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Review: Physical, physical chemistries, chemical and sensorial characteristics of the several fruits and vegetable chips produced by low-temperature of vacuum frying machine

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Department of Biology, Faculty of Mathematics and Natural Sciences, Sebelas Maret University. Jl. Ir. Sutami 36a Surakarta 57126, Central Java, Indonesia. Tel./Fax.: +92-271-663375. ♥email: volatileoils@gmail.com

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Abstract. *Setyawan AD, Sugiyarto, Solichatun, Susilowati A. 2013. Review: Physical, physical chemistries, chemical and sensorial characteristics of the several fruits and vegetable chips by produced low-temperature of vacuum frying machine. Nusantara Bioscience 5: 86-103.* Frying process is one of the oldest cooking methods and most widely practiced in the world. Frying process is considered as a dry cooking method because it does not involve water. In the frying process, oil conduction occurred at high temperature presses water out of food in the form of bubbles. Fried foods last longer due to reduced water contents leading to less decomposition by microbes, even fried foods can enhance nutritional value and beautify appearance. Food frying technology can extend the shelf life of fruits and vegetables, while the frying oil is used to enhance the flavor of the products, but the use of improper frying oil can have harmful effects on human health. Vacuum frying is a promising technology and may become an option for the production of snacks such as fruit and vegetable crisps that present the desired quality and respond to the new health trends. This technique of frying food at a low temperature and pressure makes the nutritional quality of the food is maintained and the quality of the used oil is not quickly declined to become saturated oils that are harmful to human health. This technique produces chips that have physical, physicochemical, chemical, and sensorial properties generally better than chips produced by conventional deep-fat frying methods.

Key words: chips, food, frying, preservation, vacuum frying

Abstrak. *Setyawan AD, Sugiyarto, Solichatun, Susilowati A. 2013. Review: Karakteristik fisik, kimia fisik, kimia dan sensoris beberapa keripik buah-buahan dan sayuran yang dihasilkan dengan mesin vacuum frying bersuhu rendah. Nusantara Bioscience 5: 86-103.* Proses penggorengan merupakan salah satu metode memasak yang paling tua dan paling banyak dilakukan di dunia. Proses penggorengan dianggap sebagai metode memasak kering karena proses ini tidak memerlukan air. Dalam proses penggorengan, terjadi konduksi minyak bersuhu tinggi yang mendesak air keluar dari bahan makanan dalam bentuk gelembung-gelembung. Makanan yang digoreng tahan lebih lama karena berkurangnya kadar air yang menyebabkan tidak terjadinya pembusukan oleh mikroba, bahkan makanan yang digoreng dapat ditingkatkan nilai gizi dan kualitas penampakannya. Teknologi penggorengan makanan dapat memperpanjang umur simpan buah-buahan dan sayuran, sementara itu minyak goreng yang digunakan meningkatkan cita rasa produk, namun penggunaan minyak goreng yang tidak tepat dapat merugikan kesehatan. Penggorengan hampa udara (*vacuum frying*) adalah teknologi penggorengan yang menjanjikan dan dapat menjadi pilihan untuk produksi makanan ringan seperti keripik buah dan sayuran dengan kualitas yang diinginkan dan memenuhi kecenderungan kesehatan saat ini. Teknik ini menggoreng makanan pada suhu dan tekanan rendah sehingga kualitas gizi makanan terjaga dan minyak yang digunakan tidak cepat rusak dan menjadi minyak jenuh yang berbahaya bagi kesehatan manusia. Teknik ini menghasilkan keripik yang memiliki sifat-sifat fisik, fisika-kimia, kimia, dan sensoris yang umumnya lebih baik daripada keripik yang dihasilkan dengan metode penggorengan konvensional.

Kata kunci: keripik, makanan, menggoreng, pengawetan, penggorengan hampa udara, *vacuum frying*

INTRODUCTION

All foods require preservation for several reasons, such as to prevent spoilage, to maintain availability throughout the year, to retain the nutritional value and to make value-added products (higher prices). Food spoilage or damage may occur during handling process due to the influence of physical, physiological, chemical or microbial damage. Chemical and microbial factors are the main causes of food spoilage. Several chemical and enzymatic reactions can occur during processing and storage of food (Mujumdar and Jangam 2012). Food preservation is usually done by preventing the growth of bacteria, fungi (e.g. yeast), and other microbes (although in some method, benign bacteria or fungi has been used to make certain foods, such as tempeh, oncom, and tape), as well as retarding the oxidation of fats which cause rancidity. Preservation of food can also include inhibition of visual deterioration during food preparation, such as the enzymatic browning reaction in salaks, apples, and potatoes after peeling. Maintaining or creating nutritional value, texture and flavor are important aspects of food preservation, although, historically, some methods drastically change the character of the food which is preserved. In many cases, these changes have come to be seen as a desirable quality, including cheese, yoghurt, and pickled onions. To preserve food, some methods are sometimes used together. Preserving fruit by turning into jam, for example, involves boiling (to reduce the water content of fruit and to kill microbes), the provision of sugar (to prevent their re-growth) and sealing in an airtight jar (to prevent recontamination) (Vivante 2009). There are various ways to preserve food, including canning, freezing, pickling, salting, sugaring (providing sugar syrup), irradiation, vacuum packaging, etc. The pre and/or post-processing steps are critical to reduce the drying load as well as to make better quality product. The common methods used for pre-treatment are osmotic dehydration, blanching, salting, and soaking. While post-processing such as coating, blending, packaging, etc. are also important after drying of food (Mujumdar and Jangam 2012).

Water content is a major cause of food spoilage, therefore the drying process is often done to reduce levels of water and extend the shelf life of food (Potter 1973). Drying or dehydration process by thermal is one of the most ancient food preservation and the most frequently used, which reduces water activity sufficiently to prevent bacterial growth; although some loss of quality occurs during dehydration. Drying has been applied to grains, seafood, and meat products as well as fruits, tubers, and vegetables. Food products can have wide ranges of water content; as low as 35% in grains and as high as 90% or more in some fruits (e.g., 93% in watermelon) which needs to be reduced to an acceptable value to avoid microbial growth. There is reported that microbes have different water activity (which means free water available for microbial growth in solids) (Mujumdar and Devahastin 2008). In addition, each food product must be dried using various types of suitable dryers and also using appropriate pre- and post-processing to obtain a satisfactory value addition to the dried product (Chen and Mujumdar 2008; Mujumdar and Devahastin 2008).

Traditionally, food products were commonly dried by open sun drying method. Recently various advanced drying methods have been practiced for food application as a result of the increased demand for high-quality products and to reduce energy consumption which is one of the highest costs in the food processing industries (Kudra and Mujumdar 2009). The use of some techniques, such as solar cabinet dryers, tray dryers, fluid bed dryers, vacuum dryers, freeze dryers, etc. has resulted in better product quality (Potter 1973; Chen and Mujumdar 2008; Jangam et al. 2010). These processes can also be made efficient costs in terms of energy consumption (Mujumdar and Jangam 2012).

Dehydration is one of the main processes in food preservation. Frying is the most widely practiced cooking method and the most cost-effective techniques for food preservation as well as for the production of traditional and innovative products such as processed snacks with desired quality (Mujumdar and Devahastin 2008). Food frying technology can extend the shelf life of fruits and vegetables, and frying oil can increase the flavors of the products, however, improper frying oil can have harmful effects on the consumer health (Inprasit 2011). Fruit into chips processing requires technological support so that the qualities of the resulting chips are acceptable for consumers. One way to produce healthy food without changing its original form is by using vacuum frying technology (Siregar et al. 2004).

This article begins by reviewing some of the conventional drying techniques used in food preservation. Later, it will focus on recent advances in vacuum frying technique for food production; as well as physical, physical chemistries, chemical and sensory characteristics of some chips of fruits and vegetables (incl. tubers) processed by low-temperature vacuum frying machine.

FOOD FRYING PRESERVATION

Fresh fruits and vegetables are highly perishable; shelf life is so short. If not handled properly, fruits and vegetables that have been harvested will undergo physiological, physical, chemical, and microbiological changes that become damaged or rotten. Meanwhile, the tubers usually have a longer shelf life, although some will soon rot in storage, such as cassava. One effort to maintain quality and shelf life of fruit and have a pretty good market is processed into chips. Chips are more durable than the stored fresh fruits or vegetables (incl. tubers) because of the low water contents and no longer occurring physiological processes such as fresh crops (Antarlina and Rina 2005; Shidqiana 2012).

Deep-fat (ordinary, atmospheric) frying is one of the oldest food preparation processes and is widely used in the food industry. Frying is a complex operation process which is basically the immersion of food pieces in hot vegetable oil, at a temperature of above the boiling point of water (Amany et al. 2009). This condition causes high rates of heat transfer, so that water evaporates and an oil layer covering the product surface (Hubbard and Farkas 1999; Bouchon et al. 2003). Several models have been developed to describe the moisture evaporation and oil absorption in deep-fat frying (Moreira and Bakker-Arkema 1989; Rice and Gamble 1989; Kozempel et al. 1991). Oil temperature and frying time are the main frying operation variables controlling mass transfer in deep-fat frying (Mittelman et al. 1984). The deep-fat frying seals the food by immersing in hot oil so that all the flavors and juices are retained by a crisp crust (Moreira et al. 1995; Troncoso et al. 2009). Fried is generally processed under atmospheric pressure at high temperatures. During the process, food is rapidly cooked, browned, and the texture and flavor are developed (Farkas et al. 1996a). Therefore, deep-fat frying is often selected as a method for creating unique flavors, colors, and textures in processed foods. Due to the higher heat treatment, surface darkening and many other adverse reactions may occur before the food is fully cooked (Blumenthal and Stier 1991).

Frying temperature can range from 130-190°C, but the most common temperatures are 170-190°C. The high temperature of the frying fat typically leads to the appreciated surface color and mechanical characteristics of fried foods; and besides that, heating the reducing sugar affects a complex group of reactions, called caramelization, which leading to browning development that defines the color of the final product (Arabhosseini et al. 2009). Some fat and oil decomposition products have also been involved in producing adverse health effects when frying oils degraded with continued use (Taylor et al. 1983; Hageman et al. 1989). In addition, heat toxic compound acrylamide can be formed during this process (Gokmen and Palazoğlu 2008; Pedreschi et al. 2004).

Frying is considered a dry cooking method because it does not require water. In the frying process, the food is immersed in a container of oil at a temperature of above the boiling point of water. High temperature and high heat conduction of oil, causing the cooked food preserved and even enhanced nutritional value and reduced degradation. The high temperature causes partial evaporation of water, which is moving away from foods and through the surrounding oil; and a certain amount of oil absorbed by the food replaces water lost (Inprasit 2011). Frying is often chosen as a method to create a unique flavor and texture in processed foods that can improve their overall tasty and palatability (Moreira et al. 1999). High heat transfer rates lead to the development of desirable sensory properties in fried foods (Farkas et al. 1996). During the frying process, physicochemical, physical, chemical and sensory properties of food will be modified. Texture, color and oil content are the main quality parameters of fried foods (Aguilera 1997; Moreira et al. 1999).

Texture is important for prominent sensory attributes of food preferences (Thygesen et al. 2001), and is a critical parameter for the quality of fried chips (Ross and Scanlon 2004). The texture of fried chips is known to be directly associated with specific gravity, total solids, starch content, cell size, surface area and pectin (Moyano et al. 2007). Textural changes during frying are the result of many physical, chemical and structural changes resulting in a complex process operation unit, which includes heat and mass transfer together with chemical reactions. Good quality chips should have a crispy crust about 1-2 mm, whereas most of the oil is located and awed, a soft center, like a cooked potato. For potato chips, very crunchy texture is expected all the way through since crispness is an indicator of freshness and high quality (Troncoso and Pedresch 2007). It is a well-known fact that texture of this product depends on the quality of raw potato and technological parameters used in the production process (Kita 2002). Crisp texture is associated with the dry matter of raw potato tubers (Thygesen et al. 2001). Crisps obtained from potatoes which is rich in dry matter (above 25%) can exhibit hard texture, whereas crisps of too low a specific gravity (low in dry matter), containing too much oil, are characterized by greasy and sticky texture. The dry matter of potato tubers is composed of various substances, i.e.: starch (15%), sugar, nitrogen compounds, lipids, organic acids, phenolic compound, mineral substances and non-starch polysaccharides (Amany et al. 2009).

Color development begins when a sufficient amount of drying has occurred in the chips and depends also on the drying rate and heat transfer coefficients during the various stages of frying. Color is visually regarded as one of the most important parameters in determining the quality of fried chips (Scanlon et al. 1994) and is the result of the Maillard reaction that depends on the content of reducing sugars and amino acids or proteins on the surface, as well as the temperature and frying time (Marquez and Anon 1986). The reduction in weight and size of dehydrated product and the increase in shelf stability can reduce product storage and distribution costs (Toledo et al. 1991). Da Silva and Moreira (2008) shows that the vacuum fried snacks (blue potato, green bean, mango, and sweet potato chips) retain more of their natural colors and flavors due to the less oxidation and lower frying temperature.

Oil absorption is one of the most important quality parameters of fried foods, but this is incompatible with consumer trend recently towards healthier foods and low-fat products (Bouchon and Pyle 2004). However, oil consumption derived from salty snack products is very high (Kuchler et al. 2004). Consumption of oils and saturated fats are specifically related to significant health problems, including coronary heart disease, cancer, diabetes, and hypertension (Saguy and Dana 2003). Other undesirable effects due to high temperatures in frying process and exposure to oxygen are the degradation of essential nutrient compounds and the formation of toxic molecules in the foodstuff or the frying oil itself (Fillion and Henry 1998). This information has raised a red flag on the human consumption of fried foods and has a significant impact on the snack food industry (Dueik et al. 2010). As a result, healthy low-fat snack products have acquired a new level of importance in the snack food industry (Moreira et al. 1999). However, even the health-conscious consumers are not willing to sacrifice organoleptic properties, intense full-flavor snacks continue to play an important role in the salty snacks market (Mariscal and Bouchon 2008).

Traditional deep-fat frying and vacuum frying are two common types of applied frying processes (Garayo and Moreira 2002). Vacuum frying is an alternative technique to improve the quality of dehydrated food (Song et al. 2007). It operates at relatively lower temperatures (e.g. 130ºC), thus the texture, color, flavor, and nutritional value is more preserved and naturally. Apart from high-quality retention in the final product obtained by vacuum frying, the main difference of these two techniques is the investment cost and operational cost. For vacuum frying, specially designed machinery and equipment are required. Both frying techniques have different benefits and disadvantages, therefore, it should carefully consider the required properties of raw materials and desired characteristics of the final product to avoid wasteful investment (Inprasit 2011).

DISADVANTAGES OF FRIED FOODS

Snack foods and especially fried chips, are popular forms of refreshment among consumers, because frying in oil helps to create a great flavor and texture. Frying is one of the oldest and most popular cooking methods in the world. Deep-fat frying is a method to produce dried food where an edible fat heated above the boiling water serves as a heat transfer medium, fats also migrate into food, providing nutrients and flavor (Fan et al. 2005; Tarmizi and Niranjan 2013). Unfortunately, deep-frying foods have some shortage. This process causes the foods to contain a lot of oils and saturated fats that are related to coronary heart disease, cancer, diabetes, and hypertension, as well as leads to formation of acrylamide on foods containing amino acid and reducing sugars (starch) that is carcinogenic and neurotoxic for human health.

Oil content

Oil absorption is one of the most important quality parameters of fried food, which is incompatible with recent consumer trends towards healthier food and low-fat products (Bouchon and Pyle 2004). Repeated use of oil at high temperature causes quality degradation through chemical reactions, such as oxidation, hydrolysis, and polymerization. The resulting decomposition products affect the flavor and color of the frying oil and fried products. These reactions impair the oil quality by increasing the amount of free fatty acids and polar compounds that affect consumers' health by causing a higher risk of developing cancer, hypertension, and coronary heart disease. In addition, food labors are also in danger, as they may breathe the oil vapor that can cause lung cancer (Hein et al. 1998; Goburdhun et al. 2000).

Consumer's preference for low-fat products has become the driving force of the food industry to produce lower oil content fried potatoes that still retain the desired texture and flavor. In order to obtain a low-fat product, it is critical to understand when, how and where the oil absorption occurs, so that the oil migration into the structure can be minimized. Several studies have revealed that most of the oil is confined to the surface area of fried product and is restricted to a depth of a few cells (Keller et al. 1986; Lamberg et al. 1990). Potato chips have become popular salty snacks for 150 years and retail sales in many countries are around 6 billion/year, representing 33% of total sales in the market fried foods (Garayo and Moreira 2002). However, potato chips have an oil content ranging from 35 to 45g/100g (wet basis), which is a major factor affecting consumer acceptance for oil-fried products today (Dueik and Bouchon 2011).

Rimac-Brncis et al. (2004) reported that the osmotic dehydration pretreatment can be an effective operation to produce low-fat chips. Pre-drying of potatoes is a common way to reduce fat uptake in the final fried product (Moreira et al. 1999, Krokida et al. 2001, Moyano et al. 2002). Drying step following the blanching step reduces the absorbed oil on potato chips (Pedreschi and Mayano 2005). The application of a proper coating is promising to reduce the oil content (Mellema 2003). The major oil fraction is suctioned by the microstructure of the potato piece when this is removed from the fryer during the cooling period, indicating that the tight oil absorption associated with the loss of moisture (Erdogdu and Dejemek 2010).

Oil absorption is mainly a surface phenomenon and the fried product absorbs most of the oil in the post-frying period (Doran 2007; Dueik et al. 2011). Oil absorption will result from the competition between drainage and suction into the porous crust once the food is removed from the oil (Bouchon et al. 2003). However, oil absorption during vacuum frying follows transport mechanisms are more complexly than those elucidated in conventional frying and is currently the subject of intensive study (Amany et al. 2009).

Oil absorption is a surface phenomenon that happens as the product is removed from the fryer due to temperature difference between the product and ambient temperature. Changes in temperature cause an increase in capillary pressure in the product pores, which causes the oil to flow into the opened pore spaces. The de-oiling process becomes more important during vacuum frying because of the pressurization process. Chip has increased the oil content following vacuum frying and depressurization due to rapid change in pressure (vacuum to atmospheric) (Moreira et al. 1997). De-oiling is one of the most important unit operation steps in vacuum deep-fat frying to ensure best quality products (Da Silva et al. 2009). Vacuum frying at 120°C under a pressure of 5.37kpa produce potato chips with acceptable quality and improved the quality of frying oil. De-oiling mechanisms are generally centrifuges, installed in a special vacuum dome attached to the vacuum frying (Amany et al. 2012a,b,c,d). However, it is sometimes manufactured separately.

Vacuum fried products of apple and potato chips significantly absorb lower oil than atmospheric fried (56.7% and 18% less oil in vacuum fried potatoes and apples, respectively). There are large differences in the drainage capacity of the two products. Apples significantly drained more oil from their surface than potato chips; and had smoother surfaces with higher drainage. Surface roughness and drainage capacity are inversely related ($r2$= 0.949). For potato products, vacuum fried chips have a rougher surface than the atmospheric fried ones (29% rougher), which may explain the lower drainage of the first ones, along with the higher oil viscosity at lower temperatures. The higher roughness of vacuum fried potatoes can be a result of pressure changes that suffer the tissue during depressurization and pressurization steps. Certainly, the surface roughness is a key factor determining its capacity to drain oil during the post-frying period, but there might be other factors such as crust microstructural parameters that affect the final oil content of fried products (Dueik et al. 2011). Moreno et al. (2010) determined that products with higher surface roughness absorbed more oil. However, this relationship is restricted to products of similar nature (either gluten or potato-flake based products categories) and cannot be extended when comparing different product categories.

Vacuum frying is a promising technology that is potential to produce low-fat chips (Dueik et al. 2010; Dueik and Bouchon 2011; Mariscal and Bouchon 2008). It is an efficient method to reduce the oil content in fried chips, maintain nutritional quality of products, and reduce damage to the oil deterioration. It is a technology that can be used to produce fruits and vegetable chips with the necessary degree of dehydration without excessive darkening or scorching of the product. Vacuum frying is a deep-frying process, which is carried out in a closed system, under pressures well below atmospheric levels (preferably lower than 7-8 KPa), making possible to substantially reduce the boiling point of water, and therefore, the frying temperature. The low temperatures employed and minimal exposure to oxygen account for most of its benefits, which include nutrient preservation (Da Silva and Moreira 2008), oil quality protection (Shyu et al. 1998) and a reduction in the generation of toxic compounds (Granda et al. 2004). Compared with other dehydration methods for fruits and vegetables, vacuum frying is a viable option to obtain high quality dried foods in a much shorter process. Vacuum fried products can absorb between 25 and 55% less oil than atmospheric fried products (Garayo and Moreira 2002; Dueik and Bouchon, 2010). Vacuum frying (driving from 60°C) can reduce the oil content of carrot crisps by nearly 50% (d.b.) compared with atmospheric fried crisps produced using the same driving force (Passos and Ribeiro 2009; Da Silva and Moreira 2008; Dueik et al. (2009).

Acrylamide formation

Deep-fat frying is one of the oldest and most common unit operations used in the preparation of foods. However, consumer fears have started to arise as acrylamide, a possible carcinogen, has been detected in foods exposed to high temperatures, including fried and baked foods (Tareke et al. 2002). Acrylamide is classified as possibly carcinogenic and neurotoxic to humans. It has been found in starch-rich foods cooked at high temperatures (Granda and Moreira 2005). Acrylamide was accidentally discovered in foods in April 2002 by scientists in Sweden when they found the chemical in starchy foods, such as potato chips, french fries, and bread that had been heated. Boiled foods and raw or unheated foods did not exhibit any formation of acrylamide (Mottram et al. 2002; Stadler et al. 2002; Tareke et al. 2002).

Although the researchers are still unsure of the precise mechanisms by which acrylamide formed in foods, many believe it is a by-product of the Maillard reaction. Development of acrylamide as a by-product of the Maillard browning is currently the most accepted theory (Stadler et al. 2002; Yaylayan et al. 2003). In fried foods, acrylamide can be produced by the reaction between asparagine and reducing sugars (fructose, glucose, etc.) or reactive carbonyls at temperatures above 120°C (Mottram et al. (2002).

Acrylamide formation in fried foods found to depend on the composition of raw materials as well as frying time and temperature. In potato chips, acrylamide is rapidly formed at more than 160°C, with the amount proportional to the heating duration and temperature. Free amino acids are used to reduce acrylamide, with lysine, glycine, and cysteine having the greatest effects in aqueous system. Lysine and glycine are effective at inhibiting the formation of acrylamide in wheat-flour snacks. In potato chips, the addition of 0.5% glycine to pallets reduced acrylamide by more than 70%. Soaking potato slices in a 3% solution of either lysine or glycine reduces acrylamide formation more than 80% in potato chips fried for 1.5 minutes at 185°C. These results indicate that the addition of certain amino acids by soaking the raw products in appropriate solutions is an effective way to reduce acrylamide in processed foods (Kim et al. 2005). Granda and Moreira (2005) show that during traditional frying potato, higher temperatures are used (150 to 180°C) and acrylamide produced after some time but started to degrade, resulting in a constant rate on the acrylamide content at longer times. In addition, during vacuum frying (10 Torr), acrylamide increases exponentially (but at lower levels) for all frying times.

Decreasing in pH is a way to reduce the Maillard reaction when it is undesirable (Schwartzberg and Hartel 1992). Jung et al. (2003) proposed a theory of acrylamide reduction by lowering the pH of the raw product prior to cooking. Stadler et al. (2002) observed that when pyrolyzed at 180°C in the presence of glucose, asparagine formed significant amounts of acrylamide (368 ppm). Appropriate reactants enhanced interaction when water is added to the reaction mixture, and there was an increase of the product (acrylamide) in reaction (960 ± 210 ppm).

Schwartzberg and Hartel (1992) suggested that one way to inhibit the Maillard reaction in cases where it is undesirable is the maintenance of lowest possible temperatures. Tareke et al. (2002) showed that acrylamide formation depends on temperature; it increases as the increase of temperature. Mottram et al. (2002) indicated that acrylamide formation increases with temperature from about 120-170ºC and then decreases. Surdyk et al. (2004) found that not only the temperature (above 200ºC) but also heating time increased acrylamide content in a yeast-leavened wheat bread crust. When the bread is baked at 270ºC for 18 and 32 minutes, the acrylamide content increased from about 300 ppb to 1200 ppb, respectively.

VACUUM FRYING TECHNOLOGY

Due to the increasing health concern and the trends toward healthier food snacks, vacuum fried foods have become a common product that can be found in the local markets. Various kinds of fried chips are now offered on the local market shelves, such as bananas, jackfruits, pineapples, salaks, mangoes, cassavas, potatoes, sweet potatoes, etc. Nonetheless, the vacuum frying process, similar to the atmospheric frying process, is quite complicated, involving coupled heat and mass transfer through a porous media, crust formation, product shrinkage and expansion, and so forth. These mechanisms all contribute to the difficulties in predicting the physical and structural appearance of the final product. Therefore, a better understanding of the frying mechanism and the heat and mass transport phenomena would be useful for food processors to produce and develop newly fried and vacuum fried snack foods for growing allegiance of healthy consumers (Yamsaengsung et al. 2008).

Vacuum frying is a promising technology that could be an option for the production of novel snacks such as fruit and vegetable crisps that present the desired quality attributes and respond to new health trends (Dueik et al. 2010). Fruits and vegetables are important sources of vitamins and antioxidants. However, average consumption of fruits and vegetables in modern societies is low due to early decay and rather high price (Da Silva and Moreira 2008). Fruits and vegetables are high in sugar content and heat sensitive, thus they are usually burned in temperature of usual frying process and lose their natural colors and flavors, unless the frying process takes place at low temperature (Shyu and Hwang 2001). One of the modern methods for fruits and vegetable processing in the world is the vacuum frying that can be performed at low temperatures and minimal exposure to oxygen (Maadyrad et al. 2011). This allows us to create products with the desired crispy texture and high nutritional value (Escaladapla et al. 2007).

In vacuum-frying, food is heated under a reduced pressure that lowered the boiling points of frying oil and water in food (Troncoso et al. 2009). Water can be removed from the fried food rapidly once the oil temperature reaches the boiling point of water. Colors and flavors can be better preserved in vacuum-fried food, because the food is heated at a lower temperature and oxygen content (Hidaka et al. 1991; Shyu et al. 1998). The absence of air during frying can inhibit oxidation including lipid oxidation and enzymatic browning; therefore, the color and nutrients of food can be largely preserved (Xu 1996; Gao and Liang 1999; Tarzi et al. 2011). Dehydrated food produced by vacuum frying can have crunchy texture, good color and flavor and good retention of nutrients. Vacuum frying also has less adverse effects on the quality of oil (Kato and Sato 1991).

During frying, the heat from the oil is confected to the product surface and then conducted to the product’s center, thus increasing its temperature. Water evaporates as the product reaches the boiling-point temperature. This process is generally regarded a Stephan type of heat transfer problem, which is characterized by the presence of a moving interface that divides two areas of physical and thermal properties (Farkas et al. 1996a). Farkas et al. (1996a, b) give separate equations for the two regions: the crust and the core, with a moving boundary. The study of these transport mechanism has led to an investigation of the effect of vacuum frying on the transport processes. For instance, several studies have shown that less oil is absorbed during the vacuum frying process (Garayo and Moreira 2002; Krupanyamat and Bhumiratana 1994; Choodum and Rojwatcharapibarn 2002; Yamsaengsung and Rungsee 2003). It has been suggested that the pressure difference between the internal pressure of the product and the vacuum pressure of the fryer help to reduce the amount of surface oil present at the end of the frying process, which in turn limits the total amount of oil absorbed.

Another important advantage of the vacuum frying is the reduced temperature which helps to maintain the natural color of the product while minimizing the loss of vitamins and minerals. In atmospheric frying, the products are generally fried at 160-190 ºC, and the water inside the product evaporates at approximately 100ºC depending on the presence of dissolved components. On the other hand, under vacuum frying, the boiling point of water can be reduced to as low as 35-40ºC, thus the frying temperature can be as low as 90-100ºC. Shyu and Hwang (2001) found that the optimum conditions for frying apple chips are at a pressure of 3.115 kPa, a frying temperature of 100-110ºC, a frying time of 20-25 minutes, and a concentration of immersing fructose solution of 30-40%. Garayo and Moreira (2002) found that potato chips fried under vacuum conditions (3.115 kPa and 144ºC) have more shrinkage volume and slightly softer, and lighter in color than potato chips fried under atmospheric conditions (165ºC). Vacuum frying can reduce levels of fat fries to 26.63% (which is normally 35.3-44.5% by deep-fat frying). Yamsaengsung and Rungsee (2003) also found that compared to atmospheric frying, vacuum fried potato chips retained in a more intense flavor and color.

Fruits and vegetables are generally dehydrated by freeze-drying, a process that can maintain their original flavor and color (Luh et al. 1975), but it is energy and time consuming (Flink et al. 1977). Many fruits and vegetables with high nutritional value, such as cauliflower, carrots, mangoes, and pineapples, cannot be processed by ordinary frying methods. However, they can be processed by a vacuum frying due to low temperature (Mariscal and Bouchon 2008). This technology is expected to improve the nutrition and health by producing products that taste good, keep most of their nutrition values, have lower fat contents than conventional fried chips, they also safer with little or no acrylamide formation, and they can be kept longer (Kemp et al. 2009). Compared with other dehydration technologies for fruits and vegetables, vacuum frying is a viable option to obtain high quality dried products within a much shorter process (Laura and Claudio 2009). It has been shown that vacuum fried chips (blue potato, green bean, mango, and sweet potato chips) retain more of their natural colors and flavors because of less oxidation and lower frying temperature (Da Silva and Moreira 2008). Vacuum fried potato chips and sliced guava have lower oil content and more natural colorations than the conventional frying process (Yamsaengsung and Rungsee 2003). Instead, Diamante et al. (2010) reported that hot air drying of green and gold kiwifruits at increasing temperatures (60 to 100ºC) leads to increased browning and ascorbic acid loss. Vacuum frying may be a good alternative for the production of fruit and vegetable dehydrated slices (Shyu et al. 1998, 2005).

DESCRIPTION OF VACUUM FRYING

The main factors influencing the fried products are combinations of time and temperature of the cooking process; the correct combination is required in producing food product with acceptable physical attributes (such as color, appearance, texture, and flavor) as well as preserving nutritional, but not stable, compounds such as vitamin C (Inprasit 2011). Several processes have been developed to manufacture low-fat products that possess the desired quality attributes of deep-fat fried food while preserving their nutritional and better sensory properties; such as extrusion, drying, and baking, which can be applied to raw food or formulated products. Unfortunately, none of them have been as successful as expected because they are still unable to impart the desired quality attributes of deep-fat fried food, such as amour, texture, appearance and mouthfeel (Dueik et al. 2010).

Vacuum frying is a promising technology that could be an option for the production of novel snacks such as fruit and vegetable crisps that present the desired quality attributes and respond to new health trends. This process is carried out in a closed system under pressures well below atmospheric levels, which makes it possible to substantially reduce the boiling point of water and thus the frying temperature (Garayo and Moreira 2002). In fact, most of the benefits of this technology is the result of the low temperatures employed and minimal exposure to oxygen. Said the benefits include: (i) reduction of adverse effects on oil quality (Shyu et al. 1998), (ii) preservation of natural color and amours (Shyu and Hwang 2001), (iii) reduced levels of acrylamide (Granda et al. 2004), and (iv) preservation of nutritional compounds (Da Silva and Moreira 2008).

Vacuum frying is the technique of deep-fat frying foods under pressures well below atmospheric levels, preferably below 6.65 kPa, which serves to reduce oil content, discoloration and loss of vitamins and other nutrients that are usually associated with oxidation and high-temperature processing (Garayo and Moreira 2002). One of its first applications was to reduce the formation of acrylamide in potato crisps, as this tends to occur during high-temperature processing of high carbohydrate foods (Granda et al. 2004). It has also shown some success in producing vacuum fried products with other foods, including pineapple, apples, carrots, blue potato, sweet potato, beans, mangoes and jackfruit (Da Silva and Moreira 2008; Diamante 2009; Mariscal and Bouchon 2008; Perez-Tinoco et al. 2008; Fan et al. 2005). Figure 1 shows the schematic diagram of vacuum frying system.

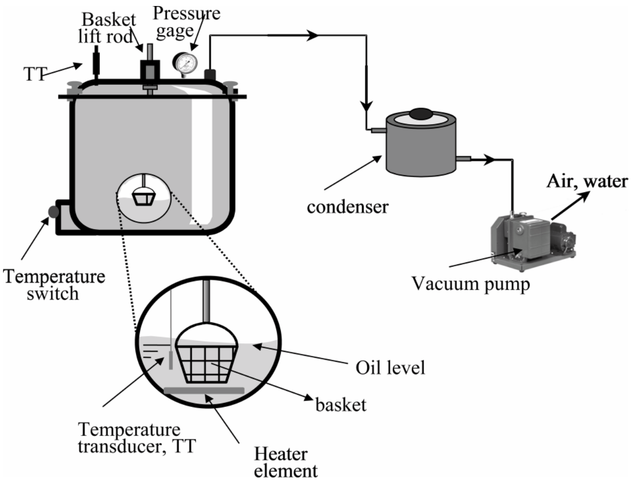

Figure 1. Schematic of the vacuum frying system (Garayo and Moreira 2002)

When the frying is carried out under atmospheric pressure, boiling point of water reduces; hence, higher temperatures are not required to remove moisture from the food. Deteriorating effect on the food due to heat will be less. The following is a brief explanation of governing theories: (i) Water evaporation under vacuum. Boiling point of water is 100ºC at atmospheric pressure. Evaporation of water at this temperature occurred together with the loss of some food nutrients. Under vacuum water is boiled and evaporated at lower temperature even at 0 ºC so that nutrients loss is reduced especially for heat-sensitive nutrients. (ii) Heat transfer. For hot air dryers, heat is transferred by convection using hot air as the medium. Air has relatively lower heat transfer coefficient. Contrast to the air, in a vacuum frying, vegetable oil has higher heat transfer coefficient. Therefore shorter time is required to reduce water content. (iii) Frying temperature. Automatic temperature control system, when used, provides a mechanism by which moisture is reduced while food temperature is controlled by the system. Constant temperature of the food results in uniformity of product quality (Inprasit 2011).

Stages using vacuum frying machine is as follows: The material to be fried is prepared (peeled and sliced with a thickness of 0.50-1 cm). If the water content is high, the spinner machine can be used to reduce the water content. Fryer tube is filled with frying oil. To 4 kg of fresh fruit, it is required 40 liters of frying oil. The raw materials are put into the frying basket; the basket position is appointed (not submerged in oil). The frying machine and gas stove is turned on and the temperature is set. Furthermore, fryer tube is closed to get the vacuum condition. After the pressure needle pointing at-680 mm Hg, the basket is lowered down into the submerged position. Raw material is fried until drying. After completed frying, the position of the basket is moved up (not submerged in oil), and the electric installation and stove is turned off. Tap of the fryer tube is opened until the pressure needle pointing at 0 mm Hg. Then, the fryer tube is opened; and chips is removed and dried by using spinner machine. Chips is cooled and packaged in plastic (PP 0.80 mm) or aluminum foil bags and then sealed (Kamsiati 2010).

The oil uptake mechanism of vacuum frying is still not fully understood. During normal operation, the product is placed inside the frying basket once the oil reaches the target temperature. The lid is then closed and the chamber is depressurized. Subsequently, the basket is immersed in the oil bath, where it remains for the required amount of time. It is then lifted out and the vessel is pressurized using a pressure release valve. This results in a sudden increase in the surrounding pressure, which may force the vapor inside of the pores to condense, which means that oil absorption may precede cooling. The low pressure may allow air to diffuse faster into the porous structure, obstructing oil passage and leading to lower oil absorption than is observed in atmospheric frying. Vacuum fried potato crisps absorb less than half the oil of crisps fried under atmospheric conditions (Garayo and Moreira 2002). Mariscal and Bouchon (2008) state vacuum fried apple slices absorbed slightly less oil, and presented better results for color preservation than atmospheric fried samples.

BENEFIT OF VACUUM FRYING

Vacuum frying may be an option for the production of fruits and vegetables with low oil content and the desired texture and flavor characteristics. It is defined as the frying process that is carried out under pressures below atmospheric levels, preferably below 50 Torr (6.65 kPa). Due to the lowering pressure, boiling points both of oil and moisture in the foods lowered (Garayo and Moreira 2002). Vacuum frying technology has the advantage of low oxygen existed in the system resulted in the low rates of frying oil oxidation and lower boiling point of below 100ºC. Vacuum fried products have better aroma and flavor similar to that of fresh fruit and tubers (vegetables). In fact most of the benefits of this technology are the results of low temperatures used and minimal exposure to oxygen. The benefits include: (i) reduction of adverse effects on the oil quality (Shyu and Hwang 1998; Shyu et al. 1998), (ii) the preservation of natural colors and flavors (Shyu and Hwang 2001), (iii) decreased of the acrylamide content (Granda et al. 2004), and (iv) the preservation of nutritional compounds (Da Silva and Moreira 2008).

Vacuum frying was tested as an alternative technique to develop low oil content of potato chips. During vacuum frying, oil temperature and vacuum pressure had a significant effect on the drying rate and oil absorption rate of potato chips. Fried potato chips at low vacuum pressure and higher temperature had less volume shrinkage. Color was not significantly affected by oil temperature and vacuum pressure. Hardness values increased with increasing oil temperature and decreasing vacuum levels. Potato chips fried under vacuum (3.115 kPa, 144ºC) had more volume shrinkage, slightly softer, and lighter in color than the potato chips fried under atmospheric conditions (165ºC). Vacuum frying is a process that could be a feasible alternative to produce potato chips with lower oil content and the desired color and texture (Garayo and Moreira 2002).

Vacuum fried products have low water content (<6%) and low water activity (aw<0.3) (Tawong 2000; Piamkhla 2004; Wongsuwan and Laosuksuwan 2006), so it has a long shelf life. Under vacuum condition, frying temperature is constant and not higher than 100ºC and frying time is not longer than 2 hours. Obviously, vacuum frying is an energy efficient process. The products are crispy and retain its original color, taste, and odor as of the natural foods (Granda et al. 2004).

Vacuum frying can process heat-sensitive commodities such as fruits being processed in the form of crisps (chips), such as jackfruit chips, apple chips, banana chips, pineapple chips, melon chips, and papaya chips, etc. Compared with conventional fryers, vacuum systems produce a much better product in terms of color appearance, aroma, and taste like a fruit because it is relatively original (Siregar et al. 2004).

In vacuum frying, vegetable oil is used as a heat transfer medium. The foods may absorb oil, therefore, there will be oil remaining in fried products making them undesirable and may raise health concern among consumers. There are many research works which have been described techniques to reduce oil absorption during vacuum frying. Pre-coating with guar gum is one of the recommended techniques. Banana coated with guar gum before frying under vacuum has lower oil content of 8% compared to vacuum fried banana without guar gum pre-coating, which has 12% oil content. Oil absorption, however, varies with the chemical properties of raw materials. Different pre-treatment techniques and processes will be applied to produce a good quality of vacuum fried products (Inprasit 2011).

In financial terms, the investment cost of vacuum frying process is much higher than that of deep frying. This is because the vacuum frying technique is basically designed for large-scale industry. There is a lack of vacuum fryer design for small scale production. Small scale producers such as farmers' group, small community enterprise, and cooperatives are difficult to buy vacuum frying machinery and equipment without financial support from the government. High investment costs are substantial disadvantage in applying vacuum frying in small-scale production (Inprasit 2011). Although, it is the cost-investment, among several deep-fat frying technologies, vacuum frying has significant strategic importance for the future fried food manufacturing. This technology offers significant benefits such as improved product safety and quality cooking oil and oxidation are reduced due to low-temperature processing (Granda et al. 2004).

RAW MATERIALS FOR VACUUM FRYING

Raw materials that are not eligible for fresh consumption and are not eligible to be sold as fresh fruits and vegetables such as too big or too small, not smooth on the surface or have defects, are selected for vacuum frying. Unqualified fruits and vegetables are cheap. They should be washed, peeled, and trimmed to remove defects and uneatable parts before vacuum frying. Defects are not detected in fried fruit products. Therefore vacuum frying should be applied to reduce waste because they can use unqualified raw material for processing. Ripe fruits, which have high sugar content, are popularly fried under vacuum because it is not possibly fried at atmospheric pressure. In the fruit and vegetable industry, many kinds of fruits and vegetables are wasted from pruning. These parts are in good quality but their sizes and shapes do not meet the processing standards. Vacuum frying help improves the commercial value of the waste (Inprasit 2011). Figure 2 shows the flow diagram for the processing of vacuum fried pineapple.

The selection of fruits suitable for vacuum frying is based on the followings (Inprasit 2011):

Variety. Chemical and physical properties of fruits and vegetables vary depending on the variety. These properties affect the quality of fried products. Thin flesh jackfruits can be fried as a lump of pulp whereas thick flesh jackfruits should be chopped into small pieces before frying. The thickness of raw materials affects the vacuum frying process. Crispy and soft texture of vacuum fried jackfruits is obtained together with uniformity of the water content when raw material thickness is efficiently controlled. Freezing is a recommended pre-treatment to obtain crispy vacuum fried products.

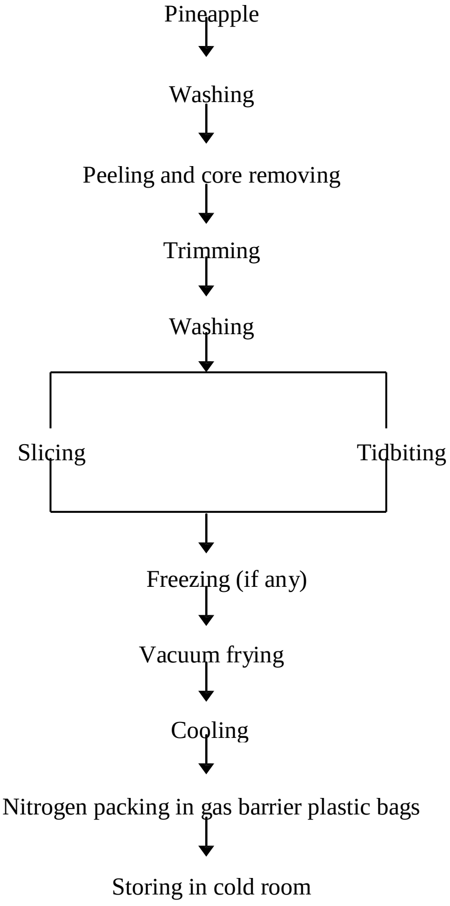

Figure 2. Flow diagram for processing of vacuum-fried pineapple (Inprasit 2011)

Ripeness. Vacuum frying is effectively used for frying high sugar fruits that have sweet taste fried products. Fruit subjected to vacuum frying should not have any astringent taste. Fruits should be ripe but not be too ripe because the high sugar content induces high oil absorption during frying. Likewise, ripe fruits should not have too soft texture due to breaking of fruits to small pieces occurs from rapid evaporation of water during vacuum frying. Vacuum frying of too ripe durian produces small pieces of fried products.

Taste. Vacuum frying is a process of evaporating of water at low temperature to retain natural flavor and minimize nutrient losses. Original fruit flavors should be considered for the selection of raw material. Stronger taste of fried products is observed when compared to the taste of raw materials. This is due to very little excreting saliva during eating fried products, therefore, a strong taste of the high concentration of flavor components is observed. Vacuum fried pineapple has a very sour taste when made from sour pineapple. Also too sweet ripe fruits should not be selected as raw materials for vacuum frying due to its high content of sugar cause caramelization.

Water content. It is usually difficult to fry high moisture fruits. Plenty of water must be removed during frying. Fruits will be burned before they dry and shrinkage will occur during water evaporation. Freezing of high moisture raw materials before vacuum frying such as longan and lychee is recommended to keep the water evaporation at a lower temperature.

Seasonal fruits. Some fruit is seasonally grown and harvested. Domestic and export markets cannot always absorb the entire production. Excess fruit during the season reduces the price. This is an important issue in developing agricultural countries. Frying can be applied to extend the shelf life of seasonal fruits.

PROCEDURE FOR HANDLING

Vacuum fried product is much susceptible to spoilage during storage, especially in tropical and humid conditions. It can easily absorb moisture from storage environments. Therefore, manufacturers should separate package of fried products that have different water content because, in the same packaging, moisture can move out from high moisture product and be absorbed by low moisture product. Then product crispiness decreases and consumer will reject the products. Fried product quality changes when stored at high temperature such as shop standing in open space or in cars and containers parking in the sun. This also causes loss of product crispiness (Inprasit 2011).

Among the important properties of deep and vacuum, fried products are nutrition values, consumer acceptability, and safety of frying oil. These qualities can be controlled by proper selection of raw materials. One of properties that affect consumer acceptance is crispiness of fried products. Crispiness of deep fried product changes rapidly after frying because it mainly consists of sugar and easy to absorb moisture. Whereas crispiness of vacuum fried product does not change much because it consists of starch, which absorbs less moisture after frying. In addition, the type of raw material thickness affects product crispiness. Thin slices required to obtain soft crispy and dried texture after frying. Manufacturers have to change frying oil when oxidized and unsafe for consumers. During the frying process, quality of frying oil should continue to be monitored. Frying oil should be changed frequently due to changes in the physicochemical properties of the oil that will affect the quality of the product and oil uptake during frying. In addition, toxic compounds can be generated in deteriorated frying oil, which is harmful to human health (Inprasit 2011).

Evaluation of frying oils can perform the following methods: (i) Sensory evaluation: Used frying oils are generally considered as deteriorated when they clearly indicate an objection smell or taste, for example, strong mildew, strongly gritty, rancid, vanish, or bitter; and showed intense smoke and foam formation during frying. These sensory impressions are objectified through further analytical criteria such as polar compounds and polymer triglycerides. Intensify the dark, however, is not a measure of deterioration. This color change is caused by the reaction of proteins with fat or sugars components. (ii) Quick tests: Colorimetric procedures to determine the amount of degradation products of fatty acids (carbonyl compounds). Color reaction aims to determine portion of the polar compounds or acid value. Redox reaction determines the amount of oxidized fatty acids. It also needs to measure the height of the foam, viscosity and dielectric properties. (iii) Analytical methods: Physical methods include determining the smoking point, viscosity, conductivity, constant dielectricity, and the Lovibond color index. Chemical methods include the determination of free fatty acids (acid value) by acid-base titration, polar compounds by chromatographic procedures, and also triglyceride polymers and oxidized fatty acids (Inprasit 2011).

Manufacturers should follow the following guidelines to control the quality of fried chips products (Inprasit 2011): (i) Manufacturers should use control sheet presented to control frying operation and also responsible operators. (ii) After frying, manufacturers should remove high moisture fried product by pressing and observing the soft texture and then bring that product to fry once more to get the low water content and desired crispiness. (iii) For storing fried products prior to packaging, manufacturers should use containers that can be sealed to prevent moisture transfer and store products in the shade at low temperatures. The best-storing method is packaged in a double polypropylene (PP) plastic bag and then placed in a sealed plastic bucket. (iv) For retail packaging, manufacturers should use containers that can be sealed to prevent moisture transfer such as aluminum foil bag, aluminum foil bag in a paper box, paper can be coated inside with aluminum foil and metal can. Fried product shelf life is not less than six months when the manufacturer follows the above guidelines. Long shelf life can be obtained when using nitrogen gas packaging. According to Piamkhla (2004), the shelf life of vacuum fried ripe banana is six months when packaged in a plastic bag that can be flushed with nitrogen or putting moisture absorbent.

LESSON LEARNED FROM SEVERAL CHIPS

Many vacuum fried products are introduced in the markets. Fruits, tubers and other vegetables are the most widely processed food with vacuum frying method, but some types of meat and fish are also treated with this method, such as shrimp, squid, green shell mussels (Taryana 2012), sepat-siam (Suwanchongsatit et al. 2004), lemuru (Manurung 2011), tongkol (Nufzatussalimah 2012), beef (Shofiyatun 2012) and others. Some types of fruits and vegetables that have been processed into chips with vacuum frying method are: banana (Garcia and Barette 2002), banana peel (Dewantara 2012), jackfruit (Alamsyah et al. 2002), durian, mango, pineapple, taro, yam, baby corn (Inprasit 2011), carrot (Fan et al. 2005), okra (Arlai 2009), garlic, sapodilla (Paramita 1999), gembili (*Dioscorea aculeata*) (Wibowo 2012), chickpea (Widaningrum et al. 2008), salaks (Maulana 2012), apple (Shidqiana 2012), tapioca (Binti Zahroni2012), cassava (Aprillia 2007), eggplant (Nur-Aeny 2012), potato (Granda et al. 2004), kiwi fruits (Diamante et al. 2011), pumpkin (Mehrjardi et al. 2012), melon (Arum 2012), sweet potato (Abdullatif 2012), tempeh (Kato and Sato 1991), etc.

Potato (*Solanun tuberosum*)

Potato (*Solanum tuberosum* L.) is one of the world's major agricultural crops and it is consumed daily by millions of people from diverse cultural backgrounds (NPC1988). The potato is best known for its carbohydrate content (approximately 26 grams in a medium potato). The potato contains vitamins and minerals, as well as an assortment of phytochemicals, such as carotenoids and natural phenols. Large variation in suitability of potato for processing of crisp and French fries have special quality demands compared to ware potatoes. Unfortunately, potato chips fried conventionally produce acrylamide that harmful to human health.

Potatoes and other foods that have a high content of the amino acid asparagine and a high accumulation of reducing sugars are subject to the formation of acrylamide during frying (Granda et al. 2004). Acrylamide has been classified as probably carcinogenic in humans (Rosen and Hellenas 2002; Tareke et al. 2002). Reducing acrylamide in food industry can only help the public perception about safety, which has suffered in recent years. Acrylamide formation can be diminished by adding amino acids such as lysine, glycine, and cysteine (Kim et al. 2005). Lowering the pH with citric acid before frying was effective in diminishing acrylamide formation (by about 73%) in French fries when fried for 6 minutes at 190 °C in an atmospheric fryer (Jung et al. 2003). However, according to Pedreschi et al. (2004), the effect of citric acid immersion on acrylamide reduction was not obvious in their experiment with potato chips fried at 170°C and 190°C. On the other hand, the blanching process led to a significant reduction in acrylamide content of their chips. Haase et al. (2003) reported that by lowering the frying temperature of potato chips from 185°C to 165°C, it was possible to reduce the acrylamide formation by half.

Among several deep-fat frying technologies, vacuum frying has a significant strategic importance for future fried manufacturing and in reducing acrylamide formation (Garayo and Moreira 2002; Granda et al. 2004). Vacuum frying reduced acrylamide formation in fried potatoes by 94%. As the frying temperature decreased from 180°C to 165°C, acrylamide content in potato chips reduced by 51% during traditional frying and by 63% as the temperature decreased from 140°C to 125°C in vacuum frying. Increased frying time increased acrylamide formation during frying for all temperatures and frying methods analyzed. However, the effect on acrylamide concentration was greater for the traditional frying than the vacuum frying (Granda et al. 2004). Acrylamide formation decreased dramatically as the frying temperature decreased from 190 to 150°C for all the pre-treatments tested. Color represented by the parameters L^* and a* showed high correlations ($r2$ of 0.79 and 0.83, respectively) with French fry acrylamide content (Pedreschi et al. 2006).

Carrot (*Daucus carota*)

Carrot (*Daucus carota* L. var. *sativa* D.C.) has the highest carotene content of any human foods (Desobry et al. 1998). Carotene, a source of pro-vitamin A, may play a role in protecting the body from numerous diseases that are associated with oxidative stress and damage (Handelman 2001), and it also has many non-antioxidant properties that affect cellular signaling pathways, modify the expression of some genes and can act as inhibitors of regulatory enzymes (Stahl and Ale-Agha 2002). To maximize the use of carrot as a source of pro-vitamin A, it is important to find an appropriate processing method to manufacture products that are not only highly preferred by consumers but also are good nutritional sources of pro-vitamin A.

Vacuum-fried carrots may be a promising snack category due to the fact that this technology makes it possible to overcome major carotenoids degradation pathways due to isomerization and oxidation and thus preserve biological activity. Vacuum fried crisps (driving force of 60°C) may reduce the oil content of carrot crisps by nearly 50% (d.b.) compared to atmospheric fried crisps produced using the same driving force. Furthermore, they preserve around 90% of trans-a-carotene and 86% trans-b-carotene, which leads to the preservation of the color of raw carrots. This is reflected by *L*, a*, b** color coordinate analyses, excellent linear correlations between *a** and trans b-carotene content (*r2* = 0.95), *b** and trans a-carotene content (*r2* = 0.78), and hue and total carotenoids content (*r2* = 0.91), when comparing values of fried crisps at bubble-end point. As a result, vacuum frying may be a useful process in the production of novel snacks that present desired quality attributes and respond to new health trends (Dueik et al. 2010).

Bananas (*Musa paradisiaca*)

Bananas (*Musa x paradisiaca* L.) are one of the world's most traded fruit in both fresh and processed forms. Bananas are an excellent source of vitamin B6, soluble fiber, and contain moderate amounts of vitamin C, manganese and potassium (USDA NND 2012). Along with other fruits and vegetables, consumption of bananas may be associated with a reduced risk of colorectal cancer (Deneo-Pellegrini et al. 1996) and in women, breast cancer (Zhang et al. 2009) and renal cell carcinoma (Rashidkhani et al. 2005). The fruit color significantly influences the market quality and consumer acceptability of fresh banana and processed bananacolor. For vacuum-fried, banana slice products are prepared by peeling and slicing before vacuum-frying. In this preparation step, as a result in slicing and waiting for processing, there is accumulation of cell fluids, especially the phenolic compounds, on the cut surface and their exposure to oxygen, leading to browning (Garcia and Barette 2002).

Phenolic compounds undergo oxidation to brown compounds that discolor fruits, reducing their quality (Rocha and Morais 2001). Discoloration is known as enzymatic browning which results from the action of a group of enzymes called polyphenol oxidase (PPO). PPO has been reported to occur in all plants and exists in particularly high amounts in mushroom, banana, apple, pear, potato, avocado and peach (Garcia and Barette 2002). PPO catalyzes, in the presence of oxygen, the oxidation of mono-and di-phenols to *o*-quinones; these products are highly reactive and can either polymerize spontaneously to form high-molecular-weight compounds or brown pigments or react with amino acids and proteins to enhance the brownish color produced (Vamos-Vigyazo 1981; McEvily et al. 1992).

Inhibition of enzymatic browning can be achieved by a number of strategies that can be divided into three classes, depending on whether they affect the enzymes, substrates or reaction products, although in some cases, two or three targets can be affected at the same time. In addition, enzymatic inhibition can be reversible or irreversible; the latter case often achieved by physical treatment (heat), while chemicals may act in one or another way. The control of enzymatic browning has always been a challenge to the food industry. For using chemical treatments, several types of chemicals are used in the control of browning; some act directly as inhibitors of PPO, others by rendering the medium inadequate for the development of the browning reaction, still others act by reacting with the products of the PPO reaction before these can lead to the formation of dark pigments (Nicolas et al. 1994). Banana chips coated with an edible coating and produced using the higher speed during the oil centrifuge step in the vacuum-frying process maintained a good quality with low oil content, representing a healthier snack for consumers (Sothornvit 2011).

Banana peel is a byproduct of the use of bananas that can be used as snack foods like banana peel chips. The banana peel contains a lot of water (68.90%) and carbohydrate (18.50%). To produce chips with good quality in terms of color, aroma, and taste, the temperature setting should not exceed 85◦C and vacuum pressure between 65-76 cm Hg (Dewantara 2012).

Kiwi fruit (*Actinidia deliciosa*)

Kiwi fruit (*Actinidia deliciosa* [A. Chev.] C.F. Liang et A.R. Ferguson) is native to southern China (Scott et al. 1986). Kiwi fruit is a highly nutritional fruit due to its high level of vitamin C and it has a strong antioxidant activity due to carotenoids, lutein, flavonoids and chlorophyll contents (Cassano et al. 2006). Furthermore, kiwi fruits have a very short shelf-life due to their highly perishable nature, and they are not only consumed as fresh fruits but also as processed foods in the form of jams, juices, canned fruits, frozen and dehydrated products (Abedini 2004; Emamjome and Alaedini 2005).

The color and the shrinkage of kiwi fruit chips were significantly ($p<0.05$) correlated with the frying temperature and time, while the crispiness was affected only by the frying temperature. There was no significant relation between the vacuum pressure and the responses except the shrinkage. Sensory evaluation indicated that there were no significant differences ($p<0.05$) between the vacuum fried kiwi slices and the dried kiwi chips except flavor. The optimum conditions for the vacuum frying of kiwi slices were found to be: 105ºC, 62 mbar, and 8 minutes, for the frying temperature, the vacuum pressure and the frying time, respectively **(**Maadyrad et al. 2011).

Shallot (*Allium cepa* var. *aggregatum*)

Shallot (*Allium cepa* L. var. *aggregatum* G. Don) is an elementary spice of Southeast Asia as well as the world. Shallots appear to contain more flavonoids and phenols than other members of the onion genus (Yang et al. 2004). It was proven to increase high-density lipoprotein (HDL) cholesterol, reduce low-density lipoprotein (LDL), reduce cholesterol in the blood and control blood sugar. Thus it would be beneficial to develop a snack from shallot. Deep-fat fried snack is one of the most tasteful products. However, high-fat content could reduce consumption due to a health concern issue; and uses high temperature in an opened system speeds up oxidation and thereby rancidity development. Vacuum frying could be used to reduce fat content, frying temperature and slow down rancidity of oil. To minimize fat content of fried snack, shallot should be fried under vacuum 551 mm Hg and 108°C for 13 minutes. The optimal vacuum frying condition was conducted to compare with the deep-fat frying. Vacuum fried shallot showed the improvement of product color as well as a decrease in fat content in the finished product. After 7 continuous vacuum frying processes, a slight change in acid value for the oil was found. Therefore, the optimal vacuum frying condition could be applied to produce fried snack from shallot (Therdthai et al. 2007).

Salaks (*Salacca edulis*)

Salaks or snake fruit (*Salacca edulis* Reinw.) is one of the horticultural commodities that have high potential to be explored and developed in Indonesia. Salaks fruit contains nutrients such as protein, carbohydrates, dietary fiber, calcium, phosphorus, iron, carotene, and thiamine that are good for body health. The mass production of salaks makes an excess amount of salaks distributed in the market; salaks become wasted and priceless. To prevent the decreasing value of salaks, it can proceed into fruit chips. The process of making salaks chips start from the frying stage. In order to pretend the composition and the taste of salaks chips, vacuum frying is used. After fried, salaks must be packaged with suitable packaging to provide a longer shelf life of salaks chips. Aluminum foil is the best packaging for salaks chips comparing to polypropylene and laminated plastic because aluminum foil has the lowest transmission rate of water and oxygen (Maulana 2012).

Melon (*Cucumis melo*)

Melon (*Cucumis melo* L.) is an annual plant that is pervasive or a year or vines. Melon fruit is an excellent source of vitamin A and vitamin C, and a good source of potassium. Optimum temperature for the manufacture of melon chips is 75°C with a time of 55 minutes. Chips with this variable has a sweet, brownish orange color, crisp, and has aromas of melon and entrained water content is equal to 92.406% (Arum 2012).

Papaya (*Carica papaya*)

Papaya (*Carica papaya* L.) is pretty much cultivated in Indonesia. Papaya fruit is a source of nutrients such as pro-vitamin A carotenoids, vitamin C, folate and dietary fiber. Papaya skin, pulp, and seeds also contain a variety of phytochemicals, including lycopene and polyphenols (Echeverri et al. 1997). Generally, processed papaya products on an industrial scale are still a household nata and candy. In fact, papaya has a huge production to be processed into other products, such as fruit chips. In vacuum frying process, administration of $CaCl_2$ can improve the texture of papaya chips. Calcium chloride is widely used to improve texture of the processed fruit and vegetable products; it can also be used for texture chips, because it can reduce the decomposition of the cells that cause tissue softening (Indera-Sari 2012).

Sweet potato (*Ipomoea batatas*)

Sweet potatoes (*Ipomoea batatas* (L.) Lam.) have been an important part of the diet in the world and are a staple of human consumption, led by New Guinea at about 500 kg per person per year. Considering fiber content, complex carbohydrates, protein, vitamins A and C, iron, and calcium, the sweet potato ranked highest in nutritional value to other vegetables (CSPI 1992). For vacuum frying, sweet potato was sliced into 2 mm thickness and pretreated with 1% (w/w) NaCl solution and 1% (w/w) $CaCl_2$ solution for 1 hour prior to frying process. Pre-treated slices were fried at atmospheric condition (180°C) and vacuum condition (120°C, 130°C, 140°C) for 5 minutes. In general, pre-treatments gave a significant effect to the texture, color and oil contents of atmospheric fried crisps. NaCl pretreated crisps showed the best crispness and color quality compared to the control. For vacuum fried crisps, breaking force (N) increased with increasing oil temperature. Oil absorption of control slices showed no significant difference ($p<0.05$) at all frying temperature, while NaCl pre-treated slices showed an increase with temperature increased. In contrast, $CaCl_2$ pre-treatment increased oil absorption with increasing frying temperature. As frying temperature increased, the lightness of crisps was decreased, while $a*$ and $b*$ value were increased in all pretreatment. The best texture of crisps was obtained at 130°C vacuum frying temperature. Comparing between atmospheric and vacuum fried crisps, there is no significant difference ($p<0.05$) in terms of fracturability of crisps. However, oil absorption of vacuum fried crisps is 7.12% less than atmospheric fried. The color of vacuum fried crisps was also lighter than atmospheric fried. Sensory evaluation revealed that consumer can accept the quality attributes of vacuum fried crisps. There is no significant difference between vacuum fried and atmospheric fried crisps in terms of color, crispness and overall acceptability (binti Ismail 2011). In Cilembu sweet potato chips, the optimum quality of the vacuum frying is 35 minutes treatment; and is obtained flavor, color, and crispness to the optimum water content of 17.4% (Abdullatif 2012).

Okra (*Abelmoschus esculentus*)

Okra (*Abelmoschus esculentus* L. Moench) is an important economic vegetable of the world. Okra is a popular health food due to its high fiber, vitamin C, and folate content. Okra is also known for being high in antioxidants. Okra is also a good source of calcium and potassium (Duvauchelle 2011). Processed okra is an important agricultural product. During processing, many of important quality compounds in okra maybe lost. The vacuum frying treatment reduced the physical and chemical quality of okra, but increased beta-carotene content. The moisture heating and vacuum fry processing affected the quality of okra chips. The processing appeared to affect the chemical quality of organically grown okra less than conventionally grown okra, especially vitamin C and beta-carotene contents. The rate of chemical decline was lower with the blanching process, especially the vitamin C content, whilst vacuum frying resulted in the highest levels of beta-carotene. The growing area, environmental conditions and climate where the different okras grew may partially affect to those of physical and chemical qualities (Arlai 2009).

Gembili (*Dioscorea aculeata*)

Gembili (*Dioscorea aculeata* L.) is one of the types of tubers that have not been cultivated and not many people know. The nutritional value is not known yet. This plant is widely grown in the rural areas which are usually used as a substitute food for rice, snack, even just left alone to grow. In this time, the processing gembili as food only to the process of boiling or steaming, so the need for the utilization gembili processed into new products that have high sales value through the manufacture of chips such as food diversity efforts. From the experiments conducted with gembili weight 300 g, frying temperature 75◦C and changing variables such as frying time of 20, 25, 30, 35 and 40 minutes in the manufacture of vacuum frying chips of gembili showed that the longer the frying pan, the water content is more and more vaporized. Water content contained in the chips greatly affects the quality of the chips which the less water content of chips have a longer shelf life and more crisp (Wibowo 2012).

Beans (*Phaseolus vulgaris*)

Bean (of the Dutch, boontjes, *Phaseolus vulgaris* L.) is a kind of beans that can be eaten. Bean is high in starch, protein, and dietary fiber and is an excellent source of iron, potassium, selenium, molybdenum, thiamine, vitamin B6, and folate. The fruits, seeds, and beans are rich in protein and vitamin that helps lower blood pressure and escort blood sugar metabolism and very suitable food by those who suffer from diabetes or hypertension. The optimum temperature for the manufacture of chips beans by using vacuum fryer is 90ºC for 30 minutes. Chips with this variable have a low bitter taste, greenish brown, very crisp, and has a very strong smell of beans and water content are 8.62% (Septiyani 2012).

Manggo (*Mangifera indica*)

Mango (*Mangifera indica* L.) is a horticultural commodity in Indonesia. Mango fruit is rich in vitamin C and carbohydrate. Much-loved mango consumers because it can be consumed fresh or in processed form. Mango is a seasonal fruit which the product will be abundant in the harvest season and rare outside of the harvest season. Mango is a perishable commodity (have a relatively short shelf life), hence the need for an alternative treatment that mango production in large quantities can be consumed to all year round. Vacuum frying mango chips with frying temperature 80◦C, for 45 minutes is the best yield that produces low water content and good organoleptic chips (Sulistyaningrum 2012).

Chickpea (*Cicer arietinum*)

Chickpeas (*Cicer arietinum* L.) are a source of zinc, folate, and protein. Chickpeas are low in fat, and most of this is polyunsaturated. Chickpeas also provide dietary phosphorus (168 mg/100 g), which is higher than the amount found in a 100 grams serving of whole milk (NDL-USDA 2008). They can assist in lowering cholesterol in the bloodstream (Pittaway et al. 2008).

In processing technology of young chickpea, it is soaked in $CaCl_2$ solution (1000 ppm, t=30'). For wet flavoring method, young chickpea was boiled with flavor, meanwhile, for dry flavoring method, young chickpea was steam blanched. Then, young chickpea vacuum fried at 65, 75, and 85°C with vacuum pressure 72 cm Hg, and packaged in aluminum foil. Yield of young chickpea chips were 13.58-14.17% with vacuum frying time range from 1.08-1.41 hours. For both flavoring methods on young chickpea chips, moisture was 6.33-7.39%; ash 4.45-6.10%; fat 33.95-42.93%; protein 10.86-12.24%; crude fiber 11.94-14.10%; free fatty acid (FFA) 0.62-0.70%; vitamin C 0.27-0.46 mg/100g; and vitamin A 135.54-265.39 ppm. Sensory evaluation showed that different treatment of flavor and temperature did not have significant effect ($P>0.05$) to all parameter (color, odor, texture, taste, crispiness, and acceptability of chickpea chips). But, flavor had significant effect ($P<0.05$) to chickpea chips taste, and temperature had significant effect ($P<0.05$) to crispiness of chickpea chips (Widaningrum et al. 2008)

Apple (*Malus domestica*)

Apple (*Malus domestica* Borkh.) is one of the most widely cultivated tree fruits, and the most widely known of the many members of genus *Malus* that are consumed by humans. Apple peels are a source of various phytochemicals with unknown nutritional value (Boyer and Liu 2004) and possible antioxidant activity in vitro (Lee et al. 2004). The predominant phenolic phytochemicals in apples are quercetin, epicatechin, and procyanidin B2 (Lee et al. 2003.

Shidqiana (2012) had been conducted a study to look for water content and organoleptic on apple chips processed by vacuum fryer. The study was conducted in 5 variables change, the length of frying time were 35, 40, 45, 50 and 55 minutes, while the fixed variable was 750 g heavy material and frying temperature was 80°C. The results indicates that water content of the chips had declined 9.45%, 7.46%, 6.44%, 5.47%, and 4.97 respectively, and of the organoleptic test the most preferred apple chips were processed with a temperature of 80°C and time of 50 minutes; at this variable the color as well, the flavor was delicious, and the crispness was crisp.

Shyu and Hwang (2001) studied the effect of processing conditions on the quality of vacuum fried apple chips. They used a single vacuum pressure condition, 3.115 kPa, and three levels of temperature, 90, 100, and 110 ºC to fry the chips. After frying, the chips were centrifuged for 30 minutes at 350 rpm to remove the surface frying oil and then packed in polyethylene bags and stored at 30ºC. Using texture (hardness) as an indicator of product quality, the optimum conditions were vacuum frying temperature of 100-110ºC, vacuum time of 20-25 minutes, and a concentration of immersing fructose solution of 30-40%.

Sapodilla or sawo (*Manilkara zapota*)

Sapodilla (*Manilkara zapota* (L.) P.Royen) is a meso American tropical fruit crop which is widespread in Indonesia, and can harvest throughout the year. Sapodilla fruit is generally consumed as a table fruit, rarely further processing. The fruit has an exceptionally sweet, malty flavor. The unripe fruit is hard to the touch and contains high amounts of saponin, which has astringent properties similar to tannin, drying out the mouth. After ripening, sapodilla cannot survive long, easily damaged and rot. For vacuum fried chips, acquired conditions which make good chips, starting with slicing fruit with a stainless steel blade in a uniform thickness, immersing the slices in a brown solution of sodium bisulfite (1000 ppm) to prevent enzymatic browning reactions.

Frying temperatures cause decreased significantly ($p < 0.05$) on water content, hardness and brightness (L value). Water content ranged from 3.45 to 5.15% (dry basis). Hardness ranged between 2.73-4.50 kg/7mm. While L values ranged between 42.58 and 50.92. Factors of frying temperature, frying time and the interaction between these two factors did not affect significantly ($p > 0.05$). On the other observations that yield, fat content, and color parameters (*a* and *b* values), yield provided the range between 24.05-26.01%. 27.35; fat content ranged from 31.05% (dry basis); value of *a* (redness) was 3.79-8.46 while the value of *b* (yellowness) was 14.78-20.00 (Paramita 1999).

Eggplant (*Solanum melongena*)

Eggplant (*Solanum melongena* L.) is one of the favorite fruit among the people that it tastes good. Nutritionally, eggplant is low in fat, protein, and carbohydrates. It also contains relatively low amounts of most important vitamins and minerals. Eggplant juice can significantly reduce weight, cholesterol levels, and aortic cholesterol (Jorge et al. 1998). In general, eggplant is consumed in fresh form or cooked vegetables. One great way to reduce the water content is to process them into fruit crisps. To improve the crispness of the product, the freezing process is conducted. Freezing process increases the level of crispness and reduce the shrinkage. Besides the freezing process, soaking the product in $CaCl_2$ is also needed in order to maintain the texture of the product during heat process (Virgiawan 2011; Nur-Aeny 2012). Meyer (1987) states that $CaCl_2$ including material hardening or firming agent for fruits and vegetables. $CaCl_2$ significantly affect the fracture but does not affect the color, flavor, and yield. Immersion on $CaCl_2$ significantly affects the water content and crispy chips and all organoleptic parameters (taste, color, appearance, crispness) (Nur-Aeny 2012). The soaking of the prepared eggplant in $CaCl_2$ has significant effects on the breaking strength but has no significant effects on water content and yield. The $CaCl_2$ soaking factor combined with freezing time has significant effects on all organoleptic parameters. Best treatment was chosen using effective index method and marks the soaking of product in 1.5% $CaCl_2$ and the freezing time of 12 hours as the best treatment (Virgiawan 2011).

Jackfruit (*Artocarpus heterophyllus*)

Jackfruit (*Artocarpus heterophyllus* Lam.) is commonly used in Southeast Asian cuisines. It can be eaten raw when ripe, but as the raw unripe fruit is considered inedible, it is best cooked. The ripe jackfruit is naturally sweet with subtle flavoring and contains a lot of energy (95 calories/100 g) and the antioxidant vitamin C (13.7 mg/100g) (NDL 1998). For vacuum frying of jackfruit, the frying condition is vacuum pressure of-70 cm Hg and temperature level of 75◦C and 80◦C. Such condition was done to minimize the heat used and therefore reduce changes in composition, color, taste, and flavor of the jackfruit. The fried product was 22% and the product has low water content of 3.58% (wet basis) with the taste, flavor, color, and volume similar to the fresh jackfruit. Financial analysis of the jackfruit production capacity of 30 kg per day showed that NPV (Net Present Value) was IDR 52.391.000 which was bigger than investment cost, IRR (Internal Rate Return) was 51% and PBP (Pay Back Period) was 1.95 years, thus jackfruit fried chips was viable to be established (Alamsyah et al. 2002).

Cassava (*Manihot esculenta*)

Cassava (*Manihot esculenta* Crantz) root is essentially a carbohydrate source. Its composition shows 60-65% moisture, 20-31% carbohydrate, 1-2% crude protein and a comparatively low content of vitamins and minerals. However, the roots are rich in calcium and vitamin C and contain a nutritionally significant quantity of thiamine, riboflavin, and nicotinic acid. Cassava starch contains 70% amylopectin and 20% amylose. Cooked cassava starch has a digestibility of over 75% (Tewe 2004).

After harvest, cassava conditions quickly change, that needs processing to longer shelf life, such as for making vacuum fried chips. Cassava varieties very significant effect on the water content, HCN levels, fat content, yield, broken power and color of chips. Blanching and freezing treatments significantly affect on water contents, levels of HCN, starch content, fat content, the fracture, taste, color, appearance and crispness of cassava sticks. The best treatment was obtained from treatment of butter, with freezing and blanching with HCN levels of 3.54 ppm, and the chips have starch content of 32.43%, the fracture 2284.19 N/m, flavor score 4.2 (good), appearance score 3.22 (rather dense) and crispness score 4.04 (crispy) (Aprillia 2007).

Another product of cassava is tapioca chips from cassava starch. In atmospheric frying, NaCl pre-treatment had greatly reduced the oil absorption of tapioca crisps but did not provide improvement on color and texture. Under vacuum frying, the oil absorption for control and pre-treated sample shows a significantly different ($p<0.05$) at all frying time range. For color values, L^*, a^*, and b^* was not affected by the NaCl pre-treatment, but was affected by the frying time. While for texture, NaCl pre-treatment increases hardness and breaking force as the frying time increases. The most suitable time of vacuum frying for tapioca crisps is at 2 minutes as it gives the best quality of crisps in terms of oil absorption, color and texture. There was a significant difference in all physical and sensory properties between atmospheric and vacuum fried tapioca crisps. The vacuum fried tapioca crisps had absorbed 53.36% less oil compared to atmospheric fried crisps. Vacuum fried tapioca crisps also had lighter color and better texture compared to atmospheric frying. However, for sensory evaluation, consumer prefers the atmospheric fried crisps rather than vacuum fried crisps (Binti Zahroni 2012).

CONCLUSION

Vacuum fried chips are potential to increase the added value of fruits and vegetables, both nutritionally and economically. Fruits and vegetables are processed with vacuum frying have better nutritional value than traditional deep-fat frying, as well as the texture, color, and another sensory character is also better. This process prevents or reduce the formation of harmful substances in the traditional deep-fat frying, such as acrylamide and excessive saturated oil, thus meet the demands of modern public health. This process also adds value to fruits and vegetables are not eligible to be sold because of defects and prevent the waste of fruits and vegetables during the harvest because of the large supply.

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