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Effect of storage and packaging on physicochemical and functional properties of *Es Puter* powder enriched with ginger extract

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ABSTRACT

Ginger (*Zingiber officinale* Rosc.) contains bioactive compounds, such as phenols, that could enrich *Es Puter*, a traditional Indonesian frozen dessert, and transform it into a functional food. Consumer demand for practical food has driven the development of *Es Puter* powder, which can be stored and redissolved in water to restore its soft texture after freezing. This study aimed to determine the effect of storage time (0 and 14 days) and selection of packaging types (plastic clips and foil sachets) on the physical quality (rehydration, dissolving time, emulsion stability, and microstructure profile with SEM) and the chemical quality (moisture content, pH value, and antioxidant activity, as well as functional group profile with FTIR) of *Es Puter* powder enriched with ginger extract. Packaging type and storage time significantly affected (p<0.05) rehydration, dissolving time, moisture content, pH value, emulsion stability, and antioxidant activity. Storage time showed effects on SEM and FTIR analyses.

Keywords: *Es Puter*, ginger, packaging, physicochemical quality, storage

INTRODUCTION

Indonesians have become more aware of nutrition and health, boosting demand for nutritious comfort foods. The health risks associated with animal products, such as lactose intolerance and high cholesterol levels, also drive interest in plant-based diets **[1]**. Fast food consumption has increased, particularly among working individuals, due to urbanization, lifestyle changes, and the expansion of the middle class. Fast food consumption increased by 40.6% during the COVID-19 epidemic, with many people consuming it 1-2 times per week **[2]**. This trend encourages fast-food innovation with healthy ingredients like ginger. Ginger is abundant in functional substances, including flavonoids, β-carotene, and ascorbic acid. Indonesia continues to produce more of it, particularly in Java. East Java contributed the most ginger (65.98 thousand tons) of Indonesia's 247.35 thousand tons of ginger production in 2022.

Ginger is a spice known for its health benefits. Three main types grown in Indonesia are elephant ginger, red ginger, and emprit ginger (Java ginger). Elephant ginger is the most widely used and has high production value **[3]**. It contains phenolic compounds such as gingerol, shogaol, paradol, and zingerone, which have antioxidant, antimicrobial, and anti-inflammatory properties. These compounds are sensitive to heat **[4]**, so it is best to process them at low temperatures to preserve their benefits. One option is to make *Es Puter*, which is stored cold and helps maintain these bioactive compounds **[5]**. *Es Puter* is a very popular traditional frozen dessert from Indonesia with similar characteristics to ice cream. Additionally, *Es Puter* made with coconut milk is a healthy alternative for people with lactose intolerance, as it does not contain cow's milk **[6]**.

Ginger can enhance the nutritional and functional value of *Es Puter*, offering a distinctive blend of sweet and spicy flavors and a sensation of both cold and heat. Its active compounds can also increase the product's

antioxidant activity **[7]**. However, traditional food production is time-consuming, which doesn't fit the current needs of consumers seeking convenient foods. As a solution, this study developed *Es Puter* powder with ginger extract. It is made by freeze-drying *Es Puter* to preserve its bioactive compounds. The powder's storage is simple, as it can be dissolved in water and then frozen to achieve a texture similar to ice cream. In addition to being more convenient for the consumer, this format also improves energy efficiency during processing and storage **[8]**. Thus, the product combines health benefits, rich flavor, and convenience in one formulation.

The quality and freshness of *Es Puter* powder enriched with ginger extract during storage depend on the length of time and type of packaging used. This product tends to clump if stored at room temperature for prolonged periods, so it requires suitable packaging that protects it from water, air, and temperature changes **[9]**. To ensure its stability, it is crucial to evaluate the *Es Puter* powder in different types of packaging. The longer the storage period, the lower its stability, which can be avoided by using proper packaging. The most common packaging options are plastic clips and foil sachets. Plastic clips are inexpensive, easy to find, and practical for adjusting portions. On the other hand, foil sachets are opaque and offer good protection against light and moisture, which helps preserve the *Es Puter* powder better **[10]**.

Previous studies have analyzed plastic clips and foil sachets as food packaging. For example, in the packaging of instant tiwul (a traditional Indonesian food made from dried cassava granules, usually steamed and eaten as a rice substitute), foil sachets offer a longer shelf life than plastic clips **[11]**. Similarly, in dangke (a traditional cheese from South Sulawesi, Indonesia, made from cow or buffalo milk using papaya sap as a natural coagulant) packaging, aluminium foil better maintained product quality compared to plastic clips **[12]**. However, no studies have yet evaluated the use of these materials for packaging instant beverages. This study packaged *Es Puter* powder enriched with ginger extract in plastic clips and foil sachets, then stored it at room temperature for 14 days. The objective was to compare how storage time and packaging type affect the physicochemical quality of the final product.

Scientific Hypothesis

Storage time and type of packaging can affect rehydration, dissolving time, moisture content, pH value, emulsion stability, and antioxidant activity of *Es Puter* powder. Additionally, the microstructure and functional groups of this product change over time.

Objectives

The objectives of this study were to determine the effect of storage time and selection of packaging types on the physical quality (rehydration, dissolution time, emulsion stability, and microstructure profile with SEM) and the chemical quality of *Es Puter* powder enriched with ginger extract, namely moisture content, pH value, and antioxidant activity, as well as functional group profile with FTIR.

MATERIAL AND METHODS

Samples

Samples description: *Es Puter* powder was obtained from drying *Es Puter* using a freeze dryer for 48 hours.

Samples collection: The samples were packed in plastic clips and foil sachets, and then stored at room temperature for 14 days.

Samples preparation: Samples were unpacked, and 1 g from each sample was prepared for examination.

Number of samples analysed: 4 samples

Chemicals

Ethanol 96%, buffer pH 4, 7, 10, along with DPPH (1,1-diphenyl-2-picrylhydrazyl) used in this study were of analytical grades with high purity and were obtained from Merck.

Animals, Plants, and Biological Materials

This study did not use animal or biological materials. The plant materials used in this study were coconut milk, coconut water, CMC (carboxymethyl cellulose), and ginger (*Zingiber officinale* Rosc.).

Instruments

The instruments used in this study were tissue, peeler, knife, basin, tray, cabinet dryer (Getra, China), blower (Sekai, Indonesia), chopper (Philips, Indonesia), aluminium foil, 40 mesh sieve, spoon, food container (Lock & Lock, Korea), permanent marker, freezer (Gea, China), beaker glass (Pyrex, Germany), filter cloth, coffee filter, Erlenmeyer flask (Pyrex, Germany), funnel, dark glass bottle, vacuum rotary evaporator (Eyela, Japan), digital scale (Tanita, Japan), measuring cup (Pyrex, Germany), dropper pipette, pan, electric stove (Kris, Indonesia), thermometer (Gea, China), analytical balance (Fujitsu, Japan), mixer (Philips, Indonesia), stopwatch, thinwall, refrigerator (Modena, Italy), homogenizer (IKA Ultra Turrax, Germany), ice cream maker (De'Longhi, Italy),

plastic cup, freeze dryer (TEFIC, China), mortar, pestle, plastic clips, foil sachets, silica gel, labels, ballpoint pens, FTIR (Thermo Fisher Scientific, United States), test tubes (Pyrex, Germany), micropipettes, vortex, UV-Vis spectrophotometer (Vernier, United States), porcelain dishes, tongs, oven (Festar, China), desiccator, pH meter (Tekcoplus, China), ruler, measuring pipette (Pyrexi, Germany), centrifuge tube, centrifuge (Hettich, Germany), Scanning Electron Microscope (Hitachi, Japan).

Laboratory Methods

Physical *Es Puter* powder analysis: The yield was determined by using the Association of Official Analytical Chemists (AOAC) method **[13]**. Rehydration was determined by referring to **[14]** with modifications. Dissolving time was determined as described in **[15]**, with modifications. Emulsion stability with the centrifugation method was determined by referring to **[16]** and **[17]**.

Chemical *Es Puter* powder analysis: The moisture and antioxidant activity were determined by using Association of Official Analytical Chemists (AOAC) methods **[13]**. This study applied the following methods: the oven method for moisture and the DPPH method for antioxidant activity. The pH was determined by using a calibrated pH meter (Tekcoplus, China).

Description of the Experiment

Sample preparation:

Ginger powder

The production of ginger powder began with peeling the ginger with a peeler, then washing it under running water until clean. The clean ginger was sliced into 2–3 cm pieces and arranged on a tray. The tray of ginger slices was placed in a cabinet dryer with a blower and dried for 3 days. After the initial drying, the ginger was coarsely ground and dried again with a blower for 2 days. The dried ginger was then crushed and sieved through a 40-mesh sieve to produce fine ginger powder.

Ginger extract

The extraction method used was maceration. Ginger powder was extracted using a 96% ethanol solution at a ratio of 1:5. A total of 200 g of ginger powder was macerated with 750 ml of ethanol, covered with aluminium foil, and left for 24 hours at room temperature. After 24 hours, the filtrate was filtered using a filter cloth, poured into an Erlenmeyer flask, and covered with aluminium foil. Meanwhile, the residue was re-macerated with 250 mL of ethanol for 2 additional 24-hour periods. The resulting filtrate was filtered using a coffee filter, combined with the previous filtrate, and then concentrated using a vacuum rotary evaporator at 50 °C to produce a thick extract.

***Es Puter* enriched with ginger extract**

A total of 50 g of sugar dissolved in 75 ml of coconut milk and 75 ml of mineral water at 80 °C. After the sugar had dissolved, coconut water was added and stirred until boiling. The mixture was cooled to 33 °C and gradually mixed with 0.88 g of CMC while stirring with a mixer for 7 minutes. Ginger extract (1.40 g) was incorporated into the dough and stirred for 5 minutes. The mixture was stored in the refrigerator for 4 hours, then homogenized at 12,000 rpm for 5 minutes before transfer into an ice cream maker pre-cooled for 30 minutes. Stirring in the ice cream maker continued for 20 minutes. The resulting *Es Puter* was transferred into a food container and stored in a freezer at −33 °C.

***Es Puter* powder enriched with ginger extract**

The production of *Es Puter* powder enriched with ginger extract was initiated by filling the *Es Puter* into plastic cups up to half their height, followed by storage in a freezer for 24 hours. The compressor freeze dryer was operated until the temperature reached −40 °C, after which the cups containing the *Es Puter* were placed on the sample holder plate. The cable was wrapped around the plate pole, and the vacuum pump was activated. Drying was conducted for 48 hours. The obtained *Es Puter* powder was weighed and packed in plastic clips and foil sachets containing silica gel, then placed into food containers. The packaged *Es Puter* powder was stored at room temperature.

Quality Assurance

Number of repeated analyses: All other analyses were carried out in quintuplicate, except for antioxidant activity, which was carried out in triplicate. SEM and FTIR were performed without replication.

Number of experiment replication: 5 reps

Design of the experiment: The study used a completely randomized design (CRD) with two factors. Factor I consisted of different storage durations (0 and 14 days), and Factor II consisted of different packaging types (plastic clips and foil sachets). The combination of these two factors resulted in 2 × 2 = 4 treatment groups. Analysis parameters, including rehydration, solubility time, moisture content, and pH, were evaluated using the CRD two-factor design. Emulsion stability, antioxidant activity, microstructure, FTIR spectra, and functional groups were examined descriptively.

Laboratory accreditation: Experiments were not performed in the accredited laboratory.

Data Access

Data are available on request from the corresponding author.

Statistical Analysis

Rehydration, dissolving time, moisture content, and pH value were analyzed using a two-way ANOVA using SPSS 25 with a confidence level of 95% (p<0.05). Data are expressed as mean ± standard deviation. Emulsion stability, antioxidant activity, and microstructure were analyzed descriptively. FTIR spectra were analyzed in OriginPro 2022 and then descriptively for functional groups.

RESULTS AND DISCUSSION

Ginger Extract Yield

This study obtained a ginger extract yield of 6.42% from 342.5 g of ginger powder, yielding 22 g of thick extract. It is consistent with **[18]**, that reported a 6.78% yield utilizing ethanol, and fulfills the criterion of less than 10%. Several parameters impact extract yield, including particle size, extraction time, technique, equipment, and solvent characteristics **[19]**. Smaller powder particles enhance surface contact with the solvent, which boosts yield **[20]**. Longer extraction durations improve yield by allowing more active chemicals to dissolve.

Table 1 Ginger powder used for extraction and the ginger extract obtained

Extraction	Ginger powder (g)	Ginger extract (g)
Extraction 1	200	16
Extraction 2	142.5	8

This study extracted ginger using the maceration technique with 96% ethanol. The extract yield can be used to assess the amount of active chemicals extracted; larger yields imply more active compounds. Maceration was selected because it is a simple procedure that does not use heat, hence preserving ginger's active components. Maceration is a simple approach that involves soaking the powder in a suitable solvent at room temperature, reducing the risk of destroying bioactive components **[21]**.

The instruments employed affect extraction outcomes, as each tool uses varying levels of pressure, temperature, and filtration. Differences in equipment settings can alter extract concentration and quality **[22]**. Some technologies aim to maximize extraction while preserving greater amounts of active chemicals, resulting in thicker, more concentrated extracts. High-pressure extraction instruments operated at low temperatures can prevent the loss of phenolic compounds in ginger and yield more focused extracts **[23]**. Simpler instruments, on the other hand, produce more diluted extracts due to lower pressure and uneven temperature control.

This study extracted phenol components from ginger simplicia using 96% ethanol as a polar solvent. Phenol compounds are coupled to glycosides and easily dissolve in polar solvents such as ethanol and water **[24]**. Ginger contains polar phenol molecules, gingerol and shogaol, which have many hydroxyl groups that bind to sugars **[25]**. The extraction efficacy is determined by how well the solvent matches the chemical's polarity, using the "like dissolves like" principle **[26]**. The polarity of the solvent directly affects extract content. Ethanol, with its polar hydroxyl groups and dielectric constant of 24.3, is helpful for extracting phenolic compounds **[27]**.

Es Puter Powder Yield

Table 2 *Es Puter* used for freeze drying and the resulting *Es Puter* powder

Freeze drying	*Es Puter* mixture (g)	*Es Puter* powder (g)
Freeze drying 1	257.45	54.8
Freeze drying 2	274.23	94.3

Freeze-drying the *Es Puter* mixture enriched with ginger extract yielded 28.04%, with a total of 531.68 g of the mix yielding 149.1 g of *Es Puter* powder. The yield can be influenced by temperature and drying time during the process **[28]**. A lower cooling temperature and longer drying time lead to a more optimal sublimation process, resulting in a lower moisture content in the dried sample. However, lower moisture content reduces the yield because the dried sample becomes more porous **[29]**. Materials dried by freeze drying have lower water content than those dried by other methods, resulting in a more porous structure and lower yields **[30]**.

Rehydration

Table 3 Rehydration of *Es Puter* powder enriched with ginger extract

Samples	Rehydration (ml)
H1K1	1.20 ± 0.01
H1K2	1.22 ± 0.02
H2K1	1.51 ± 0.03
H2K2	1.31 ± 0.01

Note: The rehydrations present the mean ± standard deviation across 5 replications. H1K1, H1K2, H2K1, and H2K2 each represent the treatment of storage time and type of *Es Puter* powder packaging enriched with ginger extract: 0 days and plastic clips, 0 days and foil sachets, 14 days and plastic clips, and 14 days and foil sachets.

The type of packaging significantly affected (p<0.05) the rehydration of *Es Puter* powder enriched with ginger extract. *Es Puter* powder stored for zero days in foil sachets had the lowest rehydration value, while powder stored for 14 days in plastic clip packaging had the highest value. These results suggest that aluminium foil packaging maintains product quality better than plastic clip packaging. Its extremely low water vapor transmission rate (WVTR), approaching 0, indicates that it effectively prevents air and water vapor from entering the package **[31]**. Plastic clip packaging has a higher WVTR than aluminium foil; therefore, its ability to prevent air and water vapor from entering the package is lower **[32]**.

Storage time significantly affected (p<0.05) the rehydration of *Es Puter* powder enriched with ginger extract. *Es Puter* powder samples stored for 14 days in foil sachets had lower rehydration results than samples stored in plastic clip bags because the former did not clump as much. This occurred because aluminium foil packaging is more effective at preventing air, water vapor, light, and fat from entering and interacting with the packaged material than plastic clip packaging is **[33]**. In contrast, plastic clip packaging is highly permeable, so it is less effective at preventing water vapor from entering, leading to product clumping **[34]**.

The interaction between packaging type and storage duration had a significant effect (p<0.05) on the rehydration of *Es Puter* powder enriched with ginger extract. The right kind of packaging for the product's characteristics can maintain product quality during storage **[35]**.

Dissolving Time

Table 4 Dissolving time of *Es Puter* powder enriched with ginger extract

Samples	Dissolving time (s)
H1K1	69.60 ± 1.14
H1K2	57.80 ± 0.45
H2K1	195.40 ± 3.58
H2K2	109.80 ± 0.84

Note: The dissolving times are the mean ± standard deviation from 5 replications. H1K1, H1K2, H2K1, and H2K2 each represent the treatment of storage time and type of *Es Puter* powder packaging enriched with ginger extract: 0 days and plastic clips, 0 days and foil sachets, 14 days and plastic clips, and 14 days and foil sachets.

The type of packaging significantly affected (p<0.05) the dissolution time of *Es Puter* powder enriched with ginger extract. The samples of *Es Puter* powder that were stored in plastic clip packaging for 14 days had the longest dissolution time. This is likely because plastic clip packaging is low-density and highly permeable, allowing water vapor and air to enter the packaging, which then causes the product to clump, which increases its dissolution time **[36]**. Conversely, aluminium foil packaging has a higher density, blocking water vapor and air more effectively **[37]**.

Storage time significantly affects (p<0.05) the dissolution time of *Es Puter* powder enriched with ginger extract. The longer the storage time, the higher the moisture content, which causes the product to clump **[33]**. The longest dissolution time was observed with Es Puter powder stored in plastic clip packaging for 14 days. Products with high moisture content or that clump have very tight pores, which makes it difficult for water to penetrate their structure. This results in a longer time needed to achieve homogeneity **[38]**.

The interaction between packaging type and storage time had a significant effect (p<0.05) on the dissolving time of *Es Puter* powder enriched with ginger extract. It is essential to maintain product quality during storage. This can only be achieved by using packaging that is suitable for the product's characteristics **[39]**.

Moisture Content

Table 5 Moisture content of *Es Puter* powder enriched with ginger extract

Samples	Moisture content (%)
H1K1	2.50 ± 0.27
H1K2	2.47 ± 0.39
H2K1	3.86 ± 0.70
H2K2	2.91 ± 0.50

Note: The moisture contents present the mean value of 5 replications ± standard deviation. H1K1, H1K2, H2K1, and H2K2 each represent the treatment of storage time and type of *Es Puter* powder packaging enriched with ginger extract: 0 days and plastic clips, 0 days and foil sachets, 14 days and plastic clips, and 14 days and foil sachets.

The storage duration has a substantial effect (p<0.05) on the moisture content of *Es Puter* powder. On day 0, the moisture content was low, with 2.50% in plastic clip packaging and 2.47% in foil sachets. After 14 days, the moisture content in plastic clips and foil sachets had increased to 3.86% and 2.91%, respectively, suggesting that moisture content increases with extended storage. High ambient humidity led to increased moisture, which interacts with the product's free water. If the air is humid, the product absorbs water. The powder is hygroscopic and has fine particles, increasing the likelihood of moisture absorption during storage **[40]**, **[41]**.

The moisture content of *Es Puter* powder was significantly altered (p<0.05) by the type of packaging used. Powder stored in foil sachets consistently had lower water content than powder stored in plastic clips at both time points. This implies that foil sachets are more successful in preventing moisture buildup. Foil sachets, made of aluminium, are less permeable to oxygen and water vapor than low-density polyethylene (LDPE) plastic clips. aluminium has a higher density (1.06 kg/m^3) than polyethylene (0.91 kg/m^3) **[42]** and a significantly lower oxygen transmission rate (OTR: 0.03 vs. 7,000 cc/m^2/24h) **[43]**. High levels of oxygen promote microbial growth, creating free water and increasing moisture **[44]**. Polyethylene has a greater water vapor transfer rate (WVTR: 7 vs. 0.05 g/m^2/24h), making plastic clips less efficient in maintaining low moisture content **[45]**.

The interaction of storage duration and packaging method had no significant effect (p>0.05) on the moisture content of *Es Puter* powder enriched with ginger extract. The findings indicate that the two variables regulate moisture content independently and do not amplify one another's effects **[40]**. Even though foil sachets are more effective than plastic clips at limiting moisture growth, the powder's water content continues to rise over time. Microbial activity during storage is the main cause of this quality reduction. This activity occurs independently of the packing style and can impair product quality and shelf life **[46]**.

pH Value

Table 6 pH value of *Es Puter* powder enriched with ginger extract

Samples	pH value
H1K1	6.35 ± 0.05
H1K2	6.27 ± 0.06
H2K1	6.82 ± 0.11
H2K2	6.59 ± 0.10

Note: The pH values present the mean value of 5 replications ± standard deviation. H1K1, H1K2, H2K1, and H2K2 each represent the treatment of storage time and type of *Es Puter* powder packaging enriched with ginger extract: 0 days and plastic clips, 0 days and foil sachets, 14 days and plastic clips, and 14 days and foil sachets.

Storage period has a substantial effect (p<0.05) on the pH of *Es Puter* powder. On day 0, the pH levels were similar: 6.35 in plastic clips and 6.27 in foil sachets. After 14 days, the pH climbed to 6.82 in plastic clips and 6.59 in foil sachets, demonstrating that pH increases with storage time. The rise in pH is caused by oxidation during storage, which degrades acidic phenolic compounds such as gingerol (from ginger) and gallic acid (from coconut milk and water). As these molecules decompose, the quantity of free acid groups reduces, increasing pH levels. This validates the results of previous research that found oxidation decreases acidity by breaking down phenolic chemicals **[47]**.

Packaging had a substantial impact (p<0.05) on the pH of *Es Puter* powder. Powder stored in foil sachets exhibited a consistently lower pH than powder stored in plastic clips for both storage durations. Foil sachets are practical barriers to air, light, and moisture which makes them capable of speeding up the breakdown of phenol chemicals. By minimizing oxygen contact, foil sachets help retain phenol chemicals and prevent severe pH rises **[48]**. Plastic clips, on the other hand, have higher oxygen permeability, allowing these chemicals to degrade faster and causing pH to increase more rapidly **[49]**. aluminium foil has been found to maintain ginger's bioactive components better than polyethylene. aluminium foil had significantly lower OTR (0.03 vs. 7,000 cc/m²/24h) **[43]**.

The interaction between storage duration and packaging type had no significant effect (p>0.05) on the pH of *Es Puter* powder. This indicates that both variables alter pH separately, and do not complement or strengthen each other's effects. Bioactive component degradation is affected by both storage duration and packaging form, but not simultaneously. Optimal packaging, such as foil sachets, can slow phenol decomposition, but not halt it completely. Phenol compounds will continue to degrade over time, increasing the powder's pH during storage **[50]**.

Emulsion Stability

Creaming is a sign of an unstable emulsion. This occurs when particles in the emulsion clump together due to flocculation **[51]**. An increasing creaming value indicates decreasing emulsion stability or instability **[52]**. Emulsion stability is essential for determining product quality after drying and storage **[53]**.

Table 7 shows that the emulsion stability of *Es Puter* powder enriched with ginger extract stored in a foil sachet is higher than that of powder stored in a plastic clip. This can be caused by the foil sachets being hermetic, airtight, and lightproof, thereby maintaining the quality of fat-containing and light-sensitive products such as *Es Puter* powder **[54]**.

In addition to the packaging type, storage time can also reduce emulsion stability. The longer the storage time, the higher the product's water content. This condition can trigger hydrolysis. Hydrolysis produces free fatty acids, accelerating fat oxidation **[55]**. Oxidation products can disrupt emulsion stability and accelerate phase separation **[56]**.

Table 7 shows that *Es Puter* powder with ginger extract stored for 0 days has already undergone creaming. This occurred due to the *Es Puter* powder manufacturing process, which involves heating and cooling. These steps can cause fat degradation and emulsion breakdown **[57]**.

Table 7 Emulsion stability of *Es Puter* powder enriched with ginger extract

Samples	Creaming index (%)
H1K1	11.11
H1K2	8.88
H2K1	15.22
H2K2	10.87

Note: H1K1, H1K2, H2K1, and H2K2 each represent the treatment of storage time and type of *Es Puter* powder packaging enriched with ginger extract: 0 days and plastic clips, 0 days and foil sachets, 14 days and plastic clips, and 14 days and foil sachets.

Antioxidant Activity

Figure 1 shows that *Es Puter* powder with added ginger extract had higher antioxidant activity than the ginger extract. The combination of coconut milk and water with ginger extract creates a synergistic effect that leads to the desired outcome. Both are rich in potent antioxidants. Coconut milk and water contain phenols, flavonoids, amino acids, and electrolytes, as well as vitamins C and E. Ginger extract contains bioactive substances, including gingerol, shogaol, and paradol. The combination of these components results in increased total antioxidant activity because they function more effectively together than when used separately. By inhibiting the breakdown of ginger's active components, the polyphenols in coconut also help stabilize them, further boosting antioxidant activity **[58]**.

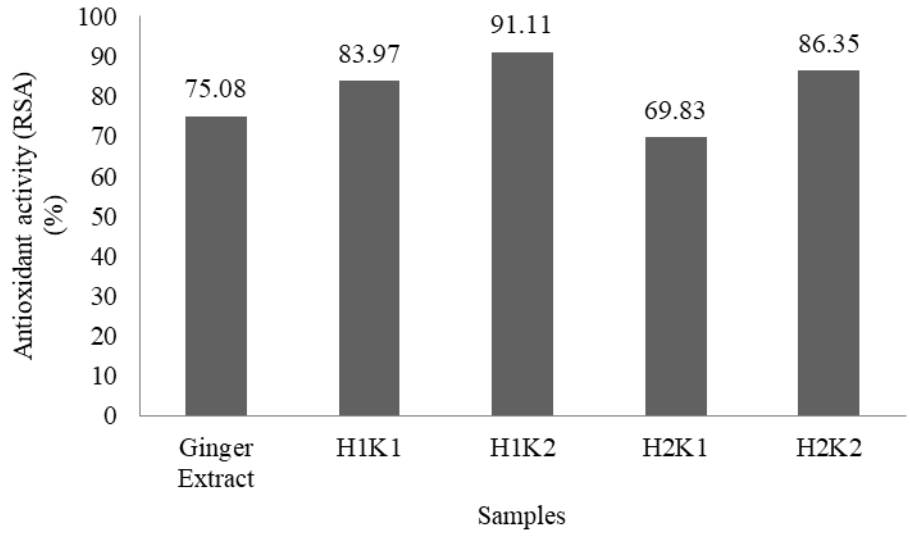


Figure 1 Antioxidant activity of ginger extract and *Es Puter* powder enriched with ginger extract.
Note: The antioxidant activity is the average of triplicate measurements. RSA = Radical Scavenging Activity. H1K1, H1K2, H2K1, and H2K2 each represent the treatment of storage time and type of *Es Puter* powder packaging: 0 days and plastic clip, 0 days and foil sachet, 14 days and plastic clip, and 14 days and foil sachet.

Emulsification and matrix formulation, two interactions that occur in *Es Puter* powder, can boost the bioavailability of antioxidants, increasing their activity compared to ginger extract, which does not undergo these interactions. While the matrix formulation can protect antioxidants from deterioration and regulate their release to enhance the product's antioxidant qualities, emulsification can boost antioxidant bioavailability by creating smaller particles that are more soluble and readily absorbed **[59]**. The antioxidants in *Es Puter* powder are more stable due to the synergistic effect of the ingredients, resulting in higher antioxidant activity than ginger extract alone.

Figure 1 illustrates that the antioxidant activity of Es Puter powder declined with storage time, likely due to phenol molecules' easy oxidation-induced degradation over time, which contributes to antioxidant activity **[60]**. Another critical factor in protecting antioxidants is packaging. Powder stored in foil sachets exhibited significantly higher antioxidant activity compared to that stored in plastic clip packaging. Plastic clip packing resulted in a 14.14% drop, but foil sachets only produced a 4.76% decrease. Plastic clips have high oxygen and moisture permeability. This accelerates oxidation and reduces the efficiency of antioxidants **[61]**.

The antioxidant activity experiment with Es Puter powder on day 0 showed results slightly different from the theoretical. According to **[62]**, chocolate powder stored in foil and plastic initially showed the same antioxidant activity. However, this study found a significant difference between powder stored in foil sachets and plastic clips on day 0. Poor packaging protection, environmental interactions, and testing conditions could be the reason. Low-density polyethylene (LDPE) plastic clips are not heat-resistant and can crack when exposed to high temperatures, humidity, or polar compounds. Since the phenolic compounds in ginger extract are polar, they can react with LDPE, causing damage even before storage, thereby affecting antioxidant stability.

Polyethylene's limited resilience to high temperatures allows for migration between the packaging and the product **[63]**. Experiments conducted during the day may diminish the antioxidant activity of Es Puter powder due to exposure to light and heat, which promote oxidation. Ethylene plastic is translucent and thin, rendering its contents prone to oxidation **[64]**. Environmental factors such as humidity, temperature, light, and the product's polar components may accelerate this process. Consequently, *Es Puter* powder stored in plastic clips had much reduced antioxidant activity than foil sachets, even before 14 days of storage.

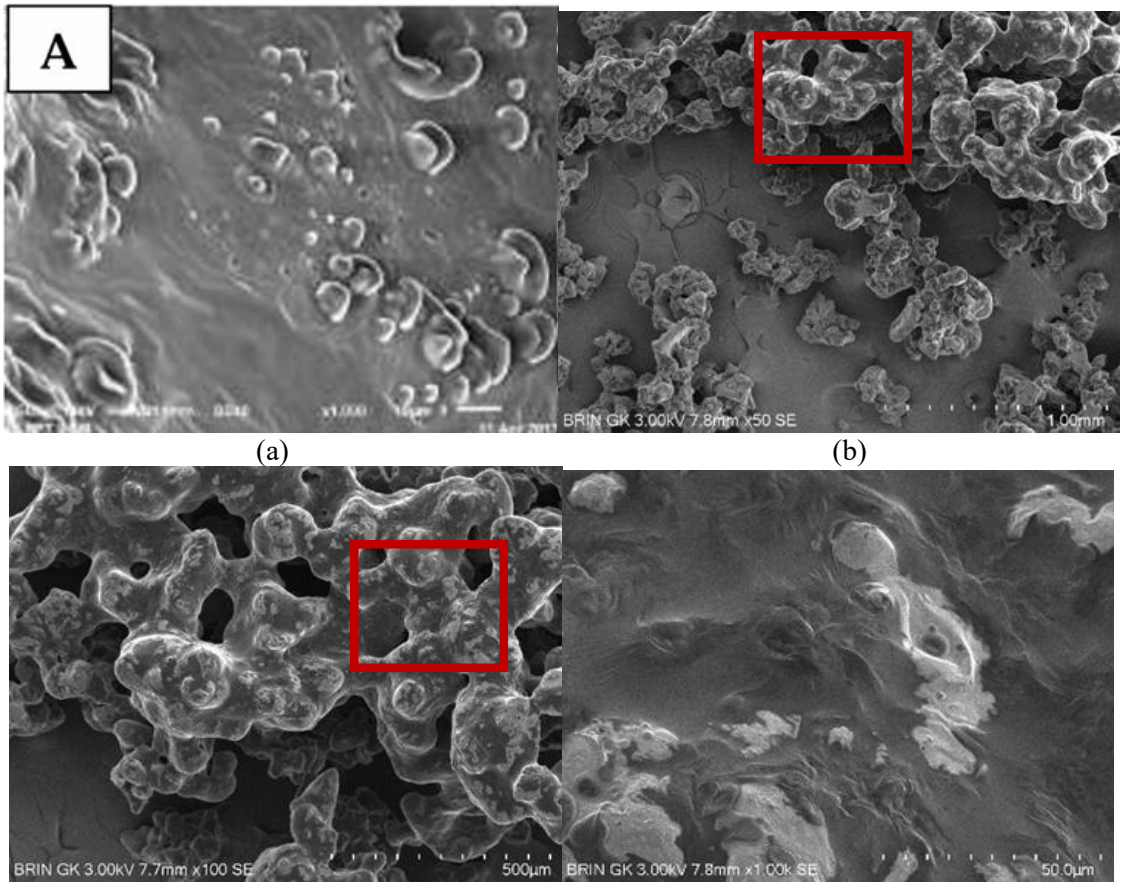
Foil sachet packaging preserves the antioxidant action of *Es Puter* powder better than plastic clips. This is attributed to its low susceptibility to degradation by oxygen, moisture, and light. Oxygen has a significant role in the oxidation of phenol molecules, whereas light increases the photodegradation of antioxidant bioactive substances such as phenol. Foil sachets efficiently shield light, water, and oxygen, reducing antioxidant degradation. Plastic clips, on the other hand, are translucent and let more light through, making them less effective. They also have a low capacity to prevent oxygen and light, limiting their usefulness in preserving bioactive components in functional meals **[11]**. Thus, foil sachets retain more antioxidant activity than plastic clips.

The antioxidant activity of *Es Puter* powder strongly depends on pH. As pH rises, antioxidant activity falls. pH and antioxidant activity are inversely related; higher pH corresponds to lower antioxidant levels **[47]**. This

drop results from structural alterations or degradation of phenol molecules such as gallic acid **[65]**. During storage, light and oxygen promote oxidation, which degrades these acidic chemicals, lowering their acidity and increasing pH. Table 6 supports these findings: samples with lower pH showed more potent antioxidant activity, whereas those with higher pH showed poorer antioxidant activity.

Scanning Electron Microscope Analysis

Using SEM, the microstructural characteristics of *Es Puter* powder can be analyzed, including the formation of air pockets and the destabilization of fat that occurs after freezing and drying **[66]**. The rehydration and dissolution time of *Es Puter* premix is affected by these air pockets when it is dissolved in water again. Fat destabilization can affect the stability of the *Es Puter* emulsion. SEM analysis can also detect impurities in *Es Puter*, even at low concentrations, which can influence recrystallization **[67]**.



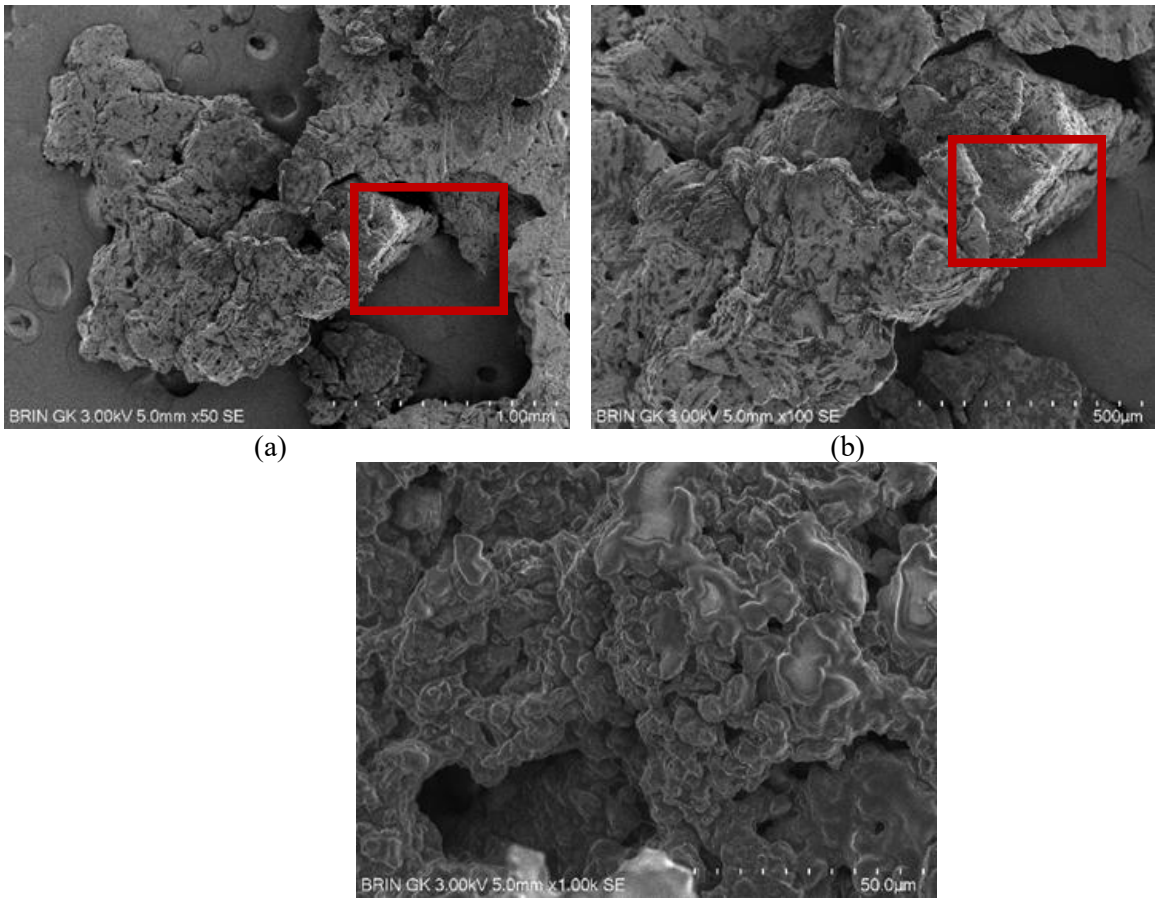
(a) (b)

(c) (d)

Figure 2 SEM profile of *Es Puter* powder enriched with ginger extract on day 0.
Note: (A) SEM profile of commercial ice cream; (B) 50x SEM profile; (C) 100x SEM profile; (D) 1000x SEM profile.

As reported in **[68]**, the microstructure of commercial ice cream has smaller air pockets than those in *Es Puter* powder enriched with ginger extract. On day 0 of storage, the air pockets in the microstructure profile of *Es Puter* powder enriched with ginger extract measure 1–3 mm. Larger pores facilitate a product's water absorption, increasing its rehydration capacity and accelerating its dissolution time **[29]**. Materials dried by freeze drying have a lower moisture content than those dried by other methods, resulting in a more porous structure **[30]**.

The serum phase is identified as the continuous phase visible across the entire surface of the ice cream microstructure **[68]**. The serum phase in commercial ice cream and popsicles is not significantly different and exhibits uninterrupted flow. Fat destabilization significantly affects the microstructure of ice cream **[69]**. The formation of fat agglomerates disrupts the uniformity and distribution of the microstructure. The microstructure of ice cream exhibits a non-homogeneous distribution, characterized by uneven spots. These spots are broken fat structures resulting from cooking, freezing, and drying processes **[70]**. Fat destabilization can lead to low emulsion stability. The separation and aggregation of fat particles that should be dispersed evenly leads to the formation of clusters, causing emulsion instability **[71]**.



(a) (b)

(c)

Figure 3 SEM profile of *Es Puter* powder enriched with ginger extract on day 14.
Note: (A) 50x SEM profile; (B) 100x SEM profile; (C) 1000x SEM profile.

The microstructure profile of *Es Puter* powder enriched with ginger extract after 14 days of storage shows smaller, denser air pockets than after 0 days, because the powder clumps together. The less porous a material is, the more difficult it is to absorb water because there is no space for absorption. This results in low rehydration capacity **[72]**. In the SEM profile of *Es Puter* powder enriched with ginger extract stored for 14 days, fat globules are clearly visible as clusters. This may be attributed to the powder's agglomerated structure, which results from particles adhering to form aggregates **[73]**.

The serum phase in the microstructure of shaved ice powder stored for 14 days is very different from that in the microstructure of commercial ice cream or shaved ice powder stored for 0 days. The serum phase, or continuous phase, is uneven due to fat globules forming large aggregates and clumping. The serum phase acts as a medium for dispersed fat globules and air pockets, helping maintain emulsion stability **[74]**. The microstructure profile shows signs of fat destabilization, including particle clumping and aggregate formation. Fat destabilization reduces emulsion stability by causing dispersed fat droplets to coalesce into larger flocs, ultimately leading to phase separation **[75]**.

Es Puter powder enriched with ginger extract stored for 14 days in aluminium foil packaging experienced clumping, which may have been caused by a poorly sealed package, allowing air and water vapor to enter and cause the product to clump. *Es Puter* powder is hygroscopic, so when water vapor enters the packaging, the ice cream powder absorbs the water vapor **[76]**. If water vapor enters the product, its moisture content will increase. If the moisture content of the powdered product is too high, it can disrupt product stability and cause clumping during storage **[77]**.

FTIR Analysis

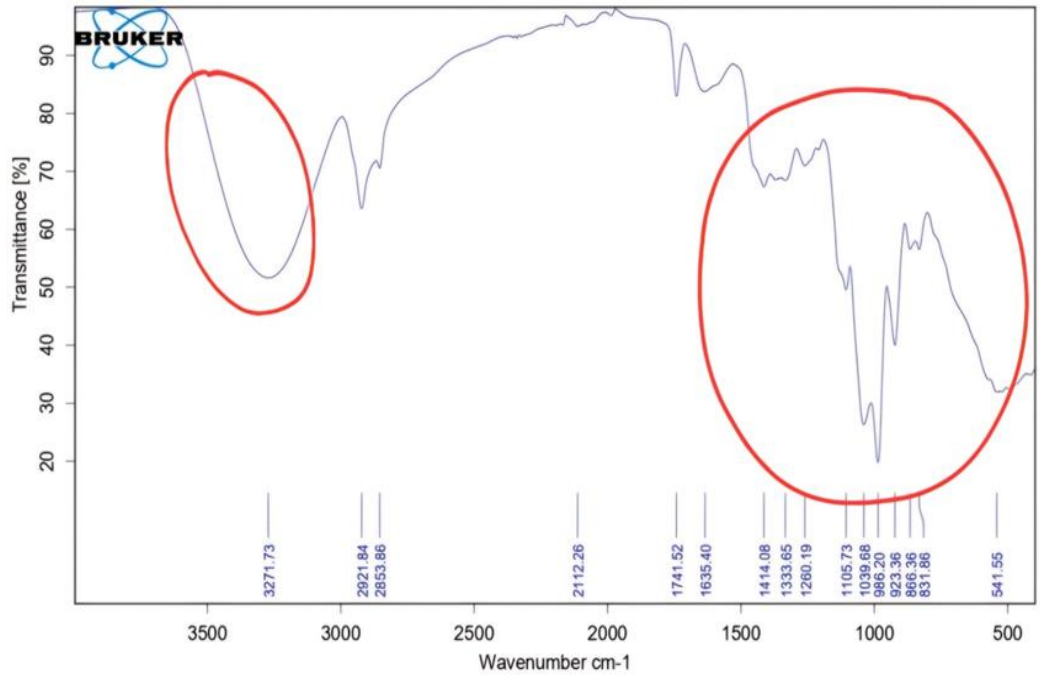


Figure 4 Spectrum of *Es Puter* powder enriched with ginger extract on day 0.

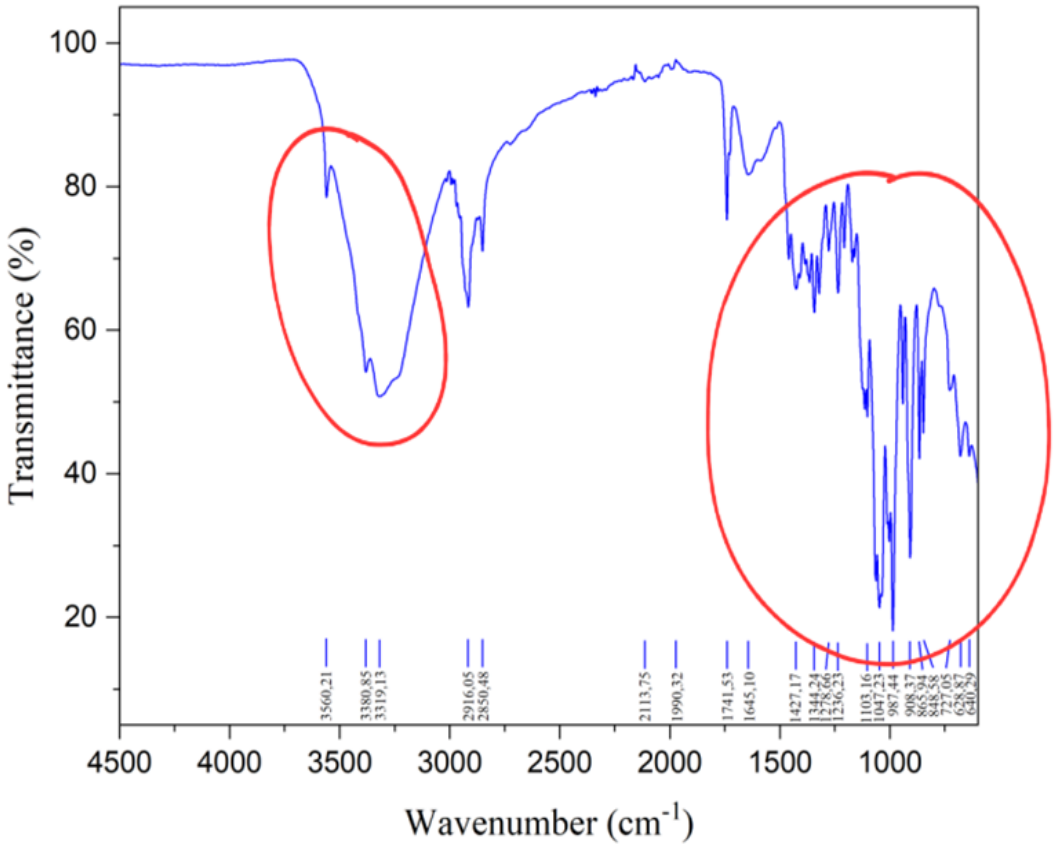


Figure 5 Spectrum of *Es Puter* powder enriched with ginger extract on day 14.

Table 8 Functional groups of *Es Puter* powder enriched with ginger extract identified on day 0.

Wavenumber (cm^{-1})	Chemical bond	Functional groups	Intensity
3272	O–H stretch, H-bond	Alcohol, phenols	M[1)]
	N–H stretch	Amines, amides (P, Sr)	M[1)]
2854–3272	O–H	Carboxylic acid	M[1)]
2854–2922	C–H stretch	Alkanes	S[1)]
2854	C–H	Aldehydes	W[1)]
2112	C≡C	Alkynes	W-M[1)]
	X=C=Y	Allene, ketene, isocyanate, isothiocyanate	M-S[1)]
1742	C=O	Esther	S[1)]
1635	C=C	Alkenes	W-M[1)]
	C=O	Amides	S[1)]
	N–H bend	Amines, amides (P, Sr)	M–S[1)]
1414	**C–O stretch symmetry**	**Amines**	**M[2)]**
1260–1334	S=O	Sulfones, sulfonates chlorides, sulfates, sulfonamides	S[1)]
1040–1334	C–N	Amines	M–S[1)]
	C–X	Fluoride	S[1)]
1040–1260	C–O	Alcohols, ethers, esters, carboxylic acids, anhydrides	S[1)]
832–986	C–H oop bend	Alkenes	S[1)]
832–866	C–H oop bend	Aromatics	S[1)]
542–866	C–X	Chlorides	S[1)]
542	C–X	Bromides, iodides	S[1)]

Note: Oop = Out-of-plane. P = Primary, Sr = Secondary. W = Weak, M = Medium, S = Strong.

Table 9 Functional groups of *Es Puter* powder enriched with ginger extract identified on day 14.

Wavenumber (cm^{-1})	Chemical bond	Functional groups	Intensity
3560	**O–H, free**	**Phenols**	**M**[1)]
3319–3381	O–H, H-bonded	Alcohol, phenols	M[2)]
	N–H stretch	Amines, amides (P, Sr)	M[2)]
2850–3381	O–H	Carboxylic acids	M[2)]
2850–2916	C–H stretch	Alkanes	S[2)]
	C–H	Aldehydes	W[2)]
2114	C≡C	Alkynes	W-M[2)]
1990–2114	X=C=Y	Allene, ketene, isocyanate, isothiocyanate	M-S[2)]
1742	C=O	Esther	S[2)]
1645	C–C	Alkenes	W-M[2)]
	C=O	Amides	S[2)]
	C=N	**Imines, oximes**	**W-M**[2)]
1427	**C–H ip deformation**	**Aromatics**	**S**[3)]
1236–1344	S=O	Sulfones, sulfonates chlorides, sulfates, sulfonamides	S[2)]
1047–1344	C–O	Alcohols, ethers, esters, carboxylic acids, anhydrides	S[2)]
	C–N	Amines	M-S[2)]
	C–X	Fluorides	S[2)]
727–987	C–H oop bend	Alkenes	S[2)]
727–849	C–H oop bend	Aromatics	S[2)]
629–727	C–X	Chlorides	S[2)]
629–640	C–X	Bromides, iodides	S[2)]

Note: Ip = In-plane, oop = Out-of-plane. P = Primary, Sr = Secondary. W = Weak, M = Medium, S = Strong.

Figure 6 *Es Puter* powder enriched with ginger extract.

As shown in Figures 4 and 5, the FTIR spectrum of ginger extract-containing *Es Puter* powder changed after 14 days of storage. Tables 8 and 9 show modest changes in the bonds produced, but both storage times exhibit identical functional groups created from the *Es Puter* components. Water, sucrose, gingerol (a phenol), and CMC all contain hydroxyl groups, which form the O-H stretch bond. O-H bonds in water and sucrose with wave numbers ranging from 3200 to 2400 cm^{-1} **[78]**. Ginger extract shows a peak at about 3300 cm^{-1}, indicating the presence of phenolic compounds **[79]**. CMC has a hydroxyl group that stretches at 3351 cm^{-1} **[80]**.

The C-H stretch bond most likely originates from the alkane chains of coconut milk fatty acids. Wavenumbers between 2850-2922 cm^{-1} imply C-H stretches from alkanes, with coconut milk peaking at 2921 cm^{-1} **[81]**. Ester groups in coconut fat at 1700-1750 cm^{-1}, supporting the C=O ester bond at 1742 cm^{-1} as a reflection of triglycerides **[82]**. The presence of C=C, C-O, and C-H bonds indicates a complex organic matrix composed of substances such as coconut milk and ginger extract, which contribute to the chemical structure of the *Es Puter* powder. These results validate the functional group contributions of the original components.

The majority of the chemical bonds representing the *Es Puter* ingredients emerged at both 0 and 14 days of storage. However, the symmetrical C-O stretching bond associated with amines, which was visible on day 0, was dissipated by day 14. After 14 days, three novel bonds were noticeable: free O-H (phenol), C=N (imine/oxime), and C-H deformation (aromatic). These alterations indicate structural changes in the *Es Puter* powder matrix resulting from the breakdown or transformation of specific chemicals over time **[83]**. Furthermore, variations in the FTIR spectrum show chemical reactions during storage, such as hydrolysis. Changes in absorption bands represent ongoing chemical processes in stored materials **[84]**.

The loss of the C-O (amine) stretch on day 14 might be due to the hydrolysis of amine-containing molecules. Moisture content studies revealed that the moisture level in *Es Puter* powder enriched with ginger extract increased over time, perhaps promoting hydrolysis and breaking down amides or esters into smaller, volatile fragments **[85]**. Furthermore, increased pH during storage may aid amine deprotonation, suggesting product deterioration owing to phenol component breakdown. This degradation can harm antioxidant bioactive substances, hastening the oxidation processes. As a result, amines can be transformed into imines or other

nitrogen-containing compounds **[86]**, as evidenced by the presence of C=N linkages in the FTIR spectrum following 14 days of storage.

On day 14, free O-H (phenol) appears, indicating that phenolic components from ginger and coconut extracts have degraded. The absorption band at 3560 cm^{-1} is associated with intramolecular hydrogen bonding in phenol lignin, consistent with previous research reporting bands at 3550-3565 cm^{-1} **[87]**. Phenolic substances are prone to oxidation during storage, and their decomposition might result in free hydroxyl groups. This procedure may also increase the pH of the *Es Puter* powder, as the degradation of acidic phenol components reduces product acidity **[47]**.

The formation of C=N bonds (imines and oximes) after 14 days of storage indicates oxidative interactions between amines and carbonyl groups. Such interactions are common during food storage and have been shown to affect flavor and color. Peak at 1645 cm^{-1}, indicating the creation of C=N through interactions between carbonyl compounds and amino groups **[88]**. Furthermore, the C-H aromatic deformation at 1427 cm^{-1} shows oxidative breakdown of phenolic rings, revealing either new aromatic intermediates or exposed aromatic groups from broken molecules. Increased moisture content plays a crucial role in phenol degradation by enhancing reactant mobility and enzyme activity, which accelerates the oxidation process **[89]**. Furthermore, increased moisture content promotes microbial development, reducing product quality **[90]**.

CONCLUSION

This study demonstrated that both storage time and packaging type significantly influenced the physicochemical properties of *Es Puter* powder enriched with ginger extract, particularly rehydration, dissolution time, emulsion stability, moisture content, pH, and antioxidant activity.

Packaging type and storage time significantly affected ($p<0.05$) rehydration, dissolution time, moisture content, and pH. However, the interaction between packaging type and storage time had no significant effect ($p>0.05$) on moisture content and pH value. Packaging type and storage time also affected emulsion stability and antioxidant activity. Meanwhile, for SEM and FTIR analyses, only the storage time affected the results, as the samples were stored solely in foil sachets.

Foil sachets consistently outperformed plastic clips in maintaining product stability, as evidenced by lower moisture absorption, slower pH rise, shorter dissolution time, greater emulsion stability, and greater retention of antioxidant activity. These outcomes confirm the hypothesis that proper packaging selection can mitigate quality degradation during storage, supporting the use of foil sachets as an effective barrier against oxygen, light, and moisture.

Although foil sachets effectively preserved the product's physicochemical quality, prolonged storage still led to structural and chemical changes, including non-porous clumping, protein hydrolysis, and fat oxidation, as evidenced by SEM and FTIR analysis.

Future research should explore the use of food additives such as anti-caking agents and butylated hydroxytoluene (BHT), to create a more stable premix formulation.

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