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Foaming properties, microstructure, and mathematical model of foam mat drying of pasta sauce based on tomato

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Abstract: In the present study, the foam mat drying technique was used to dry pasta sauce based on tomato to become powder. The effect of different egg white concentrations (3, 6, and 9%) and whipping time (2 min and 5 min) on the foam properties of pasta sauce, including foam density, foam expansion, foam viscosity, water activity, morphological and drying behaviour, were investigated. The foamed sauce was dried in a batch-type thin-layer dryer at constant conditions (temperature of 60 °C). Six thin-layer drying models were employed to determine the drying kinetics of the pasta sauce. The results showed that an increase in the egg white concentration and a decrease in the whipping time produced a foamed sauce with low foam density and viscosity and high foam expansion. The Wang and Singh model was the best model to describe the drying behaviour of foamed sauce. According to Fick's second law model, the effective moisture diffusivity of the pasta sauce ranged from 4.95×10^{-7} to 10.04×10^{-7} m^2 s^{-1}.

Keywords: drying kinetics; egg white; foamed sauce; whipping time

The demand for ready-to-cook (RTC) and/or ready-to-eat (RTE) food increases mainly due to the easiness of meal preparation (Yerlikaya et al. 2005). Pasta is an important RTC meal that is usually served with sauce. In the market, pasta sauce is generally available as a viscous product. It shows some limitations, such as short shelf life and bulky storage. The powdered sauce can be obtained by drying the viscous sauce. Previous studies reported that foam mat drying techniques are suitable to prepare a powder product from viscous products such as fruit pulp powder (Maciel et al. 2017), yoghurt powder (Krasaekoopt and Bhatia 2012), milk powder (Febrianto et al. 2012), and shrimp powder (Azizpour et al. 2016). The combination of foaming and hot air drying is a simpler and more economic alternative than spray drying and freeze drying to prepare instant powder (Balasubramanian et al. 2012; Hardy and Jideani 2017).

Foam mat drying is a process in which a liquid or semi-liquid (puree or paste) food is converted into a stable dried form product by incorporating a large volume of gasses in the presence of an edible foaming agent and/or stabiliser and then subsequently dried (Balasubramanian et al. 2012). Lately, it has received much attention due to being a relatively inexpensive and simple process, rapid drying rates at lower temperatures, and enhanced product quality (Abbasi and Azizpour 2016). Foam mat drying is suitable to dry

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viscous, sticky, heat-sensitive, and high-in-sugar food products, which are difficult to dry by other tray drying techniques (Labelle 1984). In foam mat drying, essential factors to generate stable foam are foaming agents, foam stabilisers, whipping time, and air incorporation (Balasubramanian et al. 2012). Therefore, it is important to optimise these factors to obtain stable foam.

During the drying process, it is possible to evaluate the behaviour of the solid material based on the drying kinetics. Effective mathematical models are required to obtain optimum conditions in process design, optimisation, and control. These models are needed to improve the understanding of how the drying conditions impact the food properties, minimise the number of tests required to determine optimal drying conditions, and develop efficient control strategies for the process (Erbay and Icier 2010; Mercier et al. 2015). The mathematical models that represent the behaviour of the foam mat drying process have increased the attention of various researchers (Maciel et al. 2017). The foam mat drying kinetics for food has been reported for cantaloupe pulp (Salahi et al. 2014), shrimp (Azizpour et al. 2014), pumpkin pulp (Das et al. 2015), guava pulp (Maciel et al. 2017), murici pulp (Antunes et al. 2017). Nevertheless, no drying kinetic model was found for the case of foam mat drying for the production of pasta sauce powder. Therefore, the objective of this study was to investigate the effect of different concentrations of foaming agent (egg white) and whipping times in the development of mathematical models of foam mat drying of pasta sauce.

MATERIAL AND METHODS

Material. Tomato paste (Zhejiang Ju Zhen Yuan Foodstuffs Co., China), sago starch (Javara Indigenous, Indonesia), xanthan gum (Fufeng, China), carboxymethyl cellulose (CMC) (Gunacipta Multirasa, Indonesia), sugar (Gula Putih Mataram, Indonesia), salt (Sidola, Indonesia), garlic, onion, and pepper (Gunacipta Multirasa, Indonesia), and oregano leaf powder (Hoka Jaya International, Indonesia) were used.

Sample preparation. The composition of pasta sauce was tomato paste (29%), sugar (9%), salt (2%), sago starch (1%), xanthan gum (1%), garlic (1%), onion (1%), pepper (0.4%), oregano leaves (0.3%), and the rest was water. All ingredients were mixed and heated (RI-302S; Rinnai, Indonesia) until a homogeneous mixture was obtained. For foam preparation, egg white was foamed in a 3-speed kitchen mixer (hand mixer HR1552; Philips, Indonesia) with a flat beater at speed setting 3 for a specific time according to the experimental design presented in Table 1. An amount of 0.3% CMC (based on the weight of egg white) and 450 g of pasta sauce were added to foamed egg white. This mixture was then whipped at speed setting 1 for 1 min. A 150-g sample was layered on a 40 × 30 cm aluminium tray with a sample thickness of 0.16 ± 0.02 cm. Three trays were dried in a drying oven (UFB500; Memmert, Germany) at a constant temperature of 60 °C and air velocity of 2.7 m s^{-1} for 3 h. The trays were previously weighed (EC; CAS Co., South Korea), and the samples were weighed every 30 min during the drying process. Each treatment was repeated three times, and the sample analysis was done in duplicate.

Determination of foam properties. Analysis of foam properties included foam density, foam expansion, and viscosity. The foam density of foamed pasta sauce is expressed in mass per volume in g mL^{-1}. The sample of 100 mL was carefully poured into a 100 mL measuring cylinder and weighed at ambient temperature (25 ± 1 °C) (Bag and Srivastav 2011). The foam expansion volume is measured as a per cent increase in the volume of foamed sauce. It is calculated by dividing the difference between final and initial volume by initial volume (Balasubramanian et al. 2012). The viscosity of foamed sauce was measured as the viscosity of non-Newtonian fluid using a viscometer (DV-E; Brookfield, US). It was determined using the S64 spindle at 30 rpm. The moisture content of foamed pasta sauce was determined following the procedure of Association of Official Analytical Chemists (AOAC 1990). The water activity (a_w) was measured according to the procedure described by Azizpour et al. (2016) by using a smart water activity meter HD-3A (CGoldenwell, China). The sample of 2 g was placed in the cup and a_w was measured automatically by the instrument.

Microstructure. A scanning electron microscope (JSM-IT300; Jeol, Japan) was used to study the micro-

Table 1. Experimental design

Treatment	EG (%)	WT (min)
AT2	3	2
AT5	3	5
BT2	6	2
BT5	6	5
CT2	9	2
CT5	9	5

EG – egg white concentration; WT – whipping time; A – EG 3%; B – EG 6%; C – EG 9%; T2 – WT 2 min; T5 – WT 5 min

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structure of the samples. The micrograph of dried pasta sauce was taken at an accelerating voltage of 20 kV and magnification of 500 times. Samples were scattered on a double-sided adhesive tape attached to a circular aluminium stub and then coated with gold before observation (Salahi et al. 2014).

Drying models. The experimental data were fitted using six thin-layer drying models (Equations 1–6): Newton, Henderson-Pabis, Page, logarithmic, Wang and Singh, and Thompson (Erbay and Icier 2010). If the relative humidity (RH) of drying air continuously fluctuates and the M_e value is very small compared to M_0 and M_t values, the M_e value can be neglected (Diamante and Munro 1993). In these models, the moisture ratio (MR) was simplified to M_t/M_0 instead of $(M_t - M_e)/(M_0 - M_e)$ (where: M_0 – initial dry basis moisture; M_t – dry basis moisture at the study time; M_e – dry basis moisture equilibrium).

$$MR = \exp\left(-kt\right) \quad (1)$$

$$MR = a\exp\left(-kt\right) \quad (2)$$

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

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

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

$$t = a\ln\left(MR\right) + b\left[\ln\left(MR\right)\right]^2 \quad (6)$$

where: t – time; k – drying constant (s^{-1}); a, b, c, n – model constants (dimensionless), except for the Wang and Singh model the dimension of a and b was s^{-1} and s^{-2}, respectively.

Fick's diffusion equation for particles with slab geometry was applied to calculate effective moisture diffusivity (D_{eff}). The foamed pasta sauce spread on a tray was considered for slab geometry. The equation is expressed as follows:

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (7)$$

where: D_{eff} – effective moisture diffusivity ($m^2\ s^{-1}$); L – thickness of the slab (m).

SPSS 13.0 software was used to calculate the constants and coefficients of the selected models. The procedure of non-linear regression based on the Levenberg-Marquardt algorithm was applied to determine the coefficients of the kinetic parameters (Doymaz 2013). The correlation coefficient (R^2) and the root mean square error (RMSE) were determined to evaluate the fit between the model and the experimental data. Analysis of variance (ANOVA) and Duncan's test (confidence level, α = 0.05) were performed on the obtained results in order to establish significant differences.

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}\left(MR_{pre,\,i} - MR_{\exp,\,i}\right)^2}{\sum_{i=1}^{N}\left(\overline{MR}_{pre} - MR_{\exp,\,i}\right)^2}\right] \quad (8)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,\,i} - MR_{\exp,\,i}\right)^2\right]^{1/2} \quad (9)$$

where: MR_{pre} – predicted moisture ratio; MR_{exp} – experimental moisture ratio.

RESULTS AND DISCUSSION

Foam properties. The observations for foam density, foam expansion, and viscosity of foamed pasta sauce with different independent variables are presented in Table 2. Foam density is used to evaluate the whipping properties. The foam density was reduced significantly with an increase in the egg white concentration and a decrease in the whipping time. The air was incorporated into the liquid and entrapped as bubbles during the whipping process. Lower foam density indicates that more air was entrapped into the liquid. The protein of egg white reduces the surface tension, enables foam formation, and stabilises the foaming system by improving the interfacial rheology and modifying the inter-particle forces between foam bubbles (Hardy and Jideani 2017). Therefore, it leads to a decrease in foam density as the egg white concentration increases. Similar results were reported by Abbasi and Azizpour (2016) for sour cherry powder and by Falade et al. (2003) for cowpea produced by the foam mat drying method.

The results showed that the whipping time of 2 min produced foam with a lower density than that of 5 min. An increase in whipping time could probably overbeat, which leads foam to collapse. As well as in the case of a too high aeration degree, the liquid layer between

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Table 2. Foam properties of foamed pasta sauce (mean ± SD; n = 3)

Treatment	Foam density (g mL^{-1})	Foam expansion (%)	Viscosity (mPa.s)
AT2	0.84 ± 0.01^{d}	24.16 ± 0.61^{ab}	10 426.67 ± 741.44^{c}
AT5	0.87 ± 0.01^{e}	18.68 ± 1.61^{a}	10 620.00 ± 539.26^{c}
BT2	0.78 ± 0.01^{c}	34.13 ± 2.87^{c}	9 086.67 ± 170.10^{ab}
BT5	0.80 ± 0.01^{c}	30.24 ± 1.80^{bc}	9 746.67 ± 170.10^{bc}
CT2	0.66 ± 0.01^{a}	53.38 ± 2.52^{d}	8 400.00 ± 556.78^{a}
CT5	0.71 ± 0.01^{b}	52.03 ± 1.99^{d}	8 950.00 ± 816.88^{ab}

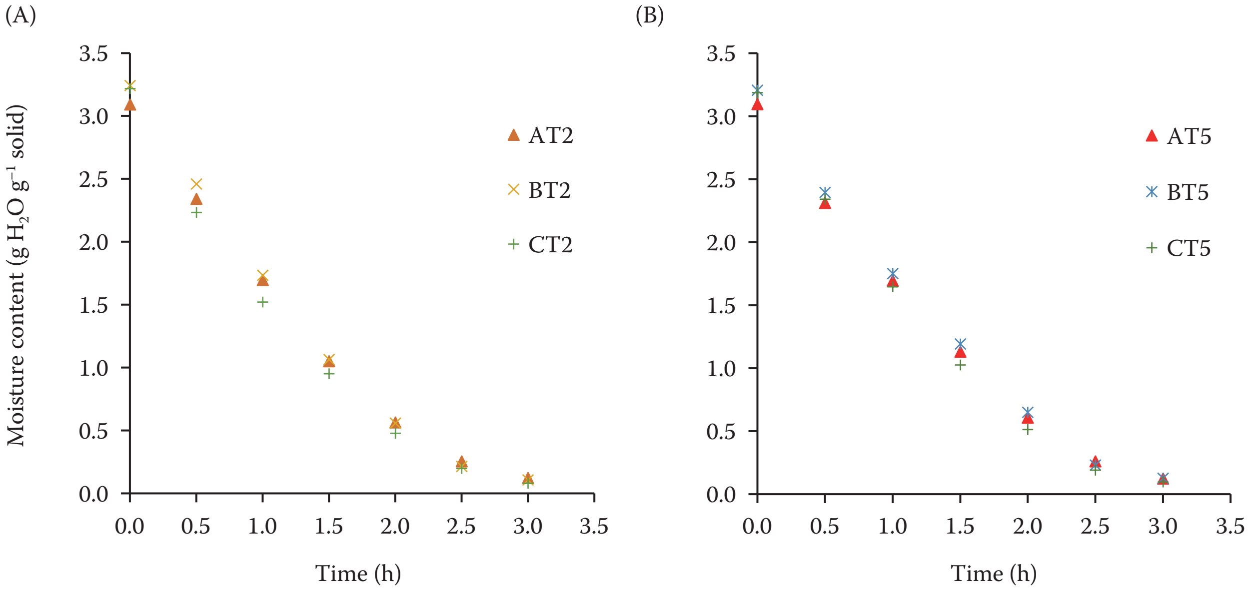
$^{a-e}$different letters within columns indicate statistically significant differences (P < 0.05); SD – standard deviation; A – egg white concentration (EG) 3%; B – EG 6%; C – EG 9%; T2 – whipping time (WT) 2 min; T5 – WT 5 min

the foam bubbles is getting thinner, and the mechanical deformation can cause the bubble wall structure to rupture (Falade et al. 2003). This study is in line with studies conducted by Falade et al. (2003) and Bag and Srivastav (2011).

The foam expansion volume indicates the amount of air incorporated into the sauce during foaming (Asokapandian et al. 2015). The rise in the egg white concentration resulted in a significant increase in expansion volume. It is related to the decrease in surface tension which triggers more air trapped in the foam. However, the increasing whipping time tended to decrease the expansion volume. Extension of the whipping time could lead to the rupture of formed foam.

Data showed that the whipping time did not give to the foamed pasta sauce significantly different viscosity. On the other hand, 9% egg white resulted in significantly lower viscosity than 3% egg white. Asokapandian et al. (2015) stated that incorporating CMC as a foam stabiliser improved the foam stability. CMC will stabilise the foam by increasing viscosity, and at higher concentrations, the solution becomes too viscous (Balasubramanian et al. 2012). At a lower egg white concentration, the CMC portion in the foam solution increased, resulting in a thicker foamed pasta sauce. Sadahira et al. (2016) noted that a lower ratio of egg white resulted in lower foam expansion as indicated by a decrease in the air bubble formation and in more viscous solution.

Drying behaviour. Figure 1 presents the drying curve of the foam layer of pasta sauce at different egg white concentrations and whipping times. The curve demonstrates a drying process characterised by a gradual



Figures 1. Drying curve of foamed pasta sauce at (A) WT 2 min and (B) WT 5 min

WT – whipping time; A – egg white concentration (EG) 3%; B – EG 6%; C – EG 9%; T2 – WT 2 min; T5 – WT 5 min

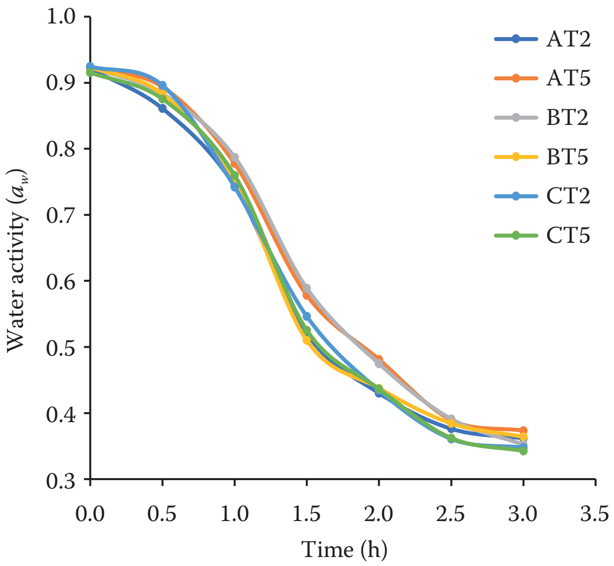


Figure 2. The water activity curve of foamed pasta sauce

A – egg white concentration (EG) 3%; B – EG 6%; C – EG 9%; T2 – whipping time (WT) 2 min; T5 – WT 5 min

decrease in moisture content over the drying process. The drying process in various treatments could be considered as a falling rate period. The increase in the egg white concentration tended to increase the drying rate of foamed pasta sauce as indicated by a low moisture content value of the sample.

The initial moisture content of pasta sauce ranged from 75.52% to 76.30% while the final moisture content after the drying process for 3 h ranged from 7.45% to 10.56%. The water activity values of pasta sauce during the drying process are presented in Figure 2. The figure shows the same trend of decreasing moisture content for all treatments. According to Mishra et al. (2017), the lower the moisture content, the lower the water activity even though the moisture content and water activity are not directly proportional. Pasta sauces had initial a_w ranging from 0.90 to 0.93. During the drying process, the a_w value of the sample decreased, then 3 h of drying resulted in dry pasta sauce with a_w values ranging from 0.34 to 0.37. These results indicated that the a_w value for all treatments was below the critical a_w value. For most food, the critical point of safe food is below 0.6–0.7, in which no microorganisms show the ability to grow (Bonazzi and Dumoulin 2011). In addition, they suggested that the main objective of drying is to decrease the water activity (a_w) of various perishable materials to values less than 0.5 to enable their storage at ambient temperature.

The MR data obtained from the foam mat drying of pasta sauce at different egg white concentrations and whipping times were fitted into thin layer drying models (Equations 1–6). The correlation coefficient and RMSE values for each drying model are presented in Table 3. Based on the statistical analysis, all models showed high R^2 values of more than 0.95 except for the Newton model. Among the models, the Wang and Singh model exhibited the highest value of R^2 and the lowest value of RMSE, agreeing with Das et al. (2015) in the drying of pumpkin pulp. The model had R^2 and RMSE values of 0.998–0.999 and 0.027–0.068, respectively.

Constants and coefficients of the Wang and Singh model are presented in Table 4. Data showed that the rise in egg white concentration leads to a reduction in the parameter '*a*' and an increase in the parameter '*b*'. On the other hand, the increase in whipping time resulted in the opposite results.

The effective moisture diffusivity (D_{eff}) values are presented in Table 4. It can be seen that the effective diffusivity of foamed pasta sauce increased as the percentage of egg white concentration increased and the whipping time decreased. The effective diffusivity of CT2 and CT5 [C – egg white concentration of 9%; T2, T5 – whipping time 2 min and 5 min, respective-

Table 3. Statistical results of the models

Treatment	Newton		Henderson Pabis		Page		Logarithmic		Wang and Singh		Thompson	
	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE
AT2	0.748	0.062	0.976	0.058	0.998	0.033	0.995	0.036	0.998	0.033	0.992	0.161
AT5	0.736	0.058	0.977	0.055	0.995	0.031	0.997	0.029	0.999	0.027	0.992	0.139
BT2	0.770	0.068	0.974	0.065	0.998	0.041	0.996	0.044	0.998	0.042	0.989	0.204
BT5	0.735	0.060	0.974	0.057	0.994	0.034	0.997	0.030	0.998	0.028	0.989	0.155
CT2	0.853	0.076	0.987	0.075	0.997	0.069	0.999	0.068	0.999	0.068	0.996	0.266
CT5	0.797	0.070	0.978	0.068	0.997	0.051	0.997	0.051	0.999	0.050	0.990	0.229

RMSE – root mean square error; A – egg white concentration (EG) 3%; B – EG 6%; C – EG 9%; T2 – whipping time (WT) 2 min; T5 – WT 5 min

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Table 4. Constants of the Wang and Singh model and effective diffusivity for foamed pasta sauce

Treatment	Constants of Wang and Singh model		Effective diffusivity ($m^2 s^{-1}$)
	a	*b*	
AT2	-0.549^{a}	0.075^{a}	$5.485E-07^{ab}$
AT5	-0.537^{a}	0.071^{a}	$4.954E-07^{a}$
BT2	-0.561^{a}	0.078^{a}	$6.538E-07^{ab}$
BT5	-0.532^{a}	0.069^{a}	$5.963E-07^{ab}$
CT2	-0.628^{a}	0.101^{a}	$1.004E-06^{c}$
CT5	-0.582^{a}	0.085^{a}	$8.386E-07^{bc}$

$^{a-c}$different letters within columns indicate statistically significant differences ($P < 0.05$); A – egg white concentration (EG) 3%; B – EG 6%; C – EG 9%; T2 – whipping time (WT) 2 min; T5 – WT 5 min; *a, b* – model constants

ly] was significantly higher than that of AT5 (A – egg white concentration of 3%; T5 – whipping time 5 min). The concentration of egg white exhibited a greater influence on the drying process, as indicated by their diffusion coefficient values.

Microstructure. Microstructures of foamed pasta sauce are presented in Figure 3. It revealed that the mat structure was uniform at the AT5 treatment. Nonetheless, the uniformity decreased, especially with increasing egg white concentration. This figure indicates that there were cavities in their structure. Franco et al. (2016) explained that these cavities were probably caused by the space left by the air bubbles contained in the yacon foams, contributing to their porosity. Higher portions of cavities arise from an increase of egg white concentration which accelerates the drying process.

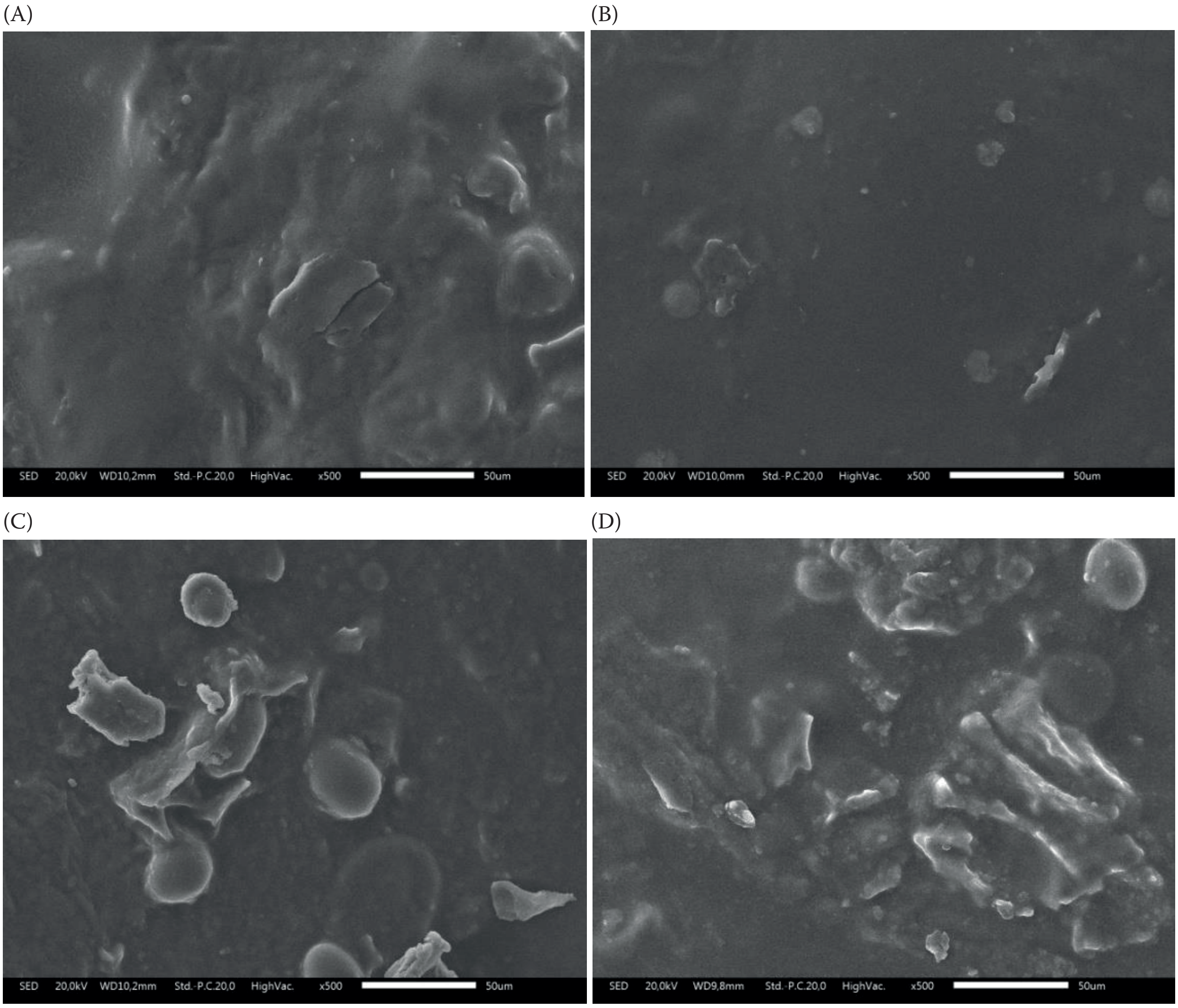

Figure 3. Scanning electron micrographs of dried foam mat sauce – (A) AT2, (B) AT5, (C) BT5, and (D) CT5

A – egg white concentration (EG) 3%; B – EG 6%; C – EG 9%; T2 – whipping time (WT) 2 min; T5 – WT 5 min

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CONCLUSION

During the drying of foamed pasta sauce, the higher concentration of egg white yielded lower foam density and viscosity of foamed pasta sauce, but it increased the foam expansion of the sample. The whipping time of 2 min produced the foamed pasta sauce with better foaming properties than those produced by the whipping time of 5 min. The foam mat drying study revealed that with the increase in egg white concentration and the decrease in whipping time, the drying rate and the effective diffusivity values increased. The Wang and Singh model was found to be the best model providing the highest R^2 and the lowest RMSE at all drying treatments. Cavities were formed when the egg white concentration was increased.

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