Pertanika J. Sci. & Technol. 31 (3): 1379 - 1411 (2023)

PERTANIKA JOURNALS

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Influence of Carrier Agents Concentrations and Inlet Temperature on the Physical Quality of Tomato Powder Produced by Spray Drying

S. M. Anisuzzaman[1, 2]*, Collin G. Joseph[3] and Fatin Nadiah Ismail[2]

[1]*Energy Research Unit (ERU), Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia*
[2]*Chemical Engineering Program, Faculty of Engineering, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia*
[3]*Industrial Chemistry Program, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia*

ABSTRACT

The study aims to obtain spray-dried tomato powders with a high and effective product yield and enhanced powder quality. The experiment for this investigation entailed the use of several carrier agents, which were maltodextrin (MD) of 4-7 dextrose equivalents (DE), MD of 10-12 DE, and gum Arabic (GA), each in varied concentrations of 5% and 10% with spray drying inlet temperatures of 140°C, 150°C, and 160°C. Powder yield, bulk density, hygroscopicity, moisture content, water solubility, water absorption, color properties, particle size, and powder morphology were all evaluated in spray-dried tomato powders. The results revealed that the stability of the tomato powder is considerably better at high temperatures and concentrations (at 10%, 160^{o}C), with MD 4-7 DE being the best carrier agent among the three tested carrier agents. According to the powder analysis, the product has a moisture content of 3.17 ± 0.29%, the highest yield percentage of 32.1%, a low bulk density of 0.2943 ± 0.01 g/cm^3, the lowest hygroscopicity at 5.67 ± 0.58 %, a high water solubility index (WSI) at 89.98 ± 1.25%, a low water absorption index (WAI) at 6.22 ± 0.22%, an intermediate particle size of 24.73 µm, and color L*, a*,b* values at 31.59 ± 0.03, 11.62 ± 0.08 and 13.32 ± 0.12. The result showed that at higher temperatures and higher concentrations, the powder characteristics are more likely to have a higher yield, WSI, and larger particle size, as well as lower bulk density, hygroscopicity, moisture content, WAI, and color index.

Keywords: Carrier agents, gum Arabic, hygroscopicity, maltodextrin, spray drying

ARTICLE INFO

Article history:
Received: 11 March 2022
Accepted: 01 August 2022
Published: 31 March 2023

DOI: https://doi.org/10.47836/pjst.31.3.15

E-mail addresess:
collin@ums.edu.my (Collin G. Joseph)
dr.anis.ums@gmail.com (S. M. Anisuzzaman)
anis_zaman@ums.edu.my (Fatin Nadiah Ismail)
*Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

INTRODUCTION

Tomatoes are readily integrated as a healthier part of a balanced diet as they contain good amounts of healthy dietary components, including carotenoids, especially lycopene, water-soluble vitamins, and phenoliccompounds (Li et al., 2018; Martínez-Huélamo et al., 2016; Raiola et al., 2014). However, its high-water content may hinder the conservation of tomato products and post-harvest losses. High moisture level results in higher water activity that promotes quality degradation as the enzymatic activity increases and microbial development (Aderibigbe et al., 2018). Due to this, drying is commonly done to preserve food products. Several drying methods have been used for the convenience of the large food industry, and such fundamental drying methods include conventional hot air drying, solar drying, spray drying, freeze drying, contact drying, infrared, and dielectric drying, as well as reaction engineering approach (REA) (Compaore et al., 2017; Hii et al., 2021; Ismail et al., 2020; Uyar et al., 2015; Ziaforoughi & Esfahani, 2016). Although conventional hot air drying has great availability, the process is time-consuming and an energy-intensive food preservation method.

Solar drying is a very inexpensive drying method, but it has numerous shortcomings since the food has been exposed to a source of contamination (Adak et al., 2017). As for freeze drying, it is much slower and more costly since it includes very complicated and multi-step processes like freezing, primary drying, and secondary drying. This technique is typically used to transform materials sensitive to heat into powder form since it preserves their natural conformations better. Another drying method is contact drying, which includes drying a product by exposing it to heated walls. This method is extensively utilized in heavy industry drying operations and is demonstrated through drum and vacuum drying (Haque & Adhikari, 2014). Infrared drying involves exposing solid food to an infrared heating source, which raises the temperature of the food surface (Ziaforoughi & Esfahani, 2016). In dielectric drying, heat is transferred directly to the product, and faster heating up is observed inside the product than on the surface. However, the drawback of this technique is that it will cause runaway heating that leads to non-uniform heating (Uyar et al., 2015). The REA may identify the product quality and functioning variables by calculating heat and mass balances at the individual droplet level (Patel & Chen, 2008).

Spray drying is one of the processes utilized to create dried food powder and can assist in reducing post-harvest losses while adding value to the raw product. The conversion process comprises the liquid feed atomization, which is then heat treated to lower its moisture content to the desired level (Lee et al., 2018). The benefit of spray drying lies in its ability to manufacture high-nutrient products with flavor retention and rapid moisture evaporation throughout the conversion of liquid feed material to dry powdery form, resulting in higher powder stability and resistance to oxidative and microbiological degradation. Powders formed by spray drying may also be kept at room temperature for extended periods without impacting their stability. Although spray drying is a potential preservation technology, converting high-value food components into particle form is challenging because of the high amount of low relative molecular weight sugars in their composition, which causes stickiness. As a result, product output will be decreased, and operational difficulties may arise. The low glass transition temperature (T_g) of the low-molecular-weight sugars prevalent in such products, notably fructose, sucrose, and glucose, is mainly accountable for powder stickiness (Bhandari & Howes, 2005; Muzaffar et al., 2015). Because of the low T_g of the tomato's low-molecular-weightsugars, tomato pulp is an excellent sample of a product that is tough to spray dry. Severalsolutes, such as maltodextrins (MD) of 4-7 dextrose equivalents (DE), MD of 10-12 DE, and gum Arabic (GA), were employed as carrier or coating agents during the spray drying process to decrease stickiness.

Measuring the T_g of the food product may not be enough to solve the problem, even though this may be the best instrument for predicting the structural behavior of the product after drying. A more realistic strategy is required to deal with sugary raw materials. Adding carrier agents has been the most utilized strategy for dealing with drying. Even though using a high quantity of carrier agents has become the most frequent way to dry such products, there is no defined strategy for optimizing carrier agent utilization. It is one of the topics that have to be addressed more thoroughly. Aside from the stickiness issue, lycopene, which is important for the red color of tomatoes, can be damaged by spray drying heat processing (Goula & Adamopoulos, 2005). Due to this, the inlet and exit air temperatures, together with the concentration of the feed, in a spray drying process are critical parameters that must be controlled. Table 1 summarizes different drying methods used in the food industry.

Table 1

Summary of different drying methods used in the food industry

Drying method	Advantages	Disadvantages	Reference
Solar drying	Inexpensive drying method	Exposed to a source of contaminations. Very vulnerable to weather conditions. Slow drying process. Also, molding of food may occur due to slow drying.	Adak et al. (2017); Ziaforoughi and Esfahani (2016)
Hot air convective drying	Great availability and moisture saturation capability.	Considered a highly destructive operation, particularly problematic for thermally sensitive materials, it consumes much time and energy.	Szadzińska et al. (2017)

Table 1 *(Continue)*

Drying method	Advantages	Disadvantages	Reference
Freeze drying	Keep most of their taste, shape, and nutritional value. It does not need to be kept cold and can be used for month's even years. Foods that have been dehydrated cannot be rehydrated as quickly as freeze-dried foods.	Expensive. Freeze-dried foods also take up almost as much space as fresh foods.	Ciurzyńska and Lenart (2011); Nowak and Jakubczyk (2020); Haque and Adhikari (2014)
Infrared drying	Short drying time, energy saving. The air is not stirred, unlike conventional convectors. The ambient humidity is pushed out without drying the ambient air.	Heat transmission to food is extremely slow. No heat retaining. The body can suffer from water loss with infrared heaters. It only provides targeted heating.	Adak et al. (2017); Ziaforoughi and Esfahani (2016)
Microwave drying	Because of technological advancement, additional parameters such as time efficiency, low energy usage, and excellent product quality may be monitored.	Heating runaway, high cost. May result in particle overheating and unfavorable degradation of bioactive constituents.	Pu et al. (2016); Zielinska and Michalska (2016); Szadzińska et al. (2017)
Radiofrequency drying	It takes less time, uses less energy, and produces better product quality	Causes runaway heating which often leads to non-uniform heating	Uyar et al. (2015)
Osmotic drying	Preserve color, fragrance, nutritional compounds, and flavor	The final moisture content is unstable. Take days until water loss reaches equilibrium	Eren and Kaymak-Ertekin (2007); da Costa Ribeiro et al. (2016)
Lyophilization	Generally preferred for converting heat-sensitive material to powder since it preserves their natural structures better.	Consume much time and has a high drying cost. Low product yield, not steady production, and the possibility of chill injury.	Wang et al. (2017); Haque and Adhikari (2014)

Table 1 *(Continue)*

Drying method	Advantages	Disadvantages	Reference
Spray drying	A common method for microencapsulation, suitable for heat-sensitive material, effective technology in protecting probiotic and bioactive compounds, and lower time consumed. Fully automated and continuous. Short residence times and suitability for both heat-sensitive and heat-resistant foods.	Low product yield due to dry particle losses. The spray dryer is bulky and also expensive to install. It has a low thermal efficiency which is much heat is wasted during operation.	Chegini and Ghobadian, (2007); Goula and Adamopoulos (2008); Souza et al. (2018); Zhu et al. (2014)

Several studies have been conducted on the effects of different carrier agents on process parameters and the qualities of spray-dried products (Souza et al., 2018; Shishir et al., 2017; Goula & Adamopoulos, 2008). However, there is a scarcity of studies that provide in-depth insight into the effects of different carrier agents on the varied characterization of powders. This study focuses on practical knowledge about additives in spray drying performance and the effects of temperature and concentration. Therefore, the main objective of this study was to study the different effects of carrier agents and examine the impact of different inputs of inlet air temperature and carrier agent concentrations on the powder properties to obtain spray-dried tomato powders with an effective product yield and an improved powder quality. The experiments of this study have used different carrier agents such as MD of 4-7 DE, MD of 10-12 DE, and GA, each in different concentrations of 5% and 10% and different spray drying inlet temperatures 140°C, 150°C, and 160°C. Based on the study, results were tested using analysis of variance (ANOVA) to relate and understand the significance of the variables towards powder characteristics.

METHODOLOGY

Materials

The materials used to produce tomato powder with carrier agents include the tomato fruit, MD of 4-7 DE, MD of 10-12 DE, and GA. The MD of 4-7 DE and 10-12 DE was purchased from Sigma-Aldrich, Munich, Germany The physical appearance of MD was found as a white hygroscopic powder produced from vegetable starch. The GA used for this study was in powder form and was sourced from A&T Ingredients Sdn. Bhd., Malaysia.

Preparation of Tomato Juice

For the preparation of tomato juice, firstly, the tomato fruit was washed with lukewarm water to get rid of unwanted impurities on the surface of the tomato, and then it was cut into smaller pieces before blanching it for about 2 min in boiling water. Blanching helped to ease the peeling of the tomato skin, and then the tomato fruit was crushed by a blender to obtain the tomato juice. The obtained tomato juice was filtered using a cloth filter.

Preparation of Tomato Juice with Carrier Agents

As for preparing tomato juice with carrier agents, firstly, 1.5 L of tomato juice was weighed in a water jug, and the carrier agents were added. Tomato-MD 4-7 DE, tomato- MD 10-12 DE, and tomato-GA juices were prepared in different concentrations of 5% and 10% of tomato juice to carrier agents. The carrier agent solutions of 5% and 10% were prepared by dissolving the carrier agents in hot water until they carrier agents were submerged enough. The tomato juice was blended with the carrier agents using the blender. Then, the mixture was constantly stirred and heated at 30 to 50°C on a stove. 1.5 L of tomato juice with 5% concentration and another 1.5 L with 10% concentration for each carrier agent were obtained. Prior to drying, the color of the samples was recorded using a Hunter Lab color spectrophotometer. The obtained findings were stated as Hunter color values L*, a*, and b*, where L* stands for brightness and darkness, a* stands for redness and greenness, and b* stands for yellowness and blueness (Caparino et al., 2012).

Preparation of Tomato Powder

The main equipment for the experiment was a pilot-scale spray dryer used to spray dried tomato juices. Figure 1 shows a schematic representation of the spray dryer.

Table 2 shows the formulation to prepare 18 different samples. The samples were fed through a pilot scale spray dryer (Mobile Minor^{TM}, GEA, USA). The height of the drying chamber cylinder is 0.62 m, with a diameter of 0.80 m and a conical base of 60^{o} angles. The spray dryer includes a peristaltic pump and a spraying mechanism that comprises a rotating atomizer or two-fluid spray nozzles with a diameter of 1.0 mm. A start-up procedure was done on the spray dryer for the spray drying process to ensure that the atomizer could function well. The start-up procedure was done by referring to the equipment manual. For each 1.5 L of juices, 500 ml was fed into the spray dryer at different inlet temperatures. The operational conditions of the drying process were carried out with the inlet temperature of the spray dryer set at the desired temperature of 140°C, 150°C, and 160°C with a fixed

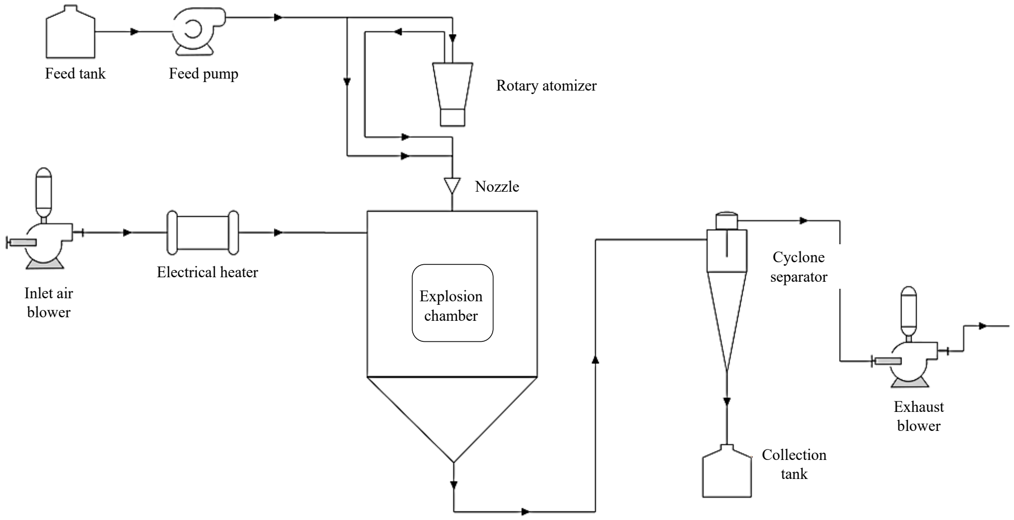


Figure 1. A schematic representation of a spray dryer

outlet temperature of 85°C. The output temperature was kept at 85°C by modulating the flow rate via the peristaltic pump. Atomization was done in co-current and fountain mode with atomizer pressure set at 5 bar. Samples were fed into the spray dryer using a peristaltic pump which controls the feed flow rate set at 18 rpm. The temperature of the outlet powder was regulated and monitored via two temperature sensors positioned in the fluid bed. After spray drying, the powdered sample was retrieved, collected from the cyclone's base, and kept in a sealable zip lock bag. The collected powdered samples were weighed and stored in an airtight container with silica gel at room temperature of 25–27°C. Samples were kept for 3–5 days weeks for further analysis. As for analyzing tomato powder, each analytical work was done in triplicate.

Table 2

Formulation of the samples

Samples	Carrier agent used	Volume of tomato juice, ml	Carrier agent concentration, %	Weight of carrier agent used, g	Inlet temperature, °C
TP1	GA	1500	5	75	140
TP2					150
TP3					160
TP4		1500	10	150	140
TP5					150
TP6					160

Table 2 *(Continue)*

Samples	Carrier agent used	Volume of tomato juice, ml	Carrier agent concentration, %	Weight of carrier agent used, g	Inlet temperature, °C
TP7	MD 4-7 DE	1500	5	75	140
TP8					150
TP9					160
TP10		1500	10	150	140
TP11					150
TP12					160
TP13	MD 10-12 DE	1500	5	75	140
TP14					150
TP15					160
TP16		1500	10	150	140
TP17					150
TP18					160

*TP = Tomato powder

Analysis of Tomato Powder

Powder Yield. Based on dry matter measurements, the process yield of powder was calculated by Equation 1 (Garofulić et al., 2016).

$$Powder\ yield, \% = \frac{a,\ \ g}{(b+c),\ \ g} x\ 100 \tag{1}$$

where *a* = weight of obtained powder, g; *b* = dry matter content, g of juice; *c* = mass, g of the carrier agents used.

Bulk Density. For bulk density, 5.0 ± 0.01 g of tomato powder was filled slowly into a 20 mL dry cylinder. The cylinder was tapped 3 times, and the apparent volume of the powder was recorded. The method is described by Caparino et al. (2012), in which the bulk density of the spray-dried powder was calculated using Equation 2.

$$Bulk\ density, \frac{g}{cm^3} = \frac{Weight\ of\ powder, g}{Volume\ of\ powder, cm^3} \tag{2}$$

Hygroscopicity. The analysis was performed using powder exposure to air relative humidity (RH) of 79.5% and checking of weight increase every 10 min until the maximum weight was reached. Approximately 0.5 g of the sample was weighed and evenly spread on a plate, then placed in the apparatus, and the analysis started. The calculation of hygroscopicity is given by Equation 3 (Oliveira et al., 2012).

$$\% \, Hygroscopicity = \frac{(\%WI + \%FW) \times 100}{100 + \%WI} \tag{3}$$

where $\%FW$ = % free water; $\%WI = ((c - b) / (b - a)) \times 100$; a = weight of plate (g); b = weight of plate + powder (g); c = weight of plate + powder in equilibrium (g)

Moisture Content. The AOAC method was utilized (AOAC, 2012) to determine powder sample moisture content. The equipment needed was an oven, crucible, and analytical balance. The crucible and lid were dried in a laboratory oven (Binder, Germany) and then cooled in a desiccator. The empty crucible with a lid was measured, and a powder sample of approximately 2 g was placed into a crucible. The weight of the crucible with 2 g of sample was recorded. The crucible was placed inside the oven without the lids. The sample was dried at 105°C in the laboratory oven (Binder, Germany) for 24 h or until a uniform weight was reached. After that, the sample was taken out from the oven, and the samples were cooled in a desiccator prior to weighing. The samples were weighed after 15 min of cooling. The samples were evaluated three times, and the mean value was recorded. The moisture content of the powder samples was calculated by Equation 4.

$$Moisture\ content, \% = \frac{(b - c), g}{(b - a), g} x100 \tag{4}$$

where a = weight of crucible + lid, b = weight of sample + crucible + lid before drying process, c = weight of sample + crucible + lid after drying process.

Water Solubility Index (WSI). The WSI of tomato powder was measured using the approach outlined by Sabhadinde 2014, in which distilled water of 20 ml was vigorously combined with the spray-dried tomato powder of 2.5 g weight in a 100 ml centrifuge tube and incubated at 37°C for 30 min in a water bath. It was then centrifuged at 10,000 rpm for 20 min. The supernatant was collected carefully into a pre-weighed beaker before being oven-dried at 103 ± 2°C. The WSI (%) was calculated as a percentage of the dried supernatant in proportion to the sample quantity (Equation 5).

$$WSI, \% = \frac{Weight\ of\ supernatant, g}{Weight\ of\ sample, g} x100 \tag{5}$$

Water Absorption Index (WAI). The WAI of tomato powder was determined by using Sabhadinde's method (2014). 2.5 g tomatopowder suspension in 20 ml distilled water was stirred for 1 h before being centrifuged at 3000 rpm for 10 min. The supernatant is discarded for the removal of free water and to obtain the wet residue only. The wet residue was then weighed. The calculation of WAI is given by Equation 6.

$$WAI, \% = \frac{Weight\ of\ residual, g}{Weight\ of\ sample, g} x100 \tag{6}$$

Color Analysis. A color spectrophotometer (Colorflex D65/10O, Hunterlab, USA) was used to study the color properties of the tomato powder. The obtained data were represented per the Hunterlab scale values of the samples. The color properties were calculated using the total color difference equation. Then, the tomato powder was dissolved in distilled water to prepare a resampling of the obtained tomato powder; for the resampling procedure of the tomato powder, Equation 7 was used so that the color comparison of the tomato powder would be fair to the feed sample in the preliminary stages of conducting the spray drying of tomato juice (Jittanit et al., 2010).

$$WDWR, g = \frac{(WFM-WDP), g}{WDP, g} x\ WPR \tag{7}$$

where *WDWR* = weight of distilled water for resampling, *WFM* = weight of feed material, *WDP* = weight of dried powder obtained, and *WPR* = weight of powder for resampling

This analysis was done in triplicates to take reading for the L*, a*, and b* values, and the mean values were taken. Prior to the sample analysis, the colorimeter was calibrated using a black tile, a white plate with L^*, a*, and b* values of L=93.87, a=-0.73, b=+2.06 and a green plate with L*, a*, and b* values of L=51.23, a=-25.32, b=15.14. For color analysis, control tomato (CT) samples prior to drying were included, in which there are 6 control samples for each carrier agent of different concentrations: CT1 for tomato juice with 5% GA, CT2 for tomato juice with 10% GA, CT3 for tomato juice with 5% MD 4-7DE, CT4 for tomato juice with 10% MD 4-7 DE, CT5 for tomato juice with 5% MD 10-12 DE and CT6 for tomato juice with 10% MD 10-12 DE. These control samples were prepared to study the color difference in the L^*, a*, and b* values before and after drying the juice at three different temperatures. All the initial values were classified as control values stated as *CT1*, CT2, CT3, CT4, CT5, and CT6 and shown in Table 3.

Table 3

Initial values of color properties of the CT samples

Control tomato (CT) samples	Color properties			Control tomato (CT) samples	Color properties		
	L^*	a*	b*		L^*	a*	b*
CT1	33.53	16.99	14.31	CT4	37.01	19.67	18.24
CT2	31.59	15.37	15.40	CT5	33.52	18.96	15.17
CT3	36.15	19.30	15.70	CT6	30.97	17.19	13.93

Particle Size. A particle size analyzer (Malvern Zetasizer, Nano Z, UK) was used to assess the particle size of tomato powder in a liquid medium. The equipment was set at an operating temperature of 25°C, and size measurement was taken in triplicate with 13 runs each. For the preparation of the analysis, 1 g of tomato powder was mixed with 10 ml of distilled water to prepare the aqueous suspensions (Tonon et al., 2011). After thorough stirring, the suspension was put into a disposable cuvette and placed in the instrument for measurement. The particle size was given in micrometers (µm), and each sample was measured in triplicate, with the mean z-average for each sample taken as the size comparisons.

Particle Morphology. A scanning electron microscope (SEM) (Carl Zeiss MA 10, Germany) was used to examine the morphological structure of tomato powders. A few samples were chosen for SEM images: the samples with 140°C and 160°C of the same concentration at 10% and another with a 5% concentration at 160°C for each powder sample of a different carrier agent. The samples were chosen likewise to compare the differences in particle morphology of the resulting tomato powder based on the concentration, inlet temperature, and type of carrier agents. Prior to SEM imaging, samples were coated using a sputter coater (EMITECH, K550X, UK) with a fine coating of gold platinum to make them conductive for SEM imaging and to obtain a much clearer image. The samples were analyzed in the SEM instrument at an accelerating 10–15 kV. Three magnifications were used to observe the sample at an objective magnification of 500x, 1000x, and 2000x magnification (Jafari et al., 2017).

Statistical Analysis. Obtained experimental data were analyzed using repeated measures ANOVA with the alpha set 0.05 to identify the significant difference and the mean scores between the samples. The statistical analysis used IBM statistical product and service solutions (SPSS) software version 28.0. All experiments were carried out in triplicate (n=3), and the data were presented as mean ± standard deviations.

RESULTS AND DISCUSSION

Powder Yield

In this study, all the powder samples were collected at the cyclone, and the hard rubber hammer periodically knocked the drying chamber during the experiment to keep the remaining powder on the drying chamber surface and its accessories as minimal as possible. The production yields of tomato powder were 17.40–32.10%, similar to the data reported by Chegini and Ghobadian (2007), with a production yield of 18–35% in the study on orange juice powder. Compared to their findings, the product yields obtained from the study are accepted as the range obtained is close to the reported product yield. Figure 2 represents the production yield of samples at varied conditions.

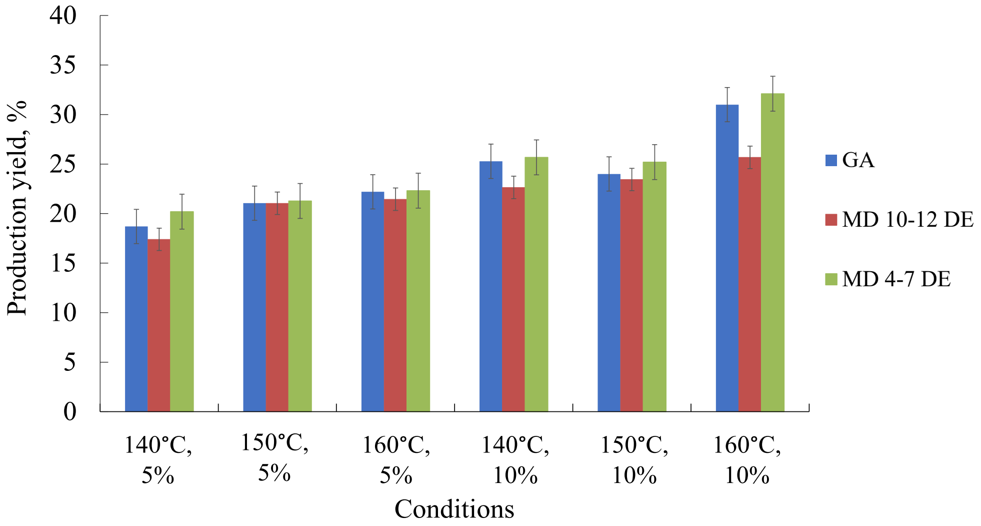


Figure 2. Production yield of samples at varied conditions (different temperatures and concentrations) with different carrier agents

The result shows that the production yield increases with the increase of carrier agents. The concentration of the carrier agents affected the powder properties. A low concentration of carrier agent may obtain the stickiness powder. The addition of carrier agents could increase the total solid content in the feed and increase the number of solid particles available in the drying system while decreasing water evaporation, thus, reducing the moisture content of the product (Tonon et al., 2008). According to Jittanit et al. (2010), a rise in MD concentration decreased the moisture content of pineapple juice powder. It was suggested that carrier agents such as MD and GA could alter the surface stickiness of low molecular weight sugars such as glucose, sucrose, fructose, and organic acids, facilitating drying and reducing the stickiness of the spray-dried product (Bhandari et al., 2005). As the inlet temperature increased, production yield increased. The increase in inlet temperatures has given the higher process yield, and it was due to the greater efficiency of heat and mass transfer processes occurring when the higher inlet air temperature was used (Phisut, 2012; Cai & Corke, 2000). As the inlet temperature increases, the moisture content of the powder produced decreases, resulting in less accumulation of wet powder on the chamber wall of the spray dryer, thus an increase in powder yield.

Characterization of Tomato Powder

All subsequently produced tomato powders were analyzed to determine the features of the physicochemical properties found in the powder. The physical properties to be determined against the resulting tomato powder include bulk density, hygroscopicity, moisture content, WSI, WAI color, particle size, and particle morphology. Table 4 shows the physical properties of the produced tomato powder. The mean scores were obtained from SPSS based on the data for the following characteristics taken in triplicates.

Table 4

Mean scores on the characteristics of tomato samples

Samples	Bulk density, g/cm^3	Hygroscopicity, %	Moisture content, %	WSI, %	WAI, %	Particle size, μm
TP1	0.3387 ± 0.01	12.00 ± 0.00	7.50 ± 0.50	87.76 ± 2.72	12.44 ± 0.23	14.577 ± 5.17
TP2	0.2943 ± 0.01	11.67 ± 0.58	7.00 ± 1.00	88.39 ± 1.35	12.00 ± 0.22	21.943 ± 1.97
TP3	0.2780 ± 0.01	11.33 ± 0.58	6.17 ± 0.29	89.37 ± 0.87	11.56 ± 0.23	26.937 ± 2.75
TP4	0.2943 ± 0.01	10.67 ± 0.58	5.50 ± 0.50	86.57 ± 1.30	12.44 ± 0.23	18.143 ± 8.09
TP5	0.2860 ± 0.01	9.67 ± 0.58	5.00 ± 0.50	89.43 ± 0.83	11.55 ± 0.24	25.053 ± 1.91
TP 6	0.2630 ± 0.01	10.00 ± 1.00	3.83 ± 0.76	88.17 ± 1.22	12.00 ± 0.22	30.273 ± 2.86
TP 7	0.3753 ± 0.01	9.33 ± 0.58	5.67 ± 1.04	87.50 ± 1.74	9.33 ± 0.23	7.352 ± 0.79
TP 8	0.3573 ± 0.01	8.00 ± 1.00	4.83 ± 2.02	88.11 ± 1.17	8.44 ± 0.23	11.367 ± 3.31
TP 9	0.3327 ± 0.01	7.33 ± 0.58	5.33 ± 1.61	89.56 ± 1.25	7.56 ± 0.23	11.880 ± 0.54
TP 10	0.3334 ± 0.01	6.67 ± 0.58	4.83 ± 0.76	88.11 ± 1.77	7.10 ± 0.23	10.352 ± 0.90
TP 11	0.3230 ± 0.01	6.33 ± 0.58	3.83 ± 1.44	89.56 ± 1.25	6.67 ± 0.23	18.843 ± 6.52
TP 12	0.2943 ± 0.01	5.67 ± 0.58	3.17 ± 0.29	89.98 ± 1.25	6.22 ± 0.22	24.733 ± 0.89
TP 13	0.4007 ± 0.02	14.00 ± 1.00	8.00 ± 0.50	86.02 ± 1.25	11.11 ± 0.22	6.884 ± 0.51
TP 14	0.3890 ± 0.01	13.67 ± 0.58	7.00 ± 1.00	88.64 ± 1.25	10.67 ± 0.23	7.044 ± 1.04
TP 15	0.3573 ± 0.01	13.33 ± 0.58	6.33 ± 0.76	89.12 ± 1.20	8.87 ± 0.22	7.460 ± 0.77
TP 16	0.3450 ± 0.01	13.33 ± 0.58	6.33 ± 0.76	88.91 ± 1.25	7.99 ± 0.23	7.961 ± 0.29
TP 17	0.3230 ± 0.01	12.33 ± 0.58	5.33 ± 1.53	88.91 ± 1.26	7.55 ± 0.22	10.697 ± 0.37
TP 18	0.3130 ± 0.01	12.00 ± 1.00	4.50 ± 0.50	89.12 ± 1.20	7.12 ± 0.22	14.337 ± 1.16

Bulk Density

According to the results of the mean scores in Table 4, the processing of tomato powder has produced a powder with a bulk density range between 0.2630 g/cm^3-0.4007 g/cm^3. Bulk density is one of the very important features for the packaging design and the calculation of transportation volume (Jittanit et al., 2011). High bulk density in the sample resulted in the tendency of powder particles to be stuck to one another (Goula & Adamopoulos, 2008). The study discovered a significant difference (p<0.05) in the effect of temperature and concentration of carrier agents on the bulk density of the spray-dried powder with the increment of the two factors. The result shows a decrease in the bulk density as the temperature and concentration of carrier agents were increased. The results of this study are supported by statements from other studies conducted by Chegini and Ghobadian (2007), which show that orange powder dried at the inlet temperature of the dryer at 130°C had a bulk density as low as 0.42 g/ml and the bulk density of orange powder dropped to as low as 0.21 g/ml when the inlet temperature was increased to 150°C. Results showed that with an increase in inlet temperature, bulk density would decrease as there is an increase in the insoluble solid content (Chegini & Ghobadian, 2007). Bulk density decreases as the apparent volume of the powdered samples obtained is higher for samples with increasing inlet temperature.

At higher temperatures, an increase in the input air temperature frequently results in the quick production of a dry layer on the droplet surface and particle size and skinning over or case hardening on the droplets. It causes the droplet surface to produce vapor-impermeable coatings, followed by the production of vapor bubbles and, as a result, droplet enlargement (Chegini & Ghobadian, 2007). Bulk density will increase when there is a decrease in the inlet temperature (Goula & Adomopoulos, 2005).

Figure 3 illustrates that the bulk density lowers as temperature increases and that there is a significant difference (p<0.05) for both concentrations. Figure 4 also shows the same trend as bulk density decreases with the increase of temperature and increasing concentration of GA, resulting in the lower bulk density followed by MD 4-7 DE. MD 10-12 DE shows a higher bulk density. However, few samples show no significant difference (p>0.05), such as MD 4-7 DE and MD 10-12 DE at all conditions except at 5%, 150°C. GA and MD 4-7 DE also shows no significant difference (p>0.05) at 5%, 140°C. It might be because of the particle size, as most of the samples obtained have no significant difference in their particle size. Smaller particles migrate downward, filling the gaps left by larger particles. The bulk density of a material with many smaller particles is greater than that of a material with a few smaller particulates.

The addition of carrier agents to feed material also has a variable influence on bulk density. Adding MD has a carrier agent's influence on the bulk density of the powdered particles. It is demonstrated by the fact that MD's skin-forming tendency increases the

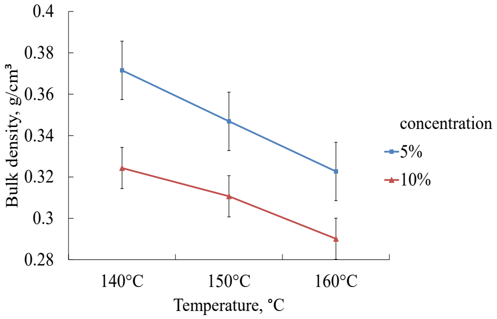


Figure 3. Effect of inlet temperature at different concentrations against estimated marginal means for bulk density

amount of air trapped in the particle and reduces thermoplasticity. According to Kwapinska and Zbicinski (2005), carrier agents with skin-forming qualities, such as MD, frequently include air bubbles, and the greater the usage of comparable carrier agents, the lower the bulk density of powders. The use of acacia GA in spray drying shows roughly equivalent observations since it has a higher T_g point due to its big molecular size. Additionally, with increasing concentrations of carrier agents, the bulk density of orange juice powder has decreased (Shrestha et al., 2007). The heavier the material, the more easily it fits into the gaps between the particles, taking up minimal space and contributing to increased bulk density values. Chegini and Ghobadian (2007) discovered that spray-dried powders with greater moisture levels had a larger bulking weight owing to the existence of water, which is much denser than the dry solid. This characteristic is consistent with the results, as tomato powders made with MD, especially MD 10-12 DE, exhibited higher moisture content and bulk density.

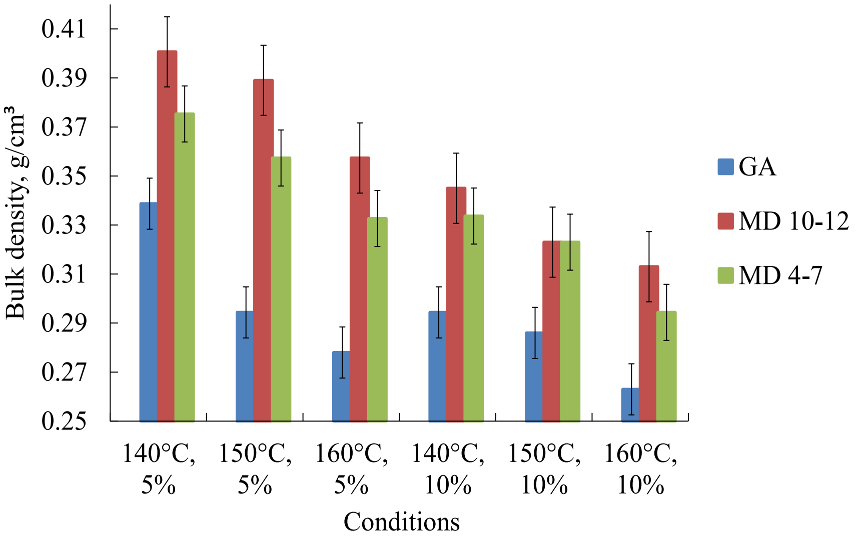


Figure 4. Effect of the conditions (different temperatures and different concentrations) with different types of carrier agents against estimated marginal means for bulk density

Hygroscopicity

As for the hygroscopicity, the result in Table 4 shows that range was at 5.67–13.67%, with TP 12 having the lowest hygroscopicity and TP 14 having the highest hygroscopicity. The results showed that the concentration and inlet temperature have significant differences ($p<0.05$) to the hygroscopicity of the tomato powder except for formulations of 5% at 140°C and 150°C; 5% at 150°C and 160°C. At 10%, the temperatures 150^{o}C and 160^{o}C also show no significant difference ($p>0.05$). Figure 5 illustrates that the increasing temperature reduces hygroscopicity and difference in concentration in affecting the powder's hygroscopicity, in which the higher concentration, 10%, resulted in a much lower hygroscopicity compared to the 5% and that the hygroscopicity decreases with an increase in temperature. By comparing the carrier agents, as shown in Figure 6, it is found that adding MD 4-7 DE produced powders with the lowest hygroscopicity, followed by GA and MD 10-12 DE. Carrier agents also showed a significant difference from one another except for sample TP6 with sample TP18 and sample TP2 with sample TP14 ($p>0.05$). The hygroscopicity decreased as the concentration of the carrier agent increased. The greater the input air temperature difference, the greater impact on the hygroscopicity of the powders, as increasing temperatures yields lower hygroscopicity values. Samples adding GA to MD 10-12 DE show no significant difference when treated, even under the same conditions. It could be due to the agent chemical structure of the carrier agent that explains the differences in water adsorption. The phenomena of adsorption of water by a carbohydrate were ascribed to the connections of the hydrogen contained in water molecules with the hydroxyl groups accessible in the amorphous and surface crystalline areas of the substrate. GA and MD of higher DE have many interactions with hydrophilic groups. As a result, it quickly absorbed moisture from the surrounding air (Tonon et al., 2011). The MD degree of polymerization also impacts the powder's hygroscopicity. The study is in accordance with Tonon et al. (2011) findings, in which the samples made with MD 10 DE had the lowest rate of moisture adsorption, but the samples made with MD 20 DE and GA were found to be much more hygroscopic, had greater adsorption of water and had lower moisture content in the powders.

The powder‘s hygroscopicity increased considerably when MD 10-12 DE was utilized as a carrier. This study found that the lower the air inlet temperature, the higher the hygroscopicity of the tomato powder. The powders generated with a high air inlet temperature had low moisture content and greater potential to absorb ambient moisture. The high drying air temperature resulted in a considerable temperature gradient at the feed drop surface. It instantly accelerated the heat transmission rate and moisture evaporation from the liquid (Muzaffar et al., 2016). Caparino et al. (2012) state that tiny particle sizes have a considerable surface area for absorbing environmental moisture. Particle size is a key component in determining particle surface area. Smaller particles will increase

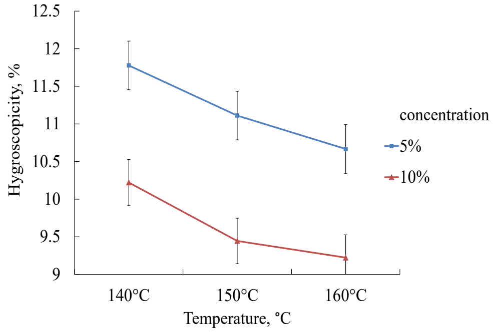


Figure 5. Effect of inlet temperature at different concentrations against estimated marginal means for hygroscopicity

the surface area, while larger particles will reduce it. Depending on the active spots in the dry matrix adsorption force, this results in greater water adsorption from the environment (Sudeep et al., 2010). This condition may result in product aggregation during storage. Food powder particles with a high hygroscopicity could exhibit a process known as caking, which causes the powder to agglomerate. This phenomenon is linked to water absorption on the particle‘s surface, which forms a saturated solution and makes the particles adhesive and capable of establishing hydrogen bonds, resulting in caking (Goula & Adamopoulos, 2008). Fruit products often have high sugar content, resulting in a hydrophilic nature and sticky powders that tend to agglomerate.

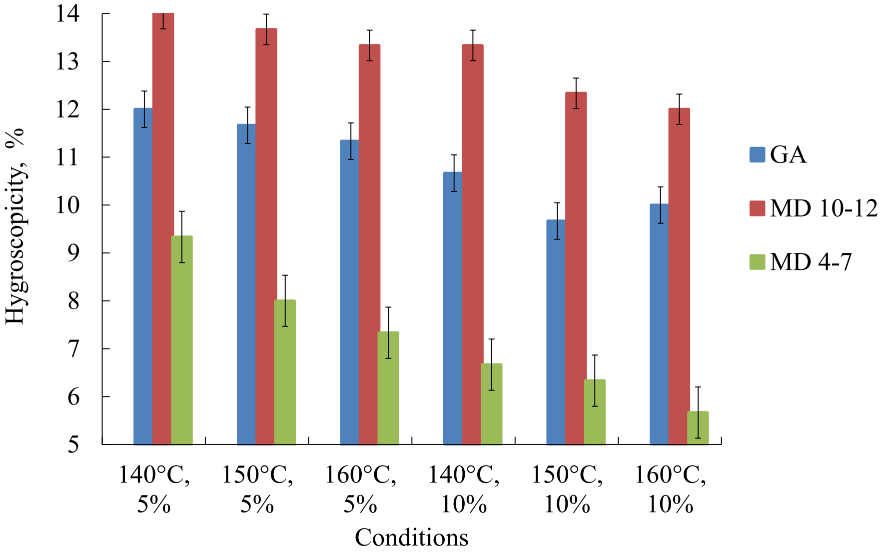


Figure 6. Effect of the conditions (different temperatures and different concentrations) with different types of carrier agents against estimated marginal means for hygroscopicity

Moisture Content

According to the result in Table 4, the percentage range of moisture content found in the resulting tomato powder is 3.17–8.00%, with TP12 having the lowest moisture content and TP13 having the highest moisture content. Variations in these results are referred to as parameters to measure the quality of a powder labeled as a dry product and similar to that reported for other food powders (Bhandari et al., 2005). The main factor affecting the stability of the powder is the moisture content since a small amount of water can press enough temperature to increase the mobility of the matrix during storage (Bhandari et al., 2005; Osman & Endut, 2009).

Based on Figure 7, increasing the concentration of carrier agents and inlet temperature on the tomato juice resulted in powder with a much lower moisture content. The concentration has no significant difference as the temperature is increased ($p>0.05$) except for samples prepared at 10%, 140°C, and 10%, 160°C ($p<0.05$). It is because, compared to 5%, the greater concentration of the carrier agent, the greater the capacity to overcome the sugars present in fruit powder, which have an extremely hygroscopic nature and absorb humidity from the adjacent air (Shrestha et al., 2007). It is also in accordance with Jittanit et al. (2010) increasing the MD content caused pineapple juice powder moisture content to decrease. The greater inlet temperature difference between 140°C and 160°C is significant because the moisture content decreases at higher temperatures.

However, the temperature significantly differs as concentration increases ($p<0.05$). Figure 8 illustrates the moisture content of the samples prepared with different carrier agents as temperature and concentration increase. The result shows no significant difference between the samples except for samples prepared at 5%, 140°C for GA and MD 10-12 DE, which are sample TP7 and sample TP13. The study found that an increase in the percentage of carrier agents used significantly impacted the moisture content of tomato powder. By increasing the carrier agent concentration, there is more potential to lower the percentage of moisture contained in the tomato powder. For example, spray drying of tomato powder with MD 4-7 DE at a drying temperature of 150°C decreased the moisture content from 4.83 to 3.38% when MD was increased from 5 to 10%. The results of this study agreed with the roselle-pineapple powder studied by Osman et al. (2009), which discovered that the increased MD content reduced the moisture content in the powder. The moisture content in tuna powder decreased from 7.47–4.63% when the MD percentage increased to 26% (Caparino et al., 2012). In addition, Jittanit et al. (2010) also supported this fact through their study of pineapple juice spray drying. The results showed that the moisture content of pineapple powder was 4–5.8% and that the increase in MD content had caused the product's moisture content to be lower. It may be due to increased solid content in food and reduced free water content for evaporation, resulting in reduced moisture content in the produced powders (Osman et al., 2009). Moreover, MD has properties to prevent sugar in powders from absorbing moisture from the surrounding air (Jittanit et al., 2010). It means that powders with lower moisture content can be obtained by increasing the percentage of MD added. An increase in the inlet temperature of the spray dryer equipment affects an insignificant difference in the percentage of moisture content in the resulting tomato powder.

With an increase in the inlet temperature, the moisture content found in the tomatoes is lower. It was supported by Osman et al. (2009) in their study of roselle-pineapple powder, in which the moisture content in the sprayed powder decreased with an increase in inlet temperature. Jittanit et al. (2011) also stated the same statement after conducting their study of tamarind powder. In addition, through studies of pineapple powder, Jittanit et al. (2010) also proved that high temperatures would reduce the humid content in the powder. His study showed that the inert content of pineapple powder decreased from 5.8 to 4.8% when the temperature increased from 130 to 170°C.

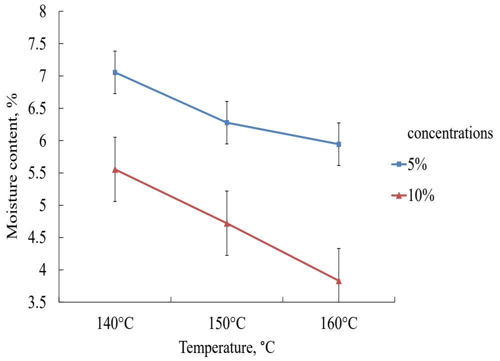


Figure 7. Effect of inlet temperature at different concentrations against estimated marginal means for moisture content

Moisture content is an important powder parameter that is linked to drying efficiency. Because it influences glass transition and crystallization characteristics, the moisture content of a microencapsulated product plays an essential role in determining its flow properties, adhesion, and storage stability (Phisut, 2012). According to the findings, an increase in the inlet air temperature decreased the moisture content of spray-dried powders, consistent with previous research. MD powders had proportionally higher moisture content as temperature

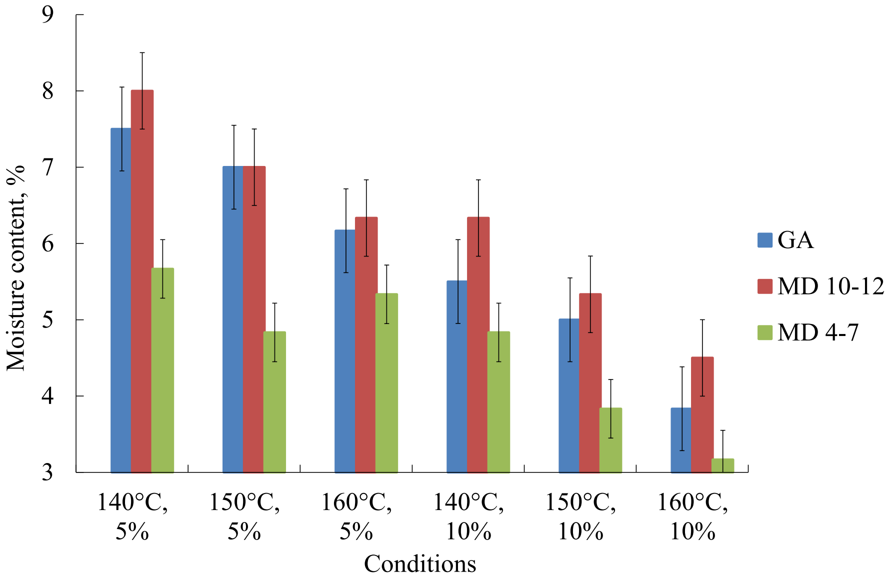


Figure 8. Effect of the conditions (different temperatures and different concentrations) with different types of carrier agents against estimated marginal means for moisture content

increased than GA results. MD‘s chemical structure can explain this tendency since lower molecular weight MD (20-25 DE) has shorter chains and a much more hydrophilic nature (Cai & Corke, 2000).

Water Solubility Index (WSI)

The reconstitution property WSI was used to investigate the influence of process factors. Based on Table 4, the WSI% ranged from 86.02–89.97% for the spray-dried tomato powder. The results in Figure 9 show a significant difference ($p<0.05$) as the temperature and concentration increased except for the conditions of 10% at 150°C and 160°C. The solubility index of spray-dried powder is affected by the properties of the powder, which are the moisture content and the size of particles (Lee et al., 2018). From the study, the moisture content decreases at increasing temperatures, and the particle size increases at increasing temperatures. The lower the particle size, the lower the solubility and flow ability of powder (Phisut, 2012).

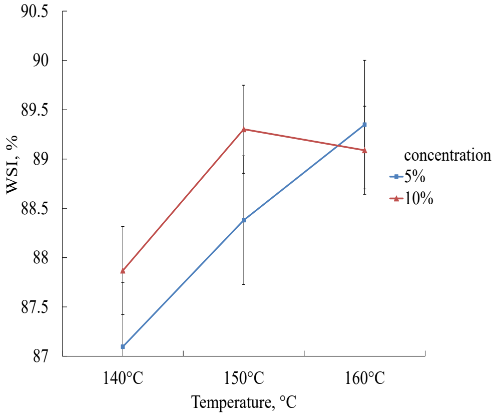


Figure 9. Effect of inlet temperature at different concentrations against estimated marginal means for WSI%

The statistical analysis also shows that there is no significant difference ($p>0.05$) between the carrier agents even though the data obtained shows that there is a slight increment between WSI% for the carrier agents, with GA giving most of the lower WSI% and MD 4-7 DE giving most of the higher WSI%, and MD 10-12 DE was somewhere in between as shown in Figure 10. The highest mean score for WSI is 89.97% (TP12), and the lowest mean score recorded was 86.02 (TP13). Phoungchandang and Sertwasana (2010) observed a similar pattern while spray-drying ginger juice. The solubility index of spray-dried powder is influenced by the underlying materials and carrier agents employed and the powder‘s properties (Goula & Adamopoulos, 2008; Grabowski et al., 2006).

Water Absorption Index (WAI)

As for the WAI of the powdered samples, the result shows that the concentration has a significant difference as temperature increases ($p<0.05$) and that temperature also has a significant difference as concentration increases ($p<0.05$). Figure 11 explains the two factors that are affecting the WAI of the powdered tomato samples. Figure 12 shows the

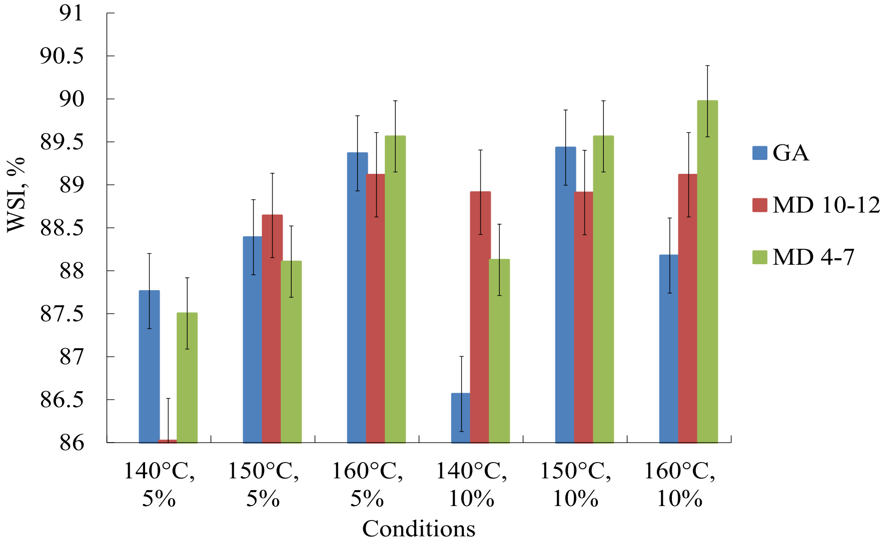


Figure 10. Effect of the conditions (different temperatures and different concentrations) with different types of carrier agents against estimated marginal means for WSI%

effect of carrier agents at varied concentrations and inlet temperatures. The figure shows that increasing the inlet temperature and concentration of carrier agents will result in lower WAI. WAI decreases gradually with the increase of the two factors. Whereas the WAI for MD 10-12 DE also decreases gradually except at 5%, 150°C to 5%, and 160°C, which decreases substantially. For GA, the WAI gradually decreases as temperature increases for the 5% samples. However, for the 10% samples, the WAI increases from 150 to 160°C. Figure 12 also shows that GA carrier agents and MD 4-7 DE have the highest significant difference ($p<0.05$).

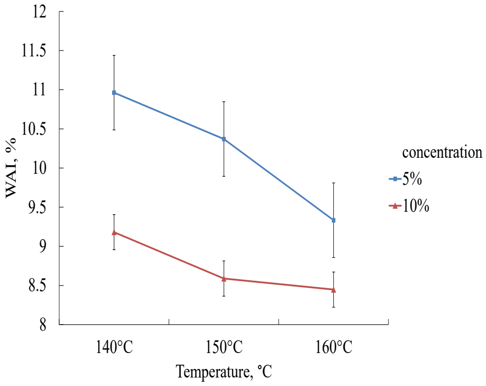


Figure 11. Effect of inlet temperature at different concentrations against estimated marginal means for WAI%

The amount of water that remains bound after applying an external force, such as centrifugation, is called the WAI. WAI is one of the immediate properties of a powder that represents a sample's ability to reassociate with water under constrained water conditions. A good rehydration powder would moisten rapidly and fully, sinking rather than floating. WAI percent results showed significant differences as the inlet temperature and carrier agent amount increased. It could be due to the samples' low hygroscopicity. The low WAI values of

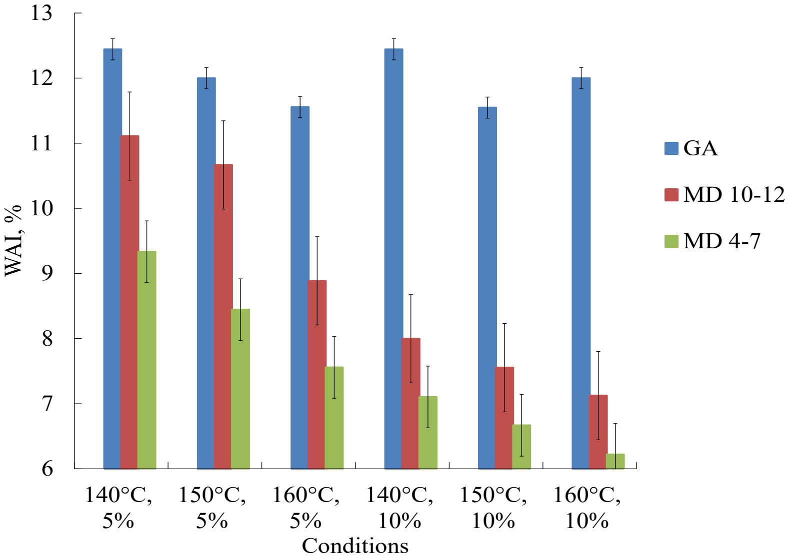


Figure 12. Effect of the conditions (different temperatures and different concentrations) with different types of carrier agents against estimated marginal means for WAI%

the WAI percent could also be attributed to the high WSI values. Based on the data obtained in Table 4, the WAI was lower in TP12 with a mean score of 6.22%, while the highest WAI mean scores were found in TP1 and TP4, both at 12.44%. The results revealed that when concentration increases, the WAI drops. As the concentration of carrier agents increases, the WAI decreases. Grabowski et al. (2006) obtained similar findings with spray-dried yellow sweet potato flour. MD can develop outer layers on the droplet surface, affecting particle surface stickiness due to the transition into a glassy state. Changes in surface stickiness diminish particle cohesion, resulting in less agglomeration and, as a result, lesser water-holding capacity of the powder.

Color Analysis

Figure 13 represents the effect of the varied conditions for the color analysis of the tomato powder. The a^* value for the control sample CT1 was 16.99. The results showed that the range of a* values for the redissolved samples were 11.93–13.16, which has a significant difference (p<0.05) from the a^* value of the control sample, CT1. The results also showed that the obtained a^* values of the redissolved samples were between 10.01–10.42, 13.31–13.81, 11.62–16.10, 13.10–14.98, and 10.83–12.04 for the other control samples of CT2, CT3, CT4, CT5, and CT6, respectively. All of which has a significant difference (p<0.05) as the concentration of the carrier agents increases and as the temperature increases. The obtained b^* values of the redissolved samples were between 17.24–18.51, 14.84–15.78, 20.34–20.80, 13.32–22.61; 19.43–21.16 and 16.72–16.98 for the control samples of CT1, CT2, CT3, CT4, CT5, and CT6, respectively (Figure 13). As for the b^* values, the result also showed a significant difference ($p<0.05$) between the redissolved samples and the control samples. The results show a decrease in a^* and b* values for each sample with different carrier agents as the concentration and inlet temperature increase. It is due to the increasing inlet temperature that causes loss of pigment and results in tomato powder products with lower a* and b* values. The decreasing a* and b* values were also caused by the increasing concentration of the carrier agents as both MD, and GA are white, while tomato juice is red; as a result, all the powder produced had a lighter color. Grabowski et al. (2006) found that a reduction in redness and yellowness was also observed when MD concentrations were raised in the manufacturing of sweet potato powders. The primary changes in the color of powders were caused by variations in the inlet temperature, which indicates that increasing the inlet temperature causes a commensurate drop in the red color. It might be because lycopene degrades significantly at higher temperatures. a* and b* values indicated that increasing inlet temperature causes loss of pigment and results in tomato powder products with lower a* and b* values. The decreasing a* and b* values are also caused by the increasing concentration of the carrier agents as both MD, and GA are white, while tomato juice is red; as a result, all the powder produced had a lighter color.

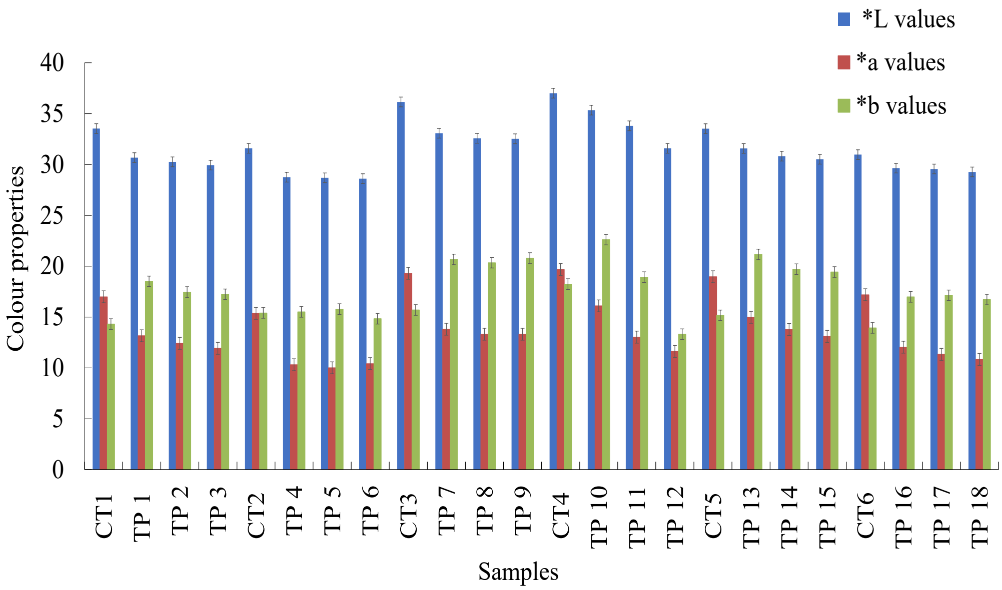


Figure 13. Effect of the conditions (different temperatures and concentrations) with different types of carrier agents against estimated marginal means for color analysis

The obtained L^* values of redissolved samples were between 29.94–30.67, 28.61–28.75, 32.53–33.07, 31.59–35.34, 30.52–31.58, and 29.27–29.64 for the control samples of CT1, CT2, CT3, CT4, CT5, and CT6, respectively (Figure 13). The average L^* value for the tomato sample solution is lower than that of the control sample, and there is a significant difference ($p<0.05$) between the L^* value in the tomato powder re-solution and the increase of carrier agent concentration across the same temperature. The reduced brightness in the solution of the tomato powder sample may be due to the reasons stated by Jittanit et al. (2010), in his note that the lower brightness is due to a small portion of the powder not being dissolved completely in the solution. In addition, the concentration of the carrier agent may also cause the color difference between the control tomato sample and the solution of the tomato powder sample. Among other reasons that affect brightness for reduction is the reaction of non-enzyme browning that occurs when the drying process is carried out. Therefore, the brightness in the solution of the tomato powder sample is lower than the brightness of the control sample. Readings of redness and higher yellowness levels in the sample can also result from non-enzymatic reactions such as the caramelization process and Maillard reaction during the drying process. These reactions can occur due to heat supplied to the samples in the drying chamber (Jittanit et al., 2010).

Particle Size

The mean particle size for tomato powder samples produced at different inlet temperatures and concentrations with different carrier agents ranged from 6.884 µm to 30.273 µm (Table 4). The results show no significant difference ($p>0.05$) at 140°C temperature for both concentrations. However, there is a significant difference at higher temperatures (150°C and 160°C) for both concentrations ($p<0.05$). At 5% concentration, the temperatures of 140 to 150°C and 150 to 160°C have no significant difference ($p>0.05$). Meanwhile, temperature 140 to 160°C significantly differs ($p<0.05$). For the 10% concentration, there is no significant difference in temperatures from 140 to 150°C, but at 140 to 160°C and at 150 to 160°C, it shows a significant difference ($p<0.05$). As for the formulations, all have significant differences ($p<0.05$) from one another except for the following pairs: T7 and T13, T8 and T14, T4 and T10, and T5 and T11. Based on Table 4, the mean score of the particle size shows that the particle size increases as the concentration and the temperature increase, and the higher score is at 10%, 160°C formulations (highest is TP6 with a mean score of 30.273 µm) and the lower score is at 5%, 140°C formulations (lowest is TP13 with a mean score of 6.884 µm). Figure 14 shows a line plot for the interaction of concentration, the temperature that shows the increase in the particle size with the increase in temperature, and the significant differences between the two concentrations.

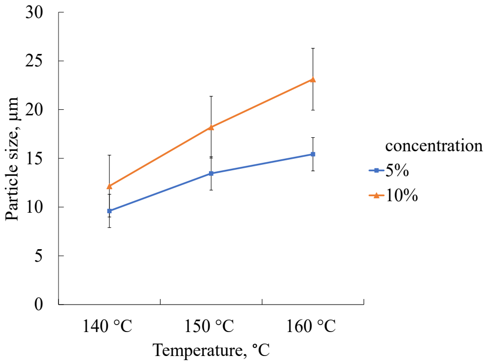


Figure 14. Effect of inlet temperature at different concentrations against estimated marginal means for particle size

Higher inlet temperatures produced bigger particles, which can be attributed to the increased swelling as the drying temperature was raised. When a particle is exposed to greater drying rates, moisture evaporation is fast, promoting the production of a hard crust that prevents particle shrinkage during spray drying. If the inlet temperature is lower, the particle remains wet for longer and contracts, reducing particle size (Gouaou et al., 2019). Tonon et al. (2008) discovered comparable properties in spray-dried acai powders. The use of carrier agents, particularly a higher MD content, has been shown to enhance the particle size of the spray-dried powder.

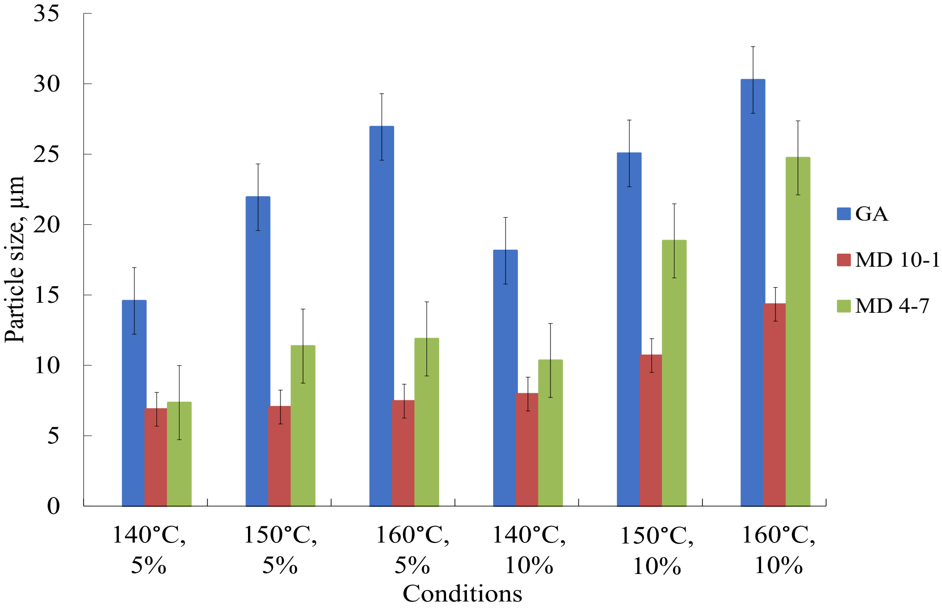
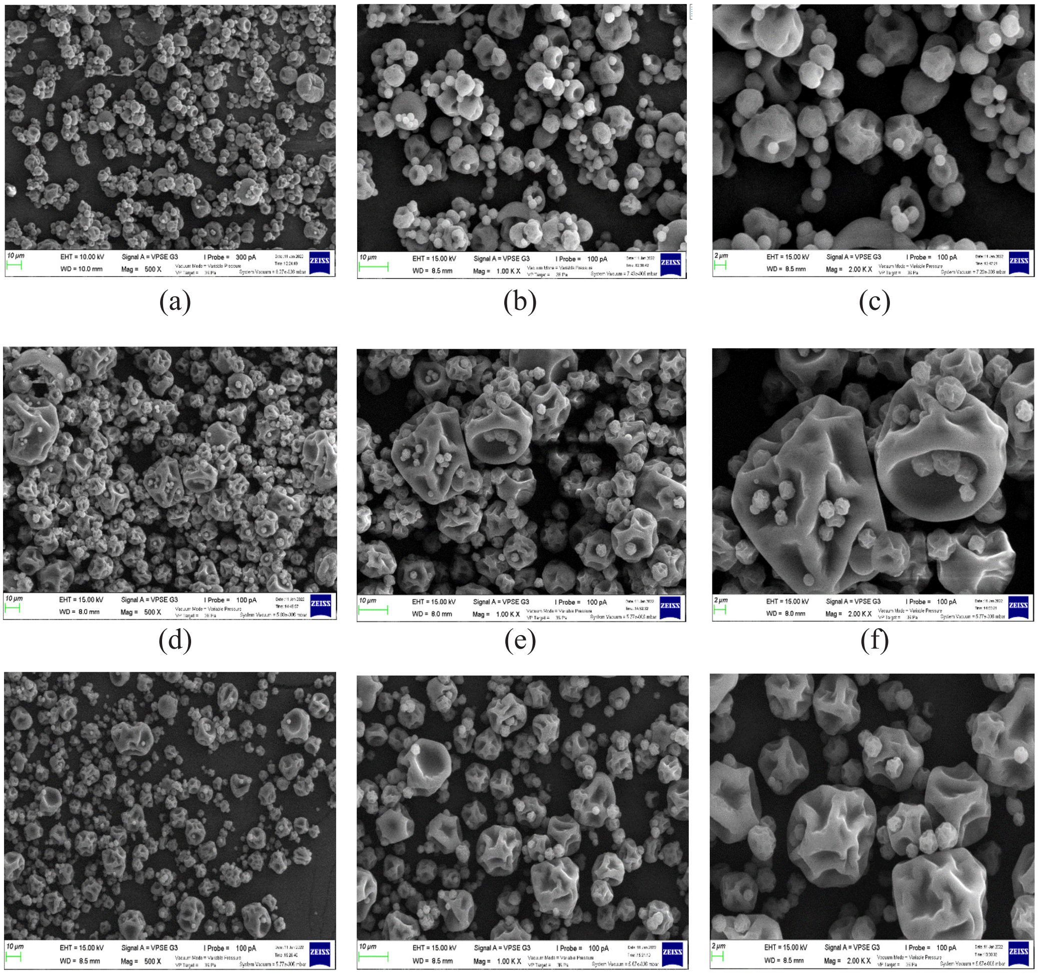


Figure 15. Effect of the conditions (different temperatures and different concentrations) with different types of carrier agents against estimated marginal means for particle size

The type of carrier agent also plays a role in affecting particle size. The size of the particles in the feed suspension likely affects spray-dried particle size and encapsulation efficiency. This quality is also significantly connected to suspension stability which is essential to feed successive steps uniformly. The latter had a larger mean diameter based on the findings of Tonon et al. (2011) when comparing MD 20 DE to the powder generated with MD 10 DE. However, it was found that the larger particle size was obtained with the addition of GA, followed by the addition of MD 4-7 DE, and the smaller particle size was obtained with the addition of MD 10-12 DE (Table 3). The findings agree with Tonon et al. (2011) for the MD 4-7 DE and MD 10-12 DE. The difference in the study is that GA produces a much larger particle size than MD. Figure 15 shows the effect of conditions (different temperatures and different concentrations) with different types of carrier agents against estimated marginal means for particle size.

Powder Morphology

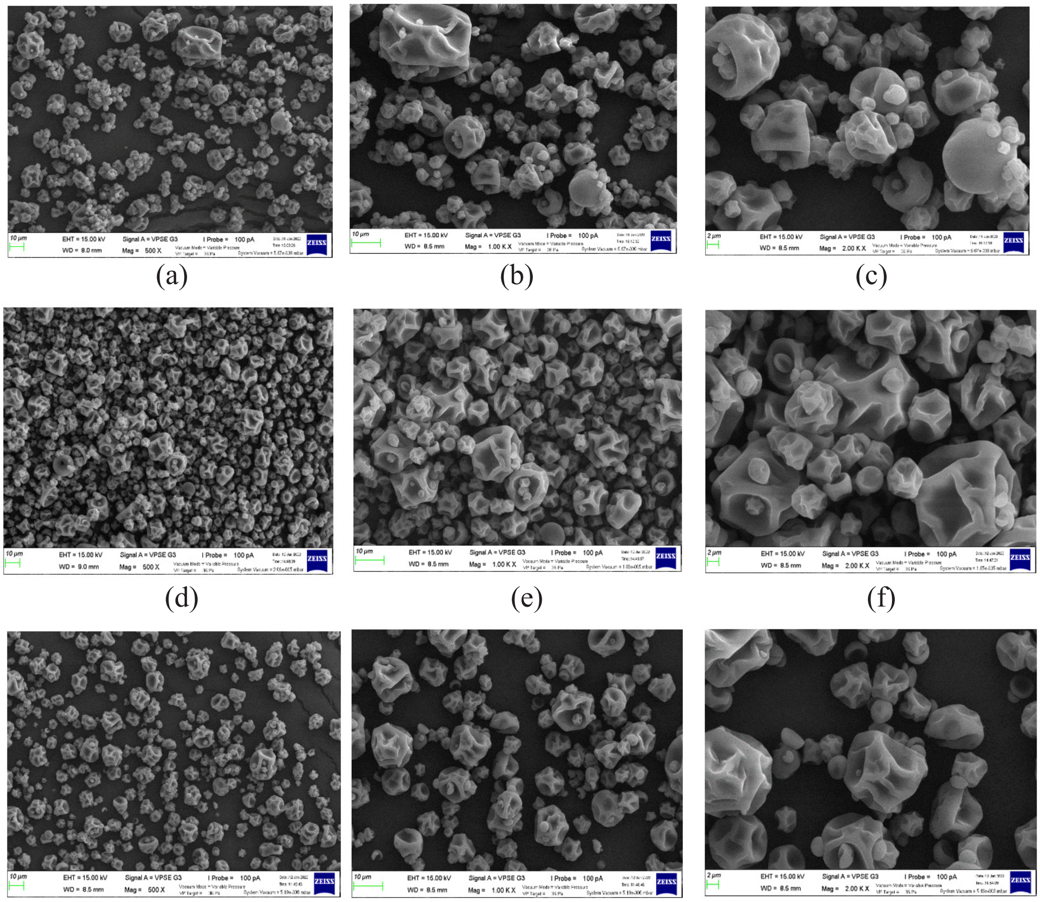
The morphology of spray-dried tomato powder produced with different conditions is shown in Figures 16, 17, and 18. As stated in the methodology, only a few samples were chosen for SEM imaging: the samples with 140°C at 10%, 160°C at 10%, and 160^{o}C at 5%. The samples were chosen likewise to compare the differences in particle morphology of the resulting tomato powder at different inlet temperatures (140°C and 160°C) and differences in powder morphology at different concentrations (5% and 10%) with different types of carrier agents (MD 4-7 DE, MD 10-12 DE, GA). For the spray drying of the tomato powder, the inlet temperature and the concentration of the carrier agents were shown to be the key factors influencing the morphology of the powder. The particle size has been varied, in which GA has formed the largest particle out of the other two carrier agents, and MD 10-12 formed the smallest particle. The particles formed were mostly wrinkled, irregular, and possessed pockmark surfaces and had some agglomeration between the samples‘ materials, these being the typical morphologies of spray-dried powders (Tonon et al., 2011). Comparing the morphology based on the type of carrier agents, the spray-dried powder with 10% GA at 160°C is considerably large, with many folds of wrinkled surfaces, larger pockmarks, and smaller particles attached to the surface. The 10% GA at 140 ^{o}C also shows the same property with a lesser wrinkled surface the 5% GA at 160°C is found to be smaller than the other two and has a smoother surface. The morphology of powders produced with MD 4-7 DE appeared to be the same as those produced with GA and only differed in size. However, smooth spherical shapes were found for the tomato powder with 5% MD 4-7 DE at 160°C. As for the powders produced with MD 10-12 DE, the morphology also follows suit to those produced with GA and differs in size. However, globular and agglomerating shapes are observed on the 5% MD 4-7 DE tomato powder at 160°C. From the observation, it was found that the higher inlet temperature led to more wrinkled particles and that the lower concentration led to some smoother particles. Lower temperature drying makes the particle wetter and much more flexible, and it collapses (Jafari et al., 2017). There was no effect of carrier type on the particle shape, as it appears that carrier agents are more likely to affect the particle size and that the concentration of carrier agents and inlet temperature is deemed to be the key factors affecting the morphology of the spray-dried powders. Nonetheless, Jafari et al. (2017) concluded from a study of pomegranate juice that a higher content of MD as a carrier produces more particle ridging due to its propensity to migrate in the outer zones of particles, limiting its endurance, which is verified by Tonon et al. (2008). Preceding research has found that wrinkles are caused by mechanical stress caused by uneven drying at various sections of liquid droplets during the initial drying step (Pourashouri et al., 2014).


(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 16. SEM images of tomato powder with the addition of GA at (a) – (c) 160°C, 5%; (d) – (f) 160°C, 10%; (g) – (i) 140°C, 10% with 500x, 1000x, 2000x magnification

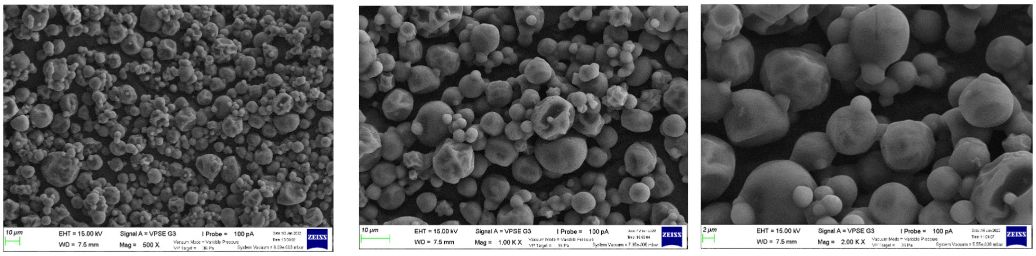


(a) (b) (c)

(d) (e) (f)

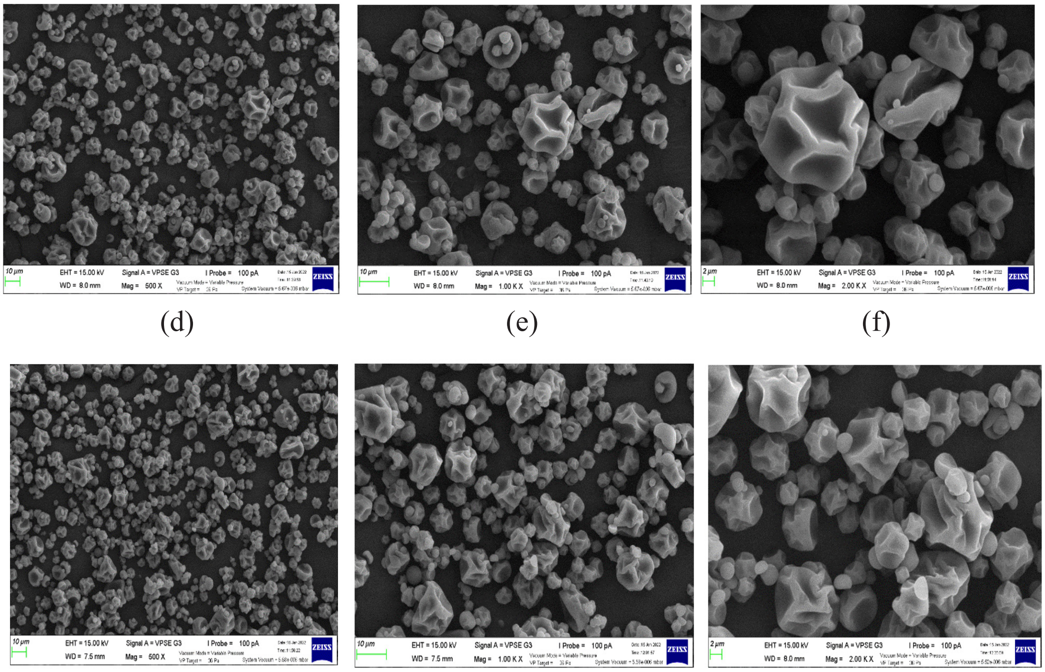
(g) (h) (i)

Figure 17. SEM images of tomato powder with the addition of MD 4-7 at: (a) – (c) 160°C, 5%; (d) – (f) 160°C, 10%; (g) – (i) 140°C, 10% with 500x, 1000x, 2000x magnification



(a) (b) (c)

Figure 18. SEM images of tomato powder with the addition of MD 10-12 at: (a) – (c) 160°C, 5%



(d) (e) (f)

(g) (h) (i)

Figure 18 (Continue). SEM images of tomato powder with the addition of MD 10-12 at: (d) – (f) 160°C, 10%; (g) – (i) 140°C, 10% with 500x, 1000x, 2000x magnification

CONCLUSION

Spray-dried tomato powder was successfully produced and prepared at different concentrations of various carrier agents at different inlet temperatures. Each spray-dried powder resulted in a satisfactory result on the physical properties. Based on the experiment, the inlet temperature and carrier agent concentration profoundly influence the powder properties. The data obtained shows that the stability of the tomato powder is much better at higher temperatures and higher concentrations, with MD 4-7 DE being the best carrier agent among the three experimented carrier agents. The result showed that at higher temperatures and higher concentrations, the powder characteristics are more likely to have a higher yield, WSI, and larger particle size, as well as lower bulk density, hygroscopicity, moisture content, WAI, and color index. The findings also showed that the type of carrier agents have significantly improved powder characteristics, with MD 4-7 DE that gives better overall performance on powder quality. The powder analysis shows that the product has a moisture content of 3.17 ± 0.29%, the highest yield percentage at 32.1%, a low bulk density of 0.2943 ± 0.01 g/cm^3, the lowest hygroscopicity at 5.67 ± 0.58%, a high WSI at 89.98 ± 1.25%, a low WAI at 6.22 ± 0.22%, an intermediate particle size of 24.73 µm, and color L*, a*, b* values at 31.59 ± 0.03, 11.62 ± 0.08 and 13.32 ±

0.12. As for powder morphology, the product shows wrinkled surfaces, larger pockmarks, and smaller particles attached to the surface. As for the recommendation, it is signified that the effect of additives, their concentration, and inlet temperature on the properties of the powder has shown distinctive characteristics under the influence of these parameters. However, the main function of higher-intensity additives can be emphasized as additives improve product yield by manipulating transition temperature.

ACKNOWLEDGEMENT

This research was supported by the Research Management Center of Universiti Malaysia Sabah (Grant No. DN21100 - Phase 1/2021). These contributions are gratefully acknowledged.

REFERENCES

Adak, N., Heybeli, N., & Ertekin, C. (2017). Infrared drying of strawberry. *Food Chemistry*, *219,* 109-116. https://doi.org/10.1016/j.foodchem.2016.09.103

Aderibigbe, O. R., Owolade, O. S., Egbekunle, K. O., Popoola, F. O., & Jiboku, O. O. (2018). Quality attributes of tomato powder as affected by different pre-drying treatments. *International Food Research Journal*, *25*(3), 1126-1132.

AOAC. (2012). *Official Methods of Analysis: Association of Official Analytical Chemists* (19th ed.). https://www.scirp.org/(S(351jmbntvnsjt1aadkposzje))/reference/ReferencesPapers.aspx?ReferenceID=1819676

Bhandari, B., & Howes, T. (2005). Relating the stickiness property of foods undergoing drying and dried products to their surface energetics. *Drying Technology*, *23*(4), 781-797. https://doi.org/10.1081/DRT-200054194

Cai, Y. Z., & Corke, H. (2000). Production and properties of spray-dried amaranthus betacyanon pigments. *Journal of Food Science*, *65*(7), 1248-1252. https://doi.org/10.1111/j.1365-2621.2000.tb10273.x

Ciurzyńska, A., & Lenart, A. (2011). Freeze-drying - Application in food processing and biotechnology - A review. *Polish Journal of Food and Nutrition Sciences*, *61*(3), 165-171. https://doi.org/10.2478/v10222-011-0017-5

Compaore, A., Dissa, A. O., Rogaume, Y., Putranto, A., Chen, X. D., Mangindaan, D., Zoulalian, A, Rémond, R., & Tiendrebeogo, E. (2017). Application of the reaction engineering approach (REA) for modeling of the convective drying of onion. *Drying Technology*, *35*(4), 500-508. https://doi.org/10.1080/07373937.2016.1192189

Caparino, O. A., Tang, J., Nindo, C. I., Sablani, S. S., Powers, J. R., & Fellman, J. K. (2012). Effect of drying methods on the physical properties and microstructures of mango (Philippine ‘Carabao’ var.) powder. *Journal of Food Engineering*, *111*(1), 135-148. https://doi.org/10.1016/j.jfoodeng.2012.01.010

Chegini, R. G., & Ghobadian, B. (2007). Spray dryer parameters for fruit juice drying. *World Journal of Agricultural Sciences*, *3*(2), 230-236.

da Costa Ribeiro, A. S., Aguiar-Oliveira, E., & Maldonado, R. R. (2016). Optimization of osmoticdehydration of pear followed by conventional drying and their sensory quality. *LWT - Food Science and Technology*, *72*, 407-415. https://doi.org/10.1016/j.lwt.2016.04.062

Eren, I., & Kaymak-Ertekin, F. (2007). Optimization of osmotic dehydration of potato using response surface methodology. *Journal of Food Engineering*, *79*(1), 344-352. https://doi.org/10.1016/j.jfoodeng.2006.01.069

Garofulić, I. E., Zorić, Z., Pedisić, S., & Dragović-Uzelac, V. (2016). Optimization of sour cherry juice spray drying as affected by carrier material and temperature. *Food Technology & Biotechnology*, *54*(4), 441-449. https://doi.org/10.17113/ftb.54.04.16.4601

Gouaou, I., Shamaei, S., Koutchoukali, M.S., Bouhelassa, M., Tsotsas, E., & Kharaghani, A. (2019). Impact of operating conditions on a single droplet and spray drying of hydroxypropylated pea starch: Process performance and final powder properties. *Asia-Pacific Journal of Chemical Engineering*, *14*(1), Article e2268. https://doi.org/10.1002/apj.2268

Goula, A. M., & Adamopoulos, K. G. (2005). Stability of lycopene during spray drying of tomato pulp. *LWT - Food Science and Technology*, *38*(5), 479-487. https://doi.org/10.1016/j.lwt.2004.07.020

Goula, A. M., & Adamopoulos, K. G. (2008). Effect of maltodextrin addition during spray drying of tomato pulp in dehumidified air: I. Drying kinetics and product recovery. *Drying Technology*, *26*(6), 714-725. https://doi.org/10.1080/07373930802046369

Grabowski, J. A., Truong, V. D., & Daubert, C. R. (2006). Spray drying of amylase hydrolyzed sweet potato puree and physicochemical properties of powder. *Journal of Food Science*, *71*(5), E209-E217. http://dx.doi.org/10.1111/j.1750-3841.2006.00036.x

Haque, M., & Adhikari, B. (2014). Drying and denaturation of proteins in spray drying process. In A. S. Mujumdar (Ed.), *Handbook of Industrial Drying* (pp. 971-983). CRC Press.

Hii C. L., Ong S. P., Yap J. Y., Putranto A., & Mangindaan, D. (2021). Hybrid drying of food and bioproducts: A review. *Drying Technology*, *39*(11), 1554-1576. https://doi.org/10.1080/07373937.2021.1914078

Ismail, M. H., Khan, K. A., Ngadisih, N., Irie M, Ong S. P, Hii, C. L., & Law, C. L. (2020). Two-step falling rate in the drying kinetics of rice noodle subjected to pre-treatment and temperature. *Journal of Food Processing and Preservation*, *44*(11), Article e14849. https://doi.org/10.1111/jfpp.14849

Jafari, S., Ghalenoei, M., & Dehnad, D. (2017). Influence of spray drying on water solubility index, apparent density, and anthocyanin content of pomegranate juice powder. *Powder Technology*, *311*, 59-65. https://doi.org/10.1016/j.powtec.2017.01.070

Jittanit, W., Niti-Att, S., & Techanuntachikul, O. (2010). Study of spray drying of pineapple juice using maltodextrin as an adjunct. *Chiang Mai Journal of Science*, *36(3),* 498-506.

Jittanit, W., Chantara-In, M., Deying, T., & Ratanavong, W. (2011). Production of tamarind powder by drum dryer using maltodextrin and Arabic gum as adjuncts. *Songklanakarin Journal of Science and Technology*, *33*(1), 33-41.

Kwapinska, M., & Zbicinski, I. (2005). Prediction of final product properties after cocurrent spray drying. *Drying Technology*, *23*(8), 1653-1665. https://doi.org/10.1081/DRT-200065075

Lee, J. K. M., Taip, F. S., & Abdullah, Z. (2018). Effectiveness of additives in spray drying performance: A review. *Food Research*, *2*(6), 486-499. https://doi.org/10.26656/FR.2017.2(6).134

Li, T., Yang, X., Yu, Y., Si, X., Zhai, X., Zhang, H., Dong, W., Gao, C., & Xu, C. (2018). Domestication of wild tomato is accelerated by genome editing. *Nature Biotechnology*, *36*, 1160-1163. https://doi.org/10.1038/nbt.4273

Martínez-Huélamo, M., Vallverdú-Queralt, A., Di Lecce, G., Valderas-Martínez, P., Tulipani, S., Jáuregui, O., Escribano-Ferrer, E., Estruch, R, Illan, M., & Lamuela-Raventós, R. M. (2016). Bioavailability of tomato polyphenols is enhanced by processing and fat addition: Evidence from a randomized feeding trial. *Molecular Nutrition & Food Research*, *60*(7), 1578-1589. https:// doi.org/10.1002/mnfr.201500820

Muzaffar, K., Dinkarrao B. V., & Kumar, P. (2016) Optimization of spray drying conditions for production of quality pomegranate juice powder. *Cogent Food & Agriculture*, *2,* 1-9. https://doi.org/10.1080/23311932.2015.1127583

Muzaffar, K., Nayik, G. A., & Kumar, P. (2015). Stickiness problem associated with spray drying of sugar and acid rich foods: A mini review. *Journal of Nutrition & Food Sciences*, *S12:003,* 1-3. https://doi.org/10.4172/2155-9600.1000S12003

Nowak, D., & Jakubczyk, E. (2020). The freeze-drying of foods - The characteristic of the process course and the effect of its parameters on the physical properties of food materials. *Foods*, *9*(10), Article 1488. https://doi.org/10.3390/foods9101488

Oliveira, D. M., Clemente, E., & da Costa, J. M. (2012). Hygroscopic behavior and degree of caking of Grugru palm (*Acrocomia aculeata*) powder. *Journal of Food Science and Technology*, *51*(10), 2783-2789. https://doi.org/10.1007/s13197-012-0814-9

Osman, A. F. A., & Endut, N. (2009). Spray drying of roselle-pineapple juice effects of inlet temperature and maltodextrin on the physical properties. In *Second International Conference on Environmental and Computer Science* (pp. 267-270). IEEE Publishing. https://doi.org/10.1109/ICECS.2009.91

Patel, K. C., & Chen, X. D. (2008). Sensitivity analysis of the reaction engineering approach to modeling spray drying of whey proteins concentrate. *Drying Technology*, *26*(11), 1334-1343. https://doi.org/10.1080/07373930802331019

Phisut, N. (2012). Spray drying technique of fruit juice powder: Some factors influencing properties of product. *International Food Research Journal*, *19*(4), 1297-1306.

Phoungchandang, S., & Sertwasana, A. (2010). Spray-drying of ginger juice and physicochemical properties of ginger powders. *ScienceAsia*, *36,* 40-45. http://dx.doi.org/10.2306/scienceasia1513-1874.2010.36.040

Pourashouri, P., Shabanpour, B., Razavi, S., Jafari, S., Shabani, A., & Aubourg, S. (2014). Impact of wall materials on physicochemical properties of microencapsulated fish oil by spray drying. *Food and Bioprocess Technology*, *7,* 2354-2365. https://doi/10.1007/s11947-013-1241-2

Pu, H., Li, Z., Hui, J., & Raghavan, G. S. V. (2016). Effect of relative humidity on microwave drying of carrot. *Journal of Food Engineering*, *190*, 167-175. https://doi.org/10.1016/j.jfoodeng.2016.06.027

Raiola, A., Rigano, M. M., Calafiore, R., Frusciante, L., & Barone, A. (2014). Enhancing the health-promoting effects of tomato fruit for biofortified food. *Mediators of Inflammation*, *2014*, Article 139873. https://doi.org/10.1155/2014/139873

Sabhadinde, V. N. (2014). The physicochemical and storage properties of spray dried orange juice powder. *Indian Journal of Fundamental and Applied Life Sciences*, *4*(4), 153-159.

Shishir, M. R. I., & Chen, W. (2017). Trends of spray drying: A critical review on drying of fruit and vegetable juices. *Trends in Food Science and Technology*, *65*, 49-67. https://doi.org/10.1016/j.tifs.2017.05.006

Shrestha, A. K., Ua-arak, T., Adhikari, B. R., Howes, T., & Bhandari, B. R. (2007). Glass transition behavior of spray dried orange juice powder measures by differential scanning calorimetry (DSC) and thermal mechanical compression test (TMCT). *International Journal of Food Properties*, *10*(3), 661-673. https://doi.org/10.1080/10942910601109218

Souza, A. L. R., Hidalgo-Chávez, D. W., Pontes, S. M., Gomes, F. S., Cabral, L. M. C., & Tonon, R.V. (2018). Microencapsulation by spray drying of a lycopene-rich tomato concentrate: Characterization and stability. *LWT - Food Science and Technology*, *91*, 286-292. https://doi.org/10.1016/j.lwt.2018.01.053

Sudeep, G., Indira T. N., & Bhattacharya, S. (2010). Agglomeration of a model food powder: Effect of maltodextrin and gum Arabic dispersions on flow behavior and compacted mass. *Journal of Food Engineering*, *96*(2), 222-228. https://doi.org/10.1016/j.jfoodeng.2009.07.016

Szadzińska, J., Łechtańska, J., Kowalski, S. J., & Stasiak, M. (2017). The effect of high power airborne ultrasound and microwaves on convective drying effectiveness and quality of green pepper. *Ultrasonics Sonochemistry*, *34*, 531-539. https://doi.org/10.1016/j.ultsonch.2016.06.030

Tonon, V. R., Brabet, C., & Hubinger, M. (2008). Influence of process conditions on the physicochemical properties of acai powder produced by spray drying. *Journal of Food Engineering*, *88*(3), 411-418. http://dx.doi.org/10.1016/j.jfoodeng.2008.02.029

Tonon, V. R., Brabet, C., & Hubinger, M. (2011). Spray drying of acai juice: Effect of inlet temperature and type of carrier agent. *Journal of Food Processing and Preservation*, *35*(5), 691-700. http://dx.doi.org/10.1111/j.1745-4549.2011.00518.x

Uyar, R., Bedane, T. F., Erdogdu, F., Palazoglu, T. K., Farag, K. W., & Marra, F. (2015). Radio-frequency thawing of food products - A computational study. *Journal of Food Engineering*, *146*, 163-171. https://doi.org/10.1016/j.jfoodeng.2014.08.018

Wang, B., Timilsena, Y. P., Blanch, E., & Adhikari, B. (2017). Characteristics of bovine lactoferrin powders produced through spray and freeze-drying processes. *International Journal of Biological Macromolecules*, *95*, 985-994. https://doi.org/10.1016/j.ijbiomac.2016.10.087

Ziaforoughi, A., & Esfahani, J. A. (2016). A salient reduction of energy consumption and drying time in a novel PV-solar collector-assisted intermittent infrared dryer. *Solar Energy*, *136*, 428-436. https://doi.org/10.1016/j.solener.2016.07.025

Zielinska, M., & Michalska, A. (2016). Microwave-assisted drying of blueberry (*Vaccinium corymbosum* L.) fruits: Drying kinetics, polyphenols, anthocyanins, antioxidant capacity, colour and texture. *Food Chemistry*, *212*, 671-680. https://doi.org/10.1016/j.foodchem.2016.06.003

Zhu, C., Shoji, Y., McCray, S., Burke M, Hartman, C. E., Chichester, J. A., Breit, J., Yusibov, V., Chen, D., & Lal, M. (2014). Stabilization of HAC1 influenza vaccine by spray drying: Formulation development and process scale-up. *Pharmaceutical Research*, *31*, 3006-3018. https://doi.org/10.1007/s11095-014-1394-3