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Effect of human massage and machine stirring processes on dehydration correlating physical texture of white radishPisitpong Intarapong^{1,*}, Thitima Wongsheree² and Thongsai Chuichua¹¹King Mongkut's University of Technology Thonburi, Ratchaburi Campus, Bangkok, Thailand²Institute of Technology Services and Research Center, King Mongkut's University of Technology Thonburi, Bangkok, Thailand*Corresponding author: pisitpong.int@kmutt.ac.th

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Abstract

The present work examines the effect of salting on the drying characteristics and quality of white radish for preservation; the findings can be useful in replacing human labor for a community enterprise of Banka district, Ratchaburi Province, Thailand. The preservation of fresh white radish using salting and sun drying can extend storage duration and add value to the product. The traditional process consists of hand massage for 1 h/day, sun drying for 6 h/day, and keeping it in plastic sack for overnight (17 h/day) to remove moisture until the weight of the product is less than 40% of the initial weight. The machine stirrer decreased moisture content in radishes faster than that of traditional human force because water inside radish moves out quickly with the osmotic pressure gradient to establish equilibrium with salt solution. With the increased rotating speed of the machine increases, the hardness of radishes gradually decreases. The optimum conditions for stirring machine were observed at 50 rpm for 1 h/day to keep their hardness over 80 newtons. The properties of salted radish from stirring machine are as follows: 11.8 wt% of salinity, 0.80-0.85 of water activity, 63 to 65 of brightness value, and 80-85 newtons of texture hardness; these properties are similar to processing radish with hand massage method. Based on the findings, this research recommends investing in a solar dryer along with machine stirrer to reduce more moisture content, prevent dust contamination, decrease the number of stirring sessions; thus, reducing drying time.

Keywords: White radish, Moisture content, Color, Drying rate, Solar dryer, Salt preservation, Osmosis

1. Introduction

Radish is rich in bioactive compounds and is a good source of crude proteins, carbohydrates, lipids, and dietary fiber [1]. This root vegetable is widely consumed, particularly in Asian countries. Fresh radishes are mainly sourced from Banka District in Ratchaburi Province, Thailand, with their production being more than 30 tons/year [2].

The drying technique used for drying fruits and vegetables is generally classified into two categories: the physical drying process of removing water by evaporation, mechanical press, etc., and the chemical drying process that includes hyperosmotic solution, alkali liquor, sulfite liquor, and acid liquor for removing water by osmotic dehydration [3]. Reduced water content inhibits microbial activity and reduces the enzymatic and chemical reaction rates. Nevertheless, one major drawback of conventional drying is the use of high temperatures during long drying times; this promotes the degradation of thermolabile antioxidant compounds [4-6]. Thus, there is a need to optimize and/or develop processing technologies that can reduce the detrimental effects of conventional drying.

Osmotic dehydration method is a chemical process of food processing that reduces water content in the food matrix without applying heat treatment. This method is widely used to dry fruits and vegetables that contain a high portion of moisture. In this process, the materials are soaked in a highly concentrated solution of salt and sugar. Fruits and vegetables do not suffer with high temperatures; thus, they do not cause much deterioration in

the quality of the fresh produce. Water removal by osmosis is based on the principle of moving water from food tissues caused by the pressure difference between intracellular food and outside solution [7].

The preservation of vegetables and fruit relates to moisture and microorganisms in food production. Research has shown that the osmotic pressure from salting and the evaporation from sun drying slow down the spoilage in fruits and vegetables and maintain their flavor and texture [8,9]. The faster the food dehumidifies, the slower is the bacterial growth. Microbial control by moisture reduction or drying is an important principle applied in food technology and has resulted in the development of many food products, such as milk powder, coffee powder, and ginger powder. The present study aimed to compare the drying time of white radish between human and machine processes. In addition, the effect of the optimum condition of stirring speed in the machine on texture hardness was observed. Water activity, texture, and color of salted radishes were also analyzed. Moreover, the osmotic pressure data is explored in the context of electrical conductivity at room temperature.

2. Materials and methods

2.1 Sample preparation and equipment

Fresh radishes (*Raphanus sativus* Linn.) were obtained from a local community enterprise group in Banka district, Ratchaburi province, Thailand. The samples were washed with water and were cut into bar slices in average dimension of 10 cm in diameter, 4 cm in length, and 2 cm in wide. Solar dryer dimensions of the drying chamber (L x W x H) were $2 \times 1.2 \times 1.2$ m with battery 30 A. The bucket size of a radish massage machine with electric control is 60 cm in diameter and 50 cm in depth, supporting the weight of raw materials up to 50 kilograms. The 20 kg of samples were mixed with salt for 1 h by using human massage or using machine stirring. After that, salted radishes were dried under normal sun dried with relative humidity (RH) approximate 60% for 6 h and kept in the chamber overnight to prevent dust contamination in radish. The moisture content was measured by weighing the sample before and after stirring, drying, and keeping. Radish experiments will use salt 12% and sodium benzoate less than 0.1% based on criteria of chemical preservative of the Bureau of Food Quality and Safety, Department of Medical Sciences Ministry of Public Health, Thailand. The protocols of salted radish in this research are shown below (Figure 1):

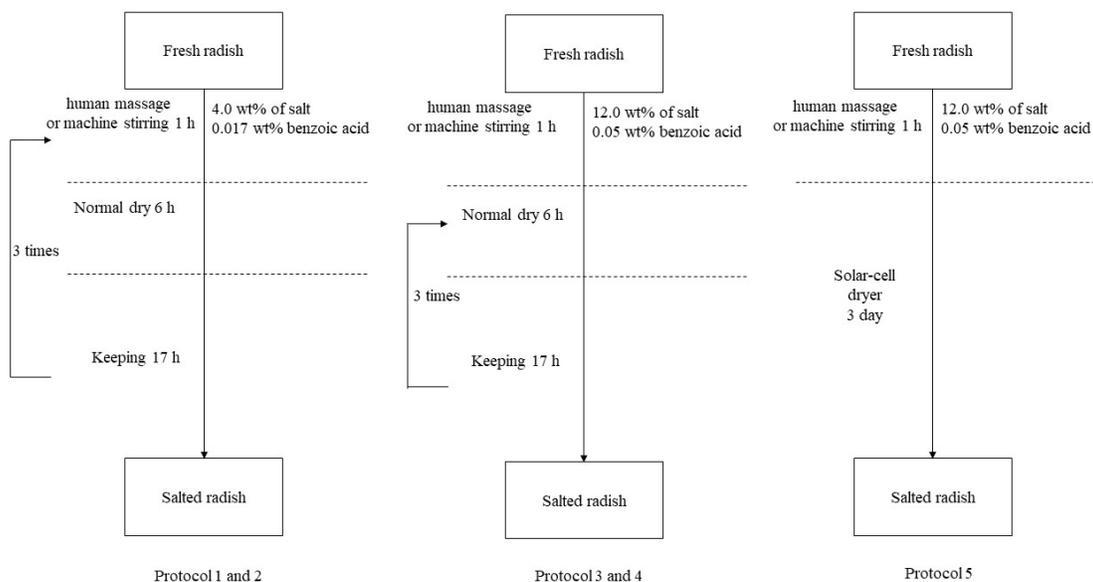


Figure 1 The protocols of salted radish in this research.

Protocol 1 (conventional recipe): The samples were mixed with 4.0 wt% of salt and 0.017 wt% sodium benzoate for 1 h by using human massage, dried under normal sun dried for 6 h, and was kept in the chamber overnight. The samples were repeated all the processes for 3 times with the same method.

Protocol 2: The samples were mixed with 4.0 wt% of salt and 0.017 wt% sodium benzoate for 1 h by using machine stirring, dried under normal sun dried for 6 h, and was kept in the chamber overnight. The samples were repeated all the processes for 3 times with the same method.

Protocol 3: The samples were mixed with 12.0 wt% of salt and 0.05 wt% sodium benzoate for 1 h by using human massage, under normal sun dried, and was kept in the chamber overnight. The samples were repeated only drying and keeping processes for 3 times with the same method.

Protocol 4: samples were mixed with 12.0 wt% of salt and 0.05 wt% sodium benzoate for 1 h by using machine stirring, under normal sun dried, and was kept in the chamber overnight. The samples were repeated only drying and keeping processes for 3 times with the same method.

Protocol 5: samples were mixed with 12.0 wt% of salt and 0.05 wt% sodium benzoate for 1 h by using machine stirring and were dried under solar-cell dryer for 3 days.

2.2 Experimental analysis

The pH and conductivity were measured using Ionix model premium line testers. The water activity of salted radish was measured using dew point water activity equipment, AQUA LAB. The softness of the processed radish was determined via a compression test using a texture analyzer (Model TA-XT plus, US). The color of salted radish was measured by a color meter (Model WR 10, FRU brand). The massage machine or rotating machinery comprised a cylindrical tank made up of stainless steel 316 that measured 50 cm in diameter and 60 cm in length and a motor 3hp having a rotor speed in of 0-100 rpm.

2.3 Drying apparatus

Drying experiments were conducted using a stirring machine that consisted of a salt process with mechanical massage and normal sun drying. Weight loss of samples was recorded using a digital balance in the range of “0-100 kg with reading accuracy of 0.001 kg”. The moisture content of the radish was evaluated for the instantaneous drying rate “Rddi” (dry basis) [9] using the below Equation:

$$RDd_i = \frac{\Delta W_i}{W_d \times \Delta t} = \frac{W_{i-1} - W_i}{W_d \times (t_{i-1} - t_i)} \quad \text{unit: } \left(\frac{10^{-3} \text{ kg}_{\text{wet}}}{\text{kg}_{\text{dry}} \cdot \text{min}} \right) \quad (1)$$

where, W_i denotes the weight of the radish at time t_i , W_{i-1} denotes the weight of the radish at the initial time t_{i-1} , W_d denotes the weight of the radish dried until the weight of the dried sample became stable (29.50 wt%)

3. Results and discussion

3.1 Salting and drying from stirring, sun drying, and keeping processes

The reduction in radish weight was investigated using the massage process, as shown in Figure 2. The weight of radish after human massage was found to be reduced by 17.4 wt% in 1h. Osmotic pressure from the salt solution plays an important role in withdrawing moisture from the cell membrane of radish. Different concentrations of the salt solution affect the water molecule passing through the semipermeable membrane of radish. In theory, the direction of solvent flow moves from the side having a lower solute concentration to the side having a higher solute concentration [10]. The water in the radish is released from its tissue to salt solution until there is no difference in pressure between the two sides. When sun-dried, some water evaporated, and the weight of the radish reduced by 15.0 wt% in 6 h. After 1 day, the moisture content in salted radish reduced to 32.6 wt%. After 3 days, the moisture content of the radish reduced by 25.8 wt%, 30.8 wt%, and 6.3 wt% via the human massage process, drying process, and keeping process, respectively.

The weight reduction of radish after applying mechanical stirring is investigated, as shown in Figure 3. After using the mechanical process, the weight of the radish reduced by 23 wt% in 1 h. The weight reduced by 10 wt% when the radish was sun-dried. After 3 days, the moisture content of radish reduced by 40.45 wt%, 20.65 wt%, and 6.84 wt% via mechanical stirring, drying, and keeping process, respectively. The mechanical process using salt enhanced the osmosis effects two-fold compared to the conventional process. It improves the ability of water molecules to flow out of the cell membrane while preserving vegetables and their essential nutrients [11] over long periods. Drying under sunlight is commonly applied to remove water from vegetables or meat due to its low investment cost. Heat exposure can cause enzymatic browning reaction (dark coloration) in foods. Exposure of cut and sliced foods to air also causes a browning reaction due to the oxidation of phenolic compounds to quinones and production of melanin [12]. This browning effect may also arise due to partially cooking, which activates enzymatic activity in the foods [13]. Moreno et al. proposed that UV radiation can degrade chlorophylls, resulting in lower lightness and hue values in fruits [14]. Nevertheless, this browning effect can be prevented in food systems by preventing/reducing exposure to oxygen and irradiation.

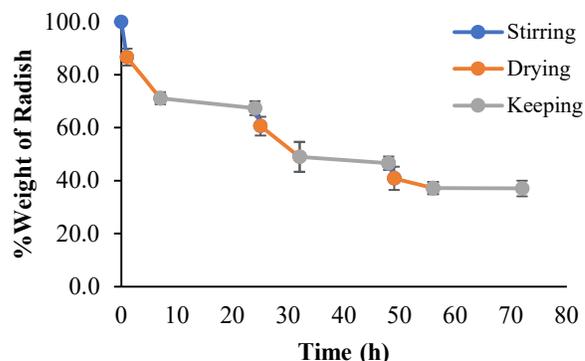


Figure 2 Weight percentage of radish stirred by humans with 4 wt% of salts (scenario 1).

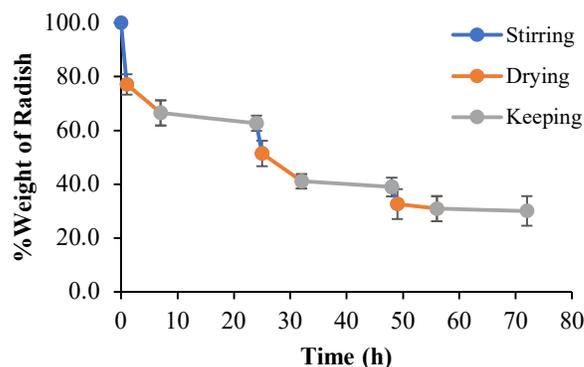


Figure 3 Weight percentage of radish stirred by machine with 4 wt% of salts at 40 rpm (scenario 2).

To understand the osmotic pressure related to weight loss in radish, the conductivity of salt solution from human massage and machine stirring is studied in Figure 4 and Figure 5, respectively. The salt is dissolved from the water that penetrates out vegetable tissues. The result is a salt solution with a higher concentration than the concentration of saline in vegetables, resulting in a high electrical conductivity at the beginning. The low conductivity of solution is observed when increasing operation time because salinity of outside solution decreases. The conductivity of water from radish massaged by humans dramatically decreased in 30 min and continued to decline until 60 min. This indicated that the rate of flow of water out of the cells is greater than the rate of flow into the cells. Whereas conductivity of water from radish stirred by machine significantly decreased in 30 minutes and was almost constant after 40 minutes. It can be suggested that there is no driving osmotic force between the outside and inside solution of the cells. The use of a stirrer allows faster access to osmotic equilibrium due to diminishing mass transfer. Li et al. [15] proposed that mechanical ultrasound influences the transfer of solute (sucrose, NaCl, water) related to mass transfer that occurs in the tissue of the fruit.

The conductivity from both human and machine processes on days 2 and 3 decreased by at least 2 times from day 1, indicating the significant reduction in the rate of water extraction of radish into the external salt concentrate. The conductivity of water from radish stirred by the machine is almost constant after 50 min. The rate of water that flows out of the cells is equal to the rate of flow into the cells. Electrical conductivity or osmotic pressure, which is observed on day 3, reaches an equilibrium point as the salt inside continues to diffuse out of the radish and into the water. Solution on days 2 and 3 manifests low water loss from radish, resulting in high salt concentrations and high values of electrical conductivity. Finally, after 3 days, the salinity in the processed radish was obtained to be 10.5% and 11.8% using human massage and stirring machine, respectively.

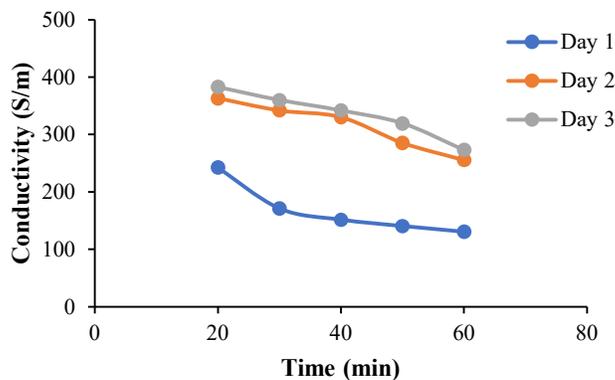


Figure 4 Conductivity of water from radish stirred by humans with 4 wt% of salts (scenario 1).

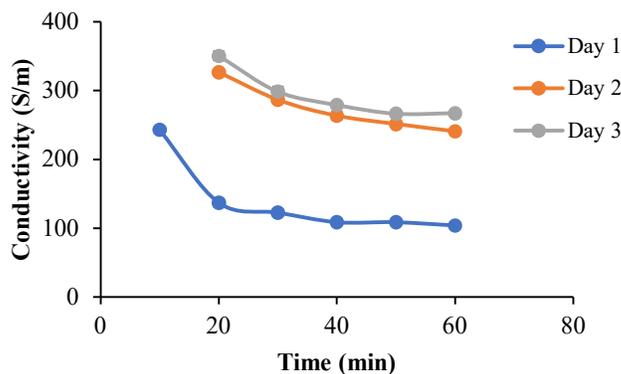


Figure 5 Conductivity of water from radish stirred by a machine with 4 wt% of salts at 40 rpm (scenario 2).

The drying rate ($\text{g}_{\text{wet}}/\text{g}_{\text{dry}} \text{ min}$) describing simultaneous water weight loss (gram) on a dry basis with time (minute) was evaluated to explain the different effect of salted massage, normal atmospheric drying, and keeping. The total moisture loss percentage for salted radish is $29.5 \pm 1.7\%$ of the total weight of the fresh radish. Table 1 shows the instantaneous drying rate from salted radish, and the highest drying rate from machine stirring is achieved at $12.74 \text{ g}_{\text{wet}}/\text{g}_{\text{dry}}/\text{min}$. The large amount of moisture loss percentage from the machine stirring process is due to a synergy effect from physical and chemical forces. There is no difference in osmotic pressure under constant salt concentration during successive experiments between hand massage and machine stirring. Due to the physical effect, the drying rate increases as the force increases. The mechanical machine could enhance the drying rate with reduced health hazards for workers. Pavkov et al. [16] reported that water in apricot fruit reduced by half during osmotic dehydration. They reported that the drying rate between human massage and machine stirring is constant after 3 days. The drying rate from normal sunlight is in the range of 0.80 to $1.2 \text{ g}_{\text{wet}}/\text{g}_{\text{dry}}/\text{min}$, and no obvious moisture loss was detected in the keeping step. A low instantaneous drying rate $\text{g}_{\text{wet}}/\text{g}_{\text{dry}}/\text{min}$ are detected after the first day. The highest water loss during osmotic dehydration was $29.1 \times 10^{-3} \text{ kgH}_2\text{O}/\text{kg}$ of dry minute under process parameters 60°C , $65\% \text{RH}$ and water loss during hot air drying was $0.76 \times 10^{-3} \text{ kgH}_2\text{O}/\text{kg}$ (40°C , 1.0 m/s) [16]. Salt concentration creating a net osmotic pressure contributes to approximately half of moisture loss in radish. However, machine stirring greatly reduces the percentage of dried radish of the fresh material and increases the drying rate of processes.

Table 1 Instantaneous drying rate from salted radish.

Day	Instantaneous drying rate ($10^{-3} \text{ kg}_{\text{wet}}/\text{kg}_{\text{dry}} \text{ min}$)			
	Stirring		Drying	Keeping
	Human	Machine		
1	7.39	12.74	0.83	0.12
2	3.74	6.23	0.82	0.07
3	3.18	3.05	0.14	0.00

3.2 Stirring speed of machine on radish texture

The hardness and water obtained from radish with various rotating speeds of the machines are shown in Figure 6. Water obtained from radish increased from 34 wt% to 39 wt% when the stirring speed of the machine was increased from 30 rpm to 90 rpm, while the texture hardness decreased from 86N to 72N. The machine force affects water removal from radish. The texture hardness of conventional salted radish is 85.0 ± 3.5 N, which is widely favored by consumers. Therefore, the appropriation speed of the machine should be operated under 50 rpm to prevent the destruction of the radish texture.

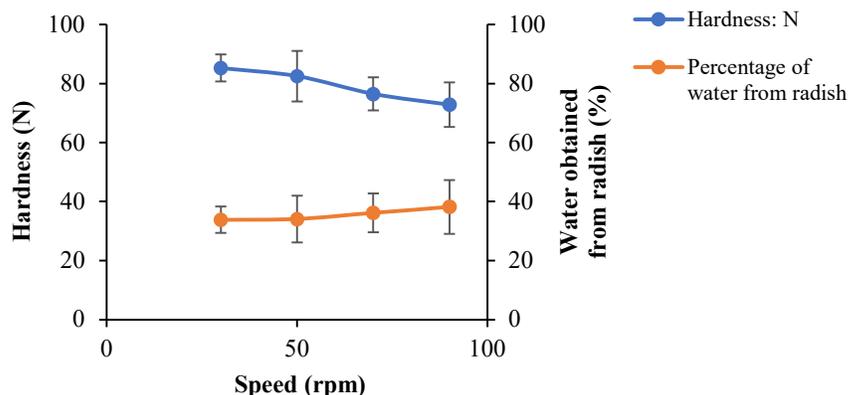


Figure 6 Hardness and water obtained from radish with various speeds of machine (scenario 2).

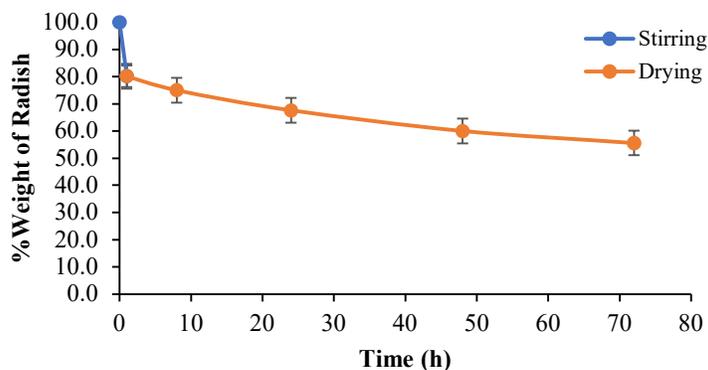


Figure 7 Weight percentage of radish stirred by humans with 12 wt% of salts (scenario 3).

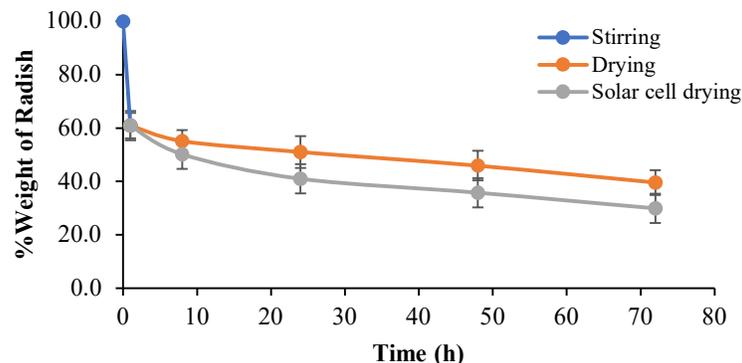


Figure 8 Weight percentage of radish stirred by a machine with 12 wt% of salts (scenario 4 and scenario 5).

3.3 Recommendation processes

To reduce the drying time while sustaining the same quality of salted products, scenarios 3 and 4 for stirring for 1 day were implemented (Figures 7 and 8). The moisture content reduced by 20 wt% and 40 wt% due to human

massage and machine stirring, respectively. The mechanical force could be used to accelerate water dehydration from radishes more than the conversion process due to the increasing effect of osmotic pressure. Nevertheless, the concentration of salt solution decreases until it reaches the same level as in the pure solvent of cell, and then the osmosis stops. After that, the normal drying process can reduce moisture by 20 wt%. The weight of radish from scenario 4 was obtained to be 41 wt% however, the conventional process requires the final radish weight to be below 37 wt%. A solar dryer can remove more moisture than normal drying, thus extending food life and preventing contamination from dust. The radish weight under a solar dryer (scenario 5) for 3 days was obtained to be 30 wt%.

Water activity (a_w) is used to evaluate the growth rate of microbes, which damage ingredients, texture, and taste in foods. In general, foods that have a water activity above 0.95 provide sufficient moisture to support the growth of bacteria, yeasts, and mold. In several cases, (a_w) is a key parameter accountable for food stability and for determining the type of microorganisms encountered in food [17]. For decades, salts have been used to preserve foods. High salt concentration is mainly used to control water activity in foods. Thus, the concepts of water activity related to the shelf stability of a product and designing a unique process for safe products with high quality. Water activity related to mechanical and massage stirring of processed radish in scenarios 1 to 5 is shown in Figure 9. In scenarios 1 and 2, the water activity was lower than 0.85, but daily stirring and drying labor was required. However, in scenarios 3 and 4, the water activity was reduced, but the water activity (>0.85) was too high for public usage. For example, *Staphylococcus aureus* (an extremely NaCl-tolerant organism) has demonstrated minimal a_w for growth: 0.85-0.86 (aerobically) and 0.90-0.91 (anaerobically) [18]. The solar-cell utilization for salted radish can lower the water activity to the same level as industrial dried food standards (<0.85). a_w below 0.85 indicates that low-moisture foods inhibit the activity of bacteria. The US Food and Drug Administration has established limits of water activity level of 0.85, which is used for determining whether the food is a low-acid canned food or an acidified food [19]. Low water activity is also important with respect to thermodynamic efficiency of the biosystem [20]. Nevertheless, undesirable texture properties, such as hardness and toughness, occur when the water activity of these products is too low.

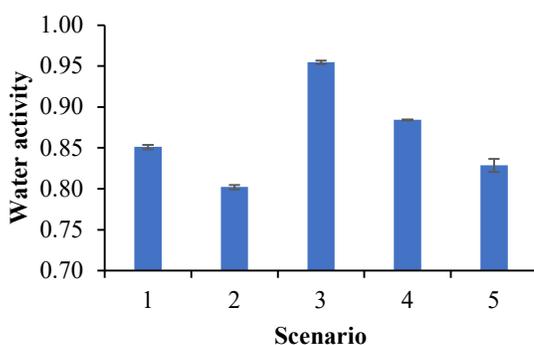


Figure 9 Water activity from processed radish.

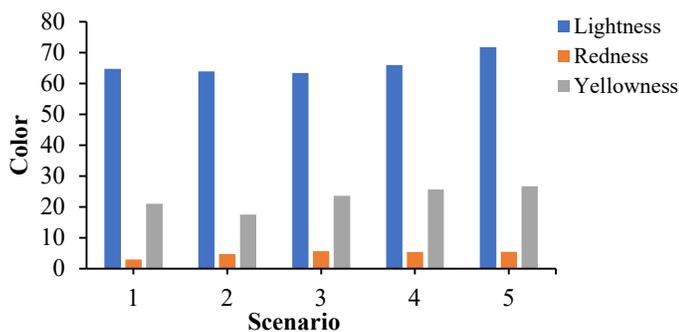


Figure 10 Color measurement of processed radish.

As shown in Figure 10, the lightness of salted radish processed via scenarios 1 to 4 (64-66) is lower than that of scenario 5 (70) due to the use of polycarbonate as a roof for solar-cell oven. This material can protect the products from the UV spectrum, such as UV-A or UV-B. However, no obvious difference in red and yellow values was observed for all scenarios.

4. Conclusion

This study determines the moisture distribution profile of salted radish under different drying methods, such as salts with stirring, normal drying, and keeping processes. Machine stirring provided a faster drying rate than the conventional massage and the standard drying and keeping process. The innovative transfer of salted radish threshing machine manages the issues of labor shortages and long-term health impacts. Based on our findings, the appropriate salted radish stirring machine conditions were 50 rpm of stirring speed, 1 h of operation time, and 3 days of solar dryer. In addition, the salted radish exhibited a salinity value of 130 g/l, $a_w < 0.85$, brightness value of 63, and texture hardness of radish 87 newtons.

5. Acknowledgments

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