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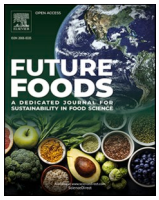

Fatty acid composition and lipid stability of cricket (*Gryllus bimaculatus*) flour preserved using ginger and garlic extracts

Jolly Oder Akullo [a,b,*], Beatrice N Kiage-Mokua [b], Dorothy Nakimbugwe [c], Justus Kwetegyeka [d], Jeremiah Ng'ang'a [e], John Kinyuru [e]

[a] Department of Animal Production and Management; Faculty of Agriculture and Animal Sciences, Busitema University, Uganda
[b] Department of Human Nutrition Sciences, School of Food and Nutrition Sciences, Jomo Kenyatta University of Agriculture and Technology, Kenya
[c] Department of Food Technology and Nutrition, School of Food Technology, Nutrition and Bio-engineering, Makerere University, Uganda
[d] Department of Chemistry, Faculty of Science, Kyambogo University, Uganda
[e] Department of Food Science and Technology; School of Food and Nutrition Sciences, Jomo Kenyatta University of Agriculture and Technology, Kenya

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ABSTRACT

Insect consumption is regarded as a sustainable diet with a high nutritional value and low environmental footprint. This study evaluated the fatty acid composition and oxidative stability of flour produced from crickets treated with ginger and garlic extracts. Ethanolic extracts of ginger, garlic and a combination were used to treat blanched cricket at a ration 1:4 (v/w). Treatments with sodium benzoate and distilled water served as positive and negative controls, respectively. Samples were dried in a hot air oven, milled to flour and packed in 10 μm polyethylene bags; stored at ambient conditions and evaluated on day on days 0, 30, and 60 of storage. Results showed that the major fatty acids in the flour were palmitic, oleic, and linoleic. During storage: palmitic acid increased from a range of 24.62 to 25.40 %; Oleic and linoleic acid decreased significantly ranging from 29.75 to 29.01 % and 32.85 to 32.21 %, respectively ($p<0.05$). The ratio of polyunsaturated fatty acid to saturated fatty acid decreased significantly during storage. The acid value, peroxide value, and thiobarbituric acid reactive substances of flour increased significantly during storage ($p<0.05$). The untreated flour was most affected than the spice treated flour. Treatment with a combination of ginger and garlic extracts is recommended due to the synergistic effect on the oil quality. Further investigation is required on the effects of various storage conditions and lengthy storage of spice preserved cricket flour on the fatty acid profile.

1. Introduction

The Food and Agriculture Organization (FAO) has reported that global food production must rise by 70 % by the year 2050 in order to meet the food demand of the increasing global population (FAO, 2017). In this regard, FAO recommends adopting sustainable diets that minimize negative environmental effects while ensuring food and nutrition security for both present and future populations. Due to their sustainability, nutritional value, ease of rearing, low environmental footprint, and animal welfare, eating edible insects is regarded as an effective alternative for achieving this goal (Babarinde et al., 2021; Ishara et al., 2022;; Wegier et al., 2018).

It is estimated that at least two billion people consume insects globally. This is creating industrial interest in insects as food in most parts of the world (Dossey et al., 2016; Raheem et al., 2019). According to Omuse et al. (2024), over 2205 insect species are consumed in 128 countries of the world; with the highest number of species (932) in Asia followed by North America (Mexico) and Africa. On the African continent, insects are consumed in 48 countries, with the Democratic Republic of Congo (DRC) having the highest insect diversity (255 species). Countries such as Uganda, Kenya, Tanzania have between 10 and 50 edible insect species (Omuse et al., 2024).

Among the edible insect species, crickets (*Acheta domesticus* and *Gryllus bimaculatus*) are probably one of the most widely farmed insects with modern mass production techniques, such as rearing in crates, bucket, aerated boxes and feeding on both commercial processed and locally produced feeds in many regions of the world (Kinyuru and Kipkoech, 2018; Kinyuru and Ndung'u, 2020; Ng'ang'a et al., 2020; Ngonga et al., 2021). Crickets have long been regarded as promising candidates to produce an affordable and sustainable source of protein for human

* Corresponding author.
E-mail address: jollyakullo@gmail.com (J.O. Akullo).

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food and animal feed because of their high protein quality and quantity (Weru et al., 2021).,. The nutritional value of several edible cricket species has been the subject of numerous kinds of research. According to Magara et al. (2021), G. *bimaculatus* has a protein and lipid content of 57–70 and 15–33 g/100 g dry weight, respectively, and the lipids contain >60 % unsaturated fatty acids (Gan et al., 2022).

Processing insects to flour is one method for introducing insects as culinary ingredients and enhances the acceptability of insect foods. However, it is critical to know that the use of edible insects in the food industry depends greatly on our ability to comprehend how changes that could occur throughout the processing and storage of flour could affect its nutritional and sensory qualities (Lucas-González et al., 2019). There are few studies that have highlighted the changes in the fatty acid composition and lipid stability of edible insect products during storage (Kamau et al., 2017).

One of the major causes of insect food deterioration is oxidative rancidity, resulting from the high level of unsaturated fatty acids (Kinyuru, 2021). The lipid oxidation process produces low-molecular off-flavor compounds and leads to the loss of unsaturated fatty acids (Embuscado, 2015; Semeniuc et al., 2016); this is an important reaction that affects the nutritional, sensory, and storage stability of food (Perez-Santaescolastica et al., 2022; Sun et al., 2011).

Therefore, minimizing oxidation is a crucial step in the processing and storage of food. In order to limit the oxidation process, synthetic antioxidants, particularly butylated hydroxyanisole, butylated hydroxytoluene, and propyl gallate, are widely used (Brewer, 2011). However, due to their toxicity and carcinogenicity, the use of these synthetic antioxidants continues to be limited (Jessica Elizabeth et al., 2017; Ribeiro et al., 2022). Therefore, there is an increasing interest in finding new, natural antioxidants that could replace synthetic preservatives (Gottardi et al., 2016; Maizura et al., 2011; Panpatil et al., 2013). Some plant extracts have been proven to function as potent antioxidants. In Uganda for instance, ginger and garlic are among the spices that are both farmed and consumed, and they serve a variety of food and therapeutic uses (Akullo et al., 2022). The phenolic compounds gingerol and shogaol in ginger (Ali et al., 2018; Baliga et al., 2011; Riaz et al., 2015) and allicin in garlic (Loghmanifar et al., 2020; Shang et al., 2019; Shobana et al., 2009) are principally responsible for their antioxidative activity. The utilization of ginger and garlic in the preservation of meat and fish food products has been reported. However, their use in insect-based foods is not sufficiently studied. Moreover, information on the effect of their use on the fatty acid composition and lipid stability of cricket flour has not been reported. Therefore, this study was undertaken to evaluate the fatty acid composition and oxidative stability of the flour produced from blanched crickets treated with ginger and garlic extracts. The study hypothesized that; Ho: Preserving cricket (G. *bimaculatus*) with ginger and garlic extracts does not affect the lipid characteristics and stability of the cricket flour.

2. Materials and methods

2.1. Spice collection and extract preparation

Fresh spices of 2.5 kg each (ginger rhizomes and garlic cloves) were bought from Lira city market in Uganda (2.2581° N, 32.8874° E), packed in airtight bags and transported to the Jomo Kenyatta University of Agriculture and Technology (JKUAT, Kenya) laboratory for processing and extraction. Samples were cleaned, washed, and rinsed using tap water. The skin was then peeled followed by crushing for extraction as shown in Fig. 1. Samples were extracted using analytical grade ethanol at room temperature (23 ± 2 °C) according to the technique of (Tanvir et al., 2017). Forty (40) g of ginger, garlic, and ginger + garlic (20 g each) were transferred into individual 500 mL conical flasks, followed by the addition of 200 mL of analytical grade ethanol. The flasks were wrapped in aluminum foil to limit the reaction of their content with light and shaken for 24 h at 300 rpm on a mechanical shaker (KS 250 basic, Ika Labortechnik-Japan). Afterwards, the solution was filtered using Whatman filter paper No 1; and the filtrate was concentrated using rotary evaporation at 50 °C. Each of the concentrated extracts was re-dissolved in distilled water to make 200 mL for the subsequent treatment of crickets.

2.2. Cricket acquisition and preparation

Adult crickets (G. *bimaculatus*) were procured from the insectPro farm in Limuru, Kenya. Prior to harvesting, crickets were starved for 48 h and given only water to empty their guts and reduce the high microbial load which is usually associated with the excreta. The live crickets were transported to the laboratory in aerated boxes, transferred into buckets, and frozen at −20 °C. Rapid freezing was necessary to inactivate and kill

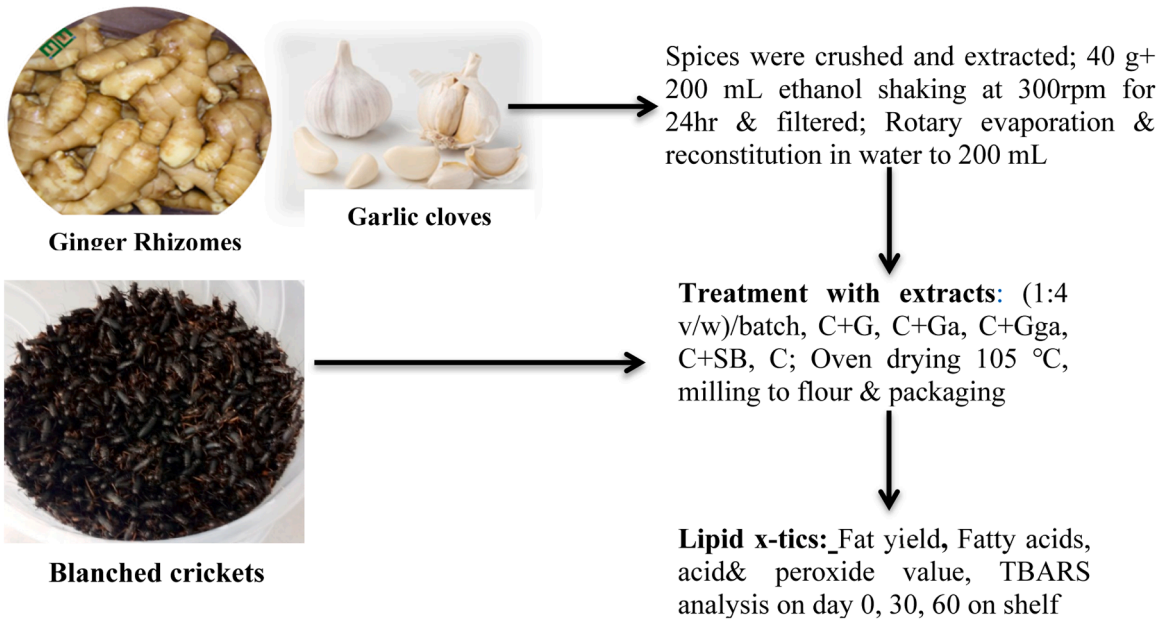

Fig. 1. Schematic diagram for the preparation of samples for analysis. G: ginger, Ga: garlic, GGa: ginger-garlic mixed, SB: sodium benzoate, C: cricket only.

the insects as well as slow down the autolytic enzymatic activity which causes rapid deterioration in insect quality after death. Frozen crickets were first allowed to thaw at room temperature for two hours prior to being washed three times in tap water in order to remove dirt and other foreign materials according to the procedures of (Fröhling et al., 2020; Kinyuru et al., 2021). The washing procedure involved swirling the crickets in a large bowl for five minutes at a cricket-to-water ratio of 1:3 (w/v) and then removing the crickets from the water using a sieve.

2.3. Treatment and processing of cricket flour

Adequately cleaned crickets were blanched in hot water for 1 min to reduce the microbial load and then divided into 5 portions of approximately 1000 g each. Three batches were chosen at random, and each was treated with either ginger (C + G), garlic (C+Ga), or a mixture of the two (C+GGa) at a ratio of 1:4 (w/v). The remaining two batches were either treated with 0.1 % sodium benzoate (C+SB) as a positive control or distilled water as a negative control (C). The samples were soaked for 30 mins in the respective solutions, drained of any excess, and then dried for two hours at 105 °C (until crisp dry) in a laboratory hot air oven (Memmert UF 110, Memmert, Schwabach, Germany) as reported in literature (Mutungi et al., 2019). The samples were taken out of the oven after drying, allowed to cool to room temperature, ground to flour using a laboratory grinder, and then sealed in zip-top low-density polyethylene bags (10 μm thickness). The packed samples were analyzed for changes in the fatty acid composition and lipid stability at 0, 30, and 60 days of storage under ambient conditions.

2.4. Extraction of lipids

Lipid was extracted from 1.0 g of dried cricket flour with chloroform/methanol according to the Folch method (1957) with modifications (Saini et al., 2021). One gram of cricket flour was dissolved in 20 parts of a chloroform/methanol mixture (2:1) and shaken on an orbital shaker KJ-201BD for 120 rpm. The mixture was kept in the freezer overnight and then filtered using Whatman filter paper No.1. Subsequently, 4 ml of 0.9 % NaCl solution was added to the filtrate, followed by vortexing using the autovortex SA6 for 30 ss and centrifuging at 30 rpm for 5 mins. The upper layer was siphoned off and disposed, while the lower layer was transferred into a pre-weighed vial and dried under a stream of nitrogen to a constant weight. The fat content of the flour was determined gravimetrically, and the results were expressed as g lipid per 100 g flour.

2.5. Preparation of fatty acid methyl esters (FAME) and analysis by gas chromatography

Derivatization of the fatty acid was done using basic esterification following the procedures of Wychen et al. (2015). About 10–15 mg of the lipid extract was weighed into Reacti-vial and 2 ml of hexane, followed by 4 ml of 4 mol/L potassium hydroxide/methanol was added. The reacti-vial was capped and incubated for 30 mins at 50 °C with gentle swirling after every 10 mins. The mixture was cooled to room temperature, and the upper layer was siphoned into clean, labeled centrifuge tubes. Subsequently, 2 ml of distilled water was added, followed by centrifugation at 4000 rpm for 5 mins. The upper layer was siphoned into a new set of freshly labeled centrifuge tubes containing a 1 mm bed of Sodium sulfate powder. The mixture was centrifuged as previously described, and the FAME was transferred into a clean GC vial, labeled and kept in the freezer, ready for GC analysis.

The components were separated by Gas chromatography on a ZB-FAME, Zebron Capillary column with a length of 30 m, an internal diameter of 25 mm, and a film thickness of 0.25 (um), Part No 7HG-G033–10, fitted with an FID detector at 260 °C. The FAME (1 μl) was injected at 240 °C in a split injection (50:1) using an autosampler. The temperature of the column was kept at 100 °C for 2 min after injection and thereafter increased to 150 °C at a rate of 25 °C/ minutes, followed by an increase of 3 °C/min to 200 °C and held for 2 min. The temperature was then increased at a rate of 8 °C and maintained at 280 °C for 10 min; the total run time was 132 min. Identification of fatty acid methyl esters in the samples were performed by comparing the retention time of the standard mixture of fatty acid methyl esters, Sigma-Aldrich CRM47885 (Supleco 37 component FAME mix). The proportion of each fatty acid was calculated as the ratio of each fatty acid to the total fatty acid content, and the result was expressed as a percentage of total fatty acids.

2.6. Determination of acid value

Acid value was determined according to the AOAC method 940.28 (AOAC, 1996). Neutral solvent was prepared by mixing 25 ml of diethyl ether with 25 ml ethanol and 1 ml of 1 % phenolphthalein indicator and carefully neutralized using 0.1 M sodium hydroxide/potassium hydroxide solution. About 1 g of each oil sample was dissolved in the neutral solvent and titrated against aqueous 0.1 M solution of sodium hydroxide/potassium hydroxide while shaking until the pink colour that lasted about 15 ss was obtained.

2.7. Determination of peroxide value and TBARS assay

The peroxide value (PV) was determined according to the IFRA Analytical Method for the determination of peroxide value (IFRA Method, 2019) with some modifications. Weighted portions of 1 g of cricket oil from each treatment and storage period were combined with 10 ml of chloroform. The mixture was immediately shaken to dissolve the oil in the chloroform. To the chloroform-oil mixture, 15 ml of acetic acid and 1 ml of potassium iodide (SSKI oral solution) were added, respectively. The mixture was then agitated for a minute and allowed to stand at room temperature in a dark environment for 5 mins. Subsequently, 75 ml of distillate water and 1 ml of starch were added to the solution. The mixture was then titrated against standardized 0.01 M sodium thiosulphate using starch solution as an indicator until the blue black colour disappeared. The peroxide value was calculated using the formula;

$$\mathrm{PV\ (mEq\,/\,kg)} = (S-B)\mathrm{x}\frac{N\mathrm{x}1000}{W} \quad (1)$$

Where: S = volume of titrant (ml) for sample, B = volume of titrant (ml) for blank, N = normality of $Na_2S_2O_3$ solution (mEq/ml), 1000 = conversion of units (g/kg).

TBARS was measured according to the procedures of Papastergiadis et al. (2012). One (1) gram of oil was weighed in a test tube, to which 5 ml of distilled water was added. The mixture was vortexed for 2 min and centrifuged at 5000 g for 5 min. The aqueous layer was collected, and the procedure was repeated twice. The supernatant was collected and 2.5 ml of the extract was mixed with 2.5 ml of TBA reagent (46 mM in 99 % glacial acetic acid) and heated in a boiling water bath for 35 min. The reaction mixture was chilled, and the absorbance was measured at 532 nm using a UV–Vis spectrophotometer (Shimadzu model UV–1601 PC, Kyoto, Japan). For quantification, standard solutions of MDA in 7.5 % TCA were prepared and used for making calibration curves. The TBARS were expressed as milligrams of malondialdehyde/kilogram.

2.8. Data analysis

Data on the fatty acid composition of the different samples was analyzed using Genstat version 12.0 software. Analysis of Variance (ANOVA) was performed and difference between mean was separated using Least Significant Difference (LSD) test at 5 % ($P = 0.05$). The post hoc test applied was Bonferroni and results were reported as means ± standard deviations.

3. Results and discussion

3.1. Fat content of cricket flour preserved with spice extracts

The lipid content varied with the storage duration as shown in Fig. 2: ranging from 26.36 to 25.27 % at the start of the storage to a range of 21.23 to 20.20 % after 60 days of storage. The decrease in fat content was significant in both the treated and the untreated flour ($p<0.05$). Previous studies reported different quantities of fat in different cricket species. Osimani et al. (2018) reported 28.75 % in powder, while Lucas-González et al. (2019) reported 24.91 % in thermally dried crickets *A. domesticus*. Jeong et al. (2021) reported 17.4 % in G. *bimaculatus*, while 21.62 % was registered in G. *assimilis* (Khatun et al., 2021). It is known that the amount of fat in edible insects varies depending on factors including the stage of development, species, habitat, feeding habits, processing techniques, and storage (Fombong et al., 2017; Lucas-González et al., 2019; Raksakantong et al., 2010). In this study, the decrease in lipid content during storage in ginger-garlic treated (4.38 %), ginger treated (4.97 %), SB (4.62 %), garlic (5.06 %), and untreated flour (5.1 %) was consistent with the decreasing proportion of the unsaturated fatty acid registered during storage, which is indicative of fat oxidation during storage.

3.2. Saturated fatty acids in cricket flour preserved with ginger and garlic extracts

The most prevalent saturated fatty acids in the cricket flour were palmitic and stearic acid which constituted 24.62 to 25.40 % and 8.70 to 9.04 % of the total fatty acids, respectively. Other saturated fatty acids detected in lower quantities were lauric (C12:0), myristic (C14:0), pentadecanoic (C15:0), heptadecanoic (C17:0), arachidic (C20:0), and behenic (C22:0) (Table 1). The findings of this study is consistent with previous reports by Osimani et al. (2018) who reported palmitic (25.52 %) and stearic (7.76 %) as the key saturated fatty acids in cricket powder. During the storage of cricket flour, there was an increase in the relative percentages of palmitic acid and stearic acid. At the end of the 60-day storage period, the untreated sample had the highest content of stearic acid (9.04 %), indicating a significant increase of 0.29 % from day 0 to day 60 of storage ($p<0.05$). The increase in proportions of palmitic and stearic acid was attributed to the reduction in the proportions of other long chain fatty acids during storage.

3.3. Monosaturated fatty acids in cricket flour preserved with ginger and garlic extracts

The major monounsaturated fatty acids in the cricket flour was oleic acid (C18:1) which made up 28.82 to 29.75 % of the total fatty acids (Table 2), Others (MUFA) detected in quantities of <1 % were myristoleic acid C14:1 cis-9), pentadecanoic acid (C15:1 cis-10), palmitoleic acid (C16:1 cis-9) heptadecenoate (C17:1 cis-10), elaidic acid (C18:1 trans-9), eicosenoic acid (C20:1 cis-11), tetracosenoate (C24:1 cis-15). During storage, oleic acid decreased by 0.02 to 0.07 % in treated samples and 0.93 % in untreated samples. This was attributed to possible biological reaction such as oxidation that occurred during storage, with a significant effect being observed in the untreated sample ($p<0.05$). Gan et al. (2022) reported a reduction of 2.86 % (from 40.29 to 37.43 %) of oleic acid after 150 days of storage of deep-fried crickets (G .*bimaculatus*) at room temperature. However, Kim et al. (2016) observed that during a 6-month storage of flour from the same species at varied temperatures, the proportions of oleic remained unchanged.

3.4. Polyunsaturated fatty acid in cricket flour preserved with ginger and garlic extracts

Linoleic acid was the most prevalent polyunsaturated fatty acid, making up 32.07 to 32.93 % of the fatty acids (Table 3). Other polyunsaturated fatty acids detected in low quantities were eicosatrieonic acid (C20:3 cis-11, 14, 17, and C20:3 *cis* 8, 11, 14). The findings of this study is in agreement with previous reports on the fatty acid profile of crickets (Agea Akullo et al., 2018; Dobermann et al., 2019; Kowalski et al., 2022). During storage the proportions of linoleic acid reduced by 0.04 to 0.07 in treated and 0.17 % in untreated samples, the reduction was attributed to biological processes such as oxidation. According to Fereidoon & Ying (2010), lipids are oxidized and hydrolyzed by oxygen and lipase during the processing and storage of foods. Moreover, the stability of different fatty acids varies, owing to the simplicity of generating fatty acid alkyl radicals which is necessary for autoxidation. Polyunsaturated fatty acids have several double bonds from which hydrogen can be abstracted, making them more susceptible (Gan et al., 2022).

Edible insects are more prone to lipid oxidation due to their high unsaturated fatty acid content (Kinyuru, 2021). In this study, changes in most polyunsaturated fatty acids varied with treatment rather than storage duration; spice extracts treated samples exhibited minimal

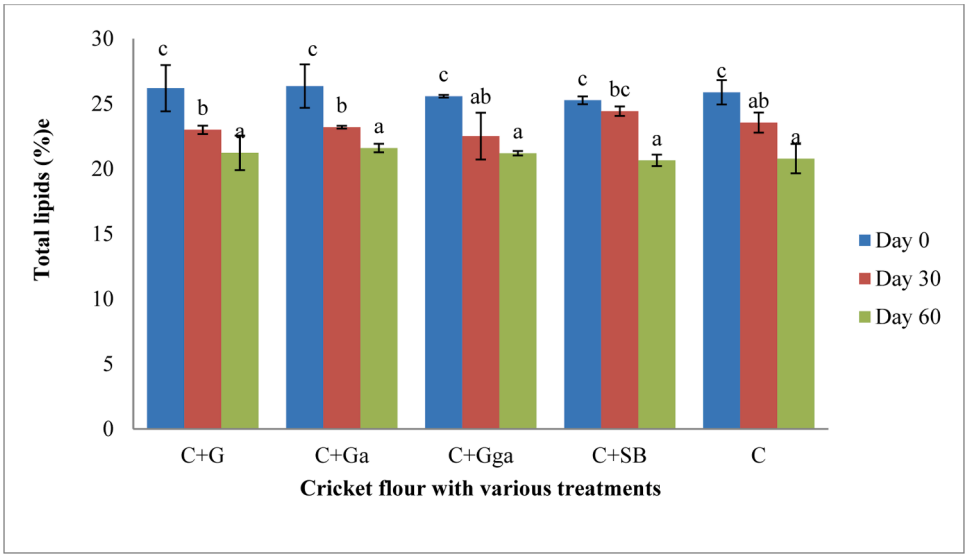

Fig. 2. Lipid content of cricket flour preserved with ginger and garlic extracts. G: ginger, Ga: garlic, GGa: ginger-garlic mixed, SB: sodium benzoate, C: cricket only. Different letter on the bars indicate significant difference for the treatments and storage periods ($p< 0.05$).

Table 1
Saturated fatty acids of cricket flour preserved with ginger and garlic extracts.

Trt	Storage (Days)	Lauric acid C12:0	Myristic acid C14:0	Pentadecanoic acid C15:0	Palmitic acid C16:0	Heptadecenoic acid C17:0	Stearic acid C18:0	Arachidic acid C20:0	Behenic acid C22:0
C + G	0	0.03±0.00^{a}	0.57±0.00^{a}	0.12±0.00^{a}	25.06 ±0.01^{a}	0.25±0.00^{b}	8.74±0.02^{ab}	0.06±0.00^{a}	0.26±0.19^{a}
	30	0.04±0.00^{a}	0.59±0.01^{a}	0.12±0.00^{a}	25.34 ±0.00^{a}	0.24±0.00^{ab}	8.73±0.04^{ab}	0.06±0.00^{a}	0.33±0.01^{a}
	60	0.03±0.00^{a}	0.58±0.00^{a}	0.13±0.00^{a}	25.27 ±0.07^{a}	0.24±0.00^{ab}	8.82±0.02^{ab}	0.06±0.00^{a}	0.25±0.20^{a}
C+Ga	0	0.04±0.00^{a}	0.59±0.01^{a}	0.12±0.00^{a}	25.38 ±0.01^{a}	0.24±0.00^{ab}	8.73±0.04^{ab}	0.06±0.00^{a}	0.23±0.16^{a}
	30	0.04±0.01^{a}	0.58±0.00^{a}	0.12±0.00^{a}	25.31 ±0.01^{a}	0.09±0.00^{a}	8.78±0.06^{ab}	0.06±0.00^{a}	0.24±0.16^{a}
	60	0.04±0.00^{a}	0.57±0.00^{a}	0.13±0.00^{a}	25.40 ±0.15^{a}	0.09±0.00^{a}	8.76±0.03^{ab}	0.06±0.00^{a}	0.12±0.00^{a}
C+Gga	0	0.04±0.00^{a}	0.57±0.00^{a}	0.13±0.00^{a}	25.05 ±0.00^{a}	0.09±0.00^{a}	8.89±0.01^{ab}	0.06±0.00^{a}	0.37±0.00^{a}
	30	0.05±0.01^{a}	0.57±0.02^{a}	0.12±0.00^{a}	25.00 ±0.04^{a}	0.17±0.11^{a}	8.90±0.12^{ab}	0.04±0.02^{a}	0.09±0.06^{a}
	60	0.04±0.00^{a}	0.58±0.00^{a}	0.13±0.00^{a}	25.28 ±0.13^{a}	0.25±0.00^{b}	8.99±0.04^{ab}	0.06±0.00^{a}	0.25±0.19^{a}
C+SB	0	0.03±0.00^{a}	0.57±0.00^{a}	0.12±0.00^{a}	24.91 ±0.16^{a}	0.24±0.00^{ab}	8.72±0.01^{ab}	0.06±0.00^{a}	0.38±0.01^{a}
	30	0.04±0.00^{a}	0.57±0.01^{a}	0.12±0.00^{a}	24.86 ±0.01^{a}	0.24±0.00^{ab}	8.74±0.03^{ab}	0.07±0.02^{a}	0.25±0.016^{a}
	60	0.04±0.00^{a}	0.57±0.00^{a}	0.13±0.00^{a}	24.93 ±0.31^{a}	0.14±0.14^{a}	8.78±0.01^{ab}	0.06±0.00^{a}	0.24±0.17^{a}
C	0	0.04±0.00^{a}	0.59±0.04^{a}	0.07±0.08^{a}	24.62 ±0.34^{a}	0.24±0.01^{ab}	8.75±0.22^{ab}	0.05±0.02^{a}	0.25±0.18^{a}
	30	0.03±0.00^{a}	0.58±0.01^{a}	0.13±0.00^{a}	25.06 ±0.20^{a}	0.24±0.00^{ab}	8.70±0.07^{a}	0.06±0.00^{a}	0.36±0.01^{a}
	60	0.050.00^{a}	0.32±0.31^{a}	0.07±0.07^{a}	25.11 ±0.72^{a}	0.17±0.12^{a}	9.04±0.13^{b}	0.06±0.01^{a}	0.15±0.01^{a}
P value		(0.200, 0.250)	(0.338, 0.270)	(0.145, 0.195)	(0.053, 0.69)	(0.032, 0.328)	(0.007,0.292)	(0.784, 0.73)	(0.766, 0.316)
		0.070	**0.227**	**0.83**	**0.55**	**0.026**	**0.041**	**0.409**	**0.571**

Results are mean ± SD, different superscripts along the column show significant difference. P values in bracket are main effect of treatment (trt) and storage, respectively; outside bracket is the interaction effect. G: ginger, Ga: garlic, GGa: ginger-garlic mixed, SB: sodium benzoate, C: cricket only; 0, 30, 60 are days of flour storage.

changes during storage compared to the untreated samples.

Due to safety issues, the use of natural antioxidants in food is much preferred compared to synthetic antioxidants (Santos-Sánchez et al., 2018; Shah and Mir, 2021; Xu et al., 2017). Ginger and garlic are among the most widely used natural antioxidants (Kumari et al., 2018; Sepahpour et al., 2018; Sofia et al., 2007). The strong antioxidant activity of ginger is due to the presence of compounds such as gingerol and shogaol (Baliga et al., 2011; Mushtaq et al., 2019; Tanweer et al., 2020), with the former being abundant in fresh ginger and the latter in dried ginger. In garlic, the active ingredients are organosulfur compounds such as allicin and allin (Feriedoon Shahidi and Hossain, 2018; Shang et al., 2019; Wang et al., 2015). These compounds exhibit antioxidant functions because they possess strong free radical scavenging activities.

3.5. *Indicators of fatty acid quality of cricket flour preserved with ginger and garlic extracts*

The study assessed nine (9) dietary indices of cricket oil; Saturated fatty acids, Unsaturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, P/S, essential fatty acids, n-6, n-3, n-6/n-3 (Table 4).The proportion of total saturated fatty (ΣSFA) acid was in the range of 35.12 to 35.25 % at day 0 and 35.28 to 35.78 % after day 60 of cricket flour storage. There was a gradual increase in the ΣSFA, which did not differ significantly among samples during storage ($p > 0.05$). This increase was attributed to the increase in the proportion of palmitic and stearic acids, which were the major SFAs in cricket flour. In a previous study, Khatun et al. (2021) reported ΣSFA of 32.01 and 35.37 % in oven dried crickets (A. *domesticus* and A. *assimilis*) respectively.

The Total unsaturated fatty acid (ΣUFA) ranged from 64.71 to 64.85 % among samples at day 0 of storage, then decreased to a range of 64.23 to 64.71 % after 60 days of sample storage as shown in Table 4. The proportion of ΣUFA reduced by 0.15, 0.32, 0.36, 0.37 and 0.52 in SB, ginger, ginger-garlic, garlic and untreated flour, respectively. Significantly lower reductions were recorded in spice treated flour compared to the untreated flour, probably due to the antioxidant effect of ginger and garlic extracts which gradually increased with the length of storage.

In a previous study, Gan et al. (2022) showed that the ΣSFA increased from 44.32 % to 46.06 % and the ΣUFA declined from 55.36 % to 53.94 % in the untreated cricket samples, while an increase of 44.47 to 46.64 % (ΣSFA) and a decline of 55.53 to 53.36 % (ΣUFA) was recorded in the rosemary-extract-treated samples stored under vacuum conditions. This trend is consistent with our findings; indicating that spice extract exhibit antioxidant properties. The variation in the proportion of the ΣSFA and ΣUFAs in the previous study and in our study was attributed to difference in the processing and storage conditions between the previous sample and samples of this study. This study samples were processed by oven drying and kept at room temperature in contrast to the prior study samples, which were deep-fried in palm oil that is low in UFA and high in SFA and stored under vacuum.

During storage, the proportion of MUFA (30.36 to 31.38 %) did not differ significantly ($p > 0.05$), while PUFA (33.61 to 34.42 %) was significantly different among treatments ($p<0.05$). The same trend was observed for the essential fatty acids. Kamau et al. (2017) reported that the proportion of MUFA and PUFA in cricket meal gradually reduced throughout the course of storage, with reductions being between 16.2 to 52.1 % at 90 days and 10.73 to 67.0 % at 180 days of storage. These loses were greater than the values detected in our study, probably due to the variation in the nature of products, packaging material, storage

Table 2
Monosaturated fatty acids of cricket flour preserved with ginger and garlic extracts.

Trt	Days	Myristoleic acid C14:1 cis-9	Pentadecanoic acid C15:1 cis-10	Palmitoleic acid C16:1 cis-9	Heptadecenoate C17:1 cis-10	Elaidic acid C18:1 trans-9	Oleic acid C18:1 cis-9	Eicosenoic acid C20:1 cis-11	Tetracosenoate C24:1 cis-15-
C + G	0	0.02±0.00^{a}	0.03±0.00^{a}	0.78±0.00^{a}	0.03±0.00^{a}	0.38±0.01^{b}	29.48 ±0.04^{ab}	0.09±0.00^{a}	0.04±0.00^{a}
	30	0.03±0.02^{a}	0.02±0.01^{a}	0.97±0.01^{a}	0.11±0.01^{a}	0.38±0.00^{b}	29.20 ±0.12^{ab}	0.15±0.10^{a}	0.04±0.00^{a}
	60	0.02±0.00^{a}	0.03±0.00^{a}	0.84±0.00^{a}	0.03±0.00^{a}	0.37±0.00^{b}	29.41 ±0.06^{ab}	0.15±0.11^{a}	0.03±0.00^{a}
C+Ga	0	0.02±0.00^{a}	0.03±0.00^{a}	0.97±0.01^{a}	0.03±0.00^{a}	0.28 ±0.00^{ab}	29.34 ±0.01^{ab}	0.16±0.10^{a}	0.02±0.03^{a}
	30	0.02±0.00^{a}	0.03±0.00^{a}	0.91±0.10^{a}	0.04±0.01^{a}	0.28 ±0.01^{ab}	29.35 ±0.20^{ab}	0.08±0.00^{a}	0.02±0.02^{a}
	60	0.02±0.00^{a}	0.03±0.00^{a}	0.97±0.00^{a}	0.11±0.11^{a}	0.29 ±0.01^{ab}	29.32 ±0.13^{ab}	0.15±0.11^{a}	0.04±0.00^{a}
C+Gga	0	0.02±0.00^{a}	0.03±0.00^{a}	0.97±0.00^{a}	0.03±0.00^{a}	0.27 ±0.00^{ab}	29.25 ±0.06^{ab}	0.07±0.03^{a}	0.04±0.00^{a}
	30	0.02±0.00^{a}	0.03±0.00^{a}	0.77±0.09^{a}	0.11±0.10^{a}	0.36±0.12^{b}	29.25 ±0.03^{ab}	0.25±0.02^{a}	0.03±0.00^{a}
	60	0.02±0.00^{a}	0.03±0.00^{a}	0.72±0.00^{a}	0.19±0.00^{a}	0.38±0.01^{b}	29.21 ±0.27^{ab}	0.24±0.04^{a}	0.04±0.00^{a}
C+SB	0	0.02±0.00^{a}	0.03±0.01^{a}	0.80±0.05^{a}	0.17±0.00^{a}	0.22±0.01^{a}	29.01 ±0.01^{ab}	0.23±0.01^{a}	0.04±0.00^{a}
	30	0.02±0.00^{a}	0.03±0.00^{a}	0.72±0.00^{a}	0.19±0.01^{a}	0.22±0.01^{a}	29.08 ±0.02^{ab}	0.23±0.02^{a}	0.04±0.00^{a}
	60	0.04±0.02^{a}	0.03±0.00^{a}	0.78±0.07^{a}	0.18±0.00^{a}	0.22±0.01^{a}	28.98 ±0.05^{ab}	0.23±0.00^{a}	0.03±0.00^{a}
C	0	0.02±0.00^{a}	0.09±0.07^{a}	0.80±0.07^{a}	0.11±0.11^{a}	0.30 ±0.01^{ab}	29.75 ±0.40^{b}	0.23±0.02^{a}	0.04±0.00^{a}
	30	0.02±0.00^{a}	0.04±0.00^{a}	0.80±0.06^{a}	0.11±0.11^{a}	0.30 ±0.01^{ab}	29.29 ±0.01^{ab}	0.24±0.00^{a}	0.04±0.00^{a}
	60	0.03±0.03^{a}	0.03±0.00^{a}	0.89±0.12^{a}	0.03±0.00^{a}	0.30 ±0.02^{ab}	28.82 ±0.04^{a}	0.09±0.01^{a}	0.00±0.00^{a}
P value		(0.854, 0.796)	(0.177, 0.24)	(0.177, 0.24)	(0.553, 0.525)	(<0.001, 0.292)	(0.040, 0.119)	(0.043,0.443)	(0.187, 0.46)
		0.885	**0.434**	**0.434**	**0.483**	**0.27**	**0.056**	**0.04**	**0.064**

Results are mean ± SD, different superscripts along the column show significant difference. P values in bracket are main effect of treatment (trt) and storage, respectively; outside bracket is the interaction effect. G: ginger, Ga: garlic, GGa: ginger-garlic mixed, SB: sodium benzoate, C: cricket only; 0, 30, 60 are days of flour storage.

Table 3
Polyunsaturated fatty acids of cricket flour preserved with ginger and garlic extracts.

Treatment	Storage (Days)	Lino elaidic acid C18:2 trans-9,12	Linoleic acid C18:2cis-9,12	Gamma linolenic acid C18:3 cis-6,9,12	Linolenic acid C18:3 cis-6,9,15	Eicosatrienoate C20:3 cis-11,14,17	Eicosatrienoate C20:3 cis-8, 11,14	Arachidonate C20:4 *cis* 5,8,11,14
C + G	0	0.06±0.00^{b}	32.44±0.04^{ab}	0.69±0.00^{a}	0.41±0.00^{a}	0.21±0.00^{a}	0.12±0.01^{a}	0.06±0.00^{a}
	30	0.06±0.01^{b}	32.07±0.12^{a}	0.69±0.00^{a}	0.39±0.00^{a}	0.21±0.00^{a}	0.12±0.01^{a}	0.12±0.09^{a}
	60	0.06±0.00^{b}	32.24±0.00^{ab}	0.72±0.03^{a}	0.41±0.03^{a}	0.21±0.00^{a}	0.13±0.02^{a}	0.05±0.01^{a}
C+Ga	0	0.04±0.00^{a}	32.38±0.02^{ab}	0.69±0.01^{a}	0.39±0.00^{a}	0.21±0.01^{a}	0.12±0.01^{a}	0.06±0.00^{a}
	30	0.04±0.00^{a}	32.36±0.23^{ab}	0.75±0.01^{ab}	0.43±0.00^{a}	0.22±0.00^{ab}	0.12±0.01^{a}	0.12±0.10^{a}
	60	0.04±0.00^{a}	32.34±0.03^{ab}	0.69±0.00^{a}	0.38±0.00^{a}	0.22±0.00^{ab}	0.13±0.02^{a}	0.11±0.10^{a}
C+Gga	0	0.05±0.00^{ab}	32.57±0.04^{ab}	0.69±0.01^{a}	0.41±0.00^{a}	0.22±0.01^{ab}	0.12±0.01^{a}	0.05±0.01^{a}
	30	0.06±0.01^{b}	32.56±0.36^{ab}	0.74±0.04^{ab}	0.46±0.03^{a}	0.20±0.02^{a}	0.16±0.05^{a}	0.06±0.01^{a}
	60	0.05±0.00^{ab}	32.50±0.08^{ab}	0.71±0.00^{a}	0.38±0.00^{a}	0.23±0.00^{b}	0.13±0.01^{a}	0.10±0.14^{a}
C+SB	0	0.03±0.00^{a}	32.85±0.22^{b}	0.74±0.04^{ab}	0.39±0.02^{a}	0.22±0.01^{ab}	0.13±0.01^{a}	0.06±0.00^{a}
	30	0.04±0.00^{a}	32.89±0.11^{b}	0.74±0.03^{ab}	0.40±0.05^{a}	0.23±0.00^{b}	0.12±0.01^{a}	0.12±0.09^{a}
	60	0.04±0.00^{a}	32.93±0.07^{b}	0.78±0.02^{b}	0.43±0.00^{a}	0.22±0.00^{ab}	0.12±0.00^{a}	0.18±0.00^{a}
C	0	0.06±0.01^{b}	32.38±0.35^{ab}	0.70±0.05^{a}	0.41±0.03^{a}	0.22±0.00^{ab}	0.13±0.01^{a}	0.06±0.01^{a}
	30	0.05±0.00^{ab}	32.28±0.13^{ab}	0.72±0.05^{a}	0.41±0.04^{a}	0.21±0.01^{ab}	0.12±0.01^{a}	0.12±0.10^{a}
	60	0.05±0.00^{ab}	32.21±0.07^{ab}	0.73±0.01^{ab}	0.40±0.03^{a}	0.23±0.00^{b}	0.13±0.01^{a}	0.06±0.02^{a}
P value		(<0.001, 0.60)	(<0.001, 0.746)	(0.022, 0.100)	(0.397, 0.286)	(0.017, 0.12)	(0.144, 0.30)	(0.739, 0.238)
		0.547	**0.648**	**0.255**	**0.031**	**0.075**	**0.094**	**0.85**

Results are mean ± SD, different superscripts along the column show significant difference. P values in bracket are main effect of treatment and storage, respectively, and outside bracket is the interaction effect. G: ginger, Ga: garlic, GGa: ginger-garlic mixed, SB: sodium benzoate, C: cricket only; 0, 30, 60 are days of flour storage.

condition, and long storage duration of products in the previous study.

The P/S ratio varied significantly (<0.05) among the samples in the range of 0.94 in the control and ginger treated samples at day 60 of storage and 0.99 in the SB treated samples at day 0 of storage (Table 4). The p/s ratio in samples treated with a combination of ginger and garlic compared favorably with the SB treated samples. Lucas-González et al. (2019) reported a P/S ratio of 1.30 and 0.98 in lyophilized and thermally dried cricket (*A. domesticus*) flour, while Kowalski et al. (2022)

Table 4
Indicators of fatty acid quality of cricket flour preserved with ginger and garlic extracts.

Trt	Days	Σ SFA	Σ USF	ΣMUFA	ΣPUFA	P/S	ΣEFA	Σn-6	Σn-3	n-6/n-3
C + G	0	35.13±0.07^{a}	64.74 ±0.07^{ab}	30.75±0.03^{a}	33.98±0.04^{abc}	0.97±0.00^{abc}	32.85±0.05^{ab}	33.73±0.05^{bc}	0.74±0.00^{ab}	45.71±0.34^{a}
	30	35.41±0.06^{a}	64.62 ±0.05^{ab}	30.81±0.09^{a}	33.65±0.03^{a}	0.95±0.00^{a}	32.56±0.12^{a}	33.25±0.04^{a}	0.74±0.01^{ab}	45.66±0.57^{a}
	60	35.61±0.14^{a}	64.42±0.14^{a}	30.81±0.16^{a}	33.61±0.03^{ab}	0.94±0.00^{a}	32.46±0.03^{a}	33.07±0.01^{a}	0.72±0.05^{ab}	44.04±0.28^{a}
C+Ga	0	35.18±0.02^{a}	64.71 ±0.01^{ab}	30.68±0.02^{a}	34.05±0.02^{ab}	0.97±0.00^{abc}	32.81±0.02^{ab}	33.29±0.03^{abc}	0.76±0.02^{b}	46.15±1.25^{a}
	30	35.34±0.20^{a}	64.55±0.22^{a}	30.65±0.08^{a}	33.97±0.14^{abc}	0.96±0.01^{ab}	32.76±0.22^{ab}	33.15±0.13^{ab}	0.72±0.01^{a}	43.75±0.13^{a}
	60	35.70±0.18^{a}	64.34±0.18^{a}	30.84±0.09^{a}	33.90±0.10^{ab}	0.95±0.01^{a}	32.71±0.02^{ab}	33.18±0.13^{ab}	0.72±0.03^{a}	43.13±1.91^{a}
C+Gga	0	35.25±0.00^{a}	64.73 ±0.01^{ab}	30.36±0.04^{a}	34.11±0.03^{abc}	0.97±0.00^{abc}	32.97±0.04^{ab}	33.76±0.04^{bc}	0.78±0.01^{bc}	44.47±0.44^{a}
	30	35.35±0.09^{a}	64.53±0.10^{a}	30.64±0.22^{a}	34.04±0.32^{abc}	0.96±0.01^{ab}	32.92±0.33^{ab}	33.41±0.38^{abc}	0.75±0.06^{ab}	45.41±0.59^{a}
	60	35.63±0.02^{a}	64.37±0.03^{a}	30.54±0.24^{a}	34.00±0.21^{abc}	0.95±0.01^{a}	32.88±0.08^{ab}	33.36±0.22^{abc}	0.73±0.01^{a}	43.31±0.90^{a}
C+SB	0	35.12±0.18^{a}	64.86±0.18^{b}	30.44±0.08^{a}	34.69±0.26^{bc}	0.99±0.01^{c}	33.34±0.03^{b}	33.78±0.26^{c}	0.76±0.05^{b}	45.07±0.20^{a}
	30	35.20±0.16^{a}	64.79 ±0.17^{ab}	30.43±0.05^{a}	34.53±0.12^{bc}	0.98±0.01^{bc}	33.29±0.03^{b}	33.67±0.18^{bc}	0.75±0.05^{ab}	45.17±3.80^{a}
	60	35.28±0.02^{a}	64.71 ±0.04^{ab}	30.39±0.11^{a}	34.42±0.07^{c}	0.98±0.00^{bc}	33.26±0.08^{b}	33.62±0.06^{abc}	0.75±0.01^{ab}	44.35±0.42^{a}
C	0	35.17±0.73^{a}	64.75 ±0.80^{ab}	31.38±1.24^{a}	34.00±0.44^{ab}	0.97±0.01^{abc}	32.79±0.38^{ab}	33.60±0.04^{abc}	0.76±0.04^{b}	45.26±1.93^{a}
	30	35.53±0.14^{a}	64.44±0.15^{a}	30.74±0.04^{a}	33.91±0.10^{abc}	0.95±0.01^{a}	32.59±0.17^{a}	33.10±0.07^{ab}	0.74±0.03^{ab}	43.76±1.80^{a}
	60	35.78±0.31^{a}	64.23±0.28^{a}	31.06±0.31^{a}	33.76±0.03^{ab}	0.94±0.01^{a}	32.41±0.05^{a}	33.05±0.06^{a}	0.72±0.03^{a}	43.48±1.35^{a}
P value		(0.07, 0.935)	(0.03, 0.88)	(0.053, 0.846)	(<0.001, 0.82)	(<0.001, 0.899)	(<0.001,0.83)	(<0.001,0.925)	(0.036, 0.268)	(0.06, 0.376)
		0.434	**0.284**	**0.707**	**0.387**	**0.11**	**0.532**	**0.508**	**0.013**	**0.056**

Results are mean ± SD, different superscripts along the column show significant difference. P values in bracket are main effect of treatment (trt) and storage, respectively; outside bracket is the interaction effect. G: ginger, Ga: garlic, GGa: ginger-garlic mixed, SB: sodium benzoate, C: cricket only; 0, 30, 60 are days of flour storage. Σ: sum; SFA: saturated fatty acids; UFA: unsaturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; P/S: PUFA/SFA; EFA: essential fatty acids; n-6: omega 6 fatty acids; n-3: omega 3 fatty acids.

and Paul et al. (2017) reported a ratio of 0.89 and 1.32 in the same species, respectively. One of the most important markers of the lipid composition of a healthy diet is the polyunsaturated to saturated fatty acid (P/S) ratio (Zhu et al., 2022). It is recommended to consume food with a P/S ratio close to 1 (Paul et al., 2017); this is associated with improved cardiovascular health and better performance of the immune system.

The proportions of n-6 and n-3 fatty acids in the samples varied significantly among the treatments (p<0.05). Samples treated with SB (33.78 to 33.62 %) and a combination of ginger and garlic extracts (33.76 to 33.36 %) had higher proportions of n-6 and n-3. Singh et al. (2020) reported a range of 35.5 to 39.8 % (p/s) and 1.92 to 2.80 (n-6/n-3) in cricket flour. In this study, ratios of n-6/n-3 did not differ significantly with both the treatment and storage duration ($p > 0.05$). Previous studies on cricket flour have reported n-6/n-3 rations of 38.55 (Osimani et al., 2018), 37.05 (Paul et al., 2017), 248.92 (Kowalski et al., 2022), and 14.9 to 18.8 (Singh et al., 2020).Variations in n-6/n-3 were attributed to the difference in the total n-6 and n-3 in the sample, which

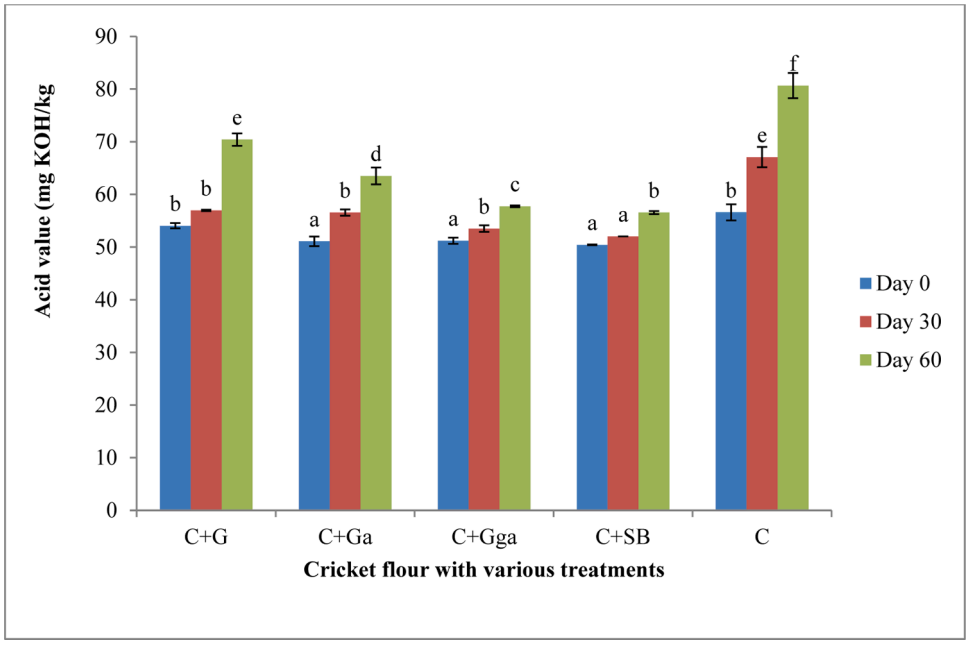

Fig. 3. Acid value of cricket flour preserved with ginger and garlic extracts. G: ginger, Ga: garlic, GGa: ginger-garlic mixed, SB: sodium benzoate, C: cricket only. Different letter on the bars indicate significant difference for the treatments and storage periods (p< 0.05).

is in turn affected by factors such as; nutrition, species, stage of the insects (Raksakantong et al., 2010). Diets with n-6/n-3 fatty acid ratio close to 6 have been associated with cardiovascular health (Fereidoon Shahidi and Ambigaipalan, 2018; Wijendran and Hayes, 2004).

3.6. Fat acidity of cricket flour preserved with ginger and garlic extracts

The acid value increased gradually during the period of storage (Fig. 3); ranging from 50.42 to 70.41 mg KOH/kg in the treated samples and from 56.60 to 80.66 mg KOH/kg in the untreated samples on days 0 and 60 of storage, respectively. The difference in the acid value was significant among treatments and across the storage period ($p<0.05$). Lower values were observed in samples treated with a combination of ginger and garlic (51.21 to 57.74) and SB (50.42 to 56.55) mg KOH/kg. This is attributed to the antioxidant effect exerted by ginger and garlic on the cricket flour during the storage period, as opposed to the untreated samples. Acid value is the measure of the free fatty acids in fats and oils, and high free fatty acid content is indicative of fat degradation (Gan et al., 2022). FFA is a source of flavors and aromas; they are used to monitor the oil stability during storage; unsaturated FFA serves as a substrate for autoxidation (Fereidoon and Ying, 2010). In this study, the initial acid value was attributed to the effect of thermal processing with the increase during storage being attributed to degradation which occurred as the duration of storage under ambient conditions.

3.7. Peroxide value of cricket flour preserved with ginger and garlic extracts

The peroxide value (PV) of a sample is the measure of the milliequivalents of peroxide contained in a Kilogram of the sample. It is often used as an indicator of the primary products of lipid oxidation (Javadian et al., 2017). The UFAs are unstable and are hydrolyzed to hydroperoxides as a result of lipid oxidation. When the generation of peroxides exceeds their breakdown, the peroxides progressively accumulate, increasing peroxide value. This study showed a significant increase in the peroxide value among treatments and storage periods ($p<0.05$); with 1.65 to 3.63 and 1.94 to 3.91 mEq/kg among the treated and untreated flour, respectively (Fig. 4). At the beginning of storage, the peroxide value is low as there is minimal lipid oxidation. However, as the product spends more days in storage, the lipid oxidation increases and there is an accumulation of the hydroperoxides, hence increasing the PV. However, in both the treated and untreated flour, the peroxide value were within the acceptable limits (10 mEq/kg) for food (Liu et al., 2019).

The peroxide value of an insect-blended extruded flour increased from 2.80 to 5.32 mEq/Kg during 9 weeks of storage (Shabo et al., 2022). In our study, PV of spice-treated samples was significantly lower than the untreated samples at all points in storage. This was attributed to the antioxidant ability of the spice extracts as a result of their high phenolic content. According to Turhan et al. (2009), phenolic antioxidants prohibit the formation of fatty acid free radicals, which do react with or absorb oxygen in the autoxidation process; hence slowing down the autoxidative processes.

3.8. Thiobarbituric acid reactive substance (TBARS) of cricket flour preserved with ginger and garlic extracts

TBARS measures the secondary oxidative products of lipid peroxidation (Papastergiadis et al., 2012). Malondialdehyde (MDA) which is a small molecule generated from hydroperoxides (primary product of lipid peroxidation), combines with thiobarbituric acid (TBA) to form MDA-TBA2 adducts, known as TBARS (Tsai and Huang, 2015). The initial TBARS in both treated and untreated cricket flour was in the range of 0.45 to 0.57 mg MDA/kg (Fig. 5). The levels significantly increased to a range of 0.82 to 1.05 mg MDA/kg after day 60 of cricket flour storage. MDA is commonly considered the final product of lipid oxidation and is what causes an unpleasant odor to develop in the oils and foods (Zhang et al., 2019). With longer storage time, the MDA concentrations in all of the study samples increased slightly ($p < 0.05$). However, ginger and garlic treated samples had minimal quantities of the MDA, hence indicating the protective effects of the spice extracts. This is consistent with earlier research on foods derived from insects (Gan et al., 2022; Singh et al., 2020; Ssepuuya et al., 2016) and other kinds of food (Liu et al., 2019; Temba et al., 2017).

4. Conclusion

In the current study, it was shown that both treated and untreated cricket flour exhibited a limited reduction in ΣUFAs and an increase in ΣSFA, implying that the cricket flour was susceptible to oxidation during storage. The beneficial effect of the spice extracts in preservation is

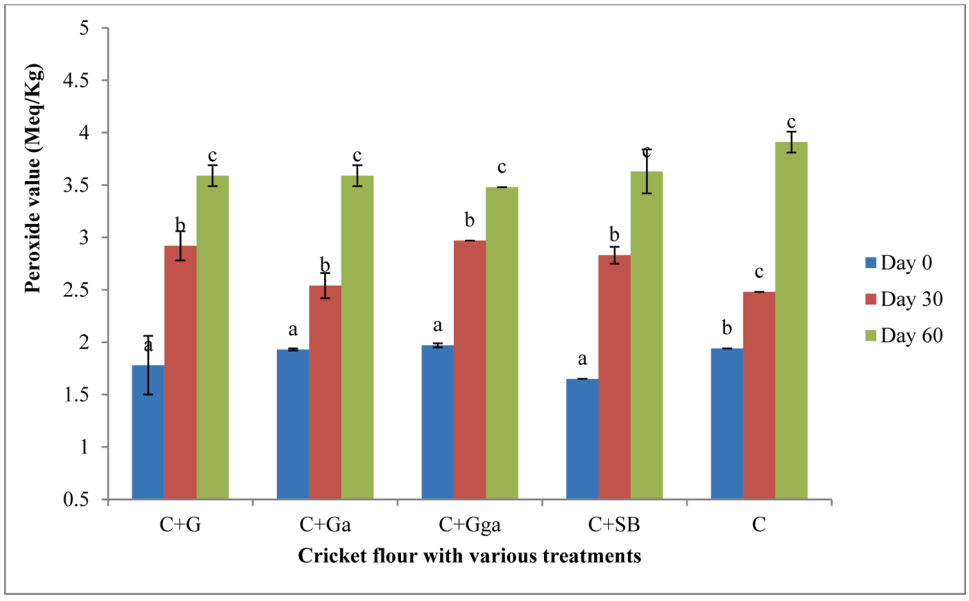

Fig. 4. Peroxide value of cricket flour preserved with ginger and garlic extracts. G: ginger, Ga: garlic, GGa: ginger-garlic mixed, SB: sodium benzoate, C: cricket only. Different letter on the bars indicate significant difference for the treatments and storage periods ($p< 0.05$).

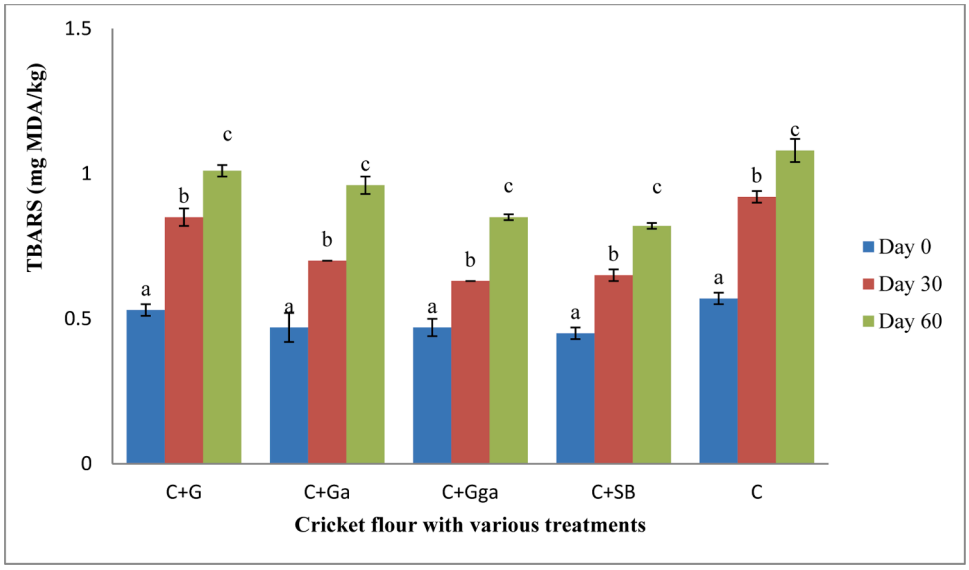

Fig. 5. TBARs of cricket flour preserved with ginger and garlic extracts. G: ginger, Ga: garlic, GGa: ginger-garlic mixed, SB: sodium benzoate, C: cricket only. Different letter on the bars indicate significant difference for the treatments and storage periods ($p < 0.05$).

shown, especially by the minimal decrease in ΣUFA and little increase in ΣSFA in samples treated with a combination of ginger and garlic extracts, which compared favorably with the positive control (SB preserved) samples. The PV and TBARs values of cricket flour increased during the 60 days of storage, but remained within acceptable limits for a safe food. Ginger-garlic preserved flour was the most stable, compared with ginger and garlic treatments used singly. The study recommends the use of a combination of ginger and garlic in the preservation of cricket and determining the effect on sensory quality and acceptability during storage at ambient conditions. Further research is also needed on the effects of different packaging materials, storage conditions, and lengthy storage of cricket flour (exceeding 60 days) on the lipid characteristics.

Ethical statement

The study did not involve use of human and animal subjects/ experimens

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CRediT authorship contribution statement

Jolly Oder Akullo: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Beatrice N Kiage-Mokua:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Dorothy Nakimbugwe:** Writing – review & editing, Validation, Supervision, Conceptualization. **Justus Kwetegyeka:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation. **Jeremiah Ng'ang'a:** Writing – review & editing, Validation, Software, Methodology, Investigation. **John Kinyuru:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Conceptualization.

Declaration of competing interest

The authors report there are no competing interests to declare

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Data availability

Data will be made available on request.

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