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Quality changes during accelerated storage and shelf-life estimation of foam-mate dried and spray-dried instant pomelo powders

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Abstract. This study examined changes in the qualities of foam-mat dried powder (FDP) and spray-dried powdered (SDP) processed from pomelo (*Citrus maxima* (Burn.) Merr.) peel extract during accelerated storage. Four storage conditions were stimulated at different temperatures (50 °C, 70 °C) and relative humidities (70 %, 90 %). During accelerated storage, the moisture content, total phenolic content (TPC), and Trolox equivalent antioxidant capacity (TEAC) of powders were decreased while the powder's color was increased, suggesting that phenol oxidation occurred. Out of those four indexes, only the changes in TPC and TEAC of both FDP and SDP were observed to be in relationship with time and can be fitted in the first-order kinetic model. By calculation, the k-value of those models and the shelf-life of FDP and SDP can be estimated using the Q_{10} value. At the normal storage condition (30 °C, RH 90 %), SDP was predicted to have longer shelf life than FDP (138 days > 128 days). The shelf-life of products at some available conditions was also estimated in this study for future reference.

Keywords: accelerated storage, *Citrus maxima* (Burn.) Merr., foam-mat dried powder, phenol oxidation, spray-dried powdered.

Classification numbers: 1.2.1, 1.3.1, 2.5.1.

1. INTRODUCTION

Pomelo (*Citrus maxima* (Burn.) Merr.) is a tropical fruit popularly grown in the Mekong Delta, Viet Nam [1, 2]. Like other citrus fruits, pomelo has a high proportion of peel, weighing up to 50 % of the total fruit [1]. Recently, bioactive compounds from pomelo peel have evoked great interest due to their potential health benefits, which were reported to have antioxidant, antibacterial, anti-diabetes, and anti-hyperglycemic activities [2-4]. The compounds responsible for these properties, such as hesperetin, naringenin, eriodictyol, and synephrine [4, 5], can quickly deteriorate in normal conditions. Thus, to preserve the stability of those molecules when withdrawn from the plant matrix, the method of extraction and conservation of the bioactive compounds must be studied and carefully handled.

Several studies were performed to extract and encapsulate pomelo peel's bioactive compounds. For Da Xanh cultivar, the extraction with ethanol 40° at the ratio of 1:1 (w/v) at

90 °C for 2 minutes and the removal of solvent by rotary evaporation at the absolute pressure of 160-180 mbar was determined to be the most effective to retain the quality of the extract [6]. Microencapsulation of pomelo peel bioactive compounds by spray-drying was proved to be adequate to protect the core materials from deterioration [7]. Alternative approaches, such as freeze-drying or foam-mat drying, can also create microencapsulation effects [8]. Although much research focuses on the production of deterioration, little to none studies the stability of the final products.

Instead of long-term storage, which can be extended up to 2 years, accelerated storage can be performed to reduce the required time. Many kinetic parameters, such as reaction rate constant, half-life, temperature coefficient, and activation energy, are often used to evaluate the thermo-sensitive compounds in foods [9, 10]. The first two parameters assess changes in the concentration of a quality attribute over time under constant temperature conditions [9]. In contrast, the latter two describe how the rate of change of that attribute varies with temperature [10]. Several authors mention that the stability of many bioactive compounds obeys the first order of reaction [11-15]. Thus, kinetic modeling can be employed to predict the self-life of bioactive products [12, 16].

This study examined changes in the qualities of foam-mat dried powder (FDP) and spray-dried powdered (SDP) processed from pomelo (*Citrus maxima* (Burn.) Merr.) peel extract during accelerated storage. The results can be used to predict the shelf-life of the products. In the Mekong Delta, Viet Nam, high production of pomelo fruits leads to the disposal of large amounts of pomelo peel. The revealed findings should aid in developing functional products as well as tackling the overburden of agricultural waste from pomelo peels.

2. MATERIALS AND METHODS

2.1. Materials

Peels of Da Xanh pomelo were collected from facilities in the Mekong Delta of Viet Nam that focused on minimal processing. The fruits originated from the Ben Tre area in Vinh Long province (Viet Nam), where they have been granted a geographical indication by the local government.

For use in the preparation of encapsulation powder, several food-grade additives were employed. RMD (resistant starch type V, GI < 10) was provided by the Essential Flavours Vietnam Company (Viet Nam). Pectin (from apple, DE 70–75 %) was purchased from Sigma-Aldrich (USA). β-cyclodextrin (BCD) was supplied by Shanghai Zhanyun Fine Chemical Co., Ltd. (Shanghai, China). Gum arabic (GA) was supplied by HiMedia (Mumbai, India), and Tween 80 was obtained from Xilong (Guangdong, China).

Ethanol (99.5 % v/v), used as the extraction solvent, was purchased from CEMACO (Ho Chi Minh City, Viet Nam).

For analytical purposes, Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and Folin–Ciocalteu (FC) reagent were supplied by Merck (Darmstadt, Germany). Gallic acid was also obtained from Sisco Research Laboratories Pvt. Ltd. (Mumbai, India). All other chemicals were of high-purity analytical grade.

2.2. Methods

2.2.1 Extracting bioactive compounds from pomelo peel

Water-soluble bioactive compounds from the Da Xanh pomelo peel were extracted according to the method given by To & Nguyen [6]. Fresh pomelo peel was shredded, soaked into an equal amount of 40 % ethanol solution (80–90 °C), and heated to 85–90 °C for 2 min. The mixture was then pressed, and the liquid fraction was recovered. Ethanol was removed from the solvent using rotary evaporation equipment (RV 10 digital V, IKA, Selangor, Malaysia), which set the absolute pressure at 160–180 mbar and the temperature at 65 °C. The process was stopped when approximately 85 % of the total weight was lost. 1 % diatomite (w/w) was then added pomelo peel extract (PPE) and the mixture was filtered through the Whatman filter paper (grade 4: 20–25 μm).

2.2.2. Microencapsulation by spray drying

The spray drying process of PPE was carried out according to To *et al.* [7]. Firstly, 50 g of the PPE was mixed with 26.33 g RMD, 0.46 g pectin, 2.65 g β-cyclodextrin, and 3.14 g GA. The mixture was then stirred, diluted with water to 30 °Bx, and homogenized at 7513 g for 5 min [17]. The obtained liquid was preheated to 60 °C before being loaded into a laboratory-type spray dryer (DHSL.SD303; DHSLKOREA, Seoul, Korea). The spray drying inlet and outlet temperatures were fixed at 180 °C and 65 °C, respectively, according to Baysan *et al.* [18]. The obtained spray-dried powdered (SDP) was directly collected from the collector and packed in mPET pouches at the weight of 10 g per sample.

2.2.3. Microencapsulation by foam-mat drying

Foam-mat drying process of PPE was carried out according to Tran [8]. The mixing process was carried out as described above but with 19.83 g RMD, 0.41 g pectin, 2.05 g BCD, 3.00 g GA, and 0.675 g Tween 80. The mixture was also stirred and homogenized at 7513 g for 5 min. Then, 0.68 g Tween 80 was added to the obtained liquid, followed by whipping till the foam was stable (no changes in total volume). The foam was evenly spread onto Teflon papers (0.09 g/cm^2), put in a convectional air dryer, setting the temperature at 60 °C, and dried till no changes in total weight. Dried foam samples were then milled and sized (< 60 mesh). The obtained foam-mat dried powder (FDP) was also packed in mPET pouches at the weight of 10 g per sample.

2.2.4. Physicochemical analysis

Moisture content was determined by the difference in weight before and after drying at 105 ºC until reaching constant weight [12].

The color of the powder was measured the same way as the tea color, according to Sinijaand Mishra [19]. 1 g of power was added to 9 mL of water (to reach 1:10 dilution). The absorbance of the filtrated liquid was then measured at 460 nm using a spectrophotometer (S60, Biochrom, USA) and multiplied by 10 for the final results.

Solubility in hot water: The solubility was evaluated in accordance with TCVN 12459:2018 standard [20]. A 2.5 g of sample was dispersed in 150 mL of boiling water and stirred gently for 30 seconds. Complete dissolution without any visible sediment was considered indicative of satisfactory solubility.

Particle size: Determine following the method described by Pathania *et al.* [21]. 1 g of the powder was dispersed in 10 mL of canola oil, and particle dimensions were measured using a calibrated ruler under a light microscope (Model BB.4260, Euromex, Duiven, Netherlands).

2.2.5 Phenolic contentand encapsulation efficiency

To determine total phenolic content, the FC assay was employed according to the method given by Siddiqua *et al.* with modifications [22]. First, 1 g of powder was dissolved in 9 mL of distilled water. The liquid (0.1 mL) was then mixed with 1.5 mL of 1:9 diluted Folin-Ciocalteu's phenol reagent, followed by 4 mL of sodium carbonate (20 %, w/v) and distilled water to achieve a total volume of 10 mL. The mixture was allowed to stand for 30 min in the dark at room temperature, and then the absorbance was measured at 738 nm using a spectrophotometer (S60, Biochrom, Massachusetts, USA). The polyphenol content was calculated as mg of gallic acid equivalents per gram of dry matter (DM) based on a standard curve.

For surface phenolic content (SPC), 1 g of sample was dissolved in 9 mL of ethanol:methanol (50:50 v/v) instead of water [23]. Phenolic content of the supernatant liquid was also quantified by the reaction with FC reagent as the method described above.

Encapsulation efficiency (EE, %) was then calculated by TPC and SPC [23] by Eq. (1).

$$EE(\%) = \frac{TPC-SPC}{TPC} x100\ \% \qquad (1)$$

2.2.6 Antioxidant capacity

The AC in the extract was determined by DPPH assay by the method described by Soto *et al.* and slightly modified [24]. First, 1 g of powder was dissolved in 9 mL of distilled water. Then, 4 ml of DPPH 0.1 mM in ethanol solution was mixed with 0.1 mL of sample, and ethanol was added up to 5 mL. Kept the mixture for 30 minutes in the dark and measured its absorbance at 517 nm using a spectrophotometer (S60, Biochrom, Massachusetts, USA). To determine the calibration curve, the absorbance values at 517 nm of some concentrations of Trolox were measured. Results were expressed as μmol of Trolox equivalent antioxidant capacity (TEAC) per gram dry matter based on a standard curve.

2.3. Accelerated storage test

Fourteen individual sample pouches (14 × 10 g) were placed in a glass jar containing a single 7 g silica gel desiccant pack [25]. The jar was then sealed with an aluminum sheet glued to the mouth, followed by a lid made of painted iron, and were stored in desiccators maintained at 75 % and 90 % relative humidity (RH) (external to the packaging) to simulate two typical storage conditions encountered in tropical regions—standard room conditions and high-humidity environments [12]. To maintain 75 % RH, saturated sodium chloride (NaCl) was placed at the bottom of the jar, while for 90 % RH, distilled water was used [12]. The desiccators were then placed in a climate-controlled chamber (Model MLR-352, PHCbi, Tokyo, Japan) and maintained at 50 °C and 70 °C for a duration of 42 days.

The kinetic of degradation of suitable index(es) can be evaluated by the first order reaction as according to Kuck *et al.* [14] as expressed in Eqs. (2) and (3):

$$C_t = C_0(\exp(-kt)) \qquad (2)$$

$$\ln(C_t/C_0) = -kt \qquad (3)$$

where C_t is concentration at different times (t), k is the constant rate and C_0 is the concentration at time zero.

The half life ($t_{1/2}$) and the temperature coefficient (Q_{10}) were calculated according to Eqs. (4) and (5) [12]:

$$t_{(1/2)} = \ln(2)/k \quad (4)$$

$$Q_{10} = (k_{T2}/k_{T1})^{10/(T2-T1)} \quad (5)$$

where k_{T2} and k_{T1} represent the kinetic rate constant at 60 and 40 ºC, respectively.

The shelf-life of a product is defined as the time period over which 90 % of the initial concentration of the medicine remains stable [26, 27]. Thus, based on the experimental data obtained in this study, a specific bioactive component will later be selected as the indicator for shelf-life estimation.

2.4. Statistical analysis

To study the changes of quality in accelerated storage conditions, assays from powders were used in a one-way completely randomized design. Data were submitted to analysis of variance (ANOVA) and means comparison by the LST test using a significance level $p < 0.05$. The graphics were generated by Excel 2016 software. The experiments were repeated three times.

3. RESULTS AND DISCUSSION

3.1. Characteristics of FDP and SDP

Although both FDP and SDP were produced using the same extract (PPE), they underwent different drying methods. This variation led to differences in the physicochemical properties of the resulting powders, as summarized in Table 1.

Table 1. Physico-chemical characteristics of pomelo powder.

Parameters	FDP*	SDP**
Moisture content (%)	4.71±0.19	3.79±0.21
Particle size (µm)	70,0-650,0	1,0-8,0
Solubility in hot water	Complete dissolution in 30 s	Complete dissolution in 30 s
Color	1.64±0.02	1.63±0.05
TPC (mg GAE/g DW)	5.57±0.03	5.19±0.01
SPC (mg GAE/g DW)	0.66±0.01	1.153±0.02
EE (%)	88.15+0.16	77.78±0.09
TAEC (µg TE/g DW)	100.54±1.30	88.13±3.30

** FDP: foam-mat dried powder; **SDP: spray-dried powdered (SDP).*

The most prominent difference between the two powders was particle size. The FDP, produced via the foam-mat drying method, exhibited particles with irregular surfaces, larger sizes, and a broad size distribution ranging from 70.0 to 650.0 µm. A similar variation in particle size resulting from foam-mat drying had been reported by Brar *et al.* [28]. In contrast, the SDP produced through spray drying consisted of spherical or near-spherical particles, with diameters ranging from approximately 1.0 to 8.0 µm, which was in agreement with the findings of Aliakbarian *et al.* and Zanoni *et al.* [21, 29, 30]. In general, smaller particle sizes result in a higher surface area-to-mass ratio, which enhances water removal during drying. In this study, the FDP exhibited a moisture content of 4.71 %, which was higher than that of SDP (3.79 %), yet both values comply with TCVN 12459-2018 standards for Pure instant coffee (≤ 5 %) [20]. The low moisture content of both FDP and SDP supports better preservation by minimizing physicochemical and microbiological degradation. Both powders also met the solubility standard for pure instant coffee, as they completely dissolved in boiling water within 30 seconds [20]. Additionally, both samples displayed similar color characteristics, as evidenced by comparable optical density values upon dissolution in water. When stored, according to TCVN 12459:2018, the color of instant powders should remain close to the original appearance of the raw material.

For bioactive compounds, both the FDP and SDP were rich in polyphenols. The TPC of FDP was 5.57 mg GAE/g DW, slightly higher than that of SDP, which was measured at 5.19 mg GAE/g DW. Correspondingly, the FDP also exhibited a higher TEAC of 100.54 µg TE/g DW, compared to 88.13 µg TE/g DW for SDP. This may be attributed to the lower additive content in the FDP formulation. In addition, the FDP also showed a lower surface total phenolic content (STP) of 0.615 mg GAE/g DW, which contributed to a higher encapsulation efficiency (EE). The smaller surface area-to-mass ratio of FDP particles, due to their lager particle size, likely enhanced the protection of phenolic compounds within the particle matrix. A higher EE suggesting that SDP may offer greater stability during storage compared to FDP [7, 8, 23].

Although the TPC and TEAC are not included in current quality standards, they are critical indicators of the functional quality of the product and should be routinely monitored during production and storage. Thus, to ensure the quality of the dried powder, four key physicochemical parameters should be closely monitored: moisture content, color, total TPC, and TEAC.

3.2. Changes in quality of FDP and SDPduring accelerated storage

To evaluate quality changes during accelerated storage, moisture content, powder color, TPC, TEAC of FDP and SDP were monitored, and the results are presented in Figure 1 and Figure 2, respectively.

Results in Figure 1(a) showed that the moisture content of FDP decreased during storage time. The moisture content of powders can be affected by environmental conditions and, in most cases, should be increased [31, 32]. However, this research showed no sign of moisture absorption of the sample despite the relative humidity of over 70 %. It showed that the dual package (glass and mPET) was effective in protecting the sample from the environment. The same trend was also observed in the storage of SDP, in which the moisture content was unchanged or even decreased during storage (Figure 2(a)).

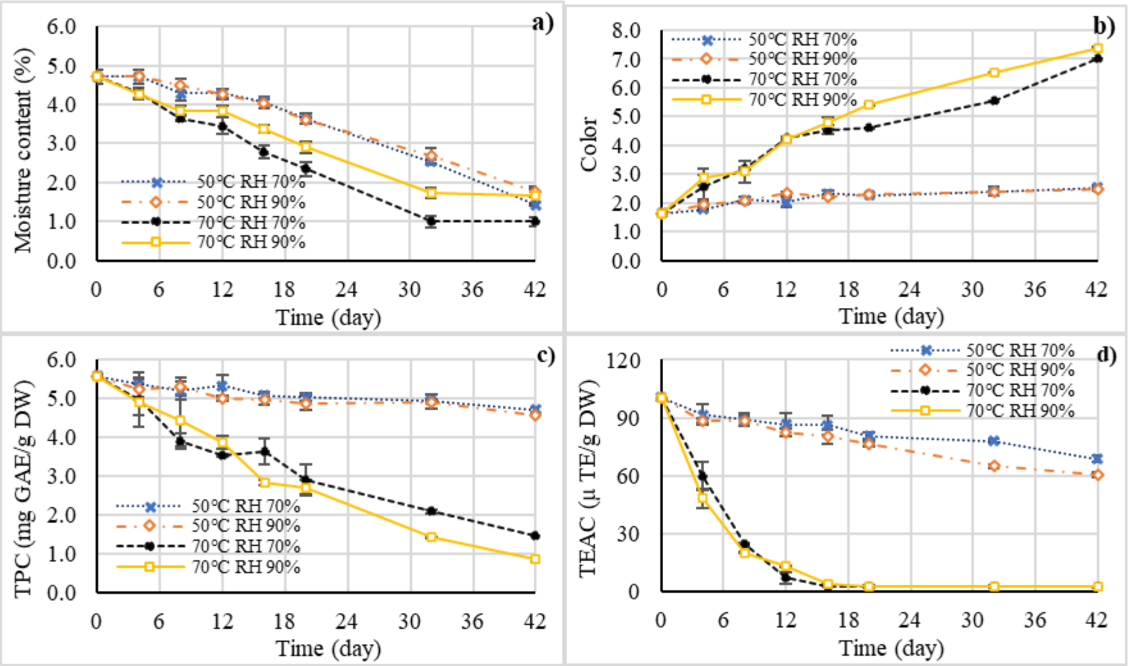

Figure 1. Changes in quality of FDP during accelerated storage: a) Moisture content; b) Color (in absorbance at 460 nm); c) Total phenolic content TPC; d) Trolox equivalent antioxidant capacity TAEC.

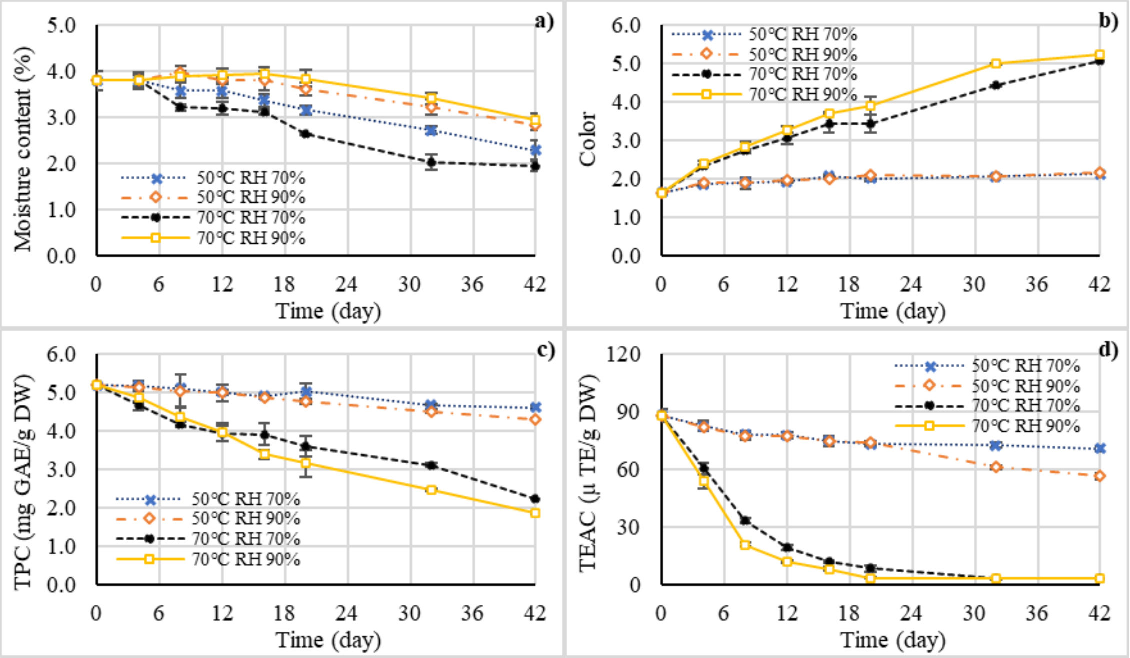

Figure 2. Changes in quality of SDP during accelerated storage:
a) Moisture content; b) Color (in absorbance at 460 nm);
c) Total phenolic content TPC; d) Trolox equivalent antioxidant capacity TAEC.

The observed reduction in moisture content may be attributed to the moisture-absorbing effect of the silica gel desiccant pack placed in each storage jar. According to the manufacturer, silica gel can absorb water approximately 25 % to 40 % of its own weight. Therefore, a 7 g silica gel packet is capable of removing approximately 1.75 g to 4.9 g of water, potentially contributing to the reduction in the sample's moisture content. As shown in Figures 1(a) and 2(a), the moisture content of both FDP and SDP remained relatively stable during the initial 4–8 days of storage. This observation is consistent with Fick's Law, which suggests that moisture transfer requires time to reach equilibrium—a process that proceeds more slowly in a closed system with static air and a larger headspace volume. A similar trend was reported by Amarakoon and Navaratne [25], in which the weight of silica gel packs was monitored and found only a slight increase during the first 8 weeks of storage, followed by a more rapid weight gain between weeks 8 and 12. Additionally, in the same study, 100 g of rice crackers stored with a 5 g silica gel packet (equivalent to the ratio used in this experiment) exhibited only a minor moisture increase—from 2.43 % to 2.74 % over 8 weeks—further supporting the effectiveness of silica gel packs in maintaining low moisture levels during storage.

However, despite the minimal changes in moisture content, the powder's color increased during storage, expressing the changes of color from yellow-green to brown in both cases of FDP and SDP (Figures 1(b) and 2(b)). The same changes can be observed in the storage of black tea, indicating the degradation of polyphenols and flavonoids [19]. In both samples, the TPC and TEAC values also decreased over time (Figures 1(c), (d) for FDP, or Figures 2(c), (d) for SDP). The loss of TPC and TEAC occurred faster at higher temperature and relative humidity.

The increase in degradation rate with rising temperature is consistent with the Arrhenius equation, which states that the reaction rate constant is strongly influenced by both temperature and activation energy [11-14]. Accordingly, higher temperatures accelerate chemical reactions responsible for the loss of phenolic compounds and antioxidant activity. In addition to temperature, exposure to high relative humidity (RH%) can adversely affect the physical and chemical stability of powders, even when the overall moisture content remains relatively unchanged. This phenomenon may be attributed to the intrinsic properties of the powder matrix. As reported by Bhandari and Howes[33], most dried food products exist in a glassy amorphous state, which can transition into a rubbery state over time. This glass-to-rubber transition occurs more rapidly under elevated environmental temperatures and humidity levels. A similar effect had been observed in spray-dried milk powder, where delayed lactose crystallization (happened due to hydrolyzed whey proteins) leaded to a stickier surface and higher equilibrium relative humidity, even at constant moisture content [34]. This increase in surface water activity enhances susceptibility to color degradation and oxidative reactions, thereby reducing the overall quality of the product, despite stable average or internal moisture levels [30, 31, 33, 34].

In summary, the results shown suggested that the loss of quality of both FDP and SDP during accelerated storage happens stronger at higher temperatures and relative humidity. Based on the results shown in Figures 1 and 2, only the changes in TPC and TEAC can be fitted in the first kinetic model. Thus, those two indexes were further employed to predict the shelf-life of products [12, 15].

3.3. Kinetics of degradation of foam-mat dried powder (FDP) and spraydried powder (SDP)

The changes in TPC and TEAC of FDP can be fitted in the first-order kinetic model (Eq. (2)) using single regression analysis on the experimental data; the results were expressed in Figure 3. Generally, a high coefficient of determination ($R^2 > 0.95$) indicated a good fit for the model. As expected, higher rate constant (k) values corresponded to more rapid degradation of TPC and TEAC under elevated temperature and relative humidity conditions, consistent with the trends discussed previously. Notably, the k values for TEAC degradation (ranging from 0.0093 to 0.2091 day^{-1}) were consistently higher than those for TPC (ranging from 0.0043 to 0.0317 day^{-1}), suggesting that antioxidant activity declined at a faster rate than the TPC.

Similarly, the changes in TPC and TEAC of SDP can also be fitted in the first-order kinetic model (Figure 4). A high coefficient of determination ($R^2 > 0.95$) was also obtained, indicating a good fit of the model. Consistent with the results observed for FDP, SDP also exhibited a faster degradation rate for the TEAC compared to the TPC. The rate constants for TEAC ranged from 0.0067 to 0.1605 day^{-1}, while those for the TPC ranged from 0.0029 to 0.0242 day^{-1}.

Table 2 summarized important parameters of the those mentioned model.

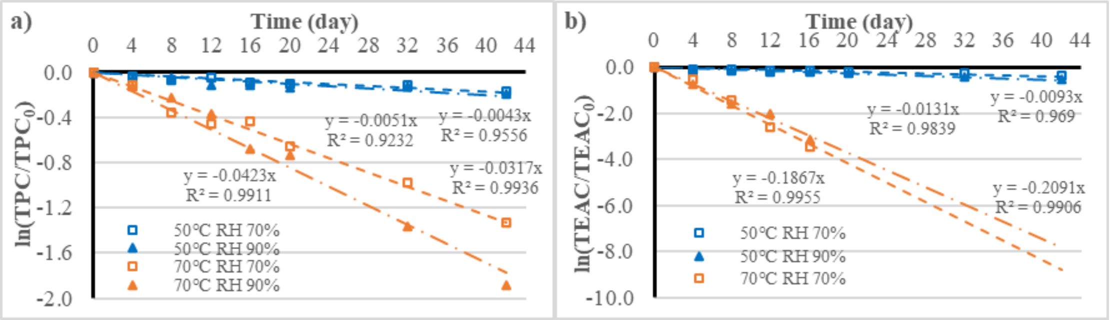

Figure 3. Kinetics of degradation of TPC and TEAC of FDP:
a) Kinetics of degradation of TPC; b) Kinetics of degradation of TEAC.

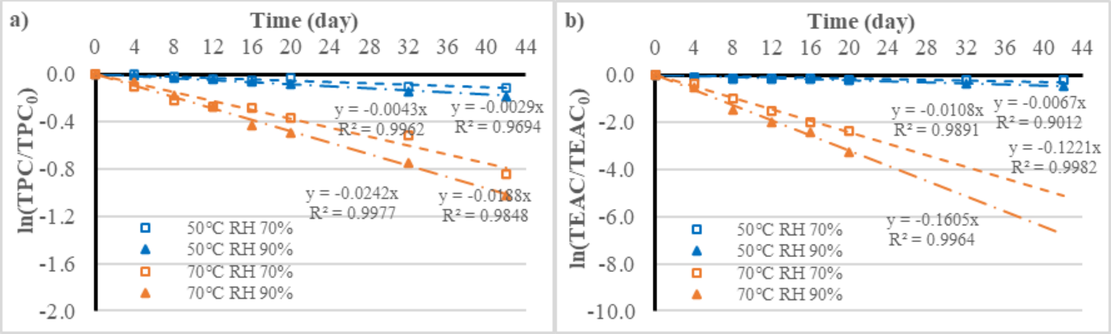

Figure 4. Kinetics of degradation of TPC and TEAC of SDP:
a) Kinetics of degradation of TPC; b) Kinetics of degradation of TEAC.

Numerous studies have reported that the degradation of TPC and TEAC follows a first-order kinetic model [11-15]. In fresh strawberries, which are rich in various phenolic compounds, Oliveira *et al.* [15]examined the degradation kinetics at 23 °C and found that both zero-order and pseudo-first-order models could adequately describe the degradation behavior of several phenolic compounds. Similarly, Arora *et al.* [18] also reported that the degradation of TPC and antioxidant capacity (AC) in diced apples also followed first-order kinetics. In their study, the degradation rate constants (k) ranged from 1.16 to 1.97 day^{-1} for AC and from 0.89 to 1.29 day^{-1} for TPC, which are significantly higher than the values observed in the present study. A comparable trend was reported by Kim *et al.* [13] for hardy kiwi purée, where both TPC and antioxidant activity decreased over time following a first-order model. In their study, k values ranged from 0.038 to 0.157 day^{-1} for TPC and from 0.046 to 0.194 day^{-1} for AC at storage temperatures ranging from 5 °C to 45 °C. These findings support the conclusion that the microencapsulation process employed in the preparation of FDP and SDP provided effective protection of phenolic compounds against degradation.

Additionally, the rate constants for TPC degradation were generally lower than those for AC degradation. A similar pattern was also observed in this study, suggesting that phenolic compounds are more stable under storage conditions than antioxidant capacity.

When compared to microparticles from other studies, the degradation rate constants (k) obtained in this study were generally similar or slightly lower. For example, Kuck *et al.* [14] reported that the degradation of anthocyanins in grape skin followed first-order kinetics and was significantly influenced by temperature and relative humidity. The rate constants for anthocyanin degradation in that study ranged from 0.024 to 0.099 day^{-1} when stored at 35–55 °C, which are slightly higher than the k values observed for TPC in both FDP and SDP in the present study. Similarly, Cassol and Noreña [12] investigated the degradation of bioactive compounds in *Hibiscus sabdariffa* powder under storage at 40–60 °C and reported rate constants ranging from 0.0259 to 0.2910 day^{-1}. These findings further supporting the conclusion that the micro-encapsulation of FDP and SDP effectively slows down the deterioration of bioactive compounds.

Table 2. Rate constant (k), coefficient of determination (R^2), half-life ($t_{1/2}$) and temperature coefficient (Q_{10}) for TPC and TEAC at different storage condition.

Sample	T	RH	TPC				TEAC			
			k (day^{-1})	R^2	t1/2	Q10	k (day^{-1})	R^2	t1/2	Q10
FDP	50	70	0.0043	0.9556	161.2	2.715	0.0093	0.9690	74.5	4.481
	70	70	0.0317	0.9936	21.9		0.1867	0.9955	3.7	
	50	90	0.0051	0.9232	135.9	2.880	0.0131	0.9839	52.9	3.995
	70	90	0.0423	0.9911	16.4		0.2091	0.9906	3.3	
SDP	50	70	0.0029	0.9694	239.0	2.546	0.0067	0.9012	103.5	4.269
	70	70	0.0188	0.9848	36.9		0.1221	0.9982	5.7	
	50	90	0.0043	0.9962	161.2	2.372	0.0108	0.9891	64.2	3.885
	70	90	0.0242	0.9977	28.6		0.1605	0.9964	74.5	

3.4. Prediction of shelf-life of SDP and FDP

The result in Table 2 also showed that, compared with the SDP, FDP has a higher Q10 value, showing that SDP's quality was more thermal dependent than FDP's. However, because the k values of SDP were much lower than the FDP, the final predicted shelf-life of SDP was still higher than FDP in most cases (Table 3).

Results in Table 3 showed that at 30 °C RH 70 %, the shelf-life of SDP was predicted to be 236 days compared to FDP was only 181 days. The predicted shelf-life of pomelo peel instant powder was much higher compared to *Polygonum multiflorum* (Thunb.) spray-dried powder, in which TPC retentions of 85 % were at 6.2 - 42.4 days, and AC retentions of 85 % were at 5.1 - 13.1 days at 30 °C [15]. However, by reducing the temperature to 10 °C, the shelf-life of SDP can be extended to 1527 days and FDP to 1332 days, almost six times longer.

Few studies have directly compared the shelf-life of powders produced by spray-drying and foam-mat drying. However, the study by Cassol and Noreña [12] investigated the preservability of *Hibiscus sabdariffa* powder produced via spray-drying and freeze-drying. In that study, the degradation of anthocyanins was modeled using a first-order kinetic approach to predict shelf-life. The temperature coefficient (Q_{10}) value ranged from 1.2 to 1.4 for spray-dried powder and 1.1 to 2.1 for freeze-dried powder, indicating that freeze-dried powder were more sensitivities to temperature than spray-dried one. However, the results showed that the shelf-life of spray-dried and freeze-dried powder can be almost equal and depended mainly on the encapsulation formula.

Overall, the results indicate that different storage strategies can be effectively employed to achieve the desired shelf-life of the products, as summarized in Table 3.

Table 3. Estimate shelf-life of products base on Q_{10} value.

Sample	T	RH	Time period (days) which concentration remains over 90 %		Shelf-life (days)
			For TPC	For TEAC	
FDP	30	70	181	227	181
	30	90	171	128	128
	10	70	1332	4566	1332
	10	90	1421	2049	1421
SDP	30	70	236	287	236
	30	90	138	145	138
	10	70	1527	5223	1527
	10	90	776	2155	776

4. CONCLUSIONS

In conclusion, the study showed that changes in TPC and TEAC of both FDP and SDP can be fitted in the first-order kinetic model. Thus, it was possible to employ an accelerated storage test to predict the shelf-life of pomelo peel FDP and SDP. In comparison, FDP has a shorter shelf-life than SDP. However, foam-mat drying can still be considered a good choice when spray drying is unavailable. Depending on the requirement of the shelf-life of products, storage conditions can be changed to be more practical and economical.

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Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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