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Drying Kinetic and the Changes of Physicochemical Properties and Bioactive Contents of Dried Tomatoes during Hot Air Drying

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Abstract: *Hot-air drying technique helps remove water content, prevents the quality of tomatoes from microbial growth, and extends their shelf life. Nevertheless, hot-air drying could affect dried products' nutritional value and physicochemical quality. Therefore, this study investigated the drying kinetics and the changes of physicochemical and bioactive compounds of local tomatoes (Cherry and Holland) during processing into dried tomatoes. To process the dried tomatoes, fresh tomatoes were pretreated with $CaCl_2$ (0.5%) for 15h and submerged in a sugar solution containing citric acid and sodium metabisulphite. The pretreated samples were boiled for 1 hour and dried in a hot-air oven (50 °C) to reach a constant moisture level. The final moisture level of Cherry (11.75% w.b) and Holland (10.35 % w.b) were achieved with 1200 min and 1020 min drying times, respectively. During the drying process, the physicochemical properties of dried Cherry and Holland tomatoes were significantly different ($p < 0.05$) between the control (fresh) and dried samples. The moisture content, water activity, and pH values were significantly decreased ($p < 0.05$) with a longer drying time. Moreover, the value L* of a colour parameter that indicated lightness value also decreased. However, the a* and b* value was significantly increased ($p < 0.05$) from fresh to dried samples. Both tomato samples' colour change (ΔE) increased with drying time. At the same time, increasing drying time resulted in the total phenolic of Cherry and Holland being reduced from fresh to dried samples by factors of 4.73 and 4.59, respectively. The total flavonoid content in both tomato varieties decreased between fresh and dried samples within the first 200 min of drying time. For Cherry tomato, the flavonoid content decreased by 1.50 for fresh to dried samples and 1.38 for Holland tomato. The result of this study can help predict the moisture loss and desirable drying time to produce a dried tomato with good quality and maintain a high number of bioactive compounds in final products.*

Keywords: Drying kinetic, Physicochemical property, Flavonoid content, Phenolic content, Hot-air drying

1. INTRODUCTION

Tomatoes (Solanum Lycopersicum L) have become an essential vegetable in human diets throughout the years due to their high mineral and anti-oxidant content [1], high sources of phenolic compounds, lycopene, flavonoid, vitamin C and other nutrients that provide health benefits to consumers [2]. Specifically, according to extensive medical studies, phenolic compounds in tomatoes can act as anti-microbial, anti-inflammatory, antioxidant, and anti-cancer, which are very beneficial to the human body [3]. However, tomatoes have a higher level of water content, making them susceptible to microbial destruction and shorter shelf life [4]. Since it is one of nature's most perishable crops, large amounts of it are thrown away during peak harvesting seasons; therefore, it needs to be preserved by applying preservation techniques to extend shelf life and improve the storage stability of the tomatoes [5]. The shelf life of tomatoes can be extended by various methods, including changing the storage environment (Cool place), adding chemical preservatives, using modified-atmosphere packing, drying, and processing into other products such as juices, purees, dried tomatoes, ketchup, and paste [6]. Nevertheless, some preservative procedure require expensive technology and equipment which may not be available in low-income and developing countries [7]. Among the preservative above, drying is a simple method used to preserve various

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foods and is widely utilised to extend fresh fruits' shelf life. The drying technique is a useful low-cost technology for reducing moisture content and decreasing microbial decay. In addition, it helps to reduce weight and volume, saving packaging and transportation costs while allowing the product to be stored at room temperature [8]. In the processing of tomatoes, there have been worries about the availability and preservation of important and beneficial nutrients in tomatoes after the processing without losing their potential to defend against disease [9]. During the drying process, the characteristics of dried tomatoes in terms of physicochemical and biochemical properties are generally changed. In addition, physical properties are also varied in dried products, including changes in size, shape, colour, and texture [10].

Therefore, drying time and temperature are considered the main factors that affect the nutritional contents and drying kinetics of dried products in the drying process. Understanding of food and agricultural product drying kinetics is required to analyze drying behavior better and identify the drying mechanism for a particular product, leading to being possible to develop a new drying system, improve an existing one, optimize drying conditions, and control the drying process [11]. Hence, the main objectives of the present study are to study the drying kinetics and to evaluate the effect of drying time at a drying temperature of 50 °C on physicochemical and bioactive compounds properties of tomatoes during processing into dried tomatoes. Two varieties of local tomatoes (Cherry and Holland tomatoes) are selected for the study.

2. METHODOLOGY

2.1 Chemicals

Aluminium chloride (Acros, Germany), sodium nitrite (Merck, Denmark), sodium hydroxide (Merck, Germany), quercetin (Sigma Aldrich, Switzerland), gallic acid (Himedia, India), sodium carbonate (Merck, Germany), folin-ciocalteau (Sigma Aldrich, Switzerland), and ethanol (Merck, Germany) were used as analytical reagents of total phenolic and flavonoid compounds. In addition, ethanol was also used as an extraction solvent.

2.2 Sample collection

Two varieties of ripened tomatoes (Holland and Cherry) were collected in June 2022 from Koh Thom, Kandal province, Cambodia.

2.3 Processing of dried tomatoes

Fig. 1 shows the unit operation process of dried tomatoes in the study. There are three main steps: preparation of tomatoes, pretreatment, and drying. In this study, the seeds of tomatoes were removed, and the Holland tomato was cut into two pieces. The cleaned fresh tomatoes were submerged separately in $CaCl_2$ (0.5% w/v) solution for 15 h. After that, they were treated with a solution containing sugar (5 % w/v), sodium metabisulphite (0.1 % w/v), and citric acid (0.1 % w/v). The tomatoes were cooked in the ingredient solution for 1 h using slight heat at around 60 °C. The pretreated tomatoes were dried in a hot-air oven (Food dehydrator, SS-20H, China) at 50 °C until constant masses were reached. To study drying kinetic, the samples were collected every 30 min for the first three hours, then every one hour until the moisture content reached the constant level.

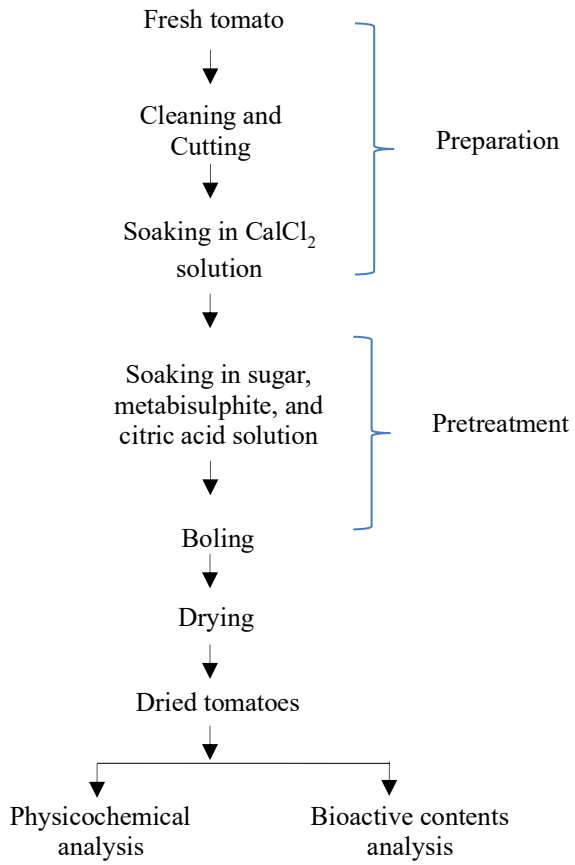

Fig. 1 Unit operation process of tomato drying

2.4 Physicochemical analysis of dried tomatoes

2.4.1 Moisture content analysis

The moisture content of dried and fresh tomatoes was determined using the hot-air oven (Memmert Beshickung/loading model 100-800, Germany) method, according to Le and Konsue [12]. About 3 g of ground sample was weighed and dried at 105 °C until the constant mass was obtained. Exact measurement was done in this study, and the

moisture content can be calculated based on the different masses of the sample before and after drying.

$$\% \text{ Moisture} = [\, W_1 - (W_2 - W_0) \times 100]/W_1 \quad \text{(Eq.1)}$$

Where:
W_1 is the mass of fresh sample (g)
W_2 is the mass of dried sample (g)
W_0 is the mass of aluminium capsule (g)

2.4.2 Water activity analysis

The water activity of dried tomatoes was analyzed using the water activity meter (AQUALAB PAWKIT). In this method, the sample was crushed into small pieces before being subjected to the measurement. The measurement of the water activity of each sample was conducted in duplicate.

2.4.3 pH determination

The pH value of fresh and dried tomatoes was determined by a pH meter (Laqua F-73-Horiba). About 5 g of ground sample was mixed with 45 ml of distilled water and subjected to measurement. The measurement of pH was also done in duplicate.

2.4.4 Color measurement

Fresh and dried tomatoes' colours were used using a Chroma colourimeter (Chroma CR400, Konica-Minolta Ltd., Osaka, Japan). The sample was analyzed with L^*, a^*, and b^* values in three different sections. In the coordinate system, the L^* value measured black and lightness (0 to 100), a^* corresponded to greenness to redness (-100 to 100), and the b^* value were analyzed on blueness to yellowness (-100 to 100). The analysis of colour value was done in duplicate. The total colour change during drying was determined as the following equation:

$$\Delta E^* = \sqrt{[(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]} \quad \text{(Eq.2)}$$

Where:
L_0^*, a_0^* and b_0^* indicate the colour value of the fresh sample
L^*, a^* and b^* represent the colour value of the dried sample

2.5 Bioactive compounds extraction

Fig. 2 shows the extraction procedure for bioactive compounds from fresh and dried tomatoes. The hydroethanolic extraction method described by Pinela et al. [13] isolated the bioactive compounds with some modifications. First, about 1 g of ground tomato was mixed with 30 ml of the ethanol/water (80:20 v/v) mixture, and the mixture was shaken at room temperature for 1 h. After that, the mixture was centrifuged at 3000 rpm for 15 min to separate the samples' liquid extract and biomass residue. The liquid extract was filtered through a membrane filter and can be used to analyse bioactive compounds.

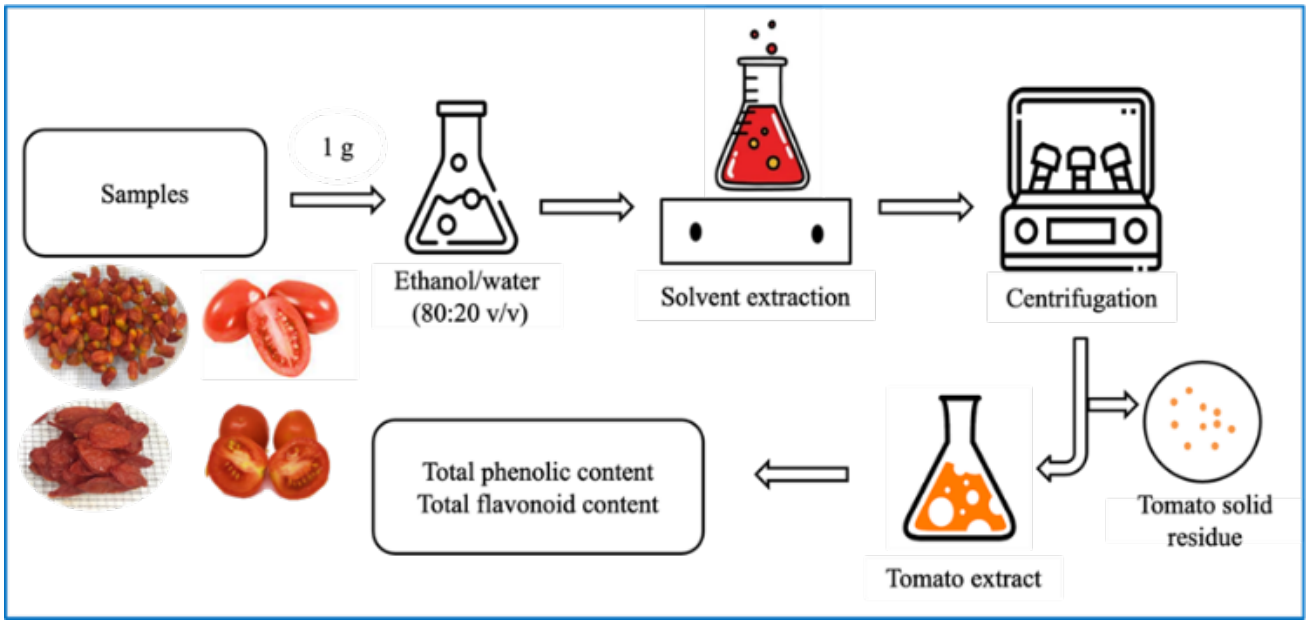

Fig.2. Procedure of solvent extraction of bioactive compounds from fresh and dried tomatoes

2.6 Analysis of bioactive compounds

2.6.1 Total flavonoid content analysis

The total flavonoid content in the tomato extract was determined using the aluminium chloride colourimetric assay according to Nour et al. [14], with some modifications. Briefly, about 0.5 g of tomato extract or standard quercetin was mixed with 2 ml of distilled water. Then, a volume of 0.15 ml sodium nitrite (5 %) was added to the solution and kept for 5 min at room temperature. Next, a volume of 0.15 ml of aluminium chloride (10%) was added to the mixture and kept for another 5 min at room temperature. Then, 1 ml of sodium hydroxide (1 M) was added to the solution and made up the volume to 5 ml with distilled water (about 1.2 ml). Quercetin solution (concentration ranged from 0.1 to 0.7 mg/g) was used as a standard calibration curve. The sample and quercetin solution were measured its absorbance using a spectrophotometer (BK-D580 Double beam, China) at a wavelength of 415 nm.

2.6.2 Total phenolic content analysis

The Folin-Ciocaltaue assay analyzed the total phenolic content in tomato extract according to Boonkasem et al. [15] with some modifications. Briefly, a volume of 0.5 ml extract or standard gallic acid was mixed with 2.5 ml of the Folin-Ciocalteu's reagent and kept for 5 min. Then, a volume of 2 ml sodium carbonate (7.5%) to the mixture for 1 h. The absorbance of the solution was measured at a wavelength of 765 nm using a UV spectrophotometer (BK-D580 Double beam, China). Gallic acid (concentration ranging from 20 to 120 µg/g) was used as a standard calibration curve.

2.10 Statistical analysis

Analysis of variance (ANOVA) was done using the SPSS Version 26.0 statistical software. One-way ANOVA analysis was used to determine statistical differences between the means of the results. The model term's statistical significance was determined with a 95% confidence interval ($p < 0.05$).

3. RESULTS AND DISCUSSION

3.1 Drying kinetic of dried tomatoes

The drying kinetics of Cherry and Holland tomatoes were studied at a drying temperature of 50 °C until the moisture content reached a constant level. The relationship between moisture content and drying time of the Cherry and Holland tomatoes is shown in Fig. 3. Continuing drying time led to a decrease in the moisture content of tomatoes. As can be seen from the result in Fig. 3, the moisture content in Holland tomato rapidly decreased from initial moisture to final moisture content level of 92.48 % to 11.75% w.b, respectively, within a drying time of 1020 min. However, the decrease of moisture content of Cherry tomato was slower than that of Holland tomato, to reach the constant moisture level (93.86% w.b to 10.35% w.b) within drying time of 1200 min. This phenomenon can be explained by the two different tomato varieties that do not balance the same moisture content simultaneously. Moreover, cutting the Holland tomato sample could faster remove water content than the Cherry tomato, which was dried as the whole tomato. The skin cover on Cherry tomatoes can also be the barrier that causes moisture content to be removed slower during the drying process. In general, dried tomatoes should have a moisture content of less than 26 % because at this level; the products can be stable and resistant to microorganisms growth, particularly fungi; therefore, it does not quickly change the taste and quality of the dried tomatoes [16].

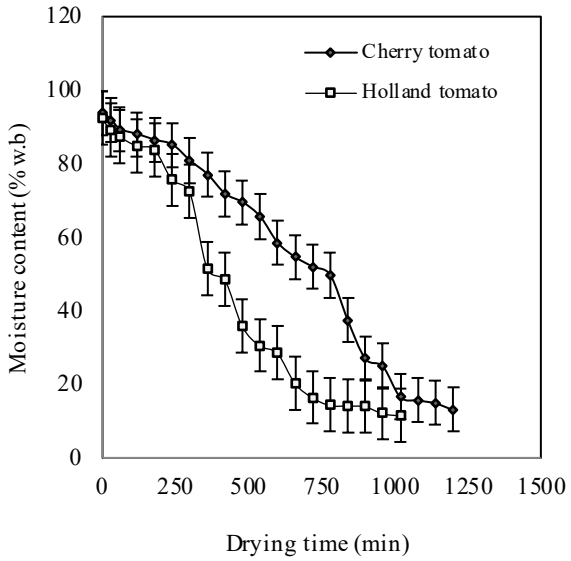

Fig. 3. Drying kinetics of dried Cherry and Holland tomatoes

3.2 Effect of drying time on physicochemical properties of fresh and dried tomatoes

In this study, dried tomatoes were collected to analyse physicochemical properties based on the drying kinetic provided in Fig. 3. The samples were collected at initial, exponential, and constant drying stages. The physicochemical properties of fresh and dried tomatoes, such as moisture, pH, water activity, and colour change, were measured. The pH value was significantly different ($p < 0.05$) between dried and control (fresh) samples for both Cherry and Holland tomatoes. As shown in Table 1, the pH value slightly decreased with increasing drying duration for both tomato varieties. The decreased pH value in dried tomatoes might be affected by pretreatment with citric acid and a long drying time. This is because, during drying, process temperature could cause the breakdown of pectin into pectenic acid, resulting in decreased pH of final products [17]. In general, different varieties of

tomatoes have additional pH values. As seen in Table 1, the pH value in fresh Cherry and Holland tomatoes was slightly different. The reason might be the sour taste in the Cherry tomato is higher than that of the Holland tomato. Therefore, it is observed that the pH of both dried tomato varieties was slightly different compared to the fresh tomatoes. Accordingly, the pH value of dried Cherry tomato was significantly different from that of dried Holland tomato, although the trend of pH value of both products decreased during the prolonged drying time. The result of water activity is linked to the result of moisture content. If the sample's moisture content decreases, the water activity value decreases. According to the result shown in Table 1, the value of water activity and moisture content of dried and control for both tomato varieties (Cherry and Holland) were significantly different ($p < 0.05$). The water activity in Cherry tomatoes was decreased from 0.993 (fresh) to 0.458 (dried), and moisture content was reduced from 92.58 to 11.75 %. While the water activity and moisture content in Holland tomatoes dropped from 0.996 (fresh tomato) to 0.460 (dried tomato) and 93.71 to 10.75 %, respectively. According to Le and Konsue [12], the food product should be chemically and biologically safe with a water activity value lower than 0.60. Moreover, the moisture content in osmotic dried foods should be between 20 and 25 % (sugar-treated fruits). The lower water activity in food prevents dried products from microbial growth and extends their shelf life because microbial can survive and grow in samples with a high water activity [7].

All colour parameters (L^*, a^*, and b^*) revealed a significant difference ($p < 0.05$) between fresh and dried samples for Cherry and Holland tomato varieties. As shown in Table 1, L^* values in dried samples were significantly lower than in fresh samples for Cherry and Holland varieties. This result also agrees with An et al. [18], who reported that the dried sample decreased in light colours after drying. Based on a previous study, the lower value of L^* might be caused by pigment degradation, browning reaction, or both during drying [19]. However, the decrease in L^* value indicated the increase of the a^* and b^* values in tomato samples. The increasing of a^* and b^* values in tomato samples indicated the colour of samples became red and yellow. After dehydration, all dried samples turned dark, yellow. After dehydration, all dried samples turned dark, red, and yellow. This can be correlated with enzymatic or non-enzymatic browning in food tissue [18]. The total colour difference (ΔE) is used to determine the variation of colour in foods after processing. As shown in Table 1, the (ΔE) value increased with extended drying time. The total colour change in Cherry tomatoes was significantly different between 180 and 1200 min drying time. While it is found that between 180 to 1020 min, a significant change of total colour appeared for Holland tomatoes.

3.3 Effect of drying duration on bioactive contents of dried tomatoes

Table 1 Effect of drying time on the physicochemical quality of fresh and dried Cherry and Holland tomatoes

Cherry tomato							
Drying time (min)	Moisture (%)	pH	a_w	Colour			
				L^*	a^*	b^*	ΔE
Fresh	93.71 ± 0.36^a	4.34 ± 0.04^a	0.993 ± 0.03^a	39.27 ± 0.58^a	14.82 ± 0.43^e	15.14 ± 0.27^d	-
180	85.50 ± 0.29^b	3.86 ± 0.02^b	0.988 ± 0.01^b	35.76 ± 0.42^b	16.10 ± 0.75^d	28.78 ± 0.29^c	14.17^d
420	70.44± 0.16^c	3.87 ± 0.02^{bc}	0.982 ± 0.02^c	36.04 ± 0.39^b	20.93 ± 0.77^c	30.33 ± 0.70^b	16.70^b
660	54.26 ± 0.24^d	3.71 ± 0.01^{bc}	0.975 ± 0.01^d	35.07 ± 0.76^c	21.21 ± 0.78^b	30.24 ± 0.44^a	16.99^b
900	27.21 ± 0.39^e	3.62 ± 0.03^c	0.714 ± 0.01^e	33.15 ± 0.48^d	22.14 ± 0.72^a	33.39 ± 0.68	20.90^a
1200	10.35 ± 0.38^f	3.60 ± 0.10^c	0.458 ± 0.01^f	33.64 ± 0.63^d	19.48 ± 0.70^e	28.42 ± 0.34^c	15.17^c
Holland tomato							
Drying time (min)	Moisture (%)	pH	a_w	Colour			
				L^*	a^*	b^*	ΔE
Fresh	92.58 ± 0.23^a	4.50 ± 0.17^a	0.996 ± 0.01^a	38.71 ± 0.55^a	14.22 ± 0.47^e	14.67 ± 0.61^d	-
180	83.26 ± 0.70^b	4.31 ± 0.01^b	0.992 ± 0.01^a	36.11 ±0.63^b	17.68 ± 0.81^d	23.85 ± 0.89^c	10.21^d
420	48.78 ± 0.63^c	4.09 ± 0.11^c	0.960 ± 0.01^b	35.85 ± 0.65^b	20.89 ± 0.38^c	25.37 ± 0.40^b	12.95^c
600	28.94 ± 0.47^d	4.17 ± 0.04^c	0.897 ± 0.01^c	32.97 ± 0.19^c	24.07 ± 0.81^a	26.22 ± 0.68	16.25^b
840	14.22 ± 0.03^e	4.14 ± 0.03^c	0.502 ± 0.01^d	32.39 ± 0.82^c	24.14 ± 0.80^a	29.07 ± 0.83^a	18.60^a
1020	11.75 ± 0.53^f	4.13 ± 0.04^c	0.460 ± 0.01^e	31.32 ± 0.84^d	21.88 ± 0.62^b	26.01 ± 0.78^b	15.59^b

3.3.1 Total phenolic content (TPC)

Fig. 4 shows the concentration of total phenolic compounds in dried Cherry and dried Holland tomatoes. As a result, the total phenolic content (TPC) in both tomato varieties was decreased at all drying times for the drying temperature of 50 °C. For the Cherry tomato, the TPC was reduced from 24.96 (fresh tomatoes) to 5.27 mg GAE/g d.b (for dried tomato) within the drying time of around 1200 min, equal to a decreasing factor of 4.73. In contrast, the TPC in Holland tomatoes was reduced by a factor of 4.59 from 19.49 (fresh tomatoes) to 4.24 mg GAE/g d.b (dried tomatoes). According to Azeez et al. [9], the decrease of TPC in dried samples with increasing drying time could be related to the long drying time, which has been reported to degrade some phenolic compounds.

In addition, it is seen that TPC in Cherry tomatoes was higher than that of Holland tomatoes for both fresh and dried samples. Based on a previous study, the different amounts of phenolic content in tomatoes varieties could be influenced by various factors, including genetic factors such as cultivar or variety, environmental factors (light, temperature, air composition, mineral nutrition, growth medium), cultural practices, harvest ripening stage, and others [3].

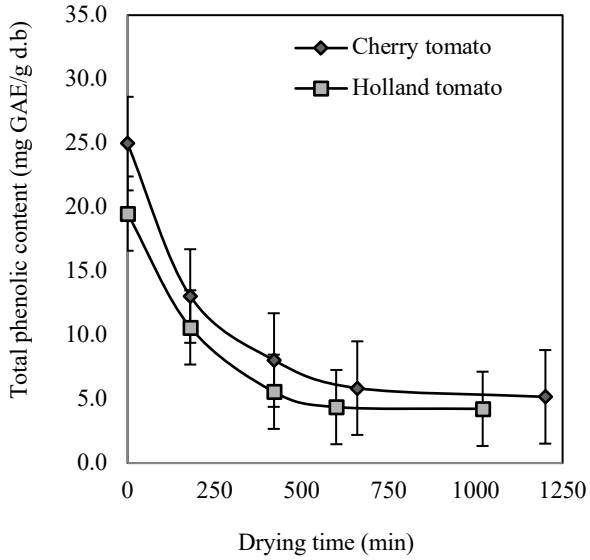

Fig. 4. Effect of drying time on phenolic compounds during processing of dried tomatoes.

3.4 Total flavonoid content (TFC)

The effects of drying time on the total flavonoid content of dried tomatoes are presented in Figure 5. As seen in Figure 5, the total flavonoid content (TFC) of both Cherry and Holland tomatoes decreased significantly during the drying time within 200 min and then became almost the same after drying time longer than 200 min. This result means flavonoid compounds are probably more resistant to heat than phenolic compounds. Within the drying period of 1000 min, the TFC decreased from 7.68 (fresh Cherry tomato) to 5.09 mg QE/g d.b (dried cherry tomato), equal to a 1.50 decreasing factor. In the same trend as the Cherry tomato, the TFC of the Holland tomato was reduced from 3.12 (fresh tomato) to 2.26 mg QE/g d.b (dried tomato), equal to a 1.38 decreasing factor. The pretreatment process might also affect the decrease of TFC in dried tomatoes.

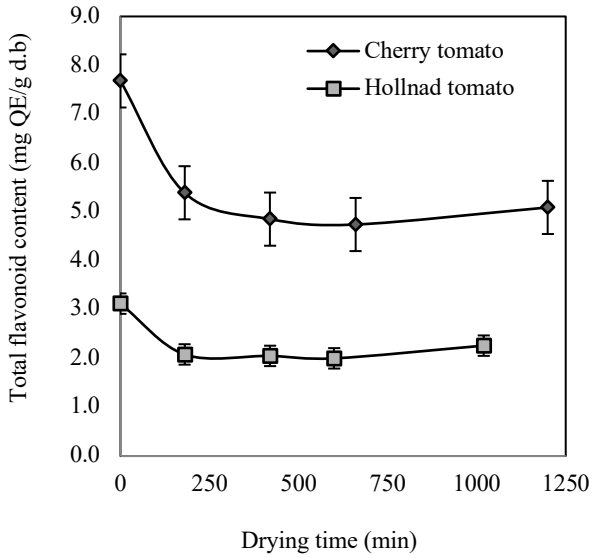

Fig. 5. Effect of drying time on flavonoid compounds during processing of dried tomatoes

Hence, the remaining flavonoids in pretreated tomatoes could be resistant to heat during the drying process with a longer drying time of 1200 min and 1020 min for dried Cherry and Holland tomatoes at the drying temperature of 50 °C. In the processing of dried tomatoes, boiling, one of the pretreatment conditions was done. This is because boiling is a pre-drying treatment that enhances mass, heat transfer, and product properties such as colour and texture (Taiwo & Adeyemi, 2009). However, this factor can negatively affect bioactive compounds in vegetables and fruits as it causes losses in various extensions of those heat-sensitive compounds (Vinha et al., 2015). The effect of pretreatment can be either positive or negative depending on the preference of final food product quality. This means optimization of the drying process, which can preserve the better quality of final dried products, could be needed.

4. CONCLUSIONS

In this study, two varieties of local tomatoes (Cherry and Holland) were selected to study the effect of drying on physicochemical properties (moisture content, water activity, pH, and colour) and bioactive compounds (total phenolic and total flavonoid contents). According to the result, the drying process of Cherry and Holland tomatoes reached a constant moisture content level of 11.75 and 10.35 %, respectively. It

was found that drying time significantly affected the physicochemical properties of dried tomatoes for both Cherry and Holland varieties. The moisture content, water activity, and L* value data decreased with increasing drying time, and however, the *a** and *b** value significantly increased with the rising drying time for both tomato varieties. Whereas the results of phenolic and flavonoid contents in Cherry and Holland tomatoes were decreased for a longer drying time. The result of this study can be useful for predicting the moisture loss and desirable drying time to produce a dried tomato with good quality and maintaining a high amount of bioactive compounds in final products.

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