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Effects of Sucrose-Sorbitol Mixture on the Properties of Osmo-Dehydrated Orange cv. Sai Nam Phueng Designed using Response Surface Methodology

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Abstract

Mandarin oranges, particularly the Sai Nam Pheung cultivar, represent a significant segment of global citrus production, valued for their high content of phenolic compounds, and ascorbic acid. However, their high moisture content limits shelf life. Osmotic dehydration is an effective method to reduce moisture content (below 15%, aw < 0.6) prior to final drying, thereby improving nutrient retention and extending shelf life. This study aimed to (i) optimize the processing factors influencing the physicochemical and sensory properties of osmo-dehydrated mandarins, and (ii) develop value-added products from low-grade fruit. Four experiments were conducted. Experiment I investigated the effect of varying sucrose and sorbitol mixture ratios (SBT75:S25, SBT50:S50, SBT25:S75, and S100). Experiment II applied response surface methodology (RSM) to optimize osmotic agent concentrations (50%, 55%, and 60% w/v), drying temperatures (50°C, 55°C, and 60°C), and drying times (36, 42, and 48 hours), resulting in 15 treatment combinations. Experiment III examined the impact of salt types (table salt and Himalayan salt) and concentrations (0.5% to 1.5% w/v), while Experiment IV assessed consumer acceptability through sensory testing. The osmotic dehydration process involved immersing fruit in syrup at a 1:5 fruit-to-solution ratio for 240 minutes, followed by tray drying. Physicochemical properties i.e., moisture content, water activity, texture, color, vitamin C, total phenolic content, and

DPPH radical scavenging activity were analyzed. Sensory evaluation employed a 9-point hedonic scale. The optimal conditions, determined through RSM, included a 55% osmotic agent concentration, 55°C drying temperature, and 42 hours drying time. The addition of 1.5% table salt significantly enhanced taste preference. Overall, sensory evaluation confirmed the desirable attributes of the product, supporting its potential for commercialization.

Keywords: Osmotic Dehydration, Sweet Orange, Sweetener, Response Surface Methodology.

Introduction

1. Overview and Significant of Citrus Fruits

Citrus fruits are one of the most popular fruit commodities due to its distinct, refreshing taste and nutritional worth (Ladaniya, 2008). Oranges account for over half of total citrus output globally (Fresh, 2017). Mandarin (cv. Sai-Nam Phung) contains various elements that are helpful to human health, including phenolic compounds, ascorbic acid, and carotenoids. Tangerine has a high moisture content (about 89% w.b.). In Thailand, Thai farmers cultivate major citrus fruits, such as sweet orange, tangerine, neck orange, aidless orange, pomelo, and lemon, which are members of the Rutaceae and Plantae families. Sweet orange (*Citrus sinensis*), Tangerine orange (*C. reticulata* Blanco), and *Citrus reticulata* - Sai Nam Pueng orange are the most popular citrus fruits in Thailand's juice industry. Because of mechanical harvesting, environmental conditions (Chen et al., 2019), the age of the tree, watering, and fertilizing low-quality orange fruit is prevalent in the business, causing economic loss and reducing the productivity or yield of juice. Wangkanil orchard in Chiang Mai, for instance, cultivates 95% of the Tangerine (cv. Sai-Nam Phung) across 400 rai. However, Tangerine (cv. Sai-Nam Phung) of inferior quality or those that have been damaged or blackened skin orange account for approximately 30 percent of yearly orange output, or 450 tons. Most low-grade Tangerine (cv. Sai-Nam Phung) have been sold at a cheaper price and processed into frozen orange juice, which necessitates a huge amount of storage space, energy, and transportation costs. Thus, osmo-dehydrated oranges might be an alternative product by adding the value to low grade oranges. Since, osmotic dehydration should be utilized to partly remove moisture before a final drying stage to create high-quality dehydrated with greater nutrient retention Pattanapa et. al (2010). The market size of dried fruits in 2020 has been reported around $15.8 billion. Since there was a growing trend of dried fruit accelerated market growth due to less perishability and easy handling and currently, the trend of dried fruits expanded over 4.6% in Thailand.

2. Principle of Osmotic Dehydration

Osmotic dehydration assists in water removal by employing syrup derived from different osmotic agents and subsequent dehydration in the air drier, where the moisture content is further reduced to approximately 15% w.b. (Aw < 0.6) to ensure product shelf stability (Verma et al., 2014). It has been observed that osmotic dehydration may decrease weight by up to 50%. It results in extended shelf-life and a little loss of scent in dried and semi-dried foods. It enhances the texture as well as the rehydration qualities. The procedure minimizes the amount of the goods, saving money on processing, storage, and transportation (Solanke et al., 2018). Recently, osmotic dehydration has gained favor as a possible alternative to standard drying and freezing methods for enhancing the quality of fruit. It is a slow process, suggesting that mass transfer must be sped up without sacrificing food quality. It has been observed that pretreatments such as blanching, freezing, high pressure, high intensity pulsed electric field, and ultrasound increase mass transfer in fruits. During osmotic dehydration, mass transfer occurs through semipermeable cell membranes present in biological materials, which is the process's most significant barrier. The state of the cell membrane may change from partially permeable to fully permeable, resulting in significant changes to tissue architecture. During osmotic water removal from food, the osmotic dehydration front progresses from the outside of the food in contact with the surrounding osmotic solution to the core, causing cell disintegration due to osmotic stress. Loss of contact between the cell membrane and the cell wall is most likely the source of cell damage produced by osmotic therapy-induced size reduction (Rastogi et al., 2000).

3. Factors influencing the Physicochemical and Organoleptic Properties

Despite, several factors affect the mass transfer during osmotic dehydration. These are the temperature of the osmotic solution, concentration of the osmotic solution, type of osmotic agent, time duration, geometry (size) of the food material, variety of the food material, osmotic solution and the food mass ratio, physicochemical properties of the food materials and operating pressure. For instance, osmotic agents or combinations of various osmotic agents are generally used. The osmotic agent must be efficient, convenient, non-toxic, and tasty. It should be easily dissolved to generate a highly concentrated solution and should not react with the product and price should be inexpensive. Moreover, osmotic agents must minimize browning reaction by inhibiting oxygen penetration, offer stability to pigments, and aid in the retention of volatile compounds during the drying of product. However, the combination of multiple osmotic agents was proved as more successful than a single osmotic agent. Solanke et al. (2018) investigated the effect of different osmotic agents on sweet orange slices during osmotic dehydration, as well as the sensory quality of osmo-convective dried sweet orange slices. 70 % W/V of sugar, jaggery, honey, and stevia were used as osmotic agents at a product/solution ratio of 1:5 w/v . The product's qualities such as moisture content, color, hardness, and sensory quality were evaluated. Osmo-convective dried sweet orange slices immersed with sugar have better qualities than honey and jaggery however shrinkage after drying, osmo-convective dried sweet orange slices immersed with stevia solution were unacceptable results especially sensory quality as it might have high shrinkage. Verma et al. (2014) introduced response surface methodology to investigate the effect of sucrose concentration at 30–70 °Brix on water loss, minimum solid gain, minimum water activity, and minimum browning index during osmotic dehydration of banana slices (*Musa cavendishii*) pretreated by high pressure processing. High pressure processing as a pretreatment of 200 MPa for 5 minutes at room temperature of 26 °C before osmotic dehydration for 4 hours at 40 °C in 60 °Brix sucrose solution, followed by dehumidified air drying at 55 °C for finished drying, can produce superior quality osmotic dehydrated banana slices with better shelf stability while saving time and energy. Using high pressure processing as a pretreatment, however, a drying temperature of 55 °C was proven to provide higher quality osmotic dehydration banana slices in terms of reduced bulk, increased taste, aw less than 0.60, and reduced dehydration time and energy. Pattanapa et al. (2010) investigated the impact of several sucrose and glycerol osmotic solutions on the quality of osmotically dehydrated mandarin, particularly mandarin cv. Sai-Nam Phung. Mandarin samples were peeled and osmotically dehydrated at 55°C in five different osmotic solutions made up of 60 % sucrose and 60 % glycerol (9:1, 8:2, 7:3, 6:4, and

5:5 w/w, respectively). Tangerine that had been osmotically dehydrated was subsequently dried for additional 360 minutes using hot air drying at 70 °C. Increases in the glycerol ratio in the mixtures caused increased water loss and solid gain during osmotic dehydration, as well as changes in the kinetic rate constants during drying. As the glycerol ratio in the mixes grew, the quality parameters of hardness, moisture content, aw , and reducing sugar all fell dramatically. An increase in the sucrose ratio in the mixtures, on the other hand, resulted in an increase in the darkness of the dried tangerine. The increase had no effect on vitamin C levels. These previous studies showed that response surface methodology (RSM) could be a useful tool to optimize the related factors suitably. However, the final drying techniques have been mostly introduced to reduce the final moisture content and water activity. For example, convective drying, tray drying, solar drying, infrared drying, vacuum drying and microwave drying.

4. Impacts of Osmotic Dehydration on the Physicochemical and Sensory Properties

Osmotic dehydration causes less heat damage to the color and taste of foods with exceptional sensory attributes. When food is dried by air or vacuum, the use of sugar or syrup as an osmotic agent avoids most of the taste loss that happens. Because the sugar envelopes the fruit pieces, enzyme and oxidative browning are suppressed, providing for excellent color retention with little or no sulfur dioxide. The removal of acid and the absorption of sugar by the fruit pieces alters the composition (sugar to acid ratio) and enhances the flavor and acceptability of the final product (Sutar & Sutar, 2013). Konopacka et al. (2009) presented a study that investigated the sensory perception and acceptability of osmo-dried and osmo-freeze-dried sour cherries, blackcurrants, and apples using various osmotic agents. The osmotic solution had a significant influence on the dried fruit's flavor and texture characteristics, as well as its sensory acceptability, according to the researchers. Dried fruit treated with sucrose, inverted sugar, or de-acidified fruit juice had a sweet taste, but dried fruit treated with concentrated apple juice had a strong acidity. When oligofructose was added to freeze-dried fruit, it produced a product with a high degree of crispness. Polyols such as galactic sorbitol and sorbitol were not recommended for osmotic impregnation of fruit because of a sense of increased hardness. Pattanapa et al. (2010) presented a study that indicates the influence of the sucrose and glycerol ratio on the hardness of dried mandarin. The lowest hardness was seen in mandarin submerged in a 5:5 (sucrose glycerol) osmotic solution. Glycerol might assist to keep the product wet but with a decreased water activity, meaning that it could help to keep the product moist but with a reduced water activity. This is explained by the fact that glycerol includes three hydroxyl groups in dried mandarin that may form hydrogen bonds with water. Consequently, higher concentration of glycerol significantly reduced the hardness of the dried mandarin.

5. Research Hypotheses

5.1 If the different osmotic agents and their mixture are related to the physicochemical and sensory properties of osmo-dehydrated orange, then the addition of varying types and mixture ratio of osmotic agents will alter these properties.

5.2 If the drying temperature, time and concentration of osmotic agent are related to the physicochemical and sensory properties of osmo-dehydrated orange, then the varying combination of these factors using RSM will alter these properties.

Research Methodology

1. Experimental Design

This research was divided into 4 experiments including experiment I: the effects of sucrose-sorbitol mixture ratio on the physical and sensory properties, experiment II: the reflect of osmosis dehydration conditions on the physicochemical and sensory properties using RSM, experiment III: the effects of type of salts and their concentration on physicochemical and sensory properties, and experiment IV: consumer testing for the final products.

2. Objectives

2.1 To optimize the processing factors on the physicochemical and sensory properties of osmo-dehydrated oranges.

2.2 To develop value added products from low-grade oranges.

3. Scope of this research

3.1 Sai Nam Phueng oranges (Sweet orange) were collected from Wanganil Orchard, Mae-ai, Chiang Mai Province, Thailand.

3.2 Sucrose and sorbitol were used as osmotic agent in the experiment.

3.3 Osmotic dehydration was carried out following methods of Solanke et al. (2018), Khatir et al. (2013), and Naknean et al. (2013) and processing conditions including concentration of osmotic agent, drying temperature, and drying time were optimized using response surface methodology (RSM).

3.4 Moisture content (MC), water activity (Aw), textural property, color, vitamin C (ascorbic acid), total phenolic content (TPC), DPPH radical scavenging activity (DPPH assay), proximate analysis were determined as physicochemical properties. The 9-point hedonic scale were examined as the sensory properties of OD.

4. Research Sample and Chemicals

Mandarin cv. Sai Nam Phueng orange was collected from Wanganil farm, Mae-ai, Chiang Mai Province, Thailand. The collected oranges were packed in plastic mesh bags and transferred for processing and analysis at Mae Fah Luang University, Chiang rai Province, Thailand. Low grade oranges were selected, particularly diameter (52-57 mm), TSS (12-13 °Brix) with similar appearance and maturity stage. Total titratable acidity (%), pH, and Total soluble solids of the sample were determined prior to osmosis dehydration treatment. Sucrose (control) was purchased from Mitr Phol Sugar Corp., Suphanburi Thailand. Sorbitol was purchased from Krungthep Chemi.LTD, Thailand. Deionized water was obtained from an in-house Milli-Q water purification system (Millipore, Bedford, MA, USA). 1,1-diphenyl-2-picrylhydrazyl (DPPH), Folin-Ciocalteu’s reagent, phenolphthalein, and sodium hydroxide were purchased from Sigma-Aldrich Ltd.

5. Research Procedures

5.1 Overall experiment

Trials were somewhat adjusted in the manner of Solanke et al. (2018), Khatir et al. (2013), and Naknean et al. (2013) with a product/solution ratio (1:5) such that the solution concentration stays nearly constant throughout the experiments. Individually weighed samples were immersed in a selected temperature for 240 minutes of processing time, with different treatments according to the serial of experiments. The experimental procedure was showed in the Figure 1. The experiment was designed using a “Randomized Complete Block Design” (RCBD), a method that ensures a balanced and unbiased allocation of treatments across experimental units to minimize variability and improve the reliability of results.

5.1.1 Experiment I

The effects of the sucrose-to-sorbitol ratio on the physical and sensory properties were investigated by varying the mixture of sucrose and sorbitol (w/w) in the syrup used for osmotic dehydration. Five treatments were tested including Treatment 1 (100% sucrose); Treatment 2 (100% sorbitol); Treatment 3 (75% sorbitol: 25% sucrose), Treatment 4 (50% sorbitol : 50% sucrose), and Treatment 5 (75% sorbitol : 25% sucrose). The sample codes denoted as S100, SBT100, SBT75:S25, SBT50:S50, and SBT25:S75, respectively. Osmotic dehydration was performed with different mixture ratio between sucrose and sorbitol with a fruit/solution ratio of 1:5 for 240 minutes, followed by tray drying at 60 °C until the Aw reach <0.6.

5.1.2 Experiment II

The optimization of osmotic dehydration conditions, with respect to the physicochemical and sensory properties of the final product, was conducted using Response Surface Methodology (RSM). Key factors influencing the product characteristics, including osmotic agent concentration (%w/v), drying temperature (°C), and drying time (h), were evaluated. A Box-Behnken Design (BBD) was employed to generate 15 experimental treatments, which varied the levels of each factor: osmotic agent concentration ranged from 50-60% w/v, drying temperature from 50-60°C, and drying time from 36-48 hours. A detailed description of each treatment is provided in Table 1.

Table 1 The independent variable and levels used in experiment II.

Independence variable (factors)	**Levels**		
	-1	**0**	**+1**
Concentration (%W/V)	50 (-1)	55 (0)	60 (1)
Drying temperature (°Celsius)	50 (-1)	55 (0)	60 (1)
Drying time (h)	36 (-1)	42 (0)	48 (1)

Table 2 Formulations in optimization condition of osmo-dehydrated orange using Response Surface Methodology (RSM) through Box-Behnken design (BBD).

Treatment	Syrup concentration	Drying temperature	Drying time
	%W/V	(°C)	(h)
1	55	50	48
2	55	50	36
3	50	50	42
4	60	50	42
5	55	55	42
6	55	55	42
7	55	55	42
8	50	55	48
9	50	55	48
10	60	55	36
11	50	55	36
12	55	60	36
13	60	60	42
14	50	60	42
15	55	60	48

5.1.3 Experiment III

The effects of different types of salts and their concentrations on the physicochemical and sensory properties were investigated by varying the type of salt (table salt and Himalayan salt) and their concentrations (0.5%, 1%, and 1.5% w/v) in the syrup obtained from Experiment II. The drying conditions were kept consistent, with an osmotic agent concentration of 55% w/v, a drying temperature of 55°C, and a drying time of 42 hours. Six treatments obtained from this experiment including Treatment 1 (table salt 0.5% w/v), Treatment 2 (table salt 1% w/v), Treatment 3 (table salt 1.5% w/v), Treatment 4 (Himalayan salt 0.5% w/v), Treatment 5 (Himalayan salt 1% W/V), and Treatment 6 (Himalayan salt 1.5% w/v).

5.1.4 Experiment IV

The final product for consumer testing was prepared using the optimal conditions identified in Experiments I–III. These conditions included a syrup composed of 75% sucrose and 25% sorbitol at a concentration of 55% w/v in water, with the addition of 1.5% table salt. The product was then dried at a temperature of 55°C for 42 hours.

5.2 Water activity (aw)

A water activity meter was used to monitor water activity at room temperature (PRE001447, Aqualab PRE, USA). To limit moisture transfer from the air to the samples, the sample was sliced into small pieces and placed in a sample cup, followed by another water activity test.

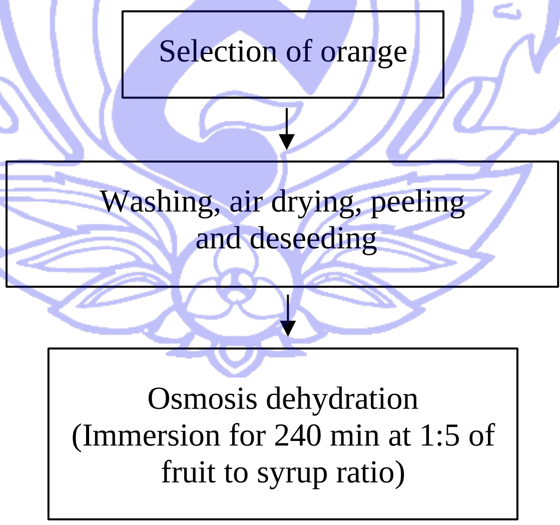

Figure 1. Experimental procedures for osmotic dehydration

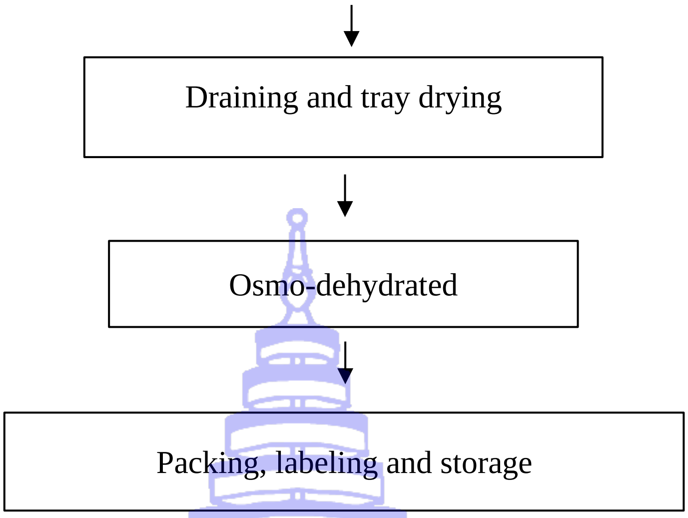

Figure 1. (continued)

5.3 Moisture Content

The aluminum can and lid was dried in a hot-air drier at 105°C for 3 hours before being moved to a desiccator to cool. The dried can was weighed and filled with all samples before being dried in a hot-air drier at 105°C for 24 hours (UF110, Memmert, Germany). The container containing dried samples were reweighted after drying (Donlao & Ogawa, 2019).

5.4 Color Measurement

To measure the color of samples, the CIELab system and a spectrophotometer was used (ColorQuest XE, HuntherLab, Japan). The L* value denotes lightness and ranges from 0 (darkest black) to 100 (brightest white). The a* value represents redness (positive values) and greenness (negative values), whereas the b* value represents yellowness (positive values) and blueness (negative values).

5.5 Vitamin C (Ascorbic Acid)

Vitamin C was measured using the technique Gironés-Vilaplana et al. (2014). The sample (450 mg) was extracted for 45 minutes at room temperature with metaphosphoric acid (1 percent, 30 mL) and filtered through Whatman No.4 filter paper. The filtrate (1 mL) was combined with 2,6 dichloroindophenol (9 mL), and the absorbance was measured at 515 nm against a blank within 30 minutes. The vitamin C content was estimated using the L-ascorbic acid calibration curve, and the results were represented as mg vitamin C per 100 grams (d.w.).

5.6 Total Phenolic Content (TPC)

TPC was determined by spectrophotometry (ThermoFisher Scientific, Waltham, USA) (Singleton et al., 1999), using gallic acid as a standard, following the method outlined by the International Organization for Standardization (ISO, 2005). Sample extracts were diluted (1:20) with distilled water, and 1.0 mL portions of the diluted solution were transferred in duplicate to separate tubes containing 5.0 mL of a 10% v/v dilution of Folin-Ciocalteu's reagent. Next, 4.0 mL of sodium carbonate solution (7.5% w/v) was added and mixed. The tubes were allowed to stand at room temperature for 60 minutes before measuring absorbance at 765 nm. Polyphenol concentrations were derived from a standard curve of gallic acid ranging from 10-100 µg/mL, with TPC expressed as gallic acid equivalents (GAE) in g/100 g (d.w.).

5.7 DPPH Free-Radical Scavenging Assay

A free radical scavenging experiment using 1,1-diphenyl-2-picrylhydrazyl (DPPH) was performed using the Molyneux (2004) technique with minor modifications. Extracted materials was diluted (1-20-fold) with distilled water before being combined with 3.9 mL 60 M DPPH solution in a volume of 100 mL. Allow the mixture to stand at room temperature for 30 minutes in a dark area. The absorbance was then be measured at 517 nm using methanol as a blank. The radical scavenging activity was measured in µmol Trolox equivalents (TE) per 100 (DW).

5.8 Sensory Evaluation

Untrained panelists composed of institute staff and students were established. The conventional procedure was used for sensory assessment. All indices were graded on a 9-point hedonic scale, with a score of 9 representing like extremely and a score of 1 representing the dislike extremely. For experiment I (36 panelists), sensory attributes such as overall liking, appearance, flavor, texture, aroma were evaluated using 9-point hedonic measures. For experiment II and III (36 panelists), sensory attributes such as overall, appearance, taste, texture, aroma were evaluated using 9-point hedonic measures. For experiment IV (50 panelists), sensory attributes such as appearance, taste, texture, smell/scent were evaluated using 9-point hedonic measures. Just about right evaluation was used to identify the suitable percentage of perceived choice on some sensory attribute was used including sourness, and texture intensity in experiment I and saltiness in experiment III.

Results and Discussion

1. Experiment I: The Effects of Sucrose-Sorbitol Mixture Ratio on the Physical and Sensory Properties

Sensory evaluation was performed using 9-pointed hedonic scale with 36 panelists. The majority of panelist was female accounted for 69.4 % while the male was 30.6 %. Most of panelist was in the age between 21-30 years old. Nine-pointed hedonic scale was used to observe to most acceptable sample using different ratio between sucrose and sorbitol in terms of various sensory attributes i.e., overall liking, appearance, flavor, texture, aroma (Table 2). The result showed that in terms of overall liking, aroma and taste were not significantly ($p > 0.05$) different among samples. However, the score of texture liking showed that samples SBT50:S50, SBT25:S75, SBT75:S25 had higher liking scores than SBT100 and S100 samples significantly ($p > 0.05$). All three samples also had a higher in appearance liking score than the S100 sample.

To select the most suitable sample from SBT50:S50, SBT25:S75, SBT75:S25 samples, percentage of perceived choice on some sensory attribute was used including sourness and hardness intensity. Among these three samples, SBT25:S75 felled in just about right of sourness, and hardness by 30.56, and 30.36 %, respectively (Table 3 & 4).

Table 3 Sensory evaluation of osmo-dehydrated orange using 9-point hedonic scale (n=36)

Sample	Sensory attributes				
	Appearance	**Flavor** ^{ns}	**Texture**	**Aroma** ^{ns}	**Overall liking** ^{ns}
S100	5.4±1.6^{b}	5.6±1.9	5.6±2.1^{b}	5.6±1.5	5.8±2.0
S25:SBT75	6.0±1.2^{ab}	6.2±2.1	6.7±1.8^{a}	5.8±1.7	6.7±2.1
S50:SBT50	6.4±1.9^{a}	6.5±2.0	6.8±1.8^{a}	5.2±2.1	6.3±2.1
S75:SBT25	5.8±1.8^{ab}	6.2±2.0	6.2±1.7^{ab}	5.6±1.5	5.9±2.1
SBT100	6.2±1.7^{ab}	6.2±2.0	5.6±2.2^{b}	5.6±1.5	5.8±2.0

Note * Data presents as mean ± standard deviation. Different letters shows significant difference in same column at $p \geq 0.05$, while ^{ns} shows non-significant difference. Abbreviations: SBT50:S50; sorbitol 50% & sucrose 50%, SBT100; sorbitol 100%, SBT25:S75; sorbitol 25% & sucrose 75%,S100;sucrose 100%, and SBT75:S25; sorbitol 75% & sucrose 25%.

Table 4 Just about right score on sourness of osmo-dehydrated orange (n=36)

Sample	Average (5)	Percentage of perceived choice				
		Not sour	Slightly sour	Just about right	Very sour	Overly sour
SBT50:S50	1.61	47.22	44.44	8.33	0.00	0.00
SBT100	2.14	25.00	38.89	33.33	2.78%	0.00
SBT25:S75	2.11	19.44	50.00	30.56	0.00	0.00
S100	2.5	16.67	33.33	33.33	16.67%	0.00
SBT75:S25	2.25	22.22	38.89	30.36	8.33%	0.00

Note *SBT50:S50; sorbitol 50% & sucrose 50%, SBT100; sorbitol 100%, SBT25:S75; sorbitol 25% & sucrose 75%, S100; sucrose 100%, and SBT75:S25; sorbitol 75% & sucrose 25%. (5) is the maximum intensity.

Table 5 Just about right score on hardness of osmo-dehydrated orange (n=36)

Sample	Average (5)	Percentage of perceived choice				
		Not hard	Slightly hard	Just about right	Very hard	Overly hard
SBT50:S50	1.61	50.00	25.00	25.00	0.00	0.00
SBT100	2.14	2.78	50.00	38.89	8.33	0.00
SBT25:S75	2.11	27.78	33.33	30.36	5.56	0.00
SBT25:S75	2.11	27.78	33.33	30.36	5.56	0.00
S100	2.5	19.44	41.67	38.89	5.56	0.00
SBT75:S25	2.25	39.44	11.11	19.44	0.00	0.00

Note * Abbreviations: SBT50:S50; sorbitol 50% & sucrose 50%, SBT100; sorbitol 100%, SBT25:S75; sorbitol 25% & sucrose 75%, S100; sucrose 100%, and SBT75:S25; sorbitol 75% & sucrose 25%. (5) is the maximum intensity.

2. Experiment II: The Optimization of Osmosis Dehydration Conditions on the Physicochemical and Sensory Properties using Response Surface Methodology (RSM)

RSM served as a vital tool for optimizing processing parameters, encompassing the concentration of the osmotic agent, dying temperature, and drying time. These variables exert significant influence over the physicochemical attributes of osmo-dehydrated orange (OD). Notably, certain treatments exhibited reduced moisture content and water activity (Aw). Given that OD falls within the category of intermediate moisture foods (IMF), recognized as shelf-stable products characterized by water activities ranging from 0.6 to 0.84 and moisture content spanning from 15% to 40% (Barbosa-Canovas et al., 2007). RSM generate in total of 15 treatments shown in Table 1 with random combination levels in each factors including concentration of osmotic gent (50 – 60 % w/v), drying temperature (50 – 60 °C), drying time (36 – 48 hours). Treatment no. 1-4, as showed, exhibited higher moisture content compared to others, particularly evident at the lowest drying temperature of 50°C (Table 5). Conversely, an escalating drying temperature trend correlated with diminished moisture content and Aw. Thus, among the examined parameters, drying temperature exerted a pronounced influence on both moisture content and Aw. This phenomenon can be attributed to the heightened drying temperature, which accelerates the drying rate, consequently facilitating extensive moisture removal from the food matrix. Treatments no. 5-15 predominantly fell within the range characteristic of intermediate moisture foods (IMF). The elevated drying temperature of 50°C exhibited a correlation with increased redness intensity (a*), a phenomenon associated with enzymatic browning reactions. This effect can be ascribed to the residual activity or activation of polyphenol oxidase (PPO) and peroxidase (POD) at higher temperatures, thereby facilitating enzymatic browning processes (Zhang et al., 2021). Among the treatments, the optimal conditions showing significant highest in all sensory attributes were observed in treatments 7 and 10 (as illustrated in Table 6). However, treatment 7 demonstrated potentially better shelf-life stability, exhibiting lower moisture content (18.16%) and water activity (0.50) compared to treatment 10, which had a moisture content of 28.55% and water activity of 0.65. In summary, the optimal conditions were identified at a concentration of 55% w/v for the osmotic agent, a drying temperature of 55°C, and a drying time of 42 hours.

Table 6 Physicochemical properties of osmo-dehydrated orange (n=3)

Treatment no.	Moisture content (%)	aw	Color parameters		
			L*	a*	b*
1	$64.35{\pm}6.15^{c}$	$0.85{\pm}0.00^{b}$	$43.35{\pm}3.82^{f}$	$4.08{\pm}0.55^{f}$	$6.70{\pm}1.60^{h}$
2	$95.66{\pm}3.47^{a}$	$0.92{\pm}0.02^{a}$	$40.33{\pm}5.60^{h}$	$3.66{\pm}0.63^{g}$	$6.91{\pm}0.99^{h}$
3	$75.66{\pm}3.03^{b}$	$0.87{\pm}0.02^{b}$	$52.18{\pm}2.01^{a}$	$8.34{\pm}2.01^{b}$	$15.76{\pm}2.08^{b}$
4	$76.00{\pm}4.08^{b}$	$0.86{\pm}0.01^{b}$	$42.16{\pm}6.00^{g}$	$4.20{\pm}1.58^{f}$	$4.92{\pm}2.35^{i}$
5	$17.74{\pm}0.00^{fg}$	$0.50{\pm}0.01^{e}$	$42.90{\pm}4.65^{fg}$	$4.70{\pm}3.20^{f}$	$7.71{\pm}5.17^{g}$
6	$18.16{\pm}0.58^{f}$	$0.50{\pm}0.00^{e}$	$45.36{\pm}8.12^{d}$	$4.06{\pm}2.28^{f}$	$7.45{\pm}4.81^{g}$
7	$18.16{\pm}0.58^{f}$	$0.50{\pm}0.00^{e}$	$48.64{\pm}3.48^{b}$	$6.32{\pm}0.91^{d}$	$11.11{\pm}0.36^{d}$
8	$16.00{\pm}1.62^{h}$	$0.49{\pm}0.00^{ef}$	$42.55{\pm}2.72^{g}$	$5.07{\pm}2.67^{e}$	$8.39{\pm}0.88^{f}$
9	$17.56{\pm}0.58^{g}$	$0.50{\pm}0.00^{e}$	$45.87{\pm}1.97^{cd}$	$6.43{\pm}0.76^{d}$	$10.87{\pm}2.62^{de}$
10	$28.55{\pm}2.71^{d}$	$0.65{\pm}0.01^{c}$	$52.05{\pm}0.27^{a}$	$7.20{\pm}1.00^{c}$	$13.41{\pm}1.50^{c}$
11	$25.42{\pm}1.50^{e}$	$0.61{\pm}0.00^{d}$	$46.12{\pm}1.96^{c}$	$6.30{\pm}0.29^{d}$	$11.47{\pm}1.01^{d}$
12	$13.48{\pm}0.80^{k}$	$0.44{\pm}0.00^{f}$	$46.35{\pm}1.52^{c}$	$9.32{\pm}1.50^{a}$	$17.13{\pm}4.08^{a}$
13	$15.13{\pm}1.04^{i}$	$0.43{\pm}0.01^{f}$	$45.59{\pm}2.99^{d}$	$7.64{\pm}0.38^{c}$	$10.62{\pm}1.30^{e}$
14	$14.68{\pm}0.58^{j}$	$0.43{\pm}0.01^{f}$	$44.38{\pm}1.96^{e}$	$7.94{\pm}1.44^{c}$	$11.83{\pm}3.18^{d}$
15	$15.13{\pm}1.04^{i}$	$0.43{\pm}0.01^{f}$	$45.59{\pm}2.99^{d}$	$7.64{\pm}0.38^{c}$	$10.62{\pm}1.30^{e}$

Note * L*; lightness, a*; redness and b*; yellowness. Data presents as mean ± standard deviation. Different letter $^{a\text{-}k}$ shows significant different in same column at $p > 0.05$.

3. Experiment III: The Effects of Type of Salts and Their Concentration on Physicochemical and Sensory Properties

The addition of salt, including table salt and Himalayan salt, was implemented to enhance the flavor profile of OD, particularly by augmenting sweetness and saltiness. Table 7 illustrated that the type of salt and its concentration slightly influenced certain physical properties, namely lightness (L*) and redness (a*). Notably, there were no significant differences observed in yellowness (b*), among samples. Furthermore, analysis using 9-point hedonic scale indicated no significant differences among the samples (Table 8).

Table 7 Sensory properties of osmo-dehydrated orange (n=36)

Treatment no.	Sensory attributes				
	Overall liking	**Appearance**	**Aroma**	**Taste**	**Texture**
1	$4.0{\pm}2.2^{de}$	$4.4{\pm}2.3^{c}$	$4.2{\pm}2.2^{c}$	$4.0{\pm}2.3^{ef}$	$4.0{\pm}2.4^{ef}$
2	$3.6{\pm}2.7^{e}$	$4.0{\pm}2.7^{cd}$	$4.0{\pm}2.7^{c}$	$3.9{\pm}2.5^{f}$	$3.4{\pm}2.4^{g}$
3	$4.4{\pm}2.5^{d}$	$4.3{\pm}2.5^{c}$	$4.2{\pm}2.6^{c}$	$4.6{\pm}2.5^{e}$	$4.3{\pm}2.6^{e}$
4	$3.5{\pm}2.8^{e}$	$3.6{\pm}2.4^{d}$	$3.6{\pm}2.5^{c}$	$3.6{\pm}2.6^{f}$	$3.6{\pm}2.7^{fg}$
5	$5.3{\pm}1.0^{c}$	$5.6{\pm}1.0^{c}$	$5.1{\pm}1.0^{c}$	$5.0{\pm}1.0^{c}$	$5.0{\pm}1.1^{c}$
6	$5.3{\pm}1.0^{c}$	$5.6{\pm}1.0^{c}$	$5.1{\pm}1.0^{c}$	$5.0{\pm}1.0^{c}$	$5.0{\pm}1.1^{c}$
7	$8.0{\pm}1.0^{a}$	$7.8{\pm}1.0^{a}$	$8.1{\pm}0.9^{a}$	$8.2{\pm}0.8^{a}$	$8.0{\pm}0.9^{a}$
8	$5.7{\pm}1.3^{b}$	$5.3{\pm}1.7^{b}$	$5.5{\pm}1.8^{b}$	$5.6{\pm}1.7^{b}$	$5.6{\pm}1.8^{b}$
9	$8.3{\pm}1.0^{b}$	$8.0{\pm}0.9^{a}$	$7.9{\pm}1.0^{a}$	$8.1{\pm}0.8^{a}$	$8.1{\pm}1.0^{a}$
10	$7.0{\pm}1.7^{a}$	$6.7{\pm}1.7^{a}$	$6.7{\pm}1.8^{a}$	$6.9{\pm}1.7^{a}$	$6.9{\pm}2.8^{a}$
11	$6.4{\pm}1.8^{ab}$	$6.5{\pm}1.6^{a}$	$6.3{\pm}1.7^{ab}$	$6.4{\pm}1.8^{ab}$	$6.5{\pm}1.7^{a}$
12	$5.3{\pm}2.3^{c}$	$5.8{\pm}1.8^{b}$	$6.3{\pm}1.8^{ab}$	$5.6{\pm}2.1^{cd}$	$5.6{\pm}1.9^{cd}$
13	$5.2{\pm}2.1^{c}$	$5.7{\pm}2.0^{b}$	$5.9{\pm}1.8^{b}$	$5.4{\pm}2.1^{d}$	$5.4{\pm}2.0^{cd}$
14	$5.8{\pm}2.0^{bc}$	$6.7{\pm}1.5^{ab}$	$6.0{\pm}1.6^{b}$	$6.1{\pm}1.6^{bc}$	$5.7{\pm}1.9^{bc}$
15	$5.5{\pm}1.8^{c}$	$5.7{\pm}1.6^{b}$	$6.1{\pm}1.5^{ab}$	$5.5{\pm}2.0^{d}$	$5.0{\pm}2.0^{d}$

Note * Data presents as mean ± standard deviation. Different letter ^{abcd} shows significant difference in same column at $p \geq 0.05$.

This phenomenon could be attributed to slight variations in the intensity of saltiness, along with other unspecified attributes, potentially leading panelists to have trouble in distinguishing among the samples. Consequently, the panelists were specifically instructed to evaluate on the perception of saltiness. Just about right was deemed optimal. The findings revealed that table salt at a concentration of 1.5% fell within the range of just about right amount of saltiness by 26.7%, garnering the high percentages among the samples (Table 9).

Table 8 Physicochemical properties of osmo-dehydrated orange (n=3)

Treatment No.	Moisture content (%)	Aw	Color (CIELAB)		
			L*	a*	b* ^{ns}
1	13.11±0.04^{a}	0.48±0.03^{a}	43.32±0.20^{e}	8.96±1.37^{abc}	15.6±2.63
2	12.48±0.23^{b}	0.44±0.07^{b}	50.36±0.34^{b}	10.03±0.65^{a}	18.19±1.02
3	12.08±0.05^{c}	0.43±0.10^{b}	48.19±0.13^{d}	10.38±0.05^{a}	16.46±0.16
4	12.18±0.25^{bc}	0.48±0.09^{a}	48.52±0.11^{d}	7.92±0.08^{bc}	15.52±0.07
5	12.21±0.04^{bc}	0.45±0.26^{ab}	49.27±0.40^{c}	9.52±0.27^{ab}	15.72±0.33
6	13.20±0.12^{a}	0.43±0.14^{b}	51.64±0.20^{a}	7.51±0.06^{c}	17.29±0.03

Note * Data presents as mean ± standard deviation. Different letter shows significant difference in same column at $p \geq 0.05$, while ^{ns} shows non-significant difference. Treatment 1 (table salt 0.5% w/v), Treatment 2 (table salt 1% w/v), Treatment 3 (table salt 1.5% w/v), Treatment 4 (Himalayan salt 0.5% w/v), Treatment 5 (Himalayan salt 1% w/v), and Treatment 6 (Himalayan salt 1.5% w/v).

Table 9 Sensory properties of osmo-dehydrated orange (n=36)

Treatment no.	Sensory attributes				
	Overall liking ^{ns}	Appearance liking ^{ns}	Aroma liking ^{ns}	Taste liking ^{ns}	Texture liking ^{ns}
1	6.3±1.9	6.6±2.0	6.8±2.0	6.3±1.7	6.3±2.2
2	6.4±1.6	6.6±1.5	7.3±1.3	6.3±1.8	6.2±2.2
3	6.5±1.6	6.8±1.4	6.8±1.7	6.1±1.6	6.1±2.0
4	6.1±2.2	6.2±1.9	6.9±1.5	6.2±1.7	5.8±2.5
5	5.8±1.9	6.1±2.1	6.9±1.9	5.9±1.7	6.0±2.2
6	6.2±1.7	6.6±2.1	7.0±1.7	6.0±1.7	5.8±2.5

Note * Data presents as mean ± standard deviation. $p \geq 0.05$, while ^{ns} shows non-significant difference. Treatment 1 (table salt 0.5% w/v), Treatment 2 (table salt 1% w/v), Treatment 3 (table salt 1.5% w/v), Treatment 4 (Himalayan salt 0.5% w/v), Treatment 5 (Himalayan salt 1% w/v), and Treatment 6 (Himalayan salt 1.5% W/V).

4. Experiment IV: Consumer Testing for the Final Products

Consumer testing was undertaken to assess the final product qualities in terms of physicochemical and sensory attributes. The optimized conditions for producing the final osmo-dehydrated orange (OD) included a syrup concentration of 55% w/v, salt concentration of 1.5% w/w, and a drying temperature of 55°C for 42 hrs. The physicochemical analysis revealed that OD retained considerable nutritional value following osmotic dehydration. For instance, total phenolic content was measured at 2.33±0.02 mg GAE/100 g, while the ascorbic acid content was found to be 33.93±0.75 mg/100g. Notably, the OD exhibited a high DPPH scavenging activity of 1,270.35±0.01 µmol Trolox/100 g (dw) possibly attributed to its ascorbic acid content, which functions as an antioxidant compound. These findings align with the study by Germer et al. (2017), which investigated the nutritional content of osmo-dehydrated orange, revealing total phenolic content of 53.37 mg GAE/100 g and ascorbic acid content of 43.06 mg/100g. Moreover, sensory evaluation using a 9-point hedonic scale with 50 panelists indicated favorable acceptability, ranging from "like slightly" to "like moderately" (6-7) across all sensory attributes.

Table 10 Just about right score on saltiness of osmo-dehydrated orange (n=36)

Treatment no.	Average (5)	Percentage of perceived choice				
		Not salty	Slightly salty	Just about right	Highly salty	Overly salty
1	1.42	70.0	20.0	10.0	0.0	0.0
2	1.61	56.7	30.0	10.0	3.3	0.0
3	1.92	50.0	16.7	26.7	3.3	3.3
4	1.86	53.3	16.7	20.0	3.3	6.7
5	1.42	70.0	20.0	10.0	0.0	0.0
6	1.75	46.7	36.7	10.0	6.7	0.0

Note Treatment 1 (table salt 0.5% w/v), Treatment 2 (table salt 1% w/v), Treatment 3 (table salt 1.5% w/v), Treatment 4 (Himalayan salt 0.5% w/v), Treatment 5 (Himalayan salt 1% w/v), and Treatment 6 (Himalayan salt 1.5% w/v).

Table 11 Physicochemical properties of osmo-dehydrated orange (n=3)

Physicochemical properties			
aw	TPC (mg GAE/100 g DW)	DPPH (µmol Trolox/100 g DW)	Ascorbic acid (mg/100g)
0.52±0.03	2.33±0.02	1,270.35±0.01	33.93±0.75

Note Data presents as mean ± standard deviation

Table 12 Sensory properties of osmo-dehydrated orange (n=50)

Sensory attributes				
Overall liking	**Appearance**	**Smell/Scent**	**Taste**	**Texture**
6.8 ± 1.5	6.6 ± 1.6	6.4 ± 1.6	7.0 ± 1.6	6.9 ± 1.1

Note Data presents as mean ± standard deviation

Conclusion

The mixture of 75% sucrose and 25% sorbitol exhibited the highest sensory attributes, with a moderate level of sourness and hardness. Utilizing response surface methodology, the study determined optimized conditions: a syrup concentration of 55% w/v and a drying temperature of 55°C for 42 hours, resulting in favorable outcomes for moisture content, water activity, appearance liking, flavor, texture and aroma. Furthermore, the addition of table salt at a concentration of 1.5% w/v to the syrup significantly enhanced taste preference among panelists, particularly in terms of perceived saltiness. The sensory evaluation confirmed that the final product met panelists' satisfaction in terms of sensory attributes, indicating promising potential for further commercialization of osmo-dehydrated orange.

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