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Article

Study on Factors Affecting Physicochemical Properties of Spray Dried Mango Powder Using Taguchi Experimental Design Approach

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Abstract

Mango is a common fruit in tropical countries. Due to its short shelf-life, it is important to study alternative preservation and consumption methods. In this study, concentrated mango juice was used to produce mango powder by using spray drying process. Four process parameters with three levels variation each, including initial total soluble solid content (13, 14, 15°Brix), maltodextrin content (20, 25, 30% w/w), inlet air temperature (170, 190, 210°C), and atomization pressure (4, 5, 6 bar) were studied. Taguchi approach of L-9 (3^4) array was used to design the experiments. Powder yield, moisture content, color difference, and solubility of the mango powder were investigated. It was found that maltodextrin content was the greatest factor affecting powder yield and color difference. The highest powder yield was 31.81%, and the least color difference (ΔE) was 3.17. Inlet air temperature and atomization pressure were the most important factor affecting to moisture content and solubility, respectively, in which average moisture content was 2.98% (w.b.) and the highest solubility value was 94.66%. For the overall production process, it was concluded that maltodextrin content was the most important parameter, while total soluble solid content provided the least impact on spray dried mango powder properties.

Keywords: Mango powder, Spray drying, Taguchi approach, physicochemical property

1. Introduction

Approximately 50% of all tropical fruits produced worldwide are mangoes [1]. The food and agriculture organization (FAO) of the United Nations estimate worldwide production of mangoes is more than 23 million tons [1]. Mango is the most common fruit in tropical countries, especially Thailand, where is recognized as one of the top mango producers in this world. Thai mangoes, when consumed, can be classified to be two major groups, ripe and unripe, according to the mango characteristics and consumer preferences. It is interesting to process ripe mango to other form of mango products since it has shorter shelf life than the unripe ones. There are many preservative and processing methods available for mango, such as drying, freeze drying, and pickling. Among them, spray drying offers advantages to the product by having longer shelf-life at room temperature and inexpensive transportation cost [2].

Spray drying is well-known to be applied with many agricultural products such as milk, coffee and fruit juice. It is a thermal process for changing liquid or slurry to dried powder product by two important processes which are droplet formation and drying by heated gas [3]. To obtain desirable physicochemical properties of spray dried product, there are many process factors that must be considered including both feeding sample itself and also spray drying parameters. For instance, moisture content, hygroscopicity, and free radical scavenging activity of spray dried amla (*Emblica officinalis*) powder were changed according to varied maltodextrin content in amla juice [4]. Moreover, air inlet temperature was reported to affect moisture content, bulk density, powder size [5], total carotenoid and total antioxidant activity [6,7] of spray dried powder. Although, there were studies of process parameters of spray dried products, most of them were limited to few factors in a particular study because number of trial would increase in logarithm scale with every single additional factor.

Taguchi approach is a widely-accepted experimental design developed by Genechi Taguchi. This experimental design provides minimum experimental trials while importance of each experimental factors still remains [8]. In this study, four factors including total soluble solid and maltodextrin content of mango juice, inlet air temperature, and atomization pressure were studied for their effects on powder yield, moisture content, color difference, and solubility of the mango powder. Three levels of each factor were varied. With Taguchi approach, number of trial in this study was reduced to be 9 trials instead of 81 trails from completely randomized design (CRD). Results of this study would suggest effect of each process factor on mango powder physicochemical properties.

2. Material and Method

2.1 Raw material and chemical reagents

Concentrated mango juice was purchased from local market in Pingtung city, Taiwan, ROC. Maltodextrin was obtained from Sigma-Aldrich (St. Louis, MO, USA).

2.2 Juice preparation

Concentrated mango juice was diluted to desired level of total soluble solid of 13, 14 and 15°Brix by adding distilled water. Maltodextrin was added to the diluted mango juice to obtain 20%, 25% and 30% (w/w) level. The prepared mango juice was refrigerated at 4°C until it is used.

2.3 Spray drying

Spray dryer (Buchi model 190, Germany) was used to dry 250 grams of prepared sample juice. Atomization pressure was arranged at 4, 5, 6 bar, and inlet air temperature was arranged at 170, 190, 210°C according to the experimental design.

2.4 The Taguchi's experimental design

Three-Level Orthogonal Double Arrays (L-9 (3^4)) array of Taguchi's approach was designed for an experiment with 4 factors and 3 levels variation each. Thus, it was applied in this study. The experimental plan was shown in Table 1. Every trials were done in triplicate.

Table 1. Application of Taguchi's orthogonal L – 9 (3^4) array to this study. Total soluble solid (TSS), inlet air temperature (IAT), maltodextrin content (MAL), and atomization pressure (ATOM) were expressed in term of °Brix, °C, percent, and bar, respectively.

Table 1. Application of Taguchi's Orthogonal

Trial	TSS	IAT	MAL	ATOM
1	13	170	20	4
2	13	190	25	5
3	13	210	30	6
4	14	170	25	6
5	14	190	30	4
6	14	210	20	5
7	15	170	30	5
8	15	190	20	6
9	15	210	22	4

2.5 Determination of moisture content

Moisture content of mango powder was determined by placing 1.5 grams of spray dried mango powder to Infrared Moisture Determination balance, FD-610 (Kelt, Japan). The powder was heated at 105°C temperature for 15 minutes. Weight difference before and after drying was used for moisture content calculation [9].

2.6 Determination of color difference

Five grams of mango powder was dissolved into 20 grams of distilled water. Then, the mango juice color was measured by using a color difference meter (model CDM-08, Laiko, Japan). Each sample was measured 3 times and find average value of color parameter in CIELAB system, L, a*, and b*. Color difference between mango powder and freshly prepared mango juice can be determined from ΔE value by the following Eq. (1).

$$\Delta E = \sqrt{(L-L_0)^2+(a-a_0)^2+(b-b_0)^2} \quad (1)$$

Where L is the lightness of the sample, a is the Greenness (-a) to Redness (+a) of the sample, b is the Blueness (-b) to Yellowness (+b) of the sample, and L_0, a_0 and b_0 represent color value of the freshly prepared mango juice [10].

2.7 Determination of solubility

One gram of mango powder was dissolved into 10 mL of distilled water. The mixture was then stirred at medium speed for 5 minutes. After that, mango juice was centrifuged at 5,000 rpm for 5 minutes to separate liquid and undissolved solid. Two mL of the separated liquid was dried at 105°C for 24 hours to find the weight of soluble solid in the liquid [11].

2.8 Data analysis

Recorded results were transformed and reported as signal/noise ratio (S/N ratio) according to Taguchi's principles. First, they were used to calculate for mean-squared deviation (MSD) values. There are three methods for MSD calculations, namely bigger is better, nominal is best, and smaller is better, according to desirable characteristic of the parameter. For powder yield and solubility, bigger is better was used (Eq. (2)), since high value of these properties were expecting. On the other hand, moisture content and color difference were calculated following smaller is better concept (Eq. (3)).

Bigger Is Better:

$$MSD = (1/y_1^2 + 1/y_2^2 + 1/y_3^2 + \cdots)/n \quad (2)$$

Smaller Is Better:

$$MSD = (y_1^2 + y_2^2 + y_3^2 + \cdots)/n \quad (3)$$

Where Y_1, Y_2, Y_3 are sample values from each condition, and n is number of samples. Finally, double calculated MSD values were calculated for their S/N ratio by substituting into the following Eq. (4).

$$S/N = -10 \times log_{10} \times MSD \quad (4)$$

2.9 Statistical analysis

Experimental results were calculated using analysis of variance (ANOVA) using the statistical package for the social sciences (SPSS) computer program version 19. Significant differences between means were determined by Duncan's multiple-range test ($p<0.05$)

3. Results and Discussion

3.1. Effect of process parameters on powder yield

Table 2. Spray dried mango powder yield (%), moisture content (M.C., % w.b.), color difference (ΔE), and solubility (SOL, %).

Table 2. Spray dried mango

Trial	Yield	M.C.	ΔE	SOL
1	21.02 ± 0.75[a]	3.43 ± 0.71[a]	3.17 ± 0.16[a]	81.17 ± 0.39[a]
2	25.51 ± 1.40[bc]	2.97 ± 0.49[a]	4.92 ± 0.28[d]	91.29 ± 0.07[c]
3	30.08 ± 1.57[d]	2.97 ± 0.68[a]	5.34 ± 0.32[d]	94.66 ± 0.30[c]
4	27.43 ± 1.95[c]	3.23 ± 0.61[a]	4.91 ± 0.17[d]	92.79 ± 0.91[c]
5	30.14 ± 2.27[d]	3.20 ± 0.44[a]	4.91 ± 0.46[d]	91.94 ± 1.00[c]
6	21.64 ± 1.74[a]	2.67 ± 0.21[a]	3.30 ± 0.20[ab]	87.77 ± 4.32[b]
7	31.81 ± 1.06[d]	3.03 ± 0.61[a]	4.38 ± 0.21[c]	88.08 ± 2.75[b]
8	24.45 ± 0.80[b]	2.83 ± 0.25[a]	3.67 ± 0.18[b]	93.52 ± 0.73[c]
9	27.21 ± 0.96[c]	2.53 ± 0.60[a]	3.69 ± 0.28[b]	87.65 ± 0.56[b]

Different letters indicate the significant difference in each trial with other treatments ($p<0.05$, Duncan test)

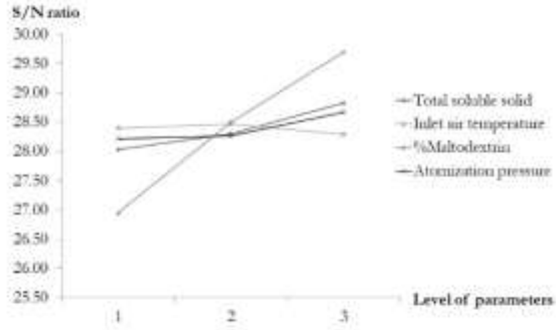

Fig. 1. Effect of processing parameters on yield of spray dried mango

Fig. 1. Effect of processing parameters on yield of spray dried mango (in term of S/N ratio). Level 1 represented 13°brix, 170°C, 20%, and 4 bar TSS, IAT, MAL, and ATOM, respectively. Level 2 represented 14°brix, 190°C, 25%, and 5 bar of TSS, IAT, MAL, and ATOM, respectively. Level 3 represented 15°brix, 210°C, 30%, and 6 bar of TSS, IAT, MAL, and ATOM, respectively.

According to Table 2, mango powder yield ranged from 21.02% - 31.81%. The highest and the lowest yield were obtained from trial 7 and 1, respectively. Effect of each process parameter on studying physicochemical property can be considered from its S/N parameter range as shown in Fig. 1. S/N values of a particular process parameter at the same level were averaged and plotted on a graph to study impact of each parameter. Wide range of S/N ratio of a particular parameter means that parameter greatly affects the observed properties. Maltodextrin concentration was the main factor that could affect yield of production in term of signal to noise ratio (S/N ratio) from 26.95 to 29.70. G.R. Chegini and B. Ghobadian (2007) studied effect of spray drying parameters on dried orange juice. They found that maltodextrin could increase product yield from 18 to 35% [12]. This was because maltodextrin was used as a binder, and could increase solid content in the sample juice directly, then, consequently, more solid could be collected from spray dryer. Conversely, inlet air temperature showed the least influence on the yield of production with S/N ratio ranged from 28.29 to 28.47. Comparison between total soluble solid and atomization pressure, total soluble solid gave higher level effect on yield of production than atomization pressure.

3.2. Effect of process parameters on moisture content

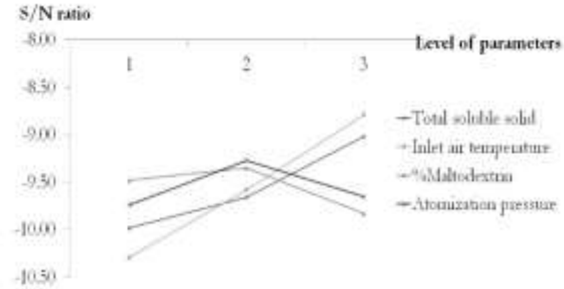

Fig. 2. Effect of processing parameters on moisture content of spray dried mango

Fig. 2. Effect of processing parameters on moisture content of spray dried mango (in term of S/N ratio). Level 1 represented 13°brix, 170°C, 20%, and 4 bar TSS, IAT, MAL, and ATOM, respectively. Level 2 represented 14°brix, 190°C, 25%, and 5 bar of TSS, IAT, MAL, and ATOM, respectively. Level 3 represented 15°brix, 210°C, 30%, and 6 bar of TSS, IAT, MAL, and ATOM, respectively.

Moisture content in a food product is one of the most important physicochemical property of foods. It greatly affects food shelf-life, especially in dried food product. Table 2 shows moisture content of spray dried mango powder. By statistical analysis, moisture contents from every trial were not significantly different from each other ($p \geq 0.05$). The highest and lowest moisture content was found in trial 1 which was 3.43% (w.b.) and trial 9 at 2.53% (w.b.), respectively. Considering S/N ratio of each processing parameter on the spray dried mango powder moisture content as shown in Fig. 2, inlet air temperature was the strongest parameter affecting moisture content. It was consecutively followed by total soluble solid (Brix), maltodextrin, and atomization pressure. It is common to know that temperature greatly affects rate of water removal from materials. Therefore, inlet air temperature played the most important role on water removal. This was not only occurred in this study but also happened in a similar one by R. V. Tonon's (2008) study who reported that inlet air temperature was the most important factor that affect moisture content of spray dried açia powder [13]. The second important parameter affecting the moisture content in this study was total soluble solid content. High total soluble solid content in a sample means less amount of water to be removed by a drying process. The same concept would apply to maltodextrin content. However, due to its hygroscopic property, when it is exposed to the environment for long time, it will absorb water from surrounding environment. G.R. Chegini and B. Ghobadian (2007) found that maltodextrin could increase product yield to 18 – 35%, but between 65 – 82% the powder tended to stick at container surface [12]. Therefore, high level of maltodextrin content would lead to high level moisture absorption and consequently resulting high moisture content mango powder.

3.3. Effect of process parameters on color difference

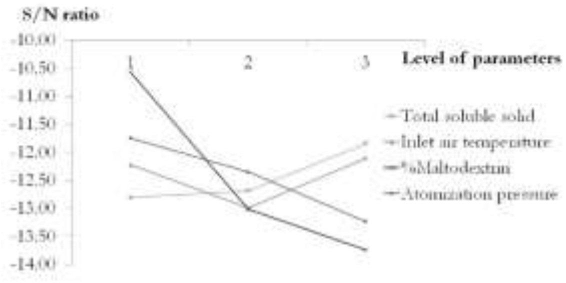

Fig. 3. Effect of processing parameters on color difference of spray dried mango

Fig. 3. Effect of processing parameters on color difference of spray dried mango (in term of S/N ratio). Level 1 represented 13°brix, 170°C, 20%, and 4 bar TSS, IAT, MAL, and ATOM, respectively. Level 2 represented 14°brix, 190°C, 25%, and 5 bar of TSS, IAT, MAL, and ATOM, respectively. Level 3 represented 15°brix, 210°C, 30%, and 6 bar of TSS, IAT, MAL, and ATOM, respectively.

Mango powder from each experiment was measured for its color explaining CIELAB system (L, a*, and b* value). ΔE value of each trial were calculated and listed in Table 2. Minimum color difference value was 3.17 from trial 1, and the maximum was 5.34 from trial 3. From Fig. 3, it was obvious that maltodextrin content in the mango juice was the main factor that affected mango powder color. Maltodextrin has white color. Thus, when maltodextrin was added into mango juice, the juice would have been more white, and therefore increase color difference value compared with the freshly prepared mango juice. The second ΔE influencer was atomization pressure. According to spray drying principles, high atomization pressure produces small droplet size of the juice, and consequently provides large surface area for drying process. This allowed heat to easily destroy pigments in the juice, and also caused heat-induced color change by caramelization and Maillard reactions. Inlet air temperature provided the third impact to the powder color. Similar result was reported by M. A. Watson (2016) who concluded that maltodextrin content significantly affected color change after spray drying of pomegranate juice while drying temperature seem to be less important [14].

3.4. Effect of process parameters on solubility

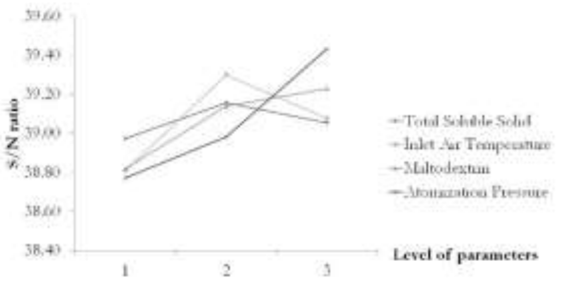

Fig. 4. Effect of processing parameters on solubility of spray dried mango

Fig. 4. Effect of processing parameters on solubility of spray dried mango (in term of S/N ratio). Level 1 represented 13°brix, 170°C, 20%, and 4 bar TSS, IAT, MAL, and ATOM, respectively. Level 2 represented 14°brix, 190°C, 25%, and 5 bar of TSS, IAT, MAL, and ATOM, respectively. Level 3 represented 15°brix, 210°C, 30%, and 6 bar of TSS, IAT, MAL, and ATOM, respectively.

Atomization pressure was the most effective parameter affecting solubility of the mango powder (Fig. 4). The highest solubility of spray dried mango powder was 94.66% (w/w), and the lowest value was 81.17% (w/w) from trial 3 and 1, respectively (Table 2). Due to atomization pressure, it inverted proportional to droplet size, high level of such the pressure will create small droplet and small powder size in consequence. It was able to be explained again that small powder size provided large surface area for dissolving into water. Thus, the highest atomization pressure in this study was 6 bar, providing the highest average S/N ratio, which equaled to 39.43. The next important parameter for solubility of mango powder was inlet air temperature. It was learnt that high inlet air temperature caused low moisture content of powder. Low moisture content allows fast dissolving process due to high concentration gradient between powder surfaces and surrounding liquid. This was happened in low and middle inlet air temperature (level 1 and 2) where S/N ratio of level 2 was higher than the level 1. However, too high temperature can slow dissolving process which occurred with the highest inlet air temperature of this study. This might be caused by too high temperature condition destroyed porous structure inside the powder [15] and then blocked water molecule to penetrate to the inner part of the powder. Hygroscopic property of maltodextrin made it became the third important factor for the powder solubility. Therefore, increasing of maltodextrin content would increase solubility of the powder.

Table 3. Summary of process parameter priorities on spray dried mango powder physicochemical properties. TSS, IAT, MAL, and ATOM stand for total soluble solid, inlet air temperature, maltodextrin content, and atomization pressure, respectively.

Table 3. Summary of process parameter priorities on spray dried mango

Properties	TSS	IAT	MAL	ATOM
Yield	Second	Fourth	First	Third
ΔE	Third	Fourth	First	Second
M.C.	Second	First	Third	Fourth
SOL	Fourth	Second	Third	First

4. Conclusions

This study showed the process parameters affected on physicochemical properties of dried mango powder. It was found that maltodextrin was the most important parameter for producing spray dried mango powder in this study since it provided the greatest effect on both product yield and color change. Atomization pressure and inlet air temperature were similar in term of factor priority. The least effect would come from total soluble solid in which it had never shown the biggest impact to the properties of dried mango powder.

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