Ginger powder and its extract as potential bio-preservatives in packaged dika kernel flour

RESEARCH ARTICLE

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ABSTRACT

Ginger powder and its extract have a high phenolic content that gives it the capability to serve as a bio-preservative (Mao et al., 2019). This study investigated the potential of ginger powder and ginger extract as preservative for packaged dika kernel flour with the view of extending its shelf life. Dika kernel flour (Bamidele & Ojedokun, 2015), ginger powder and its extract were prepared using standard methods (Noura et al., 2014). Butylated hydroxyl toluene was used as positive control. During storage, samples were drawn monthly for three months to evaluate the antioxidant activity, free fatty acid, peroxide value and fatty acid profile of the dika kernel flour (Kettawan et al., 2011). The total polyphenol content of the dika kernel flours reduced with storage (Chua et al., 2018), irrespective of the preservative or the packaging material used. Total phenolic content of dika kernel flour stored in laminated pouch with ginger extract as the preserving agent had the least percentage drop (10.94%) at the end of storage time (12 weeks) (Qu et al., 2014). The best DPPH radical scavenging ability stability (Sánchez-Moreno et al., 1998; Sánchez-Moreno, 2002; Ayustaningwarno & Anjani, 2024) was observed for dika kernel flour preserved with ginger extract packed in laminated aluminium pouch, which retained 98.18% of DPPH antioxidant activity at the end of 12 weeks. Dika kernel flour treated with ginger extract as preservative in laminated pouches had the least drop in the DPPH activities over the period of storage (Gheldof & Engeseth, 2002). The study established that the addition of ginger extract in the two packaging materials and ginger powder in laminated pouches to dika flour reduced the rate of per cent loss of the scavenging properties of stored dika flour.

Methodology

Comparative analysis of ginger powder and extract preservation using standard analytical methods over 12 weeks

Key Variables

Total phenolic content, DPPH activity, peroxide values, and fatty acid profiles in dika kernel flour

Main Finding

Ginger extract in laminated pouches showed superior preservation with only 10.94% phenolic content loss

Keywords: Dika kernel, Bio-preservatives, ginger, laminated aluminium pouch, high density polyethylene

INTRODUCTION

Antioxidants have become an irreplaceable group of food additives primarily due to its distinctive ability of prolonging the shelf-life of food products without any undesirable impact on their sensory and nutritional qualities. Recently, the increasing demand from consumers for preservative-free or naturally preserved foods has forced the food industry to turn to natural herbal and plant-derived preservatives rather than synthetic preservatives to produce safe foods.

Commonly used antioxidants in foods at present are butylated hydroxyl anisole (BHA) and butylated hydroxyl toluene (BHT), but safety concerns and health risks raised by end-users such as suppressed immune system, disruption of normal biochemical pathways and reports of carcinogenic and mutagenic effects associated with these compounds has consequently put limitations on the use of these synthetic antioxidants in foods.

01

Consumer Awareness

Growing demand for natural food preservatives has led consumers to seek alternatives to synthetic additives with potential health risks.

02

Safety Concerns

Synthetic preservatives like BHA and BHT have been associated with health issues including immune suppression and carcinogenic effects.

03

Natural Solutions

Food industry increasingly explores natural spices and plant-derived preservatives to meet consumer demands for safer food products.

Therefore, there has been an increasing significant interest to explore new sources of safe and economical antioxidant with antimicrobial potential of natural sources. This has impelled researchers to explore antioxidants from new sources such as natural spices and natural antioxidants derived from edible materials, edible by-products and residual sources which are gaining increasing attention. Spices with antioxidant properties have a lead over synthetic antioxidants since they can be labelled as spices or natural flavourings and thus avoiding the consumer's negative perception of food additives or preservatives.

Ginger (*Zingiber officinale*, *Zingiberaceae*) is a spice which is well recognized for its antioxidant properties (Ayustaningwarno & Anjani, 2024). Ginger is widely consumed as a spice and also used for food preservation. Phytochemical evaluation has shown that ginger contains antioxidants that have anticarcinogenic and anti-inflammatory effects (Mao et al., 2019). The antioxidant activity of ginger is quite high and is comparable to some synthetic antioxidants such as tertiary butyl hydroquinone (TBHQ), BHA and BHT) even in combined form. Extracts of plants contain concentrated bioactive compounds such as polyphenols which is due to its purity having removed fibre and other extraneous materials present in whole plant making it a more efficient antioxidant.

Therefore, it is important to examine the potential of ginger powder and its extract as bio-preservatives for packaged dika kernel flour, which serves as the objective of this study.

METHODOLOGY

Antioxidant Properties and Activities of the Dika kernel flour

Total phenolic content, ferric reducing power activity, and diphenyl-1-picryhdrazyl hydrate were determined monthly (Bamidele & Ojedokun, 2015).

Extraction of antioxidant

Antioxidant extraction from dika kernel flour samples followed Noura et al.'s (2014) modified method. Each 20g sample was mixed with 200ml of 80% methanol and stirred magnetically for 4 hours at ambient temperature. The extract was then filtered (Whatman No.1), and the solvent distilled off using a rotary evaporator under reduced pressure at 45°C. The crude concentrated extract was then used for subsequent analyses.

Sample Preparation

- Dika kernel flour preparation
- Ginger powder and extract preparation
- BHT as positive control
- Two packaging materials tested

Analytical Methods

- Total phenolic content determination
- DPPH radical scavenging assay
- Ferric reducing antioxidant power
- Monthly sampling over 3 months

Determination of total phenolic content

Total phenolic content was determined using the Folin-Ciocalteu's phenol reagent (oxidizing reagent), as modified from Singleton and Rossi (1965) by Gulcin et al. (2003). Gallic acid quantity was extrapolated from a standard curve (0.01 - 0.1 µg/ml), with results expressed as Gallic Acid Equivalent (GAE). Distilled water served as the blank.

DPPH (diphenyl-1-picryhydrazyl) radical scavenging activity assay

The flour's radical scavenging ability was determined using the stable radical DPPH (2, 2-diphenyl-2-picrylhydrazyl hydrate) as described by Pownall et al. (2010). DPPH reacts by accepting a hydrogen radical, leading to its reduction and a color change from deep violet to light yellow, measured spectrophotometrically at 517 nm. A standard curve was plotted using vitamin C (100-500µg) treated identically to the extract.

The percent of inhibition was calculated as given below:

$$Inhibition\ \% = \frac{A\ control - A\ sample}{A\ control} X\ 100 \qquad (1)$$

Where; A control = absorbance of the control reaction (containing all reagents except the test compound), and

A sample = absorbance of the test compound.

Sample concentration was calculated from the calibration curve plotting inhibition percentage against extract concentration.

Determination of ferric reducing antioxidant power (FRAP)

The FRAP assay uses antioxidants as reductants in a redox-linked colorimetric method with absorbance measured with a spectrophotometer (Benzie and Strain, 1999). The reducing power was expressed as equivalent concentration (EC) which is defined as the concentration of antioxidant that gives a ferric reducing ability equivalent to that of the ascorbic acid standard. The equation of the graph obtained was used to calculate the equivalent concentration based on the absorbance obtained for the extracts and this was then expressed as ascorbic acid equivalent per gram of the extract (AAE/g of the extract).

The main effects of storage time (Four levels: 0, 4, 8, 12 weeks) and packaging (two levels: HDPE, laminated aluminum pouches) on reducing potential (FRAP) of dika kernel flour samples were analyzed.

RESULTS AND DISCUSSION

Antioxidant Properties and Activities of Preserved Dika Kernel Flour

(a) Influence of storage on total phenol content during storage

Storage period was observed to have profound influence on the total phenol content with variations observed throughout the entire storage period of three months (Table 1). Total phenol content (TPC) of dika kernel flour preserved with ginger extract (Mao et al., 2019; Ayustaningwarno & Anjani, 2024) and stored in laminated aluminum pouch (Sample CL) showed the best stability with more than 89% retention while sample preserved with ginger extract but stored in high density polyethylene bag (Sample CH) was able to retain only 80% phenol content. This shows that light penetration into the packaging material had significant effect on the rate of loss of TPC (Bamidele & Ojedokun, 2015).

Total Phenolic Content

Ginger extract preserved samples showed superior phenolic retention compared to powder forms.

DPPH Activity

Radical scavenging ability remained highest in laminated aluminum pouch storage conditions.

Packaging Impact

Laminated aluminum pouches provided better protection against oxidative deterioration than HDPE.

Table 1: Influence of Storage Time on the Total Phenolic Content (mg GAE/g) of Preserved Dika Kernel Flour Samples

Samples	Storage Time (weeks)			
	0	4	8	12
A_H	38.82 ± 0.41^{cA}	32.56 ± 0.27^{cAB}	22.35 ± 0.52^{dB}	20.71 ± 0.24^{deBC}
A_L	38.82 ± 0.41^{cA}	34.45 ± 0.75^{cA}	27.35 ± 0.52^{cB}	22.81 ± 0.99^{dC}
B_H	50.82 ± 0.60^{bA}	42.79 ± 0.40^{bB}	35.71 ± 0.24^{cdC}	31.01 ± 0.34^{eD}
B_L	50.82 ± 0.60^{bA}	44.14 ± 0.54^{bAB}	41.39 ± 0.17^{cBC}	38.93 ± 0.15^{bcC}
C_H	57.23 ± 0.50^{aA}	49.71 ± 0.37^{bB}	47.35 ± 0.52^{bcB}	45.81 ± 0.99^{bC}
C_L	57.23 ± 0.50^{aA}	55.48 ± 0.52^{aAB}	54.39 ± 0.56^{aB}	50.97 ± 0.15^{aB}
D_H	56.35 ± 0.58^{abA}	48.91 ± 0.34^{bB}	47.22 ± 0.61^{bcC}	38.72 ± 0.36^{bcD}
D_L	56.35 ± 0.58^{abA}	55.38 ± 0.39^{aA}	48.63 ± 0.80^{bB}	46.16 ± 0.78^{bC}
Natural Preservative(s)				
E_H	46.29 ± 0.34^{bA}	45.12 ± 0.48^{bA}	38.92 ± 0.89^{bcB}	35.65 ± 0.57^{dC}
E_L	46.29 ± 0.34^{bA}	45.93 ± 0.47^{bA}	42.94 ± 0.22^{bcB}	40.27 ± 0.91^{cBC}
F_H	56.1 ± 0.12^{abA}	50.45 ± 0.09^{abB}	48.77 ± 0.24^{bC}	45.27 ± 0.39^{bD}
F_L	56.81 ± 0.12^{abA}	55.64 ± 0.00^{aB}	55.64 ± 0.00^{aB}	50.84 ± 0.17^{aC}

Values are expressed as mean ± standard deviation of triplicate determination. Means with different superscripts in lower case on the same column are significantly ($p < 0.05$) different while .means with different superscripts in upper case on the same row are significantly ($p < 0.05$) different.

Key: AH= Dika kernel flour stored in high density polyethylene; **AL** = Dika kernel flour stored in laminated pouches; **BH** = Dika kernel flour + ginger powder stored in high density polyethylene; **BL**= Dika kernel flour + ginger powder stored in laminated pouches; **CH** = Dika kernel flour + ginger extract stored in high density polyethylene; **CL** = Dika kernel flour + ginger extract stored in laminated pouches; **DH** = Dika kernel flour + BHT stored in high density polyethylene; **DL** = Dika kernel flour + BHT stored in laminated pouches; **EH**= Ginger powder stored in high density polyethylene; **EL** = Ginger powder stored in laminated pouches; **FH** = Ginger extract stored in high density polyethylene; **FL** = Ginger extract stored in laminated pouches**.**

According to Shahidi and Naezk (2004), natural phenols exert beneficial effects mainly through their antioxidant activities. Also, the antioxidant effect of phenolic acids is associated with the number and position of hydroxyl groups in the molecule, hence the higher the number of hydroxyl groups on the phenyl radical of an acid, the higher the antioxidant potential (Ceriello, 2008). Multiple storage conditions such as light, pH, oxygen, temperature have been listed to affect the stability of phenolic content during storage (Sharma et al., 2016). There has been a lot of reports on how exposure affect loss of phenolic content, this loss means the samples are tending towards oxidation and hydrolysis (Pristouri et al., 2010; Altemimi et al., 2017).

Qu et al. (2014) investigated the effect of storage on the phenolic stability of sterilized liquid pomegranates peel at 4 ºC in both light and dark conditions and reported that even at low temperature with exposure to light, degradation of polyphenol and browning of ascorbic acid still took place. This finding concluded that light exposure facilitates degradation of phenol even at room temperature. On the contrary, dika kernel flour (Bamidele & Ojedokun, 2015) in laminated aluminum pouches had a significant higher total phenolic content at the end of storage compared to samples stored in HDPE in the presence of light. In other words, laminated aluminum pouch preserved the total phenolic content of the dika kernel flour. Changes in total polyphenol content of dika kernel flour sample (preserved and not preserved) stored at ambient temperature for 12 weeks are shown in Figure 1. A significant decrease in the total phenolic content over 12 weeks of storage was observed in all the samples except in sample CL (stored in laminated aluminum pouches and preserved with ginger extract). The stability of total phenolic content has been reported to be dependent on quite a number of factors such as storage temperature and storage time. Ginger rhizomes are rich in polyphenols such as gingerol, shogaol and paradol (Mao et al., 2019), which may have contributed to the high phenolic content of dika kernel flour (Ayustaningwarno & Anjani, 2024). The addition of natural preservatives (ginger extract and ginger powder) to dika kernel flour increased the phenolic content of the samples particularly in samples BL and CL. However, increasing the storage period to 12 weeks slightly lowered the total polyphenol content of the dika kernel flour, irrespective of the preservative added and the packaging used. Storage at ambient temperature can cause subsequent loss of bioactive compounds (Chua et al., 2018). Compared to thecontrol, storage condition which includes, packaging materials and preservative were observed to have profound influence on TPC (Figure 1 and Table 1), with variations observed throughout the entire storage period of 12 weeks.

Total phenolic content of dika kernel flour stored in laminated pouch with ginger extract as the preserving agent had the least percentage drop (10.94%) at the end of storage time (12 weeks). The pronounced decrease in TPC, particularly for samples stored in polyethylene compared to the laminated pouches could be due to light induced degradation of the phenolics present in this packaging material. Multiple storage factors such as light, temperature, oxygen and pH have been highlighted to have affected the stability of the phenolic compounds (Kearsley & Rodriguez, 1981; Sharma et al., 2016). Several studies have reported similar decrease in phenolic content of foods with storage time. Talcott et al. (2005) reported 35% decrease in TPC of stored peanuts at 20 and 35 °C for up to 16 weeks. Likewise, green tea catechins had a decrease of 42% after storage at 20 °C for 4 months (Friedman et al., 2009).

Different phenolics behave in different manner when it comes to their degradation and this diverse behaviour could be attributed to their structural differences. The reactivity of compound is dependent on the position of the functional groups. Positions 3 and 4 in the benzene ring of flavonoids are more susceptible to dihydroxylation than others (Rice-Evans et al., 1996). Hydroxylation decreases the stability whereas methylation increases the stability of a compound (Bakowska et al., 2005).

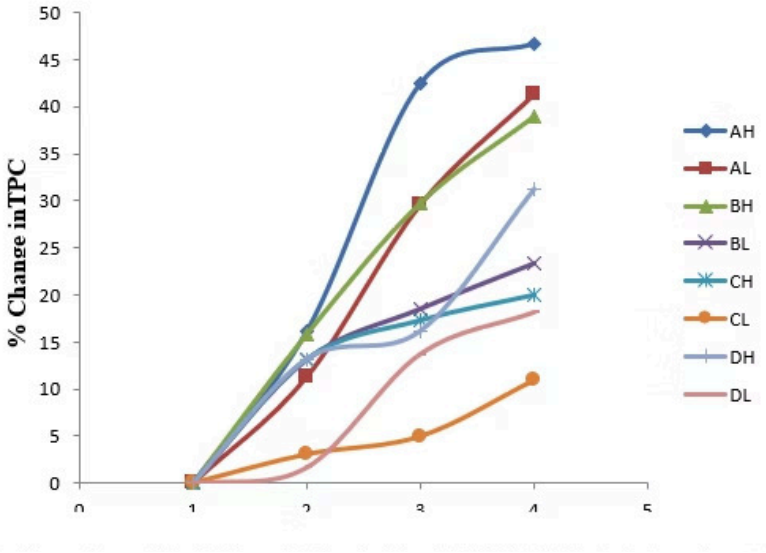

Figure 1: Percentage of Total Phenolic Content(mg GAE/g) Retained during storage of Preserved Dika Kernel Flour

Key: AH= Dika kernel flour stored in high density polyethylene; **AL** = Dika kernel flour stored in laminated pouches; **BH** = Dika kernel flour + ginger powder stored in high density polyethylene; **BL**= Dika kernel flour + ginger powder stored in laminated pouches; **CH** = Dika kernel flour + ginger extract stored in high density polyethylene; **CL** = Dika kernel flour + ginger extract stored in laminated pouches; **DH** = Dika kernel flour + BHT stored in high density polyethylene; **DL** = Dika kernel flour + BHT stored in laminated pouches.

Influence of storage on DPPH (diphenyl-1-picryhydrazyl) radical scavenging activity assay of preserved dika kernel flour

DPPH (diphenyl-1-picryhydrazyl) radical scavenging activity assay as presented in Table 2 ranged from 95.99 to 97.34% at the beginning of storage (week 0) to 70.11 to 95.57% at the end of storage (week 12).

All the samples of dika kernel flour (Bamidele & Ojedokun, 2015) exhibited significantly high radical scavenging activities. This suggests that they may readily donate free nitrogen atoms to electron deficient DPPH, therefore terminating the action of the free radical chain; hence producing a less harmful product. The best DPPH radical scavenging ability stability was observed for sample CL (ginger extract dika kernel flour packed in LAP) which retained 98.18% of DPPH antioxidant activity at the end of storage (12 weeks); obviously this can be attributed to the preservative used (ginger extract, rich in bioactive compounds (Mao et al., 2019) and known for its antioxidant properties (Ayustaningwarno & Anjani, 2024)) and packaging material (Laminated aluminum pouch), ditto for samples DL and BL as they were able to retain 98.18 and 97.77% respectively. Notably, sample AH had the least stability as only 73.01% of DPPH antioxidant activity was retained at the end of storage. Values obtained in this study are consistent with the findings of Zoric *et al.* (2017). The two-way DPPH radical scavenging ability was significantly different for laminated aluminum pouches and HDPE from week 4 of storage. It should be noted that samples stored in laminated aluminum pouches after one month exhibited significantly higher DPPH radical scavenging than those stored in HDPE. Primarily, the decrease in antioxidant activity during storage could be attributed to phenolic oxidation as a result of light exposure (Jiménez-Zamora *et al.*, 2016). The changes in DPPH directly correspond to the changes that occurred in TPC during storage stability test.

The results obtained in this study showed that dika kernel could be preserved with either ginger powder or ginger extract (Mao et al., 2019; Ayustaningwarno & Anjani, 2024) with interactions for DPPH radical scavenging during storage. DPPH as an antioxidant mechanism measures the extent of free scavenging abilities of food samples through the donation of ions to the free radical thereby inhibiting the chain reactions that could cause oxidative deterioration (Kettawan et al., 2011). The increase in DPPH scavenging activity correlates directly to the extent of antioxidant efficacy of a typical plant material (Sánchez-Moreno et al., 1998). Higher DPPH is an indication of higher free radical scavenging ability while lower DPPH is an indication of lower free radical scavenging ability. Table 2 shows that all these factors (storage time, preservatives and packaging material) significantly influenced the antioxidant activity (DPPH) of the dika kernel flour (Bamidele & Ojedokun, 2015). However, the effect of storage time and packaging material had a more pronounced effect than the preservative added.

Radical-scavenging activity using 1,1- diphenyl - 2 picrylhydrazyl (DPPH) has been extensively used in the field of food processing for screening the antioxidant capacity of agricultural produce (Sánchez-Moreno, 2002). DPPH is a stable organic free radical mostly utilized in examining the antioxidant activities of materials within a short period with an adsorption peak at 517 nm (Olagunju et al., 2018). Adsorption disappears when accepting an electron or a free radical species, which results in a noticeable discolouration from purple to yellow (Lin et al., 2007).

In comparison to the standard, the storage conditions resulted to significant percentage decrease in the antioxidant activity of the stored dika kernel flour. This decrease is as shown in Figure 2. It can be said that prolonged storage decreases the antioxidant activities of the dika kernel flour stored under different packaging material and this decrease was in the range of 0.46 - 26.99% within 0 to 12 weeks of storage.

Storage conditions and duration are known to affect food's antioxidant composition (Steiner-Asiedu et al., 2012). This study found that increased storage time significantly decreased the dika kernel flour's antioxidant activity. However, dika kernel flour stored with ginger extract in laminated pouches (CH and CL) and with ginger powder in laminated pouches (BH) exhibited the least decline in DPPH activities. This is likely due to ginger extract's rich antioxidant compounds, capable of scavenging free radicals and impeding oxidation (Mao et al., 2019; Ayustaningwarno & Anjani, 2024), confirming prior findings on dika kernel flour properties by Bamidele & Ojedokun (2015).

Table 2: Influence of Storage on DPPH (diphenyl-1-picryhydrazyl) Radical Scavenging Activity Assay (%) of Preserved dika Kernel Flour

Samples	Storage Time (weeks)			
	0	4	8	12
A_H	96.03 ± 0.14^{aA}	94.12 ± 1.57^{aA}	75.98 ± 19.10^{aC}	70.11 ± 0.78^{aD}
A_L	96.03 ± 0.14^{aA}	95.59 ± 0.82^{bA}	94.59 ± 0.36^{aA}	77.06 ± 0.92^{aC}
B_H	$96.68 \pm 0.0^{\circ}C^{aA}$	95.95 ± 0.46^{bA}	93.64 ± 2.24^{aC}	84.65 ± 0.12^{aD}
B_L	$96.68 \pm 0.0^{\circ}C^{aA}$	96.00 ± 0.82^{aA}	94.95 ± 0.11^{aA}	92.41 ± 0.71^{aC}
C_H	97.34 ± 0.54^{aA}	95.97 ± 0.43^{bA}	95.68 ± 0.57^{bA}	91.75 ± 1.78^{aC}
C_L	97.34 ± 0.54^{aA}	96.18 ± 0.71^{aA}	96.33 ± 0.49^{aA}	95.57 ± 1.32^{abC}
D_H	96.95 ± 0.12^{bA}	95.32 ± 0.78^{bA}	94.47 ± 2.13^{aA}	87.53 ± 5.41^{aC}
D_L	96.95 ± 0.12^{bA}	95.65 ± 0.18^{bA}	95.15 ± 1.66^{aA}	94.79 ± 0.46^{bC}
Natural Preservative(s)				
E_H	96.11 ± 0.13^{aA}	95.49 ± 0.53^{aA}	94.62 ± 0.71^{abC}	94.04 ± 0.53^{abC}
E_L	96.11 ± 0.13^{aA}	95.25 ± 1.17^{bA}	94.82 ± 1.42^{aA}	94.47 ± 0.14^{aA}
F_H	95.99 ± 0.11^{bA}	94.77 ± 0.71^{aA}	94.20 ± 2.38^{aA}	91.71 ± 0.85^{aC}
F_L	95.99 ± 0.11^{bA}	95.07 ± 0.21^{aA}	95.07 ± 0.00^{aA}	92.55 ± 4.77^{bA}

Values are expressed as mean ± standard deviation of triplicate determination. Means with different superscripts in lower case on the same column are significantly ($p < 0.05$) different while .means with different superscripts in upper case on the same row are significantly ($p < 0.05$) different.

Key: AH= Dika kernel flour stored in high density polyethylene; **AL** = Dika kernel flour stored in laminated pouches; **BH** = Dika kernel flour + ginger powder stored in high density polyethylene; **BL**= Dika kernel flour + ginger powder stored in laminated pouches; **CH** = Dika kernel flour + ginger extract stored in high density polyethylene; **CL** = Dika kernel flour + ginger extract stored in laminated pouches; **DH** = Dika kernel flour + BHT stored in high density polyethylene; **DL** = Dika kernel flour + BHT stored in laminated pouches; **EH**= Ginger powder stored in high density polyethylene; **EL** = Ginger powder stored in laminated pouches; **FH** = Ginger extract stored in high density polyethylene; **FL** = Ginger extract stored in laminated pouches**.**

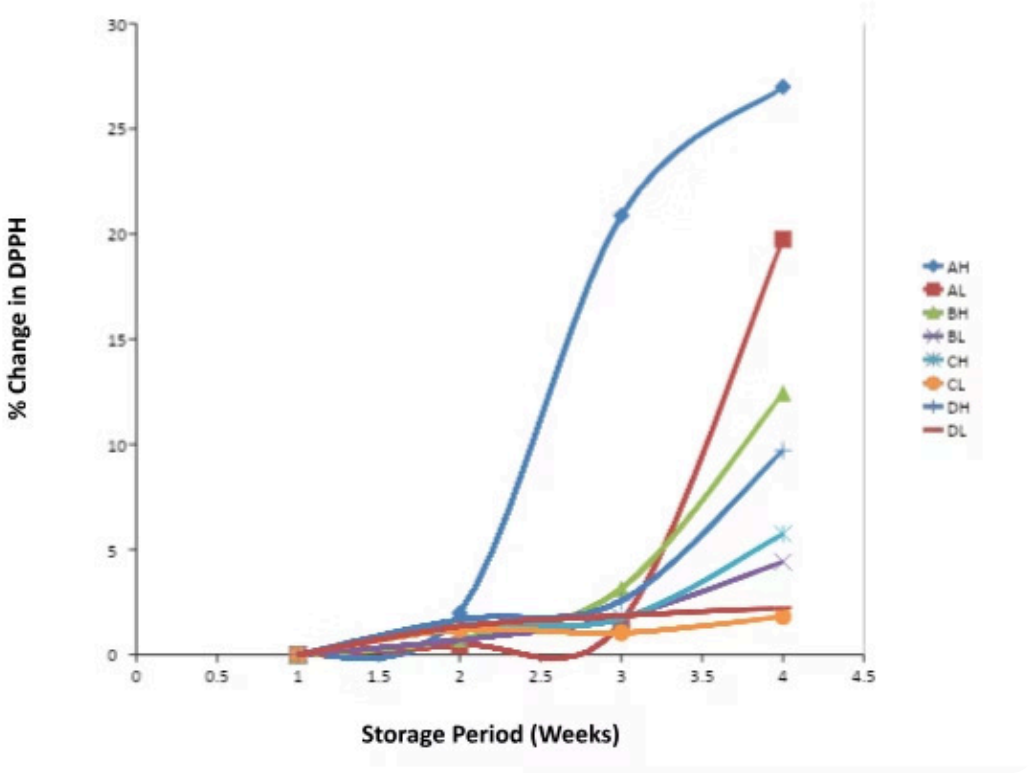

Figure 2: Percentage of Radical Scavenging Ability Retained during Stored Dika Kernel Flour

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Primarily, the loss of the antioxidant activity could be attributed to the oxidation of the phenolic compounds during storage (Jiménez *et al.*, 2016; Guimarães *et al.*, 2011), and the ability of the preserving compound and package to prevent this oxidation is the limiting factor in determining loss in free radical scavenging ability of the sample. According to Gião *et al.* (2013), oxidation of the phenolic compounds in four different aromatic herbs consisting of sage, thyme, savoury and sweet-amber lead to the reduction of their corresponding antioxidant activity by more than 30 % during one year of storage at 25 ºC in dark conditions.

Influence of Storage on the Ferric Reducing Antioxidant Power

The free radical scavenging activity ranged from 27.84 to 39.68 at the beginning of storage and these increased to a range of 37.24 to 128.35 at the end of storage. There was significant increase in the ferric reducing antioxidant power of all samples of preserved dika kernel (Bamidele & Ojedokun, 2015). Percentage change in FRAP ranged from 1.18 - 327.36% increase during storage and this changes were positively correlated with storage time, which implies as storage time increased, FRAP activities also increased.

Dika flour preserved with ginger extract (Sample CH and CL) had the most pronounced percentage increase in FRAP (274.72 and 259.74%) at the end of 12 weeks of storage, while dika flour stored in HDPE without preservatives had the least percentage increase in FRAP (33.76%). These results are supported by the findings which reported that the reducing power was not decreased during long storage period (Mao et al., 2019; Ayustaningwarno & Anjani, 2024).

Table 3: Influence of Storage on the Ferric Reducing Antioxidant Power (mg AAE/g)

Samples	Storage Time (weeks)			
	0	4	8	12
A_H	27.84 ± 0.70^{dBC}	29.15 ± 3.54^{cBC}	30.57 ± 2.12^{dB}	37.24 ± 4.84^{fA}
A_L	27.84 ± 0.70^{dC}	33.15 ± 2.12^{dB}	45.69 ± 4.14^{cAB}	46.45 ± 4.95^{eA}
B_H	39.68 ± 0.90^{aBC}	40.15 ± 0.71^{bBC}	$42.47 \pm 0.0°C^{dB}$	69.45 ± 5.66^{deA}
B_L	39.68 ± 0.90^{aC}	52.65 ± 9.89^{aBC}	59.18 ± 0.71^{aB}	76.46 ± 1.33^{dA}
C_H	34.65 ± 0.25^{bcCD}	35.15 ± 6.36^{cC}	49.64 ± 1.32^{bB}	128.35 ± 4.24^{aA}
C_L	34.65 ± 0.25^{bcD}	40.15 ± 3.54^{bC}	51.65 ± 5.66^{abB}	124.65 ± 0.07^{bA}
D_H	35.23 ± 1.13^{bD}	37.15 ± 2.12^{cC}	45.65 ± 8.46^{bB}	58.12 ± 0.71^{cA}
D_L	35.23 ± 1.13^{bD}	40.66 ± 0.08^{bC}	46.15 ± 6.36^{bB}	52.56 ± 1.11^{cdA}
Natural Preservative(s)				
E_H	112.18 ± 0.65^{bB}	111.15 ± 0.71^{bC}	140.15 ± 2.26^{bB}	151.44 ± 0.71^{cA}
E_L	112.18 ± 0.65^{bC}	105.15 ± 0.71^{cD}	130.13 ± 1.26^{bcB}	146.56 ± 2.61^{cA}
F_H	130.56 ± 1.65^{aC}	112.65 ± 0.00^{bD}	347.33 ± 5.75^{aB}	557.96 ± 1.99^{aA}
F_L	130.56 ± 1.65^{aC}	129.64 ± 8.45^{aD}	337.77 ± 1.76^{aB}	356.65 ± 3.11^{bA}

Values are expressed as mean ± standard deviation of triplicate determination. Means with different superscripts in lower case on the same column are significantly ($p < 0.05$) different while .means with different superscripts in upper case on the same row are significantly ($p < 0.05$) different.

Key: AH= Dika kernel flour stored in high density polyethylene; **AL** = Dika kernel flour stored in laminated pouches; **BH** = Dika kernel flour + ginger powder stored in high density polyethylene; **BL**= Dika kernel flour + ginger powder stored in laminated pouches; **CH** = Dika kernel flour + ginger extract stored in high density polyethylene; **CL** = Dika kernel flour + ginger extract stored in laminated pouches; **DH** = Dika kernel flour + BHT stored in high density polyethylene; **DL** = Dika kernel flour + BHT stored in laminated pouches; **EH**= Ginger powder stored in high density polyethylene; **EL** = Ginger powder stored in laminated pouches; **FH** = Ginger extract stored in high density polyethylene; **FL** = Ginger extract stored in laminated pouches

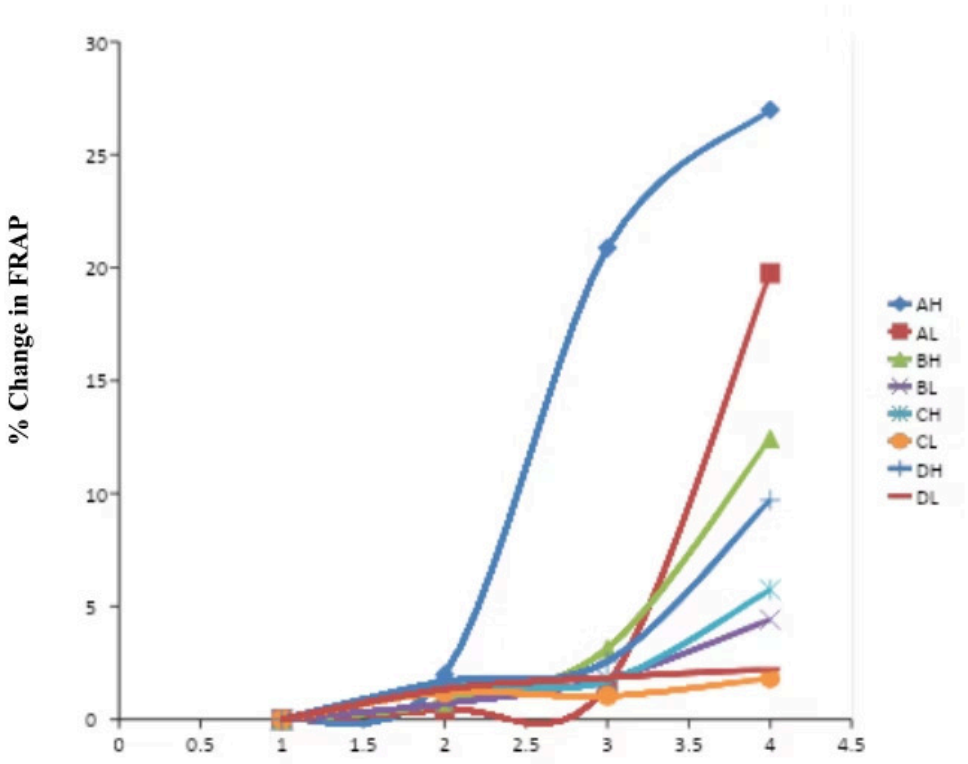


Figure 3: Percentage Increase in the Ferric Reducing Antioxidant Power (mg AAE/g) of preserved dika kernel flour

Key:AH= Dika kernel flour stored in high density polyethylene; **AL** = Dika kernel flour stored in laminated pouches; **BH** = Dika kernel flour + ginger powder stored in high density polyethylene; **BL**= Dika kernel flour + ginger powder stored in laminated pouches; **CH** = Dika kernel flour + ginger extract stored in high density polyethylene; **CL** = Dika kernel flour + ginger extract stored in laminated pouches; **DH** = Dika kernel flour + BHT stored in high density polyethylene; **DL** = Dika kernel flour + BHT stored in laminated pouches.

An effective antioxidant's radical scavenging efficiency is measured by its ability to counteract high levels of reactive radicals even at lower concentrations (Sánchez-Moreno, 2002). While reducing potential was significantly affected by storage time and packaging, clear trends emerged regarding storage time. Phenolic components can reduce DPPH free radicals but are ineffective in reducing iron (III) ions to iron (II) ions, a process known as the Fenton reaction. Changes in TPC directly correlated with DPPH changes (Gheldof & Engeseth, 2002) but inversely with FRAP during storage stability tests.

Reports indicate that low total phenolic content during storage can lead to lower antioxidant activity (Almalki, 2016). However, extending the storage period to three months resulted in higher free radical scavenging activity. As Kettawan et al. (2011) reported, higher reducing power signifies a better ability to donate electrons and free radicals, forming stable substances and interrupting free radical chain reactions. Ferric reducing power is thus considered a defense mechanism where antioxidant agents transfer electrons or hydrogen atoms to oxidants or free radicals (Ogunmoyole et al., 2009).

Ferric Reducing Antioxidant Power (FRAP) relies on the reduction of Fe^{3+} (ferricyanide complex) to Fe^{2+} in the presence of reductants (antioxidants). The reducing power of bioactive compounds has

been linked to antioxidant activity (Yen et al., 1993; Siddhuraju et al., 2002; Ayustaningwarno & Anjani, 2024). Therefore, determining the reducing power of phenolic constituents is essential to understand the relationship between their antioxidant effect and reducing power.

Biochemical Mechanism of Ginger Preservation

Ginger, through its principal bioactive compounds gingerol and shogaol, exhibits significant preservative properties, primarily by inhibiting lipid oxidation. These compounds contribute to the extended shelf life and quality maintenance of various products, as demonstrated by their role in preserving dika flour (Bamidele & Ojedokun, 2015). Their efficacy stems from a multi-faceted biochemical mechanism, involving free radical scavenging, metal chelation, enzyme inhibition, and membrane stabilization (Ayustaningwarno & Anjani, 2024).

Molecular Structure and Properties

Gingerol and shogaol are phenolic compounds with unique molecular structures that are critical to their antioxidant capabilities (Mao et al., 2019). Gingerols are a series of homologous phenolic ketones, while shogaols are their dehydrated forms, possessing a **α,β-unsaturated ketone** moiety. These structures, particularly the presence of phenolic hydroxyl groups, are directly linked to their ability to act as potent antioxidants (Semwal et al., 2015).

Free Radical Scavenging Mechanism

One of the primary mechanisms by which ginger compounds inhibit lipid oxidation is through their robust free radical scavenging activity. Gingerol and shogaol readily donate hydrogen atoms from their phenolic hydroxyl groups to neutralize reactive oxygen species (ROS), such as superoxide radicals, hydroxyl radicals, and peroxyl radicals. This electron donation stabilizes the free radicals, thereby terminating the oxidative chain reactions that lead to lipid degradation (Mao et al., 2019).

Metal Chelation Properties

Transition metals, particularly ferrous iron (Fe^{2+}) and cupric copper (Cu^{2+}), play a crucial role as catalysts in lipid oxidation processes by promoting the formation of highly reactive free radicals. Gingerol and shogaol possess metal-chelating properties, allowing them to bind to these metal ions. By forming stable complexes with Fe^{2+} and Cu^{2+}, they effectively reduce the catalytic activity of these metals, thus hindering the initiation and propagation of lipid oxidation (Shaukat et al., 2023).

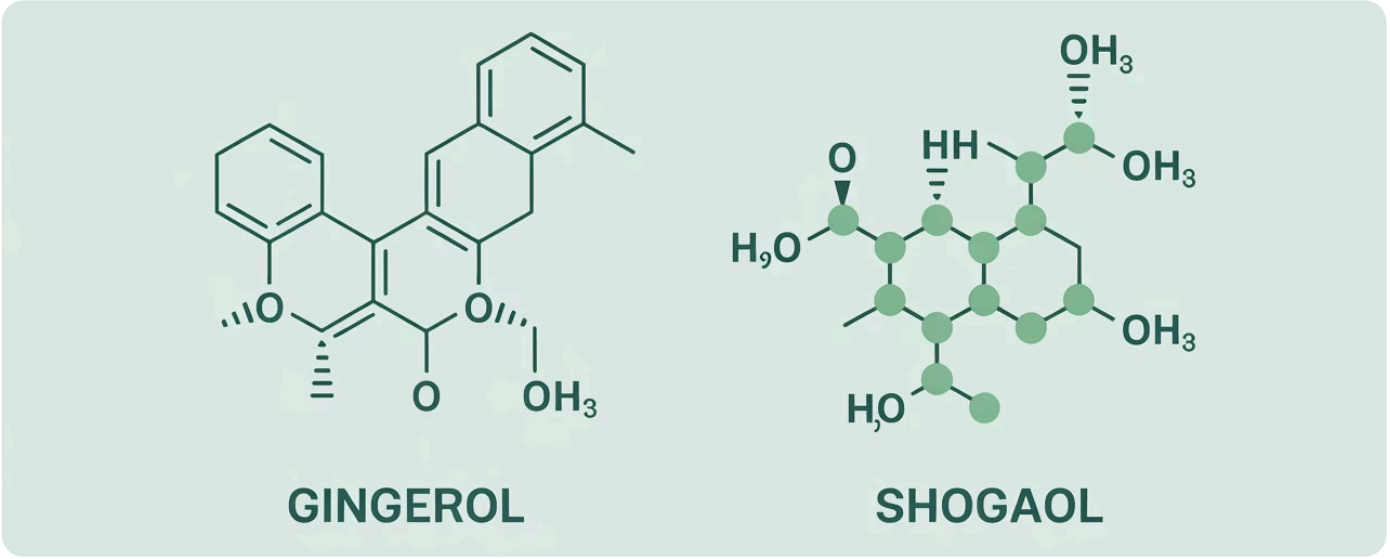
Enzyme Inhibition

Ginger compounds also exert their preservative effects by inhibiting the activity of various oxidative enzymes. Lipoxygenase, for instance, is a key enzyme involved in the initiation of lipid peroxidation in many food systems. Gingerol and shogaol have been shown to inhibit lipoxygenase and other enzymes that generate free radicals or promote oxidative reactions, further contributing to their antioxidant and preservative functions (Shaukat et al., 2023).

Membrane Stabilization Effects

Beyond their direct antioxidant and enzyme inhibitory actions, ginger compounds can also stabilize biological membranes. By interacting with the lipid bilayer of cell membranes, gingerol and shogaol can reinforce membrane integrity and reduce membrane fluidity. This physical barrier helps to protect membrane lipids from oxidative attack and prevent the leakage of intracellular antioxidants or the entry of pro-oxidants, thereby safeguarding cellular components from oxidative damage (Shaukat et al., 2023).

These combined biochemical mechanisms highlight the significant potential of ginger compounds, specifically gingerol and shogaol, in the natural preservation of food products and other biological systems.



Commercial Viability and Practical Implications

The potential of ginger as a natural preservative extends beyond its biochemical mechanisms to practical considerations for commercial adoption. Evaluating its cost-effectiveness, scalability, regulatory standing, and market acceptance is crucial for its successful integration into the food industry.

Cost-Effectiveness Analysis

- Ginger extract production costs vs synthetic preservatives (BHT, BHA)
- Economic feasibility for small-scale vs industrial food processing
- Cost per unit of antioxidant activity compared to alternatives

Scalability for Food Industry

- Industrial extraction and standardization challenges
- Shelf-life stability of ginger extracts during storage
- Integration with existing food processing equipment
- Quality control and batch-to-batch consistency

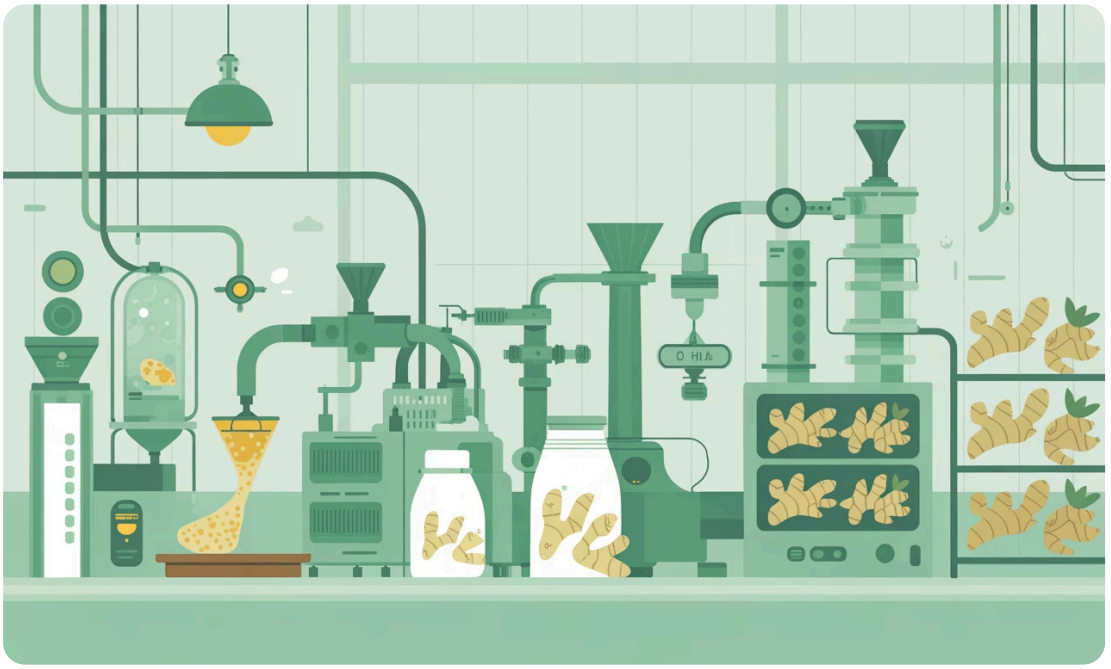
Regulatory Considerations

- FDA GRAS status for ginger extract (21 CFR 182.20, FEMA No. 2521)
- EU regulatory approval for natural preservatives
- Labeling requirements for "natural preservative" claims
- Maximum allowable concentrations in different food categories

Market Applications and Limitations

- Suitable food categories (flour-based products, oils, baked goods)
- Sensory impact considerations (flavor, color changes)
- Consumer acceptance of ginger-preserved products
- Competitive positioning against other natural preservatives (rosemary extract, tocopherols)

Understanding these facets ensures that ginger's proven antioxidant capabilities (Mao et al., 2019; Ayustaningwarno & Anjani, 2024) can be effectively translated from laboratory findings into widespread commercial applications. The FDA's GRAS status for ginger extract (21 CFR 182.20, FEMA No. 2521) provides a strong foundation for regulatory approval, paving the way for its use in various food categories. However, challenges related to industrial extraction, standardization, and sensory impacts require careful consideration to maximize market acceptance and competitive positioning against other natural preservatives like rosemary extract and tocopherols.



CONCLUSION

This study concluded that dika kernel flour (Bamidele & Ojedokun, 2015) can be preserved with ginger extract and ginger powder for 12 weeks without deterioration of the antioxidant activities of the preservative agents (Mao et al., 2019; Ayustaningwarno & Anjani, 2024). Dika kernel flour can be preserved for a period of three months without rancidity especially in laminated aluminum pouches.

The study established that the addition of ginger extract in the two packaging materials and ginger powder in laminated pouches to dika flour reduced the rate of per cent loss of the scavenging properties of stored dika flour. Based on the results, the study recommends the use of ginger extract as a natural bio-preservative for extending the shelf life of dika kernel flour, particularly when stored in laminated aluminum pouches to maximize preservation effectiveness.

01

Use Ginger Extract

Ginger extract demonstrated superior preservation properties compared to ginger powder with higher phenolic retention and DPPH activity.

02

Choose Laminated Aluminum Pouches

Laminated aluminum packaging provides better protection against light and oxygen penetration than HDPE materials.

03

Monitor Storage Conditions

Regular monitoring of antioxidant activity and phenolic content helps ensure product quality throughout storage.

04

Scale Up Applications

Natural bio-preservative systems can be implemented in commercial food processing for extended shelf life.

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Not Applicable

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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