Shelf Life Evaluation of Formulated Cookies from Hanjeli (Coix Llacryma-jobi L.) and Moringa Leaf Flour (Moringa oleifera)

by Wisnu Cahyadi -

AUTHORSHIP CONTRIBUTIONS STATEMENT

We, the undersigned, hereby declare that the article below:

Tittle	:	Shelf life evaluation of formulated cookies from Hanjeli (*Coix lacryma*-jobi L.) and Moringa leaf flour (*Moringa oleifera*)
Journal/ year, volume/issue/page	:	Food Bioscience/101787, 2022/ ISSN 2212-4292/1-11. https://doi.org/10.1016/j.fbio.2022.101787 . (Scopus Q1)
Publisher	:	Elsevier

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May 29, 2022

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United Kingdom Universities and research institutions in United Kingdom	Agricultural and Biological Sciences └ Food Science Biochemistry, Genetics and Molecular Biology └ Biochemistry	Elsevier BV	40

PUBLICATION TYPE	ISSN	COVERAGE	INFORMATION
Journals	22124292, 22124306	2013-2021	Homepage How to publish in this journal

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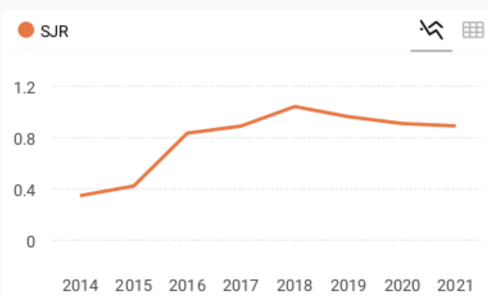

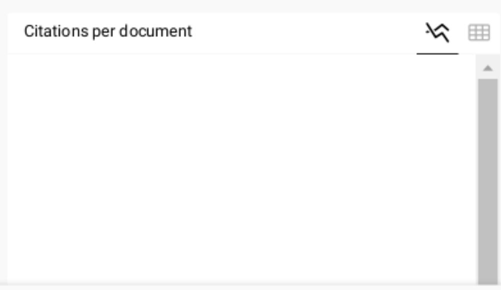

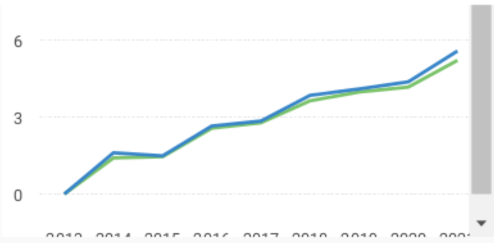

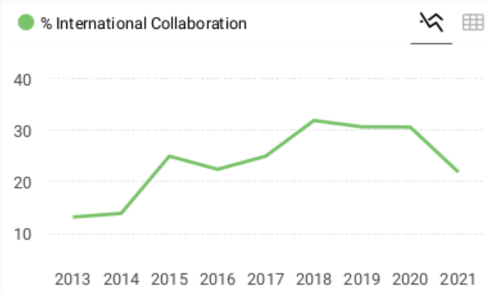

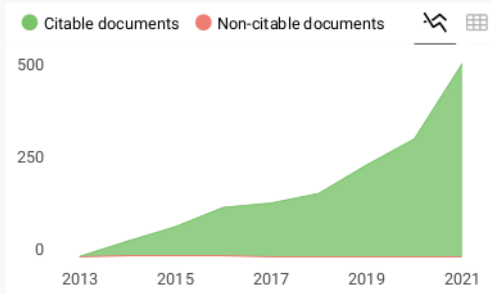

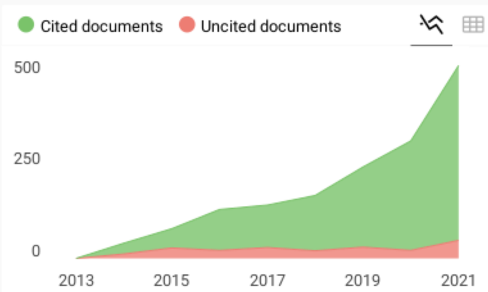

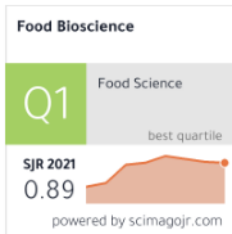

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Food Bioscience

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Shelf life evaluation of formulated cookies from Hanjeli (*Coix lacryma-jobi* L.) and Moringa leaf flour (*Moringa oleifera*)

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ARTICLE INFO

Keywords:
Coix lacryma-jobi
Moringa oleifera
Cookies
Functional food
Shelf life

ABSTRACT

Hanjeli (*Coix lacryma-jobi* L.) and moringa leaf (*Moringa oleifera*) remain underutilised despite their high nutritional value for food. In the present research, cookies made from hanjeli (*Coix lacryma-jobi* L.) with moringa leaf flour (*Moringa oleifera*) have been developed. Hanjeli cookies were measured for nutritional composition and shelf life assessment. The shelf life evaluation of hanjeli-moringa cookies was calculated using two approaches, which were accelerated shelf life testing (ASLT) methods with critical moisture content and the Arrhenius method. The results of the nutritional composition analysis showed that hanjeli-moringa cookies contain protein (9.14%), fat (24.67%), carbohydrates (61.62%), crude fibre (4.85%), and energy (505.01 Kcal). Using the Arrhenius method, the shelf life of hanjeli-moringa cookies was 95.46 days at room temperature and 97.63 days at 20 °C. Meanwhile, the shelf life of cookies using the critical moisture content approach was 170.57 days. Shelf life is influenced by initial moisture content, critical water content of the product, packaging surface area and permeability, saturated vapour pressure, and slope sorption isotherm curve. The formulated cookies have significant amounts of nutrients that are acceptable and safe for consumption, with guaranteed desirable sensory properties. The result of this study shows that hanjeli-moringa cookies can be used as an alternative food for people who need high energy in a practical way of serving or ready to eat.

1. Introduction

Cookies are a widely popular snack that is consumed by all ages, from children to adults. They are cherished because of their texture, comfort, appearance, and taste (Gouveia, Batista, Miranda, Empis, & Raymundo, 2007). Cookies also have an advantage over other baked products since they have low water content, a longer shelf life, and are affordable (Nagi, Kaur, Dar, & Sharma, 2012). Cookies can be used to increase nutrition for children, such as dietary fibre, protein, and other functional purposes, because they can be combined with various food ingredients or supplements (Sulieman et al., 2019). Furthermore, cookies are convenient, cheap, and easy to digest.

Imported wheat flour is the main ingredient for bread and cookies. To reduce the dependency on wheat flour, an alternative to wheat flour was needed. One of the alternative flours with high vegetable protein content is hanjeli flour. Hanjeli (*Coix lacryma-jobi* L.) is a cereal plant from the Gramineae family that can be used as food and feed (Nurmala, 2011). Hanjeli seeds can be consumed for staple foods such as hanjeli porridge or hanjeli rice (Masyitha, Mahdiyah, & Efrina, 2021). Hanjeli contains 67–76% carbohydrates, 14–20% protein, and other micronutrients. One hundred grammes of peeled hanjeli seed contains 10.1–15.0 g of water, 58.3–77.2 g of carbohydrates, 9.1–23.0 g of protein, 0.3–8.4 g of fibre, 0.5–6.1 g of fat, 0.7–2.6 g of ash, and 1500 kJ/100 g of energy (Masyitha et al., 2021). Hanjeli flour has the potential to be substituted for wheat flour because it has a longer shelf life. Compared to other cereals, hanjeli is higher in protein, fat, and vitamin B1 and also higher in calcium compared to sorghum, rice, and corn.

Moringa oleifera is thriving and cultivated in many countries, such as

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https://doi.org/10.1016/j.fbio.2022.101787
Received 27 February 2022; Received in revised form 25 April 2022; Accepted 11 May 2022
Available online 14 May 2022
2212-4292/

Please cite this article as: Ade Chandra Iwansyah, *Food Bioscience*, https://doi.org/10.1016/j.fbio.2022.101787

India, Malaysia, Africa, and the Philippines (Alakali, Kucha, & Rabiu, 2015). It was called a miracle plant since all parts of the plant, such as leaves, flowers, and seeds, could be used as medicine, food supplements, water purifiers, and feed (Daba, 2016). Previous studies revealed that the leaves of *M. oleifera* contain a high content of essential amino acids (Sánchez-Machado, Núñez-Gastélum, Reyes-Moreno, Ramírez-Wong, & López-Cervantes, 2010) and antioxidant properties (Siddhuraju & Becker, 2003). It also has a significant amount of potassium, calcium, magnesium, and vitamins C, E, and A (Hekmat, Morgan, Soltani, & Gough, 2015). One hundred grammes of dried leaves of moringa contains 36.9 g of carbohydrates, 24.6 g of protein, 6.3 g of fat, 32.5 mg of iron, 28.6 g of fibre, and 3.6 mg of vitamin A. Several kinds of amino acids in moringa leaves include glutamic acid, valine, aspartic acid, leucine, histidine, isoleucine, arginine, lysine, tryptophan, methionine, cysteine, and phenylalanine (Aderinola, Fagbemi, Enujiugha, Alashi, & Aluko, 2018).

Food quality depends on the composition and quality of raw ingredients used (E Bravi, Mangione, Marconi, & Perretti, 2015). A decrease in food quality can be caused by several factors, such as extrinsic and intrinsic factors. Antioxidant supplementation in food can slow lipid oxidative damage (Elisabetta Bravi, Perretti, Falconi, Marconi, & Fantozzi, 2017). An accelerated shelf life test (ASLT) is used because lipid peroxidation usually occurs slowly at room temperature (Elisabetta Bravi, Sileoni, Perretti, & Marconi, 2020). The critical factors such as temperature, moisture, and light are commonly chosen as the parameters to obtain an ASLT model (Giménez, Ares, & Ares, 2012). A previous study reported the shelf life of biscuits using the Arrhenius model, which measures the rate of lipid oxidation using three different temperatures (Calligaris, Manzocco, Kravina, & Nicoli, 2007). However, studies about the nutritional composition and shelf life of hanjeli cookies supplemented with moringa leaf flour have not yet been carried out. The focus of this study was to examine the effects of using hanjeli flour and moringa leaf flour on the nutritional composition and shelf life of hanjeli cookies supplemented with moringa leaf flour. The shelf life of hanjeli-moringa cookies was carried out using accelerated shelf life testing (ASLT) with the Arrhenius approach and critical moisture content approach. Shelf life information of food products is important for knowing the safety of food consumption. Producers must write the expiration date on the packages for consumers to examine when they consume a food product (Rahman et al., 2019). The objective of this study is to examine the nutritional composition and shelf life of hanjeli cookies supplemented with moringa leaf flour.

2. Materials and methods

2.1. Materials

Materials for hanjeli-moringa cookies are hanjeli (*Coix lacryma-jobi* var. *mayuen*) obtained from KWT Pantastik, Sumedang-West Java, Indonesia; fresh moringa (*Moringa oleifera*) bought from Kelorina SME's, Pagaden, Subang-West Java, Indonesia; wheat flour (Kunci Biru), sugar flour (Djago Bekisar), margarine (Blue Band), salted butter (Blue Band), eggs, cornstarch (Maizenaku), milk powder (Dancow), baking powder (Kopoe-Kopoe), and salt (Cap Kapal) purchased at Grand Yogya Toserba, Subang. Materials for shelf life analysis using magnesium chloride ($MgCl_2$) (Merck), potassium iodide (KI) (Merck), sodium chloride (NaCl) (Merck), potassium chloride (KCl) (Merck), and barium chloride ($BaCl_2$) (Merck) were bought from Sigma Aldrich, Singapore. The following equipment was used: a dough mixer (Electric Food Mixer, Model B25, China), baking sheet, an oven (Masema Southstar, type MSY-90AZ, China), a continuous sealer machine (Xinkaichi, FR-900, China), a texture analyser (TA-XT2, Stable Microsystems Ltd. Surrey, England, UK), a hygrometer (Onemed, Type HTC-2, Finland), a cup, glassware, and an analytical balance (Metler Toledo, Indonesia).

2.2. Preparation of samples

All of the ingredients are mixed together to make hanjeli-moringa cookies. To make the dough, first weigh each ingredient, then mix and shake the hanjeli flour, moringa leaf flour, and wheat flour, before adding milk powder, cornstarch, and salt. This is done for 1–2 min, or until all of the ingredients are well mixed. Then add margarine, butter, powdered sugar, baking powder, and eggs. They were also printed and baked for 25 min at 150 °C (Mayasti, Iwansyah, Indriati, Ekafitri, & Adriana, 2021).

2.3. Characterization of cookies

2.3.1. Nutrition composition

The protein, ash, moisture, fat, carbohydrates, and crude fibre content of hanjeli-moringa cookies were determined (AOAC, 2004). Protein content was determined using semi-Kjeldahl equipment, fat content was determined using Weibull analysis, carbohydrates were calculated, and energy was measured by direct application of Atwater factors (1 g carbohydrate = 4 kcal; 1 g lipid = 9 kcal; 1 g protein = 4 kcal). The digestion and mineral analyses of hanjeli-moringa cookies were measured using atomic absorption spectroscopy (GBC 933 AA, Australia), as previously described (López-López, Moreno-Baquero, & Garrido-Fernández, 2020).

2.3.2. Hardness

A texture analyser was used to test the texture profiles of cookies (TA-XT2, Stable Microsystems Ltd., Surrey, England, UK). The cookie samples were placed in the sample area and measured with a P36 probe. The tool settings were as follows: pre-test speed 2 mm/s, test speed 1 mm/s, post-test speed 10 mm/s, 30% strain mode, 5 s time, and trigger force 5 g. Hardness (gf) and crispness (mm) are two of the parameters obtained (Lukman, Huda, & Ismail, 2009; Solichah et al., 2021).

2.3.3. Sensory test

The sensory quality of hanjeli-moringa cookies was evaluated using the hedonic method, with the crispness score as the critical parameter, on a scale of 1 (extremely crispy) to 6 (very not crispy) (Soekarto, 2002). The test was conducted at the Organoleptic Laboratory, Research Center for Appropriate Technology Research-BRIN, involving 15 semi-trained panellists.

2.3.4. Accelerated shelf life testing: Arrhenius approach

In testing the Arrhenius approach, hanjeli-moringa cookies were stored in an incubator at 25 °C, 35 °C, and 45 °C with a storage time of 18 days with observations every three days (Syarief & Halid, 1993). Moisture content and hardness were measured. The shelf life of hanjeli-moringa cookies is calculated based on equation (1). From the Arrhenius equation, one can calculate the reaction rate constant (k) at certain storage temperature (T). Equation (2) is used to calculate the shelf life of hanjeli-moringa cookies at the storage temperature treatment (reaction order 1). The shelf life of hanjeli-moringa cookies at various storage temperatures can be estimated using equation (3) to find the value of the acceleration factor for the degradation reaction (Q_{10}). Equation (4) is used to calculate the shelf life at various storage temperatures after obtaining the degradation factor value (Q_{10}) (Syarief & Halid, 1993).

$$k = ko.e^{-\left(\frac{Ea}{RT}\right)} \quad (1)$$

$$t = \frac{lnC_0 - lnC_t}{k} \quad (2)$$

$$Q_{10} = e^{\left(-\frac{Ea}{R}\left(\frac{1}{T+10} - \frac{1}{T}\right)\right)} \quad (3)$$

$$ts_{(T2)} = \frac{ts_{T1}}{Q10^{\left(\frac{T2-T1}{10}\right)}} \quad (4)$$

Where Ct is the value of quality parameter after storage; C_0 is the value of initial quality parameter; K is the reaction rate constant; t is the time (hours); E_a is the activation energy (cal/mol); R is the gas constant value of 1.986 (cal/mol.K); T is the absolute temperature (kelvin); Q_{10} is the acceleration factor for quality degradation; $ts_{(T1)}$ is the expiration time at base temperature (hours); and $ts_{(T2)}$ is the expiration time at estimated temperature.

2.3.5. *Accelerated shelf life testing: critical moisture content approach*

Initial moisture content (M_i) was analysed using the oven method (AOAC, 2004) and expressed in dry weight (g H_2O/g solids). Critical moisture content (M_c) is the moisture content that indicates that the product is organoleptically unacceptable to consumers. This critical moisture content was determined through a series of experiments in which cookies were stored unpackaged at room temperature (30 ± 1 °C) in an open space with a relative humidity (RH) range of 75–80% for 12 h. The sampling was carried out every 3 h until they were sluggish, and the panellists measured the moisture content, hardness, crispness, and crispness score.

The sample of hanjeli-moringa cookies was weighed before being placed in a jar containing a saturated salt solution of different types. Five different salts were used to maintain respective relative humidity, namely NaOH, $MgCl_2$, NaCl, KCl, and $BaCl_2$. A constant condition is achieved if the difference in weight loss or increase in product weight when weighing three times does not exceed 2 mg/g with the storage RH is less than 90% and does not exceed 10 mg/g with the storage RH greater than 90%. If a constant weight has been achieved in the sample, a test on the water content parameter is performed (Wijaya & Nocianitri, 2008).

The slope of the isothermal curve is obtained by describing the relationship between the equilibrium moisture content of the sample and the water activity (a_w) of the storage space (a jar containing saturated salt) with modifications (Wijaya & Nocianitri, 2008).

Estimation of the shelf life of hanjeli-moringa cookies is calculated using equation (5). (Kaymak-Ertekin & Sultanoğlu, 2001).

$$\theta = \frac{\ln\frac{(Me-Mi)}{(Me-Mc)}}{\frac{k}{x}\left(\frac{A}{Ws}\right)\frac{Po}{b}} \quad (5)$$

Where Θ is the estimated shelf life (days); M_i is the initial moisture content of the product (g H_2O/g solid); M_e is the product balance moisture content (g H_2O/g solid); M_c is the critical moisture content of the product (g H^2O/g solids); $\frac{k}{x}$ is the vapour permeability of packaged water (g/m2.day.mmHg); A is the surface area of the packaging (m^2); Ws is the dry weight of packaged product (g solids); Po is the saturated vapour pressure (mmHg); b is the slope of the isothermic sorption curve.

2.4. *Statistical analysis*

The data is presented as mean ± standard deviation (std) and analysed using analysis of variance (ANOVA) with a 95% confidence interval. The data is first tested for normality. The difference between each treatment is determined using Duncan's comparison test. For data processing, R-Statistic 4.03 for Windows is used. Linear regression analysis is used to determine the relationship between variables measured by storage time. Using a *k* value from the regression equation, the Arrhenius equation is used to estimate the shelf life of hanjeli-moringa cookies (De Mendiburu, 2014).

Table 1
Nutrition composition of hanjeli-moringa cookies per 100 g.

Parameter	Value
Moisture (%)	2.44 ± 0.02
Ash (%)	2.14 ± 0.02
Protein (%)	9.14 ± 0.01
Fat (%)	24.67 ± 0.28
Carbohydrates (%)	61.62 ± 0.29
Crude fiber (%)	4.85 ± 0.11
Energy (Kcal)	505.01 ± 1.38
Minerals:	
Calcium (mg/100 g)	394.66 ± 1.56
Iron (mg/100 g)	15.99 ± 0.07
Zinc (mg/100 g)	2.69 ± 0.01
Magnesium (mg/100 g)	59.27 ± 0.6

Data are presented as means ± standard deviation (s.d) (n = 3).

3. Results and discussion

3.1. *Hanjeli-moringa cookies characteristics*

Hanjeli-moringa cookies are packaged in a laminated aluminium foil package with a packaging weight of 20 g. The nutritional composition of hanjeli-moringa cookies per 100 g is shown in Table 1. Hanjeli-moringa cookies' moisture is 2.44 ± 0.02%, lower compared with gluten-free cookies (GF) or gluten-free cookies with *moringa oleifera* leaf flour (GF-MOLF), which approximately 3.1–3.2% (Giuberti, Bresciani, Cervini, Frustace, & Marti, 2021). Cookies are considered very low moisture-content products, with 1–5% moisture content in the range, and the moisture of hanjeli-moringa cookies is in this range as well. This moisture content can indicate a long shelf life, because it basically means the product is free from microbiological spoilage (Giuberti et al., 2018; Ng, Robert, Wan Ahmad, & Wan Ishak, 2017).

Cookies also contain protein, fat, and carbohydrate content of 9.14%, 24.67%, and 61.62%, respectively. The protein content of this product is derived from the use of milk, flour, moringa leaf flour, and eggs, while the fat is obtained from the use of milk and margarine, and the carbohydrate content is obtained from the use of wheat flour and hanjeli flour. Hanjeli-moringa cookies with a protein content comparable to gluten-free cookies made with 15% *moringa oleifera* leaf flour (Giuberti et al., 2021). The hanjeli-moringa cookies have a dietary fibre content of 4.85% and can be classified as a food source of dietary fibre.

Table 2
The changes in the quality of hanjeli-moringa cookies during 18 days of storage.

Parameter	Time of Storage (days)	Temperature of Storage (°C)		
		25	35	45
Moisture content (%)	0	1.93 ± 0.01	1.93 ± 0.01	1.93 ± 0.01
	3	2.07 ± 0.01	2.11 ± 0.16	2.15 ± 0.01
	6	2.13 ± 0.03	2.14 ± 0.01	2.25 ± 0.01
	9	2.35 ± 0.04	2.35 ± 0.01	2.36 ± 0.01
	12	2.37 ± 0.06	2.39 ± 0.01	2.40 ± 0.01
	15	2.51 ± 0.01	2.86 ± 0.02	2.87 ± 1.04
	18	3.29 ± 0.02	3.39 ± 0.01	3.42 ± 0.23
Hardness (gf)	0	632.29 ± 85.32	634.38 ± 100.54	644.00 ± 59.00
	3	629.91 ± 81.51	588.67 ± 113.08	630.24 ± 75.58
	6	607.44 ± 84.21	573.39 ± 87.99	609.40 ± 76.00
	9	591.56 ± 72.12	506.82 ± 100.03	603.77 ± 68.95
	12	587.83 ± 59.09	497.76 ± 83.81	562.46 ± 54.02
	15	581.52 ± 97.11	446.74 ± 75.07	557.09 ± 72.40
	18	573.32 ± 71.45	439.28 ± 104.79	533.97 ± 100.68

Data are presented as means ± standard deviation (s.d) (n = 3).

Table 3
The estimated shelf life of hanjeli-moringa cookies based on the Arrhenius equation on various parameters and temperature.

Parameter	Temp. (°C)	(1/T) K	k	ln k	E_a	k_o	e (E_a/RT)	rate of deterioration (K)	Shelf life (days)
Moisture	25	0.0034	0.0249	−3.6929	1165.82	0.17951	0.14231	0.0255	95.4528
	35	0.0032	0.0287	−3.5509			0.15161	0.0272	89.5976
	45	0.0031	0.0281	−3.5720			0.16088	0.0289	84.4371
Hardness	25	0.0034	0.0058	−5.1499	5876.57	164.0711	0.00005	0.0080	114.3160
	35	0.0032	0.0214	−3.8444			0.00007	0.0110	82.8125
	45	0.0031	0.0106	−4.5469			0.00009	0.0149	61.0304

To make the claim that a food is a "source of fibre," it must contain at least 3 g/100 g of fibre, and to make the claim that a food is "high in fibre," it must contain at least 6 g/100 g of fibre (Foschia, Peressini, Sensidoni, & Brennan, 2013).

The total energy of hanjeli-moringa cookies is 505.01 kcal per 100 g. In addition, zinc (2.69 mg/100 g), calcium (394.66 mg/100 g), magnesium (59.27 mg/100 g), and iron (15.99 mg/100 g) were found in hanjeli-moringa cookies (Table 1). The hanjeli-moringa cookies have a higher nutritional content than the research results reported by Mayasti et al. (2021). Cookies with the use of 100% hanjeli flour contain nutrition, moisture content (3.97%), ash (1.93%), protein (9.17%), fat (23.58%), carbohydrates (61.59%), dietary fibre (7.69%), and energy (494.29 kcal). This shows that hanjeli-moringa cookies can be an alternative for people who need high-energy food in a practical way of serving or ready to eat.

3.2. *Quality change of hanjeli-moringa cookies during storage*

Prediction of shelf life and moisture content can affect physicochemical properties, chemical changes, and microbiological damage of food ingredients. The moisture content and hardness of hanjeli-moringa cookies for 18 days with observations every three days are shown in Table 2. Data shows that storage at temperatures of 25 °C, 35 °C, and 45 °C resulted in increased moisture content. The increase was caused by the evaporation of water from the product into the environment, which was influenced by the temperature and humidity of the room during storage (Solihin, Muhtarudin, & Sutrisna, 2015).

Hardness is an important physical characteristic because it is directly related to the sensory reception of food products. In Table 3, during 18 days of storage, there was a tendency to increase, both at temperatures of 25 °C, 35 °C, and 45 °C. A previous study found that adding dried moringa leaves to cookies can increase their hardness (Dachana, Rajiv, Indrani, & Prakash, 2010). It could possibly happen because the addition of non-wheat flour could increase the dough viscosity, compete for available water in the dough, and decrease the spread ratio of cookies. According to Morais et al. (2018), the increase in hardness is influenced by moisture content, humidity, storage temperature, and water activity. In this study, the increase in hardness corresponded to a decrease in the moisture content of the product during storage at different temperatures. The availability of water in biscuit products will affect gel formation due to the starch retrogradation process, which causes hardness in biscuit products.

3.3. *Accelerated shelf life testing (ASLT): Arrhenius approach*

The determination of shelf life using the Arrhenius method is based on moisture content analysis by the direct method (Chemists, 2004) and hardness. During storage, chemical changes occur, caused by the influence of environmental factors such as temperature, humidity, and air pressure or the composition of the food itself. The quality parameter that decreased the fastest during storage was indicated by the largest coefficient (R^2) value. The coefficient of determination shows the relationship between storage time (days) and moisture content. The closer the R^2 value gets to 1, it means that the relationship between storage time and moisture content is getting stronger (Nuraini & Widanti, 2020). The value of R^2 at the three temperatures is higher in order 1, so order 1 is chosen to determine the Arrhenius equation. The regression equation for the sample of hanjeli-moringa cookies at various temperatures has an order of one (see Supplementary 1).

Table 4
Estimated shelf life at various storage temperatures.

Parameter	Temp. (°C)	$(Q10)^{\Delta T/10}$	Shelf life (days) $Ts_{(T1)}$ = 35 °C	Shelf life (days) $Ts_{(T1)}$ = 45 °C
Moisture	20	0.91	97.40	97.63
	25	0.94	94.52	94.74
	30	0.97	91.72	91.93
	35	1.00	89.00	89.21
	40	1.03	86.36	86.56
	45	1.06	83.80	84.00
	50	1.09	81.32	81.51
	55	1.13	78.91	79.10
Hardness	20	0.63	129.19	130.13
	25	0.74	111.03	111.83
	30	0.86	95.42	96.11
	35	1.00	82.00	82.59
	40	1.16	70.47	70.98
	45	1.35	60.56	61.00
	50	1.58	52.05	52.42
	55	1.83	44.73	45.05

The calculation of the estimated shelf life of hanjeli-moringa cookies based on the Arrhenius equation on various parameters and temperature is shown in Table 3. For the moisture content parameter, the rate of decline in the quality of hanjeli-moringa cookies is linear with storage temperature. At a temperature of 45 °C, the rate of product decline was 0.0289 per day. While at a storage temperature of 25 °C and 35 °C, it was 0.025 and 0.027, respectively. The rate of degradation is lower when compared to similar products, such as non-wheat biscuits developed by Rahman et al. (2019), which have a 0.37–0.84% using aluminium foil. As the rate of deterioration is higher, the product's shelf life is shorter. The shelf life of hanjeli-moringa cookies is estimated to be 84.44 days at 45 °C and 95.45 days at room temperature storage at 25 °C.

The shelf life according to the hardness texture parameter, which was determined using the texture analyser tool, shows that the higher the storage temperature, the lower the shelf life of the product. The shelf life of hanjeli-moringa cookies based on hardness parameters at 25 °C, 35 °C, and 45 °C was 114 days, 82 days, and 61 days, respectively. The moisture content of hanjeli-moringa cookies increased at three different temperatures due to the interaction between the product and the environment. Thus, an adsorption process occurs, where this absorption process is the absorption of water vapour from the air into food ingredients.

According to Sarastuti and Yuwono (2015), water vapour will move from the environment to the product or vice versa until equilibrium is reached. The faster the rate of constant decrease in moisture content, the higher the temperature. This causes the shelf life of hanjeli-moringa cookies that are packaged in aluminium foil to spoil faster. Changes in moisture content in packaged products and changes in water activity. Products that have high water activity have a high risk of bacterial proliferation, destructive pathogens, and poor shelf life, and vice versa

Table 5
Changes in the crispness score, moisture, crispness, and texture hanjeli-moringa cookies.

Shelf time (hours)	[a]Crispness score	Moisture content db ($g H_2O/g$ solid)	Crispness (mm)	Hardness (gf)
0	1.27	0.0236	37.05	579.205
3	2.80	0.0290	37.70	575.674
6	2.87	0.0339	36.53	568.833
9	3.07	0.0387	37.31	446.988
12	5.20	0.0458	37.25	438.262

[a] Score crispness: 1 (extremely crispy) to 6 (very not crispy).

(Sun-Waterhouse, Teoh, Massarotto, Wibisono, & Wadhwa, 2010).

The value of the reaction acceleration factor (Q_{10}) was determined based on the value of k at storage temperatures of 35 °C and 45 °C. The Q_{10} values obtained for moisture content and hardness are 1.062 and 1.354, respectively. The value of Q_{10} will decrease further if the value of k is used at high temperatures (storage temperatures of 35 °C and 55 °C). Meanwhile, the value of Q_{10} is directly proportional to the expired date.

It is preferable to choose a value based on a higher temperature combination to obtain a minimum estimated expiration date. Furthermore, this Q_{10} value is used to estimate the shelf life at various storage temperatures, $Ts_{(T2)}$, with an expiration date at base temperature, $Ts_{(T1)}$, which is 35 °C (89 days) and 45 °C (84 days). The estimated shelf life of hanjeli-moringa cookies at various storage temperatures is shown in Table 4.

3.4. Critical moisture content approach

The initial moisture content (M_i) of the hanjeli-moringa cookies was 2.36% db. These results are lower if compared with the biscuit standard, less than 5%. According to Ekafitri, Kurniawan, Desnilasari, Surahman, and Indriati (2020), the differences in results caused by moisture content may be caused by differences in formulation, product dimensions, baking time, and baking temperature. The package size of Hanjeli-moringa cookies is 40 g and the dry weight of the material (Ws) is 1.93% db. The changes in the crispness score, moisture, crispness, and texture of hanjeli-moringa cookies are shown in Table 5.

The moisture content of the product increases (2.36–4.58%) and decreases for the hardness (579.205–423.262 gf), crispness (37.53–36.53 mm), and crispness score (1.27–5.20). The critical moisture content is obtained when the product gets a crispness score of 3.0. The obtained curve of moisture content and crispness score is: $y = 153.76x - 2.216$ (y: moisture content; x: crispness score). Based on the equation, the critical moisture content of the hanjeli-moringa cookies is 0.0387 $g H_2O/g$ solid.

The equilibrium moisture content (Me) was measured using a sorption isotherm curve at various RH salts. The Me of hanjeli-moringa cookies is 0.0652 $g H_2O/g$ solid. The hanjeli-moringa cookies exhibited an increase in weight during storage. It indicates that the hanjeli-moringa cookies were undergoing a process of vapour adsorption because their water activity (a_w) was lower than the environment.

Moisture sorption isotherms can be classified into four types based on the curve shape (Yaptenco, 2017). The moisture sorption isotherms of hanjeli-moringa cookies are classified as type II, similar to the biscuit curve (Kusnandar, Adawiyah, & Fitria, 2010). The a_w is proportional to the equilibrium moisture content (see Fig. 1A). According to Sharma, Singh, Singh, Patel, and Patil (2009), the pressure of water vapour in the material increased following an increase in the surrounding water vapour pressure.

Equilibrium moisture content is plotted in several models of mathematical equations to get the best curve models (see Supplementary 2). The mean relative determination (MRD) values generated from the Guggenheim-Anderson-DE Boer (GAB) equation, Brunauer-Emmett-Teller (BET), Oswin, Smith, Henderson, Hasley, Caurie, and Chen-Clenton are 4.719; 22.949; 27.928; 8.367; 7.734; 8.753; 8.943; and 11.106, respectively (see Supplementary 2).

Based on the smallest MRD value, the equilibrium moisture content is appropriate with the GAB equation. GAB is expressed in accordance with several types of food such as biscuits, chicken wheat crips, and extrudate products (Bhardwaj, Shiby, Pandey, & Gopalan, 2017; Ekafitri et al., 2020). The accuracy of GAB modelling can be seen in Fig. 1B. The slope of the curve sorption isotherm (b) for hanjeli-moringa cookies is 0.0171, taken from areas that pass the initial moisture content (M_o) on the model of the water sorption curves (Fig. 1B).

The permeability of packaged water vapour ($\frac{k}{x}$) is the speed or rate of water vapour transmission through a unit area of material with a flat surface and a certain thickness because of differences in water vapour

Table 6
Hanjeli-moringa cookies shelf life calculations based on the critical moisture content approach.

Parameter	Aluma
Initial moisture content ($g H_2O/g$ solid) (M_o)	0.0348
Critial moisture content ($g H_2O/g$ solid) (M_c)	0.0387
Equilibrium moisture content ($g H_2O/g$ solid) (M_e)	0.0652
$(M_e-M_o)/(M_e-M_c)$	1.1472
ln $(M_e-M_o)/(M_e-M_c)$	0.1373
Slope sorption isotherm curve	0.0171
Packaging permeability (g/m^2/day/mmHg.)	0.0005
Packaging area (m^2)	0.0340
Solid weight per package (g solid)	39.30
Saturated vapour pressure at 30 °C (mmHg)	31.82
Shelf life (days)	170.57
Shelf life (month)	5.69

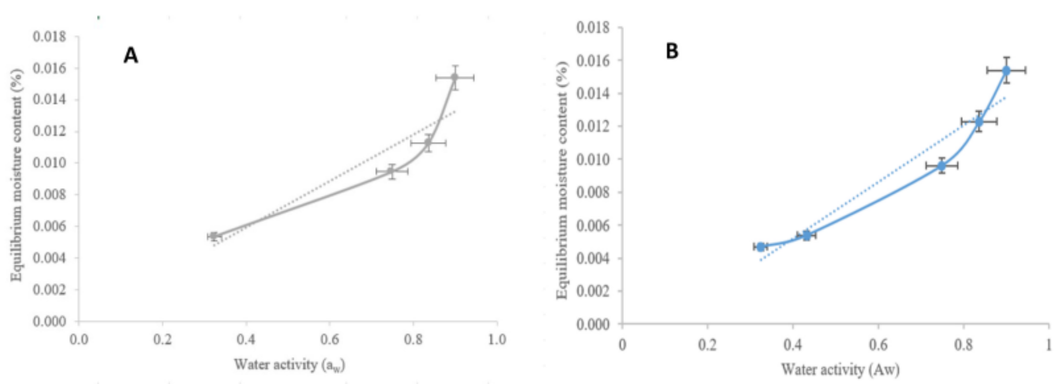

Fig. 1. Moisture sorption isotherm curves (**A**); the accuracy of GAB modeling (**B**) of hanjeli-moringa cookies. Data are presented as means ± standard error (S.E).

pressure between the product surfaces at specific conditions of temperature and RH (Kusnandar et al., 2010). The vapour permeability value of aluma packaging was low, at 0.0005 gH_2O/m^2.day.mmHg. These results were in agreement with Ekafitri et al. (2020) who reported that the shelf life of banana bar products with aluma was longer than those packaged with metalised plastic. Data and calculation results using aluma for hanjeli-moringa cookie shelf life are shown in Table 6. The surface area of the hanjeli-moringa cookies packaging is 0.0340 m^2 for solid weight per package of 39.30 g solid, with an estimated shelf life of 170.57 days or 5.69 months.

4. Conclusion

The shelf life estimation of hanjeli-moringa cookies was calculated using the Arrhenius method at different storage temperatures and the critical water method. The reaction of degrading the quality of hanjeli-moringa cookies based on moisture content and hardness followed the ordo one reaction equation. The higher the storage temperature, the faster the process of product quality degradation can be. Hanjeli-moringa cookies are packaged using aluma and have a shelf life if stored at room temperature of 95.46 days, and will be longer if stored at 20 °C (97.63 days) using the Arrhenius method. The shelf life using the acceleration method with the critical moisture content approach is 170.57 days or 5.69 months. The shelf life of a product is influenced by its initial moisture content, critical moisture content, packaging surface area, permeability, saturated vapour pressure, and slope sorption isotherm curve.

Author statement

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Acknowledgement

We are grateful to the National Research and Innovation Agency, Indonesia (BRIN) for financial (RP02-TPM18 2021) and technical support (*e*-Layanan Sains-BRIN). The authors would also like to thank Ms. Nok Afifah for her advice and consultation.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fbio.2022.101787.

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