting global poverty.

As a wild plant, Indonesian Konjac (IK) can be domesticated as an aquaculture plant. Its cultivation is relatively easy and simple. It only needs the following environment conditions,

1. Planted under a shady plant that can hold light intensity of 50-60%,
2. Loose and sandy clay soil containing lots of humus,
3. Altitude up to 1,500 masl,
4. Rainfall of 1,000-1.500 mm per year,
5. Soil pH between 6-7.5,
6. Temperature of 26-30° C, and
7. Humidity of 60-80%

The production process from harvesting the tubers to postharvest handling process to glucomannan extraction is also relatively simple. This is diagrammatically illustrated in Figures 3.2 and 3.4 in Chapter III.

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Kisroh Dwiyono, born in Trenggalek Regency, Indonesia, on April 28, 1957. After his undergraduate degree from Gadjah Mada University in 1982, he continued postgraduate program at Bogor University and got doctorate degree in 2014. The title of his thesis "Improvement process of IK bulbs (*Amorphophallus muelleri* Blume) for glucomannan agroindustry".

From 1984 to 1986 he was a lecturer and researcher at the Faculty of Agriculture, Lambung Mangurat University, Banjarmasin, Indonesia, and then from 1987 until present he continues these professions at Univesitas Nasional Jakarta, Indonesia. As an expert in *Amorphophallus*, in 2017 he was invited to deliver a short course at Taman Botani Negara in Bukit Cherakah, Shah Alam, Malaysia, on planting Titan Arum (*Amorphophallus titanum*).

His principal achievement was taken place in 2018 where he invented the production process of "Artificial Rice" made from IK tubers and potatoes. In 2014 he first authored an article entitled "Handling of postharvest IK bulbs (*Amorphophallus muelleri* Blume): A case study in Madiun, Indonesia" and published in an Indonesian journal named *Jurnal Teknologi Industri Pertanian*. Later on, in 2019 he also first authored two articles "Effect of gibberellic acid on konjac seeds germination: Evidence from data analytics" and "The quality improvement of Indonesian konjac chips (*Amorphophallus Muelleri* Blume) through drying methods and sodium metabisulphite soaking" These articles appeared in *Modern Applied Science* journal published by Canadian Center of Science and Education (doi:10.5539/mas.v13n9p107).

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1. Gold Medal Award for Outstanding Contribution in Statistics, conferred by the Islamic Countries Society of Statistical Sciences (ISOSS), 2005.
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3. Research Fellow (UDQ5 similar to VK5-Grade A), Institute for Mathematical Research (INSPEM), Universiti Putra Malaysia, 2014 – 2016.
4. Visiting Researcher, INSPEM, UPM, many times in 2004 – 2014.
5. Visiting Researcher, Curtin University of Technology, Perth, Australia, 1998.
6. Recognition from UNESCO-AEGIS (Australian Experts Group in Industrial Study) as activist in scientific knowledge production in Asia-Pacific region, 2006.
7. Excellent Service Award, Faculty of Science, Universiti Teknologi Malaysia, 2013.
8. Award in Consultation, Universiti Teknologi Malaysia, 2011.
9. Best Lecturer Award, Dept. of Mathematics, Institut Teknologi Bandung, Indonesia, 2000.
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As an internationally recognized professional, he was:

1. Consultant at The World Bank (in data quality), 2009.
2. Board of Experts, Indonesian Lecturers Association, 2017-2022
3. APEC (Asia-Pacific Econophysics Conference), Scientific Board (Indonesian representative), since 2016
4. First General Secretary of MIPANET (Network of Indonesian Higher Education Institutions on Mathematics and Natural Sciences), 2000 – 2004 (two terms).
5. Founding Member of International Statistics Forum, South Korea, 1999.

In academic affairs, he was:

1. Highest rank of Professorship in Indonesia (IV/e) conferred by the President of the Republic of Indonesia, 2000.
2. Highest grade of Professorship in Malaysia (UDQ5 setara VK5-Grade A), Universiti Putra Malaysia, 2014-2016.
3. Professor at Harvard Business School-UTM Twin Program, 2010-2013.
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5. Director, Graduate School, Indonesian Institute of Education, 2019.
6. Chairman, Council of Professors, Institut Teknologi Bandung, 2007-2008.
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