Industria: Jurnal Teknologi dan Manajemen Agroindustri
Volume 11 No 1: 19-30 (2022)

Industria: Jurnal Teknologi dan Manajemen Agroindustri
http://www.industria.ub.ac.id
ISSN 2252-7877 (Print) ISSN 2548-3582 (Online)
https://doi.org/10.21776/ub.industria.2022.011.01.3

Shelf-Life Prediction of Shallot Powder Using Accelerated Shelf-Life Testing (ASLT) Method by the Arrhenius Equation Approach

Pendugaan Umur Simpan Produk Bawang Merah Bubuk Menggunakan Metode Accelerate Shelf-Life Testing *(ASLT) Dengan Pendekatan Arrhenius*

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Received: 28th January, 2019; 1st Revision: 09th June, 2021; 2nd Revision: 14th February, 2022; Accepted: 12th May, 2022

Abstract

The storage process of shallot powder can cause a quality decrease. This study aims to estimate shelf-life of shallot powder at various storage temperatures and determine quality changes during storage. This study used a Completely Randomized Design with two factors to determine quality changes of shallot powder, i.e. the coating and storage temperature. The statistical analysis results showed that the coating, storage temperature, and interaction between the two factors affected Volatile Reducing Substances (VRS) levels. The two factors and their interaction do not influence the water content. Shelf-life estimation was performed using the Arrhenius method. Coated shallot powder has a longer shelf-life than uncoated shallot powder. Shelf-life determination was performed based on water content parameters. The shelf-life of uncoated shallot powder was 337 days at 30 °C, 322 days at 40 °C, and 309 days at 50 °C. The shelf-life of coated shallot powder was 353 days at 30 °C, 340 days at 40 °C, and 328 days at 50 °C. The coating process can extend the shelf-life of shallot powder.
Keywords: Accelerate Shelf-Life Testing (ASLT), Arrhenius, coating, shallot powder

Abstrak

Proses penyimpanan dapat menyebabkan penurunan mutu bawang merah bubuk. Penelitian ini bertujuan untuk menduga umur simpan produk bawang merah bubuk pada berbagai suhu penyimpanan dan mengetahui perubahan mutunya selama penyimpanan. Penelitian ini menggunakan Rancangan Acak Lengkap dengan dua faktor untuk mengetahui perubahan mutu bawang merah bubuk, yaitu penggunaan penyalut dan suhu penyimpanan. Hasil analisis statistik menunjukkan bahwa penyalutan, suhu penyimpanan, dan interaksi antara kedua faktor memengaruhi kadar Volatile Reducing Substance (VRS)*. Kadar air tidak dipengaruhi oleh kedua faktor dan interaksi antara kedua faktor tersebut. Pendugaan umur simpan dilakukan menggunakan metode Arrhenius. Bubuk bawang merah dengan proses penyalutan memiliki umur simpan yang lebih lama dibandingkan bubuk bawang merah tanpa proses penyalutan. Penentuan umur simpan dilakukan berdasarkan parameter kadar air, Umur simpan bawang merah bubuk tanpa penyalutan adalah 337 hari pada suhu 30 °C, 322 hari pada suhu 40 °C, dan 309 hari pada 50 °C. Umur simpan bawang merah bubuk dengan penyalutan adalah 353 hari pada suhu 30 °C, 340 hari pada suhu 40 °C, dan 328 hari pada suhu 50 °C. Proses penyalutan mampu memperpanjang umur simpan bawang merah bubuk.*
Kata kunci: Accelerate Shelf-Life Testing (ASLT), *Arrhenius, bawang merah bubuk, penyalutan*

INTRODUCTION

Shallots are easily damaged agricultural products with a relatively unstable selling price. The shallots price in the market is unstable due to unbalanced supply and demand. The prices of the shallots will decrease during the harvest season because of the high supply. The shallots' price will increase outside the harvest season due to high demand during low supply. One way to reduce shallots damage is to process them into products with low moisture content to prevent the microorganisms' (Gouda et al., 2017; Majid et al., 2019). Shallot powder is the alternative for processing shallots into products with low moisture content. The low moisture content in the ingredients causes the product to have a longer shelf life.

The shallot powder processing and storage cause the sulfur compounds contained to evaporate. Allicin compounds and alliinase enzyme activity also changed during storage. The shallots' distinctive aroma increases along with the alliinase enzyme activity increase in shallot tissue and vice versa (Mutia et al., 2014). Shallot powder were coated with a coating material (tapioca flour, CMC, Arabic gum, or maltodextrin) to prevent the decrease of shallots' characteristic aroma. Coating aims to prevent the evaporation of sulfur compounds, allicin compounds, and other shallots volatile components. The coating material acts as a protective layer to protect shallots from volatile components loss and denaturation (Mohammed et al., 2020). Tapioca flour was chosen as the coating material because it has good cohesive properties and low gas and water vapor transmission rates (Prasetyo et al., 2018). The use of 10% tapioca flour as a coating has the best effect on parameters of ash content, fat, protein, and vitamin C (Setyadjit & Sukasih, 2015).

Drying is an essential step of shallot powder processing. Drying removes all or most water from a material using heat energy (Juneja et al., 2017). Drying is performed using a tray dryer at a temperature of 60 °C. According to Manfaati et al. (2019), the 60 °C drying temperature can reduce the evaporation of volatile substances. The tray dryer consists of shelves placed in an insulated cabinet. The hot steam originates from the power source and is circulated through the thin product surface. The tray dryer has a simple, flexible installation, suitable for drying vegetables, but the process is difficult to control because periodic checks are needed so that the drying room temperature remains stable and does not affect the drying results (ur-Rehman & Awan, 2012).

Clumping usually occurs in powdered products during storage. This condition is caused by increased water content (Gamboa-Santos et al., 2012). Factors that can change powdered product quality include increased moisture content, relative humidity changes around the food storage environment, intense lighting causing discoloration and rancidity in high fat-containing foods, and food storage temperature (Paine & Paine, 1992). Consumers need information about the safe time limit for storing a product until consumed. The storage period can be obtained by estimating the product's shelf-life. The product's shelf-life is defined as the period of a product from being produced until it is unacceptable for its aroma, taste, color, nutritional value, and safety characteristics under certain environmental conditions (Apicella et al., 2018). Estimating shelf-life determines product expiration dates, provides information for new product development, expands distribution, and reduces production losses. Conventional and accelerated methods can estimate product shelf-life.

The conventional method takes a long time and is expensive because the shelf-life is estimated under normal day-to-day conditions. The acceleration method can be performed relatively quickly because the shelf-life estimation is carried out under extreme experimental conditions (high temperature, humidity above or below normal storage conditions) to accelerate the product quality degradation process. Decreasing quality can be calculated based on a mathematical equation. This method's advantage is that the test time is relatively shorter but still has good accuracy (Asiah et al., 2018). One method of acceleration is the Arrhenius model. Estimating shelf-life in this study uses the Arrhenius model of Accelerated Shelf-Life Testing (ASLT) method. According to Asiah et al. (2018), the experimental results of shelf-life should be able to provide information about shelf-life under ideal conditions, shelf-life under unideal conditions, and shelf-life under distribution conditions. The shelf-life testing temperatures in this study were 30 °C, 40 °C, and 50 °C with 70% RH. A temperature of 30 °C describes the normal state of product storage, a temperature of 40 °C describes the distribution temperature of the product, and a temperature of 50 °C represents an extreme temperature for shelf-life testing. This study aims to estimate the shelf-life of shallot powder at various storage temperatures and determine quality changes during storage.

METHODS

Tools and Materials

The equipment used in this research was a tray dryer, shallot chopper machine, dish mill, knife, container, oven, RH-meter, aluminum dish, desiccator, analytical balance, Volatile Reducing Substance (VRS) Apparatus, and apparatus for analysis. The materials used in this study were fresh shallots of Brebes variety, packaging aluminum foil (8 x 9 cm), tapioca flour, and materials used for analysis purposes (H_2SO_4 6 N, KI 20%, $Na_2S_20_3$ 0.02 N, 0.02 N $KMNO_4$, distilled water, and 1% starch solution).

Characterization of Shallot Powder

The shallot powder production refers to the modified method by Manfaati et al. (2019). The manufacturing process includes peeling shallots, washing using running water, chopping using a chopper machine, treatment with coating and without coating, drying using a tray dryer at 60 °C to a moisture content of less than 12%, and size reduction using a dish mill. Reducing the water content to 7% (wb) can prevent the microorganisms' growth of shallot powder (Mitra et al., 2012). According to the Indonesian National Standard (SNI 01-3709-1995), the moisture content of dry spice products is a maximum of 12%. The coating material used is 10% tapioca flour (Badan Standardisasi Nasional, 1995).

Characterization was performed on fresh shallots and shallot powder in this study. The characterization performed includes three parameters; yield, water content (AOAC, 2019), and Volatile Reducing Substance (VRS) content (Starowicz, 2021). The main principle of determining the VRS level is the flowing volatile substances and other odorous substances in a closed system from material to KMnO4, a volatile trapping compound. The VRS value is calculated based on the difference in the reduced KMnO4 value with the blank value (water) using the iodometric process (Starowicz, 2021).

Quality Changes of Shallot Powder During Storage

Shallot powder from this research were packaged in aluminum foil and stored at 30 °C, 40 °C, and 50 °C with relative humidity (RH) of 70%. Analysis of moisture content and VRS levels was performed during storage to see shallot powder product characteristics changes.

The study was designed using a completely randomized design with two replications consisting of two factors; coating (coated and uncoated) and storage temperature conditions (30 °C, 40 °C, and 50 °C). The data obtained were processed using the variance test (ANOVA) and Duncan's Multiple Range Test (DMRT) at a 5% significance level ($\alpha = 0.05$). The ANOVA was performed to see the treatment effect of coated and uncoated and storage temperature conditions on shallot powder's quality change parameters. The treatment that gave a significant difference at the 5% level of significance ($\alpha = 0.05$) was indicated by the Duncan's Multiple Range Test (DMRT) follow-up test. The data were processed with Microsoft Excel 19.0.

Shelf-Life Estimation of Shallot Powder

Shelf-life estimation was performed on shallot powder in aluminum foil packaging, stored at test temperatures of 30 °C, 40 °C, and 50 °C, and with relative humidity (RH) of 70%. Parameters observed during storage were moisture content and VRS content. Estimation of shelf-life begins with the data plot from the storage time analysis. The slope value, the reaction rate constant (k), is obtained from the graph. Parameter values ln k and 1/T (K degree) are then plotted. The graph slope value is ln k_0, and the intercept value is Ea/R. The k value can be determined using the Arrhenius equation. The Arrhenius model is described as follows (Jafari et al., 2017; Pombo et al., 2019; Steele, 2009):

$k = k_0 \cdot e^{-Ea/RT}$

$\ln k = \ln ko - (Ea/RT)$

$\ln k = \ln ko - \{(Ea/R) \cdot (1/N)\}$ (1)

where,

k0 = pre-exponential constant or absolute advanced constant

k = reaction rate constant at temperature T

Ea = activation energy (cal/mol)

R = ideal gas constant (1,986 cal K^{-1} mol^{-1})

T = absolute temperature (K)

The parameter value is determined at the initial condition (A_0) and critical time; when the product quality is no longer acceptable to consumers (A_t). The shelf-life of shallot powder was then calculated using zero-order reaction kinetics, assuming that the deterioration rate occurred at constant temperature and relative humidity. The equation for the zero-order rate of deterioration is:

$t = (A_0 - A_t) / k$ (2)

where,

t = shelf life (days)

A_t = concentration of A when it is critical or when it is no longer acceptable to consumers (% for the water content parameter and meq/g for the VRS level parameter)

A_0 = concentration of A at the beginning of the analysis (% for the water content parameter and meq/g for the VRS level parameter)

k = deterioration rate (per day)

RESULTS AND DISCUSSION

Shallot Powder Characterization

The drying process causes the shallot slices to evaporate water due to contact with the drying air, reducing their weight. An exponential curve can describe the relationship between weight loss and drying time. The correlation curve for the material weight loss during drying is presented in Figure 1.

Figure 1 shows that the curve looks steeper in the early and late drying stages. This result means that drying in the early stages is faster because the evaporated material moisture content is more than in the final stage. The vaporized water content decreases until equilibrium is reached. According to Gunathilake et al. (2018), the amount of water on the material's surface (free water) is quite a lot in the early drying stages, so the water evaporates quickly. This stage occurs rapidly with the water evaporation rate equal to the free water evaporation. The water content decreases more slowly as the water content decreases in the material at the final drying stage. According to Geng et al. (2022), the water movement from the inside to the surface material by diffusion and the water content transfer from the material surface to the free air occurs at the final drying stage, so the water reduction occurs slowly.

The shallots characterization was performed to determine the characteristics changes of fresh shallots before and after processing. Parameters tested were yield, moisture content, and VRS. The fresh and shallot powder's characteristics are shown in Table 1.

Coated shallot powder had a higher yield (21.95%) than uncoated ones (12.97%). This result is because the total solids due to added 10% tapioca of coating material. According to Setyadjit & Sukasih (2015), shallot powder coated with tapioca flour have more total solids than uncoated shallot powder, so the weight of dry shallots produced increases.

The drying process causes a decrease in fresh shallots' moisture content from 81.10% to around 4-5% so that the microorganisms' growth can be prevented. Shallot powder produced from this research have a moisture content value below 12%, following SNI 01-3709-1995 (Badan Standardisasi Nasional, 1995). The moisture content of coated shallot powder (4.53%) is lower than uncoated shallots powder (4.77%). These results follow research results by Setyadjit & Sukasih (2015); the moisture content value of shallot powder is lower with more added tapioca flour as a shallots powder filler. Tapioca flour has high levels of amylopectin. According to Wahyuningtyas et al. (2014), amylopectin levels in foodstuffs can form hydrogen bonds with large

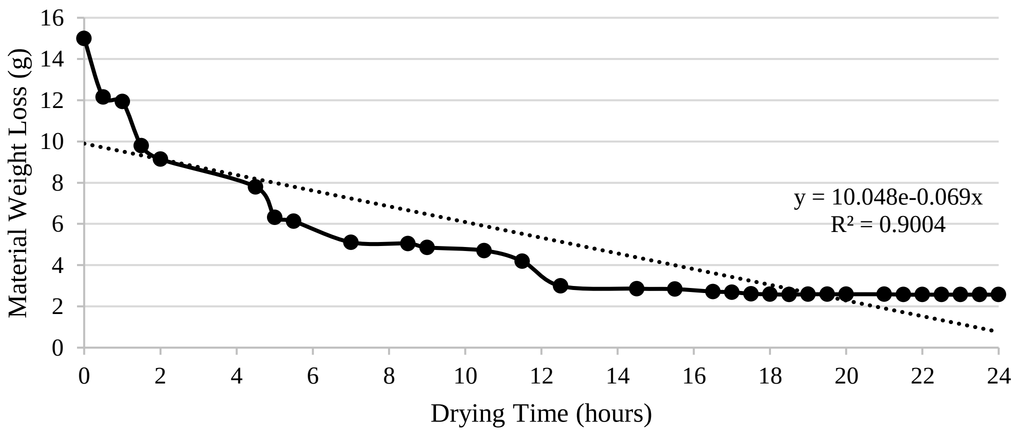


Figure 1. Correlation Curve of Uncoated Shallots Weight Loss with Drying Time

Table 1. Shallots characteristics

Parameter	Fresh Shallots	Shallot Powder	
		Uncoated	Coated
Yield (%)	-	12.97	21.95
Moisture content (%)	81.10	4.77	4.53
VRS Level (meq/g material)	12.40	28.78	18.47

amounts of water, thereby increasing the space in the material, which facilitates the water release into the air and causes lower moisture content.

Temperature, time, and moisture content affect the degradation of S-propyl-cysteine-sulfoxide precursors into volatile compounds, the aroma components in shallots. The degradation of S-propyl-cysteine-sulfoxide occurs more significantly when the temperature increases and the shallots' moisture content decrease during the drying process (Keusgen, 2011). The degradation of volatile compounds caused the VRS levels of fresh shallots to be lower than those of dried shallots.

The coated shallot powder's VRS value (18.47 meq/g) was lower than the uncoated one (28.7 meq/g). The VRS value decreases because the added tapioca flour (polysaccharides, including starch) reduces volatile components in foodstuffs (Egharevba, 2019). Tapioca flour has a low gas transmission rate, so volatile compounds in shallots, such as sulfur compounds and aldehydes, are retained (Radev & Dimitrov, 2017). Because of the volatile compounds' containment properties of this tapioca flour, the volatile compounds are expected to be preserved during the shallot powder storage period.

Quality Changes of Shallot Powder During Storage

Powder products will experience decreased quality and physical damage like product clumping due to increased water content during storage. The critical parameters observed in shallot powder storage were moisture content and VRS content. Moisture content is an observation parameter because the product is in powder form, and it is easy to increase water content during storage. The shallot powder moisture increase will cause a clumping product. Tests for VRS levels during storage were performed to determine volatile component changes. The missing volatile compounds from shallots will cause a decrease in shallot flavor and bioactive components, so the shallot powder quality decreases.

Shallots' taste and aroma components are formed when the shallots tissue is damaged. Alliinase enzyme hydrolyzes flavor precursors (S-alkyl-L-cysteine-sulfoxides) when damage tissue and produces organosulfur compounds with distinctive aroma characteristics (Keusgen, 2011; Diriba-Shiferaw, 2016). The resulting organosulfur compounds are volatile.

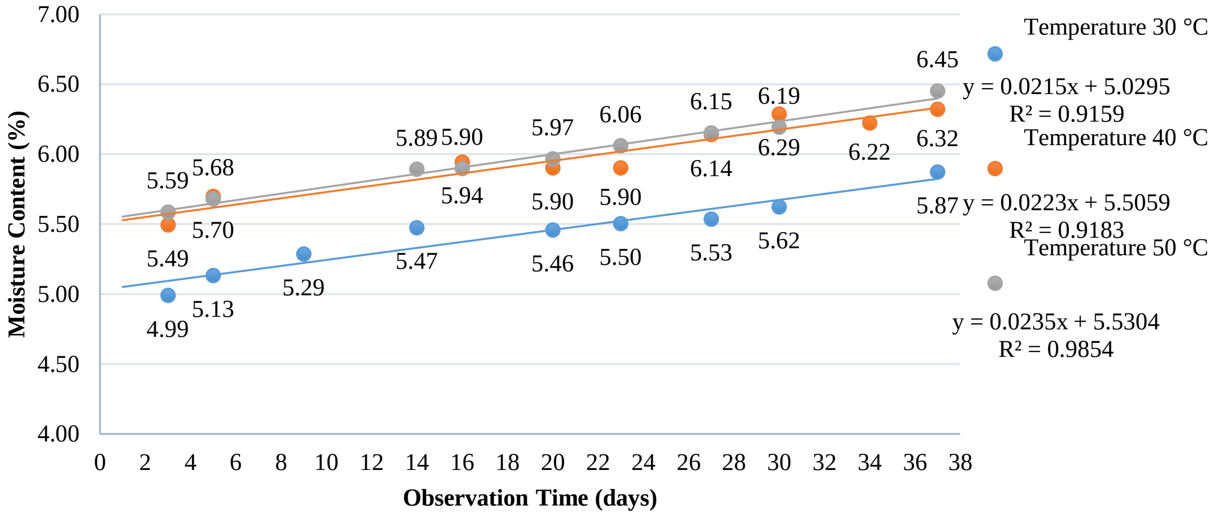
Moisture Content

Powdered products generally experience agglomeration during storage due to increased moisture content. The powdered product absorbs moisture when the atmospheric humidity and storage temperature are high, causing clumping (Robertson, 2013). When the stirage period ends, the moisture content value varies from 4.58% to 6.45%. The ANOVA results showed that the temperature treatment, coating, and their interaction did not significantly affect (α=0.05) moisture content increase. These results are shown in Figures 2 (a) and (b). The three lines of uncoated and coated treatment are close to each other, meaning the change rate of moisture content does not differ. This result could be due to the aluminum foil packaging used. Aluminum foil is a metal packaging material, a solid and thin aluminum sheet form with less than 0.15 mm thickness, flexible, and is not translucent (Armadany et al., 2015). According to Mangaraj & Goswami (2011) and Apicella et al. (2018), aluminum foil can withstand water vapor, air, and heat entering the product to provide reasonable protection for packaged products. This packaging resistance to high temperatures causes the shallot powder moisture absorption insignificant.

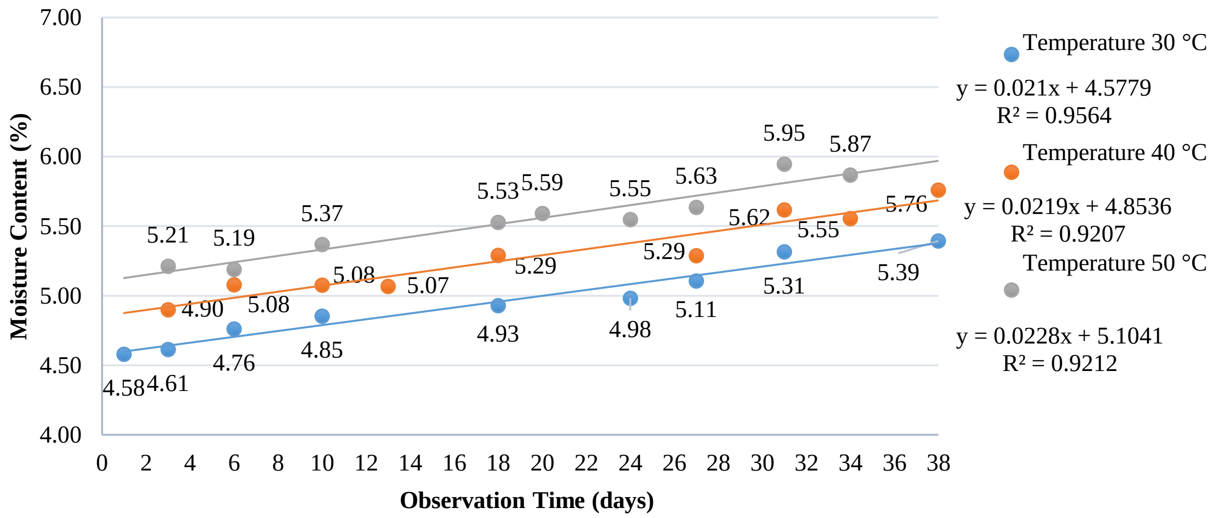
VRS Level

The smell of shallot powder will be sharper if the VRS level is high. The VRS levels of shallots are mainly composed of sulfur compounds main shallots aroma components (Tendaj & Mysiak, 2010). Decreasing VRS levels variations during storage ranged from 0.20 meq/g to 26.60 meq/g. The ANOVA results showed that using a coating, storage temperature, and the interaction between them significantly affect (α=0.05) the decrease in VRS levels rate of shallot powder.

Based on the DMRT, coated shallot powder had the lowest VRS levels decrease rate. The coefficient value indicates this in the linear regression equation in Figure 3 (b), which is lower than the coefficient value in Figure 3 (a) for temperatures of 30 °C, 40 °C, and 50 °C. DMRT also showed that shallot powder stored at 30 °C had the lowest rate of decrease in VRS levels, and the interaction between shallot powder coated and stored at 30 °C had the lowest VRS levels decrease rate. This result is also indicated by the coefficient value in the linear regression equation for storage at 30 °C had the lowest compared to other storage temperatures. The VRS levels-decrease of shallot



(a) Uncoated



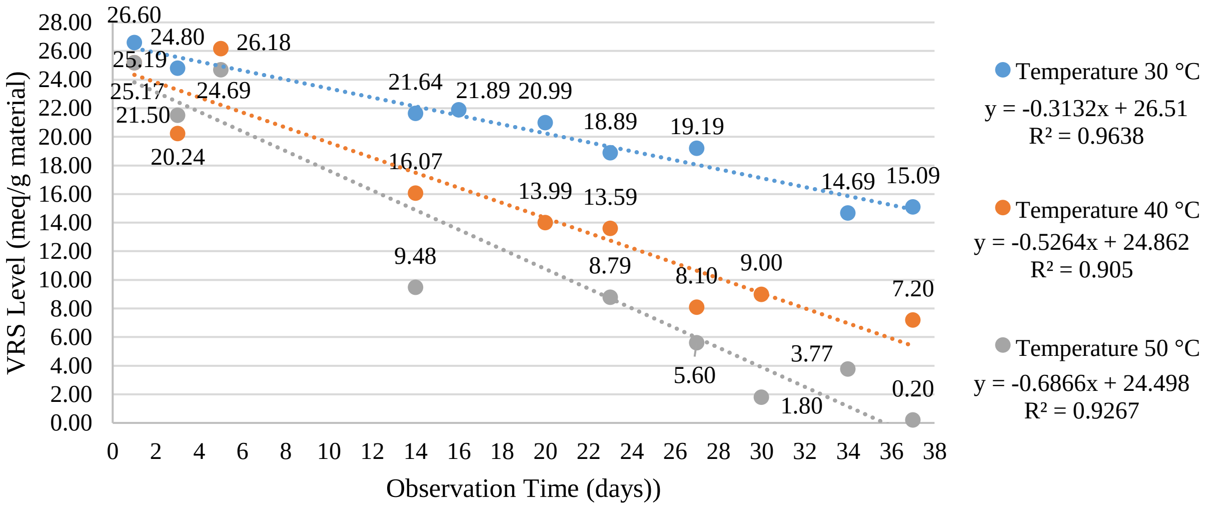
(b) Coated

Figure 2. The Relationship between Storage Time and Moisture Content of Shallot Powder at Various Storage Temperatures

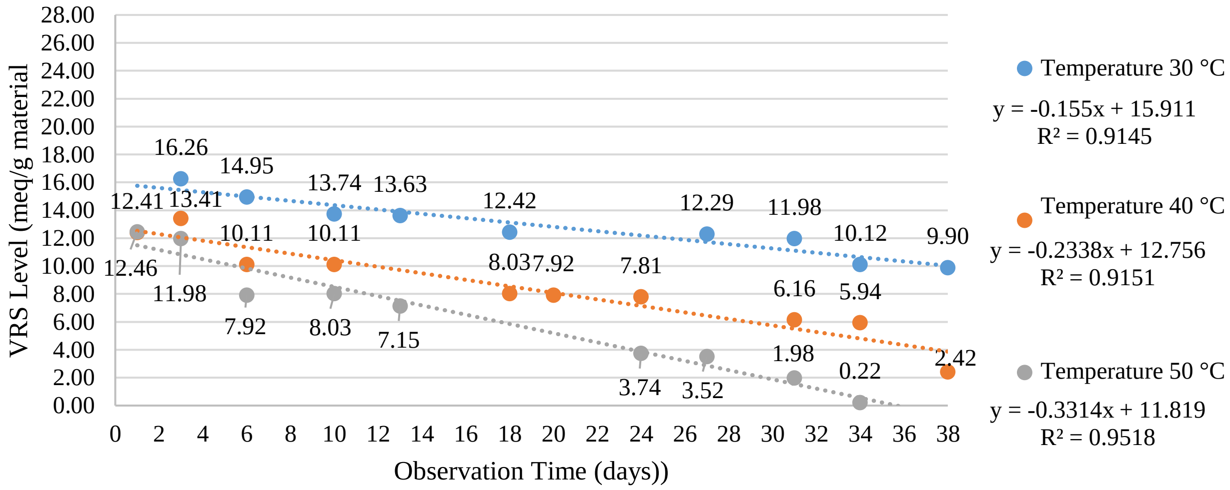
powder was caused by the evaporation of the product's volatile components during storage.

According to Ryu et al. (2020), the packaging permeability affects the evaporation of volatile components, so changes in aroma components occur during storage. Aluminum foil is packaging with lower oxygen and water vapor transmission rate than plastic packaging, such as High-Density Poly Ethylene (HDPE). The transmission rate of aluminum foil is 0.1428 g/m2/24 hours, while HDPE is 4.7725 g/m2/24 hours (Cahyo et al., 2016). This condition causes the aluminum foil packaging better withstand the volatile compounds' evaporation.

The VRS levels decrease during storage are shown in Figures 3 (a) and (b). Storage at 30 °C decreased the least VRS levels, and storage at 50 °C caused the most VRS levels to decrease. According to Siregar & Shelvira (2021), volatile compounds quickly evaporate, especially if there is a temperature increase. This condition causes the decrease rate of VRS levels at a temperature of 50 °C is higher than at temperatures of 30 °C and 40 °C. The reaction rate will also increase with temperature increase, so the damage reactions rate of the product will increase if the storage temperature is higher (Chang & Overby, 2011).



(a) Uncoated



(b) Coated

Figure 3. The Relationship between Shallot Powder Storage Time and VRS Levels at Various Storage Temperatures

The decrease of coated shallot powder's VRS levels was lower than the uncoated ones. According to Gaonkar & McPherson (2016), aroma compounds can be absorbed into the natural starch surface due to hydrogen bonds between aroma compounds and natural starch. This condition causes the decrease in VRS levels rate of coated shallots to be lower than that of uncoated ones. The volatile compounds in shallot powder can be bound by tapioca flour to minimize the reduction of the volatile compound during storage.

The interaction between the coating factor and storage temperature showed that the decrease in coated powder VRS levels rate at a temperature of 30 °C was the lowest compared to other interactions. This result is because the volatile compounds in shallots are captured by tapioca flour as a coating, and the aroma compounds can be maintained longer. The interactions also follow the analysis of variance in each treatment. The lowest rate of VRS levels decrease is at coated shallot powder at 30 °C.

Estimation of Shallot Powder Shelf-Life

Parameters observed during the shallot powder storage were moisture content and VRS content.

<u>Moisture Content</u>

Determining shelf-life begins with creating a mathematical model of the relationship between moisture content parameters and storage time. The linear regression equation for the relationship between shallot powder and storage time is presented in Table 2. The k value is a coefficient in the regression equation that shows the relationship between coating treatment, temperature, and moisture content parameters. The damage level based on moisture content parameters is high if the temperature is high. The coated shallots powder damage rate is lower than the uncoated ones.

Figure 4 shows the relationship of 1/T (temperature) and ln k of the water content test results. Each natural logarithmic value (ln) and 1/T (Kelvin) at each storage temperature is plotted as ordinate and abscissa, which the curve is shown in Figure 4. The deterioration rate is higher if the regression equation coefficient value gets small. The regression equation value for the uncoated treatment is smaller than the coated treatment, so the decline rate of the uncoated treatment quality is high.

Data plot results of the ln k with I/T value are regression equations. The slope value in the equation is the –Ea/R value, and the intercept value is the ln k_0 value for the Arrhenius equation. The values of k and ln k of the Arrhenius equation for coated and uncoated treatment for moisture content parameters at various storage temperatures can be seen in Table 3. Values of Ea, ln k_0, and k_0 for coated and uncoated treatment for moisture content parameters at various storage temperatures can be seen in Table 4.

The shelf-life value was calculated based on the zero-order reaction kinematics. The critical moisture content value based on Dry Spices SNI 01-3709-1995 is a maximum of 12% (Badan Standardisasi Nasional, 1995). The results of the product's shelf-life calculation for the moisture content parameter are presented in Table 5.

Table 2. Linear regression equation graph of the relationship between storage time (days) and moisture content (%) during storage

Treatment	Temperature (°C)	Linear Regression	R^2
Uncoated	30	Y = 0.0215X + 5.0295	0.9159
	40	Y = 0.0223X + 5.5059	0.9183
	50	Y = 0.0235X + 5.5304	0.9854
Coated	30	Y = 0.021X + 4.5779	0.9564
	40	Y = 0.0219X + 4.8536	0.9207
	50	Y = 0.0228X + 5.1041	0.9212

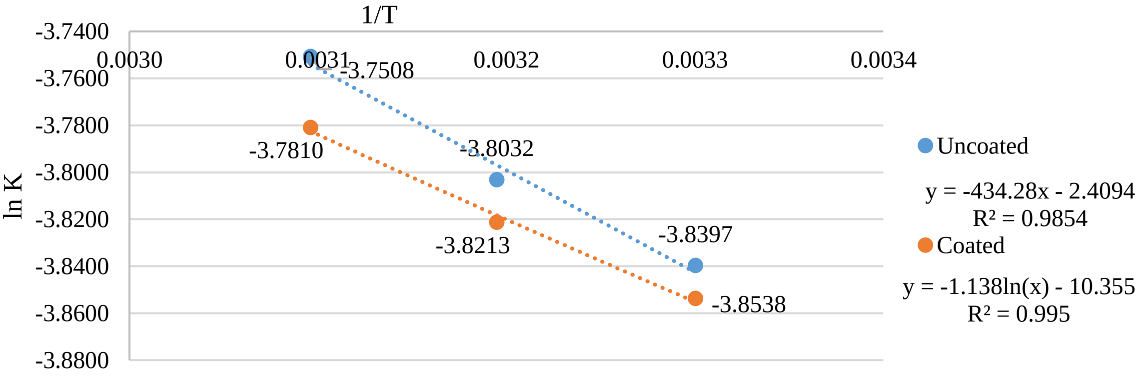


Figure 4. Graph of Relationship 1/T with ln k Value of Moisture Content (%)

Table 3. Values of k, and ln k of coated and uncoated treatment based on moisture content parameters at various storage temperatures

T (Kelvin)	1/T	Coated		Uncoated	
		k	ln k	k	ln k
303	0.0033	0.021	-3.8632	0.0215	-3.8397
313	0.0032	0.0219	-3.8212	0.0223	-3.8032
323	0.0031	0.0228	-3.7810	0.0235	-3.7508

k = constant of quality degradation; T = storage temperature

Table 5 shows that the shelf-life of coated and uncoated shallot powder is about one year. The shelf-life value of coated shallot powder for each storage temperature tends to be longer than uncoated ones. According to Egharevba (2019), starch will absorb less water if the content of amylopectin is high. Tapioca flour has a higher amylopectin content than amylose, so the moisture absorption of the coated shallot powder is lower, and its shelf-life is longer.

The shelf-life value also decreases with increasing storage temperature. This value is negatively correlated with the product quality decline rate. The shelf-life will be shorter if the deterioration rate is high. This result is because the shelf-life value is inversely proportional to the deterioration rate (k).

VRS Level

Determining shelf-life begins with creating a mathematical model of the relationship between VRS levels and storage time. The linear regression equation for the relationship between shallot powder's VRS levels and storage time is presented in Table 6. The k value in the regression equation in Table 6 shows the relationship between coating treatment, temperature, and VRS level parameters. The higher the coefficient value, the smaller the k value (rate of deterioration). Based on the VRS level parameter, the higher the temperature, the damage level is greater. The damage level of coated powder shallot is lower than the uncoated ones (k values in Table 6 are -0.3126; -0.5317; -0.6700; -0.1549; -0.2336; -0.3314).

Table 4. Values of Ea, ln k_0, k_0 of coated and uncoated treatment based on moisture content parameters at various storage temperatures

Parameters	Coated	Uncoated
Ea (kal/mol)	-799.13	-862.48
ln k_0	-2.5354	-2.4094
k_0	0.07923	0.08987

Table 5. Shelf-life period of shallot powder based on moisture content parameters

Treatment	Shelf-life (Days)		
	30 °C	40 °C	50 °C
Uncoated	338	322	309
Coated	356	341	328

Table 6. Linear regression equation graph of the relationship between storage time (days) and VRS levels during storage

Treatment	Temperature (°C)	Linear Regression	R^2
Uncoated	30	Y = -0.3126X + 26.4950	0.9639
	40	Y = -0.5317X + 25.2930	0.9039
	50	Y = -0.6700X + 23.9770	0.9365
Coated	30	Y = -0.1549X + 15.9080	0.9145
	40	Y = -0.2336X + 12.7540	0.9149
	50	Y = -0.3314X + 11.8200	0.9520

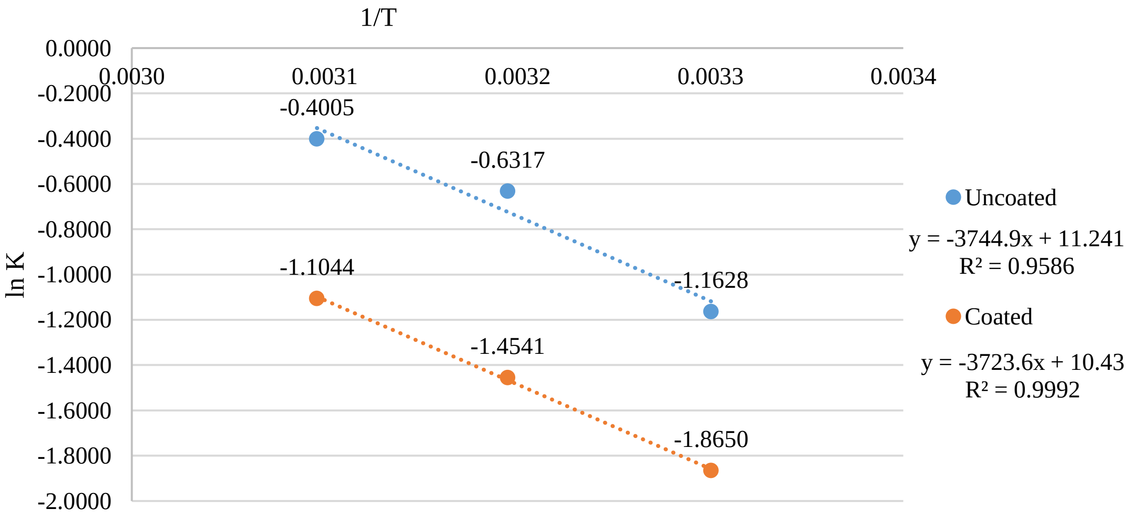


Figure 6. Relationship Graph of 1/T with the Value of ln k Test Results for VRS Levels

Figure 6 shows the relationship between 1/T (temperature) and lnk of the VRS level test results. Each natural algorithm value (ln) and 1/T (Kelvin) at each storage temperature is plotted as ordinate and abscissa shown in Figure 6 curve. The deterioration rate is higher if the regression equation coefficient value gets small. The regression equation value for the uncoated treatment is smaller than the coated treatment, so the quality decline rate of the uncoated treatment is higher than the coated ones.

The data plot results of the ln k value with I/T are a regression equation. The slope value of the equation is the –Ea/R value and the intercept value is the ln k_0 value for the Arrhenius equation. Table 7 shows the values of k and ln k of coated and uncoated treatment for VRS levels parameters at various storage temperatures. Table 8 shows the values of Ea, ln k_0, and k_0 of coated and uncoated treatments for water content parameters at various storage temperatures.

The determination of shelf-life value is based on zero-order reaction kinematics. The critical VRS level value is obtained based on the product's critical point, which is determined by examining the product's condition. The critical point has been reached when the product condition is unacceptable, and the critical VRS value is immediately tested. The results of the product's shelf-life calculation for the VRS level parameter are presented in Table 9.

The shelf life of uncoated shallot powder is shorter than coated shallot powder. This result is because the coating process slows the evaporation of volatile compounds in shallot powder; hence the shelf life of coated shallot powder is longer than uncoated ones. The coating process of shallot powder is needed to maintain the volatile compounds. Table 9 also shows that the shelf-life value of shallot powder decreases with increasing storage temperature. This value is negatively correlated with the product quality decline rate. The shelf-life will be shorter if the deterioration rate is high. This is because the shelf-life value is inversely proportional to the deterioration rate (k).

The shelf-life value based on the VRS level parameter is different from the shelf-life based on the moisture content parameter. According to Wasono & Yuwono (2014), a critical parameter is a parameter with small activation energy (Ea), which indicates a reaction runs faster and causes faster product damage. The lowest Ea value was 862.48 cal/mol for the uncoated treatment and 706.06 cal/mol for coated treatment, so the shelf-life value was based on the moisture content value calculation. The shelf-life values of uncoated shallot powder at 30 °C, 40 °C, and 50 °C were 338 days, 322 days, and 309 days, respectively. The shelf-life values of coated shallot powder at 30 °C, 40 °C, and 50 °C are 353 days, 340days, and 328 days respectively.

Table 7. Values of k and ln k of coated and uncoated treatment based on VRS level parameters at various storage temperatures

T (Kelvin)	1/T	Coated		Uncoated	
		k	ln k	k	ln k
303	0.0033	0.1549	-1.8650	0.3126	-1.1628
313	0.0032	0.2336	-1.4541	0.5317	-0.6317
323	0.0031	0.3314	-1.1044	0.6700	-0.4005

k = constant of quality degradation; T = storage temperature

Table 8. Values of Ea, ln k0, k0 coated and uncoated treatment based on VRS level parameters at various storage temperatures

Parameters	Coated	Uncoated
Ea (kal/mol)	-7395.07	-7437.37
ln k_0	10.43	11.24
k_0	33860.35	76191.10

Table 9. Shelf-life of shallot powder based on VRS level parameters

Treatment	Shelf-life (Days)		
	30 °C	40 °C	50 °C
Uncoated	72	49	34
Coated	84	57	39

CONCLUSIONS

The decrease in shallot powder quality during storage was indicated by increased water content and decreased VRS levels. The product's shelf-life was determined based on the moisture content parameter because it has the lowest activation energy. The shelf-life of uncoated shallot powder at 30 °C, 40 °C, and 50 °C were 338 days, 322 days, and 309 days. The shelf-life values of coated shallot powder at 30 °C, 40 °C, and 50 °C were 353 days, 340 days, and 328 days. The coating used can slow down the volatile compounds' decline rate and extend the product's shelf-life, so the coating process is needed to process shallot powder.

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