Effect of Drying Kinetics on the Quality of Vacuum-Dried Banana, Pineapple and Apple Slices

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I hereby certify that this work has not been accepted in substance for any degree,

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ชื่อวิทยานิพนธ์ ผลของจลนพลศาสตร์การอบแห้งต่อคุณภาพของกล้วย สับปะรดและแอปเปิ้ลอบแห้งสุญญากาศ
ชื่อผู้เขียน นางสาววรรณพิชญ์ จุลกัลป์
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บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาผลของจลนศาสตร์การอบแห้งต่อคุณภาพกล้วย สับปะรดและแอปเปิ้ลอบแห้งสุญญากาศ และเพื่อหาสภาวะที่เหมาะสมในการอบแห้งสุญญากาศผลิตภัณฑ์ นอกจากนี้ได้ทำการศึกษาเพื่อหาแบบจำลองการอบแห้งแบบชั้นบางสำหรับทำนายจลนศาสตร์การอบแห้ง การทดลองอบแห้งที่อุณหภูมิ 70 80 90 100 110 และ 120°C ความดันในห้องอบแห้ง 4 kPa ทำการอบแห้งจนกล้วย สับปะรดและแอปเปิ้ลเหลือความชื้น 5 7 และ 22 % มาตรฐานเปียก ตามลำดับ จากนั้นนำผลไม้อบแห้งที่ได้ทำการวิเคราะห์การเปลี่ยนแปลงทางกายภาพ (สี การหดตัวและลักษณะผิวสัมผัส) และวิเคราะห์ทางประสาทสัมผัส (สี ผิวสัมผัส รสชาติ ความกรอบและการยอมรับโดยรวม) เพื่อเลือกสภาวะที่เหมาะสมสำหรับการอบแห้งสุญญากาศผลไม้

ผลการทดลองพบว่าที่อุณหภูมิการอบแห้งสูงที่สุดจะใช้ระยะเวลาในการอบแห้งสั้นที่สุด ที่สภาวะนี้ผลไม้อบแห้งให้ค่าความเหลืองสูงที่สุด การหดตัวต่ำ โครงสร้างรูพรุนมีขนาดใหญ่และปริมาณมาก ค่าความกรอบสูงและความสามารถการคืนตัวสูง เมื่อเทียบกับผลไม้อบแห้งที่อุณหภูมิต่ำกว่า การวิเคราะห์ทางประสาทสัมผัสเพื่อแสดงผลความแตงต่างอย่างมีนัยสำคัญของการยอมรับจากผู้บริโภคของผลไม้อบแห้งแต่ละสภาวะ ผลพบว่าผลไม้อบแห้งที่อุณหภูมิ 120°C ให้ค่าการยอมรับโดยรวมจากผู้บริโภคสูงที่สุด ดังนั้นอุณหภูมิ 120°C ถูกพิจารณาเป็นสภาวะที่ดีที่สุดสำหรับการอบแห้งกล้วย สับปะรดและแอปเปิ้ล แบบจำลองการอบแห้งแบบชั้นบาง 6 แบบจำลอง (Newton, Logarithmic, Page, two-term, two-term exponential and diffusion approach) ถูกใช้เพื่อหาแบบจำลองสำหรับทำนายจลนศาสตร์การอบแห้ง ผลการศึกษาพบว่า Logarithmic model ถูกพิจารณาเป็นแบบจำลองการอบแห้งแบบชั้นบางที่เหมาะสมสำหรับอธิบายคุณลักษณะการอบแห้งของแอปเปิ้ล ในขณะที่ Diffusion approximation model เหมาะสมสำหรับอธิบายคุณลักษณะการอบแห้งของกล้วยและสับปะรด การศึกษานี้ค่าสัมประสิทธิ์การแพร่ยังผล (Effective moisture diffusivity) ของกล้วย สับปะรดและแอปเปิ้ลมีค่าระหว่าง $2.92\text{x}10^{-10}$ ถึง $4.52\text{x}10^{-10}$ m^2/s $2.76\text{x}10^{-10}$

ถึง $3.76 x 10^{-10}$ m^2/s และ $9.1 x 10^{-11}$ ถึง $1.89 x 10^{-10}$ m^2/s ตามลำดับ และค่าพลังงานกระตุ้น (Activation energy) ของกล้วย สับปะรดและแอปเปิ้ลมีค่า $2.96 x 10^4$ $2.56 x 10^4$ และ $4.81 x 10^4$ kJ/mol ตามลำดับ จากการศึกษาพบว่าที่อุณหภูมิการอบแห้งสูงที่สุดมีค่าสัมประสิทธิ์การแพร่ยังผล (Effective moisture diffusivity) สูงที่สุด ซึ่งค่าสัมประสิทธิ์การแพร่ยังผล (Effective moisture diffusivity) มีผลอย่างมากต่อการเปลี่ยนแปลงโครงสร้างของผลไม้อบแห้งสุญญากาศ เนื่องจากการผลไม้ทั้ง 3 ชนิด พบว่าค่าสัมประสิทธิ์การแพร่ยังผล (Effective moisture diffusivity) มีค่าสูงในผลไม้อบแห้งที่มีโครงสร้างรูพรุนขนาดใหญ่และปริมาณมากกว่า เมื่อเทียบกับผลไม้ที่มีค่าสัมประสิทธิ์การแพร่ยังผล (Effective moisture diffusivity) ต่ำ ซึ่งลักษณะโครงสร้างรูพรุนมากสัมพันธ์กับคุณภาพของผลไม้อบแห้งที่มีความกรอบสูงและสัดส่วนการคืนตัวสูง

วิธีมูลค่าปัจจุบันสุทธิ (The Net Present Value method: NPV) ถูกใช้ในการตรวจสอบโครงการอบแห้งสุญญากาศผลไม้ว่าควรทำการลงทุนหรือไม่ สภาวะการอบแห้งที่อุณหภูมิ 120°C ที่ความดัน 4 kPa ถูกใช้ในการประเมินค่าความเป็นไปได้ทางเศรษฐศาสตร์ การวิเคราะห์ทางเศรษฐศาสตร์ของการอบแห้งสุญญากาศกล้วย สับปะรดและแอปเปิ้ล พิจารณาที่จำนวนครั้งในการอบแห้ง 1 ถึง 4 ครั้งต่อวัน 1 ถึง 3 ครั้งต่อวัน และ 1 ถึง 2 ครั้งต่อวัน ตามลำดับ ผลการคำนวณพบว่าการอบแห้งสุญญากาศกล้วย สับปะรดและแอปเปิ้ลมีค่ามูลค่าปัจจุบันสุทธิ (The Net Present Value method: NPV) เป็นบวก ดังนั้นทั้ง 3 โครงการมีความน่าสนใจในการลงทุน ทางเลือกที่ดีที่สุดของโครงการคือจำนวนครั้งในการอบแห้งกล้วย 4 ครั้งต่อวัน อบแห้งสับปะรด 3 ครั้งต่อวัน และอบแห้งแอปเปิ้ล 2 ครั้งต่อวัน

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Major Program Chemical Engineering

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ABTRACT

The purpose of this study was to investigate the drying kinetics on the quality of vacuum-dried bananas, pineapples and apples and to determine the optimum conditions for the vacuum drying of the fruits. In addition, this study was performed to find the appropriate thin layer equation for predicting the drying kinetic of products. Drying experiments were carried out at drying temperatures of 70, 80, 90, 100, 110 and 120^{o}C and absolute chamber pressure of 4 kPa. The drying was performed until the final moisture content of bananas, pineapples and apples reached 5 % (w.b.), 7 % (w.b.) and 22 % (w.b.), respectively. Next, the dried products were analyzed for physical quality (in terms of color, shrinkage and texture) and sensory quality (in terms of color, texture, flavor, crispness and overall acceptability). These data were used in choosing the optimum condition for the vacuum drying of products.

From experimental results, the drying time at the highest drying temperature was the shortest. At this condition, all three types of dried fruits showed the highest degree of yellowness, lower shrinkage, larger and more pores, more crispness and more rehydration ability compared to lower drying temperatures. From sensory analysis, each drying condition showed significant effect on consumer acceptability with the drying temperature of 120^{o}C showing the highest level of acceptance. Consequently, the drying temperature of 120^{o}C was suggested as the best condition for drying of bananas, pineapples and apples. Moreover, six mathematical models (Newton, Logarithmic, Page, two-term, two-term exponential and diffusion approach) describing thin-layer drying was investigated. It was found that The Logarithmic model was considered adequate for describing the thin-layer drying behavior of apples, while the Diffusion approximation model was deemed adequate for bananas and pineapples. In this study, the effective moisture diffusivity for bananas, pineapples and apples varied from 2.92x10^{-10} to

$4.52x10^{-10}$ m^2/s, $2.76x10^{-10}$ to $3.76x10^{-10}$ and $9.1x10^{-11}$ to $1.89x10^{-10}$, respectively. The energy of activation (E_a) for bananas, pineapples and apples are $2.96x10^4$, $2.56x10^4$ and $4.81x10^4$ kJ/mol, respectively. The study found that the highest drying temperature showed the highest values of effective moisture diffusivity. The values of effective moisture diffusivity greatly affected the structural changes of the vacuum-dried fruits. From experiment results, all three types of the dried fruits at the high values of effective moisture diffusivity had larger and more pore compared to the dried fruits at the low values of effective moisture diffusivity. Moreover, the high porosity of the dried fruit structures lead to increase of crispness and rehydration ratio of the dried fruits.

The Net Present Value (NPV) method was used to determine whether or not this plan should be performed. The drying condition at temperature 120^oC and absolute chamber pressure of 30 mmHg was used to determine the economic feasibility for the vacuum drying of the fruits. The economic analysis of the banana drying, pineapple drying and apple drying were carried out at 1-4 times per day, 1-3 times per day and 1-2 times per day, respectively. The results showed that the banana, pineapple and apple drying projects show the positive NPV, so the investment projects are attractive. The best alternatives are 4 times per day to dry the bananas, 3 times per day to dry the pineapples and 2 times per day to dry the apples, respectively.

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Last but not the least, I would like to thank my family for giving birth to me at the first place and supporting me spiritually throughout my life.

Wannapit Junlakan

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CHAPTER 1

Introduction

1.1 Background and Rationale

Snack foods such as potato chips, tortilla chips, onion rings, banana chips, pineapple chips and apple chips are normally fried with vegetable oil, which provides crispness after processing. However, fried products raise major concerns by conscious consumers due to its oil content. To avoid this drying can effectively be utilized. There are many drying techniques available to dry products, but the most common technique is hot air drying. However, hot air drying yield a non-crisp product because its moisture content cannot be reduced to the desired value. Moreover the dense structure created due to its shrinkage makes the product not crispy. Therefore, this process may not be an appropriate technique for producing a snack for which the crisp texture is preferred (Thuwapanichayanan et al., 2012).

Vacuum drying is another process in which products are dried in a reduced pressure environment. That lowers the heat required for rapid drying. The lower pressures allow drying temperature to be reduced and higher quality to be obtained compared to the traditional methods, such as crispness, puffed structure, preservation of natural color, shape, aroma and flavor of fresh fruits, as well as loss minimization of vitamins and minerals (Jaya and Das, 2003). Moreover, the vacuum removes moisture from the sample while preventing the oxidation that can occur when sample exposed to air, oxidative degradations, e.g. oxidation of fat and browning reactions, are minimized (Ashraf et al., 2012).

There are many research studies drying of fruits using vacuum drying. For example, Swasdisevi et al. (2007) and Nimmol et al. (2007) studied banana slices drying in a vacuum dryer combined with heating by infrared radiation. Advantages of vacuum dryer combined with infrared radiation is a high-efficiency dryer. Because infrared radiation can penetrate into a material. Water molecules in the material vibrate and produce heat. The internal temperature of the material higher than the temperature of the surface material. Resulting external surface of the material doesn't wrinkle.

In addition, Donsì et al. (1998) and Moraga et al. (2011) studied drying of banana and apple slices using freeze-drying. Advantages of vacuum dryer of freeze drying are the process of dehydrating frozen foods under a vacuum so the moisture content changes occur directly from a solid to a gaseous state without going through the intermediate liquid state (Brown, 1999). In this process, the product maintains its original size and shape with a minimum of cell rupture (Hammami and René, 1997).

However, in this study paraffin oil as a heat source for vacuum dryer was applied because it is not high production costs compared to vacuum drying combined with heating by infrared radiation and freeze drying.

Krokida and Maroulis (1998) studied the effect of drying conditions on color changes of apple and banana during vacuum drying at 50, 70 and 90^{o}C. They found that the rate of color deterioration was found to increase as temperature increased and air humidity decreased. There are many research studies the effect of drying methods on color changes of apple (Krokida et al., 1998; Krokida et al., 1999) and banana (Chua et al, 2000; Krokida et al., 1998; Krokida et al., 1999). They found that the yellowness of dried apples by vacuum drying (80^{o}C) were significantly higher than those dried by air drying (70^{o}C). Also, they found that the yellowness of dried bananas by vacuum drying (50^{o}C) were significantly higher than those dried by air drying (90^{o}C). Léonard et al. (2008) studied the effect of vacuum drying on microstructure of banana slices during drying at 80 and 90^{o}C. They found that the porosity values indicated that an increase in the drying temperature generally led to an increase in the porosity of the samples.

While previous researchers investigated the effect of drying conditions on structural changes of apple during vacuum drying at 50, 70 and 90^{o}C (Krokida and Maroulis, 1998) and banana during vacuum drying at 50, 70, 80 and 90^{o}C (Krokida and Maroulis, 1998; Léonard et al., 2008), none have investigated the effect of vacuum drying on structural changes (in terms of shrinkage, rehydration behavior, microstructure, texture and color) of bananas, pineapples and apples at 100, 110, and 120^{o}C and absolute chamber pressure of 4 kPa. Therefore, this research was aimed to investigate the structural changes occurring in vacuum drying of bananas, pineapples and apples at 100, 110, and 120^{o}C and absolute chamber pressure of 4 kPa. However, this research was aimed to investigate the structural changes (in terms of shrinkage, rehydration behavior, microstructure, texture and color) of bananas during vacuum drying at various slice thickness (1.40-2.40, 2.50-3.50 and 3.60-4.60 mm).

1.2 Theoretical Background

1.2.1 Banana

Banana is the common name for herbaceous plants of the genus *Musa* and for the fruit they produce. Bananas come in a variety of sizes and colors when ripe, including yellow (Species Profiles for Pacific Island Agroforestry, 2006) as shown in Figure 1, purple, and red. Banana fruit is one of the high calorie tropical fruits. 100 g of fruit provides 90 calories. Besides, it contains good amounts of health benefiting anti-oxidants, minerals, vitamins and others as shown in Table 1. They are native to tropical South and Southeast Asia, and are likely to have been first domesticated in Papua New Guinea (The Australia & Pacific Science Foundation, 2007). Today, they are cultivated throughout the tropics (Species Profiles for Pacific Island Agroforestry, 2006).

During ripening process, many changes are occurred in physical, mechanical and chemical properties of banana fruits. Skin color changes during ripening from green to yellow as shown in Figure 2 and Table 2. Firmness is decreased, banana is softened and starch is converted into sugar (Marriott et al, 1981). Investigation of these changes was the subjects of many researches

Figure 1 Banana and cross section (Wikipedia, 2010).

Table 1 Composition of Cavendish banana (USDA Nutrient Database, 2011).

Nutrient	Value per 100 g of edible portion
Water	74.91 g
Energy	371 kJ (89 kcal)
Fat	0.33 g
Protein	1.09 g
Carbohydrates	22.84 g
Sugars	12.23 g
Dietary fiber	2.6 g
Potassium	358 mg (8%)
Phosphorus	22 mg (3%)
Iron	0.26 mg (2%)
Magnesium	27 mg (8%)
Manganese	0.3 mg (14%)
Calcium	5 mg (1%)
Zinc	0.15 mg (2%)
Vitamin A (equiv.)	3 µg (0%)
Vitamin B1 (Thiamin)	0.031mg (3%)
Vitamin B2 (Riboflavin)	0.073 mg (6%)
Vitamin B3 (Niacina)	0.665 mg (4%)
Vitamin B5 (Pantothenic acid)	0.334 mg (7%)
Vitamin B6	0.4 mg (31%)
Vitamin B9 (Folate)	20 µg (5%)
Choline	9.8 mg (2%)
Vitamin C	8.7 mg (10%)

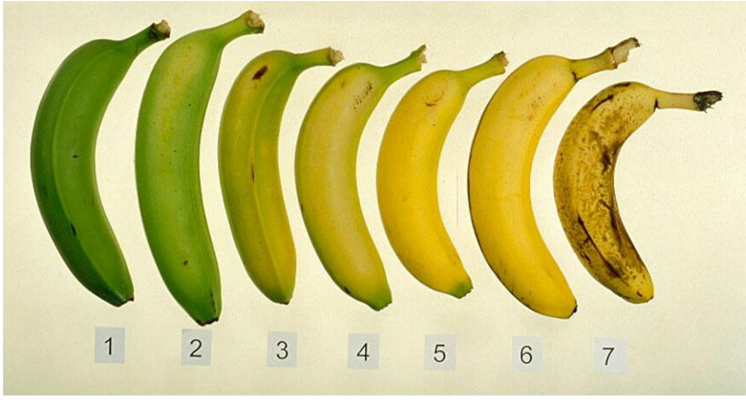


Figure 2 Color chart of banana fruits in various stages (Edwards, 2012).

Table 2 Color index according to the commercial peel color scale (Edwards, 2012).

Color Index No.	1	2	3	4	5	6	7
Peel Color	All green	Green with trace of yellow	More green than yellow	More yellow than green	Yellow with green tip and green neck	All yellow	All yellow with brown fleck

1.2.2 Pineapple

Pineapple (*Ananas comosus*) is one of the world's four famous fruits, and has special nutrition. The pineapple plant is a herbaceous perennial, 2-1/2 to 5 ft. high with a spread of 3 to 4 ft., has elongated, dark green, sharp, sword-like leaves arranged in a spiral around a central stem and a terminal inflorescence. Cone-shaped inflorescences have pale purple or red flowers. The pineapple fruit is a seedless syncarp (an aggregate fruit) and found that weighed 5 pounds or more, has a yellow peel and pleasant aroma when ripe (California Rare Fruit Growers, 1996; Power your diet, 2009). Peel color charts have been developed to help standardize pineapple maturity ratings for industry as shown in Figure 3. The fruit is low in calories (provides only 50 cal per 100 g) as shown in Table 3. That is contains no saturated fats or cholesterol; but rich source of soluble and insoluble dietary fiber like pectin. Fresh pineapple is an excellent source of antioxidant vitamin; vitamin C. It is required for the collagen synthesis in the body.

Collagen is the main structural protein in the body required for maintaining the integrity of blood vessels, skin, organs, and bones. Regular consumption of foods rich in vitamin C helps body protect from scurvy; develop resistance against infectious agents (boosts immunity) and scavenge harmful, pro-inflammatory free radicals from the body (Power your diet, 2009). Peel color charts have been developed to help standardize pineapple maturity ratings for industry as shown in Figure 4 and Table 4.

Figure 3 Pineapple and cross section (Wikipedia, 2012).

Table 3 Composition of pineapple, raw (USDA Nutrient Database, 2011).

Nutrient	Value per 100 g of edible portion
Energy	202 kJ (48 kcal)
Fat	0.12 g
Protein	0.54 g
Carbohydrates	12.63 g
Sugars	9.26 g
Dietary fiber	1.4 g
Potassium	115 mg (2%)
Phosphorus	8 mg (1%)
Iron	0.28 mg (2%)
Magnesium	12 mg (3%)
Manganese	0.9 mg (43%)
Calcium	13 mg (1%)
Zinc	0.10 mg (1%)
Vitamin A (equiv.)	3 µg (0%)
Vitamin B1 (Thiamin)	0.079 mg (7%)
Vitamin B2 (Riboflavin)	0.031 mg (3%)
Vitamin B3 (Niacina)	0.489 mg (3%)
Vitamin B5 (Pantothenic acid)	0.205 mg (4%)
Vitamin B6	0.110 mg (8%)
Vitamin B9 (Folate)	15 µg (4%)
Choline	9.8 mg (2%)
Vitamin C	36.2 mg (44%)

Figure 4 Color chart of pineapple fruits in various stages (Daicana, 2009).

Table 4 Color index according to the commercial peel color scale (Christy, 2006).

Color Index No.	0	1	2	3	4	5	6
Peel Color	All eyes are glossy bluish dark green.	All eyes are glossy dark green with traces of yellow between eyes at base.	Eyes are dark green with 1-3 eyes yellowish green at base.	About 25% of eyes from the base are yellow.	About 50% of the eyes are orange yellow.	More than 75% of the eyes are orangy yellow.	Full orangy yellow.

1.2.3 Apple

Apple fruits are one fruit that easily found in various parts of the world. It is estimated there are approximately seven thousand kinds of apples around the world. Although the shape, size, color, flavor, and texture of each different type of apple, but in general this fruit is round with a hollow at the base of the bud as shown in Figure 5. The flesh is white, crisp, juicy with sweet or sour taste, and is protected by a thin skin that is usually colored shiny. When cut off, will exit its fragrant and fresh, although there are some that smelled sharply (Rakhmawati, 2011).

A serving of apple fruit contains a lot of potassium, pectin, and cellulose. Pectin is widely available on the apple flesh and is one of the fiber is not soluble in water. While cellulose is widely available in apple fruit skin and is water-soluble fiber. Potassium itself is widely available on the apples red (Rakhmawati, 2011). These nutrients of the fresh apple are shown in Table 5.

Figure 5 Apple and cross section (Wulfsohn, 2009).

Table 5 Composition of apple, with skin (edible parts) (USDA Nutrient Database, 2011).

Nutrient	Value per 100 g of edible portion
Water	85.56 g
Energy	218 kJ (58 kcal)
Fat	0.17 g
Protein	0.26 g
Carbohydrates	13.81 g
Sugars	10.39 g
Dietary fiber	2.4 g
Potassium	107 mg (2%)
Phosphorus	11 mg (2%)
Iron	0.12 mg (1%)
Magnesium	5 mg (1%)
Calcium	6 mg (1%)
Zinc	0.04 mg (0%)
Vitamin A (equiv.)	3 µg (0%)
Vitamin B1 (Thiamin)	0.017 mg (1%)
Vitamin B2 (Riboflavin)	0.026 mg (2%)
Vitamin B3 (Niacina)	0.019 mg (1%)
Vitamin B5 (Pantothenic acid)	0.061 mg (1%)
Vitamin B6	0.041 mg (3%)
Vitamin B9 (Folate)	3 µg (1%)
Vitamin C	4.6 mg (6%)

1.2.4 Drying Mechanism

Drying is a mass transfer process consisting of the removal of water or another solvent by evaporation from a solid, semi-solid or liquid. In some products having a relatively high initial moisture content, an initial linear reduction of the average product moisture content as a function of time may be observed for a limited time, often known as a "constant drying rate period". Usually, in this period, it is surface moisture outside individual particles that is being removed. The drying rate during this period is dependent on the rate of heat transfer to the material being dried. Therefore, the maximum achievable drying rate is considered to be heat-transfer limited. If drying is continued, the slope of the curve, the drying rate, becomes less steep (falling rate period) and eventually tends to nearly horizontal at very long times. The product moisture content is then constant at the "equilibrium moisture content", where it is in dynamic equilibrium with the dehydrating medium. In the falling-rate period, water migration from the product interior to the surface is mostly by molecular diffusion, i,e. the water flux is proportional to the moisture content gradient. This means that water moves from zones with higher moisture content to zones with lower values, a phenomenon explained by the second law of thermodynamics. If water removal is considerable, the products usually undergo shrinkage and deformation, except in a well-designed freeze-drying process. The drying rate in the falling-rate period is controlled by the rate of removal of moisture or solvent from the interior of the solid being dried and is referred to as being "mass-transfer limited" (International Rice Research Institute, 2009). The saturation vapor pressure of water referred to the given temperature as shown in Table 6.

Table 6 Saturation vapor pressure of water referred to the given temperature (Wang, 2010).

T (^oC)	P (mmHg)	T (^oC)	P (mmHg)	T (^oC)	P (mmHg)	T (^oC)	P (mmHg)	T (^oC)	P (mmHg)
-10	2.1	14	12.0	38	49.7	62	163.8	86	450.9
-9	2.3	15	12.8	39	52.4	63	171.4	87	468.7
-8	2.5	16	13.6	40	55.3	64	179.3	88	487.1
-7	2.7	17	14.5	41	58.3	65	187.5	89	506.1
-6	2.9	18	15.5	42	61.5	66	196.1	90	525.8
-5	3.2	19	16.5	43	64.8	67	205.0	91	546.1
-4	3.4	20	17.5	44	68.3	68	214.2	92	567.0
-3	3.7	21	18.7	45	71.9	69	223.7	93	588.6
-2	4.0	22	19.8	46	75.7	70	233.7	94	610.9
-1	4.3	23	21.1	47	79.6	71	243.9	95	633.9
0	4.6	24	22.4	48	83.7	72	254.6	96	657.6
1	4.9	25	23.8	49	88.0	73	265.7	97	682.1
2	5.3	26	25.2	50	92.5	74	277.2	98	707.3
3	5.7	27	26.7	51	97.2	75	289.1	99	733.2
4	6.1	28	28.3	52	102.1	76	301.4	100	760.0
5	6.5	29	30.0	53	107.2	77	314.1	102	815.9
6	7.0	30	31.8	54	112.5	78	327.3	104	875.1
7	7.5	31	33.7	55	118.0	79	341.0	106	937.9
8	8.0	32	35.7	56	123.8	80	355.1	108	1004
9	8.6	33	37.7	57	129.8	81	369.7	110	1075
10	9.2	34	39.9	58	136.1	82	384.9	112	1149
11	9.8	35	42.2	59	142.6	83	400.6	114	1227
12	10.5	36	44.6	60	149.4	84	416.8		
13	11.2	37	47.1	61	156.4	85	433.6		

A drying curve, as illustrated in the Figure 6, shows how the grain moisture content (MC) and grain temperature change over time. As can be seen in the chart, the drying rate is not constant but changes over time. The temperature of the grain equally changes over time.

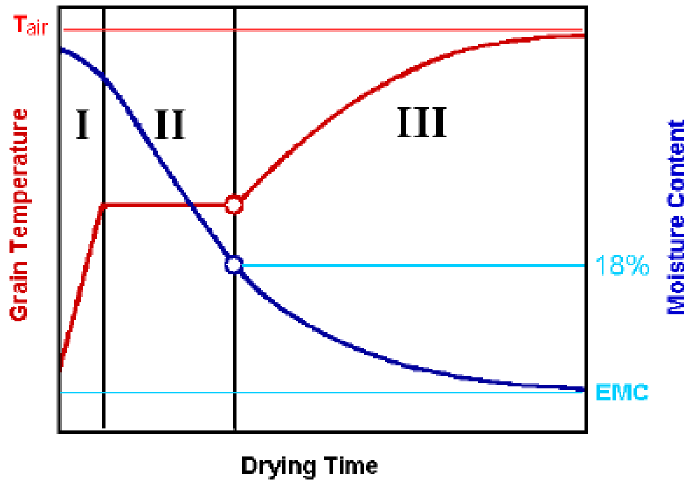


Figure 6 Theoretical drying curves with different drying periods

(International Rice Research Institute, 2009).

There are three different drying periods which will occur consecutively in time:

I. Preheating period (drying rate is almost 0):

When wet grain is exposed to hot air, initially only a very slight change in MC is observed. This happens because all the heat provided in the drying air is used to heat up the grain to the drying temperature (International Rice Research Institute, 2009).

II. Constant-rate period (drying rate is constant in time):

Once the grain is at the drying temperature, water starts to evaporate from the surface of the grain. During this period, all the heat from the drying air is used to evaporate surface moisture and the amount of moisture removed from the grain is constant in time. It is therefore called the constant-rate period. During this period, grain temperature is constant as well (International Rice Research Institute, 2009).

III. Falling-rate period (drying rate declines over time):

As time passes, it takes more time for internal moisture to appear at the surface, and evaporation of water is no longer constant in time. As a result, drying rate will decline, and some of the heat from the drying air will heat up the grain. For paddy grain, the falling-rate period typically occurs at around 18% grain moisture content (International Rice Research Institute, 2009).

By using the 18% MC and the drying curve characteristics as a guideline, a few recommendations can be made in regard to grain drying procedures. These guidelines can be used regardless whether grain is dried in the sun or by using artificial grain dryers (International Rice Research Institute, 2009).

1.2.5 Thin layer drying models

In the past 60 years, the study of drying behavior of different materials has been the subject of interest for various investigators on both theoretical and practical grounds. In the course of studies conducted regarding the drying behavior of various agricultural products, many mathematical models have been used to describe the drying process of which thin-layer drying models are the most common models (Mohammadi et al, 2008). Drying of many fruits and other agricultural products has been successfully predicted (Muthukumarappan and Gunasekaran, 1994; Afzal and Abe, 1998; Baini and Langrish, 2007). According to Parti (1993), mathematical models that describe drying mechanisms of grain and food can also provide the required temperature and moisture information.

Thin-layer drying equations fall into three categories namely, theoretical, semi-theoretical, and empirical models. The comprehensive review of these equations is reported in detail by Jayas et al. (1991). Semi-theoretical models are derived based on theoretical model (Fick's second law) but are simplified and added with empirical coefficients in some cases to improve curve fitting. In the empirical models a direct relationship is derived between moisture content and drying time and the parameters associated with it have no physical meaning at all.

Lewis (1921), cited by Jayas et al. (1991), suggested an equation that assumes the rate of change in moisture content is proportional to the difference between moisture content and equilibrium moisture content of the food.

$$MR = \frac{M_t - M_c}{M_o - M_c} = \exp(-kt) \qquad (1)$$

where, MR = moisture ratio,

M_t = moisture content at time, t (% w.b.),

M_c = equilibrium moisture content (% w.b.),

M_o = initial moisture content (% w.b.),

k = drying constant determined from the experimental data (1/h),

t = time (h)

Other authors argue that for long drying times equation one can be simplified to $MR = M_t/M_o$ instead of $MR = M_t - M_c / M_o - M_c$ due to the fact that values of equilibrium moisture content, M_c are relatively small compared to M_t or M_o (Doymaz, 2004; Doymaz and Pala, 2002; Lomauro et al., 1985).

Because of its simplicity, equation 1 has been widely used to describe drying of different crops (Bruce 1985; O'Callaghan et al, 1971; Sabbah et al., 1972). The equation, however, cannot describe the drying rate accurately throughout the drying period (Jayas et al., 1991). A modified drying equation was obtained from equation (1) by Henderson and Pabis (1961), with another constant added:

$$MR = a \quad \exp(-bt) \tag{2}$$

where, a = empirical drying constant (1/h)

b = empirical drying constant (1/h)

Equation 2 was used by several researchers to model drying of mulberry, grains and oilseeds (Doymaz, 2004; Henderson and Pabis 1961; Wang and Singh 1978; Moss and Otten, 1989). To overcome shortcomings of the Lewis model (Equation 1), Page (1949) suggested equation 3 as a drying model.

$$MR = \exp(-kt^y) \tag{3}$$

where, k = empirical drying constant (1/h) and y = empirical drying constant

Many researchers have used equation 3 to describe thin-layer drying rates (Hulasare, 1997; White et al., 1973; Syarief et al., 1984; Wang and Singh, 1978; Hutchinson and Otten, 1983; Bruce, 1985; Pathak et al., 1991).

The above equation is a modification of the theoretical model, known as the exponential or the Newtonian model (Sun and Woods, 1994). The model is described as (Nellist, 1976; Colson and Young, 1990; Pattey et al., 1988; Crisp and Woods, 1994).

$$\frac{dM}{dt} = -k\left(M_t - M_c\right) \tag{4}$$

where, k is the drying constant.

Equation 3 assumes that resistance to moisture movement and thus gradients within the material are negligible (Colson and Young, 1990). At constant temperature, pressure and humidity, this equation is valid if drying is characterized by “falling-rate”regime (Nellist, 1976) which is a characteristic of drying of low moisture content products. As quoted in Sun and Woods (1994), this model has been successfully used for banana (Hofsetz et. al., 2007); barley (Sharp, 1982; Bruce, 1985), paddy (Kachru et al., 1980), and shelled corn (Westerman et al., 1973). The drying constants in thin-layer drying equations vary with temperature (Yunfei and Morey, 1987; Verma et al., 1985).

quation 5 is the general form of a two-term model that uses the first two terms of a general series solution of Fick’s second law

$$MR = A \quad \exp\left(-Bt\right) + C \quad \exp\left(-Dt\right) \tag{5}$$

where, A, B = empirical drying constants (1/h)

C, D = empirical drying constants (1/h)

Equation 5 has been applied by Doymaz (2004) in the thin-layer drying kinetics of white mulberry. He further applied a modified version of the Page equation (Equation 6) in the same work only to conclude that the Logarithmic model (Equation 7) best described the drying process.

$$MR = \exp(-kt)^{y} \tag{6}$$

where, k = empirical drying constant (1/h)

y = empirical drying constant

$$MR = a \quad \exp(-kt) + c \tag{7}$$

where, a, c = empirical drying constants

k = empirical drying constant (1/h)

1.2.6 Goodness-of Fit Statistics for thin layer drying models

Thin-layer drying models are evaluated and compared by using statistical measures. Consequently, the quality of the fitted models is evaluated. Some of these measures can be described as follows:

1.2.6.1 Root mean square error (RMSE)

It signifies the noise in the data. Lower values of root mean square error are choosen as criteria for goodness of fit (Demir et al., 2004; Doymaz, 2005; Wang et al., 2007):

$$RMSE = \left[\frac{\sum_{i=1}^{n} \left(MR_{pre,i} - MR_{exp,i} \right)}{N} \right] \tag{8}$$

1.2.6.2 Mean sum of squares of errors (MSE) or ($\chi 2$)

It is the mean square of the deviations between the experimental and calculated moisture levels (Iguaz et al., 2003; Lopez et al., 2000; Panchariya et al., 2002). Several authors (Kingsly and Singh, 2007; Yaldiz and Ertekin, 2004; Sarsavadia et al., 1999) used the term-reduced chi square ($\chi 2$) instead:

$$x^2 = \left[\frac{\sum_{i=1}^{n} \left(MR_{pre,i} - MR_{exp,i} \right)^2}{N - Z} \right] \tag{9}$$

where, (Equation 8, 9, 11)

$MR_{exp,i}$ = the ith experimental moisture ratio

$MR_{pre,i}$ = the ith predicted model moisture ratio

N = the number of sampling times

z = the number of constants in the drying model.

1.2.6.3 Coefficient of determination (R^2)

This is equivalent to the ratio of the regression sum of squares (SSR) to the total sum of squares (SST), which explains the proportion of variance accounted for in the dependent variable by the model. It evaluates how well the model fits the data. It has been used by various authors to evaluate drying models. Higher values for R^2 are used as goodness of fit for the models (Doymaz, 2007; Panchariya et al, 2001; Saeed et al, 2006; Singh et al, 2006). The SSE and the SST can be calculated from the following formulae: Regression sum of squares:

$$SST = \sum_{i=1}^{N} \left(Y_1 - Y \right)^2 \tag{10}$$

$$SSE = \frac{\sum_{i=1}^{N} \left(MR_{pre,i} - MR_{exp,i} \right)^2}{N} \tag{11}$$

where, SSE is the reduced sum of square error

1.2.6.4 The standard error of estimate (SEE)

It represents the fitting ability of a model in relation to the number of data points (Sun, 1999), and measures the dispersion of the observed values about the regression line (Basunia and Abe, 1999; Basunia and Abe, 2001; Mwithiga and Olwal, 2005).

1.2.7 Drying rate

Drying kinetics is generally evaluated experimentally by measuring the weight of a drying sample as a function of time. Drying curves may be represented in different ways; moisture ratio versus time, drying rate versus time, averaged moisture content versus time. Several theories on the mechanism of moisture migration have been reviewed (Afzal and Abe, 1998; Dadali et al, 2007) however, only capillary and liquid diffusion theories are, generally, applicable to the drying of food materials.

Drying process can be described completely using an appropriate drying model, which is made up by differential equations of heat and mass transfer in the interior of the product and at its inter phase with the drying agent. Thus, knowledge of transport and material properties is necessary to apply any transport equation (Karathanos and Belessiotis, 1999). Such properties are the moisture diffusivity, thermal conductivity, density, and specific heat and inter phase heat and mass transfer coefficients. Sometimes, in the literature instead of these properties, the drying constant, is used. This is a lumped parameter of the properties (Saeed et al, 2008).

The drying rate can be expressed as (Ceylan et al, 2007; Doymaz, 2007; Ozbek and Dadali, 2007).

$$\text{Drying rate} = \frac{M_{t+dt} - M_t}{dt} \tag{12}$$

where, M_t = moisture content at a specific time (g water/g dry base)

M_{t+dt} = moisture content at t+dt (g water/g dry base)

t = drying time (h)

Hill and Pyke (1997) stated that drying takes place when there is a net movement of water going out of the food product into the surrounding so that the food would give up its moisture content. He further stated that the drying rate is determined by how fast the moisture migrates or diffuses from the interior to the surrounding air. Thompson and Foster (1963), on the other hand, stated that the effects of drying-air temperature and flow rate can be combined into an expression of drying speed represented by the moisture reduction in percentage per hour. Trim and Robinson (1994) argue that drying rate generally increases with increasing moisture content and air temperature or decreases with decrease in humidity.

Cape and Percy (1996) shared the opinion that another factor implicated in explaining the rate of water loss in food is the effective area across which water may be lost and that large surface area ensure rapid transfer of moisture to the surface and the ease with which moisture is removed by the air current.

1.2.8 Effective moisture diffusivity

In general, drying of foods takes place in two periods, a constant rate period and falling rate period. After a short heating period a constant rate period followed by a falling rate period which is the dominating period during drying process. The mechanism of moisture movement within a hygroscopic solid during the falling rate period can be represented by effective moisture diffusion phenomena which include liquid diffusion, vapour diffusion and other possible mass transfer mechanisms. Effective moisture diffusivity is used to represent an overall mass transport property of water in food materials (Dadali et al., 2007). During drying it is assumed that diffusivity, explained with Fick's diffusion equation, is the only physical mechanism to transfer water to the surface (Ozbek and Dadali, 2007). Effective moisture diffusion which is affected by composition, moisture content, temperature and porosity of the material is used due to limited information on the mechanism of moisture movement during drying and complexity of the process (Afzal and Abe, 1998).

The Fick's law of diffusion was used to describe the transport of water inside the sample surface in terms of diffusivity. By analytical method with an initial condition and the boundary conditions, the general solution of moisture ratio can be obtained as follows: (Crank, 1975).

For infinite slab shape;

$$MR = \frac{8}{\pi^2}\sum_{p=0}^{\infty}\left[\frac{1}{(2p+1)^2}\right]\exp\left[-\frac{(2p+1)^2\pi^2 Dt}{L^2}\right] \tag{13}$$

Considering only the first three terms;

$$MR = \frac{8}{\pi^2}\left[\exp\left(-\frac{\pi^2 Dt}{L^2}\right) + \frac{1}{9}\exp\left(-\frac{9\pi^2 Dt}{L^2}\right) + \frac{1}{25}\exp\left(-\frac{25\pi^2 Dt}{L^2}\right)\right] \tag{14}$$

For cubic shape;

$$MR = \left(\frac{8}{\pi^2}\right)^3 \sum_{p=0}^{\infty}\left[\frac{1}{(2p+1)^2}\right]^3 \exp\left[-\frac{(2p+1)^2 3\pi^2 Dt}{L^2}\right] \tag{15}$$

Considering only the first three terms;

$$MR = \left(\frac{8}{\pi^2}\right)^3\left[\exp\left(-\frac{3\pi^2 Dt}{L^2}\right) + \frac{3}{9}\exp\left(-\frac{11\pi^2 Dt}{L^2}\right) + \frac{3}{25}\exp\left(-\frac{27\pi^2 Dt}{L^2}\right)\right] \tag{16}$$

For sphere shape;

$$MR = \frac{6}{\pi^2}\sum_{p=1}^{\infty}\left(\frac{1}{p^2}\right)\exp\left(-\frac{p^2\pi^2 X^2}{9}\right) \tag{17}$$

Considering only the first three terms;

$$MR = \frac{6}{\pi^2}\left[\exp\left(-\frac{\pi^2 Dt}{r_0^2}\right) + \frac{1}{4}\exp\left(-\frac{4\pi^2 Dt}{r_0^2}\right) + \frac{1}{9}\exp\left(-\frac{9\pi^2 Dt}{r_0^2}\right)\right] \tag{18}$$

For infinite cylinder shape;

$$MR = \left(\frac{8}{\pi^2}\right)\sum_{m=1}^{\infty}\frac{4}{\lambda_m^2}\exp\left(-\frac{\lambda_m^2 Dt}{r_0^2}\right)\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{\pi^2(2n+1)^2 Dt}{L^2}\right) \tag{19}$$

Considering only the first three terms;

$$MR = \left(\frac{8}{\pi^2}\right)\left[\exp\left(\frac{-\pi^2 Dt}{L^2}\right) + \frac{1}{9}\exp\left(\frac{-9\pi^2 Dt}{L^2}\right) + \frac{1}{25}\exp\left(\frac{-25\pi^2 Dt}{L^2}\right)\right] \times$$

$$4 * \left[\frac{1}{\lambda_1^2}\exp\left\{\lambda_1^2\left(\frac{Dt}{r_0^2}\right)\right\} + \frac{1}{\lambda_2^2}\exp\left\{-\lambda_2^2\left(\frac{Dt}{r_0^2}\right)\right\} + \frac{1}{\lambda_3^2}\exp\left\{-\lambda_3^2\left(\frac{Dt}{r_0^2}\right)\right\}\right] \quad (20)$$

where, MR = the moisture ratio

D = the effective diffustion coefficient, m^2/s

L = dimension of sample,thickness, m

r = the radius of sample, m

t = drying time, s

λ_n = root of the Bessel function of the n^{th} kind of zero order

The effective diffusion coefficient (D) is conventionally described by the Arrhenius type equation as follows:

$$D = D_0 \exp\left[-\frac{E}{RT}\right] \quad (21)$$

where, D_0 = Arrhenius factor of the heterogeneous solid, m^2/h or m^2/s

E = the acrivated energy, kJ/mol K

R = universal gas constant, 8.314 kJ/kmol K

T_{abs} = absolute temperature, K

Doymaz and Akgun (2005) reported effective moisture diffusivity values in the range of 0.3 to 1.1 x $10^{-8} m^2/s$ in a temperature range of 50 to 110°C and stressed that the values increased with increasing temperature. Doymaz (2004) on analysis of the drying kinetics of the white Mulberry reported that moisture diffusivities were affected by pretreatments. The diffusivity of heat shocking and ethyl oleate treatments in his work increased up to three times that of the natural fruit.

Kingsly et al. (2007) reported values in the ranged from 1.68 to 2.84 x 10^{-9} m^2/s for thin layer drying characteristics of organically produced tomatoes. The moisture diffusivity increased as drying air temperature was increased and due to the influence of blanching on internal mass transfer of tomato during drying, blanched samples had higher moisture diffusivity values.

The temperature dependence of the effective diffusivity was represented by an Arrhenius relationship (Madamba et al., 1996; Sanjuan et al., 2003) through which activation energy could be derived. Kingsly et al. (2007) reported activation energy values of 21.1 and 22.41 kJ/mol for untreated and blanched samples respectively, for the tomato slices.

1.2.9 Factors affecting drying

1.2.9.1 Thermal properties of foods.

Thermal properties of foods depends on many factors, including composition of food, temperature and physical structure. A major component of many foods, especially fruits and vegetables is water or moisture. The physical structure of food, including density, porosity, fiber type, direction of heat flow through the sample, etc. Food or fruits and vegetables each type of diet composition and physical structure is different. Have different thermal properties (Petchkaw, 1999).

1.2.9.2 Shape and size of the material before drying.

Shape and size of agricultural products affect the mass transfer. As a result of surface to volume ratio (Yampaiboon, 2006). The size and shape of the food that has a surface area of more food. Will help to increase the efficiency of the evaporation of water from the food better. Thus, the rate of drying faster.

1.2.9.3 Temperature

The drying temperature is a factor that is important to drying. That is, when the hot air in the drying cabinet, the high temperature will cause the temperature of the air and the water temperature in food are very different. The evaporation of water in the food better, which will result is a fast-drying. However, the temperature must be suitable for drying. Not too high and result in loss of nutritional value (Ali, 2008)

1.2.9.4 Water in food

Water is an important component of food. In general, there were about 65 to 95 percent of the total weight of food. Water acts as a solvent for nutrients, transports nutrients and waste, acts as an intermediary chemical and biochemical reactions, the important properties of foods, such as the structure or the firm, nutritional value and taste. However, foods with a lot of water will spoil quickly because of changes in biochemistry, chemical and microbial growth. Therefore, to prevent spoilage of food. We must reduce the amount of water in the diet for less (Robert, 1983).

1.2.10 Quality of dried foods and deteriorative reactions during drying (United Nations Industrial Development Organization, 2012)

The quality of dried foods is dependent in part on changes occurring during processing and storage. Some of these changes involve modification of the physical structure. These modifications affect texture, rehydrability and appearance. Other changes are due to chemical reactions, but these are also affected by physical structure, primarily due to effects on diffusivities of reactants and of reaction products.

The most commonly examined properties of dried products can be classified into two major categories, engineering and quality properties. The engineering properties of the dried products involve effective moisture diffusivity, effective thermal conductivity, drying kinetics, specific heat, and equilibrium moisture content. In addition there are properties related to product quality. These properties are necessary for the determination and the characterization of the quality of dried products can be grouped into:

- Thermal properties :state of product; glassy, crystalline, rubbery and others.
- Structural properties :density, porosity, pore size, specific volume and others.
- Textural properties :compression test, stress relaxation test, tensile test and others.
- Optical properties :color, appearance and others.
- Sensory properties :aroma, taste, flavor and others.

- Nutritional characteristics :vitamins, proteins and others.
- Rehydration properties :rehydration rate, rehydration capacity.

During the last decades, much attention is paid on the quality of dehydrated foods. The specific drying method as well as the physical-chemical changes that occur during drying seems to affect the quality of dehydrated products. More specifically, drying method and process conditions affect significantly the drying constant, color, texture, density and porosity and sorption characteristics of materials. The increasing need for producing efficiently high quality and convenient products at a competitive cost has led to the employment of several drying methods in practice.

The factors that influence quality during drying have been identified briefly as in Table 7.

Table 7 Factors that influence during drying (Heldman, 1992).

Chemical	Physical	Nutritional
Browning reactions	Rehydration	Vitamin loss
Lipid oxidation	Solubility	Protein loss
Color loss	Texture	Microbial survival
	Aroma loss	

All food products deteriorate at some rate or other in a manner that depends on food type, composition, formulation, packaging and storage regime. The potential for deterioration may occur at any of the stages between the acquisition of raw materials and the eventual consumption of a finished product, and may therefore be accelerated or minimised at any of these stages also. The complete preservation systems for food and dairy products are therefore usually multi-component in that they seldom rely on one factor alone. The major deteriorative reactions, which are the major targets for preservation, are well known and relatively few (Table 8). They include some that are essentially physical in their mode of action, some that are chemical, some that are enzymatic and some that are microbiological. When preservation fails and these reactions escape control, the consequences range broadly. At the one extreme, these may be trivial though undesirable, such as loss of color or flavor, or texture change within a food.

At the other extreme, the most serious forms of deterioration are those associated with the presence or multiplication of micro-organisms, and these range from the reactions that cause undesirable spoilage to the transmission of life-threatening diseases caused by the most hazardous of the food-poisoning, micro-organisms, such as Clostridium botulinum, Salmonella, enteropathogenic Escherichia coli, Listeria monocytogenes.

Table 8 Major Food Deterioration Reactions (Gould, 1995).

Basis of reaction	Example and consequence
Physical	- Moisture movement, causing drying and toughening of texture, hydration and softening of texture, aggregation
Chemical	-Oxidation, causing oxidative rancidity, loss of colour
	-Maillard reactions, causing discolouration, change in texture
Enzymatic	-Polyphenoloxidase, causing enzymic browning
	-Lipoxygenase, causing oxidative rancidity
	-Lipase, causing lipolytic rancidity
	-Protease, causing gelation and flavour and texture changes
Microbial	-Growth of spoilage organisms, causing quality deterioration
	-Growth of toxigenic organisms, causing food poisoning
	-Presence of infectious organisms, causing food poisoning

Reactions occurring during drying can result in quality losses, particularly nutrient losses and other deteriorations caused by browning reactions. Reactions during drying may be classified as browning reactions and nutrient losses. Moreover, there occur also structural changes, which affect quality of dried fruits and vegetables.

1.2.11 Chemical changes that occur during drying (United Nations Industrial Development Organization, 2012)

1.2.11.1 Browning reactions

Browning reactions, which are some of the most important phenomena in food during processing and storage, represent an interesting research area for the implications in food stability and technology, as well as in nutrition and health. They can involve different compounds and proceed through different chemical pathways. Browning reactions in foods are of widespread occurrence, and become evident when food materials subjected to processing or to mechanical injury. They are important in terms of the alteration of appearance, flavour, and nutritive value. Browning is considered to be desirable if it enhances the appearance and flavour of a food product in terms of tradition and consumer acceptance like in the cases of coffee, maple syrup, beer, and in toasting of bread. However, in many other instances, such as fruits, vegetables, frozen and dehydrated foods, browning is undesirable as it results in off-flavours and colours. Therefore it is important to know the mechanisms and inhibition methods of browning reactions. Another significant adverse effect of browning is the lowering of the nutritive value of the food article.

Rate of browning reactions depends on temperature of drying, pH and moisture content of the product, time of heat treatment, and the concentration and nature of the reactants. Rate increases with increasing temperature, and the increase is faster in systems high in sugar content. For moisture contents above 30 %, a decrease in reaction rate is caused by dilution, whereas below 30 %, decrease is caused by the intrinsic ability of sugars to lower water activity.

Browning reactions change colour, decrease nutritional value and solubility, create off flavours, and induce textural changes. There are two important forms of browning, enzymatic and non-enzymatic (Maillard reactions, caramelization, ascorbic acid oxidation). This colour development is usually undesirable, but with knowledge of the type of reaction involved, it is easier to work out methods for controlling this change.

(1) Enzymatic Browning

A group of enzymes, collectively called "phenolase" is responsible for browning of some fruits and vegetables, such as potatoes, apples, and banana. When the tissue is bruised, cut, peeled, diseases, or exposed to any number of abnormal conditions, the colour of the fruits or vegetables is changed. The injured tissue rapidly darkens on exposure to air, due to the conversion of phenolic compounds to brown melanins. This enzyme group includes such diverse enzymes as phenoloxidase, cresolase, dopa oxidase, catecholase, tyrosinase, polyphenoloxidase, potato oxidase, sweet potato oxidase, and phenolase complex.

Phenolase is extensively distributed in plants such as roots, citrus fruits, plums, bananas, peaches, pears, melons, olives, tea, mushrooms, and others. It has a molecular weight of

Paper 31 – PAGE 4/18 128.000 and a copper content of 0.2 %, amounting to 4 Cu molecules to each enzyme molecule. The freshly prepared enzyme contains cupper in the cuprous form, but it slowly oxidizes to the cupric form on aging. This change thus not results in any loss of activity. Phenolase in the pure form is colourless. Concentrated solutions of phenolase are most stable at the neutral pH. But, heating for a short time at 60°C inactivates enzyme. Phenolase is also inhibited by substances, which form stable complexes with copper such as H2S, KCN, CO or p-aminobenzoic acid.

In plants, there are a large number of naturally occurring o-diphenolic compounds, which are oxidizable by phenolase. Actually the mechanism of action of phenolase on o-diphenolic compounds is very complicated. Since the copper is the prosthetic group of the enzyme, it has been postulated that the activity of phenolase is based on the change of the copper from the cupric to the cuprous state. Simply phenolase catalyse the oxidation of colourless phenolic compounds into o-quinones, which are red to brown in colour. O-quinones are precursors of the brown colour in cut fruits and vegetables. When they combine with amino acid derivatives, highly collared complexes forms.

The initial reaction, involving the conversion of the phenolic compound to the corresponding quinone, is dependent upon the presence of the phenolase, its copper prosthetic group, and oxygen. Advantage may be taken of this in order to control or prevent enzymatic browning in foods. This type browning is a serious problem during the dehydration process where any injury to the plant tissue, sustained through the use of heat or through poor handling procedures, can result in phenolase activation.

The enzymatic browning of foods is usually undesirable because it cuts down the acceptability of the food in question for two reasons: (1) the undesirable development of off-colour and (2) the formation of off-flavours.

Control Methods of Enzymatic Browning

(I) Heat

The application of heat to the food article at a high temperature for an adequate length of time will inactivate phenolase and all other enzymes present. Several problems may arise through the use of heat. The fruit or vegetable becomes cooked, and this in turn leads to unfavourable texture changes and the development of off-flavours. Such problems may occur for instance in the processing of pre-peeled potatoes, apples, pears, and peaches.

There is a close relationship between temperature and time with respect to the heat-treatment of foods. These factors themselves depend upon the amount of enzyme. It is therefore essential to control the heating time very carefully at high temperatures, so that the enzymes are inactivated w hile avoiding significant changes in flavour and texture. A balance should be worked out in terms of each particular raw material and desired food product.

(II) Sulphur dioxide and sulphites

Sulphur dioxide and sulphites, usually sodium sulphate, sodium bisulphate and sodium metabisulphate, are the chemical inhibitors of phenolase that has been used for years in the food industry. It can be applied by gaseous sulphur dioxide or dilute aqueous solutions of the sulphites. The gas will penetrate at a faster rate into the fruit or vegetable, but the sulphite solutions are easier to handle, as in the form of a dip in the processing plant, or as a spray. There are advantages and disadvantages in the use of sulphur dioxide or su1phites. They can be used in cases where the application of heat would result in undesirable textural changes and the development of off-flavours. The internal atmosphere of the product in question must be considered when using SO_2. Apple slices, for example, have a fair amount of oxyge n in the internal tissue, which can cause browning. It is necessary, therefore, that SO_2 penetrate the entire slice, to effectively control browning. They have antimicrobial properties and also assist in preserving vitamin C. However, their use in food material may result in an objectionable flavour and odour, or may bleach the natural colour of the food. It is toxic at high levels, and can be detected organoleptically. Perhaps the most serious disadvantage of using sulphur dioxide or sulphites in foodstuffs is their adverse destructive effect on vitamin B or thiamine. In spite of these drawbacks, this group of phenolase inhibitors is widely used in food processing, due mainly to the effectiveness and low cost of these substances.

(III) Acids

This is a widely used method for controlling enzymatic browning. The acids employed are among those, which occur naturally in tissues, particularly citric, malic, phosphoric and ascorbic acids. In general their action is to lower tissue pH and thus to decrease the rate of enzymatic browning. The optimum pH of phenolase lies within the range 6-7, and below 3 there is virtually no enzymatic activity.

Citric acid, often in conjunction with ascorbic acid or sodium bisulphite, has long been used as a chemical inhibitor of enzymatic browning. Cut fruit, such as peaches is often immersed in dilute solutions of these acids prior to processing. Citric acid possesses a double inhibitory effect on phenolase, not only by lowering the pH of the medium, but also by chelating with the copper moiety of the enzyme.

A much more significant inhibitor of phenolase is ascorbic acid. It does not have a detectable flavour at the concentration used, nor does it possess a corrosive action upon metals; in addition, its vitamin value is well known. Ascorbic acid reduces the o-quinones formed by phenolase to the original o-dihydroxphnolic compounds, which in turn prevents the formation of brown substances.

(IV) Dehydration in sugar

The fruit is partially dehydrated by reducing to 50% of its original weight by osmosis in sugar or syrup. After draining, the fruit is either frozen or dried further in an air or vacuum dryer. The sugar or syrup inhibits enzymatic browning through the complete dehydration. In addition, it has a protective effect on flavour.

(2) Non-Enzymatic Browning

During manufacturing process changes in the structure of derivative fruit products are produced, therefore these modify the colour and final aspect of the product. Although most non-enzymatic browning in food materials is undesirable because it indicates deterioration in flavour and appearance of the product involved, the development of brown colours in some products is entirely acceptable. Examples of this are the development of brown colours in baked goods during the baking process, in beer, molasses, coffee and substitute cereal beverages, many breakfast foods, and the roasting and other forms of heat preparation of meat. However, the brown colours developing in most other products are not desirable, and methods to prevent or retard such changes are in use.

There are three main non-enzymatic reaction pathways: (i) Maillard reaction, (ii) Caramelization, (iii) Ascorbic acid oxidation.

(I) The Maillard reaction

For as long as food cooked, the Maillard reaction has played an important role in improving the appearance and taste of foods. It has been a central and major challenge in food industry, since the Maillard reaction is related to aroma, taste and colour, in particularly in traditional processes such as the roasting of coffee and cacao beans, the baking of bread and cakes, the toasting of cereals and the cooking of meat. Moreover, during the Maillard reaction a wide range of reaction product is formed with significant importance for the nutritional value of foods. This can be reduced by decrease of digestibility and possibly formation of toxic and mutagenic compounds, but can also be improved by the formation of antioxidative products.

The chemistry underlying the Maillard reaction is very complex. It encompasses not one reaction pathway but a whole network of various reactions. The Maillard reaction is notoriously difficult to control. Various factors involved in food processing influence it and they can be considered as food processing variables.

The Maillard reaction has been named after the French chemist Louis Maillard (1912) who observed the formation of brown pigments or melanoidins when heating a solution of glucose and glycine.

The Maillard reaction is the action of amino acids and proteins on sugars. The carbohydrate must be a reducing sugar because a free carbonyl group is necessary for such a combination. The end product is the melanoidins, which are brown pigments. The mechanism of reaction has three stages:

(i) Initial stage (colourless)

a. sugar-amine condensation

b. Amadori rearrangement

(ii) Intermediate stage (colourless to yellow)

c. sugar dehydration

d. sugar fragmentation

e. amino acid degradation

(iii) Final stage (highly coloured)

f. aldol condensation

g. aldehyde-amine polymerisation, formation of heterocyclic nitrogen compounds.

The carbonylamino reaction can occur in acidic or alkaline media, although it is favoured under the more alkaline conditions. A number of studies have demonstrated an increase in reaction rate with a rise in pH. The relationship between the reaction rate and pH would therefore render those foods of high acidity less susceptible to this reaction, e.g., pickles.

Furfural and hydroxymethylfurfural (HMF) are the most important chemical substances produced in non-enzymatic browning processes. The HMF content is important because it indicates the degree of heating of the treated products during processing.

The role of buffers in non-enzymatic browning has been shown to increase the rate of browning for sugar -amino acid systems as a result of their influence on the ionic environment in which the reaction takes place. The temperature dependence of this reaction has been demonstrated in a number of quantitative studies, where increased rates were reported with a rise in temperature. This reaction proceeds readily in aqueous solution, although complete dehydration of the reactants results in a rapid halt in the process.

Reducing sugars are essential ingredients in this reaction, providing the necessary carbonyl groups for interaction with the free x-amino groups. The reaction, itself, is not confined to monosaccharides but can also proceed in the presence of reducing disaccharides, i.e. maltose and lactose. Non-reducing sugars, however, cannot participate unless the glycosidic bond is cleaved, thereby liberating its constituent reducing monosaccharides capable of entering the reaction. The order of reactivity appears to be greater for aldopentoses than for aldohexoses, whereas reducing disaccharides exhibit considerably less activity.

(II) Caramelization

This process is another example of non-enzymatic browning involving the degradation of sugars in the absence of amino acids or proteins. When sugars are treated under anhydrous conditions with heat, or at high concentration with dilute acid, caramelization occurs, with the formation of anhydrous sugars.

Caramels for commercial use are made from glucose syrups, but usually caramelization is the result of reactions that take place when sucrose is heated. There are three stages during this process (at 200 ^{o}C), during which water is lost and first isosacchrosan and then other anhydrides are formed. The first stage starts with the melting of sucrose, followed by foaming, which continues for 35 min. during this period one molecule of water, is lost from a molecule of sucrose. The foaming then stops. Shortly after this, a second stage of foaming starts which lasts 55 min. During this stage about 9% of the water is lost, and the compound formed is caramelan, a pigment with the average formula of $C_{24}H_{36}O_{18}$. Caramelan melts at 138 ^{o}C, is soluble in water and ethanol, and is bitter in taste. The pigment caramelen is formed during the third stage of foaming which starts after about 55 min. the formula of this pigment is $C_{36}H_{50}O_{25}$. Caramelen melts at 154 ^{o}C and is soluble in water.

The main disadvantage of this reaction is the production of unpleasant, burned, and bitter products, which can arise if this process is allowed to proceed uncontrolled. This reaction may be slowed down by bisulphites, which react with sugar to decrease the concentration of aldehydic form.

(III) Ascorbic acid oxidation

A further mechanism appears to operate during the discoloration of dehydrated vegetables in which ascorbic acid is involved. The formation of dehydroascorbic acid and diketogluconic acids from ascorbic acid is thought to occur during final stages of the drying process and is capable of interacting with the free amino acids, nonenzymatically, producing the red-tobrown discoloration. This reaction may involve Strecker degradation.

(IV) Inhibition of non-enzymatic browning

Several of factors can affect the formation of coloured complexes in food products. Among these are pH, temperature, moisture content, time, concentration and nature of reactants.

The rate of browning increases with rising temperature. Since these reactions have been shown to have a high temperature coefficient, lowering of the temperature during the storage of food products can help to minimize these processes.

Reducing the moisture content through dehydrating procedures can inhibit those reactions being moisture dependent for optimum activity. In attempting to carry out these procedures one must ensure that the dehydrated product is suitable for sale in that form, and that the product is suitably packaged so as not to permit moisture uptake during storage

Since the Maillard reaction is generally favoured at the more alkaline conditions, if this type of browning is involved, lowering of the pH might provide a good method of control.

Gas packaging is extremely useful in excluding oxygen by using an inert gas. This reduces the possibility of lipid oxidation, which in turn could give rise to reducing substances capable of interacting with amino acids. While this reaction does not appear to influence the initial carbonylamino reaction, exclusion of oxygen is thought to effect other reactions involved in the browning process.

Chemical inhibitors have been used to advantage in limiting browning reactions during the production and storage of a variety of foods. Among those widely used are sulphites, bisulphites, thiols, and calcium salts.

Sulphites proved successful in controlling a variety of browning processes. Bisulphites inhibit the conversion of D-glucose to S-hydroxymethyl- furfural, as well as the conversion of ascorbic acid to furfural by complexing through the reducing group. Consequently the formation of furfurals is blocked, thus preventing the production of the coloured pigments. They can also block the carbonyl group of the reducing sugars involved in the carbonylamino reaction.

Calcium chloride was reported to be a possible inhibitor of browning. Its inhibitory effect is due to the chelating of calcium with the amino acids.

Although the various inhibitors discussed can prevent to varying degrees of success browning from occurring, it is important to realise that the nutritional value of the foods could still have been seriously reduced. The initial stages of the Maillard reaction, for example, the carbonylamino reaction could still have rendered the amino acids unavailable even though no browning is visible during this stage. However to be certain that this stage is the one inhibited is extremely difficult to ensure.

1.2.11.2 Lipid oxidation

Lipid oxidation is responsible for rancidity, development of of -flavours, and the loss of fatsoluble vitamins and pigments in many foods, especially in dehydrated foods. Factors that affect oxidation rate include moisture content, type of substrate (fatty acid), extent of reaction, oxygen content, temperature, presence of metals, presence of natural antioxidants, enzyme activity, ultraviolet light, protein content, free amino acid content, other chemical reactions. Moisture plays an important part in the rate of oxidation.

The elimination of oxygen from foods can reduce oxidation, but the oxygen concentration must be very low to have an effect. The effect of oxygen on lipid oxidation is also closely related to the product porosity. Freeze -dried foods are more susceptible to oxygen because of their high porosity. Air-dried foods ten to have less surface area due to shrinkage and thus are not as affected by oxygen. Minimizing the oxygen level during processing and storage, and addition of antioxidants as well as sequesterants, have been recommended in the literature to prevent lipid oxidation.

1.2.11.3 Color loss

The color of foods is dependent upon the circumstances under which food is viewed, and the ability of the food to reflect, scatter, absorb, or transmit visible light. Drying changes the surface characteristics of food and hence alters the ref lectivity and color. Carotenoids are fatsoluble pigments present in green leaves and red and yellow vegetables. Chemical changes to carotoneoid and chlorophyll pigments are caused by heat and oxidation during drying. In general, longer drying times and higher drying temperatures produce greater pigment losses. Oxidation and residual enzyme activity cause browning during storage. This is prevented by improved blanching methods and treatment of fruits with ascorbic acid or sulphur dioxide. Many studies indicate that the bulk of carotene destruction occurs during storage rather than as a result of the dehydration process. Pigment retention in dried foods decreased as temperature and moisture increased. Thus it was found that the beet pigments were most stable in the powders, then slices, and least stable in solution.

The natural green pigment of all higher plants is a mixture of chlorophyll a and chlorophyll b. The retention of the natural greenness of chlorophyll is directly related to the retention of magnesium in the pigment molecules. In moist heating conditions, the chlorophyll is converted to pheophytin by losing some of its magnesium. The color then becomes an olive green rather than a grass green.

The interaction of amino acids and reducing sugars (Maillard reaction) occurs during conventional dehydration of fruits. If the fruits are sulphured, enzymatic browning can be inhibited, and the Maillard reaction retarded.

There are certain different methodologies for analysing the color. The most common methods are the RGB (red, green, blue), LAB (lightness, redness-greenness, yellowness-blueness) and XYZ scales that analyse the colour into three parameters, so that each composite color can be easily quantified by a set of three numbers.

1.2.12 Physical changes that occur during drying (United Nations Industrial Development Organization, 2012)

1.2.12.1 Rehydration, Shrinkage and Food Porosity

Rehydration is a complex process aimed at the restoration of raw material properties when dried material is contacted with water. Pre-drying treatments, subsequent drying and rehydration per se induce many changes in structure and composition of plant tissue, which result in impaired reconstitution properties. Hence, rehydration can be considered as a measure of the injury to the material caused by drying and treatments preceding dehydration. Rehydration of dried plant tissues is composed of three simultaneous processes: the imbibition of water into dried material, the swelling and the leaching of soluble.

It has been shown that the volume changes (swelling) of biological materials are often proportional to the amount of absorbed water. It is generally accepted that the degree of rehydration is dependent on the degree of cellular and structural disruption. There are a large number of research reports in which authors measure the ability of dry material to rehydrate. The ratio between the dry material mass and water mass varies from 1:5 to 1:50, temperature of rehydrating water is from room temperature to boiling. Time of rehydration varies from 2 min. to 24 h.

The degree to which a dehydrated sample will rehydrate is influenced by structural and chemical changes caused by dehydration, processing conditions, sample preparation, and sample composition. Rehydration is maximised when cellular and structural disruptions such as shrinkage are minimised.

Several researchers have found that freeze-drying causes fewer structural changes and fewer changes to product's hydrophilic properties than do other drying processes. Most of the shrinkage occurs in the early drying stages, where 40 to 50 % shrinkage may occur. To minimise shrinkage, therefore, low-temperature drying should be employed so that moisture gradients throughout the product are minimized.

Many drying techniques or pre-treatments given to food before drying are aimed at making the structure more porous so as to facilitate mass transfer and thereby speed drying rate. Porous sponge-like structures are excellent insulating bodies and generally will slow down the rate of heat transfer into the food. Porosity may be developed by creating steam pressure with in the product and a case hardened surface through rapid drying. Porosity also can be developed by whipping or foaming a food liquid or puree prior to drying the porous product has the advantages of quick solubility or reconstitution and greater volume appearance, but the disadvantages of increased bulk and generally shorter storage stability because of increased surface exposure to air, light, etc.

1.2.12.2 Solubility

Many factors affect the solubility, including processing conditions, storage conditions, composition, pH, density, and particle size. It has been found that increasing product temperatures is accompanied by increasing protein denaturation, which decreases solubility. A low bulk density is required for good dispersibility of non-fat dry milk. It was found that particle agglomeration, which increases particle size, increased sinkability. However, some scientists found that larger particles were less soluble. This was attributed to the longer drying time required to dry large particles. Thus more protein was denatured and solubility decreased. This shows that the heat treatments as well as the particle size must be considered when determining solubility.

1.2.12.3 Texture

Texture is one of the most important properties connected to product quality. Changes to the texture of solid foods are an important cause of quality deterioration. Factors that affect texture include moisture content, composition, variety, pH, product history (maturity), and sample dimensions. The chemical changes associated with textural changes in fruits and vegetables include crystallization of cellulose, degradation of pectin, and starch gelatinisation. Texture is also dependent on the method of dehydration. High air temperatures (particularly with fruits, fish and meats) cause complex chemical and physical changes to the surface, and the formation of hard impermeable skin. This is termed “case hardening”. It reduces the rate of drying and produces a food with a dry surface and a moist interior. It is minimised by controlling the drying conditions to prevent excessively high moisture gradients between the interior and the surface of the food.

On rehydration the product absorbs water more slowly and does not regain the firm texture associated with the fresh material. There are substantial variations in the degree of shrinkage with different foods (Table 9).

Drying is not commonly applied to meats in many countries owing to the severe changes in texture compared with other methods of preservation. These are caused by aggregation and denaturation of proteins and a loss of water-holding capacity, which leads to toughening of muscle tissue.

Table 9 Approximate ratios for drying, shrinkage and rehydration of selected vegetables (Fellows, 1988).

Vegetable	Drying ratio[a]	Overall shrinkage ratio[b]	Rehydration ratio[c]
Cabbage	11.5	21.0	10.5
Carrots, diced	7.5	12.0	7.0
Onions, sliced	7.0	8.0	5.5
Peppers, green	17.0	22.0	8.0
Spinach	13.0	13.5	5.0
Tomato flakes	14.0	20.0	5.0

[a] Drying ratio is the ratio between the moisture content of the dried samples at t to the initial moisture content of the samples, t is the drying time.

[b] Overall shrinkage ratio is the ratio of a volume change to the moisture-content change above the shrinkage limit.

[c] Rehydration ratio is the ratio between the masses of the rehydrated samples to the masses of the dried samples.

The rate and temperature of drying have a substantial effect on the texture of foods. In general, rapid drying and high temperatures cause greater changes than do moderate rates of drying and lower temperatures. As water is removed during dehydration, solutes move from the interior of the food to the surface. Evaporation of water causes concentration of solutes at the surface.

In powders, the textural characteristics are related to bulk density and the ease with which they are rehydrated. These properties are determined by the composition of the food the method of drying, and the particle size of the product. Low-fat foods for example fruit juices, potato and coffee) are more easily formed into free-flowing powders than re whole milk or meat extracts. Powders are 'instantised' by treating individual particles so that they form free-flowing agglomerates or aggregates, in which there are relatively few points of contact. The surface of each particle is easily wetted when the powder is rehydrated, and particles sink below the surface to disperse rapidly through the liquid. These characteristics are respectively termed wetability, sinkability, dispersibility , and solubility. For a powder to be considered 'instant', it should be complete these four stages within a few seconds. The convenience of instantised powders outweighs the additional expense of production, packaging and transport for retail products.

Textural properties are usually related to mechanical stress, which examine the viscoelastic behavior of the material. The viscoelasticity is strongly related to complex quality characteristics perceived by people as mouth feeling, etc. Characterising the viscoelastic behavior of materials is usually done by the measurement of relaxation modulus E(t) and Poisson's ratio v(t) from a simple uniaxial tension or compression test, creep test, dynamic test and the Hertz and Boussinesq technique were explained as to their principles and data analysis.

Compression tests are the most common techniques for the estimation of the texture. The simplest approach is to measure the maximum applied force or stress at fracture of the material. The quantification of difficult terms such as hardness, chewiness, has been made by a methodology called Texture Profile Analysis.

The model for compression test involves four parameters: the maximum stress, the corresponding strain, the elastic parameter (E) and the viscoelastic exponent (p). The maximum stress the maximum strain are related with moisture content through simple equations. The elastic parameter (E) and the viscoelastic exponent (p) are related to moisture content through exponential equations.

The maximum deformation and maximum strain are significantly affected by the drying method. Osmotic dehydration seems to prevent the breakage of samples due to gain of solids that cause a plasticisation of structure. On the contrary vacuum and freeze drying seem to make apple samples more fragile due to higher values of porosity that they develop compared to that of convective dried materials.

1.2.12.4 Aroma Loss

There is often decrease in the quality of the dried products because most conventional techniques use high temperatures during the drying process. Processing may also introduce undesirable changes in appearance and will cause modification of the natural "balanced" flavor and color. The dehydration technologies should be focusing on the production of dried products with little or no loss in their sensory characteristics together with the advantages of added convenience.

The properties of dried vegetables are influenc ed by chemical and physical changes. Chemical changes mainly affect sensory properties such as color, taste and aroma, whereas physical changes mainly influence the handling properties such as swelling capacity and cooking time.

Heat treatment of fruits and vegetables often reduces the number of original volatile flavor compounds, while introducing additional volatile flavor compounds through the autoxidation of unsaturated fatty acids and thermal decomposition, and/or initiation of Maillard reactions. Volatile organic compounds responsible for aroma and flavour have boiling points at temperatures lower than water. Volatiles, which have a high relative volatility and diffusivity, are lost at an early in drying. Fewer volatile components are lost at later stages. Control of drying conditions during each stage of drying minimises losses. Foods that have economic value due to their characteristics flavors, herbs and spices, are dried at low temperatures.

A second important cause of aroma loss is oxidation of pigments, vitamins and lipids during storage. The open porous of dried food allows access of oxygen. The storage temperature and the water activity of the food determine the rate of deterioration.

In dried milk the oxidation of lipids produces rancid flavors owing to the formation of secondary products including δ-lactones. Most fruits and vegetables contain only small quantities of lipid, but oxidation of unsaturated fatty acids to produce hydroperoxides, ketones and acids, causes rancid and objectionable odors. Vacuum or gas packaging, low storage temperatures, exclusion of ultraviolet or visible light, maintenance of low moisture contents, addition of synthetic anti-oxidant, or preservation of natural anti-oxidants reduce these changes.

The technical enzyme, glucose oxidase, is also protecting dried foods from oxidation. A package, which is permeable to oxygen but not to moisture and which contains glucose and the enzyme, is placed on the dried food inside a container. Oxygen is removed from the headspace during storage. Flavor changes, due to oxidative or hydrolytic enzymes are prevented in fruits by the use of sulphur dioxide, ascorbic acid or citric acid, by pasteurisation of milk or fruit juices and by blanching of vegetables.

Other methods that are used to retain flavors in dried foods include:

(1) Recovery of volatiles and their return to the product during drying,

(2) Mixing recovered volatiles with flavor fixing compounds, which are then granulated and added back to the dried product (for example dried meat powders), and

(3) Addition of enzymes, or activation of naturally occurring enzymes, to produce flavors from flavor precursors in the food (for example onion and garlic are dried under conditions that protect the enzymes that release characteristics flavors). Maltose is used as a carrier material when drying flavor compounds.

1.2.13 Nutritional changes that occur during drying (United Nations Industrial Development Organization, 2012)

1.2.13.1 Nutrient Losses

In drying, a food loses its moisture content, which results in increasing the concentration of nutrients in the remaining mass. Proteins, fats, and carbohydrates are present in larger amounts per unit weight in dried foods than in their fresh counterpart. Large differences in reported data on the nutritive value of dried foods are due to wide variations in the preparation procedures, the drying temperature and time, and the storage conditions. In fruits and vegetables, losses during preparation usually exceed those caused by the drying operation. The water-soluble vitamins can be expected to be partially oxidized. The water -soluble vitamins are diminished during blanching and enzyme inactivation. Vitamins during drying proceeds, some (for example riboflavin) become supersaturated and precipitate from solution. Losses are therefore small (See Table 10). Others (for example ascorbic acid) are soluble until the moisture content of the food falls to very low levels and react with solutes at higher rates as drying proceeds. Ascorbic acid is sensitive to high temperatures at high moisture contents. Several studies have shown that the maximum rate of ascorbic acid degradation occurs at specific (critical) moisture levels. The critical moisture level appears to vary with the product being dried and/or the dehydration process. Short drying times, low temperatures, and low moisture and oxygen levels during storage, are necessary to avoid large losses. To optimize ascorbic acid retention, the product should be dried at a low initial temperature when the moisture content is high since ascorbic acid is most heat sensitive at high moisture contents. The temperature can then be increased as drying progresses and ascorbic acid is more stable, due to decrease in moisture. Thiamin is also heat sensitive, but other water-soluble vitamins are more stable to heat and oxidation, and losses during drying rarely exceed 5-10%.

Fruits can be sun dried, dehydrated, or processed by a combination of the two. Sun drying causes losses in carotene content. Dehydration especially spray drying, can be accomplished with loss in this nutrient. Vitamin C is lost in great proportions in sun-dried fruits. Freeze drying of fruits retains greater portions of vitamin C, and other nutrients. The retention of vitamins in dehydrated foods is generally superior in all counts than in sun-dried foods.

Vegetable tissues dried artificially or in the sun tend to have losses in nutrients in the same order of magnitude as the fruits. The carotene content of vegetables is decreased as much as 80 per cent if processing is accomplished without enzyme inactivation. The best commercial methods will permit drying with losses in the order of five per cent of carotene. Thiamin content reduction can be anticipated to be in the order of 15 per cent in blanched tissues, while unblanched may lose three-fourths of this nutrient. With ascorbic acid, rapid drying retains greater amounts than slow drying. Generally the vitamin C content of vegetable tissue will be lost in slow, sun drying processes. In all events the vitamin potency will decrease on storage of the dry food.

With milk products, the nutrient level of the raw milk sand the method of processing will dictate the level of vitamins retained. Vitamin A is retained in good proportions in drum-dried and spray-dried milk. Vacuum packed dry milk can be stored with good retention of vitamin A. Thiamin losses occur during both spray and drum drying, but losses are of a lower order of magnitude than with fruit and vegetable drying. Similar results are obtained with riboflavin. Ascorbic acid losses occur during the drying of milk. Being sensitive to heat and oxidation, vitamin C may be totally lost in a drying process. With careful processing, vacuum drying and freeze -drying, ascorbic acid values can be retained in the same order of magnitude as fresh raw milk. The vitamin D content of milk is generally greatly decreased by drying. Fluid milk should be enriched with vitamin D prior to drying. Other vitamins such as pyridoxine and niacin are not materially lost.

Usually dried meat contains slightly less vitamins than fresh meat. Thiamin losses occur during processing, greater losses occurring at high drying temperature. Vitamin C is in most part lost in dried meat. Small losses of riboflavin and niacin occur.

Oil-soluble nutrients (for example essential fatty acids and vitamins A, D, E and K) are mostly contained within the dry matter of the food and they are not therefore concentrated during drying. However, water is a solvent for heavy metal catalysts that promote oxidation of unsaturated nutrients. As water is removed, the catalysts become more reactive, and the rate of oxidation accelerates. Fat-soluble vitamins are lost by interaction with the peroxides produced by fat oxidation. Losses during storage are reduced by low oxygen concentration and storage temperatures and by exclusion of light.

Table 10 Vitamin losses in selected dried foods (Fellows, 1988).

	Loss (%)						
Food	Vitamin A	Thiamin	Vitamin B_2	Niacin	Vitamin C	Folic acid	Biotin
Fruits[a]	6	55	0	10	56	-	-
Fig (sun-dried)	-	48	42	37	-	-	-
Whole milk (spray-dried)	-	-	-	-	15	10	10
Whole milk (drum-dried)	-	-	-	-	30	10	10
Pork	-	50-70	-	-	-	-	-
Vegetables[b]	5	< 10	< 10	-	-	-	-

[a] Fruits mean loss from fresh apple, apricot, peach and prune.

[b] Vegetables mean loss from peas, corn, cabbage and beans (drying stage only)

(I) Influence of Drying on Protein:

The biological value of dried protein is dependent on the method of drying. Prolonged exposures to high temperatures can render the protein less useful in the dietary. Low temperature treatments of protein may increase the digestibility of protein over native material. Milk proteins are partially denaturated during drum drying, and these results in a reduction in solubility of the milk powder, aggregation and loss of clotting ability. At high storage temperatures and at moisture contents above approximately 5%, the biological value of milk protein is decreased by Maillard reactions between lysine and lactose. Lysine is heat sensitive and losses in whole milk range from 3-10% in spray drying and 5-40% in drum drying.

(II) Influence of drying on fats:

Rancidity is an important problem in dried foods. The oxidation of fats is greater at higher temperatures than at low temperatures of dehydration. Protection of fats with antioxidants is an effective control.

(III) Influence of drying on carbohydrates:

Fruits are generally rich sources of carbohydrates, poor sources of proteins and fats. The principal deterioration in fruits is in carbohydrates. Discoloration may be due to enzymatic browning, or to caramelization types of reactions. In the latter instances, the reaction of organic acids and reducing sugars cause discolorations noticed as browning. The addition of sulphur dioxide to tissues is a means of controlling browning. The action is one of enzyme poisoning and antioxidant power. The effectiveness of this treatment is dependent upon low moisture contents. Carbohydrate deterioration is most important in fruit and vegetable tissues being dried. Slow sun drying permits extensive deterioration unless the tissues are protected with sulphates, or suitable agents. Burning sulphur is the least expensive method of obtaining such protection, and is done prior to drying.

1.2.13.2 Microbiological quality

In as much as micro organisms are widely distributed throughout nature, and foodstuffs at one time or another are in contact with soil and dust, it is anticipated that micro organisms will be active whenever conditions permit. One obvious method of control is in the restriction of moisture for growth. Living tissues require moisture. The amount of moisture in food establishes which micro organisms will have an opportunity to grow. Reducing the water activity of a product below 0.85 inhibits growth but does not result n a sterile product. The heat of the drying process does reduce their numbers, but the survival of food-spoilage organisms may give rise to problems in the reconstituted food. Recommendations for the control of micro organisms during processing are often very basic. The highest possible drying temperatures should be used to maximise thermal death even though low drying temperatures are best for maintaining organoleptic characteristics. If a process is optimised for other quality factors, there are constraints on the maximum allowable water content.

Sodium chloride is commonly employed in conjunction with drying. Salt is useful in controlling microbial growth during sun drying and dehydration processes, i.e., meat and fish drying.

The most positive control would be to start with high quality foods having low contamination, pasteurise the material prior to drying, process in clean factories, and store under conditions where the dried foods are protected from infection by dust, insects, rodents and other animals.

1.2.13.3 Storage stability

When discussing storage stability, one is concerned with the organoleptic, physical, and chemical changes that take place in the dried fruit and vegetables during storage and the rates at which these changes occur. Darkening and loss of flavour are the major types of deteriorations of dried fruits and vegetables in storage.

(1) Sulphur dioxide content, storage temperature, light, packaging material, moisture content, antimicrobial treatment and trace elements are major factors affecting storage stability. Only free sulphite is effective in retarding the formation of pigment materials. During storage, the loss of sulphur dioxide determines the practical shelf life of the dried product with respect to spoilage through non-enzymatic browning. Storage of products at semitropical or summer temperatures requires residual sulphites to prevent darkening and flavour bittering, and to make the dried fruit less favorable medium for growth of micro organisms. Sulphur dioxide helps to maintain a light, natural colour during storage. Darkening rates during storage is inversely proportional to sulphur dioxide content. Therefore, any condition accelerating sulphur dioxide loss, in turn, accelerates the darkening of the product. One way to retard sulphite loss, thereby darkening, is the addition of oxygen scavenger pouch to the sealed packed sulphured dried fruit.

(2) Storage temperature is of vital importance in relation to maintenance of quality. Storage of dried fruits and vegetables should be at relatively low temperatures to maximize storage life. There is an important effect of temperature on loss of sulphur dioxide from the dried product during storage. A 20^{o}F increase in temperature increases the rate of sulphur dioxide loss approximately 3 times. Moreover at higher temperatures, the rate of change in flavor also increases.

(3) Light, during storage, is detrimental for quality. It causes a reduction in carotene content, increases the rate and amount of sulphur dioxide loss, and thereby increases the rate of darkening. In addition, it also affects riboflavin content.

(4) Packaging material used and the package environment is another major factor in terms of storage stability. The type of package used varies with expected storage conditions. Packaging may be done under vacuum, nitrogen or atmospherically.

(5) Dried foods have moisture content below 20 % and a water activity 0.7 or below. They are hard and firm, resistant to microbial deterioration. There are critical water activities for some products below which browning is minimized. Storage stability increases with

decreasing moisture content. But, it was also reported that the maximum rate of deterioration of dried fruits occurs at a moisture content of 5-8 % moisture.

(6) Dried fruits and vegetables must be protected from rodents and insects during storage. Fumigation is often used to prevent insect infestation during storage and before packaging. In addition to fumigation, antimycotic agents (fungistats) are used to stabilize most prunes and figs against mould growth at 30-35 % moisture. Sorbic acid and sorbate salts are used as dips or sprays to prevent melding; sulphur dioxide or sulphite salts are used to preserve fruits during drying from color changes and browning, and to ward off insects. Potassium sorbate dip is the most effective one. The effectiveness depends on pH of the product.

(7) Some salts and metals are detrimental to nutritive value, flavour and storage quality. Raw materials may be exposed to these trace elements during washing or pre-treatment. Calcium has a firming effect on texture; iron and copper combine with tannins to cause blackening and may accelerate degradation of ascorbic acid. Sodium, magnesium and calcium sulphates impart bitter flavour. Certain salts of zinc, cadmium and chromium have toxic effects.

1.2.14 Storing dried food (Dry It! You'll Like It!, 1985)

To insure lasting flavor and quality, it is important to store dried foods property. The essential elements of good storage are cool temperatures and a dark, dry environment.

1.2.14.1 Cool.

For best results, store foods at 60° F. or below. Do not use a refrigerator for long term storage. It is cold but too moist. On the other hand, a freezer is ideal, though not necessary. Dried foods may be stored at warmer temperatures but remember, as temperature increases the shelf life will decrease.

1.2.14.2 Dark.

Light causes dried foods to deteriorate and lose color. Store foods in a dark area. If you use glass jars or plastic bags, place them in a larger container that eliminates light such as a large metal can, a box, or paper bag. A dark closet makes a great storage area.

1.2.14.3 Dry.

Moisture-proof, airtight containers are essential for storing dried foods. Light-weight plastic bags are slightly porous so it is wise to use heavier bags for storage, or double bag each package. Squeeze out any excess air before sealing. Glass jars make the best airtight containers. For long term storage we often use masking tape to seal the lid. This not only insures a moisture barrier but it also helps prevent insect infestation.

It is also important to be careful to maintain the quality of the dried product consist of:

(1) Package food as soon as soon as it has cooled.

Food will draw moisture rapidly when it is exposed to normal room conditions. This is especially important in humid climates.

(2) Label all packages carefully.

Include the type of food, the date, and any special preparation instructions. Fruit leathers and herbs are especially easy to confuse. Dating the packages helps organize dried food supply and makes it easier to rotate foods. It helpful to include information such as the number of portions and the fresh, pre-drying weight or quantity of the item.

(3) Store foods in small quantites or portion size packages.

Small portions are not only convenient but also help to protect your food supply. If something does spoil, the entire supply won't be contaminated. Foods will keep better. Remember that every time you open a jar to remove some food, moisture enters.

(4) Rotate your stored foods.

Always try to use the oldest first. For maximum nutrition, food should be kept no longer than a year from harvest to harvest.

1.2.15 The cause of the deterioration of dried food (TPUB, 2007)

1.2.15.1 Relative humidity

The gross changes in foods from excessive moisture are part of everyday experience. Dried, dehydrated, and freeze-dried foods are especially susceptible to this form of deterioration. These types of food are very hygroscopic (readily taking up and retaining moisture); if not properly packaged, the product will become lumpy or caked if excessive moisture is present. This condition can possibly lead to other forms of deterioration, such as bacterial growth and chemical reactions such as oxidation.

1.2.15.2 Temperature

The rate of deterioration will be significantly influenced by temperature. We can borrow a rule of chemistry (van't Hoff's rule) to estimate the rate at which the deterioration change will take place. In essence, the rule states that for every 18ºF (10ºC) increase in temperature, the rate of a chemical reaction doubles. This rule will suffice for our purposes when we apply it to chemical reactions occurring in foods. Using this general rule, we can say that for every 18ºF (10ºC) increase in storage temperature of a food, the shelf life of the food will be reduced by one half, for the deteriorative chemical reaction rate will have doubled. At low temperatures, peroxide decomposition is extremely slow, whereas at high temperatures, it is rapid.

1.2.15.3 Light

Light, another form of physical change that causes food deterioration, can cause fading of color in many food items. Some vitamins are destroyed by light, notably riboflavin, vitamin A, and vitamin C

1.2.15.4 Oxygen

Oxidative rancidity arises from the decomposition of peroxides. Peroxides are the result of the oxidation of unsaturated fats. The products resulting from the decomposition of peroxides include aldehydes, ketones, and hydrocarbons. These help to produce the flavors and odors associated with oxidative rancidity.

(1) Abnormal characteristics.

The abnormal characteristics of a product that has undergone oxidative rancidity are a paintlike or acrid (burning) odor and an abnormal (rancid) taste. The color of a food item is not normally changed due to this deteriorative process.

(2) Unsaturated fatty acids .

All foods containing unsaturated fatty acids (UFA) are susceptible to oxidative rancidity.

(I) The rates of formation and intensities of unpleasantness produced depend upon three factors. These are the composition of the lipid components, their location in the food, and the conditions of storage. In general, high concentrations of UFA, especially acids with three or more double bonds, and exposure to air at elevated temperatures result in rapid development of intense rancidity.

(II) At low temperatures, peroxide decomposition is extremely slow, whereas at high temperatures, it is rapid

Table 11 Major modes of deterioration, semi-perishables.

Semi-perishables	Mode of deterioration	Critical environmental factors
Fresh bakery Products	Staling, microbial growth, moisture loss causing hardening, oxidative rancidity	Oxygen, temperature, humidity
Breakfast cereals	Rancidity, loss of crispness, nutrient loss, breakage	Relative humidity, temperature, rough handling
Pasta	Texture changes, staling, vitamin, and protein quality loss, breakage	Relative humidity, temperature, light, oxygen, rough handling
Fried snack foods	Rancidity, loss of crispness, breakage	Oxygen, light, temperature, relative humidity, physical handling
Dehydrated foods	Browning, rancidity, loss of color, loss of texture, loss of nutrients	Relative humidity, temperature, light, oxygen
Nonfat dry milk	Flavor deterioration, loss of solubilization, caking, nutrient loss	Relative humidity, temperature
Coffee	Rancidity. loss of flavor and odor	Oxygen, temperature, lights, relative humidity
Tea	Loss of flavor, absorption of foreign odors	Oxygen, temperature, light, humidity
Canned fruits and Vegetables	Loss of flavor, texture, color, and nutrients	Temperatures

1.2.16 Vacuum dryer

Vacuum drying and hot air drying is the principle difference is the pressure inside the vacuum drying chamber. The air inside the drying chamber has a low vapor pressure, and the concentration of low humidity. When placing the material in the drying chamber and the mass transfer. Water vapor on the surface of the material is quickly spread to the surrounding air. Due to the difference of vapor diffusion and partial vapor pressure. And the liquid contained in the materials will move out to the surface with the capillary flow as a result of the surface force. These principles, resulting in reduced drying time compared to drying with hot air. The key benefits of vacuum drying include lower process temperatures, less energy usage and hence greater energy efficiency, improved drying rates, and in some cases, less shrinkage of the product (Montgomery et al., 1997; Alibas, 2012). Vacuum drying has been successfully applied to many fruits and vegetables and other heat-sensitive foods. Vacuum dried materials are characterised by better quality retention of nutrients and volatile aroma. However, the cost of the process is high (Tsami et al., 1998).

1.2.17 Vacuum dried products

Dried fruits and vegetables. The food has been popular. It is of interest to people in most countries for a long time. As can be stored for a long time. A nutritious, affordable and convenient for consumers to find edible, although not in the season. The drying of fruits and vegetables in the development of modern color and delicious taste similar to fresh fruit. And free of oil, which is the cause of obesity. Therefore, to meet the needs of consumers. The vacuum dried product development. By vacuum drying of fruits and vegetable products that are sold in many different types and brands available for purchase. Available through the internet and general store (Figure 7). The price of the product as shown in Tables 12 and 13. The product was vacuum dried and fried the response from consumers as well. Therefore, this research has focused on the development of vacuum drying of agricultural products to be effective. To help farmers add value to the addition of revenue from the sale of fresh fruit.

Figure 7 Vacuum dried products from the department store Tesco Lotus stores, Hat Yai, Songkhla province, brand Dfresh.

Table 12 Description of the product dried by vacuum drying (Information from the department store Tesco Lotus stores, Hat Yai, Songkhla province).

The product	Weight (g)	Production facilities.	Price (baht per unit)
Dried jackfruit.	50	Fruit Tech Co., Ltd. 29/2 Moo 2, Nong Prong Sub-District, Sri mahapho District, Prejeenburi 25140 Tel. 037-206333	38
Dried okra.	40	Fruit Tech Co., Ltd. 29/2 Moo 2, Nong Prong Sub-District, Sri mahapho District, Prejeenburi 25140 Tel. 037-206333	52
Dried Durian.	50	Fruit Tech Co., Ltd. 29/2 Moo 2, Nong Prong Sub-District, Sri mahapho District, Prejeenburi 25140 Tel. 037-206333	57

Table 13 Description of the product dried by vacuum drying (Information from the internet).

The product	Weight (g)	Production facilities.	Price (baht per unit)
Dried jackfruit.	120	KrobKaew Natural Foods Co., Ltd. (http://www.thaitambon.com/tambon/tsmepdesc.aspProd=05125101214&ID=770803&SME=0512510757)	35
Dried banana.	80	ThaiSmile Co., Ltd. ((http://www.tshop2u.com/product.detail_505449_en_2655414)	29
Dried Litchi	35	ThaiSmile Co., Ltd. (http://www.tshop2u.com/product.detail_505449_en_2655392)	29
Dried longan	40	ThaiSmile Co., Ltd. (http://www.tshop2u.com/product.detail_505449_en_2655401)	29
Dried pineapple	45	ThaiSmile Co., Ltd. (http://www.tshop2u.com/product.detail_505449_en_2655371)	29
Dried durian	40	ThaiSmile Co., Ltd. (http://www.tshop2u.com/product.detail_505449_en_2655362)	29

1.3 Review of Literatures

Yamsaengsung et al. (2011) studied the effect of oil temperature, frying time and ripeness, which affects the characteristics of vacuum fried bananas. Percent thickness expansion and hardness of vacuum fried banana slices at 100, 110, and 120^{o}C and 8.0 kPa after 20 min of frying. Values in the same data series with different superscripts mean that the values are significantly different ($p < 0.05$). The results showed that the frying temperature of 110^{o}C produced the highest degree of expansion. But the temperature will not affect the hardness of the product. Hardness of vacuum fried banana slices at 110^{o}C and 8.0 kPa as a function of frying time. The results showed that the first 10 min of frying, there was a rapid movement of water from within the product toward the product surface. This water mobility caused the product to become rubbery and soggy. At the same time, as the starch granules within the product were exposed to heat, water, and shear stress, they begin to gelatinize, giving structure and a more solid texture to the product. And effect of days of ripeness on the total sugar content and hardness of vacuum fried bananas fried at T = 110^{o}C and p = 8 kPa is with day 1 representing the least ripened bananas and containing the lowest sugar to starch ratio of 2.90 ± 0.20, its hardness value of 16.51 ± 1.40 N was significantly higher than those of other days of ripeness.

Nimmol et al. (2007) studied drying of banana slices using combined low-pressure superheated steam drying and far-infrared radiation (LPSSD-FIR). Comparison was of data obtained from the system with combined far-infrared radiation and vacuum drying (VACUUM-FIR) conducted in the same drying chamber. The pressure used for drying is in the range 7 to 10 kPa at 70, 80, and 90^{o}C. The drying experiments were performed until the sample moisture of 0.035 kg/kg (d.b.) was obtained. The results showed that the temperature of both LPSSD-FIR and VACUUM-FIR samples during the later stage of drying were higher than the pre-determined medium temperatures. And found that VACUUM-FIR took shorter drying time than LPSSD-FIR at 70 and 80^{o}C and LPSSD-FIR took shorter drying time than VACUUM-FIR at 90^{o}C. In the case of color changes of dried banana slices it was found that drying of the two methods give the same effect is at higher temperatures yielded darker dried banana than doing so at lower temperatures. In the case of shrinkage and rehydration behavior of dried banana slices it was found that drying of the two methods give the same effect is at lower temperatures yielded the dried products with lower degrees of shrinkage and at higher temperatures yielded the dried products with higher degrees of rehydration behavior. It was also found that the effects of drying temperature and drying pressure as well as drying method on the hardness were not significant.

Jena and Das (2007) has studied the effect of the thickness of the coconut presscake that affect the drying rate. Drying characteristics of the presscake was investigated under varying conditions of presscake thickness (2, 3 and 4 mm) and vacuum chamber plate temperature 65^{o}C at 65 mm Hg absolute. The results showed that the thickness of the coconut presscake increases will result in a very long period of drying.

Swasdisevi et al. (2007) studied drying of Cavendish banana slices using infrared-vacuum drying. The investigated drying conditions included drying temperatures (50, 55 and 60^{o}C), drying vacuum pressure (5, 10 and 15 kPa) and thickness (2, 3 and 4 mm). The drying experiments were performed until the sample moisture of 0.07 kg/kg (d.b.) was obtained. The results showed that the rate of moisture reduction increased with an increase in the drying temperature because of the increased temperature difference between the drying product and the surrounding, as well as the higher moisture diffusivity. It was also found that the rate of moisture reduction increased with decreasing absolute pressure of the drying chamber since at a lower pressure, water boils and evaporates at a lower temperature. Hence, higher drying rates were obtained. In the case of thickness changes of banana slices it was found that the drying time decreased with decreasing a sliced banana thickness because of the penetrated FIR to a sliced banana decreased with increasing thickness. In the case of color changes of dried banana slices it was found that lightness decreased with increasing surface temperature because of browning reaction occurring during drying process. And it was found that drying at lower temperatures yielded the dried products with lower degrees of shrinkage because of drying at high temperatures was caused the banana surface to become dry or the water of the banana will be removed from the surface of banana suddenly. From hardening occurred at the surface, this helps to maintain the shape of the banana. In addition, shrinkage increased with increasing pressure, because the increased pressure caused the banana surface to dry slowly. It was also found that the effects of drying temperature and drying pressure on the hardness were not significant while the hardness increased with increasing thickness.

Sogi et al. (2003) studied the water sorption isotherm and drying characteristics of tomato seeds. For the drying experiments using cabinet drying for drying of tomato seeds.

Comparison was of data obtained from the system with fluidized bed drying conducted in the same drying chamber. The investigated drying conditions included drying temperatures (50, 70 and 90^{o}C) and quantity of the raw material on a tray (4, 8 and 12 kg/m^{2}). The results showed that the Adsorption isotherms used to describe the process at best is Henderson’s model. Page's equation was finally selected to describe the drying behavior of this process. In addition, drying time decreased with decreasing quantity of the raw material on a tray. And fluidized bed drying took shorter drying time than cabinet drying.

Arévalo-Pinedo and Murr (2006) studied the drying kinetics of pumpkin (Cucurbita maxima) in nature and pre-treated by freezing and blanching was studied by using a vacuum dryer. Pre-treatment methods include blanching in boiled water at 95^{o}C for 5 min and then cooled at room temperature. Samples destined to be frozen were placed in a freezer at 20^{o}C for a period of 3 h. The frozen samples were then allowed to thaw at room temperature. The pressure used for drying is in the range 5 to 25 kPa at 50 and 70^{o}C. It was found the applied pre-treatment influence favorably in the kinetic of drying. However freezing showed greater influence than blanching. The drying kinetics of pumpkin was explained by using the diffusional model of Fick for an infinite slab with and without shrinkage. The shrinkage of pumpkin was also included into the diffusion model for determining the effective diffusion coefficient.

Jaturonglumlert and Kiatsiriroat (2010) studied combined heat and mass transfer natural convective and far-infrared drying of fruit leather. The used of the mass/heat transfer analogy in the investigation of convective heat transfer**.** The results showed that when far infrared radiation is used for drying fruits that the ratio h_t/h_m is lower than the value obtained in the case without far-infrared radiation. Hence the mass transfer will be increased. However, the ratio h_t/h_m for combined convective and far-infrared drying of longan fruit leather, not suitable for predicting the heat-mass analogy classical model. Therefore, it is adjusted by using the Nusselt number for the drying equation. It was found that the experimental data quite well within±10% deviation. And increase of far-infrared radiation heat flux results in shorter drying time.

1.3 Objectives

1. To determine the optimal conditions for vacuum drying process of agricultural products (bananas, pineapples and apples).

2. To study the mathematical model of vacuum drying of agricultural products (bananas, pineapples and apples).

3. To study the physical, chemical and sensory properties of the agricultural products (bananas, pineapples and apples) were vacuum dried.

4. To develop the baskets for vacuum drying of agricultural products (bananas, pineapples and apples).

5. To study the economics of vacuum drying of agricultural products (bananas, pineapples and apples).

CHAPTER 2

Research Methodology

Research methodology has five activities consist of;

Activities 1 Study the optimal conditions for vacuum drying process of agricultural products

Activities 2 Study the mathematical model of vacuum drying of agricultural products

Activities 3 Study the physical, chemical and sensory properties of the agricultural products were vacuum dried

Summary process of activities 1-3 shows in Figure 8.

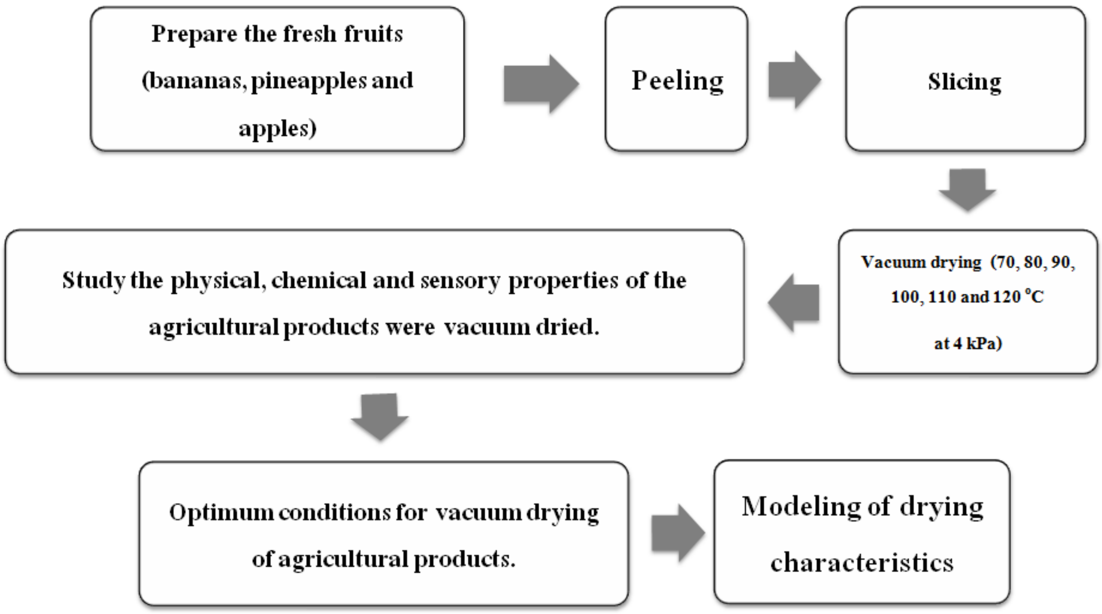


Figure 8 Summary of process for study the optimal conditions for vacuum drying process of agricultural products.

Activities 4 Development of baskets for vacuum dryer

Activities 5 Economic analysis

2.1 Preparation of Raw Materials

Fresh bananas (*Musa acuminata* variety Gros Michel banana or 'kuauyhomtong' in Thai) were purchased from a local market in Songkhla Province, Thailand. A ripeness level of green tip (color index no. 5) was used in this study (Nimmol et al., 2007). The fresh bananas had the initial moisture content in the range of 73.36–73.39% (w.b.). The bananas were peeled and sliced using a blade to 2.50-3.50 mm thickness. The diameter of the bananas was in the range of 31.50-34.50 mm.

Fresh pineapples (*Ananas comosus* variety Phuket) were purchased from a local market. The commercial ripeness (ready-to-eat) was used in this study. The fresh pineapples had the initial moisture content in the range of 84.66–85.44% (w.b.). For each experiment, the pineapples were prepared by removing the crown and skin. Then it was cut into four vertical sections, cored, and sliced by a blade to 2.50-3.50 mm thickness. Because there is a great variation in the nutrients content between the base and the top of the fruit (Miller & Hall, 1953; Ramallo & Mascheroni, 2004), only the central zone of each pineapple fruit was used in the experiments.

Fresh apples (*Malus sylvestris* variety Fuji) were purchased in the local market. The fresh apples had the initial moisture content in the range of 89.27–90.21% (w.b.). For each experiment, apple was crowns removed, peeled, cored and sliced. Apple slices with an average thickness of 5.5-6 mm were cut in a transversal direction to their axis using a slicing device. (Mauro et al., 2004). The drying experiments were performed until the final moisture content of 22% (w.b.) was reached.

The sample preparation was shown in Figure 9.

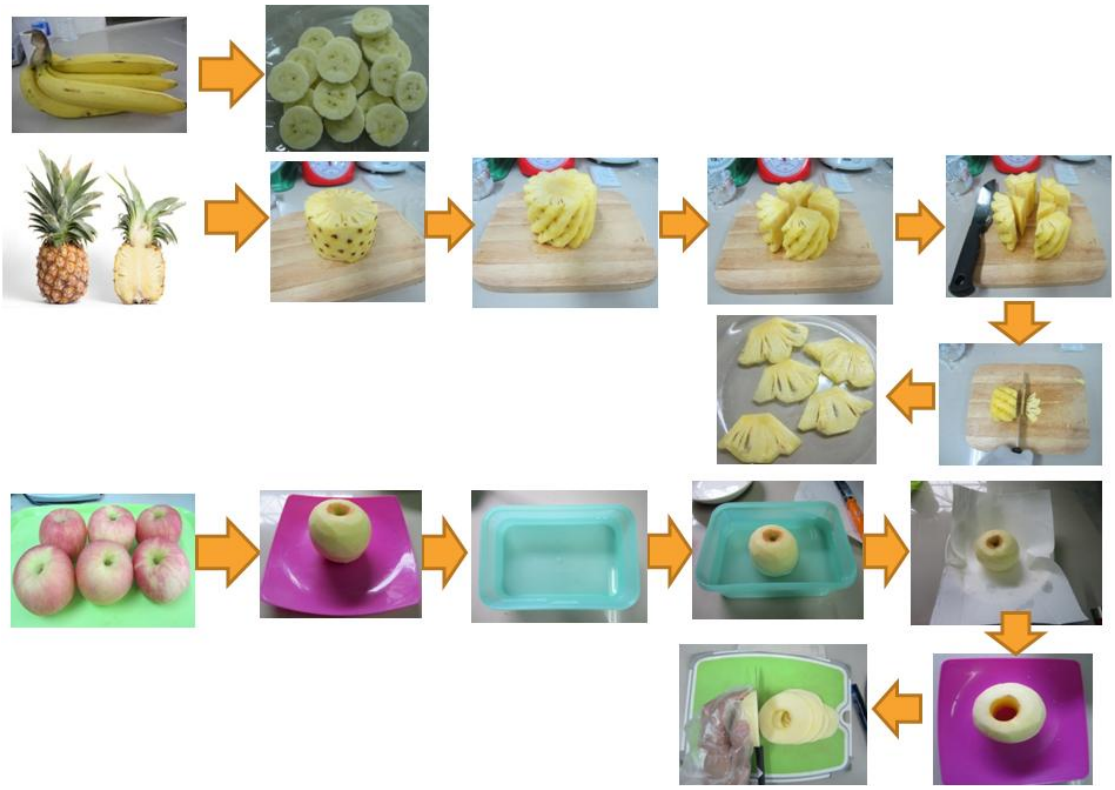


Figure 9 The preparation of raw materials for vacuum drying.

2.2 Drying Operations

The schematic diagram of the vacuum dryer is shown in Figures 10 and 11. The experimental setup consisted of a vacuum dryer, a condenser and a liquid ring vacuum pump (Model ET32030, Nash, Trumbull, CT). The vacuum dryer was constructed from a stainless steel with a diameter of 400 mm, a height of 300 mm, and a wall thickness of 6 mm. The stainless steel lid of the dryer had a thickness of 8 mm. The condenser was fabricated and assembled by the Department of Chemical Engineering, Prince of Songkla University, Hat Yai, Thailand. The condenser consisted of a 9425 mm long stainless steel tube with an internal diameter of 19 mm coiled inside a stainless steel container circulated with cooling water (Yamsaengsung et al., 2011). Paraffin oil was used as the heat source for vacuum dryer. The vacuum dryer was preheated for approximately 1 hour until the selected drying temperature was reached. Drying experiments were conducted at temperatures of 70, 80, 90, 100, 110 and 120^{o}C, and an absolute chamber pressure of 4 kPa. The fresh fruits were placed on the wire netting basket and dried in each experiment (Figure 12). The drying experiments were performed until the final moisture content of the banana dried, pineapple dried and apple dried were less than 5% (w.b.) (Acceptances of UNIDO Standards, 2012), 7% (w.b.) (Acceptances of UNIDO Standards, 2012) and 22% (w.b.) (Acceptances of UNECE Standards, 1998), respectively or when the products were crispy. All experiments were performed in triplicate. The dried fruits were stored in small plastic bags. The small plastic bags were placed inside the plastic vacuum boxes, stored in a cool and dry place, and used within a week.

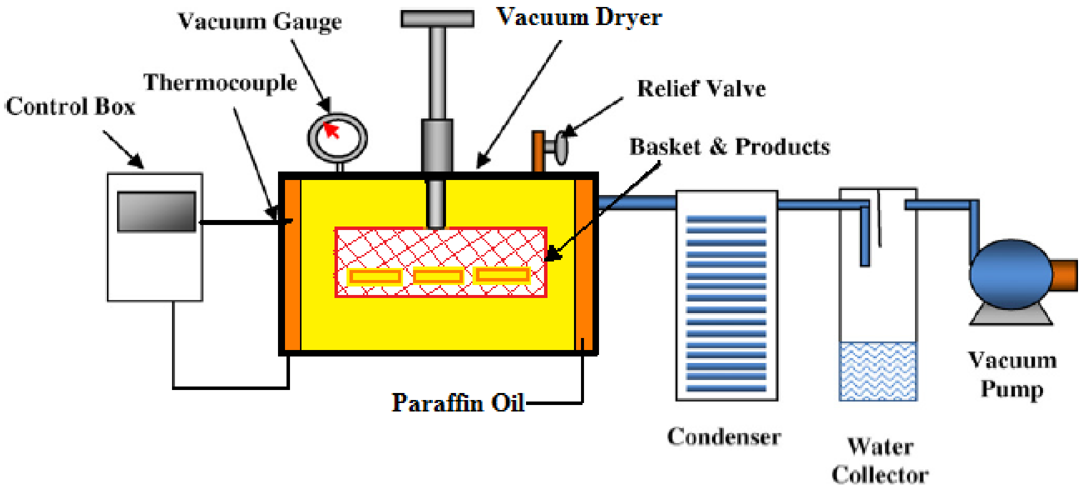


Figure 10 Schematic diagram of vacuum drying system: consisting of a vacuum dryer, a condenser, a liquid ring vacuum pump (Model ET32030, Nash, Trumbull, CT). The vacuum dryer was constructed from stainless steel with a diameter of 400 mm, a height of 300 mm, and a wall thickness of 6 mm. The stainless steel lid of the dryer had a thickness of 8 mm (Adapted from Yamsaengsung and Rungsee, 2003).

Figure 11 Photograph of vacuum drying system (Yamsaengsung and Rungsee, 2003).

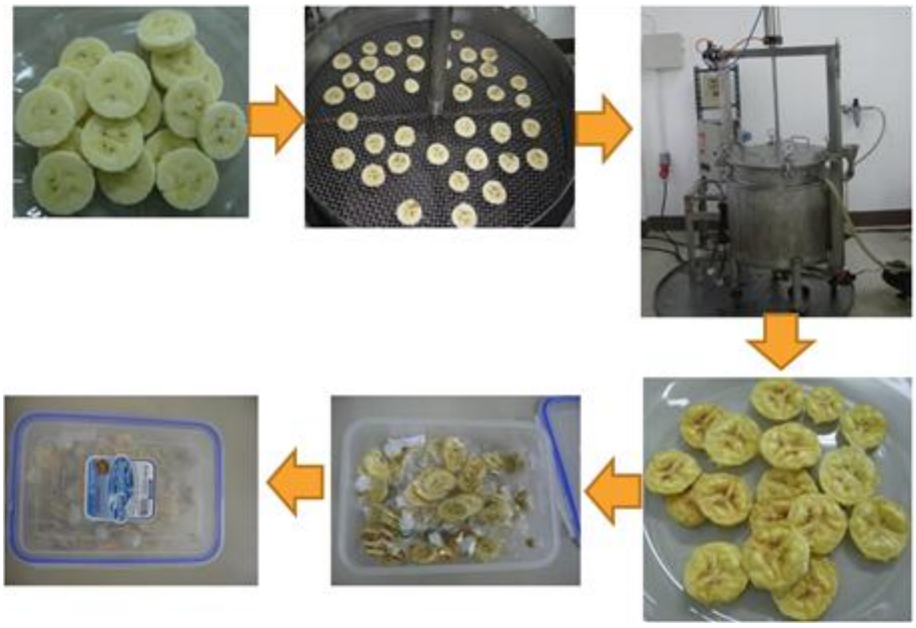


Figure 12 Vacuum drying and storing dried fruits.

2.3 Evaluation of Drying Qualities

The physical qualities of banana, pineapple and apple slices were evaluated for color, shrinkage and texture in terms of crispness and hardness. The colors of the samples were measured using a Hunter Lab color system colorimeter (Juki Model JP100, Japan) (Figure 14.). The color measurement of the samples in each condition was performed by using ten samples and the average value was reported. The color values of dried samples were compared with those of fresh samples and the normalized color changes were then calculated by the following equation (Swasdisevi et al., 2007):

$$\frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}, \quad \frac{\Delta a}{a_0} = \frac{a - a_0}{a_0}, \quad \text{and} \quad \frac{\Delta b}{b_0} = \frac{b - b_0}{b_0} \qquad (22)$$

where L, a, and b are the lightness, redness and yellowness (Figure 15.) of the dried sample, respectively, while L_0, a_0, and b_0 represent the initial values of the lightness, redness and yellowness of the sample prior to drying, respectively.

The shape of samples in this study is shown in Figure 13. The drying shrinkage of the dried sample was calculated by the following equation (Yamsaengsung et al., 2011):

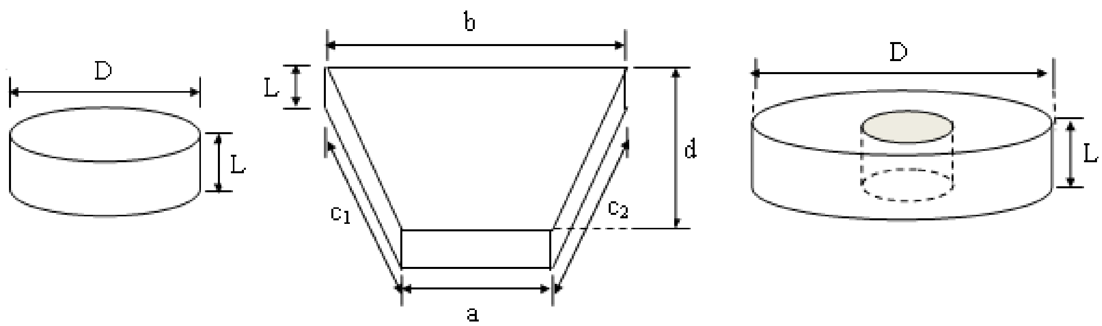


Figure 13 The shape of banana (a), pineapple (b) and apple slices (c) in this study, respectively.

$$\% \text{ Thickness shrinkage} = \left(\frac{L_0 - L}{L_0}\right) \text{x } 100, \quad \% \text{ Diameter shrinkage} = \left(\frac{D_0 - D}{D_0}\right) \text{x } 100$$

$$\% \text{ a} - \text{axis shrinkage} = \left(\frac{a_0 - a}{a_0}\right) \text{x } 100, \quad \% \text{ b} - \text{axis shrinkage} = \left(\frac{b_0 - b}{b_0}\right) \text{x } 100,$$

$$\% \text{ c} - \text{axis shrinkage} = \left(\frac{c_0 - c}{c_0}\right) \text{x } 100,$$

$$\% \text{ d} - \text{axis shrinkage} = \left(\frac{d_0 - d}{d_0}\right) \text{x } 100 \quad \text{and} \quad c = \frac{(c_1 + c_2)}{2} \tag{23}$$

where L, D, a, b, c, d and e are the thickness, diameter, a-axis, b-axis, c-axis, d-axis and e-axis of the dried sample, respectively, while L_0, D_0, a_0, b_0, c_0, d_0 and e_0 represent the initial values of the thickness, diameter, a-axis, b-axis, c-axis, d-axis, e-axis and f-axis of the sample prior to drying, respectively.

Figure 14 Hunter Lab color system colorimeter (Juki Model JP100, Japan).

Figure 15 L, a, and b color scale chart (Hunterlab, 1995).

The crispness and hardness of the final product were verified using a Texture Analyzer (Micro Stable, TA. XT. Plus, UK) (Figure 16.) fitted with a cutting probe (the guillotine) connected to a 1 kg load cell. The test implicated a Warner Bratzler or knife blade to cut the sample while measuring the maximum number of peaks (over 50 g of the force threshold). The cutting probe was set to move at a crosshead speed of 2 mm/s until it cracked the sample (Nimmol et al., 2007).

The rehydration ability of the dried samples were evaluated by soaking the samples in 600 ml of UHT milk at temperature 30^{o}C for 10 min, by a water bath. Next, the samples were taken out and eliminate excess milk on their surfaces with paper napkin. The rehydration ratio of the dried sample was then calculated by (Nimmol et al., 2007):

$$\text{Rehydration ratio} = \frac{m_{after}}{m} \tag{24}$$

where m_{after} and m are, respectively, the masses of the rehydrated and dried samples (g).

Figure 16 Texture analyzer (Stable Micro Systems, TA. XT. Plus, UK).

2.4 Sensory Analysis

To evaluate the acceptability of the product, a nine point hedonic scale test for likeness was used (Peryam & Girardot 1952; Peryam & Pilgrim 1957; Meilgarrd et al., 1999; Yao et al., 2003; Yamsaengsung et al., 2011). Sensory evaluation form for this study is shown in Appendix A.16. Thirty panelists were used in this study (graduate students from the Department of Chemical Engineering, Prince of Songkla University, Songkhla, Thailand). Results of the sensory evaluation were statistically analyzed using a one-way analysis of variance (ANOVA). Test for significant difference at 95% confidence interval ($p<0.05$).

2.5 Modeling Vacuum Drying Process of Samples

The moisture ratio (MR) of each sample during drying and the drying rate of the sample were determined by the following equations:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{25}$$

$$\text{Drying rate} = \frac{M_t - M_{t+dt}}{dt} \tag{26}$$

where M_t and M_{t+dt} are, respectively, the moisture content at t and t+dt ($kg_{moisture}$ /$kg_{dry\ matter}$), M_e is the equilibrium moisture content ($kg_{moisture}$/$kg_{dry\ matter}$), M_0 is the initial moisture content ($kg_{moisture}$/ $kg_{dry\ matter}$), t is the drying time. The equilibrium moisture content (M_e) was assumed to be zero for this experiment because it is very small as compared to M_0 (Zakipour & Hamidi, 2011).

The equilibrium moisture content (M_e) was assumed to be zero for this experiment because it is very small compared to M_0 (Zakipour & Hamidi, 2011).

Table 14 Selected thin-layer drying models for describing drying curve.

Model number	Model equation	Name	References
1	MR=exp(-kt)	Newton	O'Callaghan et al., 1971
2	MR=a exp(-kt) + c	Logarithmic	Yagcioglu et al., 1999
3	MR=exp(-kt^n)	Page	Page, 1949
4	MR=a exp(-k$_0$t)+b exp(-k$_1$t)	Two-term	Henderson, 1974
5	MR=a exp(-kt)+(1-a)exp(-kat)	Two-term exponential	Henderson, 1974; Sharaf-Elden et al., 1980
6	MR=a exp(-kt)+(1-a)exp(-kbt)	Diffusion approach	Kassem, 1998; Ertekin and Yaldiz, 2004

Drying curves (MR vs. time) were plotted and fitted by six empirical drying models (i.e., Newton's model, logarithmic model, Page's model, two-term model, two-term exponential model and diffusion approach model). To select the best model for describing the drying curve in the process of drying the thin layer drying equations in Table 14 were tested. Model coefficients were calculated using STATISTICA software. The goodness of fit was evaluated by the coefficient of determination the regression (R^2), the root-mean-square error (RMSE) and the mean square of the deviations between the experimental and calculated values for the models or chi square (χ^2) defined by Equations (27) and (28). The best model describing the vacuum drying process of the samples was chosen as the one with the highest R^2 and the least RMSE and χ^2 (Zakipour and Hamidi, 2011).

$$\mathrm{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{\frac{1}{2}} \tag{27}$$

$$x^2 = \frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{N-n} \tag{28}$$

where $MR_{exp,i}$ and $MR_{pre,i}$ are, respectively, the experimentally observed and predicted moisture ratio, N is the number of observations, n is the number constants.

2.6 Calculation of Basic Drying Parameters

The Fick's second law of diffusion was used to describe the transport of water during the food drying process in the falling rate period. Banana, pineapple and apple slices were considered as an infinite slab because the thickness of the slice was much less than its diameter. The moisture diffusivity for an infinite slab was therefore calculated by Equation (29), which was developed with assumptions of moisture migrating only by diffusion, negligible shrinkage, constant temperature and diffusion coefficient and long drying times (Crank, 1975; Rasouli et al., 2011).

$$MR = \frac{8}{\pi^2} \sum_{p=0}^{\infty} \left[\frac{1}{(2p+1)^2} \right] \exp\left[- \frac{(2p+1)^2 \pi^2 D_{eff} \theta}{l^2} \right] \quad (29)$$

where D_{eff} is the effective moisture diffusivity (m^2/s), θ is the drying time (s), l is the slab thickness (m), p is the number of terms taken into consideration.

Under the investigated experimental conditions, the drying chamber pressure showed no significant effect on the D_{eff} of the samples, while increasing the drying temperature led to an apparent increase in the effective moisture diffusivity. The temperature dependence of D_{eff} was examined by the following Arrhenius-type equation (Madamba et al., 1996; Pinaga et al., 1984; Tagawa et al., 2003):

$$D_{eff} = D_0 \exp\left(- \frac{E_a}{R_g T_{abs}} \right) \quad (30)$$

where D_0 is the constant (dimensionless), E_a is the referred to as activation energy for moisture diffusion (kJ), T_{abs} is the absolute temperature (K), R_g is the universal gas constant (8.3143 kJ/mol).

To select the best model for describing the effective moisture diffusivity in the process of drying the Arrhenius-type equation in Equation (30) were tested. Model coefficients were calculated using STATISTICA software.

2.7 Statistical Analysis

A triplicate of the entire experiments and the mean values with standard deviations were reported. The experimental data were analyzed using an analysis of variance (ANOVA). Duncan's multiple range test was used to establish the multiple comparisons of the mean values; mean values were considered at 95% confidence level (p = 0.05). A statistical program SPSS (SPSS software for Windows, SPSS Inc., USA) was used to perform all statistical calculations (Yamsaengsung et al., 2011).

CHAPTER 3

Results and Discussion

3.1 Shrinkage

Physical changes during drying of bananas, pineapples and apples can be seen in Figure 17-20, shrinkages of the fruits were increased with increase in the drying time. Also the drying make changes in natural pigment in fruits. From Figure 21, drying curves (moisture ratio vs. time) under different drying conditions were plotted. It was found that the rate of moisture reduction increased with an increase in the drying temperature.

Table 15 compares the time to dry samples, shrinkage and rehydration ratio of dried samples at various temperatures, it was found that the drying time at 120^{o}C were shorter than those at 70 to 110^{o}C. From Figure 22-25, drying shrinkage vs. drying time graphs of bananas, pineapples and apples under different drying conditions were plotted. It was found that the shrinkage rate increased with increase in the drying time. In addition, it was found that the thickness shrinkages of bananas and apples were higher than diameter shrinkage (Figures 22 and 23).

This result was similar to that of Nimmol et al. (2007) who also found that of the system with combined far-infrared radiation and vacuum drying for banana; drying at higher temperatures and lower pressures required shorter drying time. Moreover, it was found that the thickness shrinkage of dried bananas and pineapples at 120^{o}C were lower than those dried at 70 to 110^{o}C. Moreover, the thickness shrinkage of dried apples at 120^{o}C was lower than those dried at 100 and 110^{o}C. For diameter shrinkage of bananas and apples at 120^{o}C were lower than dried bananas at 70 to 110^{o}C and dried apples at 100 to 110^{o}C, respectively. In addition Table 16 shows the a-axis, b-axis, c-axis, d-axis and surface area shrinkage of the pineapple slices at various temperatures. The results showed that the drying temperatures of 100, 110 and 120^{o}C had no impact on the a-axis, b-axis, c-axis, d-axis and surface area shrinkages. Also, the a-axis and b-axis shrinkages of pineapples were higher than c-axis and d-axis shrinkages. This is due to the internal structure of pineapple fruit consists of fiber cells, which spread in the direction perpendicular to the center core. The structure of pineapple consist of the fiber from the center core to the surface was confirmed in SEM images of the cross section (vertical axis) and longitudinal section (radius axis) of the fiber structure (Figure 29). In addition, this structural characteristic helps cells maintain their shape (Gibson, 2012). So, the c-axis and d-axis shrinkage of pineapples less than a-axis and b-axis shrinkage. In addition, it was found that the thickness shrinkage of pineapple was higher than the a-axis, b-axis, c-axis, d-axis and surface shrinkage (as can be seen in Figure 25).

Yan et al. (2008) for banana and pineapple, Panyawong and Devahastin (2007) and Swasdisevi et al. (2007) for bananas reported that the shrinkage was the least at the highest temperature of drying, similar tendency were also observed of this result.

Methakhup et al. (2005) reported that the high temperature was caused the temperature difference affects the boiling point elevation of plasma concentrations of the materials tested. This is due to the existence of the condensation period and the lower evaporation rate of hot air drying than that of vacuum drying at these conditions. Swasdisevi et al. (2007) also observed that the high temperature for a short period of time, which allows some amounts of moisture inside the food vaporizing suddenly. Since hardening occurred at the surface of the product, it helps maintain the shape of the dried fruit. So, the high shrinkage value increased with decreasing surface temperature.

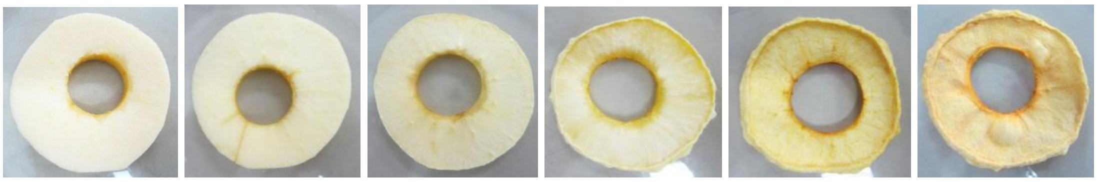
In terms of rehydration behavior it can be seen again from Table 15, it was found that the dried samples at high temperature had higher rehydration ability than compared with those dried at low temperature. Nimmol et al. (2007) reported that the high-temperature drying leads to the dried samples that have a porous structure, thus facilitating rehydration ability (as can be seen in Figure 28). In addition, the results are that all the vacuum dried bananas and pineapples in this study were higher values of rehydration ratio over the commercially available vacuum fried bananas and pineapples (greenday^{TM}).

a b c d

Figure 17 Gallery of images of dried bananas during drying at 120°C: (a) 0 min, (b) 30 min, (c) 60 min and (d) 90 min.

a b c d e f

Figure 18 Gallery of images of dried pineapples during drying at 120°C: (a) 0 min, (b) 30 min, (c) 60 min, (d) 90 min, (e) 110 min and (f) 150 min.



a b c d e f

Figure 19 Gallery of images of dried apples during drying at 100°C: (a) 0 min, (b) 30 min, (c) 80 min, (d) 180 min, (e) 330 min and (f) 495 min.

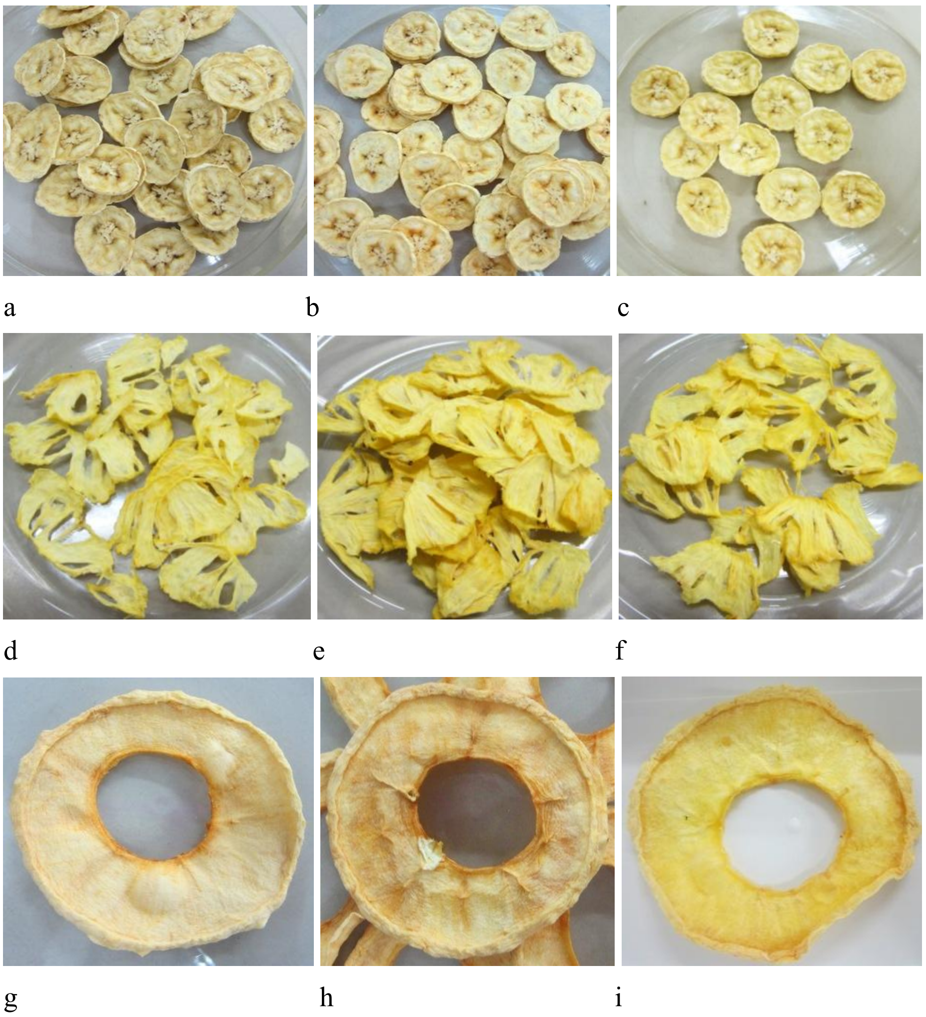
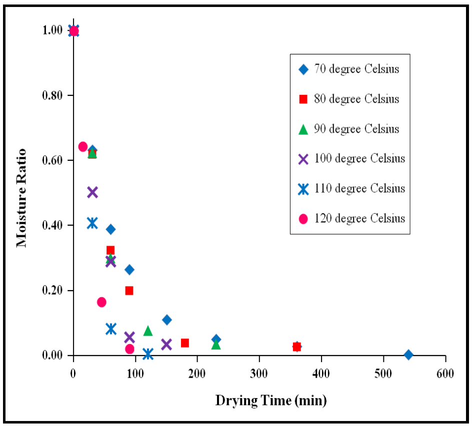
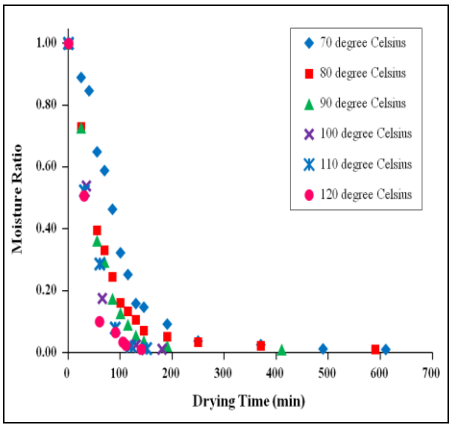


Figure 20 Gallery of images of dried fruits at various drying temperatures: (a) banana slices dried at 100°C, (b) banana slices dried at 110°C, (c) banana slices dried at 120°C, (d) pineapple slices dried at 100°C, (e) pineapple slices dried at 110°C, (f) pineapple slices dried at 120°C, (g) apple slice dried at 100°C, (h) apple slice dried at 110°C and apple slice dried at 120°C.



a



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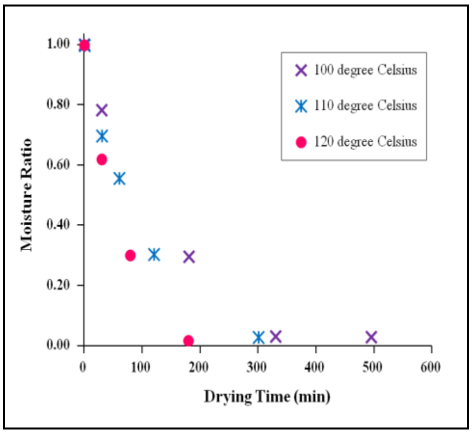


c

Figure 21 Vacuum drying curves of bananas (a), pineapples (b) and apples (c) at different drying temperatures. Note the moisture ratio of each sample during drying was determined by Equation (4) (see Appendices A.1-A.3).

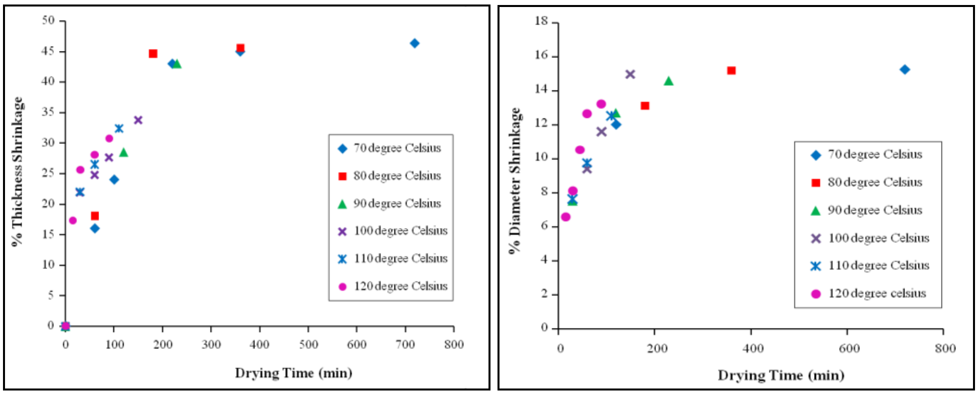
Table 15 Effects of drying temperature on drying time, shrinkage and rehydration ratio of dried banana, pineapple and apple slices (see Appendices A.1-A.9)*.

Types of fruit	Drying temperature (°C)	Drying time (mins)	% Thickness shrinkage	% Diameter shrinkage	Rehydration ratio
Vacuum dried bananas (2.5-3.5 mm slice thickness)	70	540	46.36 ± 0.76^{d}	15.24 ± 0.60^{b}	N/A
	80	360	45.50 ± 0.98^{d}	15.17 ± 0.43^{b}	N/A
	90	230	43.06 ± 1.46^{c}	14.61 ± 0.31^{b}	N/A
	100	150	33.79 ± 0.79^{b}	14.95 ± 0.53^{b}	1.637 ± 0.011^{ab}
	110	110	32.34 ± 1.02^{ab}	12.53 ± 1.30^{a}	1.751 ± 0.005^{b}
	120	90	30.77 ± 2.38^{a}	13.22 ± 0.43^{a}	1.791 ± 0.011^{b}
Commercial vacuum fried bananas (greenday™)	N/A	N/A	N/A	N/A	1.493 ± 0.053^{a}
Commercial freeze dried bananas (Well-B™)	N/A	N/A	N/A	N/A	2.183 ± 0.286^{c}
Vacuum dried pineapples (2.5-3.5 mm slice thickness)	70	610	74.38 ± 1.16^{c}	N/A	N/A
	80	590	68.38 ± 1.24^{b}	N/A	N/A
	90	410	66.14 ± 1.35^{b}	N/A	N/A
	100	180	65.71 ± 0.34^{b}	N/A	2.262 ± 0.047^{b}
	110	150	53.93 ± 2.55^{a}	N/A	2.483 ± 0.005^{c}
	120	140	51.78 ± 1.30^{a}	N/A	2.546 ± 0.007^{c}
Commercial vacuum fried pineapples (greenday™)	N/A	N/A	N/A	N/A	1.910 ± 0.078^{a}
Vacuum dried apples (5.5-6.0 mm slice thickness)	100	495	65.87 ± 1.18^{b}	22.32 ± 0.57^{c}	1.782 ± 0.012^{a}
	110	300	64.97 ± 0.94^{b}	18.47 ± 0.72^{b}	1.824 ± 0.006^{a}
	120	180	62.94 ± 0.21^{a}	13.66 ± 1.20^{a}	2.286 ± 0.040^{b}

Note: The fresh weight of the bananas, pineapples and apples were averaged 148.59 g fresh bananas, 197.03 g fresh pineapples and 242.52 g fresh apples, respectively. The drying were performed until the final moisture content of the dried bananas, pineapples and apples were less than 5% (w.b.), 7% (w.b.) and 22% (w.b.), respectively.

*Mean ± SD

$^{a\text{-}c}$In the same column with different superscripts means of each attribute that the values are significantly different (P<0.05).



a b

Figure 22 Thickness shrinkage (a) and diameter shrinkage (b) of the bananas at different drying temperatures (see Appendix A.4).

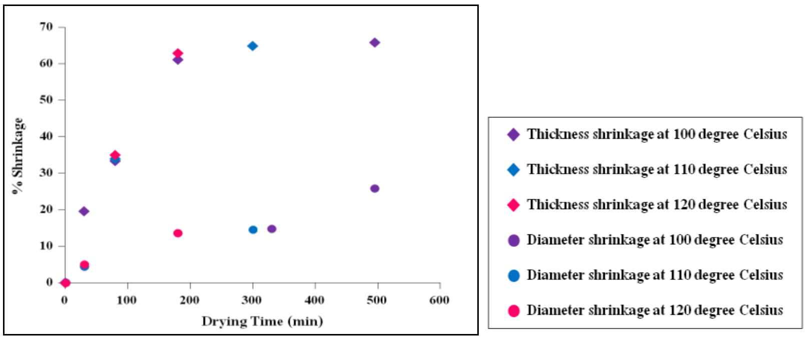


Figure 23 Shrinkage rate of apple slices at different drying temperatures (see Appendix A.6).

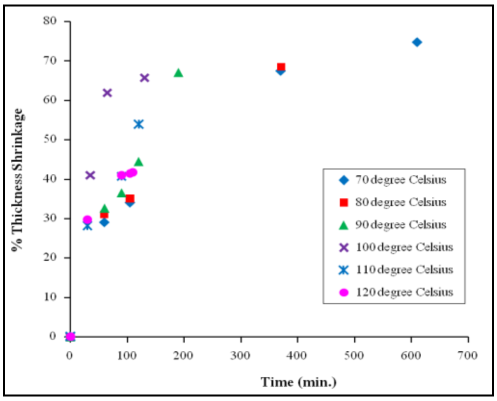


Figure 24 Thickness shrinkage of the pineapples at different drying temperatures (see Appendix A.5).

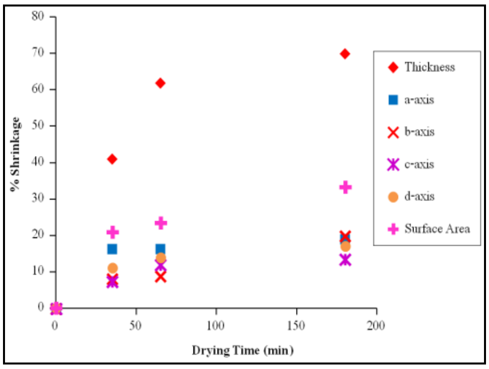


Figure 25 Shrinkage of the pineapples in different directions during drying at 100°C (see Appendix A.5).

Table 16 Effects of drying temperature on drying shrinkage of dried pineapple slices*.

Drying temperature (°C)	% Shrinkage				
	a-axis	b-axis	c-axis	d-axis	Surface area
100	24.09 ± 2.65[a]	22.45 ± 2.11[a]	13.05 ± 1.94[a]	16.15 ± 2.19[a]	33.10 ± 0.96[a]
110	24.01 ± 0.66[a]	20.45 ± 0.78[a]	10.42 ± 2.97[a]	14.59 ± 0.85[a]	32.93 ± 0.37[a]
120	23.87 ± 0.21[a]	20.20 ± 1.17[a]	11.35 ± 0.63[a]	14.23 ± 1.20[a]	32.63 ± 1.17[a]

Note: Various conditions for drying the fresh weight of the pineapples were averaged 197.03 g. The drying was performed until the final moisture content of the dried pineapples was less than 22% (w.b.).

*Mean ± SD

[a]In the same column with different superscripts means that the values are significantly different ($P<0.05$).

See Appendix A.5.

Table 17 compares the time to dry samples, shrinkage and rehydration ratio of dried bananas at different sample thicknesses and drying temperatures. It was found that the drying time decreased with increasing drying temperature, while the drying time increased with increasing thickness of samples. Limpaiboon (2011) reported similar results for air drying of pumpkin slices. Moreover, the lowest sample thickness (1.40 to 2.40 mm) and the highest drying temperature (120°C) for a short period of time (80 min) showed the lowest shrinkage and highest rehydration ability. Similar results have been reported by Aboud (2013) and Krokida and

Marinos-Kouris (2003). This is due to the thick sample and the low-temperature drying for a long period of time caused the dense structure in products due to its shrinkage. The dense structure of the dried samples leads to a decrease of rehydration ratio (Nimmol et al, 2007). Table 18 compares the time to dry samples of dried apples at different amounts of the apples. The increasing of the amounts of the samples for the drying leads to increase of moisture in the dryer. So, the drying time at large amounts of the fruits was longer.

Table 17 Effect of sample thickness on vacuum drying of banana*.

Slice thicknesses (mm)	Drying temperature (^oC)	Drying time (min)	% Thickness shrinkage	% Diameter shrinkage	Rehydration ratio
1.40 – 2.40	100	140	31.26 ± 0.51^{bc}	14.01 ± 0.29^{de}	1.93 ± 0.16^{a}
	110	100	29.97 ± 1.22^{b}	13.62 ± 0.31^{cd}	2.15 ± 0.06^{a}
	120	80	21.39 ± 1.01^{a}	12.74 ± 0.18^{abc}	2.11 ± 0.12^{a}
2.50 – 3.50	100	150	33.79 ± 0.79^{cd}	14.95 ± 0.53^{e}	1.64 ± 0.01^{a}
	110	110	32.34 ± 1.02^{bc}	12.53 ± 1.30^{ab}	1.75 ± 0.01^{b}
	120	90	30.77 ± 2.38^{b}	13.22 ± 0.43^{bcd}	1.79 ± 0.01^{c}
3.60 – 4.60	100	220	41.40 ± 3.13^{f}	14.82 ± 0.32^{e}	1.55 ± 0.02^{a}
	110	150	36.77 ± 0.90^{e}	14.24 ± 0.34^{de}	1.54 ± 0.04^{a}
	120	120	36.02 ± 0.61^{de}	11.97 ± 0.63^{a}	1.62 ± 0.03^{b}

Note: The drying was performed until the final moisture content of the dried bananas was less than 0.05 kg/kg (w.b.).

*Mean ± SD

$^{a-b}$In the same column with different superscripts means that the values are significantly different ($P<0.05$).

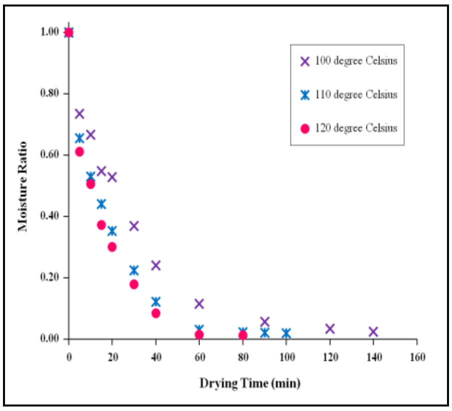
See Appendices A.1-A.9.

Table 18 Effect of amounts of apples on vacuum drying.

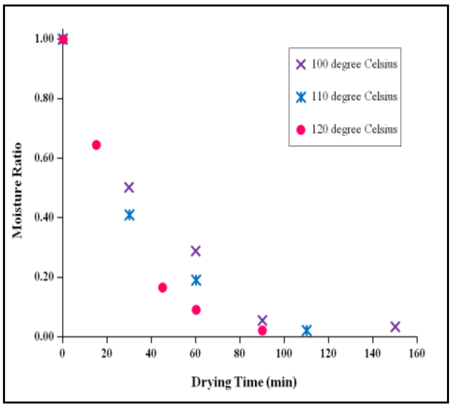
Number of fresh apples (pieces)	Drying time
6 (990 g)	3 h 20 min
18 (2,970 g)	10 h
72 (11,880 g)	24 h

Note: The drying was performed until the final moisture content of the dried apples was less than 0.22 kg/kg (w.b.) at drying temperature 120^oC.

Figure 26 shows the moisture ratio vs. drying time graphs of bananas under different the slice thickness were plotted. The drying curves (moisture ratio vs. drying time) under different slice thicknesses at the drying temperature of 120°C, is shown in Figure 27. From Figure 26 and 27, the results show the moisture evaporates from bananas very quickly at the highest drying temperatures (120°C) and the lowest sample thickness (1.40 to 2.40 mm) (Kabiru et al, 2013).



a



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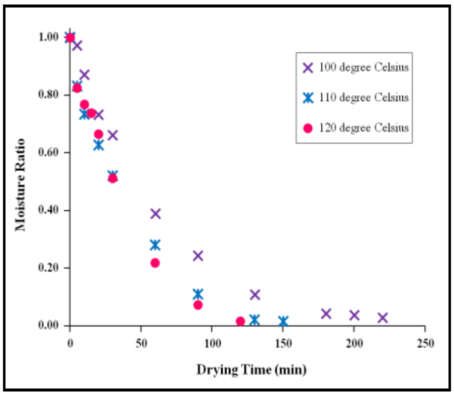


c

Figure 26 Vacuum drying curves of bananas for 1.4-2.4 mm (a), 2.5-3.5 mm (b) and 3.6-4.6 mm slice thickness (c). Note the moisture ratio of each sample during drying was determined by Equation (4) (see Appendix A.1).

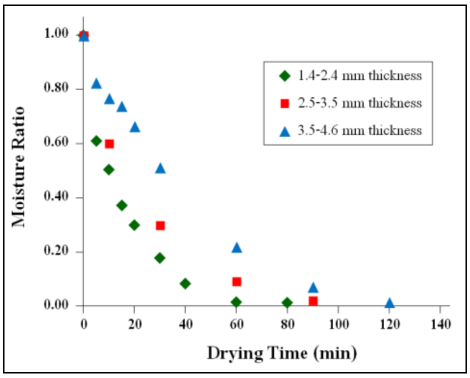


Figure 27 Effect of sample thickness on vacuum drying of bananas at 120°C. Note the moisture ratio of each sample during drying was determined by Equation (4) (see Appendix A.1).

3.2 Textural Changes: Hardness and Crispness of the Dried Products

Table 19 shows the hardness (Maximum force) and crispness (Number of peaks) of the products at different temperatures of drying. From Table 19, it was found that the hardness of those types of dried fruits at 100°C were significantly higher than those dried at 110 and 120°C. This result was similar to Thomkapanich (2006) who also found that for the vacuum drying for banana, the hardness increased with decreasing temperatures. Thuwapanichayanan et al. (2012) reported that the low temperature drying for a long period of time caused the dense structure in products (less pores) due to its shrinkage.

Table 19 Effects of drying temperature on hardness (maximum force) and crispness (number of peaks) of dried products*.

Types of fruit	Drying temperature (°C)	Maximum force (N)	Number of peaks
Vacuum dried bananas	100	45.53 ± 1.49^{c}	10.33 ± 0.58^{a}
(2.5-3.5 mm slice thickness)	110	41.20 ± 0.40^{bc}	14.00 ± 1.00^{a}
	120	35.99 ± 1.38^{ab}	17.00 ± 1.00^{a}
Commercial vacuum fried bananas (greenday^{TM})	N/A	33.18 ± 5.95^{a}	53.67 ± 10.26^{b}
Vacuum dried pineapples	100	55.86 ± 0.38^{c}	6.67 ± 1.15^{a}
(2.5-3.5 mm slice thickness)	110	46.65 ± 1.01^{b}	5.00 ± 0.00^{a}
	120	43.20 ± 0.40^{a}	9.33 ± 1.53^{a}
Commercial vacuum fried pineapples (greenday^{TM})	N/A	58.36 ± 2.61^{c}	46.33 ± 6.66^{b}
Vacuum dried apples	100	171.32 ± 35.04^{a}	9.00 ± 2.00^{a}
(5.5-6.0 mm slice thickness)	110	190.40 ± 42.61^{a}	8.67 ± 0.58^{a}
	120	120.68 ± 19.96^{a}	10.67 ± 0.58^{a}

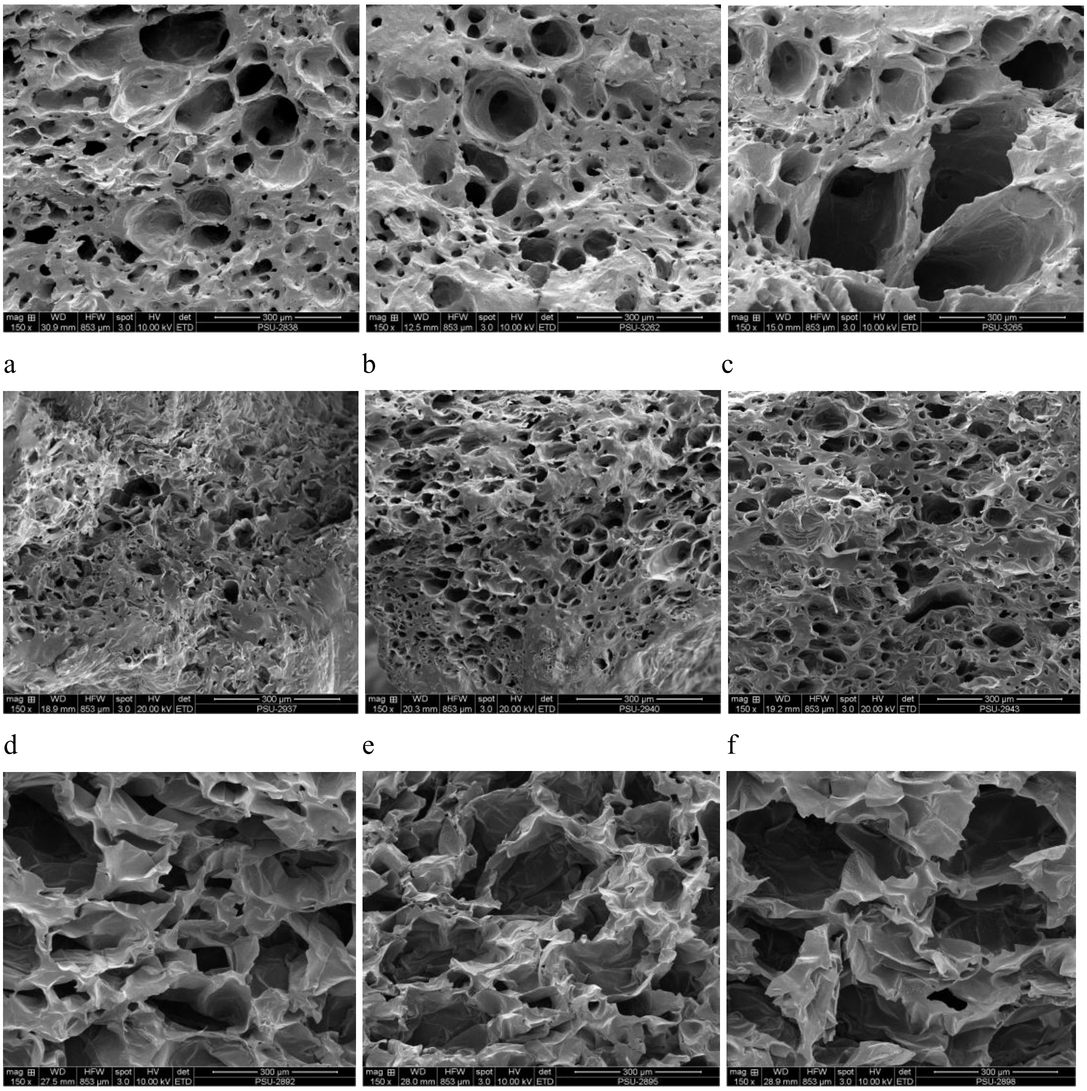
*Mean ± SD

$^{a-c}$ In the same column with different superscripts means of each attribute that the values are significantly different (P<0.05).

See Appendices A.10-A.12.

In addition, this table shows that the crispness of all types of dried fruits at 120°C were significantly higher than those dried at 110 and 100°C. There results were confirmed by SEM photographs show in Figure 28a–i, which show the cross sections of dried banana, pineapple and apples at 100, 110 and 120°C. It was found that the dried samples at high temperature (120°C) had larger and more pores compared with those dried at low temperature (100 and 110°C). Thuwapanichayanan et al. (2012) also revealed that the internal vapor pressure may have increased and this forces the food structure to be expanded, thereby producing the porous structure of food products. These results were similar to Thomkapanich (2006) who also found that of the vacuum drying for banana; the hardness of dried products increased with decreasing temperatures and the crispness of dried products increased with increasing temperatures. Also, different the initial moisture content, composition and size of each fruits lead to different pore structures of dried fruits (Magdalini et al, 1997).

In this study, the hardness and crispness of the dried bananas varied from 35.99±1.38 to 45.53±1.49 N and 10.33±0.58 to 17.00±1.00 peaks, respectively. The hardness and crispness of the dried bananas were compared with those of the commercially available bananas. The hardness and crispness of the commercially available vacuum fried bananas (greenday^{TM}) and dried bananas with combined vacuum and far-infrared radiation (VACUUM-FIR) at 90^{o}C and absolute chamber pressure of 7 kPa (Nimmol et al., 2007) were 33.18±5.95 N and 53.67±10.26 peaks (vacuum fried bananas), and 16.72±3.19 N and 36±3 peaks (dried bananas by VACUUM-FIR), respectively. The results are that all the vacuum dried bananas in this study were higher values of hardness over commercially available dried bananas by VACUUM-FIR and vacuum fried bananas. Also, the vacuum dried bananas in this study had lower values of crispness over the commercially available dried bananas by VACUUM-FIR and vacuum fried bananas. For hardness and crispness of the vacuum dried pineapples in this study were lower values of hardness and crispness over commercially available vacuum fried pineapples (greenday^{TM}). Even though vacuum dried products have lower crispness, and they did not undergo a frying process related has a healthier snack choice compared to vacuum frying.

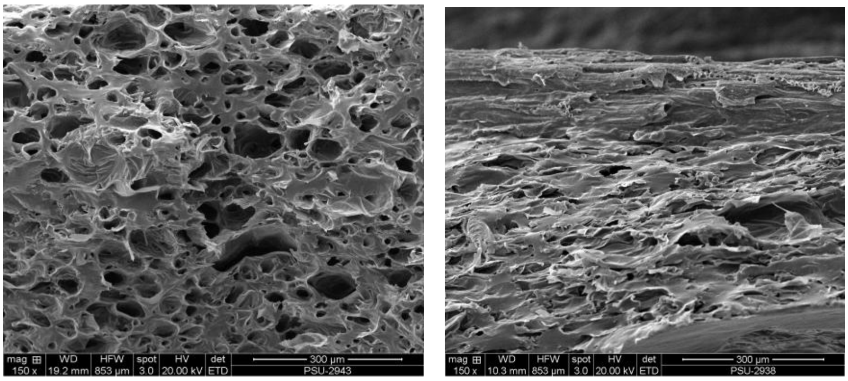


a b c

d e f

g h i

Figure 28 SEM photographs showing cross section of samples dried by (a) banana slices dried at 100^{o}C; (b) banana slices dried at 110^{o}C; (c) banana slices dried at 120^{o}C; (d) pineapple slices dried at 100^{o}C; (e) pineapple slices dried at 110^{o}C; (f) pineapple slices dried at 120^{o}C; (g) apple slices dried at 100^{o}C; (h) apple slices dried at 110^{o}C and (i) apple slices dried at 120^{o}C.



a b

Figure 29 SEM photographs showing cross section (vertical axis) (a) and longitudinal section (radius axis) (b) of pineapple dried at 120^{o}C.

Table 20 shows the hardness (Maximum force) and crispness (Number of peaks) of the dried bananas with different slice thicknesses at a drying temperature of 120 °C. It was found that the hardness of the dried samples with slice thicknesses of 1.40-2.40 mm was significantly lower than those dried with slice thicknesses of 2.50-3.50 and 3.60-4.60 mm. In addition, this table shows that the crispness of the dried samples with slice thicknesses of 1.40-2.40 mm was significantly higher than those dried with slice thicknesses of 2.50-3.50 and 3.60-4.60 mm. There results were confirmed by SEM photographs show in Figure 30a-c, which show the cross sections of dried banana, pineapple and apples with slice thicknesses of 1.40-2.40, 2.50-3.50 and 3.60-4.60 mm. It was found that the dried samples with slice thicknesses of 1.40-2.40 mm had larger and more pores compared with those dried with slice thicknesses of 2.50-3.50 and 3.60-4.60 mm. This is due to the decrease in slice thickness and the high-temperature drying for the short drying time caused the large pore structure (Nimmol et al, 2007). The porous structure of the dried samples leads to increase the crispness.

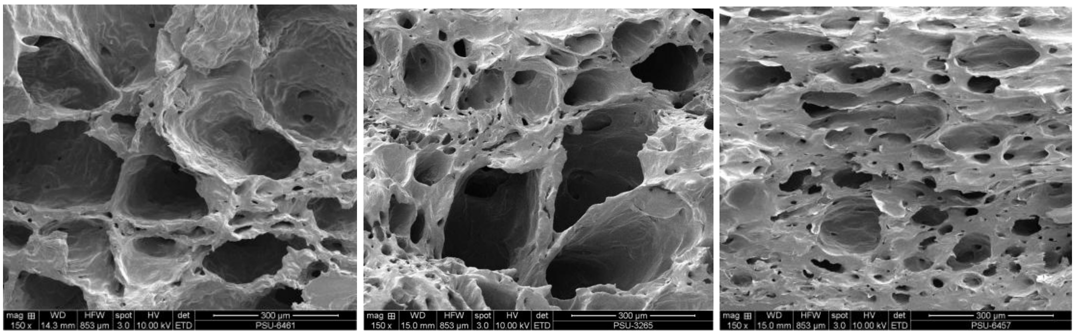
Table 20 Effects of slice thickness on hardness (maximum force) and crispness (number of peaks) of dried bananas at 120°C*.

Thickness of sample (mm)	Maximum force (N)	Number of peaks (peaks)
1.40 – 2.40	22.48 ± 0.99[a]	20.00 ± 1.00[c]
2.50 – 3.50	35.33 ± 0.40[b]	16.67 ± 0.58[b]
3.60 – 4.60	56.17 ± 2.42[c]	5.33 ± 0.58[a]

*Mean ± SD

[a-c] In the same column with different superscripts means that the values are significantly different ($P<0.05$).

See Appendix A.10.



a b c

Figure 30 SEM photographs showing cross section of dried bananas with slice thicknesses of 1.4-2.4 mm (a), 2.5-3.5 mm (b) and 3.6-4.6 mm (c) at a drying temperature of 120°C.

3.3 Color Changes of the Dried Products

As shows in Table 21, the color change of the three types of fruits undergoing various products surface temperatures. It was found that the lightness of dried bananas and pineapples at 120^{o}C were significantly lower than those dried at 100 and 110^{o}C, while, the lightness of dried apples at 120 and 110^{o}C were significantly lower than those dried at 100^{o}C. For redness and yellowness of bananas and pineapples at 120^{o}C were significantly higher than those dried at 100 and 110^{o}C. This is due to browning reaction occurring during drying process. Chua et al. (2002) reported that the different color of dried fruits under various drying conditions shows that temperature and duration of drying affects significantly browning reactions that occur during drying, lower drying temperature resulted in better color retention than drying at higher temperatures.

However, redness of dried apple at 120^{o}C were significantly lower than those dried at 100 and 110^{o}C, while drying temperature of dried apples did not significantly affect yellowness of the dried products. This is due to its long drying time and higher drying temperatures produce greater pigment losses (Soria et al., 2009).

Swasdisevi et al. (2007) studied the banana slices drying in a vacuum dryer combined with heating by infrared radiation. Bananas were dried at various vacuum pressures (5, 10 and 15 kPa) and temperatures (50, 55 and 60^{o}C). The color change (yellowness) of the dried bananas was 0.152±0.032 to 0.350±0.045. The result is that all the dried bananas in this study had lower values of yellowness, as a result of successful products in the snack fruit market.

Table 22 shows the color changes of the dried bananas with different slice thicknesses at a drying temperature of 120 °C. It was found that the lightness of the dried bananas with slice thicknesses of 1.40-2.40 mm was significantly lower than those dried with slice thicknesses of 2.50-3.50 and 3.60-4.60 mm. For the redness and yellowness of the dried samples with slice thicknesses of 1.40-2.40 mm was significantly higher than those dried with slice thicknesses of 2.50-3.50 and 3.60-4.60 mm. These results were similar to Aboud (2013) who also found that of the open sun drying (OSD) for apple.

Table 21 Effects of drying temperature on color of dried products*.

Types of fruit	Drying temperature (^oC)	$\Delta L/L_0$	$\Delta a/a_0$	$\Delta b/b_0$
Bananas	100	-0.087 ± 0.015[b]	1.027 ± 0.087[a]	0.074 ± 0.064[a]
	110	-0.099 ± 0.026[b]	1.161 ± 0.077[a]	0.110 ± 0.059[a]
	120	-0.150 ± 0.034[a]	1.451 ± 0.589[b]	0.183 ± 0.057[b]
Pineapples	100	-0.102 ± 0.012[c]	2.176 ± 0.403[a]	0.231 ± 0.107[b]
	110	-0.148 ± 0.024[b]	2.204 ± 0.324[a]	0.290 ± 0.117[a]
	120	-0.195 ± 0.020[a]	8.435 ± 0.689[b]	0.313 ± 0.047[a]
Apples	100	-0.035 ± 0.005[b]	12.176 ± 0.623[b]	0.614 ± 0.023[a]
	110	-0.090 ± 0.025[a]	14.224 ± 0.216[c]	0.639 ± 0.031[a]
	120	-0.069 ± 0.004[a]	7.552 ± 0.300[a]	0.601 ± 0.005[a]

Where $\Delta L/L_0$, $\Delta a/a_0$ and $\Delta b/b_0$ are the lightness, redness and yellow changes of the fruits, respectively.

*Mean ± SD

[a-c] In the same column with different superscripts means of each attribute that the values are significantly different (P<0.05).

See Appendices A.13-A.15.

Table 22 Effects of slice thickness on color changes of dried bananas*.

Slice thickness (mm)	$\Delta L/L_0$	$\Delta a/a_0$	$\Delta b/b_0$
1.40 – 2.40	-0.144 ± 0.024[a]	2.142 ± 0.276[b]	0.262 ± 0.022[b]
2.50 – 3.50	-0.143 ± 0.001[a]	2.267 ± 0.221[b]	0.159 ± 0.003[a]
3.60 – 4.60	-0.087 ± 0.011[b]	1.014 ± 0.026[a]	0.101 ± 0.046[a]

Where $\Delta L/L_0$, $\Delta a/a_0$ and $\Delta b/b_0$ are the lightness, redness and yellow changes of the fruits, respectively.

*Mean ± SD

[a-b] In the same column with different superscripts means that the values are significantly different (P<0.05).

See Appendix A.13.

3.4 Sensory Analysis

Table 23 shows the color, texture, flavor, crispness and overall acceptability of dried fruits. The results showed that the drying temperature of dried bananas, pineapples and apples at 120^{o}C showing the highest level of acceptance. Overall acceptability for dried bananas, pineapples and apples were 8.00±0.79, 7.77±0.73 and 7.87±1.01, respectively, which were an acceptable rate of consumers.

In this study, the overall acceptability of the dried bananas varied from 7.43±1.01 to 8.00±0.79. The overall acceptability of the dried bananas was compared with those of the commercially available bananas. The overall acceptability of the commercially available vacuum fried bananas (greenday^{TM}) and freeze dried bananas (Well-B^{TM}) were 7.83±0.75 and 8.63±0.61, respectively. The results are that all the dried bananas in this study were lower values of the overall acceptability over the commercially available freeze dried bananas. However, the vacuum dried bananas in this study and vacuum fried bananas (greenday^{TM}) showing the levels of the overall acceptability sensory qualities of dried banana is not significantly different.

Also, the dried pineapple slices in this study were 7.07±0.83 to 7.77±0.73. The overall acceptability of the dried pineapples was compared with those of a commercially available pineapple. The overall acceptability of the commercially available vacuum fried pineapples (greenday^{TM}) was 8.40±0.97. The results are that all the dried pineapples in this study were lower values of overall acceptability over the commercially available vacuum fried pineapples. Even though vacuum dried products have lower overall acceptability, and they did not undergo a frying process related has a healthy choice. In addition, vacuum drying is not high production costs compared to freeze drying.

Table 23 Sensory evaluation based on products at 30 mmHg at different temperatures of drying*.

Types of fruit	Drying method**	Color	Texture	Flavor	Crispness	Overall acceptability
Bananas	VD, 100°C	6.93±1.08^{a}	6.90±0.80^{a}	7.63±0.89^{a}	7.73±0.91^{a}	7.43±1.01^{a}
	VD, 110°C	7.13±0.73^{a}	7.20±0.76^{ab}	7.93±0.74^{ab}	7.93±0.69^{a}	7.77±0.77^{ab}
	VD, 120°C	7.13±0.90^{a}	7.33±0.66^{b}	8.07±0.78^{ab}	8.40±0.72^{b}	8.00±0.79^{b}
	VF (greenday™)	7.67±0.96^{b}	8.13±0.68^{c}	8.13±0.73^{b}	8.63±0.56^{b}	7.83±0.75^{ab}
	FD (Well-B™)	8.67±0.76^{c}	8.97±0.18^{d}	8.30±0.88^{b}	8.60±0.62^{b}	8.63±0.61^{c}
Pineapples	VD, 100°C	7.67±1.09^{b}	7.57±0.97^{a}	7.33±1.06^{a}	6.6±0.72^{a}	7.07±0.83^{a}
	VD, 110°C	7.43±0.12^{b}	7.40±0.77^{a}	7.57±0.90^{a}	7.00±0.74^{b}	7.23±0.73^{a}
	VD, 120°C	7.33±0.80^{b}	7.60±0.86^{a}	7.73±0.87^{a}	7.63±0.72^{c}	7.77±0.73^{b}
	VF (greenday™)	6.56±1.48^{a}	7.23±1.30^{a}	8.37±0.93^{b}	8.70±0.79^{d}	8.40±0.97^{c}
Apples	VD, 100°C	7.10±1.18^{a}	7.13±1.04^{a}	6.90±1.21^{a}	5.50±1.17^{a}	6.63±0.81^{a}
	VD, 110°C	6.97±0.76^{a}	6.80±0.80^{a}	7.00±1.08^{a}	6.07±1.05^{a}	6.90±0.88^{a}
	VD, 120°C	7.00±0.95^{a}	7.17±0.91^{a}	7.30±1.29^{a}	6.87±1.36^{b}	7.87±1.01^{b}

Where VD is Vacuum drying method, VF is Vacuum frying method and FD is Freeze drying method

*Mean ± SD

$^{a\text{-}b}$ In the same column with different superscripts means of each attribute that the values are significantly different (P<0.05).

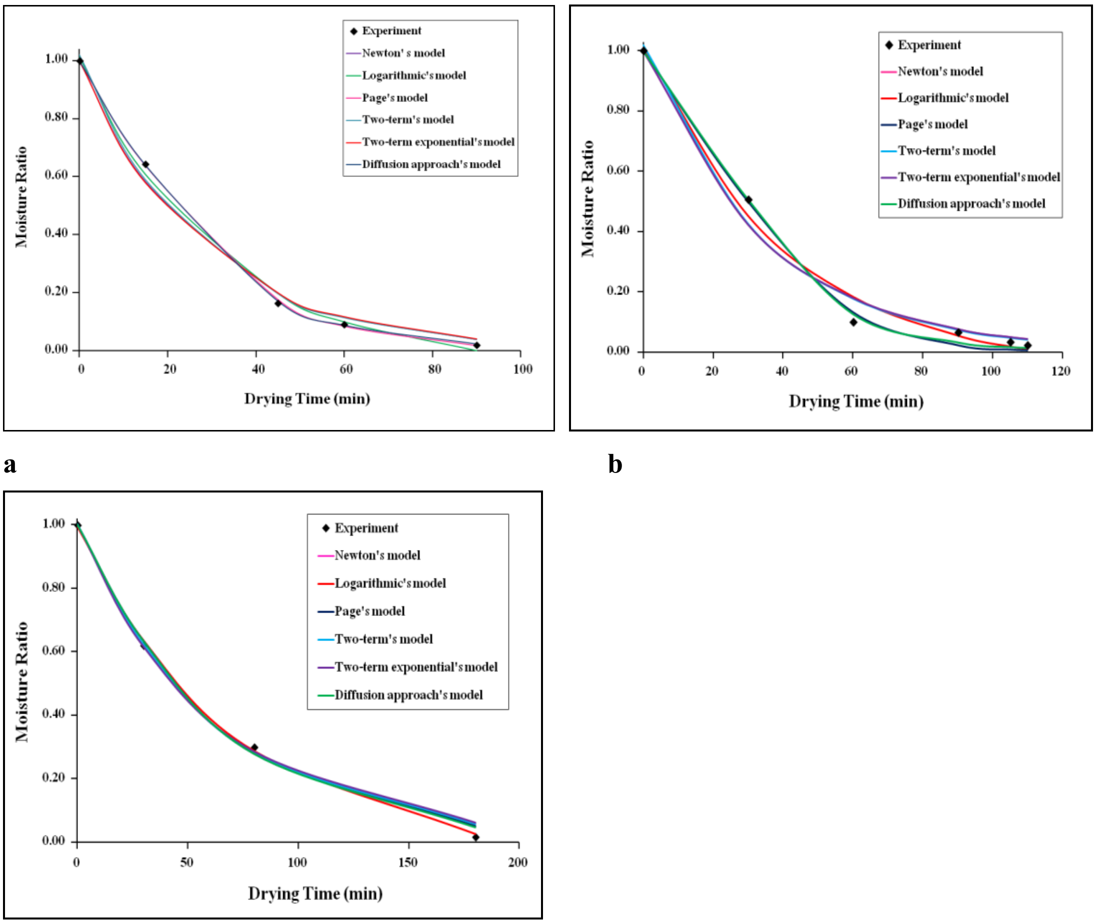
See Appendices A.17-A.19.

3.5 Modeling of Drying Characteristics

In this study, drying curves (MR vs. time) under various drying conditions were plotted and fitted to the selected thin-layer drying models listed in Table 14. The results of statistical analyses undertaken on these models for bananas, pineapples and apples are given in Tables 24. It was found that thin layer equation providing the highest R^2 and the lowest χ^2 and RMSE of the dried bananas was the Diffusion approximation. From the table, R^2, χ^2 and RMSE values were 0.99998, 0.00002 and 0.00355, respectively. In the case of the dried pineapples it was found that thin layer equation providing the highest R^2 and the lowest χ^2 and RMSE was the Diffusion approximation. From the table, R^2, χ^2 and RMSE values were 0.99685, 0.00046 and 0.01963, respectively. For the dried apples it was found that thin layer equation providing the highest R^2 and the lowest χ^2 and RMSE was the Logarithmic equation. From the table, R^2, χ^2 and RMSE values were 0.99913, 0.00016 and 0.01112, respectively. There results were confirmed by Figure 31, which shows the comparison of the prediction accuracy for six mathematical models at drying temperature of 120°C of bananas, pineapples and apples. These equations may be used for designing the drying process and prediction of drying behavior in vacuum dryer.

Table 24 Modeling of moisture ratio according to drying time for products dried at 120°C.

Types of fruit	Models	Coefficients	R^2	χ^2	RMSE
Bananas	Newton	k=0.03596	0.99286	0.00142	0.03376
	Logarithmic	a=1.07498,k=0.03149,c=-0.06228	0.99654	0.00076	0.02464
	Page	k=0.01597,n=1.23169	0.99988	0.00005	0.00659
	Two-term	a=0.51054,k_0=0.03665,b=0.51051,k_1=0.03665	0.99357	0.00128	0.03206
	Two-term exponential	a=0.01316,k=2.69959	0.99194	0.00160	0.03575
	Diffusion approach	a=-0.26858,k=0.21759,b=0.20475	0.99998	0.00002	0.00355
Pineapples	Newton	k=0.02865	0.98108	0.00278	0.04810
	Logarithmic	a=1.07564,k=0.02448,c=-0.06390	0.98588	0.00213	0.04213
	Page	k=0.00366,n=1.54179	0.99478	0.00078	0.02552
	Two-term	a=0.50952,k_0=0.02903,b=0.50952,k_1=0.02903	0.98157	0.00270	0.04748
	Two-term exponential	a=0.00002,k=1217.88611	0.98107	0.00278	0.04810
	Diffussion approach	a=-1.04254,k=0.31763,b=0.14629	0.99685	0.00046	0.01963
Apples	Newton	k=0.0158	0.99669	0.00017	0.02229
	Logarithmic	a=1.0584,k=0.0138,c=-0.064	0.99913	0.00016	0.01112
	Page	k=0.0129,n=1.0498	0.99711	0.00057	0.02072
	Two-term	a=0.5009,k0=0.0159,b=0.5009,k1=0.0159	0.99670	0.00066	0.02225
	Two-term exponential	a=0.0232,k=0.6636	0.99637	0.00072	0.02330
	Diffussion approach	a=-23.8425,k=0.0215,b=0.9871	0.99742	0.00051	0.01961



a

b

c

Figure 31 Prediction accuracy comparison for six mathematical models at drying temperature of 120^{o}C of (a) bananas, (b) pineapples and (c) apples.

The effective moisture diffusivities were estimated from the drying data represents an overall mass transfer property of moisture in the material (Pathare et al., 2006). The values of effective diffusivity of bananas, pineapples and apples in the drying process at 100, 110 and 120^{o}C are presented in Table 25. As indicated in this table, the values of D_{eff} increased dramatically as the drying temperature increased due to a larger driving force for heat and mass transfer at higher drying temperature (Wu et al, 2007). In addition, this research found that all three types of the dried fruits at the high values of effective moisture diffusivity had larger and more pore compared to the dried fruits at the low values of effective moisture diffusivity. Azizi and Peyghambarzadeh (2011) also observed that the increased evaporation rate of water from the fruits at high temperature lead to the high mass transfer rate in the product or the high values of effective moisture diffusivity. Consequently, the drying temperature greatly affected the D_{eff} values of fruits. The high values of effective moisture diffusivity were mainly related to high rates of water loss in the fruits. The porosities of the dried fruits increases as the water and volatiles were removed (Ramos et al, 2003). So, the values of effective moisture diffusivity greatly affected the structural changes of the dried fruits. Moreover, the high porosity of the dried fruit structures lead to increase of crispness and rehydration ratio of the dried fruits.

The activation energy (E_a) and diffusion constant (D_0) were determined by STATISTICA software and given in Table 25. It was found that the values of E_a and D_0 for dried apple were higher than dried banana and pineapple. This is due to the size of apple slice was larger than banana and pineapple. Also, different cell structure and chemical composition of each fruits lead to different values of the activation energy (E_a) and diffusion constant (D_0) (Suriyakanthorn and Assavarachan, 2012). The activation energy (E_a) and diffusion constant (D_0) of the dried bananas were higher than those of the experimental results of Swasdisevi et al. (2009) who used combined vacuum and far infrared radiation. The values in this experiment were E_a of 29623 kJ/mol and D_0 of 4.00×10^{-6} m^2/s compared to 9124 kJ/mol and 1.746×10^{-8} m^2/s, respectively.

Table 25 Effective moisture diffusivity and related correlation coefficient of determination (R^2) value for the various drying experiments.

Types of fruit	Temperature (^oC)	D_{eff} (m^2/s)	R^2
Bananas	70	7.60×10^{-11}	0.9602
	80	1.91×10^{-10}	0.9881
	90	2.40×10^{-10}	0.9668
	100	2.92×10^{-10}	0.9800
	110	3.68×10^{-10}	0.9834
	120	4.52×10^{-10}	0.9670
Pineapples	70	1.20×10^{-10}	0.9655
	80	2.08×10^{-10}	0.9695
	90	2.34×10^{-10}	0.9542
	100	2.76×10^{-10}	0.9617
	110	2.92×10^{-10}	0.9672
	120	3.76×10^{-10}	0.9661
Apples	100	9.10×10^{-11}	0.9787
	110	1.15×10^{-10}	0.9849
	120	1.89×10^{-10}	0.9822

Table 26 Activation energy (E_a), coefficient D_0, and related correlation coefficient of dried fruits.

Types of fruit	E_a (kJ/mol)	D_0 (m^2/s)	R^2
Bananas	2.9623×10^4	4.0000×10^{-6}	0.9600
Pineapples	2.5592×10^4	9.9822×10^{-7}	0.9586
Apples	4.8141×10^4	4.6012×10^{-4}	0.9646

3.6. Nutrition Information of the Vacuum Dried Fruits.

A nutrition facts label on a package helps consumers make healthy food choices while controlling calories. The food label includes information on calories, fat, protein, carbohydrates and other nutrients as shown in Table 27 and 28. The nutrition values of dried fruits were tested and calculated by Faculty of Agro-Industry of Prince of Songkla University.

Table 27 Nutrition values of dried fruits at 120^{o}C.

Test Items	Results (Unit)		
	Banana dried	Pineapple dried	Apple dried
Protein	5.25%	3.12%	1.50%
Crude Fat	0.24%	0.16%	0.20%
Moisture	4.97%	7.56%	6.01%
Ash	3.39%	1.67%	1.63%
Crude Fiber	1.17%	2.22%	2.84%
Total Carbohydrate	86.15%	87.49%	90.66%
Total Sugar	78.97 g/100 g samples	78.28 g/100 g samples	76.84 g/100 g samples
Energy	367.76 kcal/100 g samples	363.88 kcal/100 g samples	370.44 kcal/100 g samples

* Energy demand of nutrient intake per day recommended for population over 6 years of age is 2000 kilo calories per day.

Table 28 Energy values of dried fruits at 120^{o}C.

Type of fruits	Total energy (kcal/g dried fruit)	Amount per serving (kcal/serving)*
Vaccuum dried bananas	3.68	73.60
Vaccuum dried pineapples	3.64	72.80
Vaccuum dried apples	3.70	74.00

*Serving size: 20 g dried fruits

*Energy demand of nutrient intake per day recommended for population over 6 years of age is 2000 kilo calories per day.

3.7. Development of the Basket for the Vacuum Dryer

This study aims to apply the vacuum fryer for vacuum drying of fruits. The cooking oil in the fried products has raised major concerns from heath conscious consumers. The vacuum drying is another process to avoid having oil inside the products. The photograph of the vacuum drying system is shown in Figure 32.

This work, the basket was developed for the vacuum dryer and model and photograph of the basket show in Figure 33 and 34, respectively. The basket was constructed from stainless steel wire mesh (0.035" Wire Diameter) with a diameter of 400 mm and a height of 50 mm. All baskets (13 baskets) were stacked and placed on rack. The stack rack was constructed from stainless steel with a diameter of 405 mm and a height of 370 mm.

Table 29 shows the effect of the sample position during the drying of apples (12 samples per layer or 160 – 177 grams per layer) at 120^{o}C for 24 h. It was found that the moisture contents of the dried products at the top position (position number 1) of the dryer were higher than those dried at the bottom position (position number 6). This is due to the condenser in vacuum system will help to move the water vapor from the products and remove the evaporated moisture out of the dryer (at the top position of the dryer). The evaporation of moisture from the products at the bottom position through the products at the top position may cause the moisture accumulated in the dried products at the top position.

Figure 32 Photograph of vacuum drying system

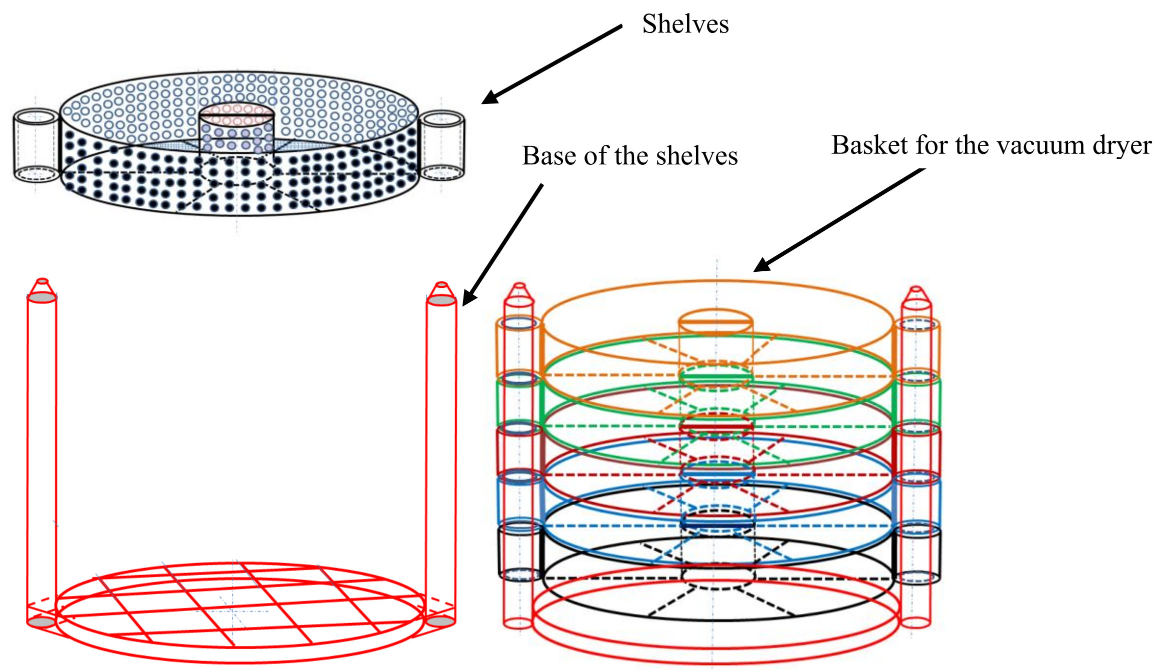
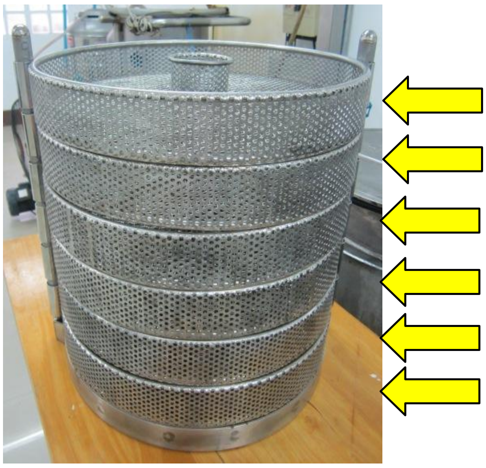


Figure 33 Schematic diagram of the basket for the vacuum dryer.

Figure 34 Photograph of the basket for the vacuum dryer.

Table 29 Effect of the sample position during the drying process at 120°C*.



Sample position	Moisture content (%wb)
1	15.23
2	10.68
3	9.00
4	7.22
5	8.23
6	5.77

* The dried apples during drying at 120°C for 24 h and the quantity of apples drying 12 samples per layer (or 160 – 177 grams per layer).

See Appendix A.20.

Figure 35, drying pressure vs. drying time graphs of bananas, pineapples and apples at a drying temperature of 120°C were plotted. It was found that the drying pressure decreased with increasing the drying time. The drying pressure of bananas, pineapples and apples was performed until 60 mmHg or 8 kPa (boiling point of water 41.5ºC) when the drying time at 12, 11 and 12 min, respectively. The drying pressure of bananas, pineapples and apples will decrease continuously until 30 mmHg or 4 kPa (boiling point of water 29ºC) when the drying time of bananas, pineapples and apples were 56, 60 and 46 min, respectively. According to the vacuum range during the dehydration process is generally from about 6 kPa to 25 kPa (Arevalo-Pinedo and Murr, 2007; Mitra et al, 2011). In this study, the pressure level inside the chamber was reduced to 8 kPa (below 25 kPa) for a short period of time (11 to 12 min). Moreover, this condition was sufficient vacuum for drying fruit. However, the pressure level in this study was reduced to the minimum pressure level 30 mmHg. This is due to the lower pressure make water boils at a lower temperature at higher altitudes. At this condition can helps to maintain the qualities such as shape and texture of the dried product.

Moisture ratio vs. drying pressure graphs of bananas, pineapples and apples during the drying process at a drying temperature of 120°C were presented in Figure 36. It was found that the moisture ratio of dried bananas, pineapples and apples during drying at an absolute chamber pressure of 60 mmHg were 0.60, 0.72 and 0.80, respectively. The drying pressure of bananas, pineapples and apples will decrease continuously until 30 mmHg. At this condition, the moisture ratio of bananas, pineapples and apples were 0.09, 0.20 and 0.42, respectively.

Designing vacuum system for drying the fruits is complex. There are many choices for vacuum pumps, which vary in size, cost, energy usage, maintenance requirements, and technology (Holland et al, 2007). The selection of pump type for the vacuum system depends on the requirements of pumping speed and vacuum pressure level.

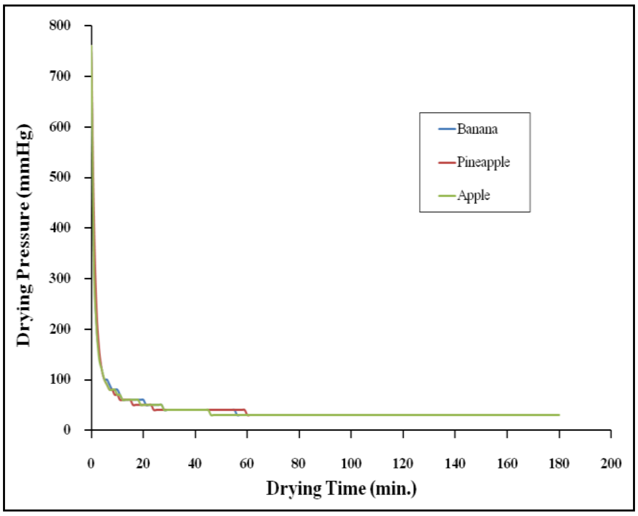


Figure 35 Effect of drying pressure during the drying process of bananas, pineapples and apples at 120°C (see Appendices A.21-A.23).

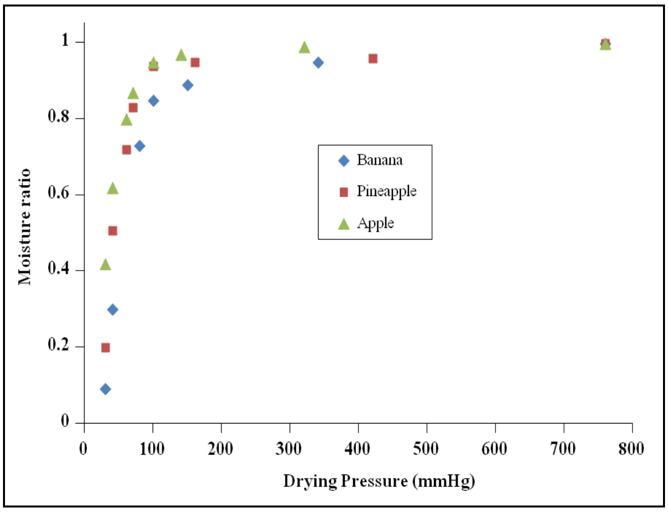


Figure 36 Vacuum drying curves of pressure change of bananas, pineapples and apples at 120°C.

3.8 Economical Analysis

In the study, the Net Present Value (NPV) method, or the present value of net cash inflows generated from the development and production process of a plan (Kodukula and Papudesu, 2006) was used to determine whether or not this plan should be performed. According to if the present value of the expected free cash flows is greater than the present value of the investment costs, the project is the worth investment (Kodukula and Papudesu, 2006). In this study, the drying condition at temperature 120^{o}C and absolute chamber pressure of 30 mmHg was used to determine the economic feasibility for fruits drying. The economic analysis of the banana drying, pineapple drying and apple drying were carried out at 1-4 times per day, 1-3 times per day and 1-2 times per day, respectively. The fresh fruits and technical information of each operation were used to determine the economic feasibility for the fruits drying as shown in Tables 30 to 32.

In addition, the important information for the Net Present Value calculation is the labor costs, the sale prices of the dried fruits and the costs of the raw materials which shown in Table 33. These data were used to calculate the NPV for choosing the best alternatives for the vacuum drying of the fruits.

The results of the NPV for the vacuum drying of the fruits are given in Tables 34 to 36. It was found that those projects showed the positive NPV, so the investment projects were attractive. Moreover, the drying of the bananas, pineapples and apples at 4, 3 and 2 times of the drying per day, respectively, showed the highest NPV. Consequently, the best alternatives for the drying of the bananas, pineapples and apples were 4, 3 and 2 times of the drying per day, respectively.

Table 30 Fresh fruits and technical information to determine the economic feasibility for vacuum drying of banana.

Detail	Drying once each day	Dried two times a day	Dried three times a day	Dried four times a day
1. The cost of electricity (Baht per month) (see Appendix B.1)	463.84	996.13	1,538.91	2,100.16
2. Feeding rate of fresh bananas (grams per day)	891.53	1,783.06	2,674.59	3,566.12
3. Yield of dried bananas (grams of dried bananas per grams of fresh bananas)	26.25	26.25	26.25	26.25
4. Rated operating capacity (grams of dried bananas per day)	234.03	468.05	702.08	936.11
5. The service life of vacuum dryer (Year)	8	8	8	8
6. Average Operating Time (min per day)	130	230	330	430
7. Purchase price of vacuum dryer (Baht)	141,050	141,050	141,050	141,050
8. Depreciation cost of vacuum dryer (Baht per year)	17,631.25	17,631.25	17,631.25	17,631.25

Note: 1 USD = 32.40 Baht (Currency Exchange Rate: 9 September 2013, http://th.rateq.com)

1 EURO = 42.50 Baht (Currency Exchange Rate: 9 September 2013, http://th.rateq.com)

Table 31 Fresh fruits and technical information to determine the economic feasibility for vacuum drying of pineapple.

Detail	Drying once each day	Dried two times a day	Dried three times a day
1. The cost of electricity (Baht per month) (see Appendix B.1)	677.67	1,427.70	2,212.94
2. Feeding rate of fresh pineapples (grams per day)	1,182.19	2,364.38	3,546.57
3. Yield of dried pineapples (grams of dried pineapples per grams of fresh pineapples)	16.28	16.28	16.28
4. Rated operating capacity (grams of dried pineapples per day)	192.46	384.92	577.38
5. The service life of vacuum dryer (Year)	8	8	8
6. Average Operating Time (min per day)	180	330	480
7. Purchase price of vacuum dryer (Baht)	141,050	141,050	141,050
8. Depreciation cost of vacuum dryer (Baht per year)	17,631.25	17,631.25	17,631.25

Note: 1 USD = 32.40 Baht (Currency Exchange Rate: 9 September 2013, http://th.rateq.com)

1 EURO = 42.50 Baht (Currency Exchange Rate: 9 September 2013, http://th.rateq.com)

Table 32 Fresh fruits and technical information to determine the economic feasibility for vacuum drying of apple.

Detail	Drying once each day	Dried two times a day
1. The cost of electricity (Baht per month) (see Appendix B.1)	840.173	1,787.916
2. Feeding rate of fresh apples (grams per day)	1,455.12	2,910.24
3. Yield of dried apples (grams of dried apples per grams of fresh apples)	12.58	12.58
4. Rated operating capacity (grams of dried apples per day)	183.05	366.11
5. The service life of vacuum dryer (Year)	8	8
6. Average Operating Time (min per day)	220	410
7. Purchase price of vacuum dryer (Baht)	141,050	141,050
8. Depreciation cost of vacuum dryer (Baht per year)	17,631.25	17,631.25

Note: 1 USD = 32.40 Baht (Currency Exchange Rate: 9 September 2013, http://th.rateq.com)

1 EURO = 42.50 Baht (Currency Exchange Rate: 9 September 2013, http://th.rateq.com)

Table 33 The costs of each operation to determine the economic feasibility for vacuum drying of bananas, pineapples and apples (see Appendices B.2-B.4).

Types of fruits	Detail	The costs of each operation (Baht per month)			
		Drying once each day	Dried two times a day	Dried three times a day	Dried four times a day
Bananas	1. The costs of raw materials	847.00	1,694.00	2,541.00	3,387.75
	2. The costs of labors	312.50	623.00	937.50	1,250.00
	3. The sale prices of dried fruits	6,903.00	13,806.00	20,709.00	27,612.00
Pineapples	1. The cost of raw materials	1,861.92	3,723.83	5,585.75	-
	2. The costs of labors	468.75	937.50	1,406.25	-
	3. The sale prices of dried fruits	5,870.67	11,714.33	17,612.00	-
Apples	1. The costs of raw materials	2,983.00	5,966.00	-	-
	2. The costs of labors	443.75	937.50	-	-
	3. The sale prices of dried fruits	9,593.00	19,186.00	-	-

Note: 1 USD = 32.40 Baht (Currency Exchange Rate: 9 September 2013, http://th.rateq.com)

1 EURO = 42.50 Baht (Currency Exchange Rate: 9 September 2013, http://th.rateq.com)

Table 34 Net Present Value of the banana-drying projects (see Appendix B.5).

The number of operations per day	Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
1 times per day	Benefits	82,014.93	163,218.08	243,617.74	323,222.17	402,031.39	480,070.24	557,330.45	633,828.57
	Costs	185,045.44	225,687.00	265,926.41	305,767.82	345,211.22	384,269.07	422,937.21	461,223.94
	Cash flow	-103,030.51	-62,468.92	-22,308.67	17,454.35	56,820.17	95,801.17	134,393.24	172,604.63
2 times per day	Benefits	164,031.85	326,440.11	487,241.35	646,452.14	804,072.48	960,152.08	1,114,674.35	1,267,672.44
	Costs	205,145.41	265,687.97	325,631.47	384,982.08	443,739.81	501,923.17	559,526.00	616,560.64
	Cash flow	-41,113.56	60,752.14	161,609.88	261,470.06	360,332.67	458,228.91	555,448.35	651,111.80
3 times per day	Benefits	246,047.77	489,660.16	730,862.03	969,678.22	1,206,108.73	1,440,228.11	1,672,011.53	1,901,508.66
	Costs	225,369.90	305,936.79	385,706.47	464,687.16	542,878.87	620,306.25	696,961.08	772,859.80
	Cash flow	20,677.87	183,723.37	345,155.56	504,991.06	663,229.86	819,921.86	975,050.45	1,128,648.86
4 times per day	Benefits	328,063.69	652,880.22	974,482.70	1,292,904.29	1,608,144.97	1,920,304.15	2,229,348.70	2,535,344.88
	Costs	245,814.22	346,623.06	446,434.40	545,258.53	643,095.44	739,976.00	835,889.91	930,857.74
	Cash flow	82,249.47	306,257.16	528,048.30	747,645.76	965,049.53	1,180,328.15	1,393,458.79	1,604,487.14

Note: The expected service life of the system is 8 year.

The maintenance costs of this system are 1,400 THB/year.

MARR is 1%.

Table 35 Net Present Value of the pineapple-drying projects (see Appendix B.5).

The number of operations per day	Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
1 times per day	Benefits	69,751.56	138,812.71	207,190.51	274,892.00	341,917.18	408,287.18	473,994.96	539,054.61
	Costs	201,501.90	258,437.03	314,808.79	370,622.99	425,879.63	480,596.12	534,766.68	588,402.90
	Cash flow	-131,750.34	-119,624.32	-107,618.28	-95,730.99	-83,962.45	-72308.94	-60,771.72	-49,348.29
2 times per day	Benefits	139,503.11	277,625.42	414,381.02	549,784.00	683,834.35	816,574.36	947,989.93	1,078,109.23
	Costs	238,104.69	331,280.30	423,533.95	514,875.14	605,303.86	694,848.64	783,499.97	871,276.86
	Cash flow	-98,601.58	-53,654.88	-9,152.93	34,908.86	78,530.49	121,725.72	164,489.96	206,832.37
3 times per day	Benefits	209,254.66	416,438.13	621,571.53	824,675.99	1,025,751.53	1,224,861.54	1,421,984.88	1,617,163.84
	Costs	275,125.53	404,955.56	533,500.93	660,774.88	786,777.42	911,548.28	1,035,074.20	1,157,381.69
	Cash flow	-65,870.87	11,482.57	88,070.60	163,901.11	238,974.11	313,313.26	386,910.68	459,782.15

Note: The expected service life of the system is 8 year.

The maintenance costs of this system are 1,400 THB/year.

MARR is 1%.

Table 36 Net Present Value of the apple-drying projects (see Appendix B.5).

The number of operations per day	Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
1 times per day	Benefits	113,976.95	226,825.75	338,557.92	449,184.97	558,706.91	667,158.26	774,527.51	880,837.69
	Costs	216,455.02	288,195.27	359,225.64	429,553.48	499,178.76	568,123.45	636,380.23	703,963.74
	Cash flow	-102,478.07	-61,369.52	-20,667.72	19,631.49	59,528.15	99,034.81	138,147.28	176,873.95
2 times per day	Benefits	227,953.89	453,651.50	677,115.84	898,369.95	1,117,413.81	1,334,316.51	1,549,055.02	1,761,675.38
	Costs	269,023.31	392,811.52	515,374.85	636,725.94	756,864.77	875,829.24	993,606.72	1,110,222.46
	Cash flow	-41,069.42	60,839.98	161,740.99	261,644.01	360,549.04	458,487.27	555,448.30	651,452.92

Note: The expected service life of the system is 8 year.

The maintenance costs of this system are 1,400 THB/year.

MARR is 1%

CHAPTER 4

Conclusions and Suggestions

4.1 Conclusions

1. Effect of temperature on vacuum drying of fruits

In this research the drying kinetics of banana, pineapple and apple were investigated in the dryer at different drying temperatures (70, 80, 90, 100, 110 and 120^{o}C). These data were used in choosing the optimum condition for the vacuum drying of the fruits. From experiment results, the drying time at the highest drying temperature was the shortest. At this condition, three types of dried fruits showed the highest degree of yellowness, larger and more pores, more crispness and more rehydration ability compared to lower drying temperature.

From sensory analysis, each drying condition showed significant effect on consumer acceptability with the drying temperature of 120^{o}C showing the highest level of acceptance. At this condition, the level of the overall acceptability from sensory qualities of bananas, pineapples and apples were 8.00±0.79, 7.77±0.73 and 7.87±1.01, respectively. Consequently, the drying temperature of 120^{o}C was suggested as the best drying condition for sliced bananas, pineapples and apples.

Moreover, six mathematical models (i.e., Newton's model, Logarithmic model, Page's model, Two-term model, Two-term exponential model and Diffusion approximation model) describing thin layer drying were investigated. It was found that The Logarithmic model was considered adequate for describing the thin-layer drying behavior of apples, while the Diffusion approximation model was deemed adequate for bananas and pineapples.

The study found that the effective moisture diffusivity for bananas, pineapples and apples varied from 2.92x10^{-10} to 4.52x10^{-10} m^2/s, 2.76x10^{-10} to 3.76x10^{-10} and 9.1x10^{-11} to 1.89x10^{-10}, respectively. The highest drying temperature showed the highest values of effective moisture diffusivity. Moreover, the research found that the values of effective moisture diffusivity greatly affected the structural changes of the vacuum-dried fruits. From experiment results, all three types of the dried fruits at the high values of effective moisture diffusivity had larger and more pore compared to the dried fruits at the low values of effective moisture diffusivity. The high porosity of the dried fruit structures lead to increase of crispness and rehydration ratio of the dried fruits.

2. Effect of slice thickness on vacuum drying of fruits

Experimental drying of bananas was carried out at different slice thicknesses under a constant drying temperature. The results showed that the drying time at the lowest slice thickness was the shortest. At this condition, the dried bananas showed the highest degree of yellowness, larger and more pores, more crispness and more rehydration ability compared to thick sample.

3. Effect of amounts of fruits on vacuum drying

The experiments were carried out at various amounts of apples under a constant drying condition. It was found that the drying time at the minimum amount of the apples was the shortest.

4. Economical analysis

In this study, the drying condition at temperature 120^{o}C and absolute chamber pressure of 30 mmHg was used to determine the economic feasibility for the vacuum drying of the fruits. The economic analysis of the banana drying, pineapple drying and apple drying were carried out at 1-4 times per day, 1-3 times per day and 1-2 times per day, respectively.

The results showed that those projects showed the positive NPV, so the investment projects were attractive. Also, the drying of the bananas, pineapples and apples at 4, 3 and 2 times of the drying per day, respectively, showed the highest NPV. Consequently, the best alternatives for the drying of the bananas, pineapples and apples were 4, 3 and 2 times of the drying per day, respectively.

4.2 Suggestions

1) Study the optimal conditions for vacuum drying process of other fruits.

2) Develop procedures for storing dried fruits to extend the shelf life of the products.

3) Improving the efficiency of vacuum dryer to dry the fruits in increasing quantities and the dried fruit quality remains the same.

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APPENDICES

Appendix A

Experimental Data

A.1 Drying Data of Banana Dried in Vacuum System

Table 37 Data of vacuum drying of bananas in 2.5-3.5 mm slice thicknesses at 70^{o}C.

Time	Sample 1				Sample 2				Sample 3				Avg. MR
(min)	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.00	4.54	77.30	1.00	20.04	4.84	75.85	1.00	20.00	4.56	77.20	1.00	1.00
30	10.99	3.58	67.42	0.63	11.98	3.79	68.36	0.64	10.57	3.46	67.27	0.63	0.63
60	5.23	2.29	56.21	0.39	5.37	2.34	56.42	0..38	5.58	2.51	55.02	0.38	0.38
90	4.47	2.33	47.87	0.28	4.10	2.17	47.07	0.26	4.30	2.21	48.60	0.29	0.28
150	3.41	2.42	29.03	0.12	3.83	2.85	25.59	0.10	3.82	2.75	28.01	0.12	0.12
230	3.05	2.64	13.44	0.05	3.71	3.27	11.86	0.04	3.41	3.06	10.26	0.04	0.04
360	2.57	2.39	7.00	0.02	3.52	3.22	8.52	0.03	3.69	3.43	7.05	0.02	0.02
540	2.60	2.50	3.85	0.01	2.61	2.50	4.21	0.01	3.40	3.23	5.00	0.01	0.01

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b.),and MR is moisture ratio.

Table 38 Data of vacuum drying of bananas in 2.5-3.5 mm slice thicknesses at 80°C.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.00	4.64	76.80	1.00	20.03	4.84	75.84	1.00	20.02	4.80	76.02	1.00	1.00
30	10.13	3.24	68.02	0.64	9.29	3.22	65.34	0.60	10.05	3.40	66.17	0.62	0.62
60	4.54	2.12	53.30	0.34	3.37	1.85	45.10	0.26	4.28	1.99	53.50	0.36	0.32
90	3.88	2.39	38.40	0.19	3.03	1.89	37.62	0.19	3.81	2.26	40.68	0.22	0.20
180	2.84	2.50	11.97	0.04	2.69	2.39	11.15	0.04	3.03	2.72	10.23	0.04	0.04
360	2.73	2.59	5.13	0.02	2.94	2.81	4.42	0.01	2.99	2.85	4.68	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 39 Data of vacuum drying of bananas in 2.5-3.5 mm slice thicknesses at 90°C.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.02	4.80	76.02	1.00	20.09	4.86	75.81	1.00	20.00	4.82	75.90	1.00	1.00
30	9.26	2.98	67.82	0.66	8.39	2.95	64.84	0.59	8.60	2.92	66.05	0.62	0.62
60	10.38	4.22	59.34	0.46	11.30	4.70	58.41	0.45	9.63	4.19	56.49	0.41	0.44
120	3.81	3.07	19.42	0.08	3.76	2.97	21.01	0.08	3.89	3.17	18.51	0.07	0.08
230	2.93	2.78	5.12	0.02	3.03	2.88	4.95	0.02	3.28	3.12	4.88	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 40 Data of vacuum drying of bananas in 2.5-3.5 mm slice thicknesses at 100°C.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.03	4.79	76.09	1.00	20.02	4.96	75.22	1.00	20.02	5.00	75.02	1.00	1.00
30	6.84	2.67	60.96	0.49	6.88	2.79	59.45	0.48	7.86	3.01	61.70	0.54	0.50
60	4.92	2.81	42.89	0.24	6.42	3.32	48.29	0.31	6.57	3.32	49.47	0.33	0.29
90	3.16	2.70	14.56	0.05	3.34	2.90	13.17	0.05	3.55	2.96	16.62	0.07	0.06
150	3.15	3.01	4.44	0.01	3.17	3.01	5.05	0.02	3.23	3.08	4.64	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 41 Data of vacuum drying of bananas in 1.4-2.4 mm slice thicknesses at 100°C.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.05	4.37	78.20	1.00	20.04	4.30	78.54	1.00	19.99	4.41	77.94	1.00	1.00
5	6.53	1.83	71.98	0.72	7.01	1.93	72.47	0.72	7.05	1.90	73.05	0.77	0.73
10	5.79	1.72	70.29	0.66	6.64	1.94	70.78	0.66	6.19	1.82	70.60	0.68	0.67
15	6.00	2.06	65.76	0.53	6.21	2.08	66.51	0.54	5.82	1.94	66.67	0.57	0.55
20	6.15	2.14	65.20	0.52	6.01	2.09	65.22	0.51	6.28	2.14	65.92	0.55	0.53
30	3.79	1.68	55.67	0.35	3.86	1.70	55.96	0.35	4.61	1.88	59.22	0.41	0.37
60	2.76	1.93	30.07	0.12	2.71	2.01	25.83	0.10	3.09	2.11	31.72	0.13	0.12
140	2.03	1.94	4.43	0.01	2.05	1.94	5.37	0.02	2.12	2.01	5.19	0.02	0.01

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 42 Data of vacuum drying of bananas in 3.6-4.6 mm slice thicknesses at 100°C.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.09	4.90	75.61	1.00	20.00	4.86	75.70	1.00	19.59	4.84	75.29	1.00	1.00
5	11.39	2.88	74.71	0.95	12.32	3.03	75.41	0.98	12.48	3.12	75.00	0.98	0.97
10	12.14	3.30	72.82	0.86	12.86	3.48	72.94	0.87	12.00	3.24	73.00	0.89	0.87
20	11.33	3.54	68.76	0.71	11.49	3.59	68.76	0.71	12.72	3.75	70.52	0.78	0.73
30	9.69	3.12	67.80	0.68	10.55	3.48	67.01	0.65	9.96	3.33	66.57	0.65	0.66
90	6.27	3.49	44.34	0.26	5.97	3.51	41.21	0.22	6.24	3.52	43.59	0.25	0.25
180	4.27	3.73	12.65	0.05	3.80	3.40	10.53	0.04	3.82	3.33	12.83	0.05	0.04
200	3.92	3.49	10.97	0.04	4.00	3.59	10.25	0.04	3.86	3.44	10.88	0.04	0.04
220	2.98	2.73	8.39	0.03	2.99	2.75	8.03	0.03	2.85	2.62	8.07	0.03	0.03

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 43 Data of vacuum drying of bananas in 2.5-3.5 mm slice thicknesses at 110°C.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.02	4.94	75.32	1.00	20.01	4.90	75.51	1.00	20.02	4.81	75.97	1.00	1.00
30	6.62	2.86	56.80	0.41	6.13	2.77	54.81	0.40	6.43	2.86	55.52	0.42	0.41
60	3.21	2.55	20.56	0.08	3.25	2.69	17.23	0.07	3.69	2.84	23.04	0.10	0.08
110	2.91	2.86	1.72	0.01	2.67	2.61	2.25	0.01	2.67	2.62	1.87	0.01	0.01

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 44 Data of vacuum drying of bananas in 1.4-2.4 mm slice thicknesses at 110^{o}C.

Time	Sample 1				Sample 2				Sample 3				Avg. MR
(min)	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.01	4.42	77.91	1.00	20.05	4.31	78.50	1.00	20.08	4.26	78.78	1.00	1.00
5	5.19	1.53	70.52	0.68	4.80	1.44	70.00	0.64	5.15	1.51	70.68	0.65	0.66
10	4.49	1.58	64.81	0.52	4.91	1.68	65.78	0.53	5.28	1.75	66.86	0.54	0.53
15	4.61	1.78	61.39	0.45	4.45	1.72	61.35	0.43	4.33	1.65	61.89	0.44	0.44
20	3.46	1.56	54.91	0.35	3.81	1.70	55.38	0.34	4.00	1.68	58.00	0.37	0.35
30	2.65	1.50	43.40	0.22	2.70	1.55	42.59	0.20	3.10	1.61	48.06	0.25	0.22
60	1.60	1.44	10.00	0.03	1.84	1.66	9.78	0.03	1.81	1.64	9.39	0.03	0.03
90	1.77	1.64	7.34	0.02	1.70	1.59	6.47	0.02	1.75	1.62	7.43	0.02	0.02
100	1.47	1.40	4.76	0.01	1.50	1.44	4.00	0.01	1.51	1.44	4.64	0.01	0.01

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 45 Data of vacuum drying of bananas in 3.6-4.6 mm slice thicknesses at 110°C.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.06	4.94	75.37	1.00	20.03	4.89	75.59	1.00	19.97	4.90	75.46	1.00	1.00
5	10.05	2.80	72.14	0.85	10.25	2.89	71.80	0.82	10.69	3.01	71.84	0.83	0.83
10	9.46	2.84	69.98	0.76	9.74	3.04	68.79	0.71	10.23	3.16	69.11	0.73	0.73
20	7.55	2.55	66.23	0.64	7.82	2.70	65.47	0.61	8.37	2.85	65.95	0.63	0.63
30	7.74	2.94	62.02	0.53	7.63	3.03	60.29	0.49	8.50	3.21	62.24	0.54	0.52
60	5.60	2.95	47.32	0.29	5.46	3.13	42.67	0.24	6.57	3.36	48.86	0.31	0.28
130	3.08	2.90	5.84	0.02	3.31	3.11	6.04	0.02	3.23	3.03	6.19	0.02	0.02
150	3.03	2.88	4.95	0.02	3.06	2.92	4.58	0.02	3.12	2.97	4.81	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 46 Data of vacuum drying of bananas in 2.5-3.5 mm slice thicknesses at 120°C.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.04	4.65	76.80	1.00	20.06	4.59	77.12	1.00	20.02	4.72	76.42	1.00	1.00
15	8.61	2.72	68.41	0.65	9.22	2.97	67.79	0.62	9.80	3.14	67.96	0.65	0.64
45	4.85	3.27	32.58	0.15	5.64	3.48	38.30	0.18	5.15	3.34	35.15	0.17	0.17
90	3.72	3.55	4.57	0.01	3.83	3.67	4.18	0.01	3.81	3.64	4.46	0.01	0.01

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 47 Data of vacuum drying of bananas in 1.4-2.4 mm slice thicknesses at 120°C.

Time	Sample 1				Sample 2				Sample 3				Avg. MR
(min)	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.01	4.53	77.36	1.00	20.04	4.42	77.94	1.00	20.00	4.42	77.90	1.00	1.00
5	4.90	1.53	68.78	0.64	4.65	1.50	67.74	0.59	4.67	1.51	67.67	0.59	0.61
10	4.13	1.44	65.13	0.55	3.68	1.39	62.23	0.47	3.99	1.44	63.91	0.50	0.51
15	3.21	1.39	56.70	0.38	3.31	1.46	55.89	0.36	3.26	1.40	57.06	0.38	0.37
20	3.02	1.49	50.66	0.30	2.90	1.51	47.93	0.26	3.59	1.63	54.60	0.34	0.30
40	2.56	1.88	26.56	0.11	2.31	1.88	18.61	0.06	2.24	1.74	22.32	0.08	0.08
60	2.20	2.09	5.00	0.02	2.18	2.07	5.05	0.02	2.23	2.12	4.93	0.01	0.02
80	1.79	1.71	4.47	0.01	1.82	1.74	4.40	0.01	1.80	1.72	4.44	0.01	0.01

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 48 Data of vacuum drying of bananas in 3.6-4.6 mm slice thickness at 120°C.

Time	Sample 1				Sample 2				Sample 3				Avg. MR
(min)	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.04	4.65	76.80	1.00	20.06	4.59	77.12	1.00	20.02	4.72	76.42	1.00	1.00
5	12.15	3.25	73.25	0.83	12.73	3.47	72.74	0.79	13.46	3.57	73.48	0.85	0.82
10	12.19	3.42	71.94	0.77	13.44	3.82	71.58	0.75	12.56	3.56	71.66	0.78	0.77
15	11.89	3.53	70.31	0.72	12.28	3.57	70.93	0.72	12.52	3.56	71.57	0.78	0.74
20	10.85	3.36	69.03	0.67	11.48	3.65	68.21	0.64	11.28	3.50	68.97	0.69	0.67
30	9.27	3.39	63.43	0.52	9.71	3.70	61.89	0.48	9.66	3.55	63.25	0.53	0.51
60	6.24	3.62	41.99	0.22	6.29	3.76	40.22	0.20	6.80	3.83	43.68	0.24	0.22
120	3.83	3.65	4.70	0.01	3.98	3.78	5.03	0.02	3.52	3.35	4.83	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

A.2 Drying Data of Pineapple Dried in Vacuum System

Table 49 Data of vacuum drying at 70°C, absolute pressure of 4 kPa.

Time	Sample 1				Sample 2				Sample 3				Avg. MR
(min)	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.01	3.07	84.66	1.00	19.98	2.91	85.44	1.00	20.05	3.02	84.94	1.00	1.00
25	11.99	1.88	84.32	0.97	11.02	1.87	83.03	0.83	11.67	1.99	82.95	0.86	0.89
40	10.27	1.82	82.28	0.84	10.65	1.76	83.47	0.86	9.98	1.74	82.57	0.84	0.85
55	10.84	2.32	78.60	0.67	10.94	2.25	79.43	0.66	10.41	2.29	78.00	0.63	0.65
70	8.39	1.95	76.76	0.60	8.71	2.05	76.46	0.55	8.49	1.90	77.62	0.62	0.59
85	7.44	8.27	68.82	0.40	8.49	2.17	74.44	0.50	8.27	2.17	73.76	0.50	0.46
100	6.53	2.41	63.09	0.31	6.37	2.39	62.48	0.28	7.11	2.27	68.07	0.38	0.32
115	5.90	2.49	57.80	0.25	5.75	2.42	57.91	0.23	6.30	2.46	60.95	0.28	0.25
130	4.56	2.05	55.04	0.22	3.45	2.03	41.16	0.12	3.47	1.95	43.80	0.14	0.16
145	4.43	2.49	43.79	0.14	4.75	2.45	48.42	0.16	4.59	2.55	43.44	0.14	0.15
250	2.75	2.27	17.45	0.04	2.55	2.10	17.65	0.04	2.73	2.22	18.68	0.04	0.04
610	2.53	2.27	10.28	0.02	1.95	1.71	12.31	0.02	1.93	1.70	11.93	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 50 Data of vacuum drying at 80°C, absolute pressure of 4 kPa.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	19.98	2.72	86.39	1.00	19.99	2.79	86.04	1.00	20.02	2.83	85.86	1.00	1.00
40	10.67	2.76	74.13	0.45	11.13	2.83	74.57	0.48	9.97	2.63	73.62	0.46	0.46
70	8.83	3.20	63.76	0.28	7.50	2.28	69.60	0.37	7.70	2.49	67.66	0.34	0.33
100	5.43	2.81	48.25	0.15	6.26	2.98	52.40	0.18	4.98	2.55	48.80	0.16	0.16
130	4.88	2.97	39.14	0.10	6.54	3.84	41.28	0.11	4.70	2.86	39.15	0.11	0.11
150	2.80	2.32	17.14	0.03	2.57	2.12	17.51	0.03	2.89	2.34	19.03	0.04	0.04
370	2.76	2.51	9.06	0.02	2.74	2.46	10.22	0.02	3.69	3.34	9.49	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 51 Data of vacuum drying at 90°C, absolute pressure of 4 kPa.

Time	Sample 1				Sample 2				Sample 3				Avg. MR
(min)	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.07	2.71	86.50	1.00	19.98	2.76	86.19	1.00	20.06	2.34	88.33	1.00	1.00
25	11.99	2.04	82.99	0.76	11.02	1.87	83.03	0.78	11.67	1.99	82.95	0.64	0.73
40	8.77	2.25	74.34	0.45	8.32	2.04	75.48	0.49	8.48	2.13	74.88	0.39	0.45
55	8.13	2.34	71.22	0.39	7.63	2.32	69.59	0.37	8.08	2.27	71.91	0.34	0.36
70	7.06	2.45	65.30	0.29	6.76	2.31	65.83	0.31	6.47	2.08	67.85	0.28	0.29
85	5.47	2.51	54.11	0.18	6.11	2.83	53.68	0.19	5.57	2.57	53.86	0.15	0.17
100	3.70	2.02	45.41	0.13	3.65	1.97	46.03	0.14	2.91	1.53	47.42	0.12	0.13
130	3.33	2.46	26.13	0.06	3.03	2.19	27.72	0.06	3.32	2.42	27.11	0.05	0.06
175	3.00	2.37	21.00	0.04	3.30	2.58	21.82	0.04	3.75	2.95	21.33	0.04	0.04
190	2.95	2.63	10.85	0.02	2.70	2.39	11.48	0.02	2.57	2.24	12.84	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 52 Data of vacuum drying at 100°C, absolute pressure of 4 kPa.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.07	2.77	86.20	1.00	20.09	2.97	85.22	1.00	20.03	2.76	86.22	1.00	1.00
35	6.00	1.77	70.50	0.38	5.92	1.80	69.59	0.40	5.69	1.65	71.00	0.39	0.39
65	4.14	2.00	51.69	0.17	4.26	2.05	51.88	0.19	3.72	1.80	51.61	0.17	0.18
130	2.71	2.36	12.92	0.02	2.46	2.14	13.01	0.03	2.65	2.29	13.58	0.03	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 53 Data of vacuum drying at 110°C, absolute pressure of 4 kPa.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.10	3.04	84.88	1.00	20.01	2.95	85.26	1.00	20.13	3.02	85.00	1.00	1.00
30	10.94	2.76	74.77	0.53	10.80	2.71	74.91	0.52	11.96	2.99	75.00	0.53	0.52
60	5.38	2.09	61.15	0.28	5.25	2.05	60.95	0.27	5.47	1.98	63.80	0.31	0.29
90	4.45	3.00	32.58	0.09	3.23	2.17	32.82	0.08	3.94	2.81	28.68	0.07	0.08
120	2.67	2.40	10.11	0.02	2.61	2.32	11.11	0.02	2.74	2.44	10.95	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 54 Data of vacuum drying at 120°C, absolute pressure of 4 kPa.

Time	Sample 1				Sample 2				Sample 3				Avg. MR
(min)	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.25	2.59	87.21	1.00	20.22	2.44	87.93	1.00	20.22	2.42	88.03	1.00	1.00
30	8.30	1.88	77.35	0.50	9.84	2.09	78.76	0.51	9.84	2.07	78.96	0.51	0.51
60	2.33	1.34	42.49	0.11	2.34	1.35	42.31	0.10	2.43	1.45	40.33	0.09	0.10
90	3.72	2.55	31.45	0.07	3.52	2.41	31.53	0.06	3.69	2.48	32.79	0.07	0.07
105	2.69	2.17	19.33	0.04	2.62	2.15	17.94	0.03	2.95	2.30	22.03	0.04	0.03
110	2.11	1.80	14.69	0.03	2.07	1.78	14.01	0.02	2.13	1.83	14.08	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

A.3 Drying Data of Apple Dried in Vacuum System

Table 55 Data of vacuum drying at 100°C, absolute pressure of 4 kPa.

Time	Sample 1				Sample 2				Sample 3				Avg. MR
(min)	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.02	1.92	90.41	1.00	20.11	2.01	90.00	1.00	20.04	1.96	90.22	1.00	1.00
30	16.91	1.99	88.23	0.81	20.12	2.50	87.57	0.75	22.44	2.77	87.66	0.79	0.78
180	7.99	2.22	71.46	0.27	8.30	2.22	73.25	0.30	7.70	1.96	74.55	0.32	0.30
330	2.66	2.13	19.92	0.03	2.37	1.82	23.21	0.03	2.50	1.99	20.40	0.03	0.03
495	2.86	2.32	18.88	0.03	2.06	1.64	20.36	0.03	2.22	1.76	20.72	0.03	0.03

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 56 Data of vacuum drying at 110°C, absolute pressure of 4 kPa.

Time	Sample 1				Sample 2				Sample 3				Avg. MR
(min)	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.03	2.25	88.77	1.00	20.02	2.07	89.66	1.00	20.08	2.13	89.39	1.00	1.00
30	13.45	1.91	85.80	0.76	12.27	1.83	85.09	0.66	10.58	1.59	84.97	0.67	0.70
60	11.82	2.08	82.40	0.59	13.32	2.28	82.88	0.56	9.14	1.69	81.51	0.52	0.56
120	9.44	2.42	74.36	0.37	7.07	2.11	70.16	0.27	7.77	2.32	70.14	0.28	0.31
300	2.70	2.22	17.78	0.03	2.87	2.34	18.47	0.03	2.89	2.28	21.11	0.03	0.03

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b),and MR is moisture ratio.

Table 57 Data of vacuum drying at 120°C, absolute pressure of 4 kPa.

Time (min)	Sample 1				Sample 2				Sample 3				Avg. MR
	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	W_t (g)	W_d (g)	%MC (w.b.)	MR	
0	20.02	1.92	90.41	1.00	20.11	2.01	90.00	1.00	20.04	1.96	90.22	1.00	1.00
30	19.54	2.67	86.23	0.66	11.48	1.70	85.19	0.64	15.25	2.10	86.23	0.68	0.66
60	15.98	2.67	83.29	0.54	10.82	1.96	81.89	0.48	11.80	2.17	81.61	0.49	0.50
180	2.44	2.13	12.70	0.02	1.94	1.70	12.37	0.02	2.00	1.75	12.50	0.02	0.02

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b), and MR is moisture ratio.

A.4 Shrinkage Data of Bananas during Vacuum Drying

Table 58 Thickness shrinkage data of bananas during drying at 70^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	2.62	2.62	0.00	2.78	2.78	0.00	2.62	2.62	0.00	0.00
60	2.62	2.21	15.54	2.78	2.32	16.65	2.62	2.17	16.94	16.38
100	3.03	2.27	25.17	2.73	2.05	25.00	2.92	2.23	23.66	24.61
220	3.13	1.77	43.62	2.92	1.65	43.43	2.98	1.75	41.34	42.80
360	3.25	1.74	46.36	3.18	1.72	45.86	2.80	1.56	44.17	45.46
720	2.88	1.77	38.73	3.00	1.65	45.00	2.90	1.75	39.66	46.36

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 59 Diameter shrinkage data of bananas during drying at 70°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	27.03	27.03	0.00	26.98	26.98	0.00	26.43	26.98	0.00	0.00
60	27.03	24.35	9.93	26.98	24.05	10.87	26.43	23.92	9.52	10.16
100	28.83	25.70	10.87	28.27	25.02	11.50	28.37	24.92	11.85	11.41
220	34.10	29.62	13.15	35.02	30.42	13.14	34.90	30.20	13.47	13.25
360	29.57	25.40	14.09	29.75	25.57	14.06	29.38	25.27	14.01	14.05
720	29.65	24.95	15.85	29.72	25.47	15.23	29.77	25.23	14.65	15.24

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 60 Thickness shrinkage data of bananas during drying at 80°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	2.95	2.95	0.00	2.92	2.92	0.00	2.62	2.62	0.00	0.00
60	2.95	1.72	41.81	2.92	1.85	36.57	2.62	1.53	41.40	39.93
180	3.12	1.73	44.39	2.93	1.63	44.32	3.00	1.65	45.00	44.57
360	2.97	1.65	44.38	3.27	1.77	45.92	2.63	1.42	46.20	45.50

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 61 Diameter shrinkage data of bananas during drying at 80^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	27.70	27.70	0.00	27.37	27.37	0.00	27.12	27.12	0.00	0.00
60	27.70	24.53	11.43	27.37	24.22	11.51	27.12	23.75	12.42	11.76
180	29.02	25.00	13.84	28.82	25.10	12.90	28.87	25.22	12.64	13.13
360	34.68	29.27	15.62	35.13	29.95	14.75	35.23	29.90	15.14	15.17

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 62 Thickness shrinkage data of bananas during drying at 90^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	2.72	2.72	0.00	3.08	3.08	0.00	3.38	3.38	0.00	0.00
30	2.72	2.19	19.26	3.08	2.40	22.16	3.38	2.67	20.99	20.80
120	2.85	2.07	27.57	3.25	2.36	27.38	3.15	2.18	30.69	28.55
230	3.17	1.78	43.68	3.25	1.82	44.10	3.10	1.82	41.40	43.06

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 63 Diameter shrinkage data of bananas during drying at 90°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	30.95	30.95	0.00	30.73	31.07	0.00	31.17	31.17	0.00	0.00
30	30.95	28.62	7.19	30.73	28.28	7.54	31.17	28.95	7.89	7.54
120	30.22	26.30	12.96	29.98	26.17	12.73	29.80	26.08	12.47	12.72
230	29.03	24.85	14.41	30.67	26.23	14.46	30.65	26.07	14.96	14.61

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 64 Thickness shrinkage data of bananas in 2.5-3.5 mm slice thicknesses during drying at 100°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	2.68	2.68	0.00	3.23	3.23	0.00	3.22	3.22	0.00	0.00
30	2.68	2.10	21.74	3.23	2.55	21.13	3.22	2.48	22.80	21.89
60	2.93	2.22	24.34	3.17	2.37	25.26	3.05	2.30	24.59	24.76
90	3.18	2.30	27.75	2.65	1.93	27.04	2.88	2..07	28.32	27.71
150	3.15	2.10	33.33	2.27	2.13	34.69	2.98	1.98	33.33	33.79

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 65 Thickness shrinkage data of bananas in 1.4 – 2.4 mm slice thicknesses during drying at 100°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	1.96	1.96	0.00	1.74	1.74	0.00	1.98	1.98	0.00	0.00
5	1.96	1.56	20.58	1.74	1.36	22.03	1.98	1.60	19.06	20.55
15	2.21	1.66	25.00	2.28	1.71	24.96	1.68	1.28	23.81	24.59
20	1.91	1.37	28.57	1.67	1.15	31.21	1.94	1.35	30.12	29.97
60	1.96	1.10	43.80	1.77	0.98	44.53	1.89	0.93	51.06	46.46
140	1.96	0.84	57.07	1.86	0.71	61.83	1.71	0.70	58.87	59.26

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 66 Thickness shrinkage data of bananas in 3.6 – 4.6 mm slice thicknesses during drying at 100°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	4.00	4.00	0.00	4.25	4.25	0.00	4.12	4.12	0.00	0.00
30	4.00	3.40	14.92	4.25	3.58	15.69	4.12	3.43	16.60	15.73
60	3.93	3.22	18.22	4.37	3.47	20.61	4.22	3.32	21.34	20.06
90	4.18	3.07	26.69	4.13	3.12	24.60	4.13	3.08	25.40	25.56
220	3.72	2.22	40.32	4.17	2.30	44.92	4.42	2.70	38.94	41.40

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 67 Diameter shrinkage data of bananas in 2.5-2.5 mm slice thicknesses during drying at 100^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	27.38	27.38	0.00	26.87	26.87	0.00	26.67	26.67	0.00	0.00
30	27.38	25.37	7.36	26.87	25.11	6.53	26.67	24.67	7.50	7.13
60	28.17	25.50	9.47	27.53	24.97	9.31	27.27	24.68	9.47	9.42
90	27.92	24.90	10.81	28.17	24.83	11.83	27.43	24.10	12.15	11.60
150	29.10	24.60	15.46	28.80	24.65	14.41	28.03	23.83	14.98	14.95

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 68 Diameter shrinkage data of bananas in 1.4-2.4 mm slice thicknesses during drying at 100^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	28.64	28.64	0.00	28.99	28.99	0.00	29.31	29.31	0.00	0.00
5	28.64	27.98	2.29	28.99	27.97	3.52	29.31	28.75	1.91	2.57
15	29.45	28.35	3.72	29.48	28.16	4.50	29.94	27.65	7.64	5.29
20	30.12	28.19	6.41	30.23	28.04	7.23	30.42	28.53	6.21	6.62
60	27.43	25.13	8.37	27.74	25.00	9.88	28.34	25.75	9.13	9.13
140	27.89	23.92	14.25	28.25	24.39	13.69	28.65	24.62	14.09	14.01

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 69 Diameter shrinkage data of bananas in 3.6-4.6 mm thicknesses during drying at 100°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	28.08	28.08	0.00	27.52	27.52	0.00	27.83	27.83	0.00	0.00
30	28.08	27.37	2.55	27.52	26.17	4.91	27.83	26.62	4.37	3.94
60	27.98	26.23	6.25	27.07	25.28	6.59	28.35	26.12	7.88	6.91
90	26.97	24.63	8.65	27.98	25.52	8.81	26.42	23.97	9.27	8.91
220	26.26	22.39	14.74	26.84	22.77	15.17	27.01	23.08	14.55	14.82

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 70 Thickness shrinkage data of bananas in 2.5-3.5 mm slice thicknesses during drying at 110°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	3.22	3.22	0.00	3.18	3.18	0.00	2.83	2.83	0.00	0.00
30	3.22	2.60	19.17	3.18	2.38	25.13	2.83	2.22	21.76	22.02
60	3.12	2.29	26.52	3.15	2.35	25.50	2.62	1.92	26.75	26.26
110	2.95	1.97	33.33	2.72	1.87	31.29	2.93	1.98	32.39	32.34

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 71 Thickness shrinkage data of bananas in 1.4-2.4 mm slice thicknesses during drying at 110°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	2.01	2.01	0.00	2.27	2.27	0.00	2.02	2.02	0.00	0.00
5	2.01	1.54	23.34	2.27	1.77	22.14	2.02	1.55	23.14	22.88
15	1.97	1.32	33.16	2.25	1.58	30.03	2.20	1.49	32.27	31.82
20	1.75	1.10	37.26	1.83	1.14	37.82	1.97	1.27	35.25	36.78
60	1.85	1.03	44.14	1.72	0.97	43.52	1.69	0.95	43.90	43.85
90	2.17	1.18	45.69	1.92	1.03	46.62	1.87	1.03	45.02	45.78
100	1.89	0.95	49.82	1.72	0.84	51.26	2.57	1.32	48.83	49.97

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 72 Thickness shrinkage data of bananas in 3.6-4.6 mm slice thicknesses during drying at 110°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	4.12	4.12	0.00	4.13	4.13	0.00	4.13	4.13	0.00	0.00
30	4.12	3.33	19.03	4.13	3.28	20.56	4.13	3.30	20.16	19.92
60	4.12	3.09	24.94	3.62	2.71	24.98	3.92	2.92	25.53	25.15
110	3.95	2.72	31.22	3.93	2.73	30.51	3.67	2.50	31.82	31.18
150	4.30	2.76	35.86	4.01	2.50	37.66	3.93	2.49	36.78	36.77

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 73 Diameter shrinkage data of bananas in 2.5-3.5 mm slice thicknesses during drying at 110°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	26.53	26.53	0.00	26.25	26.25	0.00	25.90	25.90	0.00	0.00
30	26.53	24.63	7.16	26.25	23.98	8.63	25.90	24.07	7.08	7.62
60	25.45	23.10	9.23	25.18	22.50	10.66	24.70	22.38	9.38	9.76
110	26.40	22.77	13.76	25.35	22.52	11.18	27.15	23.72	12.65	12.53

Where D_0 is diameter of sample prior to drying, D is diameter of dried sample

Table 74 Diameter shrinkage data of bananas in 1.4-2.4 mm slice thicknesses during drying at 110^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	26.99	26.99	0.00	26.95	26.95	0.00	27.00	27.00	0.00	0.00
5	26.99	25.71	4.74	26.95	26.30	2.42	27.00	25.95	3.88	3.68
15	27.01	24.61	8.87	27.38	25.89	5.44	27.53	25.58	7.07	7.13
20	26.98	23.10	14.37	26.91	23.58	12.40	27.47	24.14	12.12	12.96
60	26.09	21.79	16.50	26.33	22.56	14.31	26.71	23.23	13.05	14.62
90	26.65	22.10	17.10	26.56	23.01	13.37	26.67	22.75	14.70	15.05
100	26.26	22.69	13.61	26.84	23.10	13.93	27.01	23.41	13.32	13.62

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 75 Diameter shrinkage data of bananas in 3.6-4.6 mm slice thicknesses during drying at 110^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	26.65	26.65	0.00	25.97	25.97	0.00	26.47	26.47	0.00	0.00
30	26.65	25.07	5.94	25.97	24.84	4.33	26.47	24.70	6.68	5.65
60	25.45	23.45	7.86	25.18	23.33	7.35	24.70	22.48	8.97	8.06
150	26.18	22.50	14.05	26.18	22.50	14.06	26.66	22.76	14.63	14.24

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 76 Thickness shrinkage data of bananas in 2.5-3.5 mm slice thicknesses during drying at 120^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	2.52	2.52	0.00	2.73	2.73	0.00	3.02	3.02	0.00	0.00
15	2.52	2.10	16.57	2.73	2.25	17.68	3.02	2.48	16.56	17.31
30	2.53	1.88	25.66	2.80	2.07	26.19	2.86	2.15	25.00	25.62
60	3.12	2.27	28.14	2.78	2.00	28.90	2.88	2.05	27.27	28.11
90	3.18	2.12	33.51	2.85	2.02	29.24	3.38	2.38	29.56	30.77

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 77 Thickness shrinkage data of bananas in 1.4-2.4 mm slice thicknesses during drying at 120^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	2.08	2.08	0.00	2.09	2.09	0.00	1.89	1.89	0.00	0.00
5	2.08	1.75	15.73	2.09	1.78	14.67	1.89	1.58	16.40	15.60
15	1.60	1.12	29.79	1.83	1.29	29.69	1.98	1.38	30.02	29.83
40	2.02	1.22	39.60	2.09	1.26	39.78	2.28	1.40	38.83	39.40
80	2.09	1.20	42.42	1.90	1.12	41.33	2.26	1.34	40.70	41.49

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 78 Thickness shrinkage data of bananas in 3.6-4.6 mm slice thicknesses during drying at 120°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	3.98	3.98	0.00	3.69	3.69	0.00	4.03	4.03	0.00	0.00
5	3.98	3.71	6.62	3.69	3.37	8.84	4.03	3.59	10.93	8.80
10	4.02	3.41	15.24	4.09	3.52	13.94	3.85	3.40	11.69	13.62
15	4.29	3.72	13.35	3.97	3.18	19.92	4.08	3.38	17.17	16.81
20	3.76	2.99	20.55	4.31	3.44	20.32	4.22	3.48	17.55	19.47
30	4.08	2.90	28.98	4.43	3.15	29.08	3.87	2.64	31.70	29.92
60	3.68	2.54	30.98	3.85	2.58	32.93	3.70	2.51	32.22	32.04
120	3.84	2.44	36.46	4.01	2.55	36.27	4.24	2.74	35.33	36.02

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 79 Diameter shrinkage data of bananas in 2.5-3.5 mm slice thicknesses during drying at 120^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	28.47	28.47	0.00	28.38	28.38	0.00	28.08	28.08	0.00	0.00
15	28.47	26.53	6.79	28.38	26.53	6.52	28.08	26.27	6.47	6.59
30	29.08	26.83	7.73	27.13	24.98	8.77	28.13	25.67	7.92	8.14
60	28.10	24.55	12.63	27.90	24.30	12.90	26.88	23.55	12.40	12.65
90	27.85	24.25	12.93	29.08	25.30	13.01	29.42	25.38	13.71	13.22

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 80 Diameter shrinkage data of bananas in 1.4-2.4 mm slice thicknesses during drying at 120^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	26.35	26.35	0.00	26.76	26.76	0.00	26.83	26.83	0.00	0.00
5	26.35	25.63	2.72	26.76	25.42	4.98	26.83	25.48	5.01	4.23
15	26.87	24.67	8.19	27.20	25.31	6.93	26.85	24.80	7.62	7.58
40	27.74	24.83	10.47	28.06	25.18	10.26	28.66	25.93	9.52	10.09
80	26.50	23.07	12.93	26.75	23.39	12.69	26.89	23.48	12.69	12.74

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 81 Diameter shrinkage data of bananas in 3.6-4.6 mm slice thicknesses during drying at 120°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	28.92	28.92	0.00	29.27	29.27	0.00	29.56	29.56	0.00	0.00
5	28.92	27.88	3.58	29.27	28.21	3.62	29.56	28.54	3.43	3.54
10	30.04	28.88	3.86	30.10	29.41	2.27	30.27	29.10	3.85	3.33
15	29.85	28.81	3.48	30.20	28.54	5.52	30.37	28.85	5.01	4.67
20	28.54	26.58	6.89	29.01	27.17	6.33	28.74	27.79	3.31	5.51
30	28.46	25.72	9.63	28.80	26.59	7.67	29.04	26.40	9.09	8.80
60	30.01	26.71	11.01	30.79	27.46	10.81	31.46	28.39	9.76	10.53
120	27.87	24.34	12.64	29.42	25.93	11.86	30.50	27.02	11.40	11.97

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

A.5 Shrinkage Data of Pineapples during Vacuum Drying

Table 82 Thickness shrinkage data of pineapples during drying at 70^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	3.10	3.10	0.00	2.60	2.60	0.00	3.40	3.40	0.00	0.00
60	3.10	2.20	29.03	2.60	1.86	28.46	3.40	2.42	28.82	28.77
105	3.05	1.99	34.76	3.40	2.25	33.82	3.50	2.29	34.57	34.38
370	3.40	1.11	67.16	3.35	1.10	67.16	2.60	0.84	67.69	67.40
610	2.50	0.67	75.52	2.90	0.71	75.52	3.40	0.87	74.41	74.38

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 83 Thickness shrinkage data of pineapples during drying at 80^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	3.00	3.00	0.00	3.10	3.10	0.00	3.20	3.20	0.00	0.00
60	3.00	2.11	29.67	3.10	2.15	30.65	3.20	2.20	31.25	30.52
105	2.55	1.65	35.25	2.95	1.91	35.25	2.60	1.70	34.62	35.05
370	3.50	1.04	69.48	3.08	0.94	69.48	3.25	1.02	68.62	69.46

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 84 Thickness shrinkage data of pineapples during drying at 90°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	2.50	2.50	0.00	3.50	3.50	0.00	2.62	2.62	0.00	0.00
60	3.42	2.33	31.87	2.56	1.69	33.98	3.50	2.38	32.00	32.62
90	3.50	2.23	36.29	3.07	1.92	37.46	2.82	1.81	35.82	36.52
120	3.50	1.97	43.71	3.30	1.74	47.27	2.50	1.44	42.40	44.46
190	3.37	1.14	66.17	3.21	1.09	66.04	3.12	0.97	68.91	67.04

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample

Table 85 Thickness shrinkage data of pineapples during drying at 100°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	2.63	2.63	0.00	2.77	2.77	0.00	2.88	2.88	0.00	0.00
35	2.63	1.41	46.20	2.77	1.52	45.18	2.88	1.97	31.68	41.02
65	2.68	1.05	60.87	3.12	1.22	60.96	2.63	0.95	63.92	61.92
180	3.00	1.02	65.50	2.85	0.98	65.54	2.95	1.02	66.11	65.72

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 86 Thickness shrinkage data of pineapples during drying at 110°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	3.40	3.40	0.00	2.75	2.75	0.00	2.50	2.50	0.00	0.00
30	3.40	2.40	29.41	2.75	1.95	29.09	2.50	1.85	26.00	28.17
90	3.50	2.10	40.00	2.50	1.50	40.00	3.45	2.00	42.03	40.68
150	3.45	1.50	56.52	2.60	1.20	53.85	3.50	1.70	51.43	53.93

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 87 Thickness shrinkage data of pineapples during drying at 120°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	3.45	3.45	0.00	3.50	3.50	0.00	3.05	3.05	0.00	0.00
30	3.45	2.50	28.20	3.50	2.55	27.54	3.05	2.19	27.14	27.63
90	2.50	1.50	40.00	2.80	1.71	40.39	2.55	1.52	40.65	40.65
105	3.00	1.70	43.33	2.60	1.55	40.38	3.45	2.05	41.43	41.43
140	2.80	1.65	40.98	3.05	1.80	41.07	3.35	1.90	41.78	41.78

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 88 The a-axis shrinkage of the pineapple slices at various temperatures.

Drying temperature (°C)	Sample 1			Sample 2			Sample 3			Avg. %a-axis shrinkage
	a_0 (mm)	a (mm)	%a-axis shrinkage	a_0 (mm)	a (mm)	%a-axis shrinkage	a_0 (mm)	a (mm)	%a-axis shrinkage	
100	27.05	20.13	25.58	27.01	20.15	25.64	24.05	19.15	21.03	24.09
110	21.94	16.75	23.66	22.44	17.12	23.61	22.57	16.98	24.77	24.01
120	30.48	23.13	24.11	27.20	20.75	23.71	25.18	19.19	23.79	23.87

Table 89 The b-axis shrinkage of the pineapple slices at various temperatures.

Drying temperature (°C)	Sample 1			Sample 2			Sample 3			Avg. %b-axis shrinkage
	b_0 (mm)	b (mm)	%b-axis shrinkage	b_0 (mm)	b (mm)	%b-axis shrinkage	b_0 (mm)	b (mm)	%b-axis shrinkage	
100	55.10	44.05	20.05	53.45	41.00	23.29	54.15	41.15	24.01	22.45
110	50.53	40.00	20.84	60.03	47.45	20.96	55.23	44.43	19.55	20.45
120	46.34	36.38	21.49	51.82	41.86	19.22	56.84	45.54	19.88	20.19

Table 90 The c-axis shrinkage of the pineapple slices at various temperatures.

Drying temperature (°C)	Sample 1			Sample 2			Sample 3			Avg. %c-axis shrinkage
	c_0 (mm)	c (mm)	%c-axis shrinkage	c_0 (mm)	c (mm)	%c-axis shrinkage	c_0 (mm)	c (mm)	%c-axis shrinkage	
100	26.62	23.40	12.10	28.65	24.27	15.29	26.77	23.62	11.77	13.05
110	23.42	21.26	9.22	27.93	25.63	8.23	25.73	22.18	13.80	10.42
120	19.57	17.23	11.96	20.82	18.45	11.38	22.05	19.69	10.70	11.35

Table 91 The d-axis shrinkage of the pineapple slices at various temperatures.

Drying Temperature (°C)	Sample 1			Sample 2			Sample 3			Avg. %d-axis shrinkage
	d_0 (mm)	d (mm)	%d-axis shrinkage	d_0 (mm)	d (mm)	%d-axis shrinkage	d_0 (mm)	d (mm)	%d-axis shrinkage	
100	25.25	21.30	15.64	27.50	22.40	18.55	25.60	21.95	14.26	16.15
110	31.47	27.02	14.14	31.96	27.47	14.05	31.53	26.62	15.57	14.59
120	21.46	18.49	13.84	30.97	26.86	13.27	30.83	26.03	15.57	14.23

Table 92 The surface shrinkage of the pineapple slices at various temperatures.

Drying Temperature (^{o}C)	Sample 1			Sample 2			Sample 3			Avg. %Surface Shrinkage
	S_0 (mm^2)	S (mm^2)	%Surface Shrinkage	S_0 (mm^2)	S (mm^2)	%Surface Shrinkage	S_0 (mm^2)	S (mm^2)	%Surface Shrinkage	
100	1000.18	675.49	32.46	977.81	643.26	34.21	1045.00	703.92	32.64	33.11
110	1140.32	766.69	32.76	1317.39	886.87	32.68	1226.52	817.37	33.36	32.93
120	824.28	550.17	33.25	1223.63	840.85	31.28	1264.34	842.46	33.37	32.63

Where S_0 is surface area of sample prior to drying and S is surface area of dried sample.

A.6 Shrinkage Data of Apples during Vacuum Drying

Table 93 Thickness shrinkage data of apples during drying at 100^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	5.85	5.85	0.00	5.60	5.60	0.00	5.65	5.65	0.00	0.00
30	5.85	4.65	20.51	5.60	4.50	19.64	5.65	4.55	19.47	19.87
180	5.90	2.25	61.86	5.85	2.25	61.54	5.80	2.30	60.34	61.25
495	5.50	1.95	64.55	5.75	1.95	66.09	5.85	1.95	66.67	65.77

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 94 Diameter shrinkage data of apples during drying at 100^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	77.10	77.10	0.00	74.40	74.40	0.00	78.65	78.65	0.00	0.00
30	77.10	74.00	4.02	74.40	70.60	5.11	78.65	75.25	4.32	4.48
180	77.10	65.75	14.72	73.55	63.60	13.53	76.35	65.95	13.62	13.96
495	75.75	55.41	26.85	69.50	50.90	26.76	70.30	53.25	24.25	25.96

Where D_0 is diameter of sample prior to drying and D is diameter of dried sample.

Table 95 Thickness shrinkage data of apples during drying at 110^{o}C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	5.85	5.85	0.00	5.70	5.70	0.00	5.65	5.65	0.00	0.00
30	5.85	4.65	20.51	5.70	4.55	20.18	5.65	4.45	21.24	20.64
80	5.50	3.55	35.45	5.65	3.75	33.63	5.90	3.95	33.05	34.04
180	5.95	2.25	62.18	5.70	2.15	62.28	5.70	2.20	61.40	61.96
300	5.90	2.05	65.25	6.00	2.15	64.17	5.65	1.95	65.49	64.97

Where L_0 is thickness of sample prior to drying and L is thickness of dried sample.

Table 96 Diameter shrinkage data of apples during drying at 110°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	74.60	74.60	0.00	77.50	77.50	0.00	75.75	75.75	0.00	0.00
30	75.35	71.95	4.51	76.00	72.80	4.21	77.45	73.85	4.65	4.46
80	77.50	71.35	7.94	78.45	71.55	8.80	76.50	70.47	7.88	8.20
180	74.90	65.25	12.88	75.40	65.00	13.79	76.80	65.95	14.13	13.60
300	77.50	63.15	18.52	76.35	62.55	18.07	77.60	63.00	18.81	18.47

Where D_0 is diameter of sample prior to drying, D is diameter of dried sample.

Table 97 Thickness shrinkage data of apples during drying at 120°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Thickness shrinkage
	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	L_0 (mm)	L (mm)	%Thickness shrinkage	
0	5.50	5.50	0.00	5.87	5.87	0.00	5.97	5.97	0.00	0.00
30	5.50	4.31	21.64	5.87	4.67	20.44	5.97	4.77	20.10	20.73
80	5.65	3.64	35.58	5.76	3.73	35.24	5.90	3.89	34.07	34.96
180	5.65	2.08	63.19	5.77	2.15	62.74	5.58	2.07	62.90	62.94

Where L_0 is thickness of sample prior to drying, L is thickness of dried sample.

Table 98 Diameter shrinkage data of apples during drying at 120°C.

Time (min)	Sample 1			Sample 2			Sample 3			Avg. %Diameter shrinkage
	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	D_0 (mm)	D (mm)	%Diameter shrinkage	
0	77.50	77.50	0.00	74.50	74.50	0.00	75.32	75.32	0.00	0.00
30	74.65	70.80	5.16	76.50	72.75	4.90	77.52	73.65	4.99	5.02
80	75.50	67.95	10.00	75.05	66.95	10.79	76.85	69.41	9.68	10.16
180	72.10	61.65	14.49	72.85	63.90	12.29	75.40	64.70	14.19	13.66

Where D_0 is diameter of sample prior to drying, D is diameter of dried sample.

A.7 Rehydration Data of the Vacuum-Dried Bananas

Table 99 Rehydration data of the dried bananas in 1.4-3.4 mm slice thicknesses at various drying temperatures.

Drying temperature (°C)	Sample 1			Sample 2			Sample 3			Avg. Rehydration ratio
	m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	
100	0.55	1.01	1.84	0.54	1.14	2.11	0.64	1.18	1.84	1.93
110	0.58	1.21	2.09	0.59	1.28	2.17	0.53	1.16	2.19	2.15
120	0.65	1.37	2.11	0.63	1.26	2.00	0.54	1.20	2.22	2.11

Where m and m_{after} are, respectively, the masses of the dried and rehydrated samples (g).

Table 100 Rehydration data of the dried bananas in 2.5-3.5 mm slice thicknesses at various drying temperatures.

Drying method	Drying temperature (^{o}C)	Sample 1			Sample 2			Sample 3			Avg. rehydration ratio
		m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	
VD	100	0.64	1.05	1.64	0.56	0.91	1.63	0.62	1.02	1.65	1.64
	110	0.61	1.07	1.75	0.53	0.93	1.75	0.55	0.96	1.75	1.75
	120	0.56	1.01	1.80	0.60	1.07	1.78	0.56	1.00	1.79	1.79
VF (greenday™)	N/A	0.67	1.04	1.55	0.80	1.16	1.45	0.92	1.36	1.48	1.49
FD (Well-B™)	N/A	0.76	1.46	1.92	0.41	1.02	2.49	0.72	1.54	2.14	2.18

Where m and m_{after} are, respectively, the masses of the dried and rehydrated samples (g). VD is Vacuum drying, VF is Vacuum frying and FD is Freeze drying.

Table 101 Rehydration data of the dried bananas in 3.6-4.6 mm slice thicknesses at various drying temperatures.

Drying temperature (^{o}C)	Sample 1			Sample 2			Sample 3			Avg. Rehydration ratio
	m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	
100	0.57	0.90	1.58	0.58	0.89	1.53	0.61	0.94	1.54	1.55
110	0.62	0.97	1.56	0.52	0.78	1.50	0.56	0.87	1.55	1.54
120	0.60	0.99	1.65	0.65	1.04	1.60	0.58	0.94	1.62	1.62

Where m and m_{after} are, respectively, the masses of the dried and rehydrated samples (g).

A.8 Rehydration Data of the Vacuum-Dried Pineapples

Table 102 Rehydration data of the dried pineapples in 2.5-3.5 mm slice thicknesses at various drying temperatures.

Drying method	Drying temperature (^{o}C)	Sample 1			Sample 2			Sample 3			Avg. rehydration ratio
		m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	
VD	100	0.82	1.83	2.23	0.60	1.39	2.32	0.63	1.41	2.24	2.26
	110	0.54	1.34	2.48	0.46	1.14	2.48	0.43	1.07	2.49	2.48
	120	0.50	1.27	2.54	0.56	1.43	2.55	0.46	1.17	2.54	2.55
VF (greenday™)	N/A	0.65	1.21	1.86	0.76	1.42	1.87	0.57	1.14	2.00	1.91

Where m and m_{after} are, respectively, the masses of the dried and rehydrated samples (g). VD is Vacuum drying and VF is Vacuum frying.

A.9 Rehydration Data of the Vacuum-Dried Apples

Table 103 Rehydration data of the dried apples in 5.5-6.0 mm slice thicknesses at various drying temperatures.

Drying temperature (^{o}C)	Sample 1			Sample 2			Sample 3			Avg. Rehydration ratio
	m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	m (g)	m_{after} (g)	Rehydration ratio	
100	3.25	5.86	1.80	2.86	5.10	1.78	2.22	3.91	1.76	1.78
110	3.14	5.72	1.82	1.73	3.14	1.82	2.11	3.87	1.83	1.82
120	2.22	5.25	2.36	2.64	5.98	2.27	2.70	6.02	2.23	2.29

Where m and m_{after} are, respectively, the masses of the dried and rehydrated samples (g).

A.10 Hardness and Crispness Data of the Vacuum-Dried Bananas

Table 104 Hardness (maximum force) and crispness (number of peaks) data of dried bananas at various temperatures.

Drying method*	Drying temperature (^{o}C)	Sample 1		Sample 2		Sample 3		Avg. Maximum force (N)	Avg. Number of peaks (peak)
		Maximum force (N)	Number of peaks (peak)	Maximum force (N)	Number of peaks (peak)	Maximum force (N)	Number of peaks (peak)		
VD	100	46.94	11.00	45.67	10.00	43.97	10.00	45.53	10.33
	110	41.53	14.00	40.76	13.00	39.00	15.00	40.43	14.00
	120	34.96	16.00	34.41	17.00	36.61	18.00	35.33	17.00
VF (greenday™)	N/A	26.53	51.00	35.00	65.00	38.00	45.00	33.18	53.67

*VD is Vacuum drying and VF is Vacuum frying.

Table 105 Hardness (maximum force) and crispness (number of peaks) data of dried bananas at various sample thickness.

Sample thickness (mm)	Sample 1		Sample 2		Sample 3		Avg. Maximum force (N)	Avg. Number of peaks (peak)
	Maximum force (N)	Number of peaks (peak)	Maximum force (N)	Number of peaks (peak)	Maximum force (N)	Number of peaks (peak)		
1.40-2.40	21.62	20.00	23.56	21.00	22.25	19.00	22.48	20.00
2.50-3.50	34.41	17.00	36.61	17.00	34.96	17.00	35.33	16.67
3.60-4.60	57.74	5.00	53.38	5.00	57.38	6.00	56.17	5.33

A.11 Hardness and Crispness Data of the Vacuum-Dried Pineapples

Table 106 Hardness (maximum force) and crispness (number of peaks) data of dried pineapples at various temperatures.

Drying method*	Drying temperature (°C)	Sample 1		Sample 2		Sample 3		Avg. Maximum force (N)	Avg. Number of peaks (peak)
		Maximum force (N)	Number of peaks (peak)	Maximum force (N)	Number of peaks (peak)	Maximum force (N)	Number of peaks (peak)		
VD	100	55.44	6.00	55.97	6.00	56.17	8.00	55.86	6.67
	110	46.17	5.00	45.98	5.00	47.81	5.00	46.65	5.00
	120	42.78	9.00	43.58	8.00	43.23	11.00	43.20	9.33
VF (greenday™)	N/A	56.02	54.00	57.90	43.00	61.17	42.00	58.36	46.33

*VD is Vacuum drying and VF is Vacuum frying.

A.12 Hardness and Crispness Data of the Vacuum-Dried Apples

Table 107 Hardness (maximum force) and crispness (number of peaks) data of dried apples at various temperatures.

Drying temperature (^oC)	Sample 1		Sample 2		Sample 3		Avg. Maximum force (N)	Avg. Number of peaks (peak)
	Maximum force (N)	Number of peaks (peak)	Maximum force (N)	Number of peaks (peak)	Maximum force (N)	Number of peaks (peak)		
100	203.03	9.00	177.24	7.00	133.70	11.00	171.32	9.00
110	198.66	8.00	228.27	9.00	144.26	9.00	190.40	8.67
120	143.69	11.00	107.91	11.00	110.45	10.00	120.68	10.67

A.13 Colorimetric Data of the Vacuum-Dried Bananas

Table 108 Lightness value of dried bananas at various temperatures.

Sample	Drying Temperature (^oC)	Sample 1		Sample 2		Sample 3		Avg. L	Avg. $\Delta L/L_0$
		L	$\Delta L/L_0$	L	$\Delta L/L_0$	L	$\Delta L/L_0$		
Fresh bananas	-	76.29	-	79.21	-	78.64	-	78.05	-
Vacuum dried bananas	100	72.30	-0.088	70.54	-0.074	71.22	-0.096	71.35	-0.086
	110	70.52	-0.097	67.97	-0.129	69.16	-0.114	69.22	-0.113
	120	66.26	-0.151	65.32	-0.143	66.86	-0.163	66.15	-0.153

Where L_0 is the initial values of the lightness of the sample prior to drying, L is the lightness of the dried sample and $\Delta L/L_0$ is the normalized color change.

Table 109 Redness value of dried bananas at various temperatures.

Sample	Drying temperature (^{o}C)	Sample 1		Sample 2		Sample 3		Avg. a	Avg. $\Delta a/a_0$
		a	$\Delta a/a_0$	a	$\Delta a/a_0$	a	$\Delta a/a_0$		
Fresh bananas	-	1.11	-	1.34	-	1.06	-	1.17	-
Vacuum dried bananas	100	2.38	1.043	2.36	1.026	2.34	1.009	2.36	1.026
	110	2.53	1.172	2.53	1.172	2.56	1.197	2.54	1.163
	120	3.50	2.004	4.03	2.459	3.51	2.013	3.68	2.159

Where a_0 is the initial values of the redness of the sample prior to drying, a is the redness of the dried sample and $\Delta a/a_0$ is the normalized color change.

Table 110 Yellowness value of dried bananas at various temperatures.

Sample	Drying temperature (^{o}C)	Sample 1		Sample 2		Sample 3		Avg. b	Avg. $\Delta b/b_0$
		b	$\Delta b/b_0$	b	$\Delta b/b_0$	b	$\Delta b/b_0$		
Fresh bananas	-	19.35	-	18.96	-	19.35	-	19.22	-
Vacuum dried bananas	100	20.88	0.088	19.66	0.025	20.70	0.079	20.41	0.064
	110	21.09	0.122	21.53	0.099	21.89	0.141	21.50	0.121
	120	22.30	0.162	22.23	0.239	23.76	0.159	22.76	0.187

Where b_0 is the initial values of the yellowness of the sample prior to drying, b is the yellowness of the dried sample and $\Delta b/b_0$ is the normalized color change.

A.14 Colorimetric Data of the Vacuum-Dried Pineapples

Table 111 Lightness value of dried pineapples at various temperatures.

Sample	Drying temperature (^{o}C)	Sample 1		Sample 2		Sample 3		Avg. L	Avg $\Delta L/L_0$.
		L	$\Delta L/L_0$	L	$\Delta L/L_0$	L	$\Delta L/L_0$		
Fresh pineapples	-	79.20	-	77.93	-	79.38	-	78.84	-
Vacuum dried pineapples	100	71.73	-0.090	69.86	-0.114	70.73	-0.103	70.77	-0.103
	110	65.58	-0.168	66.72	-0.154	69.30	-0.121	67.20	-0.148
	120	63.78	-0.191	64.88	-0.177	62.81	-0.216	63.49	-0.195

Where L_0 is the initial values of the lightness of the sample prior to drying, L is the lightness of the dried sample and $\Delta L/L_0$ is the normalized color change.

Table 112 Redness value of dried pineapples at various temperatures.

Sample	Drying temperature (^{o}C)	Sample 1		Sample 2		Sample 3		Avg. a	Avg. $\Delta a/a_0$
		a	$\Delta a/a_0$	a	$\Delta a/a_0$	a	$\Delta a/a_0$		
Fresh pineapples	-	0.73	-	0.53	-	0.90	-	0.72	-
Vacuum dried pineapples	100	2.61	2.625	2.05	1.847	2.20	2.056	2.29	2.176
	110	2.26	2.139	2.10	1.917	2.56	2.556	2.31	2.204
	120	7.31	9.153	6.32	7.778	6.75	8.375	6.79	8.435

Where a_0 is the initial values of the redness of the sample prior to drying, a is the redness of the dried sample and $\Delta a/a_0$ is the normalized color change.

Table 113 Yellowness value of dried pineapples at various temperatures.

Sample	Drying temperature (^{o}C)	Sample 1		Sample 2		Sample 3		Avg. b	Avg. $\Delta b/b_0$
		b	$\Delta b/b_0$	b	$\Delta b/b_0$	b	$\Delta b/b_0$		
Fresh pineapples	-	23.17	-	22.28	-	23.72	-	23.06	-
Vacuum dried pineapples	100	30.23	0.311	31.38	0.361	29.20	0.266	30.27	0.313
	110	23.80	0.032	26.85	0.165	27.12	0.176	25.92	0.124
	120	27.76	0.204	27.81	0.206	28.08	0.218	27.88	0.209

Where b_0 is the initial values of the yellowness of the sample prior to drying, b is the yellowness of the dried sample and $\Delta b/b_0$ is the normalized color change.

A.15 Colorimetric Data of the Vacuum-Dried Apples

Table 114 Lightness value of dried apples at various temperatures.

Sample	Drying temperature (^{o}C)	Sample 1		Sample 2		Sample 3		Avg. L	Avg. $\Delta L/L_0$
		L	$\Delta L/L_0$	L	$\Delta L/L_0$	L	$\Delta L/L_0$		
Fresh apples	-	78.27	-	77.49	-	76.05	-	77.27	-
Vacuum dried apples	100	74.98	-0.030	74.43	-0.037	74.23	-0.039	74.55	-0.035
	110	71.01	-0.081	68.15	-0.118	71.85	-0.070	70.34	-0.090
	120	71.72	-0.072	72.25	-0.065	71.78	-0.071	71.92	-0.069

Where L_0 is the initial values of the lightness of the sample prior to drying, L is the lightness of the dried sample and $\Delta L/L_0$ is the normalized color change.

Table 115 Redness value of dried apples at various temperatures.

Sample	Drying temperature (^{o}C)	Sample 1		Sample 2		Sample 3		Avg. a	Avg. $\Delta a/a_0$
		a	$\Delta a/a_0$	a	$\Delta a/a_0$	a	$\Delta a/a_0$		
Fresh apples	-	0.48	-	0.46	-	0.31	-	0.417	-
Vacuum dried apples	100	5.70	12.680	5.57	12.368	5.20	11.480	5.490	12.176
	110	6.43	14.432	6.25	14.000	6.35	14.240	6.343	14.224
	120	3.56	7.544	3.69	7.856	3.44	7.256	3.563	7.552

Where a_0 is the initial values of the redness of the sample prior to drying, a is the redness of the dried sample and $\Delta a/a_0$ is the normalized color change.

Table 116 Yellowness value of dried apples at various temperatures.

Sample	Drying temperature (^{o}C)	Sample 1		Sample 2		Sample 3		Avg. b	Avg. $\Delta b/b_0$
		b	$\Delta b/b_0$	b	$\Delta b/b_0$	b	$\Delta b/b_0$		
Fresh apples	-	16.57	-	16.45	-	16.30	-	16.440	-
Vacuum dried apples	100	26.18	0.592	26.50	0.612	26.92	0.637	26.533	0.614
	110	27.20	0.655	27.27	0.659	26.36	0.603	26.943	0.639
	120	26.22	0.595	26.37	0.604	26.35	0.603	26.313	0.601

Where b_0 is the initial values of the yellowness of the sample prior to drying, b is the yellowness of the dried sample and $\Delta b/b_0$ is the normalized color change.

A.16 Sensory Evaluation Form

Name: **Product:**

Panelist No.: **Date:**

Instructions:

Taste the give samples, then place an X mark on the point in the scale which best describes your feeling. The scale is as follows:

Score/Rating	Std. Hedonic Scale
9	I like extremely
8	I like very much
7	I like moderately
6	I like slightly
5	I neither like nor dislike
4	I dislike slightly
3	I dislike moderately
2	I dislike very much
1	I dislike extremely

Score/	Color				Texture				Flavor				Flavor				Overall acceptability			
Rating	Sample A	Sample B	Sample C	Sample D	Sample A	Sample B	Sample C	Sample D	Sample A	Sample B	Sample C	Sample D	Sample A	Sample B	Sample C	Sample D	Sample A	Sample B	Sample C	Sample D
(9)																				
(8)																				
(7)																				
(6)																				
(5)																				
(4)																				
(3)																				
(2)																				
(1)																				

A.17 Sensory Data of the Vacuum-Dried Bananas

Table 117 Sensory data of dried bananas at 100°C.

Characteristics	Number of consumers																														Avg.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	score*
Color	7	6	6	6	9	9	7	7	7	6	7	6	6	5	7	8	7	6	8	9	7	6	9	8	6	6	7	7	6	7	6.93
Texture	8	6	8	8	6	7	8	6	7	7	6	7	8	6	7	6	7	5	7	7	7	6	7	8	7	6	8	7	7	7	6.90
Flavor	8	9	7	7	9	7	8	8	7	7	8	8	7	6	8	6	7	8	9	8	8	9	9	6	7	7	8	7	8	8	7.63
Crispness	8	7	7	6	8	7	7	7	7	6	9	8	7	9	9	8	8	7	9	9	8	8	8	8	7	7	8	7	9	9	7.73
Overall acceptability	7	8	7	6	9	8	9	7	7	6	9	6	7	8	7	6	7	7	8	8	8	5	9	9	7	8	7	8	6	9	7.43

*Score is "1" = "Dislike extremely", "2" = "Dislike very much", "3" = "Dislike moderately", "4" = "Dislike slightly", "5" = "Neither like nor dislike", "6" = "Like slightly", "7" = "Like moderately", "8" = "Like very much" and "9" = "Like extremely".

Table 118 Sensory data of dried bananas at 110°C.

Characteristics	Number of consumers																														Avg.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	score*
Color	7	7	6	6	8	7	6	8	7	7	8	7	7	6	8	8	7	7	7	8	8	6	8	8	7	7	6	8	7	7	7.13
Texture	7	6	9	7	7	8	8	6	7	7	6	7	8	7	7	8	7	6	7	8	7	6	7	8	8	7	8	7	8	7	7.20
Flavor	8	8	8	8	9	8	8	9	8	6	8	8	7	7	9	7	7	8	8	8	9	8	9	7	9	7	8	8	8	8	7.93
Crispness	8	8	8	8	8	8	7	8	6	7	9	8	7	9	8	8	8	8	9	9	8	8	8	7	8	7	8	8	9	8	7.93
Overall acceptability	8	8	8	7	8	8	8	7	8	7	9	7	8	7	7	9	7	8	8	8	9	6	8	9	7	9	7	9	8	8	7.77

*Score is "1" = "Dislike extremely", "2" = "Dislike very much", "3" = "Dislike moderately", "4" = "Dislike slightly", "5" = "Neither like nor dislike", "6" = "Like slightly", "7" = "Like moderately", "8" = "Like very much" and "9" = "Like extremely".

Table 119 Sensory data of dried bananas at 120°C.

Characteristics	Number of consumers																														Avg. score*
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Color	7	7	6	7	8	6	6	9	6	8	8	7	7	7	7	8	9	6	8	7	7	6	7	9	7	6	7	7	7	7	7.13
Texture	8	7	9	7	7	8	7	7	7	7	7	7	8	8	7	8	7	7	7	7	7	6	7	8	8	6	8	7	8	8	7.33
Flavor	8	9	9	8	9	7	8	8	8	7	8	8	7	7	9	7	7	8	9	8	8	9	9	7	8	7	9	9	9	8	8.07
Crispness	8	9	9	9	9	7	8	9	7	8	9	8	7	9	9	8	8	8	9	9	9	9	8	8	9	8	9	7	9	9	8.40
Overall acceptability	8	8	8	8	7	9	8	7	9	7	9	8	8	8	8	7	7	9	9	8	9	7	9	9	7	8	7	9	8	7	8.00

*Score is "1" = "Dislike extremely", "2" = "Dislike very much", "3" = "Dislike moderately", "4" = "Dislike slightly", "5" = "Neither like nor dislike", "6" = "Like slightly", "7" = "Like moderately", "8" = "Like very much" and "9" = "Like extremely".

Table 120 Sensory data of vacuum fried bananas (greenday™).

Characteristics	Number of consumers																														Avg. score*
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Color	8	7	6	7	7	6	8	9	8	9	9	6	8	8	8	7	9	7	9	7	7	7	8	9	8	8	8	6	8	8	7.67
Texture	8	7	9	7	8	9	8	8	7	8	8	8	9	9	8	9	8	8	8	8	8	7	8	8	9	7	9	8	9	9	8.13
Flavor	9	9	9	7	9	8	8	7	7	9	9	8	7	8	8	8	7	8	7	8	8	9	8	8	8	8	9	9	9	8	8.13
Crispness	9	9	9	9	9	9	9	9	9	9	9	8	7	9	8	9	8	8	9	9	8	8	9	8	9	9	9	8	9	8	8.63
Overall acceptability	7	9	8	9	7	8	9	8	8	9	7	7	7	7	7	8	8	9	7	7	7	8	8	8	8	8	8	9	8	7	7.83

*Score is "1" = "Dislike extremely", "2" = "Dislike very much", "3" = "Dislike moderately", "4" = "Dislike slightly", "5" = "Neither like nor dislike", "6" = "Like slightly", "7" = "Like moderately", "8" = "Like very much" and "9" = "Like extremely".

Table 121 Sensory data of freeze dried bananas (Well-B™).

Characteristics	Number of consumers																														Avg.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	score*
Color	9	8	9	9	9	9	9	6	9	9	9	9	9	7	9	9	9	9	7	9	8	9	9	8	9	9	9	9	9	9	8.67
Texture	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8	9	9	9	9	9	9	9	9	9	8.97
Flavor	8	8	9	8	9	8	8	9	9	8	9	8	7	9	7	9	7	9	6	9	8	9	7	9	9	9	9	9	9	7	8.30
Crispness	9	9	9	9	8	8	9	9	8	9	9	9	7	8	8	9	9	9	9	9	7	9	9	8	9	8	9	9	8	9	8.60
Overall acceptability	9	9	9	9	9	9	9	9	9	8	8	9	8	9	8	9	9	9	7	9	8	9	8	7	9	9	9	9	8	9	8.63

*Score is "1" = "Dislike extremely", "2" = "Dislike very much", "3" = "Dislike moderately", "4" = "Dislike slightly", "5" = "Neither like nor dislike", "6" = "Like slightly", "7" = "Like moderately", "8" = "Like very much" and "9" = "Like extremely".

A.18 Sensory Data of the Vacuum-Dried Pineapples

Table 122 Sensory data of vacuum dried pineapples at 100°C.

Characteristics	Number of consumers																														Avg.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	score*
Color	7	9	9	7	9	7	9	8	9	8	8	6	9	8	6	8	7	9	8	6	6	9	8	7	7	6	7	9	7	7	7.67
Texture	7	9	9	7	9	8	7	7	9	7	8	7	7	8	7	8	8	7	9	7	6	5	8	9	7	8	7	8	7	7	7.56
Flavor	8	6	6	6	6	8	7	7	7	9	7	7	7	7	9	8	7	6	8	6	7	8	9	9	9	9	7	6	7	7	7.33
Crispness	6	6	6	5	8	5	7	6	6	7	7	7	7	6	6	7	7	7	7	7	6	7	7	6	6	7	8	7	7	7	6.60
Overall acceptability	7	7	6	6	8	6	8	8	7	8	7	6	7	8	7	7	8	5	7	6	7	7	7	7	8	7	8	6	8	8	7.07

*Score is "1" = "Dislike extremely", "2" = "Dislike very much", "3" = "Dislike moderately", "4" = "Dislike slightly", "5" = "Neither like nor dislike", "6" = "Like slightly", "7" = "Like moderately", "8" = "Like very much" and "9" = "Like extremely".

Table 123 Sensory data of vacuum dried pineapples at 110°C.

Characteristics	Number of consumers																													Avg. score*
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Color	7	7	6	9	7	7	8	8	8	7	8	7	8	7	7	7	7	8	7	7	6	8	8	8	8	7	8	8	8	7	7.43
Texture	7	7	8	7	7	8	8	7	9	7	8	8	7	8	7	7	8	7	8	7	7	5	8	8	6	8	7	7	8	8	7.40
Flavor	7	7	8	6	7	8	7	6	8	8	8	7	7	7	8	8	8	7	8	7	6	9	9	8	9	9	7	7	9	7	7.57
Crispness	6	7	8	5	7	6	7	6	7	8	7	6	7	7	7	7	8	7	7	7	6	7	7	8	7	8	8	7	8	7	7.00
Overall acceptability	6	7	8	7	7	7	8	8	8	8	7	6	8	8	8	8	7	6	6	7	6	7	7	7	7	8	8	7	8	7	7.23

*Score is “1” = “Dislike extremely”, “2” = “Dislike very much”, “3” = “Dislike moderately”, “4” = “Dislike slightly”, “5” = “Neither like nor dislike”, “6” = “Like slightly”, “7” = “Like moderately”, “8” = “Like very much” and “9” = “Like extremely”

Table 124 Sensory data of vacuum dried pineapples at 120°C.

Characteristics	Number of consumers																													Avg. score*
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Color	6	7	7	7	8	7	7	8	7	7	8	7	8	6	7	6	7	7	7	8	7	7	9	9	7	8	7	8	9	7	7.33
Texture	8	6	7	7	8	8	8	7	9	6	8	7	7	8	7	7	8	8	8	8	8	6	9	7	7	9	8	7	9	8	7.60
Flavor	8	7	7	6	8	8	8	8	9	7	8	8	7	8	9	8	7	7	7	8	6	8	9	9	8	9	7	7	9	7	7.73
Crispness	8	7	7	6	6	7	8	7	7	9	8	8	7	8	8	8	8	8	7	8	8	7	8	8	8	9	8	7	8	8	7.63
Overall acceptability	8	7	7	7	6	8	8	8	9	8	8	7	8	8	8	9	8	7	7	8	7	7	8	8	8	9	8	7	9	8	7.77

*Score is “1” = “Dislike extremely”, “2” = “Dislike very much”, “3” = “Dislike moderately”, “4” = “Dislike slightly”, “5” = “Neither like nor dislike”, “6” = “Like slightly”, “7” = “Like moderately”, “8” = “Like very much” and “9” = “Like extremely”.

Table 125 Sensory data of vacuum fried pineapples (greenday™).

Characteristics	Number of consumers																														Avg.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	score*
Color	9	8	8	6	6	5	5	7	5	5	7	8	6	5	5	5	8	6	5	9	8	8	9	5	6	5	6	7	9	6	6.57
Texture	9	8	6	7	6	5	9	6	8	5	7	8	6	8	6	6	9	7	7	9	6	7	8	6	8	7	9	6	9	9	7.23
Flavor	9	9	9	8	9	9	9	9	6	6	9	9	8	9	8	7	9	8	9	9	9	9	7	8	9	7	8	9	8	9	8.37
Crispness	9	9	9	8	9	9	9	9	9	6	9	9	9	9	9	9	9	8	9	9	9	8	9	9	9	6	9	9	9	9	8.70
Overall acceptability	9	8	9	8	9	9	9	9	6	7	9	9	9	9	8	6	9	8	9	9	8	8	9	9	9	6	9	9	8	9	8.40

*Score is “1” = “Dislike extremely”, “2” = “Dislike very much”, “3” = “Dislike moderately”, “4” = “Dislike slightly”, “5” = “Neither like nor dislike”, “6” = “Like slightly”, “7” = “Like moderately”, “8” = “Like very much” and “9” = “Like extremely”.

A.19 Sensory Data of the Vacuum-Dried Apples

Table 126 Sensory data of vacuum dried apples at 100°C.

Characteristics	Number of consumers																														Avg.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	score*
Color	9	8	9	9	9	7	8	6	5	7	6	6	8	8	7	5	7	8	7	7	6	5	7	8	7	8	7	6	6	7	7.10
Texture	8	8	9	7	8	7	8	8	6	8	8	7	6	7	8	7	6	9	8	8	6	5	7	7	7	7	6	5	6	7	7.13
Flavor	5	8	5	7	7	7	7	8	7	7	7	9	4	7	6	6	6	7	7	9	9	8	7	7	7	8	6	5	6	8	6.90
Crispness	5	4	5	3	7	7	5	6	5	6	5	7	4	6	4	6	6	6	4	6	6	4	5	8	7	7	5	5	6	5	5.50
Overall acceptability	5	7	6	6	7	7	8	7	7	6	6	7	8	6	6	7	7	7	7	6	7	8	8	5	6	7	6	6	6	7	6.63

*Score is “1” = “Dislike extremely”, “2” = “Dislike very much”, “3” = “Dislike moderately”, “4” = “Dislike slightly”, “5” = “Neither like nor dislike”, “6” = “Like slightly”, “7” = “Like moderately”, “8” = “Like very much” and “9” = “Like extremely”.

Table 127 Sensory data of vacuum dried apples at 110^{o}C.

Characteristics	Number of consumers																														Avg.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	score*
Color	7	6	6	8	8	7	7	7	6	7	7	7	8	8	8	6	6	8	7	7	7	6	7	8	6	7	7	6	6	8	6.97
Texture	7	6	7	6	8	7	7	9	6	7	8	6	6	7	7	7	6	8	8	7	6	6	7	7	7	6	6	6	6	7	6.80
Flavor	6	6	6	6	8	8	7	8	7	7	8	8	5	7	6	6	7	7	8	8	9	9	6	7	7	8	6	5	6	8	7.00
Crispness	6	5	6	4	7	8	6	6	6	7	5	8	5	6	5	6	6	8	5	6	6	6	6	8	7	7	6	5	6	5	6.07
Overall acceptability	6	5	7	6	8	8	7	7	9	7	7	7	7	7	8	7	8	7	7	6	8	7	8	6	6	6	5	6	6	7	6.90

*Score is "1" = "Dislike extremely", "2" = "Dislike very much", "3" = "Dislike moderately", "4" = "Dislike slightly", "5" = "Neither like nor dislike", "6" = "Like slightly", "7" = "Like moderately", "8" = "Like very much" and "9" = "Like extremely" .

Table 128 Sensory data of vacuum dried apples at 120^{o}C.

Characteristics	Number of consumers																														Avg.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	score*
Color	8	6	7	8	8	8	9	7	7	7	6	7	7	8	8	5	6	7	7	7	7	6	7	8	6	7	6	5	7	8	7.00
Texture	9	6	6	7	8	8	7	9	6	7	7	7	7	8	7	7	6	7	9	7	8	6	7	7	8	7	6	6	7	8	7.17
Flavor	9	6	7	7	9	9	7	8	7	8	9	7	5	7	6	5	6	7	8	9	9	9	6	7	8	8	7	5	6	8	7.30
Crispness	9	7	8	3	8	9	7	6	6	8	6	9	5	6	6	7	7	9	6	6	8	6	7	8	7	8	6	6	6	6	6.87
Overall acceptability	9	6	7	6	9	9	9	9	9	8	8	8	8	7	9	8	8	7	9	8	8	9	9	8	7	7	6	7	7	7	7.87

*Score is "1" = "Dislike extremely", "2" = "Dislike very much", "3" = "Dislike moderately", "4" = "Dislike slightly", "5" = "Neither like nor dislike", "6" = "Like slightly", "7" = "Like moderately", "8" = "Like very much" and "9" = "Like extremely".

A.20 Moisture Content Data of the Dried Apple at Different Positions

Table 129 Moisture content data of the dried apple of six different positions*.

Sample position	Sample 1			Sample 2			Sample 3			Avg. %MC
	W_t (g)	W_d (g)	%MC (w.b.)	W_t (g)	W_d (g)	%MC (w.b.)	W_t (g)	W_d (g)	%MC (w.b.)	(w.b.)
1 (top position)	7.79	6.60	15.28	9.37	7.87	16.01	6.39	5.47	14.40	15.23
2	7.40	6.65	10.14	7.68	6.87	10.55	7.84	6.95	11.35	10.68
3	11.15	10.22	8.34	8.90	8.16	8.31	8.42	7.55	10.33	9.00
4	10.34	9.62	6.96	9.50	8.79	7.47	7.47	6.93	7.23	7.22
5	8.19	7.56	7.69	8.99	8.19	8.90	8.19	7.53	8.06	8.22
6 (bottom position)	8.38	7.86	6.21	9.67	9.15	5.38	9.25	8.72	5.73	5.77

Where W_t is weight of vacuum dried sample at t, W_d is weight of sample after drying by air-oven at 103°C for about 24 hours, MC is moisture content (w.b.).

* The dried apples during drying at 120°C for 24 h and the quantity of apples drying 12 samples per layer (or 160 – 177 grams per layer).

A.21 Pressure Data during the Drying Process of Bananas

Table 130 Pressure data during the drying process of bananas at 120°C.

Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)
0	760	13	60	26	50	39	40	52	40
1	340	14	60	27	50	40	40	53	40
2	200	15	60	28	40	41	40	54	40
3	150	16	60	29	40	42	40	55	40
4	120	17	60	30	40	43	40	56	30
5	100	18	60	31	40	44	40	57	30
6	100	19	60	32	40	45	40	58	30
7	90	20	60	33	40	46	40	59	30
8	80	21	50	34	40	47	40	60	30
9	80	22	50	35	40	48	40	61	30
10	80	23	50	36	40	49	40	62	30
11	70	24	50	37	40	50	40	63	30
12	60	25	50	38	40	51	40	64	30

Table 130 Pressure data during the drying process of bananas at 120^{o}C (Cont.).

Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)
65	30	81	30
66	30	82	30
67	30	83	30
68	30	84	30
69	30	85	30
70	30	86	30
71	30	87	30
72	30	88	30
73	30	89	30
74	30	90	30
75	30		
76	30		
77	30		
78	30		
79	30		
80	30		

A.22 Pressure Data during the Drying Process of Pineapples

Table 131 Pressure data during the drying process of pineapples at 120°C.

Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)
0	760	13	60	26	40	39	40	52	40
1	420	14	60	27	40	40	40	53	40
2	240	15	60	28	40	41	40	54	40
3	160	16	50	29	40	42	40	55	40
4	120	17	50	30	40	43	40	56	40
5	100	18	50	31	40	44	40	57	40
6	90	19	50	32	40	45	40	58	40
7	80	20	50	33	40	46	40	59	40
8	80	21	50	34	40	47	40	60	30
9	70	22	50	35	40	48	40	61	30
10	70	23	50	36	40	49	40	62	30
11	60	24	40	37	40	50	40	63	30
12	60	25	40	38	40	51	40	64	30

Table 131 Pressure data during the drying process of pineapples at 120^{o}C (Cont.).

Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)
65	30	80	30	95	30	110	30
66	30	81	30	96	30		
67	30	82	30	97	30		
68	30	83	30	98	30		
69	30	84	30	99	30		
70	30	85	30	100	30		
71	30	86	30	101	30		
72	30	87	30	102	30		
73	30	88	30	103	30		
74	30	89	30	104	30		
75	30	90	30	105	30		
76	30	91	30	106	30		
77	30	92	30	107	30		
78	30	93	30	108	30		
79	30	94	30	109	30		

A.23 Pressure Data during the Drying Process of Apples

Table 132 Pressure data during the drying process of apples at 120°C.

Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)
0	760	13	60	26	50	39	40	52	30
1	320	14	60	27	50	40	40	53	30
2	200	15	60	28	40	41	40	54	30
3	140	16	60	29	40	42	40	55	30
4	120	17	60	30	40	43	40	56	30
5	100	18	60	31	40	44	40	57	30
6	90	19	50	32	40	45	40	58	30
7	80	20	50	33	40	46	30	59	30
8	80	21	50	34	40	47	30	60	30
9	80	22	50	35	40	48	30	61	30
10	70	23	50	36	40	49	30	62	30
11	70	24	50	37	40	50	30	63	30
12	60	25	50	38	40	51	30	64	30

Table 132 Pressure data during the drying process of apples at 120^{o}C (Cont.).

Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)
65	30	80	30	95	30	110	30	125	30
66	30	81	30	96	30	111	30	126	30
67	30	82	30	97	30	112	30	127	30
68	30	83	30	98	30	113	30	128	30
69	30	84	30	99	30	114	30	129	30
70	30	85	30	100	30	115	30	130	30
71	30	86	30	101	30	116	30	131	30
72	30	87	30	102	30	117	30	132	30
73	30	88	30	103	30	118	30	133	30
74	30	89	30	104	30	119	30	134	30
75	30	90	30	105	30	120	30	135	30
76	30	91	30	106	30	121	30	136	30
77	30	92	30	107	30	122	30	137	30
78	30	93	30	108	30	123	30	138	30
79	30	94	30	109	30	124	30	139	30

Table 132 Pressure data during the drying process of apples at 120°C (Cont.).

Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)	Drying time (min)	Drying pressure (mmHg)
140	30	155	30	170	30
141	30	156	30	171	30
142	30	157	30	172	30
143	30	158	30	173	30
144	30	159	30	174	30
145	30	160	30	175	30
146	30	161	30	176	30
147	30	162	30	177	30
148	30	163	30	178	30
149	30	164	30	179	30
150	30	165	30	180	30
151	30	166	30		
152	30	167	30		
153	30	168	30		
154	30	169	30		

Appendix B

Economic Analysis

B.1 Electrical Energy Cost Estimating for Vacuum Drying Plant Design

The cost of the electrical energy was calculated from the limited data of the capacity and power of the electric equipment. A summary of the electric power of the equipment in this study is shown below.

A centrifugal pump 0.373 kW

A vacuum pump 0.246 kW

A fan of the cooling system 0.124 kW

A heater 2 kW

An air compressor 7.5 kW

A review of the electrical energy costs for the vacuum drying in this project is shown in Table 119.

Table 133 Electricity rates for a small general service (Applicable to business, business cum residential, industrial, government industrial institutions, state enterprises or others, including its compound with a maximum 15-minute integrated demand of less than 30 kW through a single Watt-hour meter) (PEA, 2013).

Rate (kWh)	Energy charge (Baht per kWh)
First 150 kWh. (0 – 150th)	2.76
Next 250 kWh. (151st – 400th)	3.74
Over 400 kWh.(401st - up)	3.94

The cost of electricity of an item was calculated by Equation (31).

$$Cost = WxC \tag{31}$$

Where C is the cost per unit of electricity (Baht per kWh), and W is the electric power (kW).

Estimate the electricity cost for vacuum drying of bananas.

Project 4: Dried four times a day

The information for calculating the electricity cost is shown below.

6 hours of the centrifugal pump for the fluid transportation

6 hours of the vacuum pump for the control of pressure in the vacuum drying

6 hours of the cooling fan for the cooling system in the vacuum dryer

7 hours 5 minutes of the heater for the control of temperature in the vacuum drying

40 minutes of the air compressor for the control of open-close the lid of the dryer

Calculation methods of the electricity cost for vacuum drying of bananas

First, Total up the kilowatt hours per day for the item to get total kWh/day (Units/day) which is (0.373x6)+(0.246x6)+(0.124x6)+(2x7.083)+(7.5x0.667) = 23.626 Units per day. Second, the kilowatt hours per month is calculated for the value of this plan is 23.626x25 = 590.65 Units per month (25 days per month shall constitute the normal work period for a full-time per diem employee.). Final, calculate the average cost per year of this project from the kilowatt hours per month. The information is substituted in Equation (31), which the calculation is shown below.

Table 134 Electricity records for four times of drying per day of bananas.

Rate (kWh)	Energy charge (Baht/kWh)	Service charge (Baht/month)
First 150 kWh. (0 – 150th)	2.76	150x2.76=414
Next 250 kWh. (151st – 400th)	3.74	250x3.74=935
Over 400 kWh. (401st – up)	3.94	(590.65-400)x3.94=751.161

The cost of this project per month is 414+935+751.161 = 2,100.161 Baht, or the cost of this project per year is 2,100.161x12 = 25,201.932 Baht.

Estimate the electricity cost for vacuum drying of pineapples

Project 3: Dried three times a day

The information for calculating the electricity cost is shown below.

7 hours of the centrifugal pump for the fluid transportation

7 hours of the vacuum pump for the control of pressure in the vacuum drying

7 hours of the cooling fan for the cooling system in the vacuum dryer

7 hours 55 minutes of the heater for the control of temperature in the vacuum drying

30 minutes of the air compressor for the control of open-close the lid of the dryer

Calculation methods of the electricity cost for vacuum drying of bananas

First, Total up the kilowatt hours per day for the item to get total kWh/day (Units/day) which is (0.373x7)+(0.246x7)+(0.124x7)+(2x7.917)+(7.5x0.5) = 24.771 Units per day. Second, the kilowatt hours per month is calculated for the value of this plan is 24.771x25 = 619.275 Units per month (25 days per month shall constitute the normal work period for a full-time per diem employee.). Finally, calculate the average cost per year of this project from the kilowatt hours per month. The information is substituted in Equation (31), which the calculation is shown below.

Table 135 Electricity records for three times of drying per day of pineapples.

Rate (kWh)	Energy charge (Baht/kWh)	Service charge (Baht/month)
First 150 kWh. (0 – 150th)	2.76	150x2.76=414
Next 250 kWh. (151st – 400th)	3.74	250x3.74=935
Over 400 kWh. (401st – up)	3.94	(619.275-400)x3.94=863.944

The cost of this project per month is 414+935+863.944 = 2,212.944 Baht, or the cost of this project per year is 2,212.944x12 = 26,555.328 Baht.

Estimate the electricity cost for vacuum drying of apples

Project 2: Dried two times a day

The information for calculating the electricity cost is shown below.

6 hours of the centrifugal pump for the fluid transportation

6 hours of the vacuum pump for the control of pressure in the vacuum drying

6 hours of the cooling fan for the cooling system in the vacuum dryer

6 hours 45 minutes of the heater for the control of temperature in the vacuum drying

20 minutes of the air compressor for the control of open-close the lid of the dryer

Calculation methods of the electricity cost for vacuum drying of the bananas

First, Total up the kilowatt hours per day for the item to get total kWh/day (Units/day) which is (0.373x6)+(0.246x6)+(0.124x6)+(2x6.75)+(7.5x0.333) = 20.456 Units per day. Second, the kilowatt hours per month is calculated for the value of this plan is 20.456x25 = 511.40 Units per month (25 days per month shall constitute the normal work period for a full-time per diem employee.). Final, calculate the average cost per year of this project from the kilowatt hours per month. The information is substituted in Equation (31), which the calculation is shown below.

Table 136 Electricity records for two times of drying per day of apples.

Rate (kWh)	Energy charge (Baht/kWh)	Service charge (Baht/month)
First 150 kWh. (0 – 150th)	2.76	150x2.76=414
Next 250 kWh. (151st – 400th)	3.74	250x3.74=935
Over 400 kWh. (401st – up)	3.94	(511.40-400)x3.94=438.916

The cost of this project per month is 414+935+438.916 = 1,787.916 Baht, or the cost of this project per year is 1,787.916x12 = 21,454.992 Baht.

B.2 Cost estimating from the Raw Material Costs

Calculation methods of the banana raw materials

Fresh bananas were purchased from a local market with the price of 25 Baht per kilograms.

In this study, the weight of the peeled banana is 64.89% the weight of the banana. So, the amount of the peeled bananas in 1 kilogram of bananas is 1,000x0.6489=648.90 grams. The result of the cost of the raw materials for the drying is 25 Baht/648.90 grams of the peeled bananas = 0.038 Baht/grams of the peeled bananas.

The raw material cost for four times of drying per day of bananas was used to determine the economic feasibility. The feed rate of the fresh bananas for drying once each day is 891.53 grams. So, the amount of the peeled bananas for four times of drying per day is 891.53x4=3,566.12 grams. The result of the cost of the raw materials for the drying is 0.038x3,566.12=135.51 Baht per day or 135.51 Baht per day x 300 days per year = 40,653.90 Baht per year.

Calculation methods of the pineapple raw materials

Fresh pineapples were purchased from a local market with the price of 25 Baht per kilograms.

In this study, the weight of the peeled and cored pineapple is 39.70% the weight of the pineapple. So, the amount of the peeled and cored pineapples in 1 kilogram of pineapples is 1,000x0.3970=3,970.40 grams. The result of the cost of the raw materials for the drying is 25 Baht/3,970.40 grams of the peeled and cored pineapples = 0.063 Baht/grams of the peeled and cored pineapples.

The raw material cost for three times of drying per day of pineapples was used to determine the economic feasibility. The feed rate of the fresh pineapples for drying once each day is 1,182.19 grams. So, the amount of the peeled and cored pineapples for three times of drying per day is 1,182.19x3=3,546.56 grams. The result of the cost of the raw materials for the drying is 0.063x3,546.56=223.43 Baht per day or 223.43 Baht per day x 300 days per year = 67,029.90 Baht per year.

Calculation methods of the apple raw materials

Fresh apples were purchased from a local market with the price of 20 Baht per fruit. The average weights of the apple fruit is 325 grams.

In this study, the weight of the peeled and cored apple is 74.62% the weight of the apple. So, the amount of the peeled and cored apples in 325 grams of apples is 325x0.7462=242.52 grams. The result of the cost of the raw materials for the drying is 20 Baht/242.52 grams of the peeled and cored apples = 0.082 Baht/grams of the peeled and cored pineapples.

The raw material cost for two times of drying per day of apples was used to determine the economic feasibility. The feed rate of the fresh apples for drying once each day is 1,455.12 grams. So, the amount of the peeled and cored apples for two times of drying per day is 1,455.12x2=2,910.24 grams. The result of the cost of the raw materials for the drying is 0.082x2,910.24=238.64 Baht per day or 238.64 Baht per day x 300 days per year = 71,592 Baht per year.

B.3 Labor Cost Calculations of Workers

The labor cost for each item is expressed by an average time rate for a given team, and these time rates integrate the payroll charges. The labor cost calculations of the worker each project are shown below.

Estimating the labor cost for the vacuum drying of the bananas

Project 4: Dried four times a day

Calculation methods:

The labor cost of the worker per day is calculated by multiplying the work period per day (minute per day) and the minimum wage rate (Baht per minute) together. The minimum wage rate (Baht per minute) is calculated by dividing the minimum wage per day with the work period per day, so the minimum wage rate in this study is 300 Bath per day/480 minutes per day (the work period of the worker is 8 hours/day or 480 minutes/day) = 0.625 Baht per minute. The labor cost of the worker in this study is 80 minutes per day x 0.625 Baht per minute = 50 Baht per day, or the labor cost of the worker per year is 50 Baht per day x 300 days per year = 15,000 Baht per year.

Estimating the labor cost for the vacuum drying of the pineapples

Project 3: Dried three times a day

Calculation methods:

The labor cost of the worker per day is calculated by multiplying the work period per day (minute per day) and the minimum wage rate (Baht per minute) together. The minimum wage rate (Baht per minute) is calculated by dividing the minimum wage per day with the work period per day, so the minimum wage rate in this study is 300 Bath per day/480 minutes per day (the work period of the worker is 8 hours/day or 480 minutes/day) = 0.625 Baht per minute. The labor cost of the worker in this study is 90 minutes per day x 0.625 Baht per minute

= 56.25 Baht per day, or the labor cost of the worker per year is 56 Baht per day x 300 days per year = 16,875 Baht per year.

Estimating the labor cost for the vacuum drying of the apples

Project 2: Dried two times a day

Calculation methods:

The labor cost of the worker per day is calculated by multiplying the work period per day (minute per day) and the minimum wage rate (Baht per minute) together. The minimum wage rate (Baht per minute) is calculated by dividing the minimum wage per day with the work period per day, so the minimum wage rate in this study is 300 Bath per day/480 minutes per day (the work period of the worker is 8 hours/day or 480 minutes/day) = 0.625 Baht per minute. The labor cost of the worker in this study is 60 minutes per day x 0.625 Baht per minute = 37.50 Baht per day, or the labor cost of the worker per year is 37.50 Baht per day x 300 days per year = 11,250 Baht per year.

B.4 Profitable Estimating from the Sale Price of the Dried Products

Calculation methods of the sale revenue of the dried bananas

The price of the commercial vacuum dried bananas (KUNNA™) is 59 Baht per serving. The serving size of this product is 50 grams. So, the price of the commercial product is 59 Baht per serving / 50 grams of the fruits = 1.18 Baht per gram.

The sale revenue of the products for four times of drying per day of bananas was used to determine the economic feasibility. The rated operating capacity of the dried bananas for drying once each day is 234 grams of the dried fruits. So, the amount of dried bananas for four times of drying per day is 234x4=936 grams. Next, the sale revenue of the products can be determined by multiplying the amount of the dried products and the price of the commercial vacuum dried bananas (KUNNA™) together. The result of the sale revenue for the drying is

936x1.18=1,104.48 Baht per day or 1,104.48 Baht per day x 300 days per year = 331,344 Baht per year.

Calculation methods of the sale revenue of the dried pineapples

The price of the commercial vacuum dried pineapples (Thai Smile^{TM}) is 55 Baht per serving. The serving size of this product is 45 grams. So, the price of the commercial product is 55 Baht per serving / 45 grams of the fruits = 1.22 Baht per gram.

The sale revenue of the products for three times of drying per day of pineapples was used to determine the economic feasibility. The rated operating capacity of the dried pineapples for drying once each day is 192.48 grams of the dried fruits. So, the amount of dried pineapples for three times of drying per day is 192.48x3=577.44 grams. Next, the sale revenue of the products can be determined by multiplying the amount of the dried products and the price of the commercial vacuum dried pineapples (Thai Smile^{TM}) together. The result of the sale revenue for the drying is 577.44x1.22=704.48 Baht per day or 704.48 Baht per day x 300 days per year = 211,344 Baht per year.

Calculation methods of the sale revenue of the dried apples

The price of the commercial freeze dried apples (Greenday^{TM}) is 25 Baht per serving. The serving size of this product is 14 grams. So, the price of the commercial product is 25 Baht per serving / 14 grams of the fruits = 1.79 Baht per gram.

The sale revenue of the products for two times of drying per day of apples was used to determine the economic feasibility. The rated operating capacity of the dried apples for drying once each day is 214.37 grams of the dried fruits. So, the amount of dried apples for two times of drying per day is 214.37x2=428.74 grams. Next, the sale revenue of the products can be determined by multiplying the amount of the dried products and the price of the commercial freeze dried apples (Greenday^{TM}) together. The result of the sale revenue for the drying is 428.74x1.79=767.44 Baht per day or 767.44 Baht per day x 300 days per year = 230,232 Baht per year.

B.5 Net Present Value (NPV) Calculation

The economic analysis is done to compare the various alternatives for getting the final product. The cost estimate for the each project consists of fixed cost estimates and variable cost estimates. The methodology for calculating the economic costs are shown below (Archai Pittayapak, 2003).

Estimating economic feasibility of dried banana production

Project 4: Dried four times a day

Fixed costs:

(1) Depreciation cost is the loss of value in an item over time. The straight-line depreciation method is used for this study which the straight-line depreciation calculation is shown below.

$$D = \frac{P - S}{L} \tag{32}$$

when $D =$ Depreciation, Baht/year $P =$ Purchase price, Baht

$S =$ Salvage value, Baht $L =$ Service life, year

The information for calculating the depreciation cost is shown below.

The purchase price of the vacuum dryer is 141,050 Baht.

The salvage value of the vacuum dryer is not considered in computing the depreciation expense.

The service life is 8 years.

Then the information above is substituted in Equation (32), which the result of computing the depreciation expense is 17,631.25 Baht per year.

(2) The low interest rate on savings accounts at 0.75 percent per year (The Bank of Thailand, 2013). The configuration of the Minimum Attractive Rate of Return (MARR) should be higher than the low interest rate on savings, so the MARR is assumed to be 1%.

(3) A tax and the salvage value are not considered in computing the economic costs.

Variable costs:

(1) Maintenance cost is 1,400 Baht/year.

(2) Fuel cost is 2,947.60 Baht/year.

(3) Electricity cost is 25,201.932 Baht/year.

(4) Raw material cost is 40,653.90 Baht/year.

(5) Labor cost is 1,250 Bath/month or 15,000 Bath/year.

Total sales revenue:

The revenue from the sale of the dried bananas each of the drying is 276.12 Baht. If the bananas are dried 4 times per day, the revenue from the sale of the products is 276.12x4 = 1,104.48 Baht per day or 331,344 Baht per year.

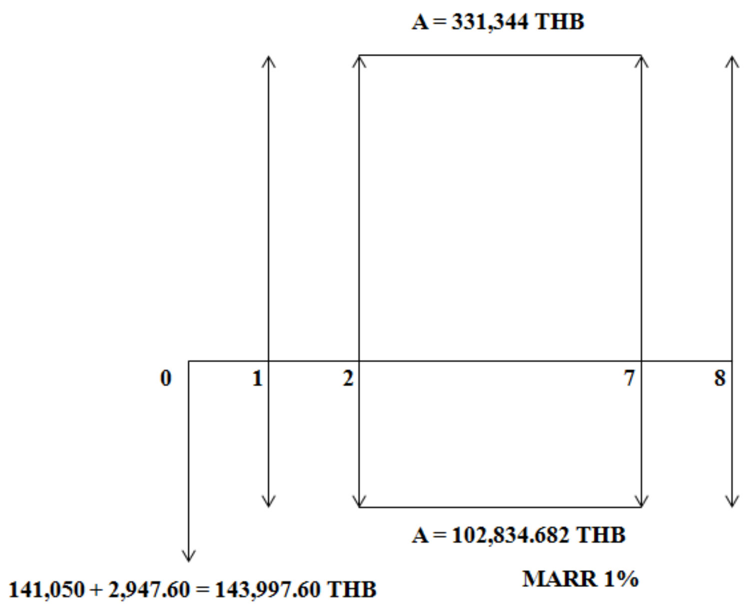
Then the result above is used to calculate the Net Present Value which is the difference between the present value of cash inflows and the present value of cash outflows. The NPV equation is shown below (Boonraeing Manasurakarn, 1459).

Net Present Value (NPV) = the present value of cash inflows - the present value of cash outflows (33)

The decision criteria

- If the NPV is positive, the project is likely to be viewed as an attractive investment.
- If the NPV is negative, the project is likely to be viewed as an unattractive investment.

Solution



The present value of cash inflows = 331,344(P/A, 1%, 8)

= 331,344 x 7.6517

= 2,535,344.88

The present value of cash outflows =

(141,050+2,947.60)+[(17,631.25+1,400+2,947.60+25,201.932+40,653.90+15,000)(P/A, 1%, 8)]

= 143,997.60 + (102,834.682x7.6517)

= 930,857.74

Then substitute the values above into the Equation 33:

The Net Present Value (NPV) = 2,535,344.88 – 930,857.74 = 1,604,487.14

The result shows the positive NPV, so the investment project is attractive.

Estimating economic feasibility of dried pineapple production

Project 3: Dried three times a day

Fixed costs:

(1) The information is substituted in Equation 32, which the result of computing the depreciation expense is 17,631.25 Baht per year.

(2) The low interest rate on savings accounts at 0.75 percent per year (The Bank of Thailand, 2013). The configuration of the Minimum Attractive Rate of Return (MARR) should be higher than the low interest rate on savings, so the MARR is assumed to be 1%.

(3) A tax and the salvage value are not considered in computing the economic costs.

Variable costs:

(1) Maintenance cost is 1,400 Baht/year.

(2) Fuel cost is 2,947.60 Baht/year.

(3) Electricity cost is 26,555.328 Baht/year.

(4) Raw material cost is 67,029.90 Baht/year.

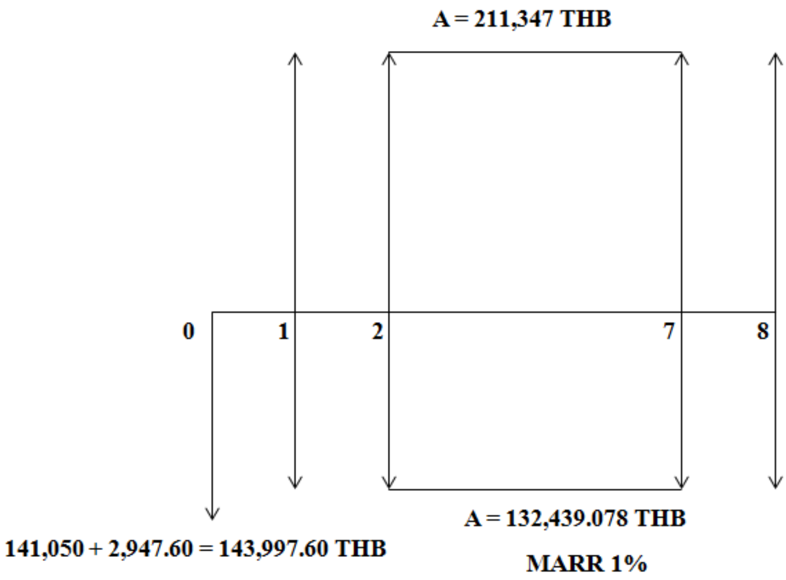
(5) Labor cost is 1,406.25 Bath/month or 16,875 Bath/year.

Total sales revenue:

The revenue from the sale of the dried pineapples each of the drying is 234.83 Baht. If the pineapples are dried 3 times per day, the revenue from the sale of the products is 234.83x3 = 704.49 Baht per day or 211,347 Baht per year.

Then the result above is used to calculate the Net Present Value (Equation (33)).

Solution



The present value of cash inflows = 211,347(P/A, 1%, 8)

= 211,347 x 7.6517

= 1,617,163.84

The present value of cash outflows=

(141,050+2,947.60)+[(17,631.25+1,400+2,947.60+26,555.328+67,029.90+16,875)(P/A, 1%, 8)]

= 143,997.60 + (132,439.078x7.6517)

= 1,157,381.69

Then substitute the values above into the Equation 33:

The Net Present Value (NPV) = 1,617,163.84 – 1,157,381.69 = 459,782.15

The result shows the positive NPV, so the investment project is attractive.

Estimating economic feasibility of dried apple production

Project 2: Dried two times a day

Fixed costs:

(1) The information is substituted in Equation 32, which the result of computing the depreciation expense is 17,631.25 Baht per year.

(2) The low interest rate on savings accounts at 0.75 percent per year (The Bank of Thailand, 2013). The configuration of the Minimum Attractive Rate of Return (MARR) should be higher than the low interest rate on savings, so the MARR is assumed to be 1%.

(3) A tax and the salvage value are not considered in computing the economic costs.

Variable costs:

(1) Maintenance cost is 1,400 Baht/year.

(2) Fuel cost is 2,947.60 Baht/year.

(3) Electricity cost is 21,454.992 Baht/year.

(4) Raw material cost is 71,592 Baht/year.

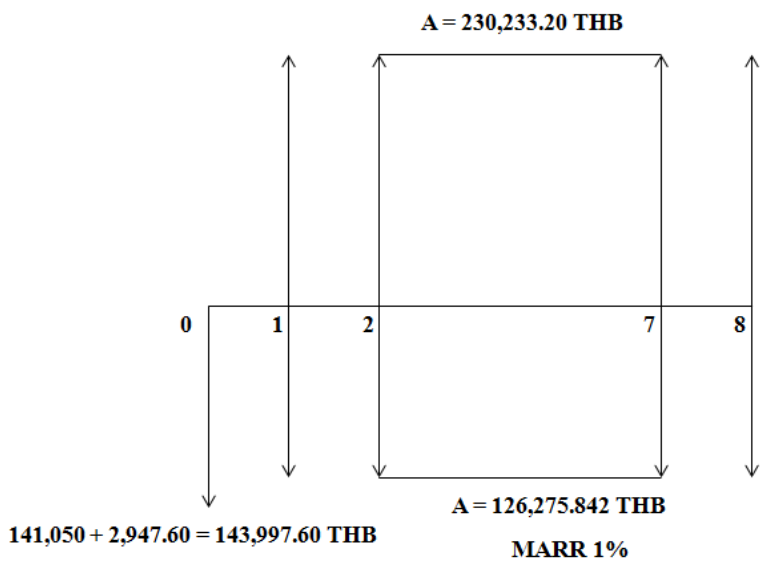
(5) Labor cost is 937.50 Bath/month or 11,250 Bath/year.

Total sales revenue:

The revenue from the sale of the dried apples each of the drying is 383.722 Baht. If the apples are dried 2 times per day, the revenue from the sale of the products is 383.722x2 = 767.444 Baht per day or 230,233.20 Baht per year.

Then the result above is used to calculate the Net Present Value (Equation (33)).

Solution



The present value of cash inflows = 230,233.20(P/A, 1%, 8)

= 230,233.20 x 7.6517

= 1,761,675.38

The present value of cash outflows=

(141,050+2,947.60)+[(17,631.25+1,400+2,947.60+21,454.992+71,592+11,250)

(P/A, 1%, 8)]

= 143,997.60 + (126,275.842x7.6517)

= 1,110,222.46

Then substitute the values above into the Equation 33:

The Net Present Value (NPV) = 1,761,675.38 – 1,110,222.46 = 651,452.92

The result shows the positive NPV, so the investment project is attractive.

VITAE

Name Wannapit Junlakan

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Educational Attainment

Degree	Name of Institution	Year of Graduation
Bachelor of Engineering (Chemical Engineering)	Prince of Songkla University, Hatyai Campus	2008
Master of Engineering (Chemical Engineering)	Prince of Songkla University, Hatyai Campus	2010

Scholarship Awards during Enrolment

- The Graduate School Research Fund from the Prince of Songkla University
- Discipline of Excellence in Chemical Engineering

List of Publication and Proceeding

Junlakan, W., Yamsaengsung, R., Tirawanichakul, S. (2013). Effects of vacuum drying on structural changes of banana slices. ASEAN Journal of Chemical Engineering, 13(1), 1-10.

Junlakan, W., Yamsaengsung, R., Tirawanichakul, S. (2013, November). Effects of vacuum drying on structural changes of banana slices. 19th Regional Symposium on Chemical Engineering (RSCE2012), Surabaya, Indonesia.

Junlakan, W., Yamsaengsung, R., Tirawanichakul, S. (2013, November). Effects of vacuum drying on structural changes of pineapple slices. 19th Regional Symposium on Chemical Engineering (RSCE2012), Surabaya, Indonesia.