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Research article

Physicochemical stability and sensory quality of selected Ethiopian coffee (*Coffea arabica* L.) brands as affected by packaging materials during storage

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A R T I C L E I N F O

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A B S T R A C T

Ethiopia's economy heavily relies on coffee, the country's primary export. However, there is a need for improvement in the current packaging materials for parchment coffee during extended storage. An experiment was conducted to evaluate the effectiveness of four different packaging materials (Jute, Woven Polypropylene internally lined with low-density propylene, Grain Pro, and Purdue Improved Crop Storage) on the quality of three brands of Parchment Coffee (Limu, Sidama, and Yirgacheffe) stored for 12 months. The results demonstrated that hermetic packaging materials like Purdue Improved Crop Storage and Grain Pro bags outperformed the Jute bag control in maintaining the original coffee quality throughout the storage period. There was a significant interaction between the coffee brands and the packaging materials for most measured parameters, except bioactive compounds. Notably, Sidama and Yirgacheffe brands stored in hermetic bags consistently achieved cup quality values above 80 %, meeting the requirements for specialty coffee grade. However, the Limu brand did not meet the specialty coffee criteria. The study recommends using hermetic storage materials such as PICS and Grain Pro bags for extended coffee storage. By adopting these methods, the renowned Ethiopian coffee brands can uphold their exceptional quality standards in the international market and ensure customer satisfaction.

1. Introduction

Green coffee beans are precious and globally traded, ranking second to oil in volume and value. Ethiopia, the birthplace of coffee, is the largest coffee producer in Sub-Saharan Africa and ranks fifth worldwide, following Brazil, Vietnam, Colombia, and Indonesia [1]. Ethiopia's contribution to global coffee production is approximately 4.2 %, accounting for 40 % of Africa's coffee production [2]. Coffee is crucial in Ethiopia's economy, representing 4–5% of GDP, 10 % of total agricultural production, 40 % of total exports, 10 % of government revenue, and 25–30 % of total export earnings [2]. Recent data reveals that Ethiopia earned nearly 1.4 billion USD from exporting 299,546.07 tons of coffee [3]. Furthermore, an estimated 25 million people involved in the coffee value chain depend on coffee as their primary source of income, either directly or indirectly [4].

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Ethiopia is renowned for its specialty coffee brands, which are exported based on their specific regions of origin and distinguished by their exceptional quality and agronomic characteristics. These brands include Ethiopian Yirgacheffe, Ethiopian Harar, Ethiopian Sidamo, Ethiopian Limu, Djimmah Coffee, and Lekempti. Notably, the Yergachaffee®, Sidama®, and Harar® brands have gained international recognition and are safeguarded by registration due to their distinct flavors and tastes [3]. These coffee varieties fetch premium prices in the global market due to their unique attributes, which must be preserved throughout the entire value chain, especially during prolonged storage periods at warehouses. The maintenance of these coffee brands' desirable physical, chemical, and sensory qualities relies on appropriate storage conditions, as a substantial portion of coffee goes through an extended storage period.

The preservation of parchment coffee beans' quality during prolonged storage heavily depends on the choice of packaging materials [5,6]. In Ethiopia, jute bags are commonly utilized for storing and exporting coffee beans under ambient storage conditions. However, jute bags possess porous properties, allowing high oxygen concentrations and moisture migration from the surrounding air to impact the stored parchment coffee beans, leading to biochemical degradation over time [7,8]. This becomes particularly problematic when coffee market prices are low, and exporters show reduced interest in marketing their coffee. Exporters have reported complaints, and conflicts have arisen between top management and store supervisors regarding coffee weight loss in warehouses during extended storage periods [9]. Consequently, the use of appropriate packaging materials has become essential during storage. Careful consideration is required to determine the appropriate type of packaging material for long-term storage of parchment and green coffee [10,11]. Therefore, it is imperative to explore alternative packaging options that can address the adverse effects of conventional packaging and storage materials on the inherent quality of parchment coffee.

Researchers have recognized the use of hermetic bags as an effective method to safeguard stored grains against insect pests and prevent oxygen and moisture migration. Aronson et al. [12]. have highlighted an initiative in Ethiopia to export coffee beans using specific hermetic packaging materials. However, more comprehensive information is needed regarding the impact of hermetic and other packaging materials on the inherent quality of coffee during extended storage periods. Therefore, conducting a detailed scientific investigation is crucial to assess the influence of various packaging materials, including hermetic options, on the stability of critical quality parameters of parchment coffee beans. This research is essential to identify suitable packaging and storage materials for Ethiopian coffee brands, ensuring the preservation of quality during storage. By doing so, exporters can maintain the reputation of Ethiopian coffee brands and effectively address weight loss concerns often associated with storage.

2. Materials and methods

2.1. Description of the study area

The experiment was conducted at Horizon Coffee Processing and Warehousing Enterprise (HCPWE) in Addis Ababa. The warehouse area has an average annual rainfall of 1017.9 mm and the minimum and maximum temperatures were 10 and 23.6 °C, respectively, with the average relative humidity of 56 % [13]. This warehouse was selected because it is considered Ethiopia's first and largest warehouse and is equipped with standard storage equipment. Furthermore, the warehouse holds certifications from UTZ, Rainforest Alliance, and organic organizations, indicating that it meets the required standards and guidelines for coffee storage and handling practices.

Parchment beans hulling processes were conducted at the Ethiopia Coffee Exporter Association (ECEA) laboratory, Addis Ababa. Laboratory analyses of green coffee (moisture content, roasted grounded, and beverage quality parameters) were conducted at the Department of Postharvest Management of Jimma University College of Agriculture and Veterinary Medicine. However, Green coffee biochemical analyses were conducted at the Ethiopian Institute of Agricultural Research (EIAR) Food Science and Nutrition Laboratory, Addis Ababa. Sensory analysis was conducted at the Coffee Quality Inspection and Certification Center (CQICC), Addis Ababa.

Table 1
Characteristics of investigated Coffee brands.

Coffee Brands	Limmu	Sidama	Yirgacheffee
Coffee Species	Arabica	Arabica	Arabica
Region, Country	Oromia, Ethiopia	Sidama, Ethiopia	SNNPR(South), Ethiopia
Zone where produced	Jimma	Sidama	Gedeo
Specific area	Limu (site suntu)	Chuko	Wonaago
Altitude (a.s.l)	1600–1750 m	1400–2200	1770–2200
Annual growing Temperature	13.242–8.24 °C	10–26 °C	15–35 °C
Annual Rainfall	16001–700 mm	1100–1800 mm	1000–2000 mm
Harvesting Season	OctoberJ – anuary	September J – anuary	September–January
Farming system	Garden coffee	Garden coffee	Garden coffee
Processing Type	Wet	Wet	Wet
Coffee type	Parchment	Parchment	Parchment
Quality grade	Q_2	Q_2	Q_2
Flavor	Spicy & winy	Floral & Spicey	Flora

Source: ERAR, 2021; Muluken & Shimelis, 2020

2.2. Experimental materials

The study collected three different brands of parchment coffee: Limu, Sidama, and Yirgacheffe, grade two. The specific characteristics of each coffee used in the study are provided in Table 1. The Limu coffee sample was obtained from Limmu, Horizon Coffee Plantation. The Sidama coffee was purchased from Arfasa General Trading plc, a coffee exporter. The Yirgacheffee parchment coffee was collected from the Yirgacheffee Coffee Farmer Cooperative Union. These brands of coffee undergo standard wet processing practices to ensure high-quality washed coffee. As a result, they are sold at premium prices in the international market and contribute significantly to export earnings.

The study also utilized four different types of storage packaging materials each having 50 kg holding capacity, with their characteristics detailed in Table 2. Grain Pro bags made of high-strength polyethylene were purchased from Nardo's coffee exporter. PICS bags were obtained from p.h.k Trading plc. Polyethylene bags were purchased from the local market, while Arega Ayenew PP Factory provided woven polypropylene (PP) bags. Jute bags were obtained from CQICC. These packaging materials were chosen based on available literature regarding their utilization for various crops, including the potential for their use in coffee and other high-value crops [14]. It is also worth mentioning that, according to Kuyu et al. [15], polyethylene bags offer advantages such as ease of sealing, good permeability for oxygen and carbon dioxide, reasonable durability, tear resistance, and an appealing appearance during storage.

2.3. Experimental design and treatment application

The experiment used a Completely Randomized Design (CRD) with a factorial arrangement. Each treatment was replicated three times to ensure reliability and reduce the impact of variability. The treatment combinations consisted of four different packaging materials: Jute, Polyethylene lined inside propylene, Grain Pro, and PICS bags, and three coffee brands: Limu, Sidama, and Yirgacheffee parchment Coffee. Randomization was performed for each replication independently, following the guidelines described by Ref. [16]. This randomization process ensured that the treatments were assigned randomly, minimizing potential biases or confounding factors that could influence the results.

In the experimental arrangement within the warehouse, wooden pallets were positioned in three replications with a height of 15 cm above the concrete floor surface. There was a distance of 50 cm between each replication and between the pallets and the walls, a Testo data logger (Testo, 184H1, Germany) was placed in the storage area to monitor the conditions within the warehouse throughout the experiment. This data logger measured the relative humidity and temperature at 2-h intervals. Representative samples were collected randomly from three parts of the stored coffee, the top, middle, and bottom, to assess the initial quality of the coffee beans at the start of the experiment (time zero). The sampling methods were adopted from Refs. [10,17,18]. Subsequently, samples were collected from each treatment at two-month intervals for analysis. These samples were thoroughly mixed and used to determine the relevant quality parameters.

2.4. Sample preparation for analysis

Sample of 1 kg of parchment coffee were taken from all treatments to analyze the quality parameter. These samples were then processed using an electrical huller to remove the parchment and manually winnowed to obtain clean coffee beans. Sieve analysis was also conducted using a rounded perforated plate screen (Pinhalense®, Brazil) with the screen holes specified at 1/64 inch in size. Since beans larger than screen number 14 are considered market-acceptable, the samples were sieved through a mesh sieve of size screen No14. The beans retained above this sieve size were used for all subsequent coffee quality analyses, following the methods outlined in Refs. [17,18]. For roasted bean biochemical and sensory quality analysis, approximately 100 g of green beans per sample were roasted using a rotary roasting machine (BRZ 4, Probat®, USA) under the guidance of a professional coffee roast master. The initial roaster cylinder was heated to 200 °C for all treatments, and the samples were roasted at 180 ± 10 °C for 5 ± 1 min. The roasted beans were then cooled rapidly on a cooling tray using cool air, and the silver skin was simultaneously removed following the guidelines of [18]. After that, 12 g of roasted beans from each sample were weighed and ground using an electronic laboratory-scale coffee grinder (VTA 6S, 22047 HAMBURG, Germany) with the middle adjustment setting to achieve a medium particle size.

Table 2
Characteristics of packaging and storage materials used for the study.

Packaging materials	Purpose in the study	Air and moisture barrier property	Thickness (μm)	Materials made
Jute bag	Control	Porous	NA	Jute fiber
woven PP bag + LDPE	Alternative storage materials	Partially porous to air	86 to 100	Polypropylene and polyethylene
Grain Pro bag	Hermetic storage material	Water and moisture proof	78	Inner liner multilayered film
PICS bag	Hermetic storage material	Water and moisture proof	80	woven PP bag and two inner liners of high-density PE

Remark: woven PP bag + LDPE = woven polypropylene bag + lined with low density polyethylene sheet, NA: Not available.
Source: (Donovan, 2018; Wang et al., 2018)

2.5. Determination of raw coffee beans physical parameters

2.5.1. Moisture content

The moisture content of the coffee beans was measured using the methodology described by Ref. [19]. Five g of green beans were dried in a convection oven (BIOBASE, DHG-9203(A), Chain) at a temperature of 105 °C for 24 h [19]. The moisture content of the coffee beans was subsequently calculated using Equation (1).

$$MC(\%) = \left(\frac{W2 - W1}{W1}\right) \times 100 \tag{1}$$

where: MC % = Moisture content (w.b), W_1= Initial weight of sample before drying, W_2= Final weight after drying.

2.5.2. Water activity

The water activity of the coffee beans was measured following the procedures outlined in Broissin-Vargas et al. [8] using a Pawkit water activity meter (Decagon, WA99163, USA) at a controlled temperature of 25 ± 0.1 °C. The standard cuvette was employed and filled with green beans up to the rim. The cuvette was positioned beneath the water activity meter's sensor, allowing room temperature measurement.

2.5.3. Hundred parchment coffee beans weight

The weight of one hundred parchment beans was determined using the methodology described by Chandrasekar and Viswanathan [20]. From each treatment, one hundred parchment beans were randomly selected. The average weight of the samples (measured in grams) was determined using a digital balance (METTLER TOLEDO, PB801 Switzerland) with triplicate measurements. After obtaining the initial weight data, the same samples were returned to their original packaging materials. A painted color was applied to differentiate these selected parchment beans from others stored. This was done to facilitate subsequent measurements of coffee bean weight at two-month intervals until the end of the experiment.

2.5.4. Green coffee beans bulk density

The bulk density of the coffee beans was measured using the methodology described by Chandrasekar and Viswanathan [20]. One hundred green coffee beans were randomly selected from each treatment, and their weights were measured using an electronic balance (METTLER TOLEDO, PB801, Switzerland). The selected samples were then poured into a graduated cylinder (Azron, EU) with a known volume of 250 mL. The beans were poured into the cylinder from a height of 15 cm, maintaining free-flowing conditions without compacting the beans inside the cylinder. The bulk density (measured in g/mL) was subsequently calculated using Equation (2).

$$BD\left(\frac{g}{mL}\right) = \frac{WCB}{MV} \tag{2}$$

where: BD (g/mL), WCB is the weight of coffee 100 beans (gram), and MV is the measured volume of coffee beans (mL).

2.6. Determination of raw and roasted coffee biochemical compounds

For the simultaneous analysis of total chlorogenic acids (CQA), Trigonelline, and caffeine contents in the raw grounded coffee samples, a modified method based on Vignoli et al. [21] was employed. The analysis was conducted using an HPLC system (Agilent 1260 Infinity II, USA) equipped with a diode array detector (DAD).

The samples were extracted and analyzed using the Folin-Ciocalteu method described by Maruf et al. [22] to determine the total phenolic content in roasted coffee. In brief, 1 mL of the filtered sample extract was mixed with 2 ml of Folin-Ciocalteau reagent (2 N) and 2.5 ml of a 7.5 % (w/v) sodium carbonate solution. The mixture was then covered with aluminum foil and allowed to stand for 30 min at room temperature. The absorbance was measured at 760 nm against a blank (excluding the sample) using a spectrophotometer (UV/VIS spectrophotometer, T80, Vietnam). Finally, the total phenolic content was expressed as milligrams of Gallic acid equivalents per gram of sample (mg GAE/100g of sample) based on the calibration curve obtained from a series of Gallic acid standards (0, 0.05, 0.1, 0.15, and 0.2 mg/mL).

2.7. Determination of chemical and sensory properties of coffee beverage

Twelve grams of roasted and grounded coffee powder was used in each cup of 250 ml capacity to prepare brew for chemical and sensory quality evaluation. The volume of water used to prepare the beverage was 250 ml per cup. In order to minimize bias, each coffee sample was assigned a unique sample code that represents the combination of the treatments. Boiled water (~93^0C) was poured into a cup containing the test portion and allowed the infusion to steep for approximately 3–4 min to permit the ground powder to settle and, then, stirred to sniff to determine the aroma of brewed coffee.

2.7.1. pH determination

The pH of the coffee brew was measured following the method described by Derossi et al. [23]. A digital pH meter (portable, CP-500, Taiwan) was used for the measurement, calibrated with the necessary standard before the analysis. To determine the pH of each sample, 20 mL of coffee brew at room temperature was taken, and the pH meter was inserted. The measurement was continued until the pH meter reading stabilized and showed a constant value. This stable number was recorded as the pH of the coffee sample.

2.7.2. Total Titratable Acidity (TTA)

The coffee brew's TTA (Total Titratable Acidity) was determined following the method described by Derossi et al. [23]. To determine the TTA, 20 mL of coffee brew at room temperature was taken. Fresh 0.1 N sodium hydroxide (NaOH) solution was added to the coffee brew gradually while stirring continuously until the pH of the brew reached 7. This endpoint indicates the neutralization of the acidity present in the coffee. The volume of the 0.1 N NaOH solution consumed during the titration was recorded. The TTA of the coffee brew was then calculated based on the volume of NaOH solution used, taking into account the concentration of the NaOH solution.

2.7.3. Total dissolved solid (TDS)

The brewed coffee's TDS (Total Dissolved Solids) was measured following the procedure outlined in Moreno et al. [24]. Each coffee brew's degree Brix (°Brix) was measured using a hand refractometer (Bellingham + Stanley, 45-02, UK). One to two drops of brewed coffee were placed on the prism of the refractometer. The refractometer was initially standardized against distilled water, representing 0 % TSS (Total Suspended Solids). The measured values on the refractometer were then converted to TDS (Xs) using Equation (3),

$$XS = \left(0.0087\ x^{\circ}Brix\right) \tag{3}$$

2.7.4. Evaluation of coffee sensory quality characteristics

The procedure described by ECX [17] for specialty coffee cup quality was followed for the sensory quality evaluation. The evaluation was carried out by trained panelists at the Coffee Quality Inspection and Certification Center (CQICC) in Addis Ababa. This procedure involved assessing various sensory attributes such as aroma, flavor, acidity, body, and overall quality according to the guidelines provided by ECX [17].

On the other hand, the color evaluation of the coffee beans was conducted using the method described by Abrar and Negussie [25]. The color score was assigned to each coffee bean based on its appearance. The following color scores were used: Bluish (15), Grayish (12), Greenish (10), Coated (8), Faded (6), and White (4). These scores represent different shades or colors observed in the coffee beans, indicating their visual appearance.

2.8. Data analysis

Before data analysis, diagnostic tools like normal plots of residuals were checked and indicated that the residuals of all the parameters were normally distributed. Then, the data were analyzed using Minitab version 19 and Repeated Measurement of Two-way Analysis of Variance (ANOVA) to investigate the significant differences in response variables. Differences between the treatment means were conducted using Tukey's test and accepted at $\alpha = 0.05$ level of significance whenever a significant difference occurred. All parameters were measured and analyzed in triplicate, and mean values with their standard deviation of mean were reported.

3. Results and discussion

3.1. Environmental conditions out and inside the warehouse

The experiment was conducted in ambient air conditions of the coffee warehouse. The outside and inside warehouse Temperature and Relative humidity were inconsistent throughout the storage time. There were fluctuations in both temperature and relative humidity over time, as indicated in Fig. 1. The mean maximum and minimum temperature of the inside warehouse during the study

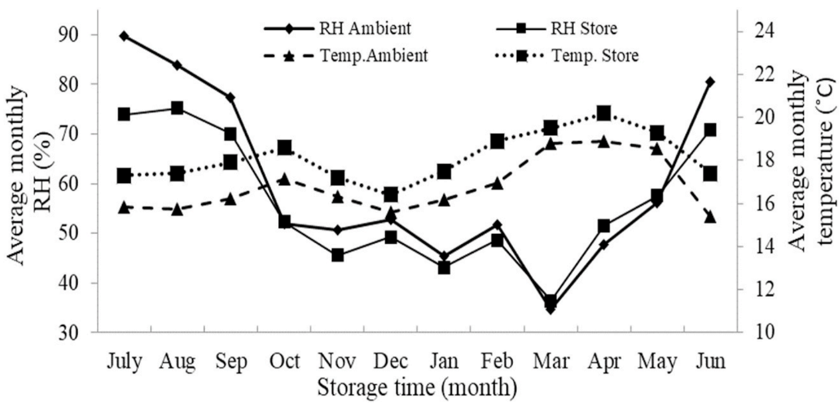

Fig. 1. Monthly average ambient air and storage warehouse for 12 months.

period were 20.2 °C and 16.4 °C, respectively, and the mean maximum and minimum relative humidity inside the warehouse were 75.2 % and 36.4 %, respectively. The mean minimum and maximum temperatures were 15.4 and 18.9 °C, respectively, outside the warehouse, while the mean maximum and minimum relative humidity outside the warehouse were 89.7 % and 34.7 %, respectively.

3.2. Effect of packaging materials on raw coffee beans' physical quality

3.2.1. Moisture content

The initial moisture content of three coffee brands before storage was 11.63, 11.31, and 10.92 % for Limu, Sidama, and Yirgacheffee coffee, respectively (Table 3). From experiment factors, packaging materials for the mean of moisture content was significantly different ($p < 0.05$), and coffee brands showed a highly significant difference ($p < 0.05$). The maximum moisture contents ranging from 11.64 % to 11 % were recorded for coffee samples stored in jute bags over 12 months. The moisture content of coffee beans of all brands stored in Jute bags decreased to 8–8.3 % in the eighth month from initial values of 10.92–11.64 %. However, values in the later months of storage values were increased again to the initial storage moisture level.

A variation in moisture content as time advances in jute bags could be associated with the migration of moisture from the storage environment with time to the coffee brands due to the porous structure of the bags with the fluctuation of warehouse environmental conditions (Fig. 1). The above result supports the findings of [15], who stated that the difference in temperature and relative humidity of ambient air created variation in the grain moisture content, where there is no means of protection. A similar observation was reported by Ref. [26], who explained that the moisture content of coffee in permeable packages decreased or increased below or above the standard when hygroscopic equilibrium under warehouse conditions lower or above than the beans.

Our study showed that samples stored in woven polypropylene bags internally lined by LDPE sheets preserved more or less consistent moisture content than Jute bags. Its result was also comparable with other types of hermetic bags used in the study. When Hermetic bags are considered, the consistent moisture content is preserved throughout the storage time. The result also agrees with the reports of Broissin-Vargas et al. (2018), who indicated that the permeability property of the jute bag caused fluctuation in the moisture content of coffee beans. Their investigation suggested that coffee beans stored in jute bags do not exceed six months because coffee quality deteriorates. The above result is also supported by the findings of Tripetch and Borompichaichartkul (2019) and Borém et al. (2019). They indicated that hermetic packaging materials ensured better preservation of coffee beans' moisture content during storage time. All coffee brands showed similar trends in moisture content decrease or increase with storage time despite variations in their initial moisture content. Fluctuation in the moisture content of beans may contribute to variations in biochemical processes upon storage, possibly contributing to the loss of specific quality parameters. The study's findings showed that using LDPE bags together with woven polypropylene bags results in more or less similar effects in preserving loss or gain of moisture like commercially available hermetic bags (Grain Pro and PICS). In the absence of commercially available hermetic bags, such packaging and storage materials can be used to minimize the impact of ambient air relative humidity on the moisture content of parchment coffee beans. Cao et al. [27]

Table 3
Effect of different packaging materials on moisture content (% wb) of coffee brands stored for 12 months.

Factors		Storage durations (in months)						
Coffee Brands	**Packaging M.**	0	2	4	6	8	10	12
Limu	Jute	$11.63^{a}\pm0.14$	$10.23^{e}\pm0.14$	$8.80^{c}\pm0.2$	$8.45^{e}\pm0.22$	$8.33^{e}\pm0.23$	$11.09^{bc}\pm0.14$	$11.64^{a}\pm0.05$
	PP + LDPE		$11.40^{abc}\pm0.09$	$11.20^{ab}\pm0.2$	$11.05^{b}\pm0.18$	$11.00^{abc}\pm0.2$	$11.33^{ab}\pm0.20$	$11.4^{abc}\pm0.2$
	GP + Jute		$11.50^{ab}\pm0.1$	$11.38^{ab}\pm0.17$	$11.17^{ab}\pm0.06$	$11.10^{ab}\pm0.1$	$11.43^{a}\pm0.14$	$11.50^{ab}\pm0.1$
	PICS		$11.59^{a}\pm0.14$	$11.53^{a}\pm0.42$	$11.43^{a}\pm0.61$	$11.40^{a}\pm0.2$	$11.53^{a}\pm0.11$	$11.55^{a}\pm0.13$
Sidama	Jute	$11.31^{b}\pm0.11$	$9.96^{ef}\pm0.19$	$8.60^{c}\pm0.4$	$8.25^{e}\pm0.1$	$8.13^{e}\pm0.23$	$10.83^{cd}\pm0.16$	$11.37^{abc}\pm0.15$
	PP + LDPE		$11.00^{cd}\pm0.09$	$10.67^{ab}\pm0.12$	$10.62^{cd}\pm0.18$	$10.6^{bcd}\pm0.2$	$11.00^{bc}\pm0.12$	$11.08^{cd}\pm0.13$
	GP + Jute		$11.08^{bcd}\pm0.12$	$10.87^{ab}\pm0.12$	$10.82^{bc}\pm0.08$	$10.8^{bcd}\pm0.2$	$11.03^{bc}\pm0.12$	$11.09^{cd}\pm0.12$
	PICS		$11.15^{bcd}\pm0.09$	$11.00^{ab}\pm0.2$	$10.80^{bc}\pm0.1$	$10.73^{bcd}\pm0.12$	$11.04^{bc}\pm0.07$	$11.10^{bcd}\pm0.1$
Yirgacheffee	Jute	$10.92^{c}\pm0.09$	$9.69^{f}\pm0.25$	$8.47^{c}\pm0.5$	$8.12^{e}\pm0.03$	$8.00^{e}\pm0.2$	$10.5^{d}\pm0.12$	$11^{cd}\pm0.1$
	PP + LDPE		$10.76^{d}\pm0.14$	$10.60^{b}\pm0.2$	$10.35^{d}\pm0.1$	$10.27^{d}\pm0.12$	$10.76^{cd}\pm0.10$	$10.86^{d}\pm0.2$
	GP + Jute		$10.82^{d}\pm0.12$	$10.70^{ab}\pm0.17$	$10.57^{cd}\pm0.03$	$10.53^{cd}\pm0.12$	$10.83^{cd}\pm0.07$	$10.88^{d}\pm0.1$
	PICS		$10.86^{d}\pm0.14$	$10.80^{ab}\pm0.2$	10.50cd ± 0.13	$10.40^{d}\pm0.2$	$10.79^{cd}\pm0.09$	$10.87^{d}\pm0.13$
	Mean	11.29	10.84	10.40	10.18	10.11	11.01	11.20
	CV	1.01	1.26	2.64	1.12	1.80	1.15	1.14

Note; the values assigned by the same letter in the column are not significantly different ($p < 0.5$) PP = polypropylene, LDPE = low density polyethylene, GP = grain pro, Packaging M. = Packaging materials. Remark: woven PP bag + LDPE = woven polypropylene bag + **lined with** low density polyethylene sheet, NA: Not available.

recently reviewed the impact of postharvest processing on aroma formation in roasted coffee and found parallels with our current findings.

3.2.2. Water activity

Initially, the water activity of Limu, Sidama, and Yirgacheffee coffee beans was 0.64, 0.63, and 0.62. On the other hand, at the end of the experiment, the water activity of coffee brands was obtained in the range of 0.65–0.62, 0.64-0.61, and 0.63-0.60 for Limu, Sidama, and Yirgacheffee coffee, respectively (Table 4).

A significant difference ($p < 0.05$) was observed due to packaging materials and coffee brands among the mean water activity over storage time. The highest mean values of water activity range from 0.65 to 0.63 was achieved when coffee brands were stored in jute bags, while the lower water activity was recorded (0.63–0.60) when coffee brands stored in PICS, Grain pro, and PP + LDPE bags after 12months storage. This finding shows that water activity decreased (from 0.48 to 0.40) and then showed a sharp increase (0.63–0.65) from eight months until the end of storage time for all coffee brands stored in Jute bags. At the same time, the remaining packaging materials have better performance in controlling the fluctuation of the water activity of coffee brands over storage time (Table 4).

This variation could be due to the pores structure of the jute bag, which leads to variation in the water activity of coffee brands with the warehouse environmental fluctuation over storage time. The present finding is supported by Ref. [8], who reported that coffee beans' water activity in jute bags changes based on the relative humidity and temperature of the storage area. Similarly [14], reported that hermetic storage materials positively ensured that coffee has the desired amount of water activity during storage time for better quality. Although hermetic packaging materials slightly fluctuated water activity among coffee types during the storage period, it resulted in more or less consistent value than conventional packaging materials. The water activity is a critical parameter to preserve the coffee quality, and it greatly depends on the moisture content of beans, relative humidity, and temperature. A recent study by Cao et al. [27] that analyzed the influence of postharvest processing on aroma development in roasted coffee shared similarities with our present research findings.

3.2.3. Hundred parchment coffee beans weight

The weight of hundred parchment beans before storage was 20.3, 19.0, and 18.1g for Limu, Sidama, and Yirgacheffee coffee, respectively. At the end of storage time, the hundred parchment beans' weight was recorded in the range of 16.3–20.4g, 15.7–18.8g, and 15.3–18.2g for Limu, Sidama, and Yirgacheffee coffee. Packaging materials had a significant ($p < 0.05$) effect on a hundred parchment beans weight for coffee brands during the storage period. The result indicates that the weight shown decreasing (16.3–15.3 g) trends up to eight months of storage and increasing (18.2–20.4g) from the tenth month to the end of the storage period for all brands of coffee stored in jute bags. Similar but slightly better values were observed for samples stored in PP + LDPE bags than jute bags. However, all hermetic packaging materials tested perform better to maintain the parchment coffee beans' weight. The parchment coffee beans' weight in all hermetic packaging materials ranged from 17.7 to 19.9 over twelve storage months (Table 5).

This variation observed between different packaging materials might be due to coffee brands from different agroecology, packaging materials, and storage environment conditions.

The fluctuation in the mass of the beans stored in jute bags might be associated with the migration of moisture out or into the beans with fluctuation of relative humidity of the warehouse with storage months (Fig. 1). This observation agrees with the report of [28], who reported that the coffee bean mass increased with the moisture content due to its hygroscopic nature. They indicated the linear relationship between the beans' weight and the ambient air's moisture content. It also agrees with the findings of [20], who reported that parchment coffee bean weight increases with the increase of moisture content of beans and vice versa, which could be associated with the absorption or release of moisture to the storage environment due to variation in water vapor difference between the product and ambient air.

Table 4
Effect of different Packaging Materials on Water activity of brands of coffee stored for 12 months' storage.

Factors		Storage durations (in Months)						
Coffee brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	$0.64^{a}\pm0.00$	$0.56^{c}\pm0.01$	$0.48^{c}\pm0.00$	$0.44^{d}\pm0.00$	$0.43^{d}\pm0.01$	$0.61^{abcd}\pm0.01$	$0.65^{a}\pm0.01$
	PP + LDPE		$0.61^{ab}\pm0.01$	$0.58^{ab}\pm0.01$	$0.57^{bc}\pm0.01$	$0.56^{bc}\pm0.01$	$0.62^{abc}\pm0.01$	$0.63^{abc}\pm0.00$
	GP + Jute		$0.61^{ab}\pm0.01$	$0.59^{ab}\pm0.01$	$0.57^{abc}\pm0.01$	$0.57^{abc}\pm0.01$	$0.61^{abc}\pm0.01$	$0.62^{abcd}\pm0.01$
	PICS		$0.62^{a}\pm0.00$	$0.60^{a}\pm0.01$	$0.59^{a}\pm0.01$	$0.59^{a}\pm0.01$	$0.62^{a}\pm0.01$	$0.63^{abc}\pm0.01$
Sidama	Jute	$0.63^{b}\pm0.01$	$0.55^{cd}\pm0.01$	$0.47^{cd}\pm0.00$	$0.42d^{e}\pm0.01$	$0.41^{d}\pm0.01$	$0.60^{cd}\pm0.00$	$0.64^{ab}\pm0.01$
	PP + LDPE		$0.60^{b}\pm0.01$	$0.57^{b}\pm0.01$	$0.56^{bc}\pm00$	$0.56^{bc}\pm0.01$	$0.61^{abcd}\pm0.01$	$0.62^{bcd}\pm0.01$
	GP + Jute		$0.61^{ab}\pm0.01$	$0.58^{ab}\pm0.01$	$0.57^{abc}\pm0.01$	$0.57^{abc}\pm0.01$	$0.61^{abcd}\pm0.00$	$0.62^{bcd}\pm0.00$
	PICS		$0.61^{ab}\pm0.00$	$0.59^{ab}\pm0.01$	$0.58^{ab}\pm0.01$	$0.56^{ab}\pm0.01$	$0.61^{abcd}\pm0.01$	$0.61^{bcd}\pm0.01$
Yirgacheffee	Jute	$0.62^{c}\pm0.01$	$0.54^{d}\pm0.00$	$0.45^{d}\pm0.00$	0.42 ± 0.00	$0.40^{d}\pm0.01$	$0.59^{d}\pm0.01$	$0.63^{abcd}\pm0.01$
	PP + LDPE		$0.60^{b}\pm0.01$	$0.57^{b}\pm0.01$	$0.56^{c}\pm0.01$	$0.55^{c}\pm0.01$	$0.59^{cd}\pm0.01$	$0.60^{d}\pm0.02$
	GP + Jute		$0.60^{b}\pm0.01$	$0.58^{ab}\pm0.01$	$0.57^{bc}\pm0.00$	$0.56^{bc}\pm0.01$	$0.60^{bcd}\pm0.01$	$0.61^{cd}\pm0.01$
	PICS		$0.60^{b}\pm0.00$	$0.58^{ab}\pm0.01$	$0.58^{ab}\pm0.00$	$0.56^{ab}\pm0.01$	$0.60^{cd}\pm0.01$	$0.60^{d}\pm0.02$
	Mean	0.63	0.59	0.55	0.54	0.53	0.61	0.62
	CV	1.23	1.07	1.33	1.2	1.51	1.11	1.32

Note; the values assigned by the same letter in the column are not significantly different ($p < 0.5$).
PP = polypropylene, LDPE = low density polyethylene, GP = grain pro, Packaging M. = Packaging material.

Table 5
Effect of different packaging materials on hundred parchment beans weight (g) of coffee brands during 12-month of storage.

Factors		Storage duration in months						
Coffee Brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	20.3^{a}±0.20	19.3^{bc}±0.20	17.99^{de} ± 0.03	16.76^{fg} ± 0.13	16.35^{g} ± 0.17	19.70^{a}±0.61	20.37^{a}±0.73
	PP + LDPE		19.97^{a}±0.02	19.5^{ab} ± 0.10	19.15^{ab} ± 0.39	19.03^{abc}±0.49	19.76^{a}±0.16	19.90^{a}±0.10
	GP + JB		20.03^{a}±0.16	19.80^{a}±0.27	19.48^{a}±0.30	19.37^{ab} ± 0.32	19.56^{a}±0.35	19.60^{abc}±0.36
	PICS		19.87^{ab} ± 0.33	19.70^{a}±0.42	19.57^{a}±0.39	19.52^{a}±0.39	19.61^{a}±0.33	19.63^{ab} ± 0.32
Sidama	Jute	19.0^{b} ± 0.19	17.86^{e}±0.14	16.83^{f}±0.21	15.99^{gh} ± 0.26	15.72^{gh} ± 0.28	18.29^{bc}±0.15	18.80^{bcd} ± 0.20
	PP + LDPE		18.45^{de} ± 0.18	18.13^{cde} ± 0.21	17.88^{cde} ± 0.17	17.80^{def}±0.20	18.55^{b} ± 0.09	18.70^{bcd} ± 0.08
	GP + JB		19.08^{c}±0.38	18.88^{bc}±0.51	18.62^{bc}±0.51	18.53^{bcd} ± 0.51	18.59^{b} ± 0.55	18.60^{cde} ± 0.56
	PICS		18.72^{cd} ± 0.06	18.47^{cd} ± 0.22	18.29^{cd} ± 0.10	18.23^{cde} ± 0.06	18.40^{bc}±0.09	18.43^{de} ± 0.12
Yirgacheffe	Jute	18.1^{c}±0.27	17.22^{f}±0.21	16.28^{f}±0.18	15.51^{h} ± 0.18	15.26^{h} ± 0.18	17.69^{bc}±0.08	18.18^{de} ± 0.14
	PP + LDPE		17.83^{ef}±0.15	17.63^{e}±0.15	17.38^{ef}±0.16	17.30^{f}±0.20	17.77^{bc}±0.09	17.87^{de} ± 0.15
	GP + JB		17.95^{e}±0.21	17.77^{de} ± 0.23	17.50^{def}±0.32	17.41^{ef}±0.35	17.62^{c}±0.41	17.67^{e}±0.44
	PICS		18.06^{e}±0.18	17.91^{de} ± 0.16	17.79cde ± 0.16	17.75^{def}±0.16	17.90^{bc}±0.12	17.93^{de} ± 0.12
	Mean	19.1	18.7	18.24	17.8	17.7	18.62	18.8
	CV	1.14	1.01	1.22	1.42	1.53	1.37	1.45

Note; the values assigned by the same letter in the column are not significantly different ($p < 0.5$).
PP = Polypropylene, LDPE = Low density polyethylene, GP = Grain pro, Packaging M. = Packaging materials.

When coffee brands were compared, the Limu coffee bean's weight was higher than the others, which agrees with the report by Ref. [20], who explained that Limu coffee beans are divided into two types based on the specific grown area from the kaffa beans are small, and from "Enaria'' has proper large beans. Therefore, the coffee used for this study was from the 'Enaria,' which may cause weight variation among brands. Similarly [29], also indicated that the Arabica bean has various weights, sizes, and volumes with their growth from region to region.

3.2.4. *Green coffee beans bulk density (BD)*

Green coffee bean bulk density is essential in determining coffee beans' processing, storage, handling activities, roasting conditions, and characteristics [30]. The initial green beans bulk density was 0.64, 0.65, and 0.66 g/mL for Limu, Sidama, and Yirgacheffee coffee, respectively (Table 6). The result showed a significant difference between packaging materials ($p < 0.05$) for bulk density.

In the present result, bulk density increased from an initial 0.73–0.76 g/mL until the eighth month for coffee brands stored in jute bags. However, from the tenth to twelve months of storage, the bulk density packed in Jute bags decreased from 0.65 to 0.63 g/mL regardless of coffee brands (Table 6). The hermetic packaging materials had a lower variation in bulk density over storage periods. The maximum bulk density was recorded to range from 0.66 to 0.73 g/mL at the eighth month of storage months, whereas the minimum was from 0.67 to 0.64 g/mL at the end of storage time.

Table 6
Effect of different packaging materials on bulk density (g/mL) for coffee brands stored during 12 months' storage.

Factors		Storage duration (In months)						
Coffee Brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	0.64^{b} ± 0.01	0.66^{bc}±0.01	0.70^{ab}c±0.01	0.72^{abc}±0.01	0.73^{abcd}±0.01	0.65^{bc}±0.00	0.63^{d} ± 0.01
	PP + LDPE		0.66^{bc}±0.00	0.68^{bc}±0.01	0.68^{cde} ± 0.01	0.68^{cde} ± 0.01	0.64^{c}±0.01	0.64^{cd} ± 0.02
	GP + JB		0.65^{bc}±0.01	0.66^{bc}±0.02	0.67^{de} ± 0.01	0.68^{de} ± 0.01	0.65^{bc}±0.01	0.64^{abcd}±0.01
	PICS		0.65^{c}±0.02	0.65^{c}±0.02	0.66^{e}±0.01	0.66^{e}±0.01	0.65^{bc}±0.00	0.64^{bcd} ± 0.00
Sidama	Jute	0.65^{ab} ± 0.02	0.68^{ab} ± 0.01	0.71^{ab} ± 0.04	0.73^{ab} ± 0.02	0.74^{ab} ± 0.02	0.66^{abc}±0.00	0.64^{bcd} ± 0.01
	PP + LDPE		0.67^{bc}±0.00	0.68^{abc}±0.01	0.71^{abcd}±0.02	0.72^{abcd}±0.02	0.67^{ab} ± 0.01	0.65$^{abcd±}$0.01
	GP + JB		0.66^{bc}±0.00	0.68^{bc}±0.02	0.70^{bcde} ± 0.01	0.71^{abcde}±0.01	0.67^{ab} ± 0.01	0.66^{abc}±0.01
	PICS		0.65^{bc}±0.01	0.66^{bc}±0.00	0.69^{cde} ± 0.02	0.70^{bcde} ± 0.02	0.66a^{bc}±0.01	0.66^{abcd}±0.01
Yirgacheffee	Jute	0.66^{a}±0.01	0.70^{a}±0.01	0.74^{a}±0.03	0.75^{a}±0.01	0.76^{a}±0.02	0.67^{a}±0.01	0.65^{abcd}±0.01
	PP + LDPE		0.67^{abc}±0.00	0.69^{abc}±0.01	0.72^{abc}±0.03	0.73^{abcd}±0.04	0.67^{a}±0.01	0.66^{ab} ± 0.01
	GP + JB		0.67^{abc}±0.01	0.68^{abc}±0.01	0.71^{bcd} ± 0.00	0.71^{abcde}±0.01	0.67^{a}±0.00	0.67^{a}±0.00
	PICS		0.67^{abc}±0.01	0.68^{bc}±0.01	0.69^{bcde} ± 0.00	0.70^{bcde} ± 0.00	0.67^{a}±0.00	0.67^{a}±0.01
	Mean	0.65	0.67	0.68	0.7	0.71	0.66	0.65
	CV	2.10	1.31	2.13	1.76	2.19	0.96	1.12

Note; the values assigned by the same letter in the column are not significantly different ($p < 0.5$) PP = Polypropylene, LDPE = Low density polyethylene, GP = Grain pro, Packaging M. = Packaging materials.

The variation observed in bulk density is the variation in hundred green coffee weights and the volume of coffee brands that contributed to the reduction in values. The result observed for bean bulk density contradicts the observation of Chandrasekar and Viswanathan (1999), who reported that the bulk density of parchments coffee beans increased as the moisture content of beans increased both for arabica and Robusta coffee beans due to the non-swelling character of the parchment and non-expansion in the volume of the parchments.

However, the present finding is in agreement with the work of [28], who reported that the bulk density of Robusta coffee beans decreased with the increase of moisture content of beans due to the increasing mass and the volume of beans. Different researchers reported similar observations on different commodities like pigeon peas, soybeans, neem seeds, Bambara groundnuts, and Maize [31–35].

3.3. Effect of packaging materials on raw coffee biochemical compounds

The analysis of variance (ANOVA) showed that there was a non-significant difference ($P > 0.05$) among packaging materials for coffee brands on all biochemical quality parameters tested during the storage time.

3.3.1. The caffeine content of raw coffee beans

Caffeine is one of the bioactive compounds of coffee, a response to stimulants for coffee and coffee beverage drinks [36]. The caffeine content of raw beans was 0.89, 0.86, and 0.81 g/100g for Limu, Sidama, and Yirgacheffee coffee before storage, respectively. However, the caffeine content was found in the range of 0.75–0.80, 0.71 to 0.81, and 0.66–0.73 g/100g for Limu, Sidama, and Yirgacheffee coffee brands, respectively, at the end of the experiment (Table 7). Even though there were no significant interaction effects ($p > 0.05$) among packaging materials and coffee brands, the highest numerical value of caffeine was observed from the Limu coffee brand starting from 6months of storage time, while the lowest mean values were observed for sidama and Yirgacheffee brands.

During storage, the caffeine content decreased until eight months compared to the initial month, and after that, it increased until twelve months compared with eight months of storage for all coffee brands. At the end of the experiment, the mean caffeine content among coffee brands was 0.71, 0.68, and 0.63 g/100g for Limu, Sidama, and Yirgacheffee coffee, respectively. Different authors' reports confirm that caffeine content varies based on coffee species, origin, and processing type [1,36,37], which was confirmed in the initial case. For instance, the raw Arabica coffee bean caffeine content ranges from 0.90 % to 1.3 % [37], whereas Ky et al. [38] reported that the caffeine content of Robusta coffees is 1.51–3.33 %. The current finding results in the Ethiopian specialty coffee beans' caffeine content (0.8–2.8 %) [1,36].

Even though the packaging materials showed insignificant differences, numerically, there is a visible difference in terms of caffeine content when the initial and final caffeine contents are compared. In the case of Limu, the caffeine content at the end of storage decreased by 15.7, 11.2, 10.1, and 13.5 % from the initial time zero value for Jute bag, PP + LDPE, Grain pro, and PICS bags, respectively. In this case, Grain Pro and PP + LDPE retained more caffeine than Jute and PICS bags alone. Better caffeine retention for Sidam (5.8 %) and Yirgacheffee (14.8 %) brands was also observed at the end of storage time when Grain Pro was used. Except in Yirgacheffee brands, PICS bags were more or less observed to be more efficient in preserving the caffeine content of coffee brands tasted. Results in Table 7 show a 13.5, 16.3, and 18.5 % decrease in caffeine content at the end of the storage period for the Limu, Sidama, and Yirgacheffee brands. This is likely due to other non-oxidation chemical processes or the negative impact of potential chemicals released from the bags to enhance caffeine degradation.

The initial variation observed between coffee brands might be due to the agroecology and genetic characteristics among coffee brands that influence the concentration of caffeine content. According to Mulu et al. [39], the caffeine content of Arabic coffee beans varied from 0.62 to 1.2 %, which agrees with the values reported in this work. The current result also agrees with the findings of Worku

Table 7
Mean values of caffeine content (g/100 g) for coffee brands stored in type of packages for 12 months.

Factors		Storage duration						
Coffee brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	$0.89^{a}\pm0.15$	$0.81^{a}\pm0.10$	$0.77^{a}\pm0.10$	$0.70^{a}\pm0.10$	$0.68^{a}\pm0.10$	$0.73^{a}\pm0.12$	$0.75^{a}\pm0.14$
	PP + LDPP		$0.88^{a}\pm0.12$	$0.83^{a}\pm0.12$	$0.77^{a}\pm0.12$	$0.74^{a}\pm0.12$	$0.78^{a}\pm0.08$	$0.79^{a}\pm0.08$
	GP + JB		$0.88^{a}\pm0.18$	$0.84^{a}\pm0.18$	$0.77^{a}\pm0.18$	$0.75^{a}\pm0.18$	$0.79^{a}\pm0.12$	$0.80^{a}\pm0.11$
	PICS		$0.79^{a}\pm0.24$	$0.75^{a}\pm0.24$	$0.68^{a}\pm0.24$	$0.66^{a}\pm0.24$	$0.75^{a}\pm0.15$	$0.77^{a}\pm0.16$
Sidama	Jute	$0.86^{ab}\pm0.15$	$0.79^{a}\pm0.12$	$0.74^{a}\pm0.12$	$0.68^{a}\pm0.12$	$0.66^{a}\pm0.12$	$0.70^{a}\pm0.13$	$0.71^{a}\pm0.14$
	PP + LDPP		$0.76^{a}\pm0.21$	$0.72^{a}\pm0.21$	$0.65^{a}\pm0.21$	$0.63^{a}\pm0.21$	$0.70^{a}\pm0.13$	$0.71^{a}\pm0.12$
	GP + Jute		$0.92^{a}\pm0.16$	$0.87^{a}\pm0.16$	$0.81^{a}\pm0.16$	$0.78^{a}\pm0.16$	$0.81^{a}\pm0.13$	$0.81^{a}\pm0.09$
	PICS		$0.79^{a}\pm0.12$	$0.74^{a}\pm0.12$	$0.68^{a}\pm0.12$	$0.66^{a}\pm0.12$	$0.71^{a}\pm0.13$	$0.72^{a}\pm0.14$
Yirgacheffee	Jute	$0.81^{b}\pm0.22$	$0.76^{a}\pm0.23$	$0.71^{a}\pm0.23$	$0.65^{a}\pm0.23$	$0.62^{a}\pm0.23$	$0.72^{a}\pm0.12$	$0.73^{a}\pm0.10$
	PP + LDPP		$0.76^{a}\pm0.21$	$0.74^{a}\pm0.13$	$0.63^{a}\pm0.19$	$0.60^{a}\pm0.21$	$0.66^{a}\pm0.12$	$0.68^{a}\pm0.10$
	GP + Jute		$0.78^{a}\pm0.21$	$0.74^{a}\pm0.21$	$0.67^{a}\pm0.21$	$0.65^{a}\pm0.21$	$0.68^{a}\pm0.17$	$0.69^{a}\pm0.17$
	PICS		$0.78^{a}\pm0.23$	$0.73^{a}\pm0.23$	$0.67^{a}\pm0.23$	$0.64^{a}\pm0.09$	$0.66^{a}\pm0.17$	$0.66^{a}\pm0.19$
	Mean	0.85	0.81	0.77	0.70	0.66	0.73	0.74
	CV	21.11	21.7	22.45	25.56	26.80	18.24	17.81

Note; the values assigned by the same letter in the column are not significantly different ($p < 0.5$).
PP = Polypropylene, LDPE = Low density polyethylene, GP = Grain pro, Packaging M. = Packaging materials.

et al. [40], who indicated that coffee's growing altitude significantly affects the caffeine content of green beans. The authors further explained that coffee grown at lower altitudes contains high caffeine and slightly lower quality grade. It also agrees with the findings of Zarebska et al. [41], who reported that the caffeine content of green beans decreased by 40 % for washed and natural drying process coffee stored in jute and grain pro bags for 12 months storage time. Agustini and Yusya [42] found that hermetic packaging such as aluminium-laminated polyethylene (ALP) and polyethylene terephthalate (PET) maintained the quality and stability of ground coffee better during storage compared to traditional packaging materials.

3.3.2. The chlorogenic acid content of raw coffee beans

Coffee is a source of phenol compounds in which Chlorogenic acid is the central part, accounting for around 12 % of the dry base of green coffee [10]. Chlorogenic acid is essential in determining a cup of coffee's quality. It has an inverse impact on the cup quality of coffee that a low concentration of present in a sample coffee type has the highest cup quality [1], which is true in the case of Sidama and Yirgacheffee brands as compared to Limu (Table 8). The initial content of Chlorogenic acid in raw coffee beans was 4.01, 3.98, and 3.80 g/100g for Limu, Sidama, and Yirgacheffee coffee before storage, respectively. However, Chlorogenic acid content was found in the range of 3.15–3.57, 3.18 to 3.51, and 3.03–3.30 g/100g for Limu, Sidama, and Yirgacheffee coffee, respectively, after 12 months of storage (Table 8). As indicated in the table, both packaging materials and coffee brands showed no significant ($p < 0.05$) difference in Chlorogenic acid content except a decrease in value with the extension of storage time.

This finding agrees with the report of Zarebska et al. [41], who reported that the Chlorogenic acid content for washed coffee stored in jute bags and Grain Pro showed no notable difference during twelve months of storage. The result of the present study is also in agreement with the work of Tripetch and Borompichaichartkul [10], who stated that the Chlorogenic acid of green coffee beans fluctuates with the environmental variation, which was observed during 12 storages in this study case despite its insignificant differences.

3.3.3. Trigonelline content of raw coffee beans

Among various chemical constituents determining the quality of Coffee, Trigonelline content is the most essential precursor influencing the aroma and flavor of a cup of coffee [43]. Trigonelline compounds in arabica green coffee beans are present in the ranges of 0.74–1.54 % (w/w) [36]. The highest level of Trigonelline in green beans is related to superior cup quality [36].

The trigonelline content of raw coffee brands was 0.98, 0.96, and 0.91 g/100g for Limu, Sidama, and Yirgacheffee coffee before storage, respectively. However, at the end of the storage period, values decreased significantly to the range of 0.53–0.74, 0.56 to 0.66, and 0.44–0.65 g/100g for Limu, Sidama, and Yirgacheffee brands, respectively (Table 9).

There was no significant difference in the mean Trigonelline content ($p < 0.05$) among packaging materials and coffee brands over twelve months of storage time. At the end of storage, the Trigonelline contents were 0.53, 0.56, and 0.44g/100g for Limu, Sidama, and Yirgacheffee coffee, respectively. Although there is no statistical difference in terms of Trigonelline's mean contents, numerically decreasing storage time trends were observed regardless of packaging materials and coffee brands. This numerical variation may be due to a decrement in moisture content and water activity that influence the stability of Trigonelline content. Low relative humidity of storage environments forces the moisture, aroma, and flavor precursor substances like Trigonelline to evaporate to the surrounding environment, which hermetic storage materials could not even protect. However, the present result contradicts the report of Zarebska et al. [41], who reported that in washed coffee, Trigonelline content lost is a small amount compared to initial and jute bags are better preserved than grain pro bags during 12-month storage time.

3.3.4. Total phenolic content

The stability of phenolic compounds in food and beverage is affected by different external factors such as storage temperature,

Table 8
Mean values of Chlorogenic acid (g/100 g) for coffee brands stored in different packaging materials for 12 months.

Factors		Storage duration (In month)						
Coffee Brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	$4.01^a \pm 0.33$	$3.80^a \pm 0.18$	$3.66^a \pm 0.18$	$3.44^a \pm 0.18$	$3.36^a \pm 0.18$	$3.33^a \pm 0.17$	$3.32^a \pm 0.17$
	PP + LDPE		$4.03^a \pm 0.30$	$3.89^a \pm 0.30$	$3.67^a \pm 0.30$	$3.59^a \pm 0.30$	$3.57^a \pm 0.28$	$3.57^a \pm 0.28$
	GP + JB		$3.97^a \pm 0.39$	$3.82^a \pm 0.39$	$3.60^a \pm 0.39$	$3.53^a \pm 0.39$	$3.49^a \pm 0.37$	$3.49^a \pm 0.36$
	PICS		$3.66^a \pm 0.45$	$3.51^a \pm 0.45$	$3.30^a \pm 0.45$	$3.22^a \pm 0.45$	$3.18^a \pm 0.46$	$3.15^a \pm 0.46$
Sidama	Jute	$3.98^a \pm 0.5$	$3.64^a \pm 0.56$	$3.50^a \pm 0.56$	$3.28^a \pm 0.56$	$3.21^a \pm 0.56$	$3.19^a \pm 0.53$	$3.18^a \pm 0.52$
	PP + LDPE		$3.78^a \pm 0.72$	$3.63^a \pm 0.72$	$3.41^a \pm 0.72$	$3.34^a \pm 0.72$	$3.32^a \pm 0.69$	$3.32^a \pm 0.68$
	GP + Jute		$3.97^a \pm 0.35$	$3.83^a \pm 0.35$	$3.61^a \pm 0.35$	$3.53^a \pm 0.35$	$3.51^a \pm 0.32$	$3.51^a \pm 0.32$
	PICS		$3.91^a \pm 0.37$	$3.74^a \pm 0.36$	$3.55^a \pm 0.37$	$3.49^a \pm 0.37$	$3.47^a \pm 0.35$	$3.46^a \pm 0.35$
Yirgacheffee	Jute	$3.8^a \pm 0.52$	$3.49^a \pm 0.36$	$3.35^a \pm 0.36$	$3.13^a \pm 0.36$	$3.06^a \pm 0.0.36$	$3.04^a \pm 0.34$	$3.03^a \pm 0.34$
	PP + LDPE		$3.59^a \pm 0.67$	$3.45^a \pm 0.67$	$3.23^a \pm 0.67$	$3.15^a \pm 0.67$	3.12a±0.64	$3.11^a \pm 0.63$
	GP + Jute		$3.76^a \pm 0.48$	$3.61^a \pm 0.48$	$3.28^a \pm 0.64$	$3.16^a \pm 0.70$	$3.13^a \pm 0.67$	$3.12^a \pm 0.67$
	PICS		$3.79^a \pm 0.59$	$3.64^a \pm 0.59$	$3.42^a \pm 0.58$	$3.34^a \pm 0.58$	$3.31^a \pm 0.55$	$3.30^a \pm 0.55$
	Mean	3.93	3.78	3.64	3.41	3.33	3.3	3.30
	CV	11.54	11.97	12.46	13.71	14.2	13.68	13.58

Note; Average values indicated in the table showed no significance difference ($P < 0.05$) for coffee brand as well packaging materials. PP = Polypropylene, LDPE = Low density polyethylene, GP = Grain pro, Packaging M. = Packaging materials.

Table 9
Mean values of Trigonelline content (g/100 g) of brands of coffee stored in types of packages for 12 months.

Factors		Storage duration (In months)						
Coffee Brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	0.98ᵃ±0.26	0.82ᵃ±0.25	0.70ᵃ±0.25	0.74ᵃ±0.21	0.76ᵃ±0.22	0.65ᵃ±0.20	0.63ᵃ±0.20
	PP + LDPE		0.91ᵃ±0.30	0.79ᵃ±0.30	0.71ᵃ±0.24	0.68ᵃ±0.23	0.55ᵃ±0.21	0.53ᵃ±0.21
	GP + JB		0.98ᵃ±0.23	0.86ᵃ±0.23	0.81ᵃ±0.23	0.79ᵃ±0.23	0.75ᵃ±0.19	0.74ᵃ±0.19
	PICS		0.71ᵃ±0.28	0.59ᵃ±0.28	0.71ᵃ±0.20	0.75ᵃ±0.23	0.67ᵃ±0.17	0.65ᵃ±0.15
Sidama	Jute	0.96ᵃ±23	0.73ᵃ±0.27	0.61ᵃ±0.27	0.66ᵃ±0.20	0.68ᵃ±0.19	0.60ᵃ±0.16	0.58ᵃ±0.15
	PP + LDPE		0.81ᵃ±0.30	0.69ᵃ±0.30	0.71ᵃ±0.20	0.72ᵃ±0.18	0.59ᵃ±0.15	0.56ᵃ±0.15
	GP + Jute		0.90ᵃ±0.20	0.77ᵃ±0.20	0.72ᵃ±0.20	0.71ᵃ±0.20	0.67ᵃ±0.16	0.66ᵃ±0.15
	PICS		0.91ᵃ±0.17	0.78ᵃ±0.17	0.81ᵃ±0.07	0.82ᵃ±0.07	0.70ᵃ±0.07	0.68ᵃ±0.07
Yirgacheffee	Jute	0.91ᵃ±0.25	0.62ᵃ±0.07	0.50ᵃ±0.07	0.52ᵃ±0.18	0.53ᵃ±0.22	0.46ᵃ±0.22	0.44ᵃ±0.22
	PP + LDPE		0.87ᵃ±0.36	0.75ᵃ±0.36	0.78ᵃ±0.22	0.79ᵃ±0.19	0.67ᵃ±0.19	0.65ᵃ±0.19
	GP + Jute		0.73ᵃ±0.24	0.60ᵃ±0.24	0.65ᵃ±0.17	0.66ᵃ±0.16	0.58ᵃ±0.11	0.56ᵃ±0.10
	PICS		0.92ᵃ±0.31	0.80ᵃ±0.31	0.75ᵃ±0.31	0.73ᵃ±0.31	0.63ᵃ±0.27	0.61ᵃ±0.26
	Mean	0.95	0.83	0.70	0.72	0.72	0.63	0.61
	CV	26	29.88	35.14	28.76	28.60	28.46	28.58

Note; Average values indicated in the table showed no significance difference (P < 0.05) for coffee brand as well packaging materials PP = polypropylene, LDPE = low density polyethylene, GP = grain pro, Packaging M. = Packaging materials.

light, exposure to air, and storage time [44]. Most of these factors could be managed using appropriate packaging materials with sound barriers to those environmental factors.

The initial content of total Phenolic content of ground coffees was 895.32, 834.25, and 798.13 mg GAE/100g for Limu, Sidama, and Yirgacheffee coffee, respectively. At the end of the storage period, the total phenolic content of ground coffees was recorded in the range of 686.97–671.96, 674.38-670.94, and 646.01–633.89 mg GAE/100g for Limu, Sidama, and Yirgacheffee coffee respectively (Table 10).

There was a significant difference ($p < 0.05$) in the mean of total phenolic content among the interaction effect of packaging materials and coffee brands during twelve months of storage. Total phenolic contents showed decreasing trends for all coffee brands throughout storage periods regardless of packaging materials. For instance, at the end of the storage period, the content for different packaging materials decreased from 23.3 to 24 % (average 23.8 %) for Limu, from 19.2 to 19.6 % (average 19.4 %) for Sidama and from 19.1 to 21.6 % (average 20.2 %) for Yirgacheffee brands. This implies that the decrease in percentage between the initial and final storage time is not as significant for the Sidama and Yirgacheffee brands but is higher in the case of Limu. According to the study result, storage time has a critical impact on packaging materials in terms of minimizing the decrease in total phenolic content.

Selmar et al. [45] also indicated the decreasing tendency with storage time and reported a sharp decline in total phenolic content until ten months of the storage time. Among the coffee brands, Limu exhibited significantly higher phenolic content than the remaining two coffee brands during storage time. The work of Agustini and Yusya [42] also stated that in comparison with the conventional packaging materials, hermetic packaging like aluminium-laminated polyethylene (ALP) and polyethylene terephthalate (PET) packaging preserved the quality and stability of the ground coffee during storage. This finding is also supported by the finding of Zhang et al. [44], who reported that the TPC of wheat crops decreased throughout storage time when stored under different storage conditions (aerated and vacuum), explaining that the phenolic acid profiles were influenced more by storage time than storage conditions in all cultivars.

The result variation observed among coffee brands might be due to the different amounts of chlorogenic acids in raw coffee types and the influence of prolonged storage time. A similar observation is reported by Gloess et al. [46], who indicated that the origin and genetic makeup of coffee significantly influence total phenolic content. However, it contradicts the work of Tripetch and Borompichaichartkul [10], who reported that the total phenolic content of green coffee beans during four months' storage showed no significant variation among packaging materials. However, it showed significant variation after six months of storage.

3.4. Effect of packaging materials on coffee beverage chemical quality attributes

The result showed a significant difference between the interaction effect of packaging materials and coffee brands ($p < 0.05$) in all coffee beverage chemical quality attributes tested during the storage time.

3.4.1. Acid level (PH) of coffee brew

The initial pH values of coffee brew before storage were 5.01, 5.06, and 5.12 for Limu, Sidama, and Yirgacheffee coffee brands. At the end of the storage period, the pH values range from 4.74 to 4.80, 4.83 to 4.85, and 4.85 to 4.92 for Limu, Sidama, and Yirgacheffee coffee brands, respectively (Table 11). This implies that the pH of the coffee brew with storage time declines regardless of packaging materials and coffee brands.

The variation observed among coffee brands regarding pH might be due to genetic differences, agroecology, and genetic composition. The results of the present study agree with the finding of Fuller and Rao [47], who reported that the pH value of Ethiopian coffees ranges from 4.85 to 5.10, except for a small quantity of variation observed for Limu brands in which the pH range of 4.74–5.01 was recorded. The lowest pH value observed for Limu coffee is because it had more chlorogenic acid in raw beans than other coffee

Table 10
Mean values of Total phenolic content (mg GAE/100 g) of coffee brands stored in types of packaging materials during 12 months.

Factors		Storage duration (In Months)						
Coffee Brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	895.32[a]± 16.76	854.58[a]±10.9	813.39[abc]± 12.48	785.70[a]± 8.22	776.47[a]±13.07	712.13[a]±8.98	679.96[ab] ± 12.89
	PP + LDPE		862.12[a]±1.95	827.75[a]± 11.3	786.62[a]±19.20	772.91[ab] ± 22.2	712.29[a]±12.02	681.98[ab] ± 17.8
	GP + Jute		856.84[a]±3.48	815.05[ab] ± 13.26	776.95[abc]±16.77	764.25[abc]±19.3	708.69[ab] ± 15.19	680.91[ab] ± 19.3
	PICS		855.24[a]±6.12	820.04[a]± 15.44	779.35[ab] ± 13.29	765.79[abc]±13.2	713.24[a]±11.64	686.97[a]±13.97
Sidama	Jute	834.25[b] ± 13.64	818.32[b] ± 8.56	803.18[abcd]± 11.71	766.86[abcd]±19.70	754.75[abc]±22.8	698.88[abc]±7.79	670.94[abc]±22.9
	PP + LDPE		818.44[b] ± 5.16	800.69[abcd]± 17.16	764.28[abcd]±14.27	752.14[abc]±15.62	700.30[abc]±12.98	674.38[abc]±20.1
	GP + Jute		817.84[b] ± 7.33	802.71[abcd]± 9.68	758.28[abcd]±9.36	743.47[abc]±15.31	673.51[bcd] ± 6.48	671.06[abc]±15.37
	PICS		819.15[b] ± 3.58	803.89[abcd]± 22.4	760.89[abcd]±17.15	746.56[abc]±16.74	664.53[cd] ± 4.03	673.43[abc]±8.02
Yirgacheffee	Jute	798.13[c]± 18.73	782.23[c]±16.44	765.55[d] ± 13.58	732.97[d] ± 12.08	722.10[c]±13.2	657.68[d] ± 24.4	625.48[c]±30.5
	PP + LDPE		785.61[c]±8.32	773.62[bcd] ± 16.71	743.62[bcd] ± 8.08	733.62[abc]±8.14	675.21[bcd] ± 14.31	646.01[abc]±18.5
	GP + Jute		786.86[c]±12.29	774.45[bcd] ± 16.92	740.89[bcd] ± 4.20	729.70[bc]±11.22	673.51[bcd] ± 5.12	645.42[abc]±13.26
	PICS		783.42[c]±15.55	770.18[cd] ± 15.31	739.91[cd] ± 12.66	729.82[bc]±15.14	664.53[cd] ± 10.07	631.89[bc]±9.52
	Mean	842.57	820.05	797.54	761.36	749.29	692.46	664.04
	CV	1.95	1.09	1.84	1.69	2.06	1.61	2.55

Note; the values assigned by the same letter in the column are not significantly different ($p < 0.5$). PP = Polypropylene, LDPE = Low density polyethylene, GP = Grain pro, Packaging M. = Packaging materials.

Table 11
Change of pH value of coffee brands stored in different packaging materials over 12 months of storage time.

Factors		Storage duration (In months)						
Coffee brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	$5.01^{b} \pm 0.06$	$4.98^{ab} \pm 0.02$	$4.93^{a} \pm 0.02$	$4.86^{a} \pm 0.00$	$4.84^{a} \pm 0.01$	$4.75^{cd} \pm 0.01$	$4.74^{bc} \pm 0.01$
	PP + LDPE		$4.94^{b} \pm 0.04$	$4.91^{a} \pm 0.06$	$4.85^{a} \pm 0.01$	$4.83^{a} \pm 0.01$	$4.78^{bcd} \pm 0.04$	$4.77^{abc} \pm 0.05$
	GP + Jute		$4.96^{ab} \pm 0.02$	$4.92^{a} \pm 0.02$	$4.84^{a} \pm 0.03$	$4.82^{a} \pm 0.03$	$4.81^{abcd} \pm 0.03$	$4.80^{abc} \pm 0.03$
	PICS		$4.98^{ab} \pm 0.02$	$4.93^{a} \pm 0.03$	$4.84^{a} \pm 0.04$	$4.81^{a} \pm 0.04$	$4.74^{d} \pm 0.02$	$4.72^{c} \pm 0.03$
Sidama	Jute	$5.06^{ab} \pm 0.06$	$5.01^{ab} \pm 0.02$	$4.96^{a} \pm 0.03$	$4.92^{a} \pm 0.05$	$4.91^{a} \pm 0.08$	$4.86^{abc} \pm 0.06$	$4.85^{abc} \pm 0.06$
	PP + LDPE		$5.01^{ab} \pm 0.03$	$4.95^{a} \pm 0.02$	$4.92^{a} \pm 0.01$	$4.91^{a} \pm 0.01$	$4.85^{abcd} \pm 0.04$	$4.84^{abc} \pm 0.05$
	GP + Jute		$5^{ab} \pm 0.03$	$4.94^{a} \pm 0.03$	$4.91^{a} \pm 0.03$	$4.90^{a} \pm 0.03$	$4.86^{abc} \pm 0.04$	$4.85^{abc} \pm 0.05$
	PICS		$5.01^{ab} \pm 0.03$	$4.93^{a} \pm 0.04$	$4.88^{a} \pm 0.02$	$4.86^{a} \pm 0.02$	$4.85^{abcd} \pm 0.03$	$4.84^{abc} \pm 0.04$
Yirgacheffee	Jute	$5.12^{a} \pm 0.08$	$5.04^{a} \pm 0.03$	$4.96^{a} \pm 0.03$	$4.94^{a} \pm 0.09$	$4.93^{a} \pm 0.1$	$4.92^{a} \pm 0.09$	$4.92^{a} \pm 0.09$
	PP + LDPE		$5.03^{ab} \pm 0.03$	$4.97^{a} \pm 0.09$	$4.93^{a} \pm 0.01$	$4.92^{a} \pm 0.03$	$4.88^{abc} \pm 0.02$	$4.87^{abc} \pm 0.03$
	GP + Jute		$5.02^{ab} \pm 0.03$	$4.96^{a} \pm 0.02$	$4.94^{a} \pm 0.03$	$4.93^{a} \pm 0.04$	$4.90^{ab} \pm 0.01$	$4.89^{ab} \pm 0.02$
	PICS		$5.04^{ab} \pm 0.06$	$4.97^{a} \pm 0.03$	$4.95^{a} \pm 0.08$	$4.94^{a} \pm 0.09$	$4.90^{ab} \pm 0.08$	$4.85^{abc} \pm 0.08$
	Mean	5.12	5.00	4.95	4.89	4.88	4.84	4.83
	CV	0.99	0.61	0.68	0.66	0.85	0.79	0.92

Note; the values assigned by the same letter in the column are not significantly different ($p < 0.5$).
PP = Polypropylene, LDPP = Low density polyethylene, GP = Grain pro, Packaging M. = Packaging materials.

brands, as indicated in Table 8 and Section 3.3.2. Chlorogenic acid is one of the acidity sources for coffee beans and beverages and contributes to the most significant portion of acids formed in the coffee brew. It is degraded into quinic and caffeic acids by hydrolysis during roasting and, as a result, could contribute up to 66 % of the acidity or astringency of coffee beverages [36]. However, the results in this study do not agree with the findings of Gloess et al. [46], who reported that Yirgacheffe coffee brands had the lowest pH value of any brand of Ethiopian coffee. This might happen because, during storage time, the chemical composition of Limu coffee brands might efficiently hydrolyze to acidity. Likewise, Coradi et al. [48] reported that coffee from extended storage could lead to greater acidity. These greater acidity levels may be linked to the increase of potassium leaching and electric conductivity, which are demonstrated due to degeneration of the cellular membranes. Similarly, observations reported by Angelovič et al. [49] indicated that the pH value of maize crops significantly decreased over six months of storage. On the other way around, when packaging materials are considered, there was as such no significant effect was observed except for Jute and PICS bags in the case of Limu Coffee. In most cases, throughout the storage time, the PP + LDPE bag showed more or less consistent results for all brands of coffee. Agustini and Yusya [42] found that hermetic packaging such as aluminium-laminated polyethylene (ALP) and polyethylene terephthalate (PET) maintained the quality and stability of ground coffee better during storage compared to traditional packaging materials.

3.4.2. *Total Titratable Acidity of coffee brew*

Total titratable acidity (TTA) measures all acidic protons, including non-dissociated protons that can be neutralized by adding a strong base [26.45]. In this finding, the coffee brew's initial titratable acidity value before storage was 2.29 mL, 2.09 mL, and 1.88 mL for Limu, Sidama, and Yirgacheffee coffee, respectively. At the end of the storage period, the total titratable acids were recorded in ranges of 3.53–3.70 mL, 3.17–3.37 mL, and 2.63–2.73 mL for Limu, Sidama, and Yirgacheffee coffee, respectively (Table 12).

There was an increasing trend in titratable acidity values as storage time advances, regardless of coffee brands and packaging materials used. This might be due to a proportional increase in total acidity due to the release of chemical compounds that contribute to

Table 12
Change of Total Titratable Acids (mL) value of coffee brands stored in different packaging materials during 12 months'

Factors		Storage duration (In Months)						
Coffee Brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	$2.29^{a} \pm 0.15$	$2.68^{ab} \pm 0.1$	$3.17^{a} \pm 0.15$	$3.24^{a} \pm 0.17$	$3.27^{a} \pm 0.23$	$3.49^{a} \pm 0.22$	$3.53^{a} \pm 0.31$
	PP + LDPE		$2.78^{a} \pm 0.1$	$3.2^{a} \pm 0.17$	$3.30^{a} \pm 0.08$	$3.33^{a} \pm 0.06$	$3.64^{a} \pm 0.15$	$3.70^{a} \pm 0.17$
	GP + JB		$2.78^{a} \pm 0.16$	$3.23^{a} \pm 0.21$	$3.26^{a} \pm 0.22$	$3.27^{a} \pm 0.25$	$3.49^{a} \pm 0.21$	$3.53^{a} \pm 0.23$
	PICS		$2.80^{a} \pm 0.10$	$3.33^{a} \pm 0.12$	$3.38^{a} \pm 0.15$	$3.40^{a} \pm 0.20$	3.59a±0.20	$3.63^{a} \pm 0.21$
Sidama	Jute	$2.09^{b} \pm 0.15$	$2.38^{bcd} \pm 0.19$	$2.77^{abc} \pm 0.45$	$2.92^{abcd} \pm 0.38$	$2.97^{abcd} \pm 0.15$	$3.13^{abc} \pm 0.17$	$3.17^{abcd} \pm 0.15$
	PP + LDPE		$2.55^{abc} \pm 0.09$	$2.93^{abc} \pm 0.32$	$2.96^{abcd} \pm 0.16$	$3^{abcd} \pm 0.15$	$3.19^{ab} \pm 0.16$	$3.23^{abc} \pm 0.21$
	GP + Jute		$2.58^{ab} \pm 0.14$	$3.03^{ab} \pm 0.21$	$3.13^{ab} \pm 0.16$	$3.17^{ab} \pm 0.15$	$3.14^{abc} \pm 0.09$	$3.13^{abcd} \pm 0.12$
	PICS		$2.45^{abcd} \pm 0.05$	$2.83^{abc} \pm 0.15$	$3.01^{abc} \pm 0.09$	$3.07^{abc} \pm 0.12$	$3.32^{a} \pm 0.17$	$3.37^{ab} \pm 0.21$
Yirgacheffee	Jute	$1.88^{c} \pm 0.14$	$2.18^{cd} \pm 0.14$	$2.47^{bc} \pm 0.21$	$2.59^{bcd} \pm 0.31$	$2.63^{bcd} \pm 0.35$	$2.72^{bcd} \pm 0.19$	$2.73^{bcd} \pm 0.25$
	PP + LDPE		$2.12^{d} \pm 0.10$	$2.43^{bc} \pm 0.25$	$2.58^{bcd} \pm 0.22$	$2.63^{bcd} \pm 0.21$	$2.69^{bcd} \pm 0.05$	$2.7^{cd} \pm 0.10$
	GP + Jute		$2.15^{d} \pm 0.10$	$2.33^{c} \pm 0.15$	$2.43^{cd} \pm 0.12$	$2.47^{cd} \pm 0.12$	$2.61^{cd} \pm 0.19$	$2.63^{cd} \pm 0.35$
	PICS		$2.08^{d} \pm 0.18$	$2.30^{c} \pm 0.17$	$2.40^{d} \pm 0.13$	$2.43^{d} \pm 0.15$	$2.54^{d} \pm 0.14$	$2.57^{d} \pm 0.15$
	Mean	2.09	2.46	2.84	2.93	2.97	3.13	3.16
	CV	7.00	5.05	7.80	6.32	6.68	5.58	6.70

Note; the values assigned by the same letter in the column are not significantly different ($p < 0.5$).
PP = Polypropylene, LDPP = Low density polyethylene, GP = Grain pro, Packaging M. = Packaging materials.

more acidity with increased storage time.

There was a significant difference between the interaction effect of packaging materials and coffee brands ($p < 0.05$) in the mean titratable acidity values of coffee brew during the storage time. At the end of the storage time, the highest value of TTA, ranging from 3.13 to 3.7 mL, was recorded for the Limu and Sidama coffee brands. In contrast, the lowest values, ranging from 2.57 to 2.73 mL, were recorded for Yirgacheffee coffee brands. Although a significant interaction effect is observed, the result clearly shows that coffee brands highly influenced titratable acidity than packaging materials. The variation observed in titratable acidity might be due to the presence of acidity levels among coffee types because of their genetic makeup. This observation is in line with the result of the pH value because the highest titratable acidity values indicate the highest acidity level. The highest acidity in the coffee brew is usually associated with low quality because it creates undesirable tastes [26]. The current finding agrees with the work of Angelovič et al. [50], who reported that total titratable acids of maize crops significantly increased with pH value decrease over storage time.

3.4.3. *Total dissolved solid (TDS%)*

The initial total dissolved solid values of coffee brew before storage were 1.62 %, 1.74 %, and 1.84 % for Limu, Sidama, and Yirgacheffee coffee, respectively. The total dissolved solids ranging from 0.99 to 1.07, 1.04–1.16, and 1.16–1.28 % were recorded for Limu, Sidama, and Yirgacheffee coffee brands at the end of the storage period (Table 13).

There was a significant difference between the interaction effect of packaging materials and coffee brands ($p < 0.05$) in coffee brew's mean total dissolved values during the storage time. Except for Limu coffee brands stored in Jute and PICS bags in which minimum TDS values of 0.99 % were obtained, the other treatment combination is statistically similar in TDS at the end of the storage time. The difference value recorded for Limu coffee brands stored in Jute and PICS bags at the end of storage time might be due to coffee brands' difference in responding to storage environment fluctuation. The chemical interaction between packaging materials and the chemical composition of Limu beans might be the possible reason for the significant reduction in TDS observed. There was a decreasing trend in TDS values as storage time advanced, regardless of packaging materials and coffee brands. This observation is supported by the findings of Asiah et al. [51] and Borém et al. [26], who indicated that the TDS of coffee brew decreased during storage due to hydrolysis of sugar content, which affected the sensory quality or cup quality of the coffee brew. Moreover, this finding agrees with Mishra and Kar [52], who reported that total soluble solids and total sugars decreased with the increase in the storage period for strawberry cultivars.

3.5. *Effect of packaging materials on coffee sensory quality attributes*

There was an interaction effect ($p < 0.05$) in the mean value of coffee sensory quality among packaging materials and coffee brands for color and total cup quality evaluated over storage duration.

3.5.1. *Coffee beans color*

The preservation of the green color of coffee beans is paramount during storage because visual characteristics often determine commercial acceptance [8]. While for a better coffee (sample), the blue to grayish signifies the most desirable attribute of appearance/color [53]. The coffee brands' bean color score at the start of the experiment was 13.3, 15, and 12.8 % for Limu, Sidama, and Yirgacheffee coffee, respectively (Table 14). The bean's color values ranging from 10 to 14, 11.33–14, and 10–11.3 % were recorded for Limu, Sidama, and Yirgacheffee coffee at the end of the storage period.

There was a significant difference between the interaction effect of packaging materials and coffee brands ($p < 0.05$) in the mean beans' color values during the storage time. The highest color change was observed from all coffee brands stored in jute bags, while all coffee brands stored in hermetic packaging materials showed a moderate change in the color of the beans. The change in bean color for

Table 13
Change of Total dissolved Solid value (^{o}Brix) of coffee brands stored in different Packaging Materials during 12 months'

Factors		Storage duration (In month)						
Coffee Brands	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	$1.62^{b} \pm 0.09$	$1.54^{c} \pm 0.06$	$1.51^{abc} \pm 0.1$	$1.27^{bc} \pm 0.12$	$1.19^{ab} \pm 0.13$	$1.02^{c} \pm 0.05$	$0.99^{b} \pm 0.05$
	PP + LDPE		$1.51^{c} \pm 0.05$	$1.45^{bc} \pm 0.1$	$1.28^{abc} \pm 0.05$	$1.22^{ab} \pm 0.09$	$1.05^{bc} \pm 0.04$	$1.02^{ab} \pm 0.05$
	GP + JB		$1.52^{c} \pm 0.04$	$1.36^{c} \pm 0.05$	$1.21^{c} \pm 0.07$	$1.16^{b} \pm 0.1$	$1.09^{abc} \pm 0.03$	$1.07^{ab} \pm 0.05$
	PICS		$1.55^{bc} \pm 0.03$	$1.45^{bc} \pm 0.1$	$1.32^{abc} \pm 0.1$	$1.28^{ab} \pm 0.1$	$1.03^{bc} \pm 0.04$	$0.99^{b} \pm 0.05$
Sidama	Jute	$1.74^{ab} \pm 0.14$	$1.64^{abc} \pm 0.05$	$1.57^{abc} \pm 0.15$	$1.39^{abc} \pm 0.11$	$1.33^{ab} \pm 0.1$	$1.09^{abc} \pm 0.02$	$1.04^{ab} \pm 0.00$
	PP + LDPE		$1.65^{abc} \pm 0.15$	$1.57^{abc} \pm 0.17$	$1.44^{abc} \pm 0.16$	$1.39^{ab} \pm 0.17$	$1.20^{abc} \pm 0.06$	$1.16^{ab} \pm 0.1$
	GP + Jute		$1.65^{abc} \pm 0.00$	$1.51^{abc} \pm 0.15$	$1.46^{abc} \pm 0.09$	$1.45^{ab} \pm 0.1$	$1.21^{abc} \pm 0.09$	$1.2^{ab} \pm 0.1$
	PICS		$1.67^{abc} \pm 0.03$	$1.62^{abc} \pm 0.1$	$1.45^{abc} \pm 0.15$	$1.39^{ab} \pm 0.17$	$1.20^{abc} \pm 0.11$	$1.16^{ab} \pm 0.1$
Yirgacheffee	Jute	$1.84^{a} \pm 0.10$	$1.71^{abc} \pm 0.05$	$1.62^{abc} \pm 0.1$	$1.49^{abc} \pm 0.07$	$1.45^{ab} \pm 0.1$	$1.21^{abc} \pm 0.09$	$1.16^{ab} \pm 0.1$
	PP + LDPE		$1.80^{a} \pm 0.13$	$1.77^{a} \pm 0.15$	$1.61^{ab} \pm 0.1$	$1.57^{a} \pm 0.17$	$1.32^{ab} \pm 0.06$	$1.28^{a} \pm 0.1$
	GP + Jute		$1.77^{ab} \pm 0.05$	$1.68^{ab} \pm 0.1$	$1.60^{ab} \pm 0.15$	$1.57^{a} \pm 0.17$	$1.28^{ab} \pm 0.17$	$1.22^{ab} \pm 0.17$
	PICS		$1.78^{ab} \pm 0.05$	$1.67^{ab} \pm 0.1$	$1.55^{ab} \pm 0.07$	$1.51^{ab} \pm 0.1$	$1.24^{abc} \pm 0.09$	$1.19^{ab} \pm 0.13$
	Mean	1.73	1.65	1.56	1.42	1.38	1.16	1.12
	CV	6.30	3.64	7.05	7.35	9.18	6.00	7.09

Note; the values assigned by the same letter in the column are not significantly different ($p < 0.5$). PP = Polypropylene, LDPP = Low density polyethylene, GP = Grain pro, Packaging M. = Packaging materials.

Table 14
Effect of packaging materials on raw coffee bean color (%) change for coffee brands during 12 months storage.

Factors		Storage duration (in months)						
Coffee types	Packaging M.	0	2	4	6	8	10	12
Limu	Jute	$13.3^{ab} \pm 2.00$	$11.5^{a} \pm 0.87$	$10^{b} \pm 0.00$	$9d^{e} \pm 1.73$	$8.67^{bcd} \pm 2.31$	$13.11^{a} \pm 1.30$	$14^{a} \pm 1.73$
	PP + LDPE		$13.3^{a} \pm 1.44$	$13.33^{ab} \pm 2.89$	$11.33^{bcd} \pm 1.38$	$10.67^{abcd} \pm 1.16$	$10.11^{c} \pm 0.19$	$10^{b} \pm 0.00$
	GP + JB		$13.5^{a} \pm 0.00$	$13^{ab} \pm 1.16$	$11.25^{bcd} \pm 0.75$	$10.67^{abcd} \pm 1.16$	$10.67^{abc} \pm 0.88$	$10.67^{ab} \pm 1.16$
	PICS		$12.67^{a} \pm 2.08$	$12.33^{ab} \pm 2.52$	$11.58^{abcd}_{\pm 0.38}$	$11.33^{abcd} \pm 1.16$	$10.22^{bc} \pm 0.19$	$10^{b} \pm 0.00$
Sidama	Jute	$15^{a} \pm 0.0$	$13.67^{a} \pm 1.26$	$12.33^{ab} \pm 2.52$	$8.58^{de} \pm 1.28$	$7.33^{cd} \pm 2.31$	$12.89^{ab} \pm 1.06$	$14^{a} \pm 1.73$
	PP + LDPE		$14.5^{a} \pm 0.87$	$14^{ab} \pm 1.73$	$12.75^{abc} \pm 1.98$	$12.33^{abc} \pm 2.52$	$11.78^{abc} \pm 2.08$	$11.67^{ab} \pm 2.89$
	GP + Jute		$15^{a} \pm 0.00$	$15^{a} \pm 0.00$	$14.25^{ab} \pm 1.30$	$14^{ab} \pm 1.73$	$11.78^{abc} \pm 0.86$	$11.33^{ab} \pm 1.16$
	PICS		$15^{a} \pm 0.00$	$15^{a} \pm 0.00$	$15^{a} \pm 0.00$	$15^{a} \pm 0.00$	$12.5^{abc} \pm 0.00$	$12^{ab} \pm 0.00$
Yirgacheffe	Jute	$12.8^{b} \pm 2.5$	$11.5^{a} \pm 1.80$	$11.33^{ab} \pm 1.16$	$7.33^{e} \pm 0.75$	$6^{d} \pm 0.00$	$10.44^{abc} \pm 0.96$	$11.33^{ab} \pm 1.16$
	PP + LDPE		$13.2^{a} \pm 2.02$	$13^{ab} \pm 1.73$	$10.75^{cde} \pm 0.43$	$9.33^{abcd} \pm 0.00$	$10^{c} \pm 0.00$	$10^{b} \pm 0.00$
	GP + Jute		$12.2^{a} \pm 1.26$	$12^{ab} \pm 0.00$	$11^{bcd} \pm 0.87$	$10.33^{abc} \pm 1.16$	$10.67^{abc} \pm 0.88$	$10.67^{ab} \pm 1.16$
	PICS		$14.5^{a} \pm 0.87$	$15^{a} \pm 0.00$	$14.25^{ab} \pm 1.30$	$14^{ab} \pm 1.73$	$11.22^{abc} \pm 1.13$	$10.67^{ab} \pm 1.16$
	Mean	13.72	13.4	13.03	11.42	10.89	11.28	11.36
	CV	11.65	8.11	9.6	8.83	12.16	6.89	8.53

Note; Average followed by same letter in same column do not differ significantly (P < 0.05). PP = Polypropylene, LDPE = Low density polyethylene, GP = Grain pro, Packaging M. = Packaging materials.

coffee stored in jute bags ranged from 6 % to 8.7 (Faded to Greenish) until eight months, and the changes were increased to 11.3–14 % (Greenish to Grayish) at the end of the storage time.

This variation might be due to the correlation between types of packaging materials, moisture content of the coffee brands, and coffee beans' chemical changes under prolonged storage time, which could have determined the green coffee beans' color. As a result of the permeability property to the fluctuation of the environment in the warehouse, the changes in colors of coffee brands stored in jute bags were increased throughout the storage periods. Moisture movement in and out of the packaging materials leads to moisture absorption by the beans because of their hygroscopic nature and rewet beans in the storage area, resulting in significant changes in color. Moreover, conventional packaging materials like jute bags are permeable to oxygen and favor the oxidation process, resulting in color change. The current finding is supported by the finding of different authors who reported that significant variation was observed among coffee beans stored in conventional and hermetic packaging materials in terms of bean color change [6,10,14].

3.5.2. Total cup quality

The initial cup quality of coffee brands before storage was 84.9, 83.8 and 82.3 % for Limu, Sidama, and Yirgacheffee coffee, respectively. The total cup quality value ranged from 75 to 79.1, 81.1 to 82.2, and 81.4–82.5 % for Limu, Sidama, and Yirgacheffee coffee, respectively, at the end of the experiment (Table 15). There was a significant interaction effect ($p < 0.05$) among packaging materials and coffee brands on total cup quality. Limu coffee stored in PICS, PP + LDPE, Grain Pro, and jute bags scored the minimum total cup quality value ranging from 75 to 79.1 % over twelve months' storage, which could be graded as Grade 3. According to ECX specialty grade classification, the total cup quality score <80 % is graded to Grade 3 for the commercial market. On the other hand, Sidama and Yirgacheffee coffees stored in PICS, PP + LDPE, Grain pro, and jute bags scored the highest total cup quality values ranging from 81.1 to 82.5 % over the storage periods and entered the Specialty grade level.

Table 15
Effect of packaging materials and coffee brands on total cup quality score (%) value during 12 months storage time.

Factors		Storage duration (In months)						
Coffee types	Packaging. M.	0	2	4	6	8	10	12
Limu	Jute	$83.3^{a} \pm 0.59$	$82.3^{ab} \pm 0.48$	$81.56^{a}_{\pm}1.13$	$81.14^{ab} \pm 1.1$	$81^{ab} \pm 1.09$	$79.4^{ab} \pm 1.23$	$79.06^{abc} \pm 1.56$
	PP + LDPE		$82.5^{ab} \pm 0.34$	$81.53^{a} \pm 0.86$	$80.9^{ab} \pm 0.74$	$80.7^{ab} \pm 0.71$	$76.5^{bc} \pm 0.43$	$75.64^{cd} \pm 61$
	GP + JB		$82.13^{ab} \pm 1.01$	$81.25^{a} \pm 1.75$	$78.65^{b} \pm 0.6$	$77.8^{bc} \pm 0.84$	$77.6^{bc} \pm 1.87$	$77.61^{bcd} \pm 2.12$
	PICS		$79.76^{b} \pm 1.72$	$76^{b} \pm 2.54$	$75.48^{c} \pm 0.96$	$75.3^{c} \pm 2.02$	$75.1^{c} \pm 1.29$	$75.11^{d} \pm 1.71$
Sidama	Jute	$83.8^{ab} \pm 1.09$	$83.03^{ab} \pm 1.92$	$82.33^{a} \pm 2.82$	$81.9^{a} \pm 1.5$	$81.8^{ab} \pm 2.65$	$81.2^{a} \pm 0.32$	$81.08^{ab} \pm 0.88$
	PP + LDPE		$83.33^{ab} \pm 1.25$	$82.72^{a} \pm 1.25$	$82.70^{a} \pm 0.15$	$82.6^{a} \pm 0.59$	$81.8^{a} \pm 0.73$	$81.6^{ab} \pm 0.94$
	GP + Jute		$83.24^{ab} \pm 0.53$	$83.03^{a} \pm 1.19$	$82.78^{a} \pm 0.37$	$82.69^{a} \pm 0.29$	$82.3^{a} \pm 0.31$	$82.2^{a} \pm 0.36$
	PICS		$83.21^{ab} \pm 1.01$	$82.47^{a} \pm 0.84$	$82.35^{a} \pm 1.87$	$82.31^{a} \pm 2.21$	$81.93^{a} \pm 1.86$	$81.86^{a\pm}1.83$
Yirgacheffe	Jute	$84.9^{b} \pm 1.43$	$83.93^{a} \pm 1.81$	$82.97^{a} \pm 1.41$	$82.26^{a} \pm 1.11$	$82.03^{a} \pm 1.54$	$81.5^{a} \pm 1.5$	$81.4^{ab} \pm 1.88$
	PP + LDP		$84.18^{a} \pm 1.36$	$83.53^{a} \pm 0.97$	$83.15^{a} \pm 0.54$	$83.03^{a} \pm 0.39$	$82.21^{a} \pm 0.2$	$82.03^{a} \pm 0.26$
	GP + Jute		$84.11^{a} \pm 0.50$	$83.58^{a} \pm 1.31$	$83^{a} \pm 0.71$	$82.78^{a} \pm 0.54$	$82.2^{a} \pm 0.94$	$82.08^{a} \pm 1.13$
	PICS		$84.2^{a} \pm 1.23$	$83.28^{a} \pm 1.5$	$83.19^{a} \pm 0.71$	$83.17^{a} \pm 0.52$	$82.6^{a} \pm 0.38$	$82.5^{a} \pm 0.55$
	Mean	84	82.99	82.59	81.46	81	80.7	80.2
	CV	1.23	1.36	1.24	1.06	1.38	1.28	1.37

Note: Average followed by same letter in same column do not differ significantly (P < 0.05). PP = Polypropylene, LDPP = Low density polyethylene, GP = Grain pro, Packaging M = Packaging materials.

The possible reasons for total cup quality variation among coffee brands could be due to variations in genetic makeup and growing agroecology. Sidama and Yirgacheffe coffee's inherent properties might contribute to maintaining the total cup quality over storage time. On the contrary, Limu coffee beans might have a lower inherent quality to resist the impact of packaging materials or possibly chemical reactions with the components of hermetic packaging materials that could decrease their cup quality attribute.

When the initial and final total cup quality were compared, the Limu brand showed a decrease in total cup quality by 5.1 % (Jute bag), 9.2 % (PP + LDPE), 6.8 % (GP + Jute), and 9.8 % (PICS). For this coffee brand, the Jute bag showed better cup quality retention than others. However, for the Sidama brand, the quality decreased by 3.2 % (Jute bag), 2.7 % (PP + LDPE), 1.9 % (Grain pro), and 2.3 % (PICS), relatively better than the Limu brand with superior results for samples stored in Grain pro. In the case of the Yirgacheffee brand, total cup quality is comparatively closer to the Sidama brand with a quality reduction of 4.1 % (Jute bag), 3.4 % (PP + LDPE), 3.3 % (Grain pro), and 2.8 % (PICS). Results in this study showed that Sidama and Yirgacheffee respond better to hermetic storage materials in terms of preserving better total Cup quality than the Limu brand, which performed for the Jute bag. This might be the demand for ambient oxygen for various chemical and biochemical processes in Limu coffee beans to develop desired cup quality parameters as compared to samples stored in hermetic bags.

The present finding agrees with the report of Behailu et al. [11] that Limu, especially 'Enaria' coffee cup quality, has no outstanding value, and Beans also quickly fade and look soft. These characteristics influence total cup quality and extended storage time when stored in airtight storage packages. Moreover, Wintgens [54] and Worku et al. [40] reported that coffee beans produced at a lower altitude in hot and humid environments have lower flavor and bean structure due to fruits maturing quickly. Hence, Limu coffee is grown at a medium altitude compared to Yirgacheffee, and Sidama coffee might also contribute to an observed variation in total cup quality (Table 1). The recorded result for total cup quality also aligns with the value recorded for other parameters. In the present study, higher values of chlorogenic acid, TPC, TTA, and lower values of pH were recorded for Limu coffee brands than the two types of brands. These all contribute to the lower value of total cup quality observed.

Except for the slight variation observed in Limu coffee brands, the report of Borém et al. [26], and Donovan et al. [14], supports the present finding, stating that the cup quality of the coffee was better maintained at above 80 % in hermetic storage (PICS, Grain Pro, hermetic big) bags than non-hermetic storage bags for extended storage time.

4. Conclusion

In Ethiopia, Jute bags (conventional packaging) are commonly used to store coffee beans under ambient storage conditions, and there is limited usage of hermetic packaging technology for Parchment coffee bean storage in warehouses. These kinds of packaging materials expose the beans to ambient atmospheric conditions, leading to moisture loss and most of the desirable physicochemical quality parameters. Therefore, alternative packaging materials suitable for selected coffee brands are needed to reduce desirable quality loss during extended storage. The study evaluated the effect of four hermetic and one non-hermetic packaging material on the physical, chemical, and sensory properties of raw and coffee brew of three Ethiopian coffee brands (Limu, Sidama, and Yirgacheffe coffee) Stored for twelve months under ambient environmental conditions. The results revealed that the interaction effect of coffee brands and packaging materials had a significant effect ($p < 0.05$) on most of the parameters measured over the storage time except bioactive compounds. All coffee brands showed wider variability in physical, chemical, and sensory properties.

Compared with all hermetic packaging materials, jute bags did not protect against losing most quality parameters. In contrast, the hermetic packaging materials (Grain Pro and PICS) showed better performance in minimizing the extent of loss of quality parameters of studied coffee brands. Even if the effect of PP + LDPE is relatively inferior to commercially available hermetic bags, it performed better than conventionally used Jute bags in terms of preserving most of the quality parameters during storage time. The study results showed that most quality parameters significantly reduced after six to eight months of storage, and it is better to avoid storing parchment coffee beans for more than six or eight months. As expected, the Sidama and Yirgacheffee brands' quality parameters were found to be better than Limu, and they respond better to hermetic storage than the latter. The present work indicated that Sidama and Yirgacheffee parchment coffee brands can be kept for a year when stored in these hermetic bags with minimum loss of raw beans and total cup quality characteristics. Therefore, coffee exporters are advised to use hermetic (PICS and Grain Pro) bags to maintain inherent cup quality attributes and better market price for Sidama and Yirgacheffee coffee. However, the cup quality of Limu parchment coffee was degraded as the storage time advanced, regardless of the packaging materials used. Thus, it is better to sell Limu-washed coffee brands without storing them for longer.

Ethical statement

The study adhered to the ethical principles outlined in Jimma University's approved rules and regulations for conducting research. The Research and Ethical Review Board (RERB) of the College of Agriculture and Veterinary Medicine of Jimma University comprehensively reviewed the project and provided a serial code of AgVmPHM/16/1 upon registration.

Consent from participants

During data collection, particularly for sensory evaluation, participants were informed of the study's objective, their rights, and the voluntary nature of their participation before starting to score their sensory perception. They were assured that their idea would be kept confidential and used solely for research purposes. Participants were also informed that there were no known risks associated with taking part in the study, and they were free to withdraw from participation at any time without penalty.

Consent for publication

Not applicable.

Data availability

Data are available upon request from the corresponding author. Corresponding author email: chalagowe@gmail.com; or chala.gowe@ju.edu.et.

CRediT authorship contribution statement

Firehiwot Assefa Eshete: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yetenayet B. Tola:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Chala G. Kuyu:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Formal analysis, Data curation, Conceptualization. **Kassaye Tolessa:** Resources, Funding acquisition, Data curation. **Dinka Mulugeta:** Resources, Investigation. **Shitaye Gure:** Writing – review & editing, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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