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Controlled Temperature Condition to Optimize the Storage Period and the Seeds Quality of Five Coffee Varieties

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Abstract

There is increasing interest of Indonesian coffee farmers to propagate coffee plants by using generative seeds due to easiness on distribution and production. The harvest time of coffee seed and the time for sowing/planting is separated by six months. This requires coffee seeds to be stored at least for the period. Technology for coffee storage is challenging due to the characteristic of coffee seeds as intermediate seeds which are sensitive to drying. The development of efficient and effective storage methods for coffee seeds is urgently needed. This study was aimed to evaluate the germination viability and quality of coffee seedlings obtained from the seeds that have been stored for up to 12 months in the warehouse. This study employed five coffee varieties including three Arabica coffee (USDA 762, P 88, and Gayo 1), and two Robusta coffee (propellegitim and Hibiro). One kilogram package of each variety (four replications) was stored in the warehouse at a temperature of 20 °C ± 2 °C. Each replication of the coffee seeds was then evaluated for germination viability and seedling quality on 0, 3, 6, 9, and 12 months of storage. Fresh coffee seeds (without storage) were used for comparison. The results showed a decrease in seeds' moisture content during storage. Arabica coffee seeds were able to maintain their viability after six months of storage and Robusta coffee seeds after three months. Fresh coffee seeds showed the best seedling growth performance and seedling quality index. Arabica coffee USDA 762 stored for six months was able to produce seedlings with high plant performance, root length, stem diameter, and number of leaves similar to that of seedlings generated from fresh seed. Robusta coffee seedlings sown from fresh seeds had better quality compared to those from stored ones.

Keywords: Coffee, evaluation, seed storage, seedling quality, viability

INTRODUCTION

Coffee is an important plantation commodity in Indonesia with high economic value. Arabica, for example, has been sold for around USD 6.64 per kg in 2024 early March harvest season (Statista, 2024). Increasing the price of coffee beans can encourage farmers to develop and expand their coffee plantations. According to the Directorate General of Plantations of the Republic of Indonesia (Ditjenbun) (2022), coffee plantations in Indonesia are mostly managed by smallholders (98.30%), while large state-owned plantations and large private plantations only account for 1.04% and 0.66%, respectively. Smallholder plantations contribute to 99.32% of the national production. Coffee production in Indonesia has shown a steady increase from 2016 to 2022, from 632,000 to 789,970 tons. However, coffee production was slightly decreased in 2023 to 784,310 tons. This is due to old plants and the use of planting materials with unknown genetic quality. Coffee plantations in Indonesia cover an area of approximately 1.27 million hectares in 2023, with a distribution of plant conditions as follows: damaged or unproductive plants (9.44%), non-productive (young) plants (15.32%), and productive plants (75.24%) (Ditjenbun, 2022).

Generative propagation using seeds is the most commonly used method by coffee farmers to produce coffee seedlings. Coffee seeds are easy to obtain (Wibowo *et al.*, 2020). Further, for Arabica coffee, generative propagation resulted in a low variation rate due to its self-pollinating nature (Nasiro *et al.*, 2017). On the contrary, seedlings of Robusta coffee and other coffee species propagated through generative seeds showed high segregation because they are cross-pollinating plants (Wibowo & Sumirat, 2022). Additionally, seed propagation is preferred by coffee farmers in Indonesia because the seeds are easy to distri-bute, allowing more accessibility to areas far from seed producers. Currently, the Indonesian Coffee and Cocoa Research Institute (ICCRI) in Jember, East Java is the main coffee seeds producer, while smallholder coffee plantations in Indonesia are spread across Sumatra, Sulawesi, Bali, East Nusa Tenggara, and so on (Ditjenbun, 2022). Through seed propagation, superior coffee planting materials can be distributed to all regions in Indonesia.

The current problem with coffee seeds is the mismatch between the harvest and the planting period. In Indonesia, coffee seeds are harvested from May to July, while the coffee planting period is at the beginning of the rainy season (November to December). Coffee seedlings from seeds will be ready for planting when they are 10-12 months old after sowing (Permentan, 2014) and the maximum age limit for certified coffee seedlings is 12 months (Kepmentan, 2021). If planting is done in November to December, then sowing can be done in January-February. This requires seeds to be stored so that coffee seedlings can be planted at the beginning of the rainy season and should be still in optimal condition. Coffee seeds are classified as intermediate seeds (Eira *et al.*, 2006; Wibowo *et al.*, 2020; Penido *et al.*, 2021) because they are tolerant to drying for a certain degree but sensitive to totaly drying (desiccated).

Drying temperature, moisture content, and storage temperature play an important role in coffee seed storage. The optimal temperature for coffee seed storage is still debated among researchers. Nasiro *et al.* (2017) suggested that Arabica coffee seeds can be stored at a temperature of 15 °C, while Da Rosa *et al.* (2011) reported that storing coffee seeds at a temperature of 20 °C can produce good quality coffee seedlings. Wibowo et al. (2020) concluded that storage at a temperature of 20-22 °C can maintain the viability of Arabica coffee seeds to > 90% for six months. However, the maximum storage limit for coffee seeds from different varieties needs to be evaluated. A previous study on seed storage evaluation was carried out on 6-month period and was only carried out on Arabica coffee seeds. Furthermore, it only evaluated the seed germination viability. More study is needed to determine the maximum storage limit for coffee seeds at controlled temperature, on both Arabica and Robusta coffee seeds, and its effect on the quality of seedlings produced.

This research aimed to evaluate the germination viability/quality and seedling quality of Arabica and Robusta coffee seeds after be stored at a temperature-controlled condition for 12 months. Evaluations on seed germination quality and seedling quality were conducted periodically every 3 months. The results of this study could be a reference in developing an optimum seed storage procedure for coffee seeds suitable for Indonesia conditions.

MATERIALS AND METHODS

Materials

Five coffee varieties were used in this study. This included three Arabica coffee (USDA 762, P 88, and Gayo 1) and two Robusta coffee (propelegitim and Hibiro). Arabica coffee seeds were harvested from the Andungsari (Bondowoso, East Java). The seeds were obtained from a single variety plantation. Gayo 1, especially, originated from a parent plantation that was designated by the Ministry of Agriculture in 2018 through Indonesian Ministerial Decree No. 82/Kpts/KB.020/9/2018. Propelegitim seeds were the offspring of a biclonal hybrid of Robusta coffee (BP 42 × BP 358), while Hibiro seeds were the offspring of a biclonal hybrid of BP 936 × BP 534. These seeds were harvested in 2020 (June–August), These coffee seeds were then stored for 12 months in the controlled-temperature-warehouse from September 2020 to August 2021.

Seeds Storage Treatment

Coffee seeds were processed by sun-drying until the moisture content (MC) reached 35-45% based on the method stated by the Ministry of Agriculture (Kepmentan, 2021). Coffee seeds were fumigated with aluminum phosphide at a dose of two tablets/ton and left to sit for three days in a closed room. The seeds were then packaged in plastic bags (Rahardjo, 2012). For this study, each coffee variety was prepared in 4 packages (@ 1 kg) and stored at a temperature of 20 °C ± 2 °C (humidity of 57-60%) in the seed storage warehouse for 12 months. The seed storage warehouse was 23.5 m long and 8.8 m wide with a total capacity of five tons. The seed storage warehouse was divided into an administration room, sorting room, packaging room, transit room, and storage room. The storage room was lined with heat-insulating material to minimize heat transfer from inside to outside the room or vice versa so that the temperature inside the storage room is relatively constant. Lighting uses one compact fluorescent lamp. Sampling of coffee seeds was done at the beginning of storage and every three months to determine moisture content, seed viability, and the quality of the coffee seedlings. Fresh coffee seeds (without storage) were also sampled for comparison.

Evaluation of the Seeds Viability and Seedling Quality

Germination and seedling quality tests were conducted at 0, 3, 6, 9, and 12 months of storage. Twenty-five coffee seeds were taken from each package. The parchment layer of the coffee beans was removed, and then the coffee seeds were soaked in a 0.2% (m/v) fungicide solution overnight. Germination testing was conducted using a paper/towel test and left for 21 days (Sudrajat *et al.*, 2017). The percentage of germination was calculated using the formula:

$$\text{Germination percentage} = \frac{nKN}{N} \times 100\%$$

where nKN is the number of seeds germinated on the 21st day; N is the total number of seeds (25 seeds) (Sudrajat *et al.*, 2017; Wibowo *et al.*, 2020).

The counted coffee seedlings were then transplanted into 40 x 30 x 15 cm pots. The planting medium was soil and sand (1:1 ratio). The seedlings were maintained for three months after transplanting (±4 months after germination). Evaluations were done on the seedling, including seedling height, stem diameter, number of leaves, seedling root length, fresh weight of seedlings, dry weight of seedlings, root-shoot ratio, and seedling quality index. The seedling quality index was calculated based on the following formula (Kurniaty *et al*., 2010; Yustika *et al*., 2022):

$$\text{Seedling Quality Index} = \frac{w_d}{\frac{h}{s_g} + \frac{w_s}{w_r}}$$

Where W_d was the total dry weight of the seedlings; h was the height of the seedling; S_g was the stem diameter; W_s is the dry weight of the stem; W_r is the dry weight of the root.

Statistical Analysis

The data was analyzed using SAS 9.0 software (SAS, NC, USA). Split-plot analysis of variance (ANOVA) was done. Duncan's multiple range test at a 95% confidence level and orthogonal polynomial analysis was done as a post-hoc test to determine the best storage treatment.

RESULTS AND DISCUSSION

ANOVA results showed that the variety of coffee seeds significantly ($p < 0.01$) affected the results for all observed parameters (Table 1). Each variety exhibited different performances in the germination and seedling growth phases (Rosa *et al*., 2010; Wibowo, 2021). Replications and the interaction between variety and replications showed no significant effects. Storage period significantly ($p < 0.01$) affected the seed viability and seedling quality parameters. The interaction between variety and the storage period of coffee seeds significantly ($p < 0.01$) affected all observed parameters. This was similar to that of Nasiro *et al*. (2017) who reported that there was a significant relationship between the storage period of coffee seeds and the growth performance of coffee seedlings.

Seed Moisture Content

Coffee seeds need to be stored at 35-45%, as per the regulation (Ditjenbun, 2021). This was a standard procedure for storing

Table 1a. F-value of germination and seedling quality components

Source of variability	df	GM	SH	SD	RL	NL
Variety	4	558.00 **	129.00 **	366.97 **	73.70 **	30.61 **
Replic.	3	1.05 ns	0.15 ns	0.80 ns	1.03 ns	0.21 ns
Variety*Replic.	12	0.62 ns	1.00 ns	0.38 ns	1.31 ns	0.70 ns
Storage period	4	627.23 **	264.38 **	642.50 **	234.26 **	78.06 **
Variety*SP	16	84.89 **	46.22 **	115.43 **	33.37 **	4.67 **

Notes: ns = not significant; (*) = significant at α = 0.05; (**) = significant at α = 0.01. Replic. = replication; SP = storage period; GM = germination; SH = seedling height; SD = stem diameter; RL = root length; NL = number of leaves.

Table 1b. F-value of germination and seedling quality components

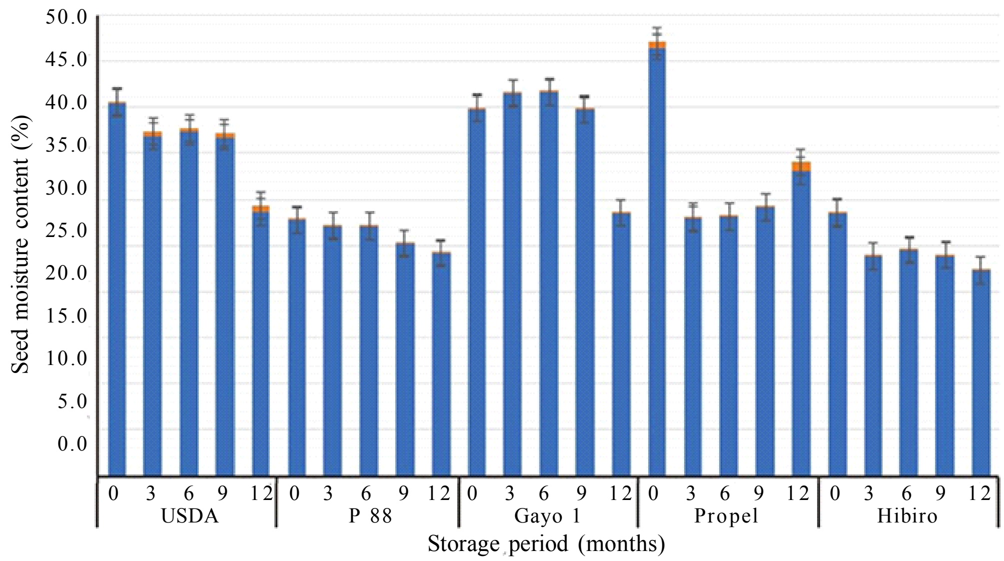
Source of variability	df	FW	DW	SRR	SQI
Variety	4	40.62 **	22.91 **	86.30 **	19.18 **
Replic.	3	0.61 ns	0.05 ns	0.64 ns	1.26 ns
Variety*Replic.	12	1.14 ns	1.74 ns	0.73 ns	1.92 *
Storage period	4	168.27 **	125.72 **	83.60 **	131.29 **
Variety*SP	16	14.37 **	10.30 **	31.11 **	11.59 **

Notes: ns = not significant; (*) = significant at a = 0.05; (**) = significant at a = 0.01. Replic. = replication; SP = storage period; FW = fresh weight; DW = dry weight; SRR = shoot root ratio; SQI = seedling quality index.

coffee seeds in this study. The MC of the seeds is expected to decrease after 12 months of storage. The initial MC of the coffee seed samples varied between varieties, even though all samples underwent the same procedures. This discrepancy might be due to the parchment, which can mask the actual MC of the seed. Some varieties exhibited high MC despite the dry appearance of the parchment.

The results showed that coffee seeds stored with an initial MC below 30% experienced a decrease of less than 10%. Arabica P 88 seeds, for example, had an initial MC of 27.7% and decreased by 3.6% to 24.1% after 12 months. Similarly, Robusta Hibiro seeds showed a decrease in MC from 28.5 to 22.3% (6.2% decrease). However, seeds stored with higher initial MC showed a more significant decrease. Arabica USDA 762 and Gayo 1 seeds (MC of 40.5% and 39.9%, respectively) experienced a decrease of 11.3-11.8% to 28.7 and 28.6%, respectively. Robusta propelegitim seeds showed the highest decrease of MC (13.4%) from 46.5% to 33.1% after 12 months (Figure 1).

Each variety exhibited a unique rate of moisture loss during storage. This was in agreement with Huang *et al*. (2014) who reported that coffee varietal differences influence the rate of moisture loss during storage. The decrease in MC was not always linear, as seen in Robusta propelegitim seeds. Penido *et al*. (2021) explained that fluctuations in seed MC during storage can be attributed to various factors, including packaging type and the amount of air within the packaging. Seeds with high initial MC generally experience a greater decrease than those with low



	USDA 0	USDA 3	USDA 6	USDA 9	USDA 12	P 88 0	P 88 3	P 88 6	P 88 9	P 88 12	Gayo 1 0	Gayo 1 3	Gayo 1 6	Gayo 1 9	Gayo 1 12	Propel 0	Propel 3	Propel 6	Propel 9	Propel 12	Hibiro 0	Hibiro 3	Hibiro 6	Hibiro 9	Hibiro 12
STNDV	0.22	0.50	0.41	0.46	0.67	0.04	0.05	0.04	0.09	0.18	0.05	0.13	0.09	0.07	0.03	0.61	0.28	0.07	0.00	0.98	0.12	0.03	0.13	0.13	0.01
SMC	40.5	36.8	37.3	36.8	28.7	27.7	27.1	27.1	25.2	24.1	39.9	41.5	41.6	39.8	28.6	46.6	27.9	28.1	29.1	33.1	28.5	23.8	24.5	23.9	22.3

Figure 1. Variation in the moisture content of coffee seeds after 12 months of storage period (bar indicate standard deviation)

initial MC. This was similar to the result of Razak *et al*. (2020) that the initial MC also affects moisture changes during storage. The rate of decrease may be due to the movement of water within the seed, both adsorption and desorption, during storage. The presence of the seed parchment creates air spaces between the seed and the parchment, further influencing moisture movement.

Storage of coffee seeds with a moisture content of 35-45% is believed to maintain high seed viability. However, this study show a different results. Arabica Gayo 1 seeds (MC 28.6%) were still able to produce seed germination rates of up to 92%. Similarly, Arabica P 88 seeds (MC 27.1-27.7%) showed high seed germination rates (86-98%). This was in agreement with Guimaraes *et al*. (2013) whos showed that Arabica coffee seeds with MC of 21.44, 23.27, and 24.45% still produced germination rates of 90.5, 92.0, and 90.5%. Wibowo *et al*. (2020) also reported that Arabica Gayo 2, BLP, and Kartika 1 seeds with MC of 21.11%, 25.65%, and 26.85% still had high germination potential (95.0%, 95.8%, and 94.2%, respectively). This showed that MC was not the only factor affecting the seed viability. Other environmental factors, such as humidity and oxygen proportion also affects the rate of seed deterioration (Nasiro *et al*., 2017; Vitis *et al*., 2020).

There is a relationship between initial moisture content and the viability of coffee seeds. However, reducing the moisture content of seeds after harvest to a certain threshold increases seeds' storability. Coffee seed storage is still possible with an initial MC of < 30% (Guimaraes *et al*., 2013; Nasiro *et al*., 2017; Wibowo *et al*., 2020) and above 12% (Penido *et al*., 2021). Nasiro *et al*. (2017) recommended an initial MC of 17-22% for storing coffee seeds. The optimal initial MC of coffee seeds for long-term storage is still debatable due to the varying results of the study. More study is needed to determine the threshold for reducing seed MC for coffee storage. The results will be very useful for the development of coffee seed storage technology in the future.

Seed Viability After Storage

Seed viability is an important aspect of determining the potential ability of the seeds to be grown normally in the planting medium. The quality standard of coffee seeds must cover 3 aspects of quality, namely (i) genetic quality (planting material origin and purity), (ii) physiological quality (germination ability), and (iii) physical quality (moisture content, physical purity of seeds, and seed health) (Kepmentan, 2021). Coffee seed is considered a seed with good physiological quality if the germination rate exceeds 80%. Based on this quality standard, only Gayo 1 coffee seeds met the standard of physiological quality after 12 months of storage, which can still maintain their viability up to 92% (Table 2). Arabica coffee seeds experienced a significant decrease in the germination rate after being stored for longer than six months. In this study, USDA 762 and P 88 Arabica coffee seeds showed a decrease in seed germination to only 52.0% and 24.0% after nine months of storage. Wibowo *et al*. (2020) also reported that 6 of the 9 Arabica coffee varieties stored for six months at a temperature of ± 20 °C were still able to maintain their germination potential of more than 85%. On the contrary, Robusta coffee seeds showed different results. Their viability has decreased significantly only after three months of storage. Propelegitim and Hibiro Robusta coffee seeds had a germination rate of 54.0% and 70.0%, respectively after three months of storage. Further evaluation conducted after six months of storage showed that Hibiro Robusta coffee seeds only had a germination percentage of 15.0% while propellegitim seeds did not grow at all. This showed that Robusta coffee seeds

Table 2. Germination percentage of the five coffee varieties' seed after various storage period

Storage period (months)	Germination (%)				
	Variety				
	USDA 762	P 88	Gayo 1	Propel.	Hibiro
0	98.0 a	98.0 a	93.0 a	78.0 ab	93.0 a
3	97.0 a	95.0 a	90.0 ab	54.0 d	70.0 c
6	89.0 ab	86.0 ab	100.0 a	0.0 g	15.0 f
9	52.0 d	24.0 e	100.0 a	0.0 g	0.0 g
12	27.0 e	0.0 g	92.0 a	0.0 g	0.0 g

Notes: The value followed by different letter in the same column was significantly different based on Duncan's multiple range test at α = 5%. Propel. = Propellegitim.

deteriorated faster than Arabica coffee seeds. If Robusta coffee is harvested in July-August, then the seeds can only be stored until December. Longer storage carried out beyond the harvest year will significantly reduce the seed viability.

Ideally, coffee seeds should germinate soon after drying, and their viability will decline during storage (Rosa *et al.*, 2011). Coffee seeds are classified as forest plant seeds (Sudrajat *et al.*, 2017) and fall into the category of intermediate seeds. This type of seed requires high moisture content to maintain its viability during storage but is more tolerant to partial drying compared to recalcitrant seeds (Vitis *et al.*, 2020). Intermediate seeds also have a longer storage life than recalcitrant seeds but shorter compared to orthodox seeds. Bareke *et al.* (2022) explained that intermediate seeds have a shelf life of less than 12 months, and Penido *et al.* (2021) reported that coffee seeds can be stored for up to 9 months. Similar results were obtained from this study, which showed that four out of five coffee varieties had a seed storage life of less than 12 months. Only Arabica Gayo 1 seeds were able to maintain their viability (~92%) after 12 months of storage.

Seedlings Quality

Seed germination ability is a major factor affecting the morphological quality of seedlings (Silva *et al.*, 2019). Storage duration significantly affects the decrease in germination rate and slows down the emergence of seedlings, and seedling growth (Garoma *et al.*, 2017; Silva *et al.*, 2019). Modifications of storage temperature, packaging, and MC are needed to maintain seed viability during storage. Coffee seed stored in dry MC (11-12%) is unsuitable for field nurseries due to its lower rate of seedling emergence and development compared to that stored in high MC (Rosa *et al.*, 2011; Nasiro *et al.*, 2017; Penido *et al.*, 2021). Storing coffee seeds in wet conditions resulted in better seedling quality for the same storage period.

The coffee seedling's quality was evaluated after 3 months of sowing of the stored seeds. Robusta Hibiro seedlings had the highest plant height (14.49 cm), root length (11.41 cm), and stem diameter (2.088 mm) at the beginning of seed storage. However, stored seeds showed decreased growth (Table 3). In contrast, Arabica USDA 762 and Gayo 1 coffee seedlings showed good seedling growth even after 12 months of storage. In both Arabica coffee varieties, the storage period did not significantly affect the growth of seedling height. On the other hand, Arabica P 88 showed good seedling growth from seeds stored for six months or less (Table 3). Storage for more than six months resulted in no seedlings produced. For USDA 762 and Gayo 1 varieties, the root length of the seedling decreased significantly after 9 (USDA 762) and 12 months (Gayo 1) of storage at 5.81 cm and 4.23 cm, respectively.

Each variety tested had the best stem diameter development on seedlings obtained from unstored seed (0 month). Its development showed a decrease in seedlings obtained from three months of stored seeds. However, seedlings from 6-12 months stored seeds showed more stable development of the stem diameter. For example, Arabica P 88 coffee seedlings had a stem diameter of 1.99 mm (unstored seeds) and were not significantly different from that of seedlings obtained from six months stored seed (1.88 mm). Arabica Gayo 1 seedlings had a stem diameter of 2.05 mm (unstored seed), experienced a decrease in development in three months of stored seed (1.58 mm), and remained similar to that obtained from seeds stored for 12 months (1.69 mm) (Table 3). Variations in plant height and stem diameter affect the sturdiness of seedlings in the nursery (Fatma *et al.*, 2022)

The number of leaves on the seedlings obtained from unstored seeds was more than that obtained from stored seeds in all varieties evaluated. Arabica coffee seedlings from unstored seeds had around 4-5 leaves, while seedlings from stored seeds only had 2-4 leaves after three months of sowing. Similarly, Robusta coffee seedlings from unstored seeds had 3-4 leaves compared to an average of 2 leaves on the seedlings from stored seeds (Table 3). At the same duration of storage, Robusta coffee seedlings had fewer leaves compared to Arabica coffee seedlings. This was because Robusta coffee has longer internodes compared to Arabica coffee. At the same seedling age, the number of leaf pairs in Robusta coffee is less than that of Arabica coffee because they have different growth types (Kepmentan, 2021). Transplantable seedlings from seeds, as required in Kepmentan (2021), must be 4-12 months old with a minimum of four pairs of leaves for Arabica coffee and three pairs of leaves for Robusta coffee. In this study, the evaluation of seedling quality was carried

Table 3. The coffee seedlings height, root length, stem diameter and number of leaves of the five coffee varieties obtained from seed after various storage periods

Storage period	Variety									
	Seedling height (cm)					Root length (cm)				
(months)	USDA 762	P 88	Gayo-1	Propel.	Hibiro	USDA 762	P 88	Gayo 1	Propel.	Hibiro
0	10.15 bc	8.52 cdef	10.19 bc	11.75 b	14.49 a	8.14 cd	11.56 a	10.80 ab	11.73 a	11.41 a
3	8.06 cdef	7.65 def	7.71 def	8.99 cde	9.63 bcd	4.48 gh	4.56 gh	5.23 fgh	6.73 cdef	5.85 efgh
6	8.94 cde	7.00 ef	7.65 def	-	7.06 ef	9.01 bc	7.41 cde	7.72 cde	-	6.35 defg
9	6.57 f	-	7.65 def	-	-	5.81 efgh	-	7.30 cde	-	-
12	8.34 cdef	-	8.83 cde	-	-	5.27 fgh	-	4.23 h	-	-
Storage period	Variety									
	Stem diameter (mm)					Number of leaves				
(months)	USDA 762	P 88	Gayo-1	Propel.	Hibiro	USDA 762	P 88	Gayo 1	Propel.	Hibiro
0	1.89 ab	1.99 a	2.05 a	1.95 a	2.08 a	4.55 abc	4.85 a	4.78 ab	3.75 abcd	3.70 abcde
3	1.31 ef	1.44 def	1.58 cd	1.35 ef	1.43 def	3.15 abcde	3.35 abcde	2.70 defg	1.55 hig	1.73 fghi
6	1.87 ab	1.88 ab	1.71 bc	-	1.88 ab	3.80 abcd	3.08 bcdef	3.00 cdef	-	1.57 hi
9	1.26 f	-	1.51 cde	-	-	1.57 hi	-	1.00 i	-	-
12	1.58 cd	-	1.69 bc	-	-	2.18 efgh	-	2.80 cdefg	-	-

Notes: Means of each variable with the same letter are not significantly different based on Duncan's multiple range test at $\alpha = 5\%$. Propel. = Propellegitim.
*-, cannot be evaluated due to non-existent/death seedlings

out until three months after sowing. Thus, it was understandable that it still did not meet the requirements for field transplanting based on the regulations in Indonesia.

Seedlings obtained from unstored seeds had a higher fresh weight than those obtained from stored ones. This was evaluated both in Arabica and Robusta coffee seedlings in this study. This showed that storage treatment significantly affected the fresh weight of the seedlings obtained. On the other hand, the duration of seed storage (3-12 months) did not significantly affect the fresh weight of the seedlings obtained (Table 4). Similar results were also shown in the dry weight of the seedlings. Storage treatment did significantly affect the dry weight of the seedling. However, the dry weight of the seedlings from the same variety obtained from seeds stored for 3 to 12 months was not significantly different (p> 0.0.5).

A low shoot-to-root ratio indicates that root growth is higher than shoot growth, and vice versa. All seedlings obtained from stored seeds have a higher shoot-to-root ratio compared to that from unstored seeds. This indicated that storage treatment affected the root growth negatively. In the Arabica coffee USDA 762 and Gayo 1, it was shown that the shoot-to-root ratio of the seedlings obtained from seeds stored for 12 months was higher than that obtained from unstored seeds. This may be related to the decrease of MC of the seeds during storage. Penido *et al*. (2011) showed that storing coffee seeds with high moisture content (29-41%) for nine months was able to produce heavier dry root weight compared to storage with low moisture content (11-13%) while producing seedlings with similar dry shoot weight. Storage with high initial MC helps to maintain the ability of coffee seeds to produce seedlings with good root growth.

This growth of the seedlings can be evaluated by using the seedling quality index.

Table 4. The coffee seedlings fresh weight, dry weight, shoot root ratio and seedling quality index of the five coffee varieties obtained from seed after various storage periods

Storage period	Variety									
	Fresh weight (g)					Dry weight (g)				
(months)	USDA 762	P 88	Gayo 1	Propel.	Hibiro	USDA 762	P 88	Gayo 1	Propel.	Hibiro
0	0.80 abc	1.12 a	0.99 ab	0.98 ab	1.05 a	0.28 abc	0.40 a	0.30 abc	0.34 ab	0.37 ab
3	0.24 e	0.40 de	0.39 de	0.25 e	0.46 cde	0.16 d	0.20 cd	0.18 cd	0.16 d	0.22 bcd
6	0.48 cde	0.54 cde	0.52 cde	-	0.36 de	0.22 bcd	0.21 cd	0.22 bcd	-	0.20 cd
9	0.31 e	-	0.52 cde	-	-	0.13 d	-	0.19 cd	-	-
12	0.39 de	-	0.61 bcd	-	-	0.15 d	-	0.19 cd	-	-
Storage period	Variety									
	Shoot root ratio					Seedling quality index				
(months)	USDA 762	P 88	Gayo 1	Propel.	Hibiro	USDA 762	P 88	Gayo 1	Propel.	Hibiro
0	2.82 cde	2.08 e	3.02 bcde	2.78 cde	2.72 de	0.033 bcd	0.064 a	0.037 bc	0.039 b	0.039 bc
3	4.78 abcd	6.03 ab	4.98 abcd	3.79 abcde	5.63 abc	0.015 de	0.018 de	0.018 de	0.015 de	0.018 de
6	3.47 abcde	5.02 abcd	4.02 abcde	-	6.92 a	0.028 cde	0.023 de	0.028 cde	-	.020 de
9	6.77 a	-	4.30 abcde	-	-	0.010 de	-	0.020 de	-	-
12	4.39 abcde	-	5.29 abcd	-	-	0.016 de	-	0.018 de	-	-

Notes: Means of each variable with the same letter are not significantly different based on Duncan's multiple range test at á = 5%. Propel. = Propellegitim.
*-, cannot be evaluated due to non-existent/death seedlings

A high seedling quality index (SQI) indicates a relatively tall and thin seedling, while a low SQI represents a sturdy seedling (Fatma *et al.,* 2022). The results showed that Arabica coffee seedlings sown from unstored seeds had a higher SQI compared to that of stored seeds. The highest SQI was Arabica P88 from unstored seed (0.064), while the lowest SQI was Arabica USDA 762 seedling obtained from seed that had been stored for nine months (0.010). Seedlings with low SQI have the potential to be more sturdy when planted in the field (Fatma *et al.*, 2022). On the contrary, Masilewi *et al*. (2022) stated that the higher the value of the SQI, the greater the level of seedling growth strength. However, the seedlings evaluated in this study were still not suitable to be planted in the field due to their low SQI value (< 0.09). Seedlings ready for transplanting must have a SQI > 0.09. This SQI value was expected to increase as the coffee seedlings grow to transplantable age.

CONCLUSIONS

The storage period of coffee seeds significantly affected the seed viability and the growth performance of seedlings. There was an interaction between the storage duration of seeds and the type of coffee variety stored. The moisture content of the seeds decreased during storage. Arabica coffee seeds could maintain their viability for up to six months of storage, while Robusta coffee can only maintain its viability for up to three months of storage. Thus, the optimal seed storage period was six months for Arabica coffee and three months for Robusta coffee, calculated from September. Unstored coffee seeds produced better seedling development performance. However, Seedling of USDA 762, P 88, Gayo 1, and Hibiro still showed good performance in plant height, root length, number of leaves, and stem diameter even after the seeds were stored for six months. Among seedlings obtained from stored seeds, the SQI of USDA 762, P 88, Gayo 1, and Hibiro showed the best results after being stored for six months. On the other hand, Robusta coffee Propelegitim showed the least seed viability, seed performance, and SQI among the five varieties evaluated.

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AUTHOR CONTRIBUTIONS

The first author is the originator of the research idea and contributed significantly to data collection, analysis, and the preparation of this publication. The second author contributed to the review of the manuscript and provided valuable suggestions for the discussion. The third author contributed to the design and evaluation of the coffee seed storage facility during the research.

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