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Research article

Effect of packaging materials and storage duration on the functional quality of red hot peppers (*Capsicum annum* L.) pods

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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

The preservation of the functional quality of red pepper requires appropriate packaging materials, storage duration, and condition. This study evaluated the effect of the packaging materials and the storage duration on the functional quality of the red hot pepper pod for ten months at ambient storage temperature (25±2 °C) in four packaging materials: Jute sacks, Fertilizer Liner Sheet (FLS), Fertilizer Woven Polypropylene + Liner Sheet (FWPP + LS), and PICS bags (Purdue Improved Crop Storage) using two-factor factorial designs. The samples were analyzed at two-month intervals for water activity (aw, extractable color, total phenolic compounds, pungency index and oleoresin content. Except for aw, other functional qualities of red hot pepper degrade with advanced storage in all packaging materials. At the end of storage, the maximum values of aw (0.76) and the minimum values of aw (0.38) were recorded in jute sacks and PICS bags. Extractable color (ASTA units) decreased from 225.42 to 133.11, 228.71–139.09, 274.29–171, and 288.91–218.98 in jute bags, FLS, FWPP + LS, and PICS bags, respectively. Phenolic compounds (GAE mg/g dry samples) degraded from 2.32 to 1.02, 2.33–1.37, 2.4–1.35, and 2.59–1.85 in jute bags, FLS, FWPP + LS and PICS bags, respectively. The pungency index (Abs/g dry samples) of the samples changed from 4.55 to 2.56, 5.49–4.00, 5.00–3.49, and 4.74–2.72 in jute bags, FLS, FWPP + LS, and PICS bags, respectively. The oleoresin content (%) decreased from 12.88 to 7.18, 12.92–7.78, 13.19–8.45 and 13.58–9.88 in jute sacks, FLS, FWPP + LS and PICS bags, respectively. The study revealed that the PICS bags retained the highest functional qualities compared to other packaging materials.

1. Introduction

Pepper (*Capsicum* spp.) is one of the oldest and most widely grown crops in the world. The capsicum species have been used as a spice since 5500 BCE in prehistoric records. The primary origins of capsicum species are believed to be in Central and South America, and secondary origins occur in Mexico and Peru. Later, it was spread to the New World Tropics and brought to Asia and Africa in 1493 [1]. As it spread throughout the world, its popularity as a spice increased, leading to a multitude of regional varieties [2]. Known for their versatility as a vegetable, spice or condiment in fresh, dried or processed foods, hot peppers are currently the second most

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important vegetable grown worldwide, after tomatoes [3]. Asia, the United States, Europe, and Africa contributed 65 %, 13.3 %, 11.9 %, and 10.1 % of global pepper production, respectively [4].

Red peppers have long been used as food additives and as decorative plants. In addition, it is used as dried spices (whole fruits and powder); fresh, as multicolored, green, and red whole fruits in sauces, pastes, canning, and pickling [5]. Due to its antimicrobial, antitumor, immunosuppressive, and antioxidant properties, it is also used as a medicinal herb for pain management [6]. It prevents stomach problems such as acid reflux, gastritis, flatulence, and loss of appetite [7]. In addition, it has antiatherosclerotic, antidiabetic, and antihypertensive drug properties and helps to control dyspepsia, oxidative stress, inflammation, and body weight [8].

Red pepper carotenoids are beneficial to humans in a variety of ways, such as providing provitamin A and a natural color of food [9]. Oleoresins and ground pepper also enhance the taste and color of soups, stews, sausages, cheese, snacks, salad dressings, sauces, pizza, candies, and drinks [10]. Furthermore, oleoresin contains vitamin C, phenolic compounds, proteins, fats, carbohydrates, dietary fiber, sodium, potassium, calcium, magnesium, iron, zinc, copper, pungent compounds, and manganese [11]. Due to its essential function as an artificial food coloring, it serves as a source of income for many countries that produce red hot peppers [12].

Hot red pepper is one of the most widely grown vegetable crops in Ethiopia. FAOSTAT [13] stated that Ethiopia is the second largest producer of hot red pepper after Madagascar in Africa. About 3 131 154.28 quintals of dry pods were harvested from 174, 463.62 ha in the 2019/2020 production year and took 73.13 % of the area covered by vegetables at national level in 2019/20 [14]. Additionally, Titus et al. [15] reported that dry chillies and peppers took a share of 83 % of the spices produced in Ethiopia. Ethiopians use hot red pepper powder for coloring; it gives pungency and flavour to food. Mark [16] indicated that the Ethiopian adult consumes up to 15g of red hot pepper product per day. Ethiopia is listed in a few countries that produce capsicum oleoresin and powder for the export market [17]. In addition to red hot peppers, sweet peppers, chilies, and bird eye are cultivars that are being produced in the country that have a low demand [18]. Most Ethiopians prefer the dark brown 'Mareko' and 'Halaba' types [19].

However, the fading of the color of red pepper during processing and storage is a significant threat to the quality of red hot pepper products during storage due to several intricate factors [19–23]. Consequently, dishonest vendors are adulterating red pepper products with synthetic materials such as rhodamine, Sudan dyes, oils, and water-adjuvant and oil-soluble dyes [24,25]. Therefore, it is crucial to address issues such as inappropriate storage methods [26], inefficient post-harvest handling and pepper production methods [27], and a shortage of agricultural inputs, post-harvest technology and expertise [28].

In Ethiopia, red hot pepper is stored in the traditional storage structure constructed from wood sticks and mud 'Gotera', filled in a sack and placed in 'Kot', on the floor and stem with the stem at the farmer level, while whole sellers and retailers store the red hot pepper pod on the ground in a pile, in polypropylene bags and in jute bags for an average period of 3.9 months, while assemblers store pepper in jute bags, in piles on the floor of a store room, and in woven polypropylene bags from 15 days up to 2 years [21,29]. The use of hermetic bags is rare for pepper storage; however, the use of hermetic bags can improve the re-drying of red pepper due to moisture absorption in storage, causing mold development and color change on the product.

Purdue's Improved Crop Storage (PICS) technology is a triple layer bag composed of two polyethylene bags and one outer woven polypropylene bag developed with the intention of cow pea storage to reduce insect infestation by reducing oxygen level in the storage. However, the PICS bag is currently being used in the storage of grains and legume crops [30–32]. Furthermore, Hong et al. [33] reported that packaging materials with high gas barrier properties are good for the storage of red peppers. In this case, the triple layer of the PICS bag can minimize the physicochemical and functional qualities of the red pepper pod that deteriorated due to the reaction of oxidation during storage. The practice of reusing the inner lining of fertilizer-woven polypropylene with a single HDPE polyethylene bag for crop storage is also common in Ethiopia. For instance, Seifu et al. [34] reported that the efficacy of the non-hermetic fertilizer bag (woven polypropylene bag lined with single layer polyethylene) is better compared to hermetic bags compared to polypropylene bags and jute bags that are not hermetic for 12 months of storage duration on the quality of faba bean seeds in ambient storage. Furthermore, Damte and Tiruaynet [35] reported that the higher the efficacy of hermetic storage packaging materials such as the Grain Prosuper bag, Purdue's Improved Crop Storage (PICS) bag and fertilizer bag than the polypropylene bag during storage of tef, durum wheat, lentil, and chickpea seeds for 24 months. Perhaps there is no scientific information on how hermetic packaging materials and storage durations affect the functional quality of the red hot pepper pod (*Capsicum annuum* L, var. Marako Fana) during storage. Therefore, this study aimed to investigate the effect of packaging materials (polypropylene bag + single inner polyethylene liner, jute bags, polyethylene liner bags, and PICS) and storage duration on the functional quality of red hot pepper pods.

2. Materials and methods

2.1. Materials

Aacetone, methanol, ethanol, and petroleum ether were bought from Ranchem chemicals found at Kirkos Subcity in Addis Ababa city, Ethiopia. Others such as sodium hydroxide, distilled water, gallic acid, sodium tungstate, sodium molybdate, phosphoric acid, hydrochloric acid, lithium sulfate, bromine, metaphosphoric acid, and $NaHCO_3$ were obtained from Ambo University Chemistry and Biology department Laboratories.

2.2. Collection and preparation of samples

The fully ripened red hot pepper pod (var. *Mareko Fana)* was purchased from the pepper producer of the Jimma zone Omonada woreda. Red pepper pods were sorted to remove foreign materials, damaged pods, and stalks. The cleaned pods were dried under an open sun on canvas until a constant weight was achieved. A 150g pod of uniform appearance is packed in each packaging material. For each packaging material, six packed samples were prepared for random sampling at intervals every two months and stored at ambient temperature (25 ± 2 °C) for ten consecutive months.

2.3. Characteristics of the storage materials used

Four types of packaging materials were used for this experiment, with a size of 40x30 cm. The packaging materials were purchased from the local market in Jimma, Ethiopia. The PICS bag is the triple layer consisting of outer woven polypropylene with 100 μm and the inner two high density polyethylene bags each having a thickness of 80 μm. Fertilizer bag (woven polypropylene bags with a single inner polyethylene liner). The thickness of the fertilizer bags and polyethylene liner bags were 125 and 112.52 μm respectively (Table 1). The outer woven polypropylene and jute bags were resized and sewn, while polyethylene plastics were carefully thermally sealed using a pedal seaming machine for barrier functions against water vapor and oxygen migration and 150 g of red hot pepper pod was filled and tithed. The samples were stored at ambient (25±2 °C) for later analysis. Polyethylene sheet liners and jute sacks were used to represent conventional packaging materials used by farmers, assemblers, whole sellers, and retailers, while PICS bags and fertilizer woven polypropylene with single liner were used to represent alternative hermetic technologies.

2.4. Experimental design and treatment combination

A complete randomized design (CRD) was used to establish the study. For this experiment, a two-factor factorial design with three replications was used. The two independent variables were packaging materials (four levels of packaging material: NJS, PICS, LDPE and WPP + LDPE) (Fig. 1) and storage duration (months) (five levels of storage durations: 2, 4, 6, 8, and 10). The quality analyzes of the stored samples were carried out for ten months every two months. The baseline data used to assess the trend of loss of functional quality parameters were the initial values measured at time zero prior to the start of storage.

2.5. Methods

2.5.1. Determination of water activity (aw)

The water activities (aw) of the prepared samples were determined using a Pawkit water activity meter (Decagon Devices, Inc., Pullman, Washington, USA) at ambient temperature (25±2 °C) [36]. The sample cup was half filled with 5 g of powder to ensure the accuracy of the result and to avoid the powder from covering the instrument sensor. The Pawkit water activity meter was placed on the cup and the water activity level of the samples was measured in 5 min.

2.5.2. Determination of extractable color

The extractable color was determined following the ASTA 20.1 method (American Spice Trade Association) (Eq. (1)) [37]. A 0.1 g pod powder sample was weighed and placed in a 100 ml volumetric flask. The volumetric flask was covered with aluminium foil to hinder light exposure since we did not get the amber coloured type. The samples were then diluted in 100 ml of acetone and kept in the dark at room temperature for 16 h for incubation. Finally, the solution was shaken and waited until settled, after the sample was settled, the absorbance was measured using UV-VIS spectrophotometer (Optizen POP, Korea) at a 460 nm wavelength with acetone as the blank. Finally, the results were reported in ASTA units as follows.

Total extractable color (ASTA units) = (Absorbance at 460*16.4)/ (sample weight (g) (1)

2.5.3. Determination of the total phenolic content (TPC)

The total phenolic compound of the red pepper pod was determined using the method of [38]. A 0.1g powder was extracted in 30 ml of methanol (70%V/V). The sample containing the solvent was shaken for 30 min. The Folinciocalteau reagent was prepared by dissolving 10 g of sodium tungstate and 2.5 g of sodium molybdate in 70 ml of water. Then 5 ml of 85 % phosphorus acid and 10 ml of concentrated hydrochloric acid were added and refluxed for 10 h. Then 15 g of lithium sulfate, 5 ml of water and 1 drop of bromine were added and refluxed for an additional 15 min. The solution was cooled to room temperature and filled to the mark in a 100 ml measuring flask using water. 1 ml of the sample extract was taken into a test tube to be mixed with 5 ml of Folinciocalteau reagent (diluted 10x) and 4 ml of 7.5 % Na_2CO_3. The tubes were covered with aluminum foil and allowed to stand for 30 min at room temperature before absorbance was read at 765 nm using a UV/Vis spectrophotometer (Optizen POP, Korea). Gallic acid solution was

Table 1
Characteristics of the packaging materials used in the study.

Packaging materials	Number of Inner liner	Size (cm^2)	Thickness (μm)		Density (g/cm^3)	
			Liner	Polypropylene	Liner	Polypropylene
PICS	Two polyethylene sheet liners	40x30	80	100	0.704 for each	0.341
Fertilizer Woven polypropylene bag	One polyethylene sheet liner	40x30	112.52	125	0.555	0.342
Fertilizer liner sheet	–	40x30	112.52			
Jute sack	–	40x30	Porous		1	

Fig. 1. Red pepper pod samples packed in different storage materials, a = jute sacks, b = PICS bags, c = fertilizer liner sheet (FLS), d = fertilizer-woven polypropylene + liner sheet.

used as standard. Total polyphenols were expressed as mg/100 g of Gallic acid equivalents from the calibration curve.

2.5.4. *Measurement of pungency*

The pungency of the samples was assessed using the Hossain and Bala technique [39]. The 4 g sample was weighed and placed on whatman number two filter paper and washed with acetone until a colorless acetone solution was obtained, indicating no further extraction. Then, acetone was added to the extract until the volume of the extract reached 100 ml. The extract was kept at room temperature for 3 h. The extract was then shaken and 5 mL of the solution was poured into a beaker and heated in a 90 °C water bath until the acetone was completely dry and a dark red crude extract was left. To this end, 5 ml of 0.1 N sodium hydroxide and 3 ml of a solution containing 3 % phosphomolybdic acid were added to the sample and left at room temperature for an hour. Finally, the optical density of the samples was measured at 650 nm using a UV-VIS spectrophotometer (Optizen POP, Korea). The optical density value obtained was used as the pungency index. Samples with higher optical densities are believed to have been hotter because of the presence of more capsaicin.

2.5.5. *Determination of the Oleoresin content*

Oleoresin was extracted in a Soxhlet apparatus using acetone as a solvent [40]. A 20 g powder of the samples was placed on a thimble and placed on a Soxhlet apparatus. The apparatus was set with 150 ml of acetone solvent and extraction was carried out for 6 h. After extraction, the dark red extract obtained was cooled, filtered by Whatman number two filter paper, and allowed to concentrate. The volume of concentrated dark red extract was recorded and 5 ml of the extract was poured into a Petri dish. The excess acetone was allowed to evaporate from the Petri dish at room temperature to obtain a thick sticky dark brown mass. This crude dried mass was weighed and the oleoresin content was calculated using the following formula (Eq. 2):

$$C = D \text{ x } V/5\text{x}20 \times 100\% \tag{2}$$

where C = oleoresin content (%), D = weight of oleoresin obtained from 5 ml of extract and V = total volume of extract obtained.

2.6. *Statistical analysis*

Statistical analysis was performed using Minitab version 21 software. For each response variable, the validity of the model assumptions (normal distribution and constant variance assumptions in error terms) was verified by examining the residuals as described by Montgomery (2020) [41]. The independence assumption was met by random selection of samples and randomization of the order of the experiment. For the interaction effects of significant ($p < 0.05$) and marginally significant ($0.05 < p < 0.1$) interaction effects, a

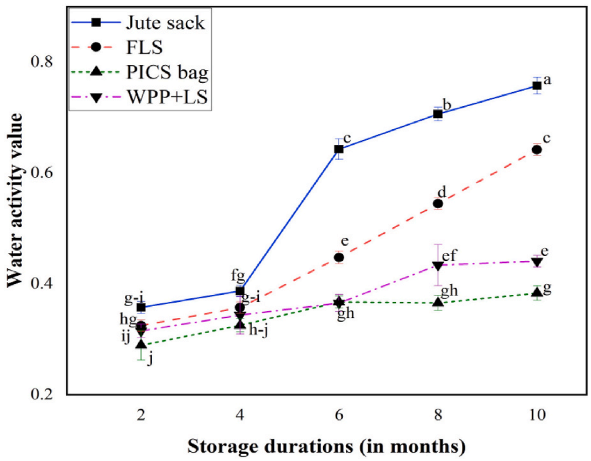

Fig. 2. Effect of packing materials and storage duration on water activity values of red hot pepper pod. Means that share the same letter are not significantly different at α = 0.05 level of significance.

multiple means comparison of the 20 treatment combinations was performed using the Tukey multiple range test at the level of significance of 5 % to generate the grouping of letters.

3. Results and discussion

The statistical results of the water activity, ASTA value, TPC, pungency index and oleoresin of the hot red pepper pod during the study months are presented in Figs. 2–6. The interaction effect of the packaging materials and the storage duration was highly significant in all the response variables ($p < 0.05$).

3.1. Water activity (aw)

Water is a by-product of the Maillard reaction, which enhances the mobility of the reactant and increases the value of the water activity [42]. Elevated water activity and higher temperature cause the red pepper color to brown and black tarnish [43]. The value of water activity of the samples in the present study increased from 0.36 to 0.76, 0.32–0.64, 0.31–0.44 and 0.29–0.38 in Jute sacs, FLS, FWPP + LS and PICS bags, respectively, at storage duration of 10 months (Fig. 2). The change in low water activity in PICS bags with extended storage time is attributed to the superior moisture barrier characteristic of PICS bags [44]. This is in agreement with the findings of Kumari et al. [45], who reported the minimum water activity of green gram stored in hermetic bags after four months of storage compared to jute and plastic polythene bags. For the preservation of colour, a water activity value of 0.3–0.6 is deemed safe [46]. However, the aw of the samples stored in PICS bags and WPP + LDPE bags were considered intermediate aw at all storage durations (less than 0.6) and can inactivate microbial or mold growth and enzyme activity [47]. However, the values of the water activity values in the Jute bags and FLS after the fourth storage month were above the recommended level and have a potential for color degradation. Water activity in this range is also good for controlling lipid oxidation and maillard browning [48].

3.2. Extractable color content

Color is the most important quality attribute of pepper powder because it determines the quality and market price of the product [49]. The red color of red peppers is comprised of cryptocapsin, capsanthin, and capsorubin structures of carotenoids. The stability of carotenoids during storage depends on the variety, drying and storage temperature, exposure to light, and the permeability of oxygen and moisture in packaging materials [50]. Degradation of carotenoids due to oxidation directly affects the quality and quantity of red pepper [51].

In the present study, the extractable color content decreased as the storage duration increased in all packaging materials. In the 10th month of storage, the color decreased from 225.42 to 133.11 228.71–139.09, 274.29–171.09 and 288.91–218.98 ASTA units in Jute sacs, FLS, FWPP + LS and PICS bags with percentage loss of 40.95, 40.77, 37.62 and 24.20, respectively (Fig. 4). The loss of extractable color occurs due to the degradation of carotenoids caused by various factors during storage [51]. The extraction color loss rate in the PICS bags was steady compared to the jute sacks, LDPE and WPP bags. This is due to the barrier property of PICS against light, moisture, and oxygen [52,53]. Addala et al. [54] also reported that temperature significantly affects the rate of extractable color degradation, indicating that lower storage temperatures are preferable for better color preservation. Similarly, Boon et al. [55] stated that lowering the water activity of food samples using moisture, air and light-resistant packaging materials slows the rate of carotenoid degradation during storage. Furthermore, packaging materials with poor moisture barrier capacities allow the product to re-absorb

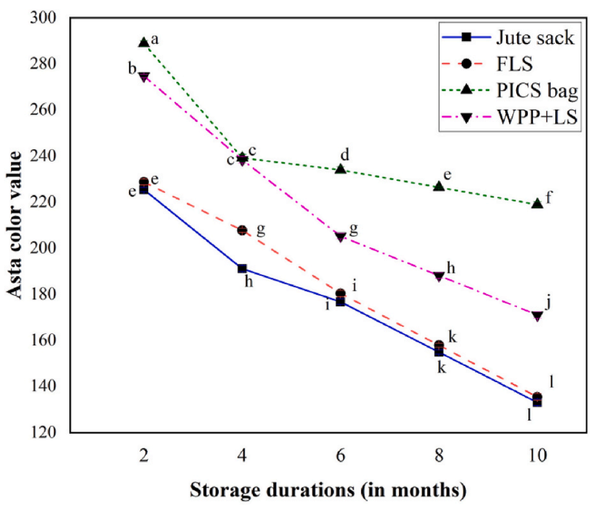

Fig. 3. Effect of packing materials and storage duration on the color value (ASTA units) of the red hot pepper pod. Means that share the same letter are not significantly different at α = 0.05 level of significance.

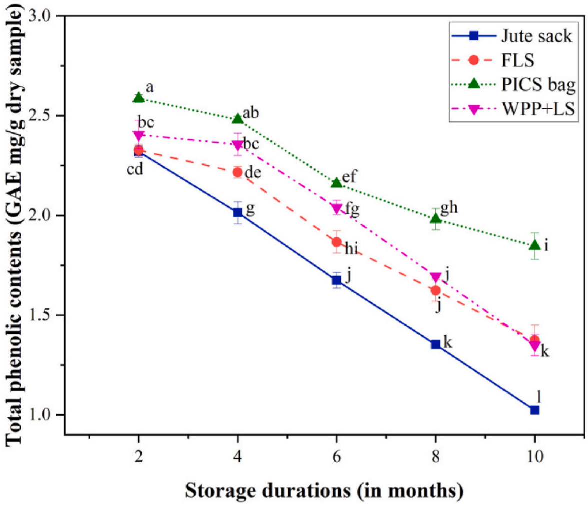

Fig. 4. Effect of packing materials and storage duration on total phenolic compounds (GAE mg/g dry sample) of red hot pepper pod. Means that share the same letter are not significantly different at α = 0.05 level of significance.

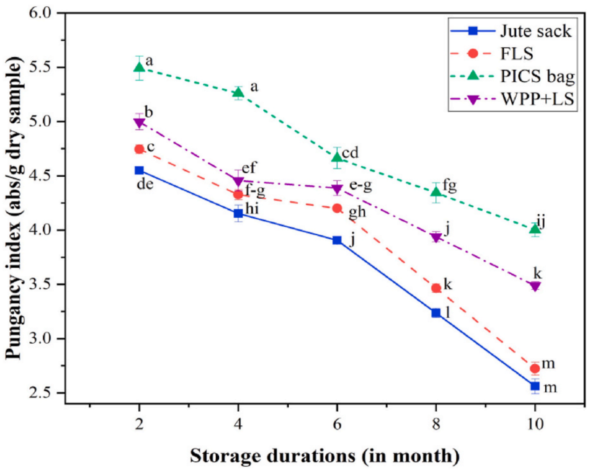

Fig. 5. Effect of packing materials and storage duration on the fungus index (Abs/g) of the red hot pepper pod. Means that share the same letter are not significantly different at α = 0.05 level of significance.

moisture, leading to discolouration and flavour deterioration [56].

3.3. Total phenolic content (TPC)

The total phenolic compound of red pepper contributes a greater share of the total antioxidant activity of red pepper [57,58]. Its antioxidant activity is good for human health and helps prevent the degradation of the quality of red pepper during drying, processing, and post-harvest handling by activating the defense mechanism for singlet oxygen formation [59]. However, the stability of total phenolic compounds during storage depends on the type of packaging materials, storage temperature, and time [60].

The TPC content of the present study degraded from 2.32 to 1.02, 2.33–1.37, 2.4–1.35 and 2.59–1.85, and GAE mg/g of dry samples in Jute sacks, FLS, FWPP + LS and PICS, respectively, during storage of the 10th moth (Fig. 4). The percentage loss of TPC was 56.03, 41.20 %, 43.75 and 26.00 and in jute bags, FLS, FWPP + LS and PICS bags. The decrease in TPC with an increase in storage duration could be due to storage conditions not being ideal due to oxygen, enzymes, light, water activity, chemical modification, reactions with metal ions, and temperature [61]. Mrázková et al. [62] also confirmed that extended exposure to sunlight, oxygen, and elevated temperatures during storage decreases the stability of phenolic compounds.

The red hot pepper pod samples packed in PICS bags showed the best total retention capacity of phenolic compounds. The higher loss of total phenolic compound recorded for FLS bags and jute bags is attributed to their lower hermetic property to oxygen and water vapor compared to PICS bags [63]. Additionally, Elsawy et al. [64] reported the loss of phenolic compounds caused by the oxidation of

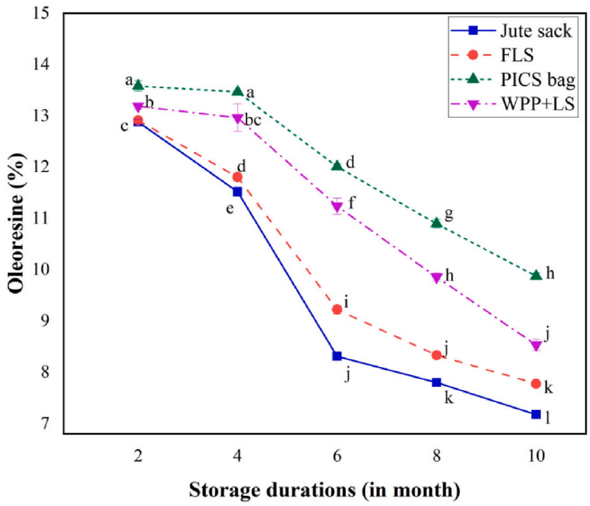

Fig. 6. Effect of packing materials and storage duration on the oleoresin content (%) of the red hot pepper pod. Means that share the same letter are not significantly different at α = 0.05 level of significance.

phenolic compounds during prolonged storage in non-hermetic packaging materials.

3.4. Pungency index (PI)

The pungency index of red hot peppers is an indicator of the heat produced by capsaicinoids, which are alkaloids in the pods of red hot peppers. The content of red pepper pungency compounds varies with variety, growth condition, and ripening stage, post-harvest handling and storage conditions [60,65,66]. Pungent compounds have antioxidant effects and pungent cultivars have greater stability during storage than nonpungent cultivars [67]. Compared to other antioxidant compounds of red pepper, such as phenolic compounds, total carotenoids and vitamin c capsaicinoids have the greatest stability to degradation by oxygen, light, temperature, moisture, and other factors during storage [68].

The PI obtained in this study decreased with a prolonged storage time. At the end of storage time, the PI value of pods stored in jute sacks, FLS bags, FWPP + LS and PICS bags decreased from 4.55 to 2.56, 4.74–2.72, 5.00–3.49 and 5.49–4.00 (Abs/g dry samples) with a percentage loss of 43.76, 42.63, 30.20 and 27.14, respectively (Fig. 5). Studies also showed that as the chance of diffusion of air, moisture, and exposure to light increases, the rate of loss of pungency increases [69]. Long-term exposure to light and oxygen during storage also leads to loss of capsaicinoids [52].

Compared to other packaging materials, samples packed in PICS bags experienced fewer oxidation reactions and retained a higher pungency index. This is also linked to the triple layer of PICS bags that inhibit permiablity to storage conditions. Consistent with our findings, Chetti et al. [52] reported that an increase in the risks of oxidation and moisture absorption of samples stored in jute bags from the storage environment causes the degradation of pungency active ingredients and decreases the content of capsaicin. Iqbal et al. [60] also showed greater loss of capsaicinoid in jute bags at a temperature of 30 °C compared to FLS bags after 5 months. Additionally, pungency compounds in vacuum packed samples remained stable for the first two to three months, but decreased after six months of storage [52,68].

3.5. Oleoresin content

Oleoresin is an oil-soluble crude extract that is a dark red or black-red in color and has a viscous texture. Red pepper oleoresin is used for its spicy characteristics and food coloring [70]. Oleoresin also contains phenolic compounds and antioxidant activities in addition to capsaicinoids and coloring materials that have health benefits [71]. The red pepper variety used to process pepper powder is preferable for the extraction of oleoresin. The pungency and color of oleoresin depend on the variety used for extraction [72] Krithika and Naik [73] reported that high pungency capsicum varieties are produced in Africa, India, and China. Cantrill [74] revealed that a kilogram of paparika extract replaces 12–15 kg of pepper powder in terms of color intensity. The color of the oleoresin extract has greater stability than that of the dry pod. However, the stability of oleoresin is affected by carotenoid degradation and other bioactive compounds due to oxidation at higher temperature and exposure to light [75].

The oleoresin content of peppers ranged from 10.6 to 37.2 % depending on variety, drying methods, extraction methods and other factors [76,77]. In this study, the values of the oleoresin content were stable for the first two months regardless of the packaging materials; however, it showed a very sharp decline after 60 days. At the 10th month of storage, the oleoresin content of the samples reduced from 12.88 to 7.18, 12.92–7.78, 13.19–8.45 and 13.58–9.88(%) samples in Jute sacks, FLS, FWPP + LS, and PICS with a percent loss of 44.25, 39.78, 30.33 and 27.25 respectively (Fig. 6). This could be related to the deterioration caused by oxidation of the active compounds in the red paper [78].

The maximum oleoresin content was recorded in samples stored in PICS bags, followed by WPP + LDPE bags, while the minimum content was recorded in Jute bags. This is in agreement with a finding by Anjaneyulu and Sharangi [79], who reported a reduction in the oleoresin content of red pepper samples from 9.5 to 6.83, 9.50–7.42, 9.50–7.94, 9.50–8.79, 9.50–8.53 and 9.50–8.31 %, after two months of storage in gunny bags, gunny bags lined with polyethylene, paper pouch, laminated aluminum, low-density polyethylene and high-density polyethylene, respectively.

4. Conclusions

The study showed that the effect of interaction between the packaging materials and the storage durations had significantly impacted the functional qualities of the red hot pepper pod during the storage duration of ten months. The minimum and safe water activity value of the samples was recorded in PICS bags. The lower percent loss of extractable color, total phenolic compounds, pungency index and oleoresin content, which were 24.20, 26.00, 27.14 and 27.25 %, was recorded for the red pepper samples stored in PICS bags at the end of storage duration. The maximum loss of functional qualities of the red hot pepper pod was recorded for samples stored in Jute bags with magnitude of 40.95, 56.03, 43.76 and 44.25 % for extractable colour, pungency index and oleoresin content, respectively, at ten months storage period. The study also revealed that the use of FLS without the outer WPP bags is not effective compared to FWPP + FLS because the WPP protects the liners, especially from light and mechanical damage. At the end of the storage period, the percent loss of extractable color, total phenolic compounds, pungency index and oleoresin was 40.77, 41.20 %, 42.63, 39.78, and 37.62, 43.75, 30.20 and 30.33, respectively. Generally, the PICS bag hermetic packaging material showed the best protection of the functional qualities of red hot pepper throughout storage duration followed by FWPP + LS. Finally, a study on the impact of packaging materials, storage methods, and storage duration on safety and other nutritional quality parameters is recommended.

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Data availability statement

All the data used in this study are presented in the article.

CRediT authorship contribution statement

Obse Fikiru: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hana Zinabu Dulo:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Sirawdink Fikreyesus Forsido:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization. **Yetenayet B. Tola:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization. **Tessema Astatkie:** Writing – review & editing, Software, Data curation.

Declaration of competing interest

The authors declare that they have no conflict of interests.

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