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Effect of different packaging materials on storage stability of *Gardenia erubescens* Stapf. & Hutch. dried fruits and powder

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ABSTRACT

Gardenia erubscens fruits have been identified as a valuable source of nutrients and antioxidants, which are beneficial for human health. To preserve the nutritional properties of fruits after drying, appropriate packaging material should be considered. The objective of this study was to explore the effects of different packaging materials namely high-density polyethylene, low-density polyethylene, single-layer polyethylene, double-layer polyethylene and laminated paper bags on moisture content (MC), water activity (a_w), pH, color, ß-carotene, vitamins A and C, and microbial load of dried *G. erubscens* fruit and powder. The samples were stored under ambient conditions for 12-weeks. The results showed that MC and a_w of the dried fruits and powder increased while pH decreased as the storage progressed irrespective of the packaging material type. The redness (a^*), yellowness (b^*) and total color change (ΔE^*) values of both dried fruits and powder were significantly ($p<0.05$) affected by the storage period. Packaging material on the other hand affected ($p<0.05$) a^* and b^* of the dried fruits and ΔE^* of the fruit powder. Beta-carotene, vitamin A and C contents decreased after storage in both packaging material. Microbial results of the dried fruits and powder for the 12-weeks storage in ambient conditions were in acceptable limits, regardless of the type of packaging material. The results suggest that dried *G. erubscens* fruits and powder may be stored in any of the packaging materials investigated for 3 months under ambient conditions without appreciable loss of quality.

1. Introduction

Gardenia erubscens is one of the most important underutilized fruit-bearing shrub species common in tropical Africa (Ouédraogo et al., 2019). The fruit is recognized as highly nutritious food due to its high content of nutrimental and bioactive compounds including dietary fiber, carbohydrates, vitamins, phenols, ß-carotene and very crucial minerals such as iron, calcium, potassium and zinc (Achaglinkame et al., 2019; Bello et al., 2008; Thiombiano et al., 2014). The consumption of fruits with a high antioxidant composition has been reported to reduce risk of degenerative diseases such as cancer, heart disease, inflammation, arthritis, immune system decline, brain dysfunction, and cataracts (Alissa and Fern, 2017; Leong and Shui, 2002). More recently, scientists have suggested that some micronutrients and minerals such as those of *G. erubscens* can be used as a proactive dietary supplement to help manage symptoms and to reduce the risk of severe illness from COVID-19 (Galanakis et al., 2021; Moreb et al., 2021; Galanakis, 2020; Galanakis et al., 2020; Iddir et al., 2020). However, *G. erubscens* fruits are seasonal and highly perishable after harvest which predominantly limits their consumption and wider utilization. Various techniques have been applied to fruits processing to prolong the shelf-life and reduce postharvest losses. Drying is an option to preserve the fruits not only in dried/powder form, but to retain the bioactive compounds (Deng et al., 2019; Tan, Sulaiman, Rukayadi, & Ramli, 2021). Dried fruits are widely used by bakery, confectionary, sweet and distilling industries in various teas, puddings and food for infants and children (Karam et al., 2016). Fruit powders are particularly used as intermediate products in beverage industry as functional food additives for improving nutritional value of foodstuff, as natural colorants or as flavoring agent in yogurts, ice creams, fruit bars etc. (Camire et al., 2007).

Studies have shown that dried fruits and vegetables can be stored in glass jars, metallic containers and plastic and paper bags (Akanbi and Oludemi, 2004; Hossain and Gottschalk, 2009; Khodifad et al., 2018; Miranda et al., 2014; Ranđelović et al., 2014). Although glass jars and metallic containers provide excellent protection to the stored products owing to their inertness and impermeability, they are bulky and take

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up more storage space (Miranda et al., 2014). Additionally, glasses are heavy which increases storage and transportation costs along the value chain (Miranda et al., 2019; Miranda et al., 2014). While glass containers easily break at the slightest manhandling making the product prone to losses, metallic containers may rust at any little exposure to moisture and air if not well coated (Deshwal and Panjagari, 2020). This may contaminate the product and compromise its quality (Bhunia et al., 2013). Plastic packages, on the other hand, do not only provide protection to stored products but are also light and less bulky which helps to reduce costs associated with storage space and transportation (Miranda et al., 2019). Aside plastics, paper bags are also light, less bulky, attractive, and environmentally friendly due to their biodegradability (European Carton Makers Association, 2019; Han et al., 2018; Kirwan, 2011). Therefore, interest in the food industry is currently being shifted to the use of plastics such as polyethylene, polypropylene, polystyrene, among others, and paper bags for the packaging of dried food products as well as fresh produce (Bhunia et al., 2013; European Carton Makers Association, 2019; Han et al., 2018; Miranda et al., 2019).

Although dried fruits/powder are relatively stable because of their intrinsic low pH, low water activity, and the presence of natural antimicrobial compounds, they are sensitive to temperature, light, moisture/humidity, and oxygen, which are critical factors for storage (Deng et al., 2022; Miranda et al., 2019; Udomkun et al., 2016). This is because these factors can alter quality attributes of the food product such as moisture content, water activity, color, pH, microbial load, polyphenols, carotenoids and vitamin C (Deng et al., 2022; Östbring et a., 2020; Hymavathi and Khader, 2005; Pua et al., 2008; Udomkun et al., 2016). By carefully considering all these factors, it is possible to select, design, develop and apply packaging materials to maintain the quality and shelf life of packaged processed agricultural products (Kim and Seo, 2018). Various research works on the storage stability of dried fruits and powder, type of packaging, storage conditions, processing parameters and type of additives and concentrations have been reported in the literature. Khodifad et al. (2018) investigated the effect of laminated aluminum foil and polyethylene bags with and without vacuum packaging and glass bottle on custard apple powder under ambient storage conditions. Sagar and Kumar (2014) suggested that high density polyethylene (HDPE) gauge with storage conditions of 7°C and 85% relative humidity were better suited for preserving qualities of bael powder. Also, Irwandi et al. (1998) agreed that HDPE is more effective to retain quality such as physicochemical characteristics, microbial stability and sensory properties of durian leather. It should however, be noted that properties of the packaging materials play a critical role for shelf-life stability of dried fruits (Udomkun et al., 2016).

Review of literature showed that, there is currently no study conducted on the effects of different packaging material on storage stability of dried *G. erubscens* fruits and powder. Considering these gaps and the recent disruptions of innovations and technologies in the food sector within the COVID-19 pandemic and post-lockdown era (Galanakis et al., 2021), the present study was to evaluate the effect of different packaging materials such as high-density polyethylene (HDPE), low-density polyethylene (LDPE), single-layer polyethylene (SLPE), double-layer polyethylene (DLPE), and laminated paper (LP) bags on quality change (moisture content, water activity, color, pH, ß-carotenes, vitamins A and C, and microbial load) of dried *G. erubscens* fruits and powder during storage. This fundamental exploration of appropriate packaging material is beneficial to the packaging industry and storage of dried *G. erubscens* fruits and powders.

2. Materials and methods

2.1. Sample preparation

Fresh *Gardenia erubscens* fruit samples were purchased from Wiaga market in the Builsa North District, Upper East region, Ghana. The fruits were packed in net bags and transported to the laboratory in the early hours of the day to avoid deterioration caused by high temperatures. *G. erubscens* fruits were visually sorted based on size, color (yellow) and absence of physical damage for the experiments. After which the fruits were washed thoroughly with running tap water, dissected to remove seeds, re-washed and sliced into 3 mm thickness using an electrical slicing machine (Ritterwerk, E16, Germany). The sliced samples were dried at 60 °C using "Hohenheim HT mini" cabinet dryer (Innotech-Ingenieursgesellschaft mbH, Altdorf, Germany) (Korese et al., 2021). The dried fruits of 9.37% moisture content (wet basis) were removed from the drying chamber and allowed to cool to room temperature (25±2 °C) for about 1 hour to attain thermal equilibrium with the environment. Portions of the dried slices were milled into powder using Dzire mill (BL-DZ314H, China). The dried fruits and powders were collected in HDPE, LDPE, SLPE, DLPE, and LP bags for further use in the storage study.

Table 1
Water vapor and oxygen permeability of films and paperboard of the evaluated package bags (Wang et al., 2018).

Package material	WVP[#]	OP[#]
High density polyethylene (HDPE)	<40	>40000
Low density polyethylene (LDPE)	40-400	>40000
Polyethylene (PE)[§]	23	50000 - 200000
Paperboard (P)[¥]	13800	-

[#] WVP: moisture permeability in g.μm/m^2.day.kPa; OP: Oxygen permeability in cm^3.μm/m^2.day.atm.

[§] SLPE bags consist of single layer of polyethylene and moisture and oxygen permeability is expected to be within the range mentioned above.§DLPE bags consist of two layers of polyethylene and the moisture and oxygen permeability is expected to be much lower than mentioned here.

[¥] substrate: paperboard, 178 g/m^2, 190 μm; coating: cellulose microfibril basecoat, 11 g/m^2, ~8 μm¥LP bags are categorized as a laminate of polyethylene and paperboard layers and the moisture permeability is expected to be much lower than mentioned here.

2.2. Packaging and storage

Five packaging materials, namely 50 μm high-density polyethylene (HDPE) bag (150 × 220 mm), 13 μm low-density polyethylene (LDPE) bag (200 × 300 mm), single-layer polyethylene (SLPE) bag (252 × 170 mm), double-layer polyethylene (DLPE) bag (252 × 170 mm), and laminated paper (LP) with dimension 205 × 130 × 51 mm were used in this study. These packaging materials are commonly used in the supply of flours, powders and spices in Ghana. The SLPE and DLPE consisted of 53 μm and 106 μm polyethylene, respectively while LP laminate consisted of the 53 μm polyethylene and 524 μm paperboard layers. Film thickness was measured using a digital micrometer (E12054, China) with an accuracy of 0.001 mm. Water vapor and oxygen permeability of plastic films and paperboard of the evaluated package bags are presented in Table 1. About 150 g each of dried *G. erubscens* fruits and powder samples were filled in the bags and then sealed under atmospheric conditions. The sealed samples were stored in ambient conditions for 3 months. Temperature and humidity were recorded every 5 min using temperature/humidity sensors (Testo 174H, accuracy ±0.2 °C and ±3%) throughout the storage period. The mean temperature and humidity were 28.37 °C and 70.17%, respectively over a 12-week period with ranges of 25.90 °C – 33.00 °C and 56.00% – 78.00%, respectively (Fig. 1). Evaluation of moisture content, water activity, color parameters, pH, and microbial loads were carried out at 0, 1, 2, 3, 4, 5, 6, 8, 10 and 12 weeks' intervals. Sensitive nutrients such as β-carotene, vitamin A and vitamin C of the samples were assessed before and after the storage period.

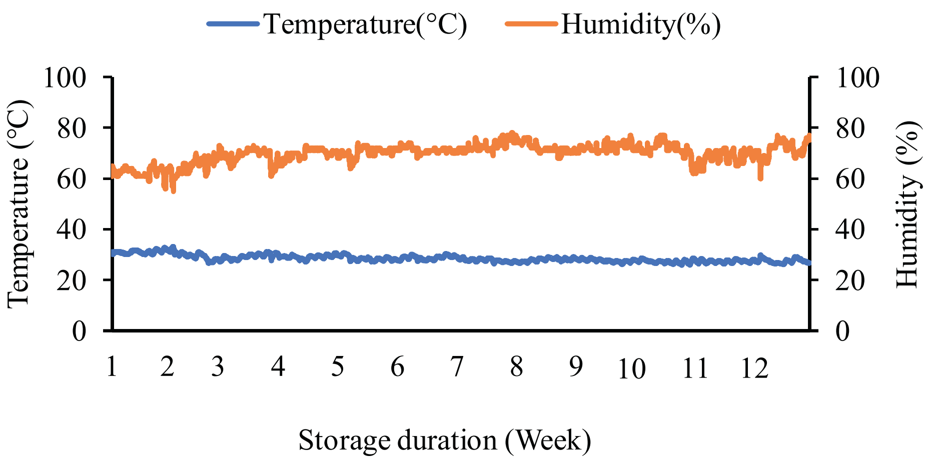

Fig. 1. Variation of temperature and relative humidity at the storage location for dried *G. erubscens* fruits and powder.

2.3. Moisture content and water activity determination

The moisture content (MC) of the *G. erubscens* dried fruits and powder was measured following hot air oven methods at 105°C for 3 h (AOAC, 2012), while the water activity (a_w) was determined by using a water activity meter (LabSwift-aw, Novasina AG, CH-8853 Lachen, Switzerland) as described by Korese et al. (2021). All measurements were carried out in triplicate.

2.4. pH determination

The pH of the dried fruits and powder during storage was determined following procedures of Lengkey and Lobo (2016) with modification. Briefly, one gram of each milled sample was dissolved in 10 mL of distilled water and the pH was then measured using a pH meter (BASIC 20, Crison Instruments, Spain) after the solution was stirred and left to rest for ten minutes. Prior to pH measurement, the pH meter was calibrated using standard solutions with known pH of 7.00 and 4.01.

2.5. Color determination

The color of dried *G. erubscens* fruits and powder was measured throughout the storage period using a hand-held chroma meter (Konica Minolta, CR-400, Japan). Color of the samples were indicated by CIELab color scales L*, a* and b*. The total color change (ΔE) values were calculated using Eq. 1 (Izli et al., 2018).

$$\Delta E = \sqrt{\left(L_o^* - L_t^*\right)^2 + \left(a_o^* - a_t^*\right)^2 + \left(b_o^* - b_t^*\right)^2} \quad (1)$$

Where L_0*, a_0*, and b_0* are the initial L*, a* and b* values of the samples while L_t* a_t*, and b_t* are the L*, a* and b* values at time (t) in weeks for stored *G. erubscens* samples.

2.6. Determination of β-carotene, vitamin A and vitamin C

With little modification, β-carotene and vitamin C contents of the *G. erubscens* samples were determined in accordance with the methods of AOAC (2010) with the aid of a spectrophotometer (UV/VIS Excellence UV5, Mettler Toledo, Switzerland) at 450 nm and 520 nm, respectively before and after storage. Briefly, extracts for vitamin C and β-carotene were obtained by centrifuging about 10 g of each powdered sample in 50 mL of 5% metaphosphoric acid acetic acid solution and 50 mL of 95% ethanol, respectively at 3000 rpm for 15 min using a Rotofix 32 A centrifuge (Andreas Hettich GmbH and Co. KG, Tuttlingen, Germany). The extracts were then used to determine the β-carotene and vitamin C contents spectrophotometrically in triplicates. Vitamin A content of the samples was determined using the conversion ratio of 13 µg β-carotene to 1 µg retinol activity equivalent vitamin A as outlined by Haskell et al. (2004).

2.7. Microbial analysis

Microbial quality of the dried fruit samples was assessed, taking total bacteria count and total fungal (mold and yeast) count as key measurable parameters (AOAC, 1995) using Plate Count Agar (PCA) and Potato Dextrose Agar (PDA) plus Chloramphenicol selective, respectively as media. A gram of sample was dissolved in 9 mL of 0.1% Buffered Peptone Water in a test tube to give a stock solution. Serial dilutions up to 10^{-3} were then made from the stock and spread plated on PCA and PDA plates in duplicates. The PCA plates were incubated at 37°C for 24 h, while the PDA plates were incubated at 29°C for 72 h. All colonies formed after the given incubation periods were counted with the aid of a colony counter (J. P. Selecta, s.a, Barcelona, Spain), and the means expressed as the natural logarithm of colonies formed per gram (log CFU/g). All media and reagent used were purchased from Merck, Germany.

2.8. Statistical analysis

The data generated from this study were analyzed using general linear model in GenStat statistical package (12th edition) with mean separation executed by Tukey post hoc option in the same statistical tool at 95% significance level ($p < 0.05$).

3. Results and discussion

3.1. Moisture content and water activity

The variation in MC and a_w of dried *G. erubscens* fruits and powder is shown in Fig. 2. From the results, it was found that both MC and a_w of the samples increased progressively with storage period under each of the packaging materials (Fig. 2). The initial MC of the dried fruits and powder was 9.17% and 8.97%, respectively. Upon completion of the storage duration (12 weeks), the final MC was increased by 1.26, 0.57, 1.09, 0.60 and 0.45 times for the fruits and 1.14, 0.76, 1.12, 0.80 and 0.49 times for powder when stored in HDPE, LDPE, LP, DLPE and SLPE bags, respectively. According to Noren et al. (2019) and Franco et al. (2016), the hygroscopic characteristics of some foods depend mainly on their chemical composition and air relative humidity. Thus, the gain in moisture content of the product at the end of the experiment can be attributed to the permeability of the packaging materials (Dak et al., 2014), favouring the absorption of moisture from the storage environment. The a_w on the other hand was observed to be in the range of 0.44 – 0.57 for dried fruits and 0.41 – 0.58 for the powder after the storage period. The relationship between a_w and food deterioration is well known in the literature. Labuza and Altunakar (2020) and Fernández-López (2009) reported that microbial growth, lipid oxidation

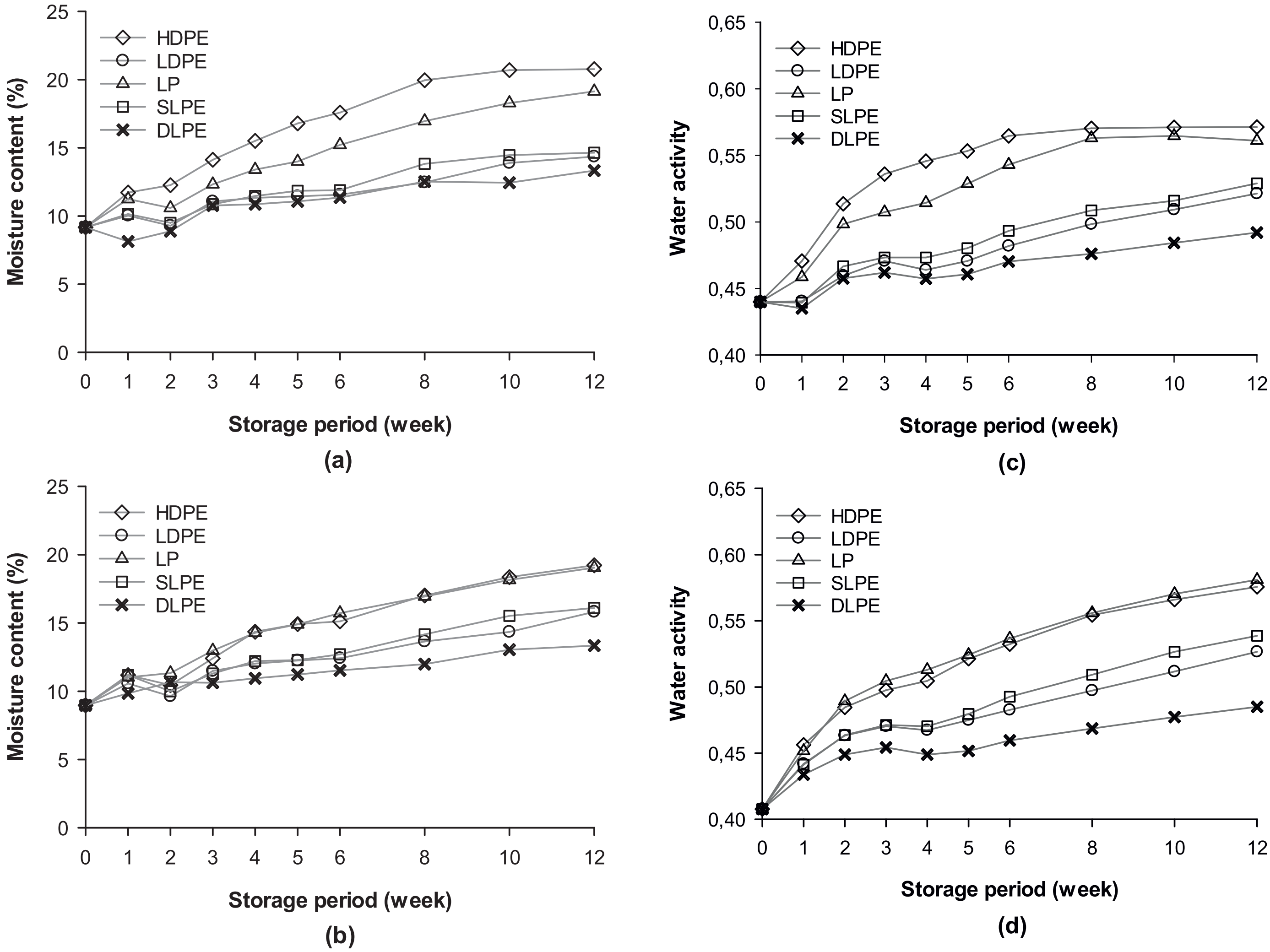

Fig. 2. Effect of the packaging material on moisture content and water activity of *G. erubscens* fruit products during storage. (a) and (c): dried fruits, (b) and (d): powder.

and Maillard browning is not possible in foods with a_w lower than 0.60. Therefore, the a_w of both dried fruits and powder in this study was in acceptable range for 12 weeks of storage under the different packaging materials.

The study also revealed a significant ($p<0.05$) interaction between storage period and packaging material on MC and a_w of the samples. The MC and a_w was significantly ($p<0.05$) higher in both dried *G. erubscens* fruits and powders stored in the HDPE bags compared to similar samples stored in DLPE bags. Irwandi et al. (1998) and Pavani and Aduri (2018) reported similar results where durian fruit leather and dried leafy vegetables stored in HDPE material were found to record slightly higher MC compared to LDPE packaging materials. DLPE bags on the other hand was observed to provide better protection against moisture absorption due to its double-layer following the relatively lower MC and a_w values recorded.

3.2. pH

pH for all the samples generally declined as the storage period progressed, irrespective of the packaging material (Fig. 3). Similar observations, where the pH tended to decrease at the end of the storage period was also reported by Kumar et al. (2020), Obadina et al. (2018) and Kadam et al. (2011) for sweet corn kernel, cherry and plum tomato powder and reconstituted mandarin pulp powder, respectively. The general decline in pH with storage duration could be attributed to the occurrence of biochemical reactions during storage (Ibrahim, 2016). The increase in MC and a_w during storage could partly contribute to the behaviour of pH as moisture and a_w are two of the fundamental drivers of biochemical reactions (Ojewumi et al., 2016). pH plays a vital role in controlling microbial proliferation and growth as microbes are pH-specific (Coton and Leguerinel, 2014). A pH above 6.0 is suitable for most spoilage and pathogenic bacteria to thrive with optimum growth (Coton and Leguerinel, 2014; Jay, 2000). However, pH values recorded in this study were all below 6.0 which will not support the survival, growth, and proliferation of spoilage and pathogenic bacteria. Molds and yeasts, however, can grow at a pH of as low as about 2.0 but prefer 4.0-5.0 for optimal growth and production (Jay, 2000). The values recorded in this study were slightly above the fungal preferred pH range mentioned above. This, therefore, projects the ability of fungal to grow in the stored dried *G. erubscens* fruit samples. Nonetheless, physical fungal growth was not observed in the stored fruits during the 12-week storage period.

3.3. Color

Color is one of the most important appearance attributes which significantly influences consumers' acceptability (Xiao et al., 2014). The color parameters of dried *G. erubscens* fruits and powder for different

Table 2
Effect of packaging material and storage period on the color of dried *G. erubscens* fruits and powder.

Packaging material		L*		a*		b*		ΔE*	
		Dried fruits	Powder	Dried fruits	Powder	Dried fruits	Powder	Dried fruits	Powder
	Before storage	60.44±3.08	71.71±1.16	5.16±1.30	3.90±0.58	37.53±3.07	39.05±1.13	-	-
	Storage period (weeks)								
	1	59.35±1.55^{abcde}	71.59±1.45^{abcde}	5.51±2.90^{abc}	3.70±0.67^{abc}	36.83±4.85^{abc}	37.20±1.09^{a}	5.16±1.80^{a}	2.47±0.70^{a}
HDPE bag	2	56.87±2.97^{de}	73.56±1.62^{abcde}	4.46±1.33^{abc}	3.68±0.72^{abc}	32.81±1.94^{abc}	36.69±0.59^{a}	6.28±3.06^{a}	3.35±0.85^{a}
	3	66.91±1.21^{ab}	74.65±1.75^{abcde}	3.38±1.40^{abc}	3.35±0.63^{abc}	37.23±4.66^{abc}	37.33±1.44^{a}	7.82±2.28^{a}	3.85±1.36^{a}
	4	60.22±6.34^{abcde}	73.82±1.32^{abcde}	5.55±1.54^{abc}	3.70±0.68^{abc}	33.46±3.87^{abc}	35.23±1.37^{a}	7.39±3.21^{a}	4.51±1.60^{a}
	5	61.84±6.47^{abcde}	74.10±1.25^{abcde}	5.82±1.25^{abc}	4.19±0.38^{abc}	37.39±1.75^{abc}	36.26±0.63^{a}	5.40±3.62^{a}	3.83±0.84^{a}
	6	62.36±4.94^{abcde}	73.54±1.17^{abcde}	6.07±1.75^{abc}	4.05±0.38^{abc}	35.31±3.83^{abc}	36.63±1.25^{a}	6.28±2.16^{a}	3.36±0.71^{a}
	8	62.44±5.85^{abcde}	75.69±3.10^{ab}	6.67±1.40^{ab}	3.52±0.96^{abc}	33.24±0.84^{abc}	35.63±0.61^{a}	7.12±2.11^{a}	5.95±1.14^{a}
	10	64.59±5.35^{abc}	72.67±1.30^{abcde}	6.64±1.63^{ab}	4.72±0.89^{abc}	36.95±2.28^{abc}	35.77±1.27^{a}	6.47±2.97^{a}	3.78±1.28^{a}
	12	59.25±5.25^{abcde}	71.83±1.01^{abcde}	6.98±1.61^{a}	4.92±0.42^{ab}	31.97±2.24^{abc}	35.30±1.07^{a}	7.86±1.58^{a}	4.03±0.98^{a}
	1	61.50±5.42^{abcde}	72.66±2.25^{abcde}	3.04±0.43^{bc}	4.02±0.64^{abc}	34.91±4.45^{abc}	37.33±1.90^{a}	7.10±1.39^{a}	3.15±1.24^{a}
LDPE bag	2	63.89±6.76^{abcd}	71.00±1.36^{de}	2.84±1.83^{c}	4.51±0.34^{abc}	30.43±5.63^{c}	37.37±2.05^{a}	10.61±4.96^{a}	2.74±1.19^{a}
	3	59.74±2.98^{abcde}	73.11±1.83^{abcde}	4.30±1.07^{abc}	3.85±0.81^{abc}	35.45±3.25^{abc}	38.00±1.81^{a}	4.09±2.58^{a}	2.48±1.86^{a}
	4	59.60±5.53^{abcde}	71.76±1.70^{abcde}	4.69±1.90^{abc}	4.31±0.53^{abc}	32.03±2.33^{abc}	36.89±0.95^{a}	7.67±2.24^{a}	3.63±0.50^{a}
	5	63.16±4.53^{abcd}	72.51±1.70^{abcde}	4.62±1.34^{abc}	4.13±0.44^{abc}	33.42±3.85^{abc}	36.82±1.50^{a}	7.28±1.25^{a}	2.80±1.62^{a}
	6	55.50±1.81^{e}	73.71±1.02^{abcde}	5.79±1.49^{abc}	4.01±0.47^{abc}	31.95±2.08^{abc}	37.65±1.10^{a}	7.88±1.50^{a}	2.61±1.20^{a}
	8	61.55±1.85^{abcde}	74.19±1.87^{abcde}	6.39±0.82^{abc}	4.38±0.76^{abc}	34.46±2.98^{abc}	36.67±1.02^{a}	4.58±1.39^{a}	3.79±1.48^{a}
	10	60.79±5.04^{abcde}	75.34±0.90^{abc}	5.56±0.93^{abc}	3.47±0.33^{abc}	37.58±4.03^{abc}	35.61±0.64^{a}	5.24±2.91^{a}	5.06±0.93^{a}
	12	60.33±4.92^{abcde}	73.44±0.87^{abcde}	5.90±1.59^{abc}	4.23±0.29^{abc}	33.75±3.05^{abc}	36.22±1.14^{a}	6.48±1.45^{a}	3.40±1.25^{a}
	1	57.73±3.57^{de}	73.26±1.57^{abcde}	4.85±1.23^{abc}	3.90±0.80^{abc}	36.10±3.66^{abc}	38.36±1.97^{a}	4.82±3.23^{a}	2.71±1.19^{a}
LP bag	2	56.33±3.50^{de}	72.71±2.04^{abcde}	5.79±0.86^{abc}	3.48±0.40^{abc}	30.64±2.85^{bc}	36.55±2.17^{a}	8.70±2.73^{a}	3.59±1.48^{a}
	3	64.19±2.48^{abc}	72.30±1.04^{abcde}	3.26±1.02^{abc}	4.13±0.54^{abc}	38.00±2.92^{abc}	36.48±2.11^{a}	5.19±2.10^{a}	3.13±1.52^{a}
	4	65.07±4.29^{abc}	74.58±2.42^{abcde}	4.92±0.82^{abc}	3.44±0.85^{abc}	37.62±3.18^{abc}	36.25±1.49^{a}	6.04±3.23^{a}	4.51±1.91^{a}
	5	62.90±3.94^{abcde}	75.57±1.32^{abc}	5.12±1.24^{abc}	3.08±0.60^{c}	36.91±8.28^{abc}	36.16±1.37^{a}	7.14±5.47^{a}	4.99±1.68^{a}
	6	62.46±7.34^{abcde}	75.12±0.59^{abcd}	5.73±1.10^{abc}	3.59±0.47^{abc}	36.38±4.90^{abc}	36.66±1.70^{a}	7.72±3.43^{a}	4.41±0.99^{a}
	8	63.26±2.29^{abcd}	73.83±2.19^{abcde}	6.17±1.49^{abc}	3.96±0.97^{abc}	39.75±2.98^{ab}	35.68±1.35^{a}	4.67±2.55^{a}	4.36±1.90^{a}
	10	60.62±5.11^{abcde}	72.47±1.53^{abcde}	6.71±1.77^{ab}	4.33±0.64^{abc}	36.79±4.28^{abc}	36.41±0.35^{a}	5.61±3.46^{a}	3.16±0.22^{a}
	12	60.96±4.94^{abcde}	70.76±1.29^{e}	6.97±2.48^{a}	5.03±0.55^{a}	33.10±2.70^{abc}	35.12±0.83^{a}	8.01±2.65^{a}	4.40±0.74^{a}
	1	57.14±2.93^{cde}	72.00±1.62^{abcde}	4.58±1.29^{abc}	4.28±0.57^{abc}	37.10±3.58^{abc}	37.95±0.93^{a}	5.09±2.24^{a}	2.01±0.76^{a}
SLPE bag	2	67.21±3.74^{a}	72.42±1.18^{abcde}	3.96±1.55^{abc}	3.91±0.35^{abc}	40.59±3.76^{a}	36.74±1.55^{a}	7.83±4.96^{a}	2.91±0.78^{a}
	3	59.77±6.73^{abcde}	71.49±1.14^{bcde}	5.34±1.17^{abc}	4.05±0.40^{abc}	35.19±1.96^{abc}	36.47±2.26^{a}	7.82±3.05^{a}	2.99±1.95^{a}
	4	66.78±2.02^{ab}	75.81±1.81^{a}	3.06±1.50^{bc}	3.23±0.76^{bc}	35.93±5.28^{abc}	37.93±2.59^{a}	8.26±2.97^{a}	5.02±1.50^{a}
	5	59.37±5.55^{abcde}	72.65±2.60^{abcde}	4.35±1.44^{abc}	3.83±1.02^{abc}	30.64±0.77^{bc}	36.37±0.76^{a}	8.61±1.57^{a}	3.69±1.20^{a}
	6	60.35±6.27^{abcde}	73.53±1.74^{abcde}	6.41±0.84^{abc}	4.24±0.56^{abc}	34.21±2.96^{abc}	36.98±0.75^{a}	6.24±4.00^{a}	3.11±1.19^{a}
	8	62.68±8.01^{abcde}	73.80±2.73^{abcde}	5.04±1.38^{abc}	4.23±1.23^{abc}	30.91±1.67^{abc}	35.34±0.66^{a}	9.52±4.10^{a}	4.90±1.49^{a}
	10	59.81±5.12^{abcde}	73.10±1.34^{abcde}	6.14±1.01^{abc}	4.19±0.47^{abc}	33.59±3.70^{abc}	36.49±0.25^{a}	6.70±2.45^{a}	3.14±0.68^{a}
	12	59.54±5.20^{abcde}	73.78±1.26^{abcde}	6.45±1.24^{abc}	3.97±0.58^{abc}	33.20±3.92^{abc}	35.24±0.44^{a}	7.33±1.82^{a}	4.50±0.62^{a}
	1	57.50±3.49^{cde}	71.34±1.52^{cde}	3.62±2.25^{abc}	4.19±0.51^{abc}	31.36±2.00^{bc}	38.24±1.25^{a}	8.09±0.88^{a}	1.99±0.51^{a}
DLPE bag	2	55.09±4.91^{e}	71.64±2.04^{abcde}	4.77±0.80^{abc}	3.59±0.36^{abc}	33.07±3.35^{abc}	36.31±0.80^{a}	7.39±5.33^{a}	3.24±1.15^{a}
	3	56.86±7.00^{de}	72.87±1.91^{abcde}	4.53±0.98^{abc}	3.82±0.43^{abc}	34.31±3.56^{abc}	35.80±1.63^{a}	8.11±4.02^{a}	3.63±2.22^{a}
	4	58.49±3.90^{bcde}	73.78±1.68^{abcde}	4.14±1.31^{abc}	3.50±0.60^{abc}	32.59±5.04^{abc}	38.21±1.41^{a}	6.97±4.25^{a}	2.84±1.24^{a}
	5	57.13±6.74^{cde}	73.00±2.25^{abcde}	5.13±2.47^{abc}	4.02±0.95^{abc}	34.82±3.88^{abc}	36.39±1.43^{a}	8.10±2.73^{a}	3.83±0.76^{a}
	6	62.30±3.99^{abcde}	73.36±0.82^{abcde}	4.79±0.80^{abc}	4.27±0.72^{abc}	32.45±2.15^{abc}	37.22±1.47^{a}	6.70±1.38^{a}	2.86±0.94^{a}
	8	63.68±4.08^{abcd}	74.05±2.25^{abcde}	4.69±1.37^{abc}	3.90±0.93^{abc}	31.93±3.53^{abc}	36.36±0.86^{a}	7.84±2.60^{a}	3.93±1.81^{a}
	10	62.15±5.19^{abcde}	73.85±0.91^{abcde}	5.72±1.01^{abc}	3.89±1.15^{abc}	32.98±3.73^{abc}	37.06±1.54^{a}	7.10±2.97^{a}	3.21±1.52^{a}
	12	60.08±4.00^{abcde}	74.55±1.61^{abcde}	6.15±1.32^{abc}	3.83±0.36^{abc}	32.53±2.07^{abc}	35.53±0.84^{a}	6.43±1.73^{a}	4.73±1.05^{a}
Effects									
Storage period (SP)		NS	***	***	*	***	***	***	***
Packaging material (PM)		NS	NS	*	NS	***	NS	NS	*
SP*PM		**	***	*	*	***	NS	NS	NS

Values (means ± standard deviations) with different superscripts in the same column are significantly different. NS denotes not significant while *, **, and *** denote $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively at 95% confidence level.

packaging material and storage duration are shown in Table 2. Generally, there was no obvious trend in L*, a*, b* and ΔE* throughout the storage period (Table 2). Nonetheless, the colour properties were significantly ($p<0.05$) affected by the storage period except for L* of the dried *G. erubescens* fruit slices. The packaging material on the other hand significantly ($p<0.05$) affected only a* and yellowness (b*) of the dried fruit slices and ΔE* of the fruit powder. In terms of storage period-packaging material interaction effect, considerable ($p<0.05$) differences were recorded in L* and a* for *G. erubescens* fruit powder and in L* and b* for the dried fruits. These color values indicate that the samples retained their L* and b* with a minimal overall color difference (ΔE*). The ΔE* during the storage period was however higher for the dried fruits compared to the powder in all the packaging materials investigated. Generally, the change in color of dried *G. erubescens* fruits and powder during storage could be associated with moisture sorption properties of the products, since the a_w values of the dried fruits and powders (Section 3.1) were within the range that is optimum for various deleterious reactions (Ong et al., 2012). Nevertheless, previous studies indicated that color change in food is usually associated with factors such as moisture content, water activity, sugar content, storage temperature and time which caused non-enzymatic browning in the stored food product (Tan et al., 2021; Trippetch and Borompichaichartkul, 2019; Irwandi et al., 1998). Irwandi et al. (1998) also reported that heat processing and subsequent storage of fruit products is often accompanied by an unattractive discoloration which may be due to non-enzymatic browning or oxygen effects on other compounds in the fruit. The findings in this study suggest that color properties of the *G. erubscens* samples may change during storage, but this change may not be numerically drastic following the fairly constant trends generally observed. Further, the findings also indicate that packaging material, especially those un-

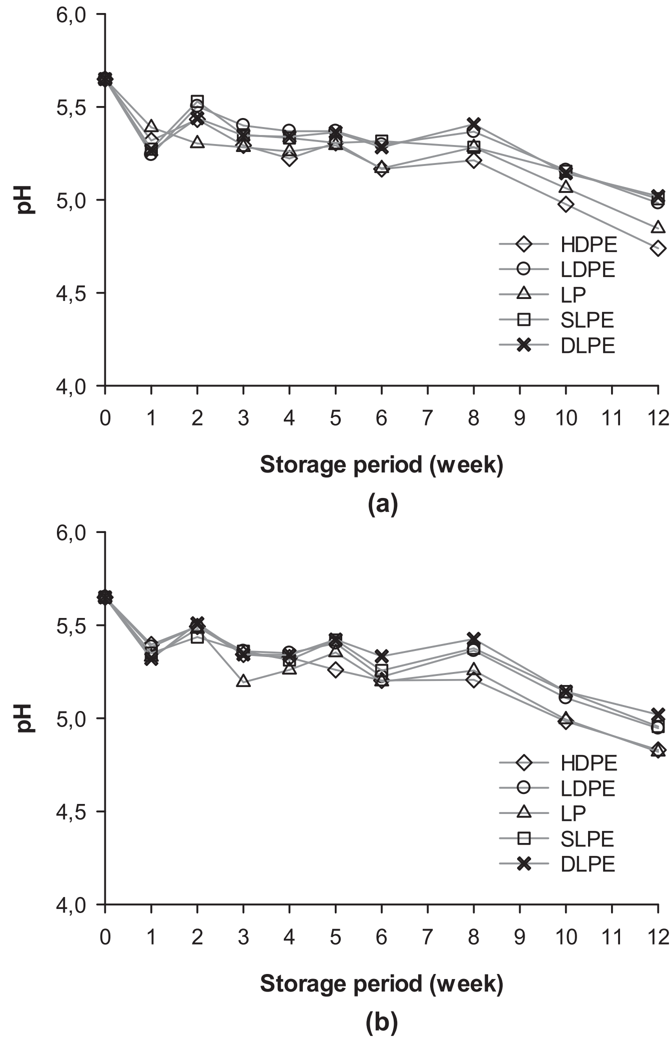

Fig. 3. Effect of the packaging material on pH of *G. erubscens* fruit products during storage. (a): dried fruits, (b): powder.

derstudied, may not be a key issue as far as preserving the color of the dried *G. erubscens* fruit product is concerned.

3.4. Beta-carotene and vitamin A and C contents

The roles of vitamins A and C, and β-carotene cannot be underestimated as far as promotion and maintenance of human health is concerned. While β-carotene and vitamin A facilitate gene expression, cell growth, eye and skin health and boosting of immunity (Aslam et al., 2017; Fiedor and Burda, 2014), vitamin C enhances the absorption of non-hem iron and the production of collagen and connectives tissues in addition to improving immune power (Dave and Patil, 2017; Pullar et al., 2017). The effect of packaging material and storage duration on β-carotene and vitamins A and C is shown in Table 3. It was found that all compounds were significantly ($p<0.05$) affected by the packaging material and the storage duration. It was further observed that β-carotene content reduced by ranges of 97.40% in HDPE to 97.84% in DLPE, and 96.85% in SLPE to 98.08% in LDPE, respectively for the dried fruits and powder when compared with the ß-carotene content of dried fruits and powder before storage. Similarly, vitamin C content reduced in ranges of 88.64% in DLPE to 92.53% in LP, and 86.04% in SLPE to 92.50% LP after the storage period for the dried fruits and powder, respectively. Almost the same margins of reduction as recorded by β-carotene content were observed with regards to vitamin A content. The significant reductions in these bioactive compounds is due primarily to volatilization and degradation (Koncsek et al., 2016; Östbring et al., 2020). Hymavathi et al. (2005) reported high percent losses of ß-carotene in mango powders stored in polyester poly and metallized polyester pouches for 6 months under ambient storage temperature (27-32°C) conditions. Breda et al. (2012) in their study also reported a decrease in vitamin C content of powdered guavira pulp stored in LDPE under accelerated storage conditions. Similarly, Obadina et al. (2018) and Hymavathi et al. (2005) observed a reduction in vitamin C content of cherry and plum tomato and mango powders stored in PE bags and polyester poly and metallized polyester pouches as the storage period increased under ambient storage conditions (25-32°C).

Significant differences ($p<0.05$) were observed among the packaging materials for all the three bioactive nutrients determined for both dried fruits and powder samples. The DLPE recorded a higher vitamin C (30.65±1.23 mg/100 g) for the dried fruits, which was about 1.52 times lower (20.14±1.26 mg/100 g) in the LP. However, no statistical differences ($p>0.05$) existed between vitamin C content in HDPE and LP as well as among LDPE, DLPE and SLPE for dried fruits. In relation to vitamin C content of the powder, the highest value (37.67±1.27 mg/100 g in SLPE) was 1.86 times higher than the lowest value (20.22±1.22 mg/100 g in LP). Also, only values of LDPE and SLPE were statistically similar among the packaging materials. With regard to β-carotene and vitamin A contents for the dried fruits, HDPE recorded the highest values which were about 1.20 times the lowest values as recorded by DLPE. Apart from HDPE which differed from all the other packaging materials, at least two of the other packaging materials shared some similarities in their β-carotene and vitamin A contents. In terms of the same nutrients for *G. erubscens* powder, all the packaging materials recorded similar values except LDPE which was significantly different from the rest. However, the findings showed that packaging materials used retained more vitamin C content as compared to β-carotene content. The lower values of β-carotene and vitamin C recorded by HDPE and LP in this study could be attributed to dilution as a result of high mois-

Table 3
β-carotene, vitamin A and C contents of dried *G. erubscens* fruits and powder before and after storage.

	β-carotene (µg/100g)		Vitamin A (µg/100g)		Vitamin C (mg/100g)	
	Dried fruits	Powder	Dried fruits	Powder	Dried fruits	Powder
Before storage	1237.45±13.44	1237.45±13.44	95.19±1.03	95.19±1.03	269.76±11.08	269.76±11.08
After storage						
Packaging material						
HDPE	32.15±1.02^{a}	38.59±0.25^{a}	2.47±0.08^{a}	2.97±0.02^{a}	22.84±0.07^{b}	24.52±0.00^{c}
LDPE	29.40±0.37^{b}	23.82±1.89^{b}	2.26±0.03^{b}	1.83±0.15^{b}	28.92±1.2^{a}	35.88±1.38^{a}
LP	28.42±0.17^{bc}	37.25±3.60^{a}	2.19±0.01^{bc}	2.87±0.28^{a}	20.14±1.26^{b}	20.22±1.22^{d}
DLPE	26.75±0.22^{c}	38.33±0.75^{a}	2.06±0.02^{c}	2.95±0.06^{a}	30.65±1.23^{a}	29.81±0.03^{b}
SLPE	29.37±0.70^{b}	38.93±1.18^{a}	2.26±0.05^{b}	2.99±0.09^{a}	29.76±0.01^{a}	37.67±1.27^{a}
P-value	0.002	0.002	0.002	0.002	<0.001	<0.001

Values (mean ± standard deviation) with different superscripts in the same column are significantly different.

ture gain (Stacewicz-Sapuntzakis et al., 2001). These findings however partly agree with the findings of Pavani and Aduri (2018) about the effect of HDPE and LDPE on β-carotene and vitamin C contents of dried leafy vegetables during storage.

3.5. Microbial growth

There was no noticeable growth of bacteria and fungi in both dried *G. erubscens* fruits and powder before and after storage irrespective of the packaging material, except in between where marginal growths were observed (Fig. 4). Similar findings have been reported by Irwandi et al. (1998) for cabinet-dried Durian fruit leather stored in similar packaging materials where growths at the start and end of storage were relatively lower than those in between. The results further showed no trends concerning effect of packaging material on the microbial growth of the samples. A similar trend was observed for the growth of yeast and mold. These values however did not exceed the bacterial count limit of 6 log CFU/g and mold and yeast limit of 4 log CFU/g for dried edible food products (International Commission on Microbiological Specifications of Foods, 2005), indicating that the *G. erubscens* fruits and powder were microbiologically safe even after three months of storage. These relatively minimal microbial loads recorded go to affirm the projected effect of the relatively lower moisture content, water activity, and pH of the samples on microbial growth in them.

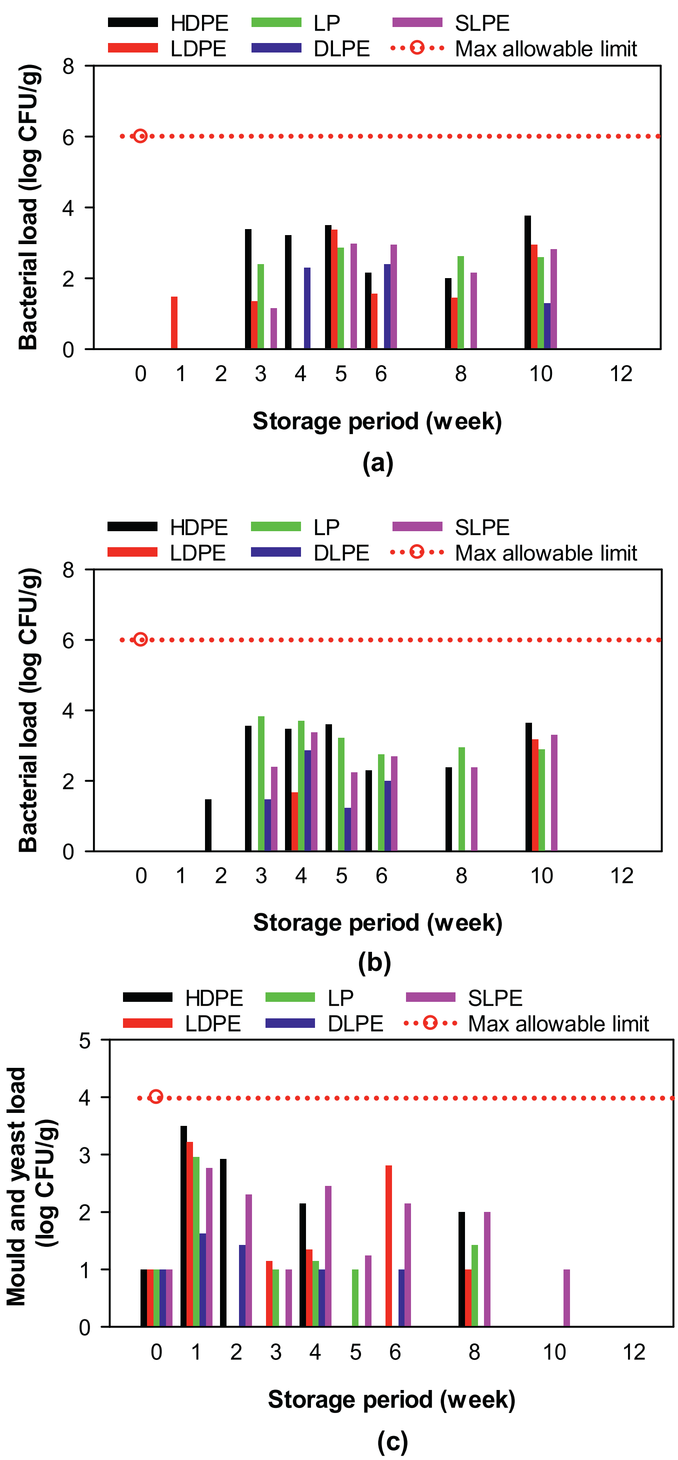

Fig. 4. Effect of the packaging material on bacterial and fungal (mould and yeast) load of *G. erubscens* fruit products during storage. (a) and (c): dried fruit, (b) and (d): powder.

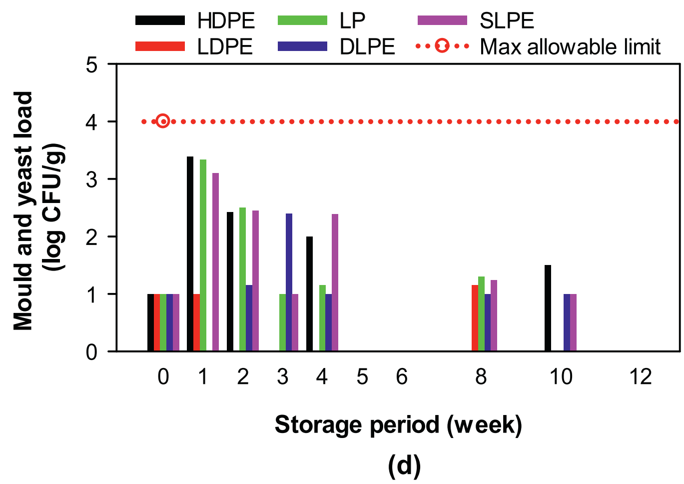

Fig. 4. Continued

4. Conclusion

The results indicated that storage period and packaging material generally had a significant ($p<0.05$) effect on the quality attributes measured. Generally, MC and a_w of the stored dried *G. erubscens* fruits and powder increased across the storage period while the pH decreased. The MC, a_w and pH values however did not exceed 20%, 0.60, and 5.50, respectively. Also, a*, b* and ΔE* values of both dried fruits and powder were significantly ($p<0.05$) affected by the storage period while packaging material on the other hand significantly ($p<0.05$) affected only a* and b* of the dried fruits and ΔE* of the fruit powder. However, ß-carotene, vitamin A and vitamin C contents were significantly ($p<0.05$) affected by packaging material and storage period. Bacterial and fungal loads for both *G. erubscens* fruits and powder were far below the maximum permissible limits of 6 log CFU/g and 4 log CFU/g, respectively, regardless of the packaging material. The findings, suggest that storing dried *G. erubscens* fruits and powder might not require sophisticated packaging materials and environmental conditions to retain microbial and nutritional quality but that any of the packaging materials used in this study could serve that purpose under ambient conditions. Further investigation is however necessary to understand the changes in textural and rehydration properties of dried *G. erubscens* fruits during long term storage.

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.

CRediT authorship contribution statement

Joseph Kudadam Korese: Conceptualization, Methodology, Formal analysis, Supervision, Funding acquisition, Writing – original draft, Writing – review & editing. **Matthew Atongbiik Achaglinkame:** Investigation, Formal analysis, Writing – original draft. **Frederick Adzitey:** Validation, Writing – review & editing.

Ethical Statement - Studies in humans and animals

None.

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