



Shelf-Life Estimation of Black, Red and Yellow Honey Coffee Using Critical Moisture Content Approach

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Abstract. Honey process is a newly developed coffee processing technique. Based on the washing intensity, honey coffee categorized into black, red, and yellow honey coffee. Once the green bean coffee obtained, they are roasted then ground. However, the shelves-life of Arabica honey-processed ground coffee has not yet been estimated. Therefore, this study aimed to predict the shelf life of Arabica honey-processed ground coffee (black, red, and yellow honey) using the critical moisture content approach. The analysis in this study was conducted descriptively so that it can explain the predicted shelf life of honey ground coffee stored in metallized plastic packaging. The results indicated that the critical moisture content for yellow, red, and black honey ground coffee products was 5.55% (db), 7.44% (db), and 8.51% (db), respectively. The moisture sorption isotherm (MSI) curves were described by the linear equations $y = 1.0672x - 0.741$ for yellow honey, $y = 2.3315x - 1.6017$ for red honey, and $y = 0.55x - 0.308$ for black honey. Using the Labuza equation at 80% relative humidity (RH) and 30°C, the estimated shelf life of Arabica ground honey coffee in metallized plastic packaging ranges from 2.51 to 2.67 years.

Keywords: Arabica; ASLT; Coffee; Honey.

Type of the Paper: Regular Article.



1. Introduction

Bondowoso regency, East Java Province is known for the specialty coffee production [1,2]. There are three main classifications of coffee processing: dry, semi-wet, and wet methods [3]. The dry processing method has been developed into several techniques. One of the newly developed techniques in coffee processing is honey process [4]. After harvesting, the mature red cherries are processed in a pulper machine to separate the outer skin from the coffee beans. After that, the coffee beans dried under the sunlight until 12 % of moisture content was obtained. In this process, the mucilage on the coffee beans is retained and acts as a substrate for fermentation. During pulping, the intensity of washing varies, producing three types: black honey (100% of mucilage retained), red honey (50% retained), and yellow honey (25% retained) [5]. Compared to other processing types of coffee, honey coffee provides unique organoleptic properties such as caramel, honey, chocolate, cereal, dried cane, mild citric acidity, and smooth body [4].

The honey processing methods used by farmers can vary, and the variation can be seen in the amount of water used during processing. This technique is called "pulped-natural" which is similar to the "wet method", but uses less water overall, making it more popular with farmers in

areas with limited water supplies. The sorted fruit is pulped to remove the skin and most of the pulp. It is then cleaned with water and sun-dried, similar to the dry method. Honey coffee can be classified according to the total amount of surface pulp remaining on the coffee bean, which can be identified by its color. The cherries are peeled directly, using only a small amount of water, and the beans are parchment-dried, with the pulp mostly on top. Honey coffee brews vary in flavor depending on whether they contain a lot, medium, or little pulp, known as black honey, red honey, or yellow honey. Overall, it can be said that coffee that has undergone this process is sweeter, more pronounced, and free from excessive acidity [6].

The quality of coffee was affected by the postharvest handling and processing methods of coffee [7]. The drying process is one of the important post-harvest procedures which develop color, taste, as well as distinctive flavor of coffee [8]. The primary drying method used in coffee processing is sun drying [9]. Green coffee beans must be dried to a maximum moisture content of 12.5%, which can be achieved through proper drying techniques [10,11]. Besides drying, storage techniques are also critical as they determine the physical, biological, chemical, and sensory characteristics of green coffee beans [12,13].

Five parameters must be considered in storing fresh or processed food. The first parameter is the temperature of the storage room. The rate of biochemical reactions in food is affected by temperature. Low temperatures will be able to reduce damage to food and suppress the development of microbes. The second parameter is the humidity of the storage warehouse. If the humidity of the storage room exceeds the equilibrium relative humidity, the product will absorb excess moisture during storage. The third parameter is the air composition of the storage room. Controlling the air composition in the storage room for raw food has many benefits, for example, for some materials that have the potential to experience oxidation reactions, the room is designed to be oxygen-free, and adequate ventilation is needed to prevent anaerobic fermentation that will cause off-flavors. The fourth parameter is the light in the storage room. The presence of light can trigger various reactions in food. The fifth parameter is the presence of organisms in the storage room that can damage or reduce the quality of food, such as insects and rodents [14].

Research on coffee storage is interesting to study because the coffee product distribution process requires a certain amount of time to reach consumers and also requires the right storage method before entering the next coffee harvest season. Previous research on coffee storage has reported that quality deterioration is often caused by changes in moisture content and water activity during storage [15,16]. Higher moisture content resulting from exposure to excessive humidity causes an increase in water activity (A_w), which accelerates undesirable physical, chemical, and microbial changes. These include reduced powder solubility, non-enzymatic browning, food degradation, and microbial growth [17]. Previous studies on shelf-life estimation of ground coffee

have mostly focused on conventional Arabica or Robusta coffee using Arrhenius-based accelerated storage methods and lipid oxidation parameters [18,19]. However, studies applying the Accelerated Shelf-Life Test (ASLT) using the critical moisture content approach to honey-processed Arabica ground coffee are still very limited. This method requires a relatively short testing time and offers a good level of precision and accuracy [20]. Moreover, no specific information is available regarding the shelf-life characteristics of black, red, and yellow honey ground coffee. Therefore, this study addresses this gap by estimating the shelf life of Arabica honey ground coffee using the critical moisture content approach. Besides, the information regarding shelf life of honey ground coffee will be important to determine the product expiration date. Therefore, this study aims to estimate the shelf life of ground Arabica honey coffee (black, red, and yellow honey) using the critical moisture content approach.

2. Materials and Methods

2.1 Materials

The samples used in this study consisted of black, red, and yellow honey-processed Arabica coffee originating from Ijen Mountain, Sumberwringin Village, Bondowoso. Arabica Blue Mountain coffee cultivated at an altitude of 1000–2000 m above sea level (MASL) was harvested in August 2024, processed using the honey method, and subsequently used as the research material. The chemicals used were five types of salts which are used to regulate relative humidity (RH), namely NaNO_3 , NaCl , KCl , BaCl_2 , and K_2SO_4 . Another chemical used was distilled water. The tools used for this study were porcelain cups, chambers to determine sorption isotherms, oven, analytical scales, incubator, thermometers, and hygrometers.

2.2 Production of Roasted Honey Coffee

Arabica coffee cherries obtained from Sumberwringin village, Bondowoso regency were processed into black, red and yellow honey coffee. The red coffee cherries were pulped using a pulper machine. The peeled coffee beans then get a variation of washing intensity, namely without washing (black honey), washing once (red honey), and washing twice (yellow honey). The coffee beans were then dried for 10 days until they reached a moisture content of 12%, followed by a resting period of approximately one month and hulling to obtain green coffee beans [5]. Three types of honey coffee such as black, red and yellow honey coffee were then roasted using medium to dark profile. After roasting, each sample was ground to a fine particle size and sieved using a 60-mesh sieve.

2.3 Preparation for Sample Storage

Saturated salt solutions were prepared by adding an excess of salt crystals to distilled water until undissolved crystals were visible. Five salt solutions (NaNO_3 , NaCl , KCl , BaCl_2 , and K_2SO_4) were placed in each storage container. Then, 2 grams of ground coffee were placed in each storage

container with the saturated salt solutions for 15 days without packaging at a temperature of $30 \pm 1^\circ\text{C}$. These five salt solutions were used to ascertain the equilibrium moisture content [21].

2.4 Shelf-life Estimation Using Critical Moisture Control Approach

2.4.1. Initial moisture content (M_i)

The initial moisture content (M_i) was determined using the oven method and expressed on a dry basis (g H_2O /g solids).

2.4.2. Solid Weight (W_s)
The initial weight of the sample (W_o) was measured. The solid weight per package (W_s) was then calculated by correcting W_o with the initial moisture content (M_i).

2.4.3. Critical moisture content (M_c)
The samples stored at ambient temperature for specific period without wrappers [22]. Periodically, the samples were evaluated by thirty untrained panelists who observed the appearance of the ground coffee. The evaluation was considered complete when the panelists gave a mean score of 3 (somewhat clumpy), which indicated the critical point for the product's appearance. The moisture content of samples at this point was then measured to determine the critical moisture content (M_c).

2.4.4. Moisture sorption isotherm curve (MSI)

The samples were conditioned at various levels of relative humidity (RH). Five saturated salt solutions with different water activity (A_w) values were used, as shown in Table 1.

Table 1. Content of A_w and RH of five saturated salt solutions at 30°C

No	Saturated salt solution	Water Activity (a_w)	Relative humidity (%)
1	NaNO_3	0.73	73
2	NaCl	0.76	76
3	KCl	0.84	84
4	BaCl_2	0.9	90
5	K_2SO_4	0.971	97.1

The moisture level balance was determined by storing the coffee in low humidity (RH 73%) to high humidity (RH 97.1%) conditions. The results of the product water content test in each environment with different humidity were then graphed for isothermic sorption and a linear equation was obtained. Environmental humidity (RH 73% - 97.1%) was obtained by dissolving a certain amount of salt/base in distilled water as listed in Table 1.

2.4.5 Packaging Permeability

The permeability of the metallized plastic packaging was determined by measuring its Water Vapor Transmission Rate (WVTR) at 95% relative humidity and 38°C .

2.4.6 Packaging Surface Area (A)

The surface area (A) was calculated from the total area of both sides of the package and expressed in m^2 .

2.4.7 Shelf-Life Calculation

The shelf life was calculated assuming a constant temperature of 30°C and relative humidity

of 80%, using the following Eq. (1) [23].

$$T = \frac{\ln[(M_e - M_i)/(M_e - M_c)]}{\left(\frac{k}{x}\right)\left(\frac{A}{W_s}\right)\left(\frac{P_0}{b}\right)} \quad (1)$$

Annotation:

- T : shelf-life (days)
 M_e : Moisture content at equilibrium (g H₂O/g solid)
 M_i : Initial moisture content (g H₂O/g solid)
 M_c : Critical moisture content (g H₂O/g solid)
 $\frac{k}{x}$: packaging permeability (g H₂O/day. m². mmHg)
 A : surface area of the packaging (m²)
 W_s : Solid weight of the packaging (g)
 P₀ : saturated water vapor pressure (mmHg)
 B : slope value of the sorption isotherm curve.

3. Results and Discussion

3.1 Initial Moisture Content (Mi) and Solid Weight (Ws)

The initial moisture content (Mi) is a fixed value for a product, measured immediately after manufacture and before distribution [24]. In the research, Mi was determined by using thermogravimetric method with a dry basis calculation at temperature of 105°C. Solid weight is the weight of coffee solids without the presence of water in a sample [20]. The results were shown on Table 2.

Table 2. Mi and Ws of Three Types of Honey Coffee

No.	Type of Coffee	Initial Moisture Content (Mi)	Solid Weight (Ws)
1.	Yellow honey	2.837 %	29.149 gram
2.	Red honey	3.479 %	28.956 gram
3.	Black honey	2.960 %	29.112 gram

3.2 Critical Moisture Content (Mc)

Critical moisture content (Mc) is the moisture level at which the sample becomes organoleptically unacceptable to consumers [25]. Determination of critical moisture content of samples is done by storing specimen inside a high humidity container [26] and conducting organoleptic testing on the stored product periodically [27]. For hygroscopic food products in powder form, temperature and humidity are critical factors. An increase in RH leads to an increase in moisture content, which subsequently impacts coffee quality [26]. Determination of critical water content of ground coffee was carried out at storage RH conditions of 73%, 76%, 84% 90% and 97.1%. This RH was obtained using saturated salt solutions of NaNO₃, NaCl, KCl, BaCl₂, and K₂SO₄ as presented in Table 1.

The critical moisture content was determined when the panelists' average response in the multiple comparison test was ≤ 3 . The rejection response from the panelists indicates that the sample has reached critical quality. The sample that has been rejected by the panelists is ground coffee that has experienced clumping. The moisture content of the ground coffee that had reached this critical quality threshold (based on panelist response) was then measured using the

thermogravimetric method to determine its critical moisture content (Mc). Critical water content of ground coffee presented in Table 3.

Table 3. The Mc of Three Types of Arabica Honey Coffee

No.	Types of Samples	Critical Moisture Content (% dry basis)
1.	Yellow honey	5.55
2.	Red honey	7.44
3.	Black honey	8.51

The critical water level of each ground coffee is different. This is likely due to the different initial moisture contents (Mi) of the products. The Mi influences the material's adsorption of moisture from the environment as it strives to reach equilibrium. 3.3. *Equilibrium Moisture Content (Me) and Moisture sorption isotherm (MSI) Curve*

Ground coffee samples were placed in various kinds of saturated salt solutions with various RH. The higher the water activity (Aw) of the saturated salt solution, the greater the equilibrium moisture content of the ground coffee sample. By this stage, it will be obtained the value of Me. The moisture sorption isotherm (MSI) curve represents the relationship between the moisture content (dry basis) of a specimen and the relative humidity (RH) or Aw. Me from the study outcomes was organized with the Aw to obtain MSI curve [16]. The MSI curves for yellow, red, and black honey coffee are presented in Fig. 1, Fig. 2, and Fig. 3 respectively.

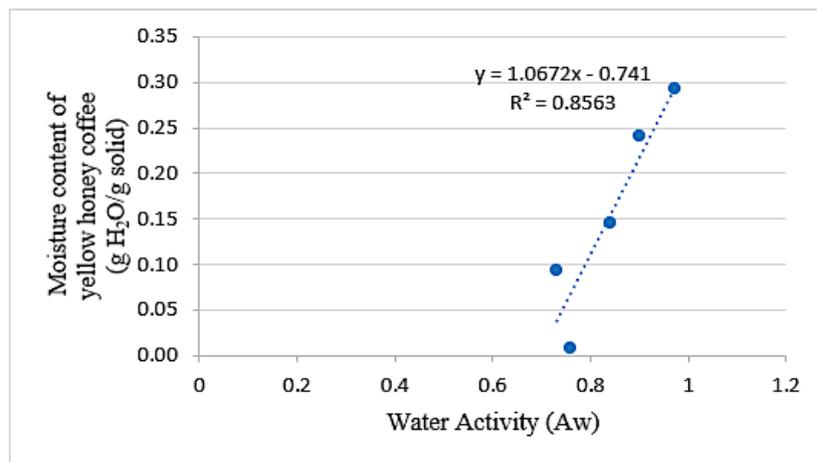


Fig. 1. MSI of arabica yellow honey coffee

The Oswin model was used to produce the isothermal sorption curve. The isotherm sorption curve for Arabica yellow honey coffee (Fig. 1) showed a linear relationship between Aw and Me, described by the equation $y = 1.0672x - 0.741$ with $R^2 = 0.8563$. Arabica red honey coffee (Fig. 2) had a linear equation $y = 2.3315x - 1.6017$ with $R^2 = 0.8777$ and Arabica black honey coffee (Fig. 3) had a linear equation $y = 0.55x - 0.308$ with $R^2 = 0.9561$.

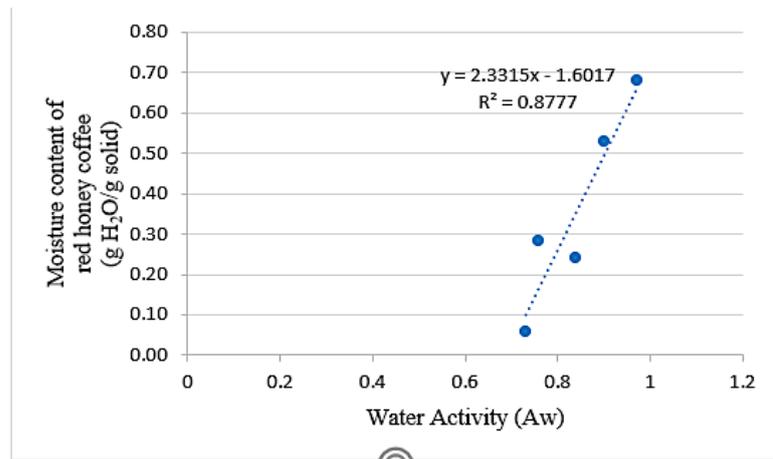


Fig. 2. MSI of arabica red honey coffee

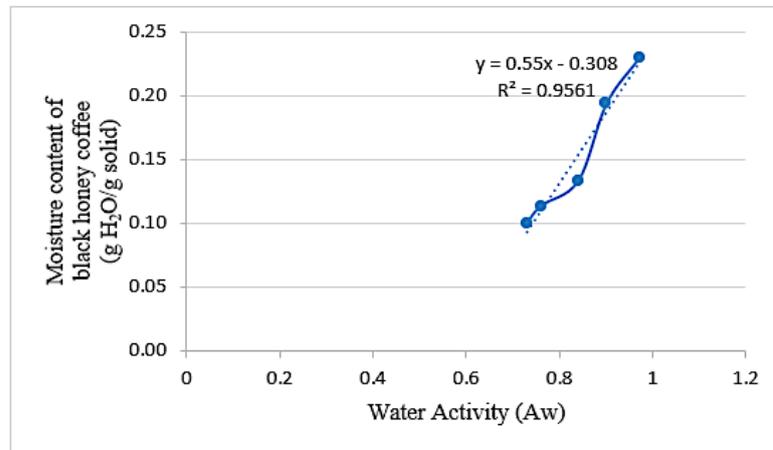


Fig. 3. MSI of arabica black honey coffee

3.4 Calculation of Product Shelf-Life

The shelf life of Arabica honey coffee in metallized plastic packaging was calculated using the is Labuza model. Several variables were used in this calculation: M_i , M_c , M_e , k/x , b , A , W_s and P_o [27]. The parameter values used for the shelf-life calculation are presented in Table 4.

Table 4. Estimated Shelf-Life Result of Arabica Honey Ground Coffee

Product	Yellow Honey	Red Honey	Black Honey
Type of packaging	Metallized plastic		
Critical moisture content (M_c, g H₂O/g solid)	0.056	0.074	0.085
Surface area of packaging (two sides, A, m²)	0.03	0.03	0.03
WVTR (g H ₂ O/m ² day) at 38°C RH 95%	0.6957	0.6957	0.6957
Initial moisture content (M_o, g H₂O/g solid)	0.0284	0.0348	0.0296
Initial solid weight per packaging (W_s .gram)	29.1489	28.95604	29.112
Pure water vapor pressure (P_o mmHg)			
at 38°C	49.692	49.692	49.692
at 30°C	31.824	31.824	31.824
Permeability (k/x):(g H ₂ O/m ² day.mmHg)	0.0140	0.0140	0.0140
Linear curve of MSI	1.0672	2.3315	0.55
Moisture equilibrium (M_e g H ₂ O/g solid) at RH 80%	0.1128	0.2635	0.132
Product shelf life at RH 80% and 30°C	Ln ($M_e - M_o$)/($M_e - M_c$)		
	0.3881	0.1902	0.7787
$k/x*(A/W_s)*(P_o/b)$	0.000429679	0.000197987	0.000834789
Shelf life (in days)	903.2666	960.7462	932.8572
Shelf life (in months)	30.1089	32.0249	31.0952
Shelf life (in years)	2.51	2.67	2.59

Based on the data in [Table 4](#), all ground honey coffee samples stored at 80% RH and 30°C in metallized plastic packaging demonstrate comparable durability, with a shelf life of several years. The yellow honey, red honey and black honey coffee's shelf life were 2.51, 2.67, and 2.59 years, respectively. This can be achieved with appropriate packaging, proper storage conditions, and well-controlled environmental conditions (temperature and humidity) in the storage area [\[28,29\]](#). However, improper product treatment before and during storage can actually shorten the product's shelf life [\[30,31\]](#).

It is essential that ground coffee packaging meets safety standards. Freshly processed ground coffee should be stored immediately in appropriate packaging under controlled temperature and humidity, while maintaining proper hygienic practices [\[32\]](#). If these conditions cannot be controlled, it will result in product damage that includes microbiological, physicochemical and sensory aspects, thus shortening the shelf life [\[33\]](#). The characteristics of the packaging used to pack ground coffee products will play a major role in the ground coffee storage process during distribution [\[34\]](#). The permeability characteristics of the packaging serve as the primary barrier to moisture adsorption and desorption [\[35\]](#). The storage conditions of the product in the warehouse, including room RH and room temperature, must also be maintained stable or not fluctuate during storage [\[29\]](#).

4. Conclusions

The shelf life of ground honey coffee was estimated using the Accelerated Shelf-Life Test (ASLT) based on the critical moisture content approach. Clump formation in stored ground coffee indicated product deterioration, specifically the loss of its free-flowing property. The estimated shelf life for yellow, red, and black honey ground coffee packed in metallized plastic at 80% relative humidity and 30°C was 2.51, 2.67, and 2.59 years, respectively.

Abbreviations

Not applicable.

Data availability statement

Data will be shared upon reader request.

CRediT authorship contribution statement

Dyah Ayu Savitri: Writing of original draft, conceptualization, methodology, research work, data curation, resources, preparation, investigation, original draft writing, review and editing; **Setiyono**: formal analysis, supervision, conceptualization, validation; **Susan Barbara Patricia Sembiring Meliala**: conceptualization, data curation; **Ayu Puspita Arum.**: writing and review; **Fauziatun Nisak**: investigation; **Sean Zheva Danuartha**: investigation, editing.

Declaration of Competing Interest

The authors of this manuscript declare no competing interest.

Declaration of Use of AI in the Writing Process

Nothing to disclose.

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