

Kinetics of color change and shelf life of nutmeg squash packaged in transparent, amber, and green glass bottles

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Abstract

Problems related to the unstable quality of nutmeg squash products, especially the color change during storage, are thought to be caused by inappropriate packaging techniques. The current packaging technique is not optimal for protecting the carotenoid pigments in the nutmeg squash from exposure to light and oxygen, resulting in discoloration during storage. This study aimed to produce a nutmeg squash product with a more stable quality during storage. This was carried out by monitoring the color change of nutmeg squash in transparent, amber, and green glass bottles, and by determining its shelf life using color quality as the main indicator. The Arrhenius kinetic model was used to examine the nutmeg squashes' color changes during storage at 30, 45, and 55°C for 14 days. The results showed that nutmeg squash products packaged in green glass bottles preserved the highest quality, as seen in the smallest total color difference (ΔE^*), indicating less carotenoid photodegradation. Based on the L^* (lightness) value quality attribute, the shelf life estimations of nutmeg squash products packaged in transparent, amber, and green glass bottles were 1, 1.5, and 2 months at 30°C, respectively. The estimated shelf life of nutmeg squash at 30°C, based on color score, was 0.8 months in transparent, 0.9 months in amber, and 1.4 months in green glass bottles. These results suggest that the appropriate glass bottle color can be applied to the packaging of nutmeg squash to maintain its color and quality.

1. Introduction

Nutmeg is one of Indonesia's spices and is widely used in cooking, food preservation, and medicine (Wijaya, 2019). Nutmeg belongs to the genus *Myristica*, specifically *Myristica fragrans*. The nutmeg tree requires a warm, humid tropical climate and well-drained, fertile soil (Naeem *et al.*, 2016). Nutmeg fruit consists of seed, mace, and flesh (pericarp/rind). Nutmeg seeds are commonly used as spices in culinary to support meaty flavors or in soups (Rahardiyana *et al.*, 2020). Nutmeg mace usually gives a bright orange saffron-like color in dishes (Naeem *et al.*, 2016). Nutmeg flesh (pericarp/rind) is the largest part of the nutmeg fruit, about 75% of the total weight. Nutmeg flesh (pericarp/rind) can be processed into jam, pickle, syrup, juice, sweets, jelly, and squash (Naeem *et al.*, 2016; Suwarda *et al.*, 2021). The utilization of nutmeg flesh (pericarp/rind) is still considered to be low compared to nutmeg seed and mace. Indonesia mainly exports nutmeg as milled or unmilled nutmeg seed and mace (Directorate General of

Estate Crops, 2019). Besides spices and food ingredients, nutmeg seed and mace are commonly processed into nutmeg oil. The nutmeg oil is obtained by distillation. Nutmeg oil has a clear, yellowish appearance, sometimes faintly green, and has an aroma specific to nutmeg (Rahardiyana *et al.*, 2020).

One of the products that can be produced from nutmeg flesh (pericarp/rind) is nutmeg squash. Phytonutrients or phytochemical compounds found in nutmeg include 90 $\mu\text{g}/100\text{ g}$ of β -cryptoxanthin and 16 $\mu\text{g}/100\text{ g}$ of β -carotene (Agbogidi and Azagbaekwe, 2013). The compounds β -cryptoxanthin and β -carotene are carotenoid pigments that give color to nutmeg squash. Carotenoids give yellow, orange, and dark red colors. Carotenoids are very sensitive to oxygen and light. Without oxygen and light, carotenoids in food are stable even at high temperatures (Belitz *et al.*, 2009).

Squash is a drink obtained from a mixture of fruit

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juice and sugar, which is diluted first with water before consumption. Processing nutmeg flesh into nutmeg squash can contribute to building the local economy and supporting the development of processed spice product businesses in Indonesia. Problems related to the unstable quality of nutmeg squash products, especially the color change during storage, are thought to be caused by inappropriate packaging techniques. The current packaging technique is not optimal for protecting the carotenoid pigments in the nutmeg squash from exposure to light and oxygen, resulting in discoloration during storage. Light-sensitive food compounds like carotenoids are called photosensitizers (Singh and Mukherjee, 2022). Photosensitizer molecules generally have a chromophore structure capable of absorbing photon energy from light and producing singlet oxygen or reactive oxygen species (ROS) (Kwon *et al.*, 2018).

Packaging techniques with dark-colored packaging can protect the product from exposure to light. Andersen and Skibsted (2010) emphasized that the light transmission characteristics of packaging materials determine which wavelengths can pass through the material and at what intensity. An example is the packaging of beer and wine. Most beers are packaged in brown or green bottles or aluminum cans to reduce photodegradation. In wine, light often causes discoloration, which reduces consumer acceptance. A study by Arapitsas *et al.* (2020) showed a faster color change in wine packaged in transparent glass bottles (flint glass bottles) compared to dark green glass bottles during storage in a condition that resembled the storage condition in a supermarket. Lan *et al.* (2021) in their research concluded that bottle color plays a key role in preventing rosé wine from exposure to light, which causes a decrease in quality, with the order of prevention levels from highest to lowest being amber bottles, green bottles, and flint bottles.

The problem related to the quality of nutmeg squash is that the color change significantly affects consumer acceptance. Our research aimed to produce a nutmeg squash product with a more stable quality during storage. This was done by testing the color change of nutmeg squash products in three different glass bottle colors, namely transparent, amber, and green, and also estimating the shelf life of nutmeg squash in three glass bottle colors based on the quality attributes of the nutmeg squash color. The shelf life estimation of nutmeg squash is carried out in an accelerated shelf life test using the Arrhenius kinetic model. Producing a good quality nutmeg squash product and stability during storage through proper packaging is expected to encourage business development for Indonesian spice-processed products with high economic value.

2. Materials and methods

2.1 Raw materials

The fresh nutmegs were derived from a local nutmeg garden in Bogor, Indonesia. Fresh nutmeg has green-yellowish to brownish skin, white to light green fruit flesh, white or red mace, and light to dark brown seeds. Nutmeg fruit is shown in Figure 1.



Figure 1. Nutmeg fruit. (a) Fresh and unpeeled, (b) fruit flesh and (c) seed with mace.

2.2 Nutmeg squash production

Nutmeg fruit was peeled, cut in half, and separated from the seed. The fruit flesh was soaked in 1% brine solution, drained, and extracted with the same amount of water in a kitchen blender. The nutmeg flesh juice was obtained after filtration using a filter cloth. The juice was heated at 80°C for 5 min, then 1% egg white was added and stirred. The heating was stopped, and then the juice was left until the eggs and cloudy particles settled completely. Only the clear juice part was taken and added with 0.025% sodium benzoate and 48% sugar, then it was heated and stirred at 85°C for 10 min. The nutmeg squash was then hot-filled into the sterilized glass bottle.

2.3 Determination of physicochemical properties of nutmeg squash

2.3.1 Total dissolved solids

The total dissolved solids (TDS) of nutmeg squash were measured using a portable pH/EC/TDS/Temperature Meter (HI9811-51) by placing the probe directly into the sample and recording the TDS value.

2.3.2 pH

The pH of nutmeg squash was measured using a portable pH/EC/TDS/Temperature Meter (HI9811-51). The probe was immersed directly into the sample, and the pH reading was recorded after the value remained constant.

2.3.3 Total soluble solids

The total soluble solids (TSS), expressed as °Brix, of nutmeg squash were measured using a handheld refractometer (range: 0–90°Brix) by placing a drop of the sample on the refractometer's prism and expressed as °Brix.

2.3.4 Antioxidant activity

The antioxidant activity of nutmeg squash was determined using the ferric reducing antioxidant power (FRAP) method as described by Benzie and Strain (1996). The FRAP reagent was prepared by mixing acetate buffer (300 mM, pH 3.6), TPTZ (10 mM in 40 mM HCl), and $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ (20 mM) in a 10:1:1 ratio. The sample was mixed with FRAP reagent and incubated at 37°C for 4 min. The absorbance was read at 593 nm, and antioxidant activity was calculated using a standard curve of FeSO_4 .

2.3.5 Total carotene

The total carotene of nutmeg squash was determined by using UV/VIS spectrophotometry as described by Scott (2001). Carotenoids were extracted from the nutmeg squash using a 4:6 acetone-hexane mixture, vortexed, and centrifuged. The hexane layer was filtered and its absorbance measured at 450 nm. A calibration curve was used to calculate total carotene.

2.4 Storage study using three different bottle colors

The produced nutmeg squash was hot-filled and closed immediately into three different sterilized glass bottles, i.e., transparent, amber, and green glass bottles (Figure 2). They were stored for 14 days at 30, 45, and 55°C. Nutmeg squash color and sensory evaluations were conducted after 3, 7, 11, and 14 days.



Figure 2. The produced nutmeg squash is packaged in transparent, amber, and green glass bottles.

2.4.1 Determination of nutmeg squash color

Nutmeg squash color was based on measurement of CIELab values (L^* : lightness, a^* : redness and greenness, b^* : yellowness and blueness, C^* : Chroma, h° : hue) by using a chromameter CR-400 Konica Minolta. The nutmeg squash color difference from the start of storage was calculated as ΔE^* (total color difference) as in equation (1) (Wibowo et al., 2015).

$$\Delta E^* = ((L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2)^{1/2} \quad (1)$$

2.4.2 Sensory analysis of nutmeg squash color

The sensory analysis of nutmeg squash color was evaluated by 10 panelists. The panelists were asked to score the nutmeg squash color on a semantic scale between 1-10 (1 represents light, 10 represents dark) and state whether the nutmeg squash color was still acceptable. The responses were statistically processed using Analysis of Variance (ANOVA) and the Duncan test in IBM SPSS Statistics 24.

2.4.3 Kinetic analysis of nutmeg squash color changes during storage

Nutmeg squash lightness value (L^*) changes and color scores during storage were modeled using a first-order reaction equation as in equation (2).

$$\ln C = \ln C_0 - kt \quad (2)$$

where C is the lightness value (L^*) or color score at time t , C_0 is the lightness value (L^*) or color score at time zero, k is the first-order rate constant, and t is the storage time (day).

Temperature reliance on color changes was ascertained by using the Arrhenius equation (3).

$$k = k_0 \cdot e^{-E_a/RT} \quad (3)$$

where k is the rate constant, k_0 is the pre-exponential factor, E_a is the activation energy (kJ/mol), R is the gas constant (8.314 J/mol.K), and T is the absolute temperature in K.

The inverse of absolute temperature ($1/\text{Temperature}$) to $\ln k$ was plotted to get equation (4).

$$\ln k = \ln k_0 - \left(\frac{E_a}{R}\right) \frac{1}{T} \quad (4)$$

From equation (4), the k_0 value will be obtained and the shelf life of nutmeg squash products packaged in different glass bottle colors can be calculated as in equation (5).

$$\text{Shelf life} = (\ln C_0 - \ln C^*)/k_0 \quad (5)$$

where C_0 is the initial quality value (lightness value (L^*) or color score at time zero), and C^* is the critical quality limit value.

3. Results and discussion

3.1 Physicochemical properties of nutmeg squash

The physicochemical properties of nutmeg squash are presented in Table 1. The nutmeg squash had a pH of 3.0 ± 0.1 and total soluble solids (expressed as °Brix) of $34.6 \pm 0.9\%$, which was comparable to mixed fruit squash in Jothi et al. (2014), which had a pH of 4.55-5.01 and °

Brix of 40%. The nutmeg squash derived from nutmeg fruit flesh contained 2.21 ± 0.62 mg/1000 g total carotene. Nutmeg has been known to have negligible amounts of carotenoids. Kandlakunta *et al.* (2008) examined the carotene content of some plant origins; they found that nutmeg mace has $17,900 \pm 0.83$ $\mu\text{g}/100$ g total carotenoids, of which $2,170 \pm 0.23$ $\mu\text{g}/100$ g is β -carotene. Antioxidant activity examination of nutmeg squash using the FRAP method resulted in $8,875.2 \pm 1,467.9$ mg/kg. Assa *et al.* (2014) evaluated the antioxidant activity of nutmeg flesh, seed, and mace extract using FRAP and DPPH methods. That study found that nutmeg seed extract had higher antioxidant activity than mace and flesh. Nutmeg fruit flesh extract has antioxidant activity (IC_{50}) of 7.29 ± 0.03 $\mu\text{g}/\text{mL}$ (Souri *et al.*, 2008). Sipahelut *et al.* (2019) studied the influence of drying methods on antioxidant activity, which shows that nutmeg fruit flesh-derived oil with shade-drying treatment has significantly higher antioxidant activity (72.82%, DPPH method) compared to fresh and sun-drying treatments (24.18% and 45.66%, respectively).

Table 1. The physicochemical properties of nutmeg squash.

Parameters	Amount
Total dissolved solids (ppm)	534.2 ± 19.0
Total soluble solids, expressed as °Brix (%)	34.6 ± 0.9
pH	3.0 ± 0.1
Total carotene (mg/1000 g)	2.21 ± 0.62
Antioxidant activity (mg/kg)	8875.2 ± 1467.9

Values are presented as mean \pm standard deviation (SD).

3.2 Kinetics of nutmeg squash color changes during storage

The freshly produced nutmeg squash product has an L^* value of 48, a^* value of 0.09, a b^* value of 5.31, a C^* value of 5.31, and an h° value of 89.03. After 14 days of storage, nutmeg squash exhibited lower L^* values and increased b^* and C^* values compared to the freshly prepared sample. The largest color difference from the initial nutmeg squash product color was in the nutmeg squash product, which had been stored for 14 days in a transparent glass bottle at 55°C as indicated by the largest total color difference (ΔE^*) value of 31.95. In contrast, the smallest color difference from the initial nutmeg squash product color was in the nutmeg squash product, which had been stored for 3 days in a green glass bottle at 30°C as indicated by the smallest total color difference (ΔE^*) value of 1.76 (Table 2). After 14 days of storage at 30°C , nutmeg squash products in green glass bottles also exhibited the smallest total color difference (ΔE^*) value among all glass bottle colors.

The total color difference (ΔE^*) represents the relative difference between two specified color points to pinpoint how far apart those two colors reside within a

color space (CIELab) (del Mar Pérez *et al.*, 2007; Nambi *et al.*, 2015), where the color difference between two products with an ΔE^* value more than 5 can be noticeable by the observer as two different colors (Mokrzycki and Tatol, 2011).

L^* (lightness) value of nutmeg squash products tended to decrease during storage, indicating that the nutmeg squash's color is getting darker during storage. The largest decrease in L^* (lightness) value occurred in nutmeg squash products stored in transparent glass bottles. The smallest L^* (lightness) value decrease occurred in nutmeg squash products stored in green glass bottles.

Changes in the L^* (lightness) value of nutmeg squash products during storage at three storage temperatures (30 , 45 , 55°C or 303 , 318 , 328K) were plotted on a graph to determine the rate constant (k). The selected reaction kinetics are first-order based on the correlation coefficient and references related to the kinetics of carotenoid oxidative degradation reactions (Song *et al.*, 2017). The Arrhenius equation was obtained from the plot between the absolute temperature inverse ($1/\text{temperature}$) to $\text{Ln } k$ (Table 3).

The initial quality value of L^* (lightness) was 48.00, while the critical quality limit value of L^* (lightness) was 27.76, which was obtained from the L^* (lightness) value of nutmeg squash products when more than 50% of panelists did not accept the color of nutmeg squash products. The degradation constant (k) was obtained from the Arrhenius equation for each bottle color at each storage temperature, where y is $\text{Ln } k$ and x is $1/\text{temperature}$. The difference in quality value divided by the degradation constant (k) can estimate shelf life.

Based on the L^* value (lightness) quality attribute, nutmeg squash products have the shortest shelf life in transparent glass bottles. Packaging of nutmeg squash products in amber and green glass bottles resulted in a longer shelf life of nutmeg squash products. The results of estimating the shelf life of nutmeg squash products packaged in transparent, amber, and green glass bottles were 1, 1.5, and 2 months at 30°C or 303K , respectively (Table 4). Storage at low temperature (4°C or 277K) extends the shelf life to 2.1, 2.4, and 4.1 months in transparent, amber, and green glass bottles, respectively.

Nutmeg contains carotenoids such as carotene- β (16 $\mu\text{g}/100$ g) and crypto-xanthin- β (90 $\mu\text{g}/100$ g) (Agbogidi and Azagbaekwe, 2013). Carotenoid has several conjugated double bonds in the chain, thus making it susceptible to degradation at high temperatures, low pH, light, and oxygen levels (Borsarelli and Mercadante, 2009). Wibowo *et al.* (2015) reported that the change in

Table 2. Changes in nutmeg squash color during storage in three different glass bottle colors at three different temperatures.

Color of glass bottle	Storage temperature (°C)	Storage time (days)	Measurement results					ΔE^*
			L*	a*	b*	C*	h°	
The initial color attribute of freshly produced nutmeg squash		0	48.00	0.09	5.31	5.31	89.03	-
Transparent	30	3	49.25	-0.41	8.41	8.42	92.85	3.38
		7	46.67	1.13	10.46	10.52	83.81	5.42
		11	38.69	-0.38	18.29	18.30	91.21	15.98
		14	39.13	2.21	16.25	16.39	82.25	14.24
	45	3	59.75	0.20	12.55	12.39	89.12	13.80
		7	46.23	2.19	21.90	22.00	84.28	16.82
		11	44.95	1.97	19.13	19.23	84.12	14.28
		14	39.40	0.13	9.59	9.59	89.24	9.61
	55	3	48.19	0.48	16.25	16.25	88.31	10.95
		7	42.08	1.42	16.86	16.92	85.24	13.05
		11	42.45	0.91	16.35	16.37	86.83	12.38
		14	27.76	7.61	28.86	29.85	75.23	31.95
Amber	30	3	50.76	-0.01	9.85	9.85	90.10	5.31
		7	44.65	1.26	11.92	11.99	83.97	7.50
		11	45.72	0.61	6.65	6.68	84.76	2.70
		14	40.90	1.83	19.52	19.60	84.63	15.98
	45	3	53.85	-0.01	6.69	6.69	90.07	6.01
		7	51.91	0.23	14.14	14.14	89.11	9.66
		11	50.05	1.22	18.04	18.07	86.13	12.94
		14	39.41	3.22	24.61	24.82	82.56	21.36
	55	3	52.22	0.77	15.28	15.63	87.19	10.85
		7	45.30	0.40	15.55	15.56	88.56	10.59
		11	40.08	4.27	29.19	29.50	81.68	25.50
		14	40.94	2.57	20.62	20.77	82.93	17.04
Green	30	3	49.52	-0.19	6.15	6.16	91.79	1.76
		7	48.35	0.93	10.86	10.90	85.11	5.62
		11	46.68	1.18	12.40	12.46	84.59	7.29
		14	41.90	0.01	15.32	15.33	87.70	11.72
	45	3	56.05	0.29	12.12	12.12	88.81	10.55
		7	45.83	2.09	19.70	19.81	83.99	14.69
		11	45.78	4.18	28.19	28.50	81.57	23.55
		14	40.90	-0.46	5.68	5.69	94.67	7.13
	55	3	59.15	0.39	16.48	16.49	88.65	15.79
		7	47.54	0.16	12.89	12.89	89.47	7.59
		11	47.23	2.00	20.27	20.37	84.36	15.10
		14	40.44	3.37	22.77	23.01	81.59	19.31

orange juice color to brown or darkening during storage was attributed to carotenoid and ascorbic acid degradation.

Carotenoids are susceptible to UV and visible light photodegradation at 400 and 500 nm (Duncan and Chang, 2012). Packaging that completely blocks light is foremost to protect carotenoid-containing food or beverages from photodegradation by light; however, it lacks product content visibility for consumers. Kishimoto (2019) reported that sunlight exposure resulted in a more severe loss of carotenoids from extra

virgin olive oil (EVOO) stored in clear glass bottles than that stored in amber glass bottles, while clear glass bottles covered with aluminum foil preserved the most carotenoids. A study by Atencio *et al.* (2022) revealed that the color fading of carotenoid-containing beverages under UV/Vis light exposure happened in a shorter time than the same beverage stored in the dark. It corresponded to the observed decline of all-trans-carotenoid concentrations with higher light exposure and temperature. Besides light exposure and high temperature, dissolved oxygen content in the beverage was also highly correlated with carotenoid losses

Table 3. The Arrhenius equation (first-order) of changes in the L* (lightness) value of nutmeg squash products during storage packaged in three different colored glass bottles.

Color of glass bottle	Arrhenius equation (first-order)					
	y = (slope)x + (intercept)					
	Ln k	Temperature (K)	1/Temperature (K ⁻¹)	Intercept	Slope	Coefficient of determination (R ²)
Transparent	-3.99541	303	0.0033	3.1029	-2174.7	0.6999
	-3.94248	318	0.003145			
	-3.3992	328	0.003049			
Amber	-4.43966	303	0.0033	-0.1711	-1302.9	0.8408
	-4.35053	318	0.003145			
	-4.09235	328	0.003049			
Green	-4.69948	303	0.0033	3.1637	-2372.8	0.943
	-4.21313	318	0.003145			
	-4.12274	328	0.003049			

Table 4. The shelf life estimation of nutmeg squash products in three different colors of glass bottle packaging based on the L* (lightness) value quality attribute.

Color of glass bottle	Arrhenius equation (first-order)	Temperature (K)	Ln k	k	Shelf life (days)	Shelf life (months)
Transparent	y = -2174.7x + 3.1029	277	-4.74800	0.00867	63	2.1
		303	-3.99541	0.01840	30	1
		318	-3.94248	0.01940	28	0.9
		328	-3.39920	0.03340	16	0.5
Amber	y = -1302.9x - 0.1711	277	-4.87571	0.00764	72	2.4
		303	-4.43966	0.01180	46	1.5
		318	-4.35053	0.01290	42	1.4
		328	-4.09235	0.01670	33	1.1
Green	y = -2372.8x + 3.1637	277	-5.40237	0.00451	122	4.1
		303	-4.69948	0.00910	60	2
		318	-4.21313	0.01480	37	1.2
		328	-4.12274	0.01620	34	1.1

(Atencio *et al.*, 2022). Van Aardt *et al.* (2001) demonstrated that an amber PET bottle, which entirely blocked UV and visible wavelengths below 450 nm and partially blocked wavelengths between 450 and 700 nm, provided better protection than a clear bottle, as confirmed by lower oxidation off-flavor volatile compound concentrations.

3.3 Color score of nutmeg squash during storage

The average color score of nutmeg squash tends to increase during storage, which means the squash's color gets darker (Table 5). In general, the higher the storage temperature, the darker the squash's color. The average color score of nutmeg squash packaged in green glass bottles for 14 days at 30°C was significantly lower, which means it was significantly brighter than nutmeg squash packaged in transparent or amber glass bottles at the same temperature and storage time.

Changes in the color score of nutmeg squash products during storage at three storage temperatures (30, 45, 55°C or 303, 318, 328K) were plotted on a graph to determine the rate constant (k). The selected reaction kinetics are first-order based on the correlation

coefficient and references related to the kinetics of carotenoid oxidative degradation reactions (Song *et al.*, 2017). The Arrhenius equation was obtained from the plot between the absolute temperature inverse (1/temperature) to Ln k (Table 6).

The initial quality value of the nutmeg squash color score was 1.0, while the critical quality limit value of the color score was 8.3, which was obtained from the color score of nutmeg squash when more than 50% of the panelists did not accept the color of nutmeg squash. The degradation constant (k) is obtained from the Arrhenius equation for each bottle color at each storage temperature, where y is Ln k and x is 1/temperature. Based on the color score quality attributes, nutmeg squash has the shortest shelf life in transparent glass bottles. Packaging nutmeg squash in amber and green glass bottles results in a longer shelf life for nutmeg squash. The results of the estimation of the shelf life of nutmeg squash packaged in transparent, amber, and green glass bottles were 0.8, 0.9, and 1.4 months at 30°C or 303K, respectively (Table 7). Storage at low temperatures (4°C or 277K) extends the shelf life to 1.4, 2.0, and 4.9 months in transparent, amber, and green

Table 5. Color score of nutmeg squash during storage packaged in three different colored glass bottles.

Color of glass bottle	Storage temperature (°C)	Average of nutmeg squash color score after days of storage		
		7 days	11 days	14 days
Transparent	30	3.1±1.3 ^a	3.4±1.8 ^{ab}	3.5±1.2 ^b
	45	6.9±1.4 ^{de}	6.1±1.2 ^d	6.7±1.8 ^e
	55	7.9±2.3 ^e	4.7±1.6 ^c	8.4±1.1 ^f
Amber	30	3.3±1.3 ^a	2.4±1.7 ^a	3.7±1.9 ^b
	45	4.8±1.6 ^{ab}	4.7±2.2 ^c	6.5±1.6 ^{de}
	55	6.3±1.4 ^d	8.0±1.1 ^e	6.7±0.9 ^e
Green	30	2.9±1.7 ^a	2.7±1.9 ^{ab}	2.2±0.8 ^a
	45	4.8±1.8 ^{ab}	6.3±1.3 ^d	5.4±1.3 ^{cd}
	55	6.0±1.7 ^{cd}	6.1±1.2 ^d	8.3±0.5 ^f

Values are presented as mean±standard deviation (SD). Values with different superscripts in the same column are statistically significantly different ($p < 0.05$).

Table 6. The Arrhenius equation (first-order) of changes in the color score of nutmeg squash products during storage packaged in three different colored glass bottles.

Color of glass bottle	Arrhenius equation (first-order)					
	$y = (\text{slope})x + (\text{intercept})$					
	Ln k	Temperature (K)	1/Temperature (K ⁻¹)	Intercept	Slope	Coefficient of determination (R ²)
Transparent	-2.4407	303	0.0033	3.9393	-1923.4	0.9167
	-2.02495	318	0.003145			
	-1.97688	328	0.003049			
Amber	-2.5823	303	0.0033	6.0631	-2610.8	0.9618
	-2.07147	318	0.003145			
	-1.94351	328	0.003049			
Green	-2.95844	303	0.0033	11.354	-4318.6	0.9417
	-2.07068	318	0.003145			
	-1.90919	328	0.003049			

Table 7. The shelf life estimation of nutmeg squash products in three different colors of glass bottle packaging based on the color score quality attribute.

Color of glass bottle	Arrhenius equation (first-order)	Temperature (K)	Ln k	k	Shelf life (days)	Shelf life (months)
Transparent	$y = -1923.4x + 3.9393$	277	-3.00438	0.049569	43	1.4
		303	-2.4407	0.0871	24	0.8
		318	-2.02495	0.132	16	0.5
		328	-1.97688	0.1385	15	0.5
Amber	$y = -2610.8x + 6.0631$	277	-3.36217	0.03466	61	2.0
		303	-2.5823	0.0756	28	0.9
		318	-2.07147	0.126	17	0.6
		328	-1.94351	0.1432	15	0.5
Green	$y = -4318.6x + 11.354$	277	-4.23661	0.014456	146	4.9
		303	-2.95844	0.0519	41	1.4
		318	-2.07068	0.1261	17	0.6
		328	-1.90919	0.1482	14	0.5

glass bottles, respectively. These results agreed with the L* (lightness) value-based nutmeg squash shelf life estimation that exhibited the most extended shelf life in green glass bottles.

4. Conclusion

This study concluded that nutmeg squash packaged

in green glass bottles preserved the highest quality, as seen in the smallest total color difference (ΔE^*), indicating less carotenoid photodegradation. It was also confirmed by the most extended shelf life estimation of nutmeg squash packaged in green glass bottles among all three glass bottle colors. Based on the L* (lightness) value, the shelf life estimations of nutmeg squash

packaged in transparent, amber, and green glass bottles were 1, 1.5, and 2 months at 30°C, respectively. These results suggest that the appropriate glass bottle color can be applied to the packaging of nutmeg squash to maintain its color and quality. These findings might also be applied to other carotenoid-containing beverage products. Examining the total carotenoid changes during storage is suggested to complement the results.

Conflict of interest

The authors declare no conflict of interest.

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References

- Agbogidi, O.M. and Azagbaekwe, O.P. (2013). Health and nutritional benefits of nutmeg (*Mystica fragrans* Houtt.). *Scientia Agriculturae*, 1(2), 40-44.
- Andersen, M.L. and Skibsted, L.H. (2010). Light-induced quality changes in food and beverages. In Skibsted, L.H., Risbo, J. and Andersen, M.L. (Eds). *Chemical Deterioration and Physical Instability of Food and Beverages*, p. 113-139. Sawston, UK: Woodhead Publishing. <https://doi.org/10.1533/9781845699260.1.113>
- Arapitsas, P., Dalledonne, S., Scholz, M., Catapano, A., Carlin, S. and Mattivi, F. (2020). White wine light-strike fault: A comparison between flint and green glass bottles under the typical supermarket conditions. *Food Packaging and Shelf Life*, 24, 100492. <https://doi.org/10.1016/j.fpsl.2020.100492>
- Assa, J.R., Widjanarko, S.B., Kusnadi, J. and Berhimpon, S. (2014). Antioxidant potential of flesh, seed, and mace of nutmeg (*Myristica fragrans* Houtt). *International Journal of ChemTech Research*, 6(4), 2460-2468.
- Atencio, S., Verkempinck, S.H., Reineke, K., Hendrickx, M. and Van Loey, A. (2022). Heat and light stability of pumpkin-based carotenoids in a photosensitive food: A carotenoid-coloured beverage. *Foods*, 11(3), 485. <https://doi.org/10.3390/foods11030485>
- Belitz, H., Grosch, W. and Schieberle, P. (2009). *Food Chemistry*. Germany: Springer. <https://doi.org/10.1007/978-3-540-69934-7>
- Benzie, I.F. and Strain, J.J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. *Analytical Biochemistry*, 239(1), 70-76. <https://doi.org/10.1006/abio.1996.0292>
- Borsarelli, C.D. and Mercadante, A.Z. (2009). Thermal and photochemical degradation of carotenoids. In Landrum, J.T. (Ed.) *Carotenoids: Physical, Chemical, and Biological Functions and Properties*, p. 229-250. Boca Raton, USA: CRC Press.
- del Mar Pérez, M., Saleh, A., Yebra, A. and Pulgar, R. (2007). Study of the variation between CIELAB ΔE^* and CIEDE2000 color-differences of resin composites. *Dental Materials Journal*, 26(1), 21-28. <https://doi.org/10.4012/dmj.26.21>
- Directorate General of Estate Crops. (2019). *Tree Crop Estate Statistics of Indonesia 2018-2020 Nutmeg*. Jakarta, Indonesia: Secretariat of Directorate General of Estates, Directorate General of Estates, Ministry of Agriculture.
- Duncan, S.E. and Chang, H.H. (2012). Implications of light energy on food quality and packaging selection. *Advances in Food and Nutrition Research*, 67, 25-73. <https://doi.org/10.1016/B978-0-12-394598-3.00002-2>
- Jothi, J.S., Karmoker, P. and Sarower, K. (2014). Quality assessment of mixed fruit squash: physico-chemical analysis, sensory evaluation, and storage studies. *Journal of the Bangladesh Agricultural University*, 12(1), 195-201. <https://doi.org/10.22004/ag.econ.209918>
- Kandlakunta, B., Rajendran, A. and Thingnganing, L. (2008). Carotene content of some common (cereals, pulses, vegetables, spices and condiments) and unconventional sources of plant origin. *Food Chemistry*, 106(1), 85-89. <https://doi.org/10.1016/j.foodchem.2007.05.071>
- Kishimoto, N. (2019). Influence of exposure to sunlight on the oxidative deterioration of extra virgin olive oil during storage in glass bottles. *Food Science and Technology Research*, 25(4), 539-544. <https://doi.org/10.3136/fstr.25.539>
- Kwon, S., Orsuwan, A., Bumbudsanpharoke, N., Yoon, C., Choi, J. and Ko, S. (2018). A short review of light barrier materials for food and beverage packaging. *Korean Journal of Packaging Science and Technology*, 24(3), 141-148. <https://doi.org/10.20909/kopast.2018.24.3.141>
- Lan, H., Li, S., Yang, J., Li, J., Yuan, C. and Guo, A. (2021). Effects of light exposure on chemical and sensory properties of storing Meili Rosé wine in colored bottles. *Food Chemistry*, 345, 128854. <https://doi.org/10.1016/j.foodchem.2020.128854>
- Mokrzycki, W.S. and Tatol, M. (2011). Colour difference ΔE -A survey. *Machine Graphics and*

- Vision, 20(4), 383-411.
- Naeem, N., Rehman, R., Mushtaq, A. and Ghania, J.B. (2016). Nutmeg: A review on uses and biological properties. *International Journal of Chemical and Biochemical Sciences*, 9(6), 107-110.
- Nambi, V.E., Thangavel, K., Shahir, S. and Geetha, V. (2015). Evaluation of colour behavior during ripening of Banganapalli mango using CIE-Lab and RGB colour coordinates. *Journal of Applied Horticulture*, 17(3), 205-209. <https://doi.org/10.37855/jah.2015.v17i03.38>
- Rahardiyani, D., Poluakan, M. and Moko, E.M. (2020). Physico-chemical properties of nutmeg (*Myristica fragrans* Houtt) of North Sulawesi nutmeg. *Fullerene Journal of Chemistry*, 5(1), 23-31. <https://doi.org/10.37033/fjc.v5i1.146>
- Scott, K.J. (2001). Detection and measurement of carotenoids by UV/VIS spectrophotometry. *Current Protocols in Food Analytical Chemistry*, 00(1), F2.2.1-F2.2.10. <https://doi.org/10.1002/0471142913.faf0202s00>
- Singh, A. and Mukherjee, T. (2022). Application of carotenoids in sustainable energy and green electronics. *Materials Advances*, 3(3), 1341-1358. <https://doi.org/10.1039/d1ma01070k>
- Sipahelut, S.G., Kastanja, A.Y. and Patty, Z. (2020). Antioxidant activity of nutmeg fruit flesh-derived essential oil obtained through multiple drying methods. *EurAsian Journal of BioSciences*, 14(1), 21-26.
- Song, J., Wang, X., Li, D. and Liu, C. (2017). Degradation kinetics of carotenoids and visual colour in pumpkin (*Cucurbita maxima* L.) slices during microwave-vacuum drying. *International Journal of Food Properties*, 20(supp. 1), S632-S643. <https://doi.org/10.1080/10942912.2017.1306553>
- Souri, E., Amin, G., Farsam, H. and Barazandeh, T.M. (2008). Screening of antioxidant activity and phenolic content of 24 medicinal plant extracts. *DARU: Journal of Pharmaceutical Sciences*, 16(2), 83-87.
- Suwarda, R., Suneth, R.F. and Sondari, D. (2021). Potential and opportunities of nutmeg pericarp as functional foods. *E3S Web of Conferences*, 306, 04007. <https://doi.org/10.1051/e3sconf/202130604007>
- Van Aardt, M., Duncan, S.E., Marcy, J.E., Long, T.E. and Hackney, C.R. (2001). Effectiveness of poly(ethylene terephthalate) and high-density polyethylene in protection of milk flavor. *Journal of Dairy Science*, 84(6), 1341-1347. [https://doi.org/10.3168/jds.S0022-0302\(01\)70164-6](https://doi.org/10.3168/jds.S0022-0302(01)70164-6)
- Wibowo, S., Grauwet, T., Santiago, J.S., Tomic, J., Vervoort, L., Hendrickx, M. and Van Loey, A. (2015). Quality changes of pasteurised orange juice during storage: A kinetic study of specific parameters and their relation to colour instability. *Food Chemistry*, 187, 140-151. <https://doi.org/10.1016/j.foodchem.2015.03.131>
- Wijaya, S. (2019). Indonesian food culture mapping: a starter contribution to promote Indonesian culinary tourism. *Journal of Ethnic Foods*, 6, 9. <https://doi.org/10.1186/s42779-019-0009-3>