Emirates Journal of Food and Agriculture. 2023. 35(5): 442-451
doi: 10.9755/ejfa.2023.v35.i5.3096
http://www.ejfa.me/

RESEARCH ARTICLE

The effect of sugar cane concentration on foam-mat drying kinetics and physicochemical properties of dried-tomato pasta sauce

Nok Afifah*, Novita Indrianti, Lia Ratnawati, Devry Pramesti Putri, Lista Eka Yulianti, Laila Rahmawati, Siti Khudaifanny D.F.A. Putri, and Achmat Sarifudin

Research Center for Appropriate Technology-National Research and Innovation Agency Jl. K.S. Tubun No. 5 Subang 41213, West Java, Indonesia

ABSTRACT

We investigated the effect of sugar cane level and foaming process on the foaming properties, drying kinetics, and physicochemical properties of dried pasta sauce. Experiments were conducted on drying pasta sauce based on tomatoes, both non-foamed and foamed, at selected sugar cane concentrations (0, 15, and 30% g sugar/g concentrated tomato) and a constant drying temperature of 60 °C. The results indicated that the density and viscosity of foamed pasta sauce were lower than that of non-foamed pasta sauce, thereby increasing the drying rate. The higher the sugar cane concentration, the higher the density and viscosity of pasta sauce, resulting in a slower drying rate. The Page model was found as the best model to describe the drying kinetics of pasta sauce. The foaming process and reducing sugar cane concentration generally decreased the final moisture and sucrose content, water activity, water solubility index, and hygroscopicity. Moreover, they increased protein content, water absorption index, and the color of dried pasta sauce. Considering the drying rate and physicochemical properties, we proposed the foaming process and less sugar concentration to produce dried-tomato pasta sauce.

Keywords: Drying kinetics; Foaming process; Pasta sauce powder; Sugar cane

INTRODUCTION

Pasta, including spaghetti, is generally served with tomato sauce (Nakanishi et al., 2018). Pasta sauce is sugar-rich food formulated using tomato paste and sugar. Kim et al. (2010) reported that tomato paste and sugar ratio affected pasta sauce acceptance. It is generally available as a viscous product, which is limited due to its short shelf-life (Fabiano et al., 2000). Drying is one of the methods of preserving pasta sauce by evaporating some water to form a powder product.

However, the drying of sugar-rich foods such as pasta sauce is complex, as they contain low molecular weight components like sugar, citric acid, and others (Bag and Srivastav, 2011). The spray-drying process is widely applied in the food industry to convert acid and sugar-rich foods into powder (Muzaffar et al., 2015). Foam-mat drying is simpler than other methods (such as freeze-drying or spray-drying) because it is less expensive, less complicated, and less time-consuming (Hardy and Jideani, 2017). Furthermore, Rajkumar et al. (2007) suggested that foam-mat drying is suitable for heat-sensitive, viscous, sticky, and high-sugar content food products. When converted to stable foams, materials with high sugar content can be dried rapidly in air to yield instant powders (Rajkumar et al., 2007). In foam-mat drying, foam structure dries rapidly due to increased material surface area by incorporating gas/air and forming porous structures. The more porous the foam structure enhances the heat transfer and drying rate. As a result, a higher nutritional and organoleptic quality will be obtained (Lewicki, 2006).

The drying kinetic models representing the foam-mat drying process behavior have increased the attention of various researchers (Maciel et al., 2017). Drying is estimated to consume 10–15% of the total energy requirements of all food industries (Buzrul, 2022). Describing and modeling

***Corresponding author:**
Nok Afifah, Research Center for Appropriate Technology-National Research and Innovation Agency Jl. K.S. Tubun No. 5 Subang 41213, West Java, Indonesia. **E-mail:** syabiljafa2008@gmail.com

Received: 04 September 2022; **Accepted:** 12 March 2023

the drying process is important for selecting suitable drying conditions to design equipment, optimize production, and improve food quality (Erbay and Icier, 2010; Buzrul, 2022). As drying process involves heat treatment, so there must be some effect on the physicochemical characteristics of final product (Abbasi and Azizpour, 2016). The foam mat drying for sugar-rich foods revealed mainly about the fruit drying, including mango pulp (Rajkumar et al., 2007), yogurt powder (Krasaekoopt and Bhatia, 2012), milk powder (Febrianto et al., 2012), sour cherry (Abbasi and Azizpour, 2016), and guava pulp (Maciel et al., 2017). Sadahira et al. (2016) reported that proteins, sugars, and polysaccharides might interact, which affected foaming and rheological properties. They evaluated the effect of sugar on the foaming process and the physical properties of dried products. However, no studies have examined the effect of sugar cane concentration on the physicochemical properties of dried pasta sauce, moreover its effect on drying kinetics. Thereover, this study was carried out to investigate the effect of the foaming process and sugar cane concentration on the drying kinetics and physicochemical properties of dried pasta sauce.

MATERIALS AND METHODS

Materials

The materials used to prepare pasta sauce powder included concentrated tomato (Wilmond, Zhejiang Ju Zhen Yuan Foodstuffs Co., Longquan, Zhejiang, China), sugar cane (PT. Gula Putih Mataram, Indonesia), xanthan gum (Fufeng, China), Carboxyl Methyl Cellulose/CMC (PT. Gunacipta Multirasa, Indonesia), salt (PT. Sidola, Indonesia), garlic, onion, and pepper (produced by PT. Gunacipta Multirasa, Indonesia), oregano leave powder (PT. Hoka Jaya International, Indonesia), and vinegar 25% (Indomaret, Indonesia). Sugar cane employed in this study contained sucrose of 97.1% and moisture content of 0.61%

Sample preparation

The samples were prepared following the procedure reported by Afifah et al. (2022) with slight modifications. The composition of pasta sauce (percentage of concentrated tomato weight) was salt (6%), onion (4%), garlic (4%), salt (2%), oregano leaves (1.5%), xanthan gum (1%), vinegar (1%) and water (200%), while sugar cane was added following the treatments, namely 0%, 15%, and 30%. All ingredients are mixed and cooked for 5 min.

The composition of foamed pasta sauce (percentage of pasta sauce weight) was egg white (9%) and CMC (0.1%). In order to prepare the foamed samples, the pasta sauce, CMC, and egg white were whipped in a 3-speed kitchen mixer (Philips hand mixer HR1552) at a speed setting of 3 for 5 min. 300 g of sample was layered on a 40x30 cm aluminum tray with 0.14 + 0.03 cm thickness. Three trays were dried in a drying oven (Memmert UFB500) at a constant temperature of 60 ^{o}C and air velocity of 2.7 m/s for 10 h. The trays were previously weighed, and the samples were weighed every hour during the drying process. The dried pasta sauce was pulverized using a blender (Philips HR2115) and sieved by the 20-mesh screen. The sample was stored in a sealed plastic bag and kept in the refrigerator prior to analysis. Each treatment was repeated three times, and the sample analysis was duplicated.

Analysis of foaming properties of pasta sauce

The viscosity of foamed sauce was determined using a viscometer (Brookfield DV-E, United State of America). The spindle S64 was dipped in the sample until the spindle's shaft was immersed and measured at 60 rpm.

The foam density (FD) of foamed pasta sauce is expressed in mass over volume in g/mL. 100 mL of the sample was poured into a 100 mL measuring cylinder and weighed at ambient temperature (25^{o}C + 1) (Bag and Srivastav, 2011).

Analysis of chemical properties of dried pasta sauce

The moisture content was determined following AOAC (1990) procedure using a hot air oven (Memmert UM500). Sucrose content was analyzed using the Luff–Schoorl method following the procedure outlined in OJEU (1979) No L 239/24 (OJEC, 1979).

Protein content was measured according to the Dumas combustion method by using DuMaster (Buchi D-480, Switzerland). 0.2 g of samples are weighed into tin foil, placed into a sample loader, dropped into a hot furnace (950 ^{o}C), and flushed with oxygen for very rapid and complete combustion. The protein content was measured automatically by the instrument using a conversion factor of 6.25

The water activity (a_w) was measured by using a smart water activity meter HD-3A (CGoldenwell, China) according to the procedure described by (Azizpour et al., 2016). The sample of 2 g was placed in the cup and a_w was measured automatically by the instrument.

Analysis of physical properties of dried pasta sauce

The water absorption index (WAI) and water solubility index (WSI) were evaluated following the procedure described by Azizpour et al. (2016) and Shaari et al. (2017) with slight modifications. 1 g of sample was placed in a centrifuge tube of 50 mL and added to 40 mL of distilled water. The sample solution was stirred using a vortex mixer VM-300 for 10 min and centrifuged at 4,000 xg for 20 min. The supernatant was transferred into a weighing bottle and dried overnight in an oven at 105 ^oC. The hydrated powder remaining in the centrifuge tube was then weighed. The WSI was calculated as a percentage of the total dry solids in the original weight of the sample. The WAI was calculated using equation 1.

$$WAI = \frac{m_{rc}}{m_0 - m_{re}} \quad (1)$$

where m_{rc} is the weight of the residue centrifugation (g), m_0 is the weight of sample (g), m_{re} is the weight of evaporated residue.

Hygroscopicity was measured using the procedure reported by Shaari et al. (2017) with slight modification. 2 g of sample was placed in a crucible dish and stored in an airtight desiccator filled with a saturated solution Na_2SO_4 (81% RH) at 25 ^oC for seven days. The difference in weight was calculated to determine the hygroscopicity (1 g of adsorbed moisture per 100 g dry solids) according to equation 2.

$$Higroscopicity = \frac{(\Delta m / m_s) + m_a}{1 + \Delta m / m_s} \quad (2)$$

where Δm corresponds to the increase of sample's weight (g), m_s is the sample's initial weight (g), and m_a is the free water present in the sample before measurement (g/100 g).

The color of samples was measured by a chromameter (3NH, China) according to Azizpour et al. (2016). The sample was put in an instrument dish and placed in the dish chamber. The sensor of the color meter then read the color parameters automatically. The color parameters (L*, a*, and b*) define a three-dimensional color space, in which L* demonstrates brightness (on a lightness–darkness scale), positive-negative a* values measure the redness-greenness, and positive-negative b* values represent yellowness-blueness, respectively.

Drying models

The experimental data were fitted using three thin-layer drying models (equation 3-5), including the Page model, the Logarithmic model, and the Wang and Singh model (Erbay and Icier, 2010).

$$MR = \exp(-kt^n) \quad (3)$$

$$MR = a\exp(-kt) + c \quad (4)$$

$$MR = 1 + at + bt^2 \quad (5)$$

where M_o is the initial dry basis moisture, M_t is the dry basis moisture at the study time, M_e is the dry basis moisture equilibrium, t is time, k is drying constants (s^{-1}), and a, b, c, n are model constants (dimensionless), except for Wang and Singh model dimension of a and b was s^{-1} dan s^{-2}, respectively. In these models, the moisture ratio (MR) was simplified to M_t/M_o instead of $(M_t - M_e)/(M_o - M_e)$. the M_e value can be neglected if the M_e value is very small compared to M_o and M_t values (Diamante & Munro, 1993).

Statistical analysis

The procedure of non-linear regression based on the Levenberg-Marquardt algorithm was used to calculate the coefficients of the kinetics parameters (Doymaz, 2013) using SPSS 13.0 software. The correlation coefficient (R^2) and the root mean square error (RMSE) were determined to evaluate the fit between the experimental data and the model (equation 6-7). An analysis of variance (ANOVA) and Duncan test (confidence level, α= 0.05) was performed on the obtained results of different sugar concentrations to establish significant differences. Comparing results of without and with foaming process was carried out by the Paired-t test.

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N} \left(MR_{pre,i} - MR_{exp,i} \right)^2}{\sum_{i=1}^{N} \left(\overline{MR}_{pre} - MR_{exp,i} \right)^2} \right] \quad (6)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} \left(MR_{pre,i} - MR_{exp,i} \right)^2 \right]^{1/2} \quad (7)$$

where MR_{pre} is the predicted moisture ratio based on the selected model and MR_{exp} is the experimental moisture ratio.

RESULTS AND DISCUSSION

Foaming properties of pasta sauce

The effect of sugar cane concentration on the foaming properties of pasta sauce is presented in Table 1.

Data are expressed as mean ± standard deviation (n=3). Values with different superscript uppercase letters in the same row indicate significant differences ($P < 0.05$); Values with superscript lowercase letters in the same column indicate significant differences ($P < 0.05$)

As sugar concentration increased, the viscosity of pasta sauce with or without foaming increased significantly. Jo and Yoo (2019) reported that sugar has hydroxyls that are attracted to water molecules. In the aqueous system, the water concentration could be reduced in the presence of sugar, resulting in a decrease in polymer-solvent interactions. In addition, the attractions in the sugar-water system lead to much larger molecules, resulting in higher viscosity. Nastaj et al. (2021) also reported a rise in foamed sauce viscosity by increasing sugar concentration. Raikos et al. (2007) pointed out the relation of foam solution viscosity with surface tension. The addition of sucrose increases surface

Table 1: Viscosity and density of pasta sauce

Chemical properties	Sugar concentration (%)	Without foaming	Foaming
Viscosity (mPa.s)	0	7 353.33+187.71^{Aa}	6 776.67+289.19^{Aa}
	15	8 676.67+270.06^{Bb}	7 396.67+51.32^{Ab}
	30	10 816.67+85.05^{Bc}	8 316.67+35.12^{Ac}
Density (g/mL)	0	1.06+0.01^{Ba}	0.70+0.01^{Aa}
	15	1.09+0.01^{Bb}	0.79+0.01^{Ab}
	30	1.12+0.01^{Bc}	0.82+0.01^{Ac}

Data are expressed as mean±standard deviation (n=3). Values with different superscript uppercase letters in the same row indicate significant differences (P<0.05); Values with superscript lowercase letters in the same column indicate significant differences (P<0.05)

tension of solutions and decreases the surface activity of globular proteins due to their lower hydrophobicity, resulting in a more viscous solution. Therefore, protein molecules tend to remain in a continuous phase thus do not adsorb at the air-water interface, affecting protein foamability (Nastaj et al., 2021). The viscosity of foamed pasta sauce was significantly lower than that of pasta sauce without foaming, as Rajkumar et al. (2007) reported. The foaming process involves incorporating a foaming agent (egg white) into semi-liquid foods by subsequent whipping, resulting in a more dilute liquid.

The density of pasta sauce without and with foaming increased significantly by adding sugar concentration. In addition, the foam density of foamed pasta sauce was significantly lower than pasta sauce without foaming. The added sugar in pasta sauce caused the solution to be denser, resulting in higher density. The density increase of foamed pasta sauce is likely related to increased sauce viscosity, allowing less air to be incorporated. The lower air entrapped, the higher the foam density, as Raikos et al. (2007) reported. In the foamed pasta sauce system, sugars, proteins, and polysaccharides may interact with each other. According to Lau and Dickinson (2005), the sugar addition increased continuous phase viscosity which caused decreasing air incorporation. The high viscosity possibly hindered the incorporation of air bubbles during whipping and influenced molecular diffusion, decreasing the adsorption rate of protein (Sadahira et al., 2018). Raikos et al. (2007) reported that sucrose created a less favorable thermodynamic environment for protein so that sucrose could limit protein unfolding and the development of protein-protein interactions.

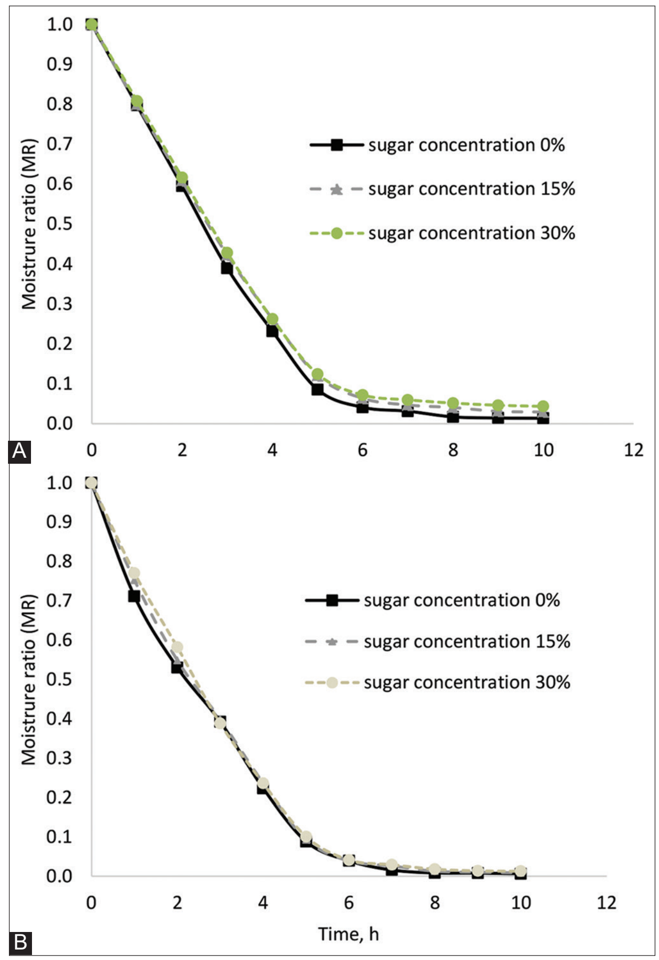

Fig 1. Moisture ratio of pasta sauce during the drying process (A: without foaming and B: with foaming).

Drying kinetics model

The effect of sugar cane concentration on non-foamed and foamed pasta sauce on dimensionless moisture content (Me) during drying is illustrated in Fig. 1.

The MR decreased fast in the early part of drying and tended to be constant after 7 h. The moisture content was decreased with a reduction in sugar concentration and incorporation of foaming and stabilizing agent. The time utilized to attain a moisture content of ~10% w.b. (wet base) for non-foamed samples was 455, 494, and 518 min at the sugar concentration of 0, 15, and 30%, respectively, while foamed pasta sauce took drying time of 446, 452, and 458 min. It indicates that the drying rate of foamed sauce was faster than that of non-foamed sauce. The drying rate relates to the surface area of material that exposures heat (Bag and Srivastav, 2011). As shown in Table 1, the foamed sauces had more expanse than that of non-foamed sauce, resulting in a more porous structure and a larger liquid surface area, enhancing the heat transfer and drying rate. In addition, Rajkumar et al. (2007) reported that a decrease in viscosity due to foaming operation eased the moisture movement through the foamed pulp and decreased the time required for drying. Likewise, the sugar added to the sauce will inhibit the incorporation of air in the emulsion, reducing the surface area. Similar results were reported by Rajkumar et al. (2007), Abdel Rahman (2012), and Gupta and Alam (2014). Abdel Rahman (2012) observed that the high level of sucrose created leathery layers on the surface of the puree (case hardening), decreasing its vapor pressure.

The constants, coefficients, and statistical analysis values of the models are summarized in Table 2.

The selection of models considered that the semi-theoretical and empirical models require small amounts of time compared to the theoretical models and do not need the geometry assumptions of a typical food or its mass diffusivity and conductivity (Ertekin and Firat, 2015). The Page model and the Logarithmic model (represent semi-theoretical models) and the Wang and Singh model (represent empirical models) were applied and compared to illustrate the drying kinetics of MR profile. The Page model and Logarithmic model describe the drying kinetics as an exponential function derived by analogs with Newton's law of cooling and Fick's second law of diffusion, respectively. The Wang and Singh model illustrated the process as a new quadratic function (Erbay and Icier, 2010). Mathematical model fitting resulted in R^2 greater than 0.98 in all the treatments, indicating a good fit model. According to statistical analysis of all models, the Page model obtained the highest value of R^2 and the lowest value of RMSE in the sugar concentration range studied. Table 2 shows that for the Page model, the 'k' (the drying constant) values of foamed sauce were higher than that of pasta sauce without foaming. Moreover, the addition of sugar decreased the 'k' value. The "k" value of the non-foamed sauce on sugar cane concentration of 15% was higher than that of a concentration of 0%, but the 'n' value was lower, resulting in a slower drying rate. It was consistent with the viscosity and density of pasta sauce.

Chemical properties of dried pasta sauce

Table 3 illustrate the effect of sugar cane concentration and foaming process on the water activity, moisture, sucrose, and protein content of dried pasta sauce.

Data are expressed as mean ± standard deviation (n=3). Values with different superscript uppercase letters in the same row indicate significant differences (P < 0.05); Values with superscript lowercase letters in the same column indicate significant differences (P < 0.05)

The moisture content of dried pasta sauce without foaming increased significantly as the sugar concentration increased. Although it was not significantly different, a similar trend was observed in the foamed pasta sauce. The foamed pasta sauce had a significantly lower moisture content at the same sugar concentration than that of non-foamed pasta sauce. This result is in good agreement with the drying rate and drying constants value of pasta sauce in Figure 1 and Table 2. The foaming process creates tiny bubbles, which causes a larger surface area for moisture evaporation. The foaming process made the drying mass extremely porous and easier to dry to its deepest layers (Sangamithra et al., 2014). Therefore, the foaming treatment resulted in lower moisture content for the same drying time (10 h). An increase in the sauce viscosity is proportional to the increase in the sugar concentration. The thicker sauce hinders the incorporation of air in the emulsion, reducing the surface area of heat transfer and resulting in the higher moisture content of the dried product.

Table 2: Constants, coefficients, and statistical analysis values of the drying model

Drying model	Sugar concentration (%)		Coefficient	R^2	RMSE
Page	Without foaming	0	k=0.189 n=1.509	0.997	0.041
		15	k=0.192 n=1.423	0.997	0.019
		30	k=0.188 n=1.429	0.994	0.022
	Foaming	0	k=0.268 n=1.279	0.992	0.029
		15	k=0.234 n=1.356	0.995	0.024
		30	k=0.212 n=1.417	0.997	0.019
Logarithmic	Without foaming	0	a=1.139 k=0.302 c = -0.09	0.983	0.039
		15	a=1.123 k=0.288 c = -0.080	0.985	0.041
		30	a=1.111 k=0.292 c = -0.064	0.983	0.043
	Foaming	0	a=1.092 k=0.319 c = -0.077	0.990	0.032
		15	a=1.112 k=0.308 c = -0.084	0.989	0.035
		30	a=1.122 k=0.303 c = -0.086	0.987	0.038
Wang and Singh	Without foaming	0	a = -0.250 b=0.015	0.994	0.031
		15	a = -0.240 b=0.014	0.995	0.034
		30	a = -0.238 b=0.014	0.994	0.034
	Foaming	0	a = -0.257 b=0.016	0.994	0.026
		15	a = -0.252 b=0.016	0.996	0.028
		30	a = -0.250 b=0.015	0.996	0.029

In this study, sugar cane was added to pasta sauce as a sweetening agent. The effect of sugar cane concentration and foaming process on sucrose content of dried pasta sauce is presented in Table 3. There is a tendency that the higher concentration of sugar cane used, the higher the sucrose content contained in these dried pasta sauces. While at the same sugar concentration, no significant difference in sucrose content was observed in foamed pasta sauce and non-foamed pasta sauce. Sugar cane has a moisture content of 0.61%, sucrose content of 97.1%, and inverted sugar of 1.24%. Thus, the addition of sugar cane increased the sucrose content of dried pasta sauce.

As shown in Table 3, the foaming treatment had a significantly lower water activity (a_w) than that of without foaming. As the sugar concentration increased, the water activity of the sample tended to increase. Generally, sugar can reduce water activity (Davis, 1995). Furthermore, at high sugar concentrations, water activity tends to be affected by the amount of low molecular weight substances (sucrose) due to the colligative property of water (Pongsawatmanit et al., 2002). In this study, the increased water activity by increasing the sugar cane level suggested that free water in the examined systems dominated the overall water activity. This result was strengthened with the final moisture content of dried pasta sauce.

The protein content of dried pasta sauce with and without foaming decreased significantly by adding sugar cane concentration. The presence of sucrose decreases the adsorption of ovalbumin protein because ovalbumin forms hydrogen bonds with the sugar molecules (Raikos et al., 2007). This result agrees with the previous study reported by Jamhari et al. (2018). It is due to the increase of sugar cane levels increasing the proportion of total solid content. Table 3 shows that the protein content of foamed pasta sauce was significantly higher than that of non-foamed pasta sauce. Protein albumen in egg white is widely used as a foaming agent due to its good foaming stability (Noordia et al., 2020). Egg white, so-called albumen, contains about 9.7-10.6% protein. Using of egg white as a foaming agent could enhance the protein content of pasta sauce powder under foam mat drying. Kandasamy et al. (2012) reported that the biochemical compositions in the foamed dried papaya powder were significantly higher than those of the non-foamed dried papaya powder. A similar result was also reported by Teoh et al. (2016) that the protein content in foam mat dried corn flour was higher than the protein content in non-foamed dried corn flour.

Table 3: Moisture content, sucrose content, water activity, and protein content of dried pasta sauce

Chemical properties	Sugar concentration (%)	Without foaming	Foaming
Moisture content, % (wet base)	0	$6.87{+}0.30^{Ba}$	$3.49{+}0.21^{Aa}$
	15	$10.87{+}0.36^{Bb}$	$3.82{+}0.23^{Aa}$
	30	$11.92{+}0.41^{Bc}$	$4.14{+}0.39^{Aa}$
Sucrose content % (dry base)	0	$6.54{+}1.62^{Aa}$	$7.48{+}1.32^{Aa}$
	15	$23.29{+}2.20^{Ab}$	$23.01{+}0.31^{Ab}$
	30	$33.12{+}2.48^{Ac}$	$34.67{+}3.07^{Ac}$
Water activity (a_w)	0	$0.30{+}0.01^{Ba}$	$0.20{+}0.02^{Aa}$
	15	$0.32{+}0.01^{Ba}$	$0.23{+}0.01^{Aa}$
	30	$0.36{+}0.01^{Bb}$	$0.29{+}0.01^{Ab}$
Protein content, % (dry base)	0	$12.10{+}0.34^{Ac}$	$17.90{+}0.08^{Bc}$
	15	$9.17{+}0.18^{Ab}$	$14.13{+}0.24^{Bb}$
	30	$7.12{+}0.14^{Aa}$	$11.31{+}0.08^{Ba}$

Data are expressed as mean±standard deviation (n=3). Values with different superscript uppercase letters in the same row indicate significant differences (P<0.05); Values with superscript lowercase letters in the same column indicate significant differences (P<0.05)

Physical properties of dried pasta sauce

The hydration properties of dried pasta sauce, including water absorption index, water solubility index, and hygroscopicity are presented in Table 4.

Data are expressed as mean ± standard deviation (n=3). Values with different superscript uppercase letters in the same row indicate significant differences (P < 0.05); Values with superscript lowercase letters in the same column indicate significant differences (P < 0.05)

The water absorption index (WAI) shows instant powder's ability to re-associate under limited water conditions. The WAI value of the foaming sample is significantly higher than that without foaming at the same sugar concentration. According to Shaari et al. (2017), the absorption capacity of the liquid into the material is influenced by moisture content, porosity, total solids content, and powder texture. In line with Pua et al. (2010), the foamed powders have a larger surface area to enhance the contact area between powder and water. This finding is consistent with the density of foamed pasta sauce in Table 1. In addition, the

Table 4: Water absorption index, water solubility index, and hygroscopicity of dried pasta sauce

Physical properties	Sugar concentration (%)	Without foaming	Foaming
Water Absorption Index (WAI), g/g	0	$7.25{+}0.23^{Ab}$	$9.83{+}0.36^{Bb}$
	15	$6.58{+}0.08^{Aa}$	$9.46{+}0.14^{Bb}$
	30	$6.39{+}0.20^{Aa}$	$8.84{+}0.08^{Ba}$
Water Solubility Index (WSI), g/g	0	$0.68{+}0.01^{Aa}$	$0.66{+}0.01^{Aa}$
	15	$0.75{+}0.01^{Bb}$	$0.71{+}0.01^{Ab}$
	30	$0.83{+}0.01^{Bc}$	$0.76{+}0.01^{Ac}$
Hygroscopicity, g/100 g	0	$5.31{+}0.37^{Ba}$	$2.70{+}0.16^{Aa}$
	15	$8.62{+}0.27^{Bb}$	$3.16{+}0.11^{Aa}$
	30	$10.38{+}0.72^{Bc}$	$3.42{+}0.25^{Aa}$

Data are expressed as mean±standard deviation (n=3). Values with different superscript uppercase letters in the same row indicate significant differences (P<0.05); Values with superscript lowercase letters in the same column indicate significant differences (P<0.05) free hydroxyl group present in the foaming agent facilitates the binding of water molecules from the surrounding environment, thereby affecting the water absorption index in dry food (Shaari et al., 2017). The results showed that the added sugar concentration tended to lower the WAI score for dried pasta sauce. The addition of sugar concentration reduces the WAI score also in rice flour extrudate (Silva et al., 2009). Samples without added sugar had a higher WAI score than those with added sugar. The addition of sugar produces a powder with higher water content, resulting in more sticky powder and less surface to bind water (Munawar et al., 2020). Samples with a higher water content also have the potential to cause clumps, which causes additional time needed to break the bonds between particles so that the water adsorption power decreases (Widyasanti et al., 2018). This result is in agreement with the moisture content of dried pasta sauce presented in Table 3.

The water solubility index (WSI) indicates the ability of the powder to dissolve and mix homogeneously with water. The results of this study indicate that the foaming treatment and the addition of sugar significantly affect the WSI score. The sugar concentration treatment significantly increased the WSI score of all treatments. The addition of sugar increases the WSI score in rice flour extrudates (Silva et al., 2009). It is because sucrose has a low molecular weight that contributes to increasing the total dissolved solids content, thereby increasing the solubility of the product (Silva et al., 2009; Pui et al., 2021). Generally, the foaming treatment had a trend of lowering the WSI score. This could be because the egg albumin protein will be denatured and coagulated during the drying process, which causes the solubility of the powder in water to decrease (Affandi et al., 2017).

Pasta sauce powder is expected to be hygroscopic due to its high sugar content. The effect of sugar addition and foaming process on hygroscopicity is mentioned in Table 4. The hygroscopicity of non-foaming pasta sauce exhibited significantly higher than that of foaming pasta sauce. The sugar concentration significantly increased the hygroscopicity of non-foaming pasta sauce. The higher hygroscopicity suggests easier moisture adsorption of pasta sauce powders. Hygroscopicity is related to physical properties, chemical content, and microbiological stability (Shaari et al., 2017). In addition, hygroscopic properties are related to solubility properties and the hydroxyl group (Davis, 1995). The hygroscopicity of powders with high sugar levels is attributed to the amorphous state of sugar and loose free-flowing nature at high moisture content (Jaya and Das, 2004). Sugars are responsible for strong interaction with water molecules due to the polar terminal. The moisture adsorption is attributed to the links between the hydrogen present in water molecules and the hydroxyl groups available in the amorphous regions of sugars. This result is consistent with the moisture content of pasta sauce. The moisture content of foaming treatment was lower than non-foaming treatment, implying that less hydrogen is available to bind to the hydroxyl group of sugar, resulting in lower hygroscopicity. Shaari et al. (2017) observed a similar result that non-foamed powder's hygroscopicity was higher than foam mat dried powder.

Color is one of the most critical parameter quality attributes of the dried product to the nutritional value. The result concerning the effect of sugar addition (0%, 15%, 30%) and the effect of the foaming process are presented in Table 5.

As the increasing sugar addition in the drying process without foaming, a*, b* increased not significantly, while L* decreased significantly. On the other hand, the increased sugar added in the drying process with the foaming agent shows that a*, b* increased significantly and not significantly, respectively. While L* decreased significantly. Similar results were observed by Gupta and Alam (2014) and Sramek et al. (2015).

Viuda-Martos et al. (2012) reported that lightness (L*) in foods is related to several factors, such as concentration and type of pigments present, water content, and water concentration on the surface. Tomato paste color is affected by carotenoid pigment compounds (lyco-red) with the major carotenoids of tomato are lycopene, β-carotene, cis-lycopene, phytoene, phytofluene, and lutein (Rizk et al., 2014). Akanbi and Oludemi (2007) reported that the raw tomato had a bright-light red color and changed into dark red after being exposed to heat due to lycopene is a heat-sensitive pigment. This change may be due to the isomerization of lycopene from all transform to cis-isomers (Yildiz and Baysal, 2007). This is in line with Kadam et al. (2012) that the change in lycopene content of dried powder was due to its heat-labile nature. The higher lightness of foaming treatments is due to

Table 5: The color parameters of dried pasta sauce

Color	Sugar concentration	Without foaming	Foaming
Lightness-darkness (L)	0	48.06+0.96^{Ac}	55.11+1.16^{Bc}
	15	38.01+0.97^{Ab}	44.99+0.75^{Bb}
	30	33.17+0.48^{Aa}	42.81+0.58^{Ba}
Redness-greenness (a)	0	10.80+0.89^{Aa}	12.98+0.27^{Aa}
	15	10.66+0.09^{Aa}	13.37+0.53^{Bab}
	30	10.99+0.34^{Aa}	13.97+0.40^{Bb}
Yellowness-blueness (b)	0	11.51+0.88^{Aa}	15.42+0.71^{Ba}
	15	11.62+0.12^{Aa}	17.84+1.14^{Bb}
	30%	11.65+0.25^{Aa}	19.24+0.09^{Bb}

*) Data are expressed as mean±standard deviation (n=3). Values with different superscript uppercase letters in the same row indicate significant differences (P<0.05); Values with superscript lowercase letters in the same column indicate significant differences (P<0.05)

the white color of the egg as a foaming agent. The decrease of the L* value was more prominent in tomato paste with foaming agents; egg white as foaming agents could decline in lycopene. The decrease of lycopene could indicate the changes in color to the darkness.

The increase in a* and b* values is possibly related to the browning reaction. However, there were no significant ($p<0.05$) results concerning the a*, b* value by increasing sugar cane concentration, especially at treatment without foaming agent addition. Moreover, pasta sauces are subjected to high temperatures during the drying process may cause enzymatic and non-enzymatic browning (Maillard reactions). The Maillard reaction must have a molecule containing an amine (egg protein), a reducing sugar (sugar cane), and water. This result is consistent with sucrose content and protein content in Table 3. Furthermore, Davis (1995) explained that as sugar dehydrates to hydnoxymethyl-furfunal, α-dicarboxyl compounds form with pigments. It suggests that as amino sugars develop, they begin to impart color to the food.

Regarding the quality parameters of food powders, lower values of water content, water activity, hygroscopicity, more excellent water absorption and solubility index are desirable properties to be applied in food formulations due to the storage stability (Bakar et al., 2013). The foaming process and decrease in sugar cane concentration promise to produce dried pasta sauce by maintaining its quality. Moreover, these processes revealed a faster drying rate, which needs lower energy consumption.

CONCLUSIONS

Based on the study, it was observed that reducing sugar cane concentration and foaming process reduced the viscosity of pasta sauce and improved the incorporation of air in the emulsion, resulting in lower density and a faster drying process. Based on the three models we proposed, the Page model was the fitted model to describe the drying kinetics. In addition, the foaming process and decreasing sugar cane level reduced water activity, water solubility index, hygroscopicity, enhanced water absorption index, and color of dried pasta sauce. It is suggested that free water dominates in the interaction of water, sugar, and protein. Therefore, foam mat drying and reducing sugar cane concentration holds a good process in preparing pasta sauce powder.

ACKNOWLEDGEMENT

We thank the National Research and Innovation Agency, Republic of Indonesia and the R&D team of the Research Center for Appropriate Technology.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

Authors' contributions

Contributions of each author are listed below:

Nok Afifah: funding acquisition, methodology, laboratory work, validation, writing and editing.

Novita Indrianti: methodology, laboratory work, validation, writing and editing.

Lia Ratnawati: laboratory work, writing and editing.

Lista Eka Yulianti: laboratory work, writing and editing.

Devry Pramesti Putri: laboratory work, writing and editing.

Siti Khudaifanny Dasna Febrianti Asna Putri: laboratory work

Laila Rahmawati: writing and editing.

Achmat Sarifudin: supervision, review and editing.

REFERENCES

Abbasi, E. and Azizpour, M. 2016. Evaluation of physicochemical properties of foam mat dried sour cherry powder. LWT Food Sci. Technol. 68: 105-110.

Abdel Rahman, G. H. 2012. Effect of sucrose levels on drying rate and some quality characteristics of tamarind (*Tamarindus indica*) leathers. J. Sci. Technol. 13: 75-84.

Affandi, N., W. Zzaman, T. A. Yang and A. M. Easa. 2017. Production of *Nigella sativa* beverage powder under foam mat drying using egg albumen as a foaming agent. Beverages. 3: 1-15.

Afifah, N., A. Sarifudin, R. Kumalasari, N. Indrianti, L. Ratnawati, M. A. Karim, U. Hanifah, A. Haryanto, Y. H. Siregar, L. Rahmawati and A. Taufan. 2022. Foaming properties, microstructure, and mathematical model of foam mat drying of pasta sauce based on tomato. Czech J. Food Sci. 40: 130-137.

Akanbi, C. T. and F. O. Oludemi. 2007. Effect of processing and packaging on the lycopene content of tomato products. Int. J. Food Prop. 7: 139-152.

Azizpour, M., M. Mohebbi and M. H. H. Khodaparast. 2016. Effects of foam-mat drying temperature on physico-chemical and microstructural properties of shrimp powder. Innov. Food Sci. Emerg. Technol. 34: 122-126.

Bag, S. K. and P. P. Srivastav. 2011. Optimization of process parameters for foaming of bael (*Aegle marmelos* L.) fruit pulp. Food Bioprocess Technol. 4: 1450-1458.

Bakar, J., S. C. Ee, K. Muhammad, D. M. Hashim and N. Adzahan. 2013. Spray-drying optimization for red Pitaya peel (*Hylocereus polyrhizus*). Food Bioprocess Technol. 6: 1332-1342.

Buzrul, S. 2022. Reassessment of thin-layer drying models for foods: A critical short communication. Processes. 10: 1-14.

Da Silva, M. C., C. W. P. De Carvalho and C. T. Andrade. 2009. The effects of water and sucrose contents on the physicochemical properties of non-directly expanded rice flour extrudates. Ciênc. Tecnol. Aliment. (Campinas). 29: 661-666.

Davis, E. A. 1995. Functionality of sugars: Physicochemical interactions in foods. Am. J. Clin. Nutr. 62(1 Suppl): S170-S177.

Diamante, L. M. and P. A. Munro. 1993. Mathematical modelling of thin layer solar srying of sweet potato slices. Solar Energy. 51: 271-276.

Doymaz, I. 2013. Determination of infrared drying characteristics and modelling of drying behaviour of carrot pomace. J. Agric. Sci. 19: 44-53.

Erbay, Z. and F. Icier. 2010. A review of thin layer drying of foods: Theory, modeling, and experimental results. Crit. Rev. Food Sci. Nutr. 50: 441-464.

Ertekin, C. and M. Z. Firat. 2015. A comprehensive review of thin layer drying models used in agricultural products. Crit. Rev. Food Sci. Nutr. 57: 37-41.

Fabiano, B., P. Perego, R. Pastorino and M. Del Borghi. 2000. The extension of the shelf-life of 'pesto' sauce by a combination of modified atmosphere packaging and refrigeration. Int. J. Food Sci. Technol. 35: 293-303.

Febrianto, A., S. Kumalaningsih and A. W. Aswari. 2012. Process engineering of drying milk powder with foam mat drying method, A study of the effect of the concentration and types of filler. J. Basic Appl. Sci. Res. 2: 3588-3592.

Gupta, K. and M. S. Alam. 2014. Mass and color kinetics of foamed and non foamed grape concentrate during convective drying process: A comparative study. J. Eng. Technol. Res. 6: 48-67.

Hardy, Z. and V. A. Jideani. 2017. Foam-mat drying technology: A review. Rev. Food Sci. Nutr. 57: 2560-2570.

Jamhari, E. Suryanto, Sundari and D. A. Laksmiwati. 2018. The effect pf sugar cane level and drying methods on chemical and physical qualities beef "dendeng". Bull. Anim. Sci. 42: 67-71.

Jaya, S. and H. Das. 2004. Effect of maltodextrin, glycerol monostearate and tricalcium phosphate on vacuum dried mango powder properties. J. Food Eng. 63: 125-134.

Jo, W. and B. Yoo. 2019. Effect of sucrose on rheological properties of xanthan gum-locust bean gum mixtures. Food Sci. Biotechnol. 28: 1487-1492.

Kadam, D. M., R. A. Wilson, S. Kaur and Manisha. 2012. Influence of foam mat drying on quality of tomato powder. Int. J. Food Prop. 15: 1211-1220.

Kandasamy, P., N. Varadharaju, S. Kaleemullah and R. Moitra. 2012. Preparation of papaya powder under foam-mat drying technique using egg albumin as foaming agent. Int. J. Bio Resorce Stress Manag. 3: 324-331.

Kim, J. H., Y. Lee, N. Joo, K. Choi and C. Sohn. 2010. Development and application of a novel tomato sauce using natural seasoning. Korean J. Food Cookery Sci. 26: 138-145.

Krasaekoopt, W. and S. Bhatia. 2012. Production of yogurt powder using foam-mat drying. AU J. Technol. 15: 166-171.

Lau, C. K. and E. Dickinson. 2005. Instability and structural change in an aerated system containing egg albumen and invert sugar. Food Hydrocoll. 19: 111-121.

Lewicki, P. P. 2006. Design of hot air drying for better foods. Trends Food Sci. Technol. 17: 153-163.

Maciel, R. M. G., M. R. A. Afonso, J. M. C. da Costa, L. S. Severo and N. D. De Lima. 2017. Mathematical modeling of the foam-mat drying curves of guava pulp de secagem em Camada de espuma de polpa de Goiaba. Revista Brasileira de Engenharia Agricola e Ambiental, 21: 721-725.

Munawar, N., N. Azhar, N. S. Rohaizad and N. Hussain. 2020. Characterization of watermelon rind powder using foam mat drying with different types of foaming agents and temperatures. Asian J. Fundam. Appl. Sci. 1: 1-10.

Muzaffar, K., G. A. Nayik and P. Kumar. 2015. Stickiness problem associated with spray drying of sugar and acid rich foods: A mini review. J. Nutr. Food Sci. S12: 11-13.

Nakanishi, Y., K. Irie and M. Murata. 2018. Factors affecting the suitability of boiled pasta with tomato sauce for eating. Food Sci. Technol. Res. 24: 159-167.

Nastaj, M., S. Mleko, K. Terpilowski and M. Tomaczynska-Mleko. 2021. Effect of sucrose on physicochemical properties of high-protein meringues obtained from whey protein isolate. Appl. Sci. 11: 4764.

Noordia, A., Y. S. Mustar and N. W. Kusnanik. 2020. Foam mat drying of banana juice: Varieties of ripe banana analysis and egg albumen foam. Food Sci. Technol. 40: 465-468.

OJEC. 1979. Laying Down Community Methods of Analysis for Testing Certain Sugars Intended for Human: Vol. No L 239/2. Available from: https://www.eur-lex.europa.eu/legal-content/en/txt/pdf/?uri=celex:31979l0796&from=fr [Last accessed on 2021 Sep 14].

Pongsawatmanit, R., P. Thanasukarn and S. Ikeda. 2002. Effect of sucrose on RVA viscosity parameters, water activity and freezable water fraction. Sci. Asia. 28: 129-134.

Pua, C. K., N. S. A. Hamid, C. P. Tan, H. Mirhosseini, R. B. A. Rahman and G. Rusul. 2010. Optimization of drum drying processing parameters for production of jackfruit (*Artocarpus heterophyllus*) powder using response surface methodology. LWT Food Sci. Technol. 43: 343-349.

Pui, L. P., R. Karim, Y. A. Yusof, C. W. Wong and H. M. Ghazali. 2021. Effects of inlet temperature and carrier concentration on spray-dried "cempedak" (*Artocarpus integer*) fruit powder and its reconstitution properties. Acta Sci. Pol. Technol. Aliment. 20: 135-148.

Raikos, V., L. Campbell and S. R. Euston. 2007. Effects of sucrose and sodium chloride on foaming properties of egg white proteins. Food Res. Int. 40: 347-355.

Rajkumar, P., R. Kailappan, R. Viswanathan and G. S. V. Raghavan. 2007. Drying characteristics of foamed alphonso mango pulp in a continuous type foam mat dryer. J. Food Eng. 79: 1452-1459.

Rizk, E. M., A. T. El-kady and A. R. El-bialy. 2014. Characterization of carotenoids (lyco-red) extracted from tomato peels and its uses as natural colorants and antioxidants of ice cream. Ann. Agric. Sci. 59: 53-61.

Sadahira, M. S., M. I. Rodrigues, M. Akhtar, B. S. Murray and F. M. Netto. 2016. Effect of egg white protein-pectin electrostatic interactions in a high sugar content system on foaming and foam rheological properties. Food Hydrocoll. 58: 1-10.

Sadahira, M. S., M. I. Rodrigues, M. Akhtar, B. S. Murray and F. M. Netto. 2018. Influence of pH on foaming and rheological properties of aerated high sugar system with egg white protein and hydroxypropylmethylcellulose. LWT Food Sci. Technol. 89: 350-357.

Sangamithra, A., S. Venkatachalam, S. G. John and K. Kuppuswamy. 2014. Foam mat drying of food materials: A review. J. Food Process. Preserv. 39: 1-10.

Shaari, N. A., R. Sulaiman, R. A. Rahman and J. Bakar. 2017. Production of pineapple fruit (*Ananas comosus*) powder using foam mat drying: Effect of whipping time and egg albumen concentration. J. Food Process. Preserv. 42: 1-10.

Sramek, M., R. M. Schweiggert, A. Van Kampen, R. Carle and R. Kohlus. 2015. Preparation of high-grade powders from tomato paste using a vacuum foam drying method. J. Food Sci.

80: E1755-E1762.

Teoh, L. S., O. Lasekan and S. Azeez. 2016. Quality characteristics and volatile compounds of foam mat dried corn flour. J. Food Qual. 39: 456-464.

Viuda-Martos, M., Y. Ruiz-Navajas, A. Martin-Sánchez, E. Sánchez-Zapata, J. Fernández-López, E. Sendra, E. Sayas-Barberá, C. Navarro and J. A. Pérez-Álvarez. 2012. Chemical, physico-chemical and functional properties of pomegranate (*Punica granatum* L.) bagasses powder co-product. J. Food Eng. 110: 220-224.

Widyasanti, A., N. A. Septianti and S. Nurjanah. 2018. Effect of maltodextrin addition on the physicochemical properties of tomato powder processed by foam mat drying. Agrin. 22: 22-38.

Yildiz, H. and T. Baysal. 2007. Color and lycopene content of tomato puree affected by electroplasmolysis. Int. J. Food Prop. 10: 489-495.