The Influence of Drying Temperature to The Physicochemical, Thermal and Rheological Characteristics of Dried Tomato Powder

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Abstract. Tomatoes are both nutritious and inexpensive, but due to their high moisture content, they are more readily damaged. Converting tomatoes into powder is a useful option for reducing post-harvest losses and enhancing tomatoes shelf life. Foam mat drying is a cost-effective way of drying tomatoes while maintaining quality. In this study, we observed into the physicochemical, thermal, and rheological characteristics of tomato powder as influenced by different temperatures for drying (50°C, 60°C, 70°C, 80°C). The result observed that moisture content, water activity (aw), hygroscopicity, water absorption index (WAI) and color decreased, however water solubility index (WSI) tendency to rise as drying temperature increased. Thermal research revealed that raising the drying temperature reduced the weight loss of tomato powder. The peak temperature shifted to a higher temperature as the drying temperature increased. For the rheological behavior, different drying temperature influenced on the viscosity and shear stress of tomato powder. A drying temperature of 70°C was discovered to be the optimal treatment for producing tomato powder with the following characteristics: moisture content (4.65%), aw (0.24), hygroscopicity (4.28%), WSI (79.62%), WAI (252.77%), L value (53.45), a value (15.84), and b value (8.77).

Keyword: Tomato powder, foam mat drying, physicochemical characteristics, thermal characteristics, Rheological behavior.

1 Introduction

Tomato (*Lycopersicum excelentum Mill*) is one of horticultural commodity that are easily growth and obtained in Indonesia. Tomato not only has a good taste but also rich in some of essential nutrients and low price [1]. Ripe tomatoes contained around 34.38 mg of vitamin C, 1.98 grams of fiber content and 1.53 grams of protein [2]. However, tomato fruit has a lot of moisture content (almost 93-95%), so it easily damaged in fresh condition and makes
its storage and transportation very difficult. The high moisture content of tomato fruits makes them more easily decomposed by microorganisms. Microorganisms such as fungus and bacteria induce rot and other flaws in preserved tomato fruits, making them unbearable. The loss of tomato quantity is related to the amount, which is more prevalent in Indonesia, whereas the loss of quality is due to its nutrients, caloric composition, acceptability, and edibility [3].

In order to achieve the second agenda of Sustainable Development Goals (SDGs 2030), which focuses on reducing lack of food, establishing food safety, boosting nutrition, and advocating for agricultural sustainability, food preservation techniques are used to reduced post-harvest losses such as in tomato [3]. Drying is a suitable preservation method for removing moisture from food. For the manufacturing of food powder, many dried procedures can be applied including drum dried, freeze dried, spray dried, and foam mat dried [2][4]. Drum drying is a drying technique using high temperatures which causes loss of nutrients and results in an undesirable odor in the final product [5]. Freeze drying and spray drying process provide good quality product, but they are more expensive and time-consuming drying process [6]. The most basic method for removing water from fruit and vegetable extract is foam mat drying. The drying procedure for foam mats changes a water-based product into a steady foam. In the following stage, the foam will be spread out into a thin layer and air dried [7]. The benefits of foam mat drying include its adaptability for all kinds of juice, nutritional quality retention, ease of reconstitution, and low cost of powder manufacture [8]. The quick drying at lower temperatures in foam mat drying technology has an environmental impact, as it reduces energy usage [9]. In addition, foam mat drying is also applicable for drying foods that are typically challenging to dry due to their high sugar content, heat sensitivity, stickiness, and viscosity [7].

Several authors discovered that the temperature of drying had implications on the characteristics of foam-mat dried powder. Asokapandian et al., has found that muskmelon powder moisture content decreased as drying temperature increased [10]. Hariyadi et al., revealed that the best operating temperature for the production of tomato powder is at 50°C [2]. According to Hossaine et al., the greater the drying temperatures decreased TSS and pH, but increased titratable acidity content and antioxidant activity of tomato powder [11]. Belal et al., concluded that the rate of drying influenced the physical properties of powder [12]. Drying temperatures affected the rheological models of cress seed gum solution [13]. Athmaselvi et al., were investigated thermal properties of tropical fruit powder [14]. However, no studies have investigated the effect drying temperature in thermal and rheology characteristics of dried powdered tomato. The study's goal was to explore the influence of drying temperature (50°C to 80°C) on the physical-chemical, thermal, and rheological characteristics of dried tomato powder.

2 Materials and method

2.1 Materials

The resources for this study, including fresh ripe tomatoes ((dark red and free of blemishes) and eggs, were bought from the Subang market. Carboxymethyl cellulose (CMC) Food Grade (Gunacipta Multiras Co, Indonesia) and maltodextrin food grade (Alfa Food Chemical) were used in this study as a foam stabilizer.

2.2 Sample preparation
Tomatoes were cleaned up with running water to eliminate dirt and other unwanted materials. Next, they were blanched at 96°C temperature for 3-4 min. After peeling the tomatoes were crushed for 3 min using a blender and filtered to get pureed tomatoes. Furthermore, pureed tomato was blended with 15% of egg white, 10% of maltodextrin and 0.33% of CMC. This mixture was whipped using a manual mixer (HR1552; Phillips, Indonesia) with a speed control of 950 rpm for 4.9 minutes. The foamed tomato was poured to reached a thickness of 3 mm into an aluminium tray (40 x 30 cm). The trays were followed to dry in drying oven (UFB500; Memmert, Germany) at different drying temperature (50°C, 60°C, 70°C and 80°C) for 5 hours. The dried tomato was ground in a blender (Philips HR2115) and sieved through a 20-mesh screen. The sample was packed into laminated foil bags and kept in the refrigerator until analysis.

### 2.3 Physicochemical analysis

The moisture content was done as chemical analysis; water activity ($a_w$), hygroscopicity, water solubility index (WSI), water absorption index (WAI), and color were done as physical analysis. The moisture content of tomato powder was tested by drying them in a hot air oven until they reached consistent weights following the Association of Official Analytical Chemists protocol [15]. The water activity ($a_w$) was determined using a water activity meter HD-3A (CGoldenwell, China), in accordance by Azizpour et al. [16]. The WSI, WAI and hygroscopicity of tomato powder were examined using the procedure outlined by Afifah et al [17].

A chromameter (3NH, China) was employed to determine the color evaluation of tomato powder. The sample was put in a borosilicate glass cuvette and positioned in dish chamber. Next the detector of the chromameter has been set on the sample and it was read automatically. Corresponding L* values demonstrate lightness, a* values (positive or negative) represent the red or green color, and b* values (positive or negative) represent yellow or blue color.

### 2.4 Thermal analysis

Thermal analyses of tomato powder were measured using a thermal analyzer (DTG-60 SHIMADZU, Japan), as described by Athmaselvi et al, with slightly modification. The experiments were performed under a nitrogen flow. Amount of 5 mg were heated at a rate of 10 °C/min in an aluminium pan with nitrogen gas (100 mL/min) from 0 to 400 °C [14].

### 2.5 Rheological analysis

Rheological properties of tomato powder solution were measured with Thermo Scientific HAAKE MARS 40 Rheometer (Thermo Hakee Co. Ltd, Germany) at a constant temperature of 25°C. The measurements were employed using a concentric cylinder viscometer with a stationary outer cylinder with a spinning measuring bob.

### 2.6 Statistical analysis

The study had a fully randomised design, with different drying temperature treatments (50°C, 60°C, 70°C, and 80°C). SPSS 13.0 program was applied for statistical analyses. Each treatment was performed three times with three analysis repeats. The analysis of variance, also known as an ANOVA, was used to statistically examine the collected data.
To test the difference among the data, the Duncan Multiple Range Test (DMRT) method was applied, with a level of significance of 0.05. Selection of the best treatment with effectiveness index method de Garmo was determined from the highest result value (Nh) as described in Kartikasari et al. [18]. First, the variable weight value (BV) was calculated based on respondent ratings of the importance of each variable. Then, divide the difference between the treatment value and the smallest value by the difference between the treatment value and the highest value to get the effectiveness value (Ne). The result value (Nh) of each variable obtained by multiplying the weight value (BV) by effectiveness value (Ne).

### 3 Results and discussion

#### 3.1 Physical and chemical characteristics of tomato powder

Physical and chemical characteristics of dried tomato powder are summarized in Table 1. With varying drying temperatures, dried tomato powder's moisture content values ranged from 3.61% to 7.47%. Tomato powder's low moisture content resulted in reduced microbiological activity and chemical reactions. The moisture content of tomato powders trended downward as drying temperature increased (p<0.05). Dried tomato powder produced at 80°C drying temperature had the lowest moisture content. At a greater temperature for drying, the heat energy went quickly into the foam, increasing moisture evaporation [19]. As stated by Pinto et al., with enhancing drying temperature, the water content of encapsulated carotenoid powder lowered [20].

Table 1 showed that the water activity (a_w) of tomato powder were relatively low in ranges of 0.173 to 0.339. All tomato powder samples exhibited a_w values below 0.4, which could be prevents microbial growth [19]. Trend observed that the higher drying temperature tended to decrease the a_w of tomato powder. The lowest a_w was showed in sample at 80°C drying temperature. During whipping process, the egg white as a foam stabilizer could create foam, which will extend the surface, increasing the contact among the drying air and the object being dried and therefore evaporating more water. Decreased a_w is closely related to decreased water content, at higher temperature the structure of food powder is more porous, so that made the drying faster and decreased the moisture level of powder [16]. A similar observation has also revealed in dried Nigella sativa powder [21].

**Table 1.** Physicochemical properties of dried tomato powder

<table>
<thead>
<tr>
<th>Physicochemical properties</th>
<th>Treatments</th>
<th>50°C</th>
<th>60°C</th>
<th>70°C</th>
<th>80°C</th>
</tr>
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<tbody>
<tr>
<td>Moisture content (%)</td>
<td></td>
<td>7.47±0.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.21±0.11&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.65±0.24&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.61±0.21&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Water activity</td>
<td></td>
<td>0.34±0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.29±0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.24±0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.17±0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Hygroscopicity</td>
<td></td>
<td>6.43±0.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.25±0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.28±0.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.37±0.06&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Water solubility index (%)</td>
<td></td>
<td>76.98±0.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>78.98±0.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>79.62±0.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80.03±0.93&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Water absorption index (%)</td>
<td></td>
<td>275.17±12.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>255.79±3.46&lt;sup&gt;a&lt;/sup&gt;</td>
<td>252.77±6.70&lt;sup&gt;b&lt;/sup&gt;</td>
<td>249.57±9.47&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Color</td>
<td></td>
<td>57.58±0.21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>54.09±0.07&lt;sup&gt;c&lt;/sup&gt;</td>
<td>53.44±0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>51.65±0.20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>L</td>
<td></td>
<td>16.40±0.09&lt;sup&gt;c&lt;/sup&gt;</td>
<td>15.86±0.15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.84±0.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.59±0.05&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>a</td>
<td></td>
<td>21.65±0.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.29±0.15&lt;sup&gt;c&lt;/sup&gt;</td>
<td>18.77±0.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>16.08±0.304&lt;sup&gt;a&lt;/sup&gt;</td>
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The mean value in a similar row with the same superscript lowercase letters does not differ much (p>0.05)

The capacity of a material to take in water from its surroundings is known as hygroscopicity [22]. The least amount of hygroscopicity of tomato powder was showed at
80°C (Table 1). Araújo and Pena explained that increasing drying temperature decreased the flour’s hygroscopicity [23]. This behavior is associated with an increase in temperature caused the water molecules to become activated, thus diminishing the attracting force between the water molecules and lowering the equilibrium water content and consequently decreasing the hygroscopicity [24]. Brites et al., also revealed that the enhancing temperature of drying reduced the hygroscopicity of yacon powder [25].

The water solubility index assesses a food powder's tendency for dissolving in water [26]. The water solubility index (WSI) of tomato powder produced at 50°C was less than the sample prepared at 60°C. The solubility increased with the increasing drying temperature but did not differ significantly. Generally, at higher temperatures, the food structure becomes more permeable, this accelerated the reduction of moisture content. Lower moisture content enhanced the surface area thereby allowed more interaction between powder and water, resulting enhancement of WSI [27]. The similar finding was observed by Asokapandian et al. that as drying temperature increased, muskmelon powder's water solubility increased [10].

The capacity of food powder to take up water is defined by the water uptake (WAI) [10]. The variety of the WAI value was 249.57% to 275.17%. It was clear in Table 1 that the enhancing of drying temperature reduced WAI value but did not differ significantly at 60°C, 70°C, dan 80°C. This finding attributed to the reduced moisture content of powders which dried at greater temperatures, where the higher moisture content may contribute to water absorption [28]. Close results were reported that foam-mat dried lime powder decrease in WAI as the temperature increased [29].

Color is one of physical parameter in food that used to indicate the quality and reflects their desirability [13]. The color difference between different drying temperature was displayed in $L$, $a$, and $b$ values (Table 1). The $L$ values were ranged 51.65 to 57.58. The $a$ and $b$ values were recorded between 13.59 and 16.40 and 16.08 and 21.65, respectively. The lightness ($L$ value), redness ($a$ value) and yellowness ($b$ value) of tomato powder decreased with increasing drying temperature. The lower lightness in tomato powder was caused by the oxidation of carotenoid and the caramelization due to an enhance in drying temperature [20]. During drying process in high temperature, fruit pulp run into browning reaction and decrease in brightness level at the end of the process [28]. The brightness level decreased as the raised drying temperature in foam-mat dried lime juice [29]. According to Asokapandian et al., the reduction in red and yellow color with increase in drying temperature may be correlated with carotenoid degradation and Maillard reaction [10].

### 3.2 Thermal properties

Thermogravimetric analysis was used to study the thermal characteristics of tomato powder at various drying temperatures. The TGA (thermogravimetry analysis) curves of all sample showed in one step thermal decomposition and started to lose weight at 199.19°C. This reduction of weight could be explained as water loss during the increase of temperature [30]. As shown in Figure 1, the TGA curve demonstrated a more stable phase after evaporation of water and other chemicals at temperatures ranging from 350 to 400°C. Similar result was found in thermal analysis of guava powder [14]. The weight loss of tomato powder at 50°C to 80°C were 46.50%, 30.50%, 22.77%, and 22.14% respectively. The increasing drying temperature had observed lower the weight loss of tomato powder. This is might be caused by the use of heat at a greater drying temperature increased the evaporation of the foam moisture so that decreased moisture content and reduced the weight loss of sample [31].
The thermograms (DTA curves) of tomato powder at various drying temperature are displayed in Figure 1. In the presence of different temperature, the thermograms of all sample exhibited endothermic peak. This peak of endothermic represents the processes of water evaporation and pectin melting in tomato powder [32]. Peak temperatures of the endothermic peak of the tomato powder shifted to a higher temperature at 161.63°C, 160.00°C, 162.94°C, and 162.33°C when drying temperatures rises (50°C to 80°C). The enthalpy values of the endothermic transition at 50°C to 80°C temperatures for drying were 97.90mcal; 66.50mcal; 57.78mcal; and 55.01mcal respectively. The enthalpy of endothermic transition of tomato powder tended to decrease with increasing drying temperature. This result related to the moisture content of tomato powder. Liu et al., revealed that with decreasing moisture content, the endothermic peaks developed a shoulder. They also stated that the heat energy of endothermic process decreased with
reducing moisture content [33]. Figure 1 also showed that the exothermic peak appeared in the DTA curves for tomato powder all treatments. As the drying temperature increased, the exothermic peak temperature also increased to a higher temperature. It centered at 300.75°C, 301.03°C, 302.88°C, and 303.33°C when temperatures for drying were 50°C to 80°C, respectively. The exothermic transition of tomato powder might be affected by moisture content [33].

### 3.3 Rheological properties

The viscosity and shear stress versus shear rate of dried tomato powder are illustrated in Figure 2.

**Fig 2.** Rheology characteristics of tomato powder in different drying temperature (TP 50 is tomato powder at 50°C; TP 60 is tomato powder at 60°C; TP 70 is tomato powder at 70°C; and TP 80 is tomato powder at 80°C)
Different drying temperature influenced on the viscosity and shear stress of dried tomato powder. The viscosity graphs of each sample decreased and the shear stress increased with increasing shear rate. The flow curve of dried tomato powder exhibited a non-Newtonian behavior. This behaviour of tomato powder flow charts is able to be credited to the large molecular weight of pectins thus decreased the viscosity [34]. The high drying temperature exhibited the higher viscosity of tomato powder. Enzyme inactivation during drying could further prevent pectin degradation. These results are similar with observation of Moniri et al., that reported high drying temperatures resulted the high amount of viscosity of cress seed gum solution [13].

The best treatment was determined based on the calculation of the total result (Nh) by considering their moisture content, $a_w$, hygroscopicity, WSI, WAI, and color on tomato powder. The total result (Nh) at 50°C, 60°C, 70°C, and 80°C temperatures for drying treatment was 0.50; 0.47; 0.57; dan 0.50, respectively. Based on the data presented above, it was found that temperature for drying of 70°C had the greatest total Nh value and was the most effective method for producing tomato powder.

4 Conclusion

The study observed that drying temperature affected significantly the physicochemical of dried tomato powder. It was showed that the moisture content, water activity (Aw), hygroscopicity, water absorption index (WAI) and color decreased, however water solubility index (WSI) tended to trend upward as temperatures for drying increased. Thermal analysis resulted that the increasing drying temperature had observed lower the weight loss of tomato powder. As the drying temperature enhanced, the endothermic and exothermic peak temperature also increased to a higher temperature. The viscosity graphs of tomato powder decreased and the shear stress increased with increasing shear rate. Moreover, the drying temperature treatment of 70°C was found as the most effective treatment to produce a good physicochemical characteristic of dried tomato powder.

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References


