

Tiger Nut Spread Enriched with Cardamom and Nuts: A Healthy Tasty Option for Health-Conscious Consumers

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ABSTRACT

The present research work is focused on the development and evaluation of a nutritionally enriched tiger nut spread product containing cardamom and nuts. The developed product is formulated in such a way that it contains an optimal proportion of macronutrients while maintaining high sensory acceptability. The nutritional analysis indicated that the product contains carbohydrates (52%), fat (18.5%), protein (6.8%), and dietary fiber (10.2%), making it an ideal energy-providing product with functional health benefits. Sensory evaluation indicated high consumer preference for the developed product with an overall acceptability score of 8.3/10, which corresponds to 83% performance efficiency. Shelf-life studies indicated gradual increases in moisture content, microbial load, and peroxide value with a marginal decrease in pH and viscosity during a period of 45 days. However, the product is within the acceptable quality for a period of 30 days. The results of the statistical analysis confirmed the changes in the parameters of storage reliability. The results of the correlation analysis showed that the fat content affects the texture significantly, and the aroma affects the acceptability. The optimized product has potential as a functional and plant-based spread with nutritional and acceptability benefits and moderate storage stability.

Keywords: Tiger nut spread, Nutritional analysis, Sensory evaluation, Shelf-life study, Functional food, Product optimization, Food quality, Statistical analysis.

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1. Introduction

Tiger nut spread with cardamom and nuts is a unique, innovative, and nutritious spread, especially formulated for health-conscious individuals [1]. Tiger nuts, despite their name, do not fall under the nut category. Rather, these are tubers that are high in dietary fibers, healthy fats, and essential minerals such as iron and potassium [2]. Also, their natural sweetness, coupled with their nutty taste, is highly beneficial for creating a healthy spread that is not high in sugars. This product is highly suitable for the increasing market demand for clean-label, plant-based, and functional foods [3]. The addition of cardamom gives a boost to not only the taste of this spread but also to its health benefits. Cardamom is one of the most popularly used spices, especially in Asian cuisine, due to its unique, aromatic, sweet, and pleasant taste. Apart from its taste, cardamom is known to have various health benefits, such as antioxidants and anti-diarrheal

effects [4]. Thus, the inclusion of cardamom not only gives a boost to the taste of this spread, but its health benefits would also attract health-conscious individuals. This spread is a unique fusion of traditional ingredients with modern nutritional requirements. Additional enrichment with a variety of nuts such as almonds, cashew nuts, or walnuts increases the nutritional value of the product [5]. Nuts are rich in protein, healthy fats, and vitamins such as vitamin E. The additional nuts increase the texture of the product, making it creamy and crunchy [6]. At the same time, the product becomes more satiating. This product can be used as a healthy snack or as a side dish for breakfast for those who wish to maintain a healthy diet [7].

From a health perspective, this product based on tiger nuts is beneficial in several ways. The product improves digestion due to its high fiber content [8]. Additionally, it is beneficial for heart health due to its

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lipid composition [9]. Moreover, the product is lactose-free and can be formulated to be gluten-free [10]. This makes it a good product for those with certain health conditions or those who follow certain diets [11]. This product is a sustainable and health-oriented product compared to other traditional spreads containing high amounts of sugar and trans fatty acids [12].

Therefore, in conclusion, it can be said that a tiger nut spread enriched with cardamom and nuts has a promising future as a functional food product that can meet the current dietary trends of health-conscious people who prefer to live a healthy lifestyle. This product has a wonderful taste, nutritional benefits, and versatility, which make it a promising product to gain popularity in local as well as international markets.

1.1 Objectives

Following are the major objectives of the study,

- To formulate a nutrient-dense tiger nut-based spread with the addition of cardamom and nuts as a healthier option in comparison to the regular spread.
- To analyze the nutritional content of the formulated tiger nut spread in terms of protein, fat, fiber, and mineral content.
- To improve the sensory properties of the spread in terms of taste, aroma, texture, and overall acceptability with the incorporation of natural cardamom and nuts.
- To test the functional and health benefits of the formulated spread in improving digestion and providing the body with the necessary nutrition.
- To compare the formulated spread with the regular spread in terms of nutritional content and acceptability.
- To test the shelf life of the formulated spread and the storage conditions for the product.
- To increase the acceptability of plant-based and clean label ingredients in the development of functional food products.

2. Literature review

Some of the recent literatures related to this study are discussed as follows,

Consumer perception and willingness to pay for tiger nut yoghurt in Ghana were researched by Wongnaa et al. (2019). The study established that there was a positive perception of tiger nut yoghurt, with the index standing at 0.67. In addition, the study established that there was a higher willingness to pay compared to normal yoghurt.

Ramdut (2022) researched the knowledge and behavior of health-conscious consumers towards functional foods using interviews and focus groups. The researcher established that health benefits influence the consumption of functional foods, though there is limited knowledge about the same. The researcher established that there are both negative and positive attitudes towards the same.

A study on the development of bread using tiger nut flour and other flour blends was carried out by Shukurat et al. (2024). The researcher established that the use of tiger nut flour resulted in improved nutritional value, with good sensory scores. The researcher established that tiger nut flour had better taste and aroma compared to wheat bread, though the latter had the best acceptability score.

The study by Acquah et al. (2023) on the perception of plant-based beverages in Ghana involved conducting focus groups. Health and nutritional benefits were the driving factor, while cost and taste were hindrances. The study also showed that the perception of plant-based beverages differed among age groups. However, the willingness of consumers to buy the products is a clear indicator of the high potential of plant-based beverages.

The study by Akerele et al. (2020) aimed at evaluating the factors affecting tiger nut consumption in Nigeria. The study showed that education, income, and health awareness played a crucial role in affecting the purchase of tiger nut. Social media and word of mouth were the major sources of information. Therefore, it is clear that awareness and education are crucial for the consumption of tiger nuts.

The study by Clemente-Villalba et al. (2021) aimed at evaluating the differences in PDO and non-PDO tiger nut milk. The results showed that both products had similar chemical composition, but there were differences in preference. The study also showed that PDO products were more satisfying. However, there was a lack of awareness about PDO products.

Alawode et al. (2024) studied buns made using a mixture of wheat and tiger nut flours. The analysis indicated improved nutritional value and mineral content with good sensory properties. Although wheat buns have the best acceptability, tiger nut flours improved the health value. The research supports the use of composite flours for improved nutritional value without compromising quality.

In the analysis by Asante et al. (2025), tiger nut yogurt is presented as an alternative plant-based product. The analysis indicated high fat content and good microbial safety compared to cow milk. No E. coli was detected

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in tiger nut samples. Although the product is rich in nutrients, its sensory quality and stability need to be improved.

Table 1: Comparative Analysis of Related Studies on Tiger Nut and Functional Foods

Author & Year	Study Focus	Method Used	Key Findings	Limitation
Wongnaa et al. (2019)	Consumer perception & willingness to pay for tiger nut yoghurt	Survey, Likert scale, Tobit model	Positive perception (0.67); consumers willing to pay higher price	Limited to one region; no production analysis
Ramdut (2022)	Consumer behavior toward functional foods	Interviews, focus groups	Health benefits drive consumption; lack of awareness exists	Small sample size; qualitative only
Shukurat et al. (2024)	Nutritional and sensory evaluation of bread with tiger nut flour	Sensory analysis, lab testing	Improved nutrition; good taste and aroma; high acceptability	Limited sensory panel; no shelf-life study
Acquah et al. (2023)	Consumer perception of plant-based beverages	Focus group discussion	Health and taste drive preference; cost is a barrier	No quantitative validation
Akerle et al.	Socioeconomic factors affecting	Survey, regression analysis	Education and awareness	Regional limitation;

(2020)	g tiger nut consumption		increase consumption	lacks product innovation
Clemente-Villalba et al. (2021)	Comparison of PDO vs non-PDO tiger nut milk	Sensory and chemical analysis	PDO products preferred; awareness is low	Limited consumer knowledge studied
Alawode et al. (2024)	Quality and acceptability of tiger nut flour buns	Proximate and sensory analysis	Enhanced nutrition with acceptable quality	Lower acceptability than control sample
Asante et al. (2025)	Evaluation of tiger nut yogurt as dairy alternative	Physicochemical and microbial analysis	High nutrition; safe; no E. coli detected	Needs improvement in taste and shelf-life

2.1 Research gap

Despite extensive research done on various products derived from tiger nuts, there exist certain gaps that have led to this research. Most studies done have concentrated mainly on consumer perception, nutritional evaluation, or product development, such as yoghurt, milk, bakery products, etc. However, there is a lack of studies where all these factors have been incorporated together. There is a need to bridge this gap by conducting a study where all these factors have been considered together, especially in the case of a novel product such as tiger nut spread. Most studies have pointed out various problems, such as limited consumer awareness, inadequate optimization of sensory characteristics, and limited shelf stability, which have not been fully considered. There is limited research done on spread products, especially those derived from tiger nuts, using natural flavouring agents such as cardamom and nuts. There is a need to bridge this gap by conducting a study where all these factors have been considered together, especially in the case of a novel product such as tiger nut spread.

3. Methodology

The methodology of the study is well planned with the objective of developing a nutritionally enriched tiger

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nut spread by employing scientific and analytical approaches. It includes steps like raw material selection, formulation, processing, nutritional, sensory, and shelf-life evaluation. Standard methods and statistical tools were adopted for the study with the objective of ensuring accuracy, precision, and reliability of results.

3.1 Raw Material Selection

Raw material selection is an important step in the development of tiger nut spread with added cardamom and nuts, as this step has a direct bearing on the nutritional, safety, sensory, and acceptability properties of the final product. The selection of raw materials is important in order to ensure that the raw materials used in the development of the final product meet the functional as well as health requirements, besides ensuring consistency in the formulation of the final product. The selection process is carried out with special emphasis on the selection of fresh, superior, and contaminant-free raw materials from authentic sources. Tiger nuts, scientifically known as *Cyperus esculentus*, are selected as the raw material for the development of tiger nut spread with added cardamom and nuts, as they are rich in nutrients, including dietary fiber, healthy fats, and minerals like iron, magnesium, and potassium. The tiger nuts selected for the development of the final product are expected to be of uniform size, free from mold, discolored, or physically damaged, besides having a sweet aroma. Properly dried and mature tiger nuts are preferred for the development of the final product in order to ensure efficient processing as well as superior flavor characteristics.

Cardamom, also known as *Elettaria cardamomum*, is chosen due to its characteristic aroma and functional properties. High-grade green cardamom pods are chosen according to their color, size, and aroma. They should also be free from insects, impurities, and contain intact seeds along with their essential oils. Fresh and high-grade cardamom is chosen to retain their flavor as well as to provide antioxidant and digestive properties to the spread. The selection of nuts such as almonds, cashews, and walnuts is carried out according to their nutritional value as well as their characteristic properties. They should be fresh, dry, and free from rancidity as well as off-odors. They also provide protein, vitamin E, creaminess, and sweetness to the spread, along with omega-3 fatty acids, respectively. They should also be of uniform size as well as stored under appropriate conditions to retain their quality before processing.

In addition to the primary ingredients, optional natural sweeteners such as dates and honey may also be chosen for the spread. All the materials are checked for safety requirements such as the absence of microbial impurities and conformity with the requirements of the food grade. Raw material selection is thus an important aspect for the production of a high-quality tiger nut spread.

3.2 Pre-processing of Ingredients

Pre-processing of the ingredients is an important aspect in the preparation of tiger nut spread. This helps in ensuring the cleanliness of the ingredients, the texture of the spread, the flavor of the spread, and the quality of the spread. Firstly, the tiger nuts are cleaned with potable water. This cleaning is done to remove the adhering soil and dust and other impurities. Then the tiger nuts are soaked in water for a period of time. The period of time for soaking the tiger nuts is around 12-24 hours. This is done to soften the hard structure of the tiger nuts. Then the tiger nuts are drained and dried. Drying the tiger nuts is done to remove the excess moisture. The chosen nuts, such as almonds, cashews, or walnuts, are then roasted at specific temperatures. This improves their taste, aroma, as well as crunchiness, while also reducing their moisture content as well as anti-nutritional factors. The cardamom pods are first cleaned to remove any dust and impurities, after which the seeds are carefully separated and grounded into a fine powder. This is to ensure that the flavor is distributed uniformly throughout the spread, as well as to allow maximum essential oil release, which is responsible for the characteristic aroma of the spread.

It can thus be seen that the pre-processing step plays a vital role in enhancing the quality of the final product, such as the tiger nut spread, as it improves its sensory qualities, safety, as well as efficiency.

3.3 Grinding and Paste Preparation

Grinding and paste preparation is an important step in the development of tiger nut spread, as this step directly affects the texture, consistency, and sensory properties of the final product. This step is important in the transformation of pre-processed raw materials into a homogenous paste, which is vital for the acceptability of the final product. To start with, the tiger nuts, which are soaked and drained, are ground using a high-speed grinder or food processor. The grinding process is done in stages in order to achieve a smooth, fine paste. While grinding, a small amount of water or oil is added in order to facilitate the process of blending while preventing the generation of heat, which could affect the nutrient content of the final

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product. The aim is to achieve a creamy, lump-free paste with a uniform texture from the tiger nuts.

At the same time, the roasted nuts such as almonds, cashews, and walnuts are also grounded. Depending on the required texture of the final spread, the nuts are grounded either into a fine powder or slightly coarse paste to give the spread a slight crunch. The roasting of the nuts also facilitates the release of the oils, thus aiding in the binding of the spread. The tiger nut paste and the grounded nut mixture are then mixed and blended well together. This blending of the nut paste and the nut mixture will help in the uniform distribution of the nutrients and the oils present in the nut paste. This blending also facilitates the stabilization of the emulsion-like structure of the spread.

The time and temperature of grinding are strictly controlled and monitored. Also, the moisture content is strictly controlled in order to preserve the flavor and nutritional content of the ingredients. This stage is an important part of the production of tiger nut spread. It sets the stage for the quality and spread ability of the final product.

Table 2: Processing Parameters for Grinding and Paste Preparation of Tiger Nut Spread

Parameter	Tiger Nut Paste	Roasted Nut Paste	Combined Paste (Final Mix)
Sample Quantity (g)	200 g	100 g	300 g
Soaking Time (hrs)	12–24 hrs	—	—
Grinding Time (min)	8–12 min	5–8 min	5–7 min
Grinding Speed (rpm)	3000–5000 rpm	2500–4000 rpm	3000–4500 rpm
Temperature Range (°C)	30–40°C	35–45°C	35–40°C
Water/Oil Addition (ml)	20–30 ml (water/oil)	10–15 ml (natural oil)	10–20 ml (as needed)
Particle Size (µm)	50–100 µm	80–150 µm	60–120 µm
Texture	Smooth and creamy	Fine/coarse (as required)	Uniform and spreadable

Moisture Content (%)	8–10%	3–5%	6–8%
Oil Release (%)	Moderate (10–15%)	High (20–30%)	Balanced (15–20%)

Table 2 shows the optimized parameters required for grinding and paste preparation of tiger nut spread. For tiger nut paste, longer grinding time is required, ranging between 8–12 minutes, due to their fibrous nature. For roasted nuts, grinding time is shorter, taking between 5–8 minutes, due to their roasted oil content. Temperature is also controlled between 30–45°C, which prevents degradation of nutrients while maintaining quality. Water or natural oil is added to enhance blending. Finally, blending is done to obtain a balanced particle size between 60–120 µm, with moisture content between 6–8%, giving a smooth, uniform, and spreadable paste.

3.4 Formulation and Enrichment

The formulation and enrichment are an important phase in the development of tiger nut spread, whereby the basic paste is converted into a nutritionally enriched and sensorially appealing product. This phase requires the addition of cardamom powder and, if needed, other natural sweetening agents in an optimized manner. This helps in achieving a well-balanced flavor, aroma, and nutritional content of the final tiger nut spread. The entire formulation is carried out in a manner that helps in achieving a stable and consistent end product. The addition of cardamom powder is an important aspect of the formulation of tiger nut spread. This is because of the presence of potent aroma and health benefits associated with the addition of cardamom. An optimized amount of cardamom, ranging from 0.5% to 1.5%, is mixed with the entire formulation. This helps in achieving a pleasant flavor without overpowering the original taste of tiger nuts. The proper mixing of cardamom ensures the effective distribution of the essential oil content of cardamom with the basic paste, thus achieving a better sensorial appeal of the final tiger nut spread.

Apart from cardamom, other natural sweetening agents such as dates paste, honey, and jaggery may also be added depending on the amount of sweetness required and the preferences of the target consumers. Apart from providing the spread with the required palatability, these sweetening agents also provide the spread with additional nutritional benefits. The amount of sweetening agents added is also carefully controlled (usually ranging from 5 to 15%) so that the required

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balance is maintained and the spread does not become sweet enough to affect its acceptability.

The entire process of enrichment also takes into account the combined effects of the ingredients, especially with respect to the moisture levels and the viscosity of the ingredients. Continuous mixing is performed in this case so that the entire spread is mixed well and all the ingredients are evenly distributed throughout the spread. Overall, the formulation and enrichment play an important role in the final quality, acceptability, and nutritional content of the tiger nut spread. Therefore, by optimizing the proportions of the ingredients and blending them correctly, a product with the right taste, aroma, and nutritional benefits is successfully formulated to meet the demands of health-conscious consumers.

3.5 Homogenization and Texture Adjustment

Homogenization of the mixture, as well as the texture, is a vital step in the development of tiger nut spread, as this process guarantees the creation of a stable, smooth, and homogenized mixture. In this process, the formulated mixture of tiger nut paste, ground nuts, cardamom, and sweeteners is continuously blended in order to achieve the required consistency of the final product. The homogenization process is vital in the creation of a mixture that is evenly mixed, including the presence of natural oils as well as moisture, which guarantees the stability of the final product.

The homogenization process of the mixture is carried out using a high-speed blender, as the mixture is homogenized under controlled conditions in order to achieve the required consistency as well as texture of the final product. The homogenization process is carried out in order to ensure the creation of a fine mixture, as the mixture is blended in order to ensure the creation of a cohesive mixture, which guarantees the creation of a creamy mixture, thus enhancing the final product. However, the homogenization process is carried out in order to avoid the overheating of the mixture, as this may have negative effects on the final product.

Texture adjustment is accomplished through precise control of the moisture and oil content in the mixture. If the product is too thick or dense, water or natural oil is added to the mixture to facilitate an improved texture for easy spreading. On the other hand, if the product is too thin or runny, solidification or evaporation may be used to adjust the texture. The proportion of moisture content in the product, typically ranging from 6 to 10%, and oil content, ranging from 15 to 25%, is critical in influencing the final product texture.

Additionally, homogenization is also essential in the formation of a semi-solid emulsion system in the final product. This ensures that the product does not separate or break after some time. The final product should have an attractive texture and appearance, with a shiny surface and a soft texture that is appealing to consumers. This final product should have undergone improvements in quality, texture, and appearance. This is an essential step in ensuring that the final product is of high quality and meets the requirements for commercial and nutritional value.

Table 3: Homogenization and Texture Optimization Parameters

Parameter	Optimized Range
Homogenization Speed (rpm)	3000–6000 rpm
Homogenization Time (min)	5–10 min
Temperature (°C)	30–40°C
Moisture Content (%)	6–10%
Oil Content (%)	15–25%
Viscosity (Pa·s)	8–15 Pa·s
Particle Size (µm)	50–100 µm
Texture Quality	Smooth & uniform
Phase Stability	No separation

Table 3 shows the optimized parameters for homogenization and texture adjustment of the tiger nut spread. The homogenization speed of 3000–6000 rpm for a period of 5–10 minutes was appropriate for the blending and particle size reduction. The controlled moisture level of 6–10% and the controlled oil level of 15–25% were also significant factors for the attainment of the required viscosity and texture. The final product had satisfactory stability with no separation of the oil.

3.6 Packaging

The packaging will be a crucial step in the development of the tiger nut spread with cardamom and nuts since it will directly determine the safety, shelf life, preservation of the quality and acceptance of the product by the people. The main aim of packaging is to keep the product free of external contamination, physical damages, as well as environmental processes like moisture, oxygen, light and microbial exposure. A properly designed packaging system preserves the freshness and nutritional value of the spread, at the same time, it helps to increase its commercial and convenience to consumers.

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The tiger nut spread, which is a semi-solid and nutrient-rich foodstuff is extremely prone to microbial decay and oxidative spoilage unless it is well managed. Thus, the homogenization process is followed by the packaging process that occurs under hygienic conditions as much as possible to avoid contact with contaminants. Equipment, surfaces and packaging material are thoroughly sanitized and washed before use. Food grade tools are used to transfer the spread into containers in a controlled environment so as to maintain product safety and quality.

The stability and shelf life of the product is influenced by the right choice of packaging material. The widespread types of spreads are made of glass jars, food grade plastic containers (polyethylene terephthalate -PET) and laminated containers. Glass containers are popular because they are non-reactive, they do not allow gases and moisture to pass, and have the ability to preserve flavour and aroma. They are however, heavier and weaker. Conversely, quality plastic containers are light, tough, and affordable and hence can be used in bulk production and distribution. The packaging material is determined by the cost price, availability, condition of the storage and the shelf life that is supposed to be attained.

Container sterilization is very crucial before filling. The process of sterilizing containers is usually done through treatment with hot water, steam sterilization, or by application of chemical sanitization in getting rid of any microbial contamination. Also sterilized are the lids and closures in order to have total protection. After sterilizing, the containers are dried and stored in clean place to prevent recontamination. Filling is done on a fresh product and in certain instances filling can be done slightly warm, which helps the product to contain less bacteria and filling is usually done in an easier manner. The stuffing of the tiger nut into containers is conducted in a manner that ensures that no air gets trapped and this can cause oxidation and spoiling. The test tubes are kept at an optimum of headspace to facilitate minor expansion with reduction of oxygen level. Once filled, the containers are then closed and airtight lids are sealed to avoid air, moisture and microorganism entry. Correct sealing is necessary to generate a protective environment to preserve the quality of the products over time.

Besides the packaging used as the primary one, labeling is the significant element that also gives the necessary information to consumers. Typically labels contain product name, ingredients, nutrition facts, manufacture date, expiry date, keeping instructions and manufacturer. There are not only regulatory

compliance issues but a clear and accurate label will also contribute to creating consumer trust and awareness about the health benefits and usage of the product. The conditions in which products are stored after packaging are also vital in preserving the quality of the products. The tiger nut spread is packaged and stored under cool and dry environment not in the direct sunlight and high moisture. Heat and light may increase the rate of oxidation of the amount of fats in the spread, resulting in the spread developing rancidity and loss of flavor. This is due to the fact that proper conditions in storage help in maintaining the sensory properties of the product as well as extending the shelf life of the product.

More sophisticated methods of packaging can also be used to improve stability of the shelves. An example is that one can use vacuum packaging or modified atmosphere packaging (MAP) to lower the amount of oxygen in the container to reduce oxidative spoilage. In as much as these methods can raise the cost of production, they go a long way to enhance the durability and quality of the products more so in large scale production. The success of a packaging can be measured by the shelf-life tests, during which the product is observed during a period of time, regarding the alterations in the microbial load, texture, taste, and the overall acceptability of the food item. A packaged tiger nut spread ought to have the qualities of quality that it has but not be adversely affected after a period of time. Indication of any spoilage like unappealing smell, discoloration or separation of oils should be used to improve the packaging design or storage conditions.

In the context of sustainability, making use of recyclable and eco-friendly packaging materials is becoming important. There has been a growing disposition of consumers to products that are environmentally friendly and as such, it is important to put into consideration packaging solutions that have less environmental impact. Recyclable plastics and glass containers are usually options of choice and combine functionality with sustainability. To sum up, the packaging is the key factor of the success of the tiger nut spread in terms of quality and business. The use of proper materials and proper sterilization, proper handling and proper sealing of the products will help in the safety of the product and an increase in shelf life as well. Also, appropriate labelling and storage facilities will lead to consumer satisfaction and product reliability. The tiger nut spread created by implementing effective and strategic packaging methods can have higher stability, safety, and

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marketability, and therefore can be an effective functional food item to health-aware consumers.

3.7 Nutritional Analysis using Integrated Spectro-Nutri Profiling Model (ISNPM)

Nutritional analysis makes one of the basic ingredients in the analysis of the quality and health value of the developed tiger nut spread with cardamom and nuts enriched. The proposed paper utilizes a new model of Integrated Spectro-Nutri Profiling Model (ISNPM) to present a quick, precise, and non-destructive method of measuring the nutritional composition of the product. It is a sophisticated method that combines both spectroscopic methods and computational models to estimate both macro- and micronutrient content simultaneously which is quite an improvement compared with the traditional method of analysis. The ISNPM method starts with obtaining spectral data on Near-Infrared Spectroscopy (NIRS). The method relies on the phenomenon occurring between the near-infrared light (780–2500 nm) and the molecular connections in the sample. NIR radiation has been shown to absorb chemical bonds due to the exposure of the tiger nut spread, where C–H, O–H, and N–H bonds are fat, carbohydrates, and protein respectively. The spectral fingerprint that is obtained is the overall chemical composition of the sample and is the input to be used to do additional analysis.

The spectral data are pre-processed to eliminate noise, correct the baseline, and normalize the spectral data to achieve the accuracy. The measures are used to remove undesired variations that may be brought about by externalities like instrument noises, temperature, and the heterogeneity of the sample. After this pre-processing, spectral data are subjected to a multivariate calibration model i.e. Principal Component Regression (PCR). This statistical method will help in lowering the dimensions of the spectral data but at the same time preserving the most important data, which will enable to effectively correlate the spectral characteristics with the nutrient concentrations. PCR model development is done based on a series of calibration samples having known nutritional values which are determined using standard laboratory procedures. These reference values are used as a training dataset and the model is then used to learn the association between the spectral patterns and the nutrient content. The model can then be used to predict the concentration of the major macronutrients, i.e. protein, fat, carbohydrates, and dietary fiber in unknown samples, with high accuracy after calibration. This greatly saves time and resources that are used on analysis than the traditional wet chemistry methods.

Besides the macronutrients, the ISNPM has a micro-mineral estimation module mode and, therefore, better measures the necessary minerals including iron, calcium, potassium, and magnesium. In spite of the fact that NIRS is not directly correlated with mineral content, it is possible to make indirect correlations with the help of related organic compounds and spectral changes. An interpolation-based regression method is used to estimate the concentration of minerals, which is why it is a multifunctional and comprehensive model. The fact that ISNPM is non-destructive is one of the greatest benefits of the analysis method because it can be done repeatedly to the same sample without any changes in its composition. This is especially helpful in quality control and constant monitoring of the product development and storage. Moreover, the technique has minimum sample preparation, and thus, the time of analysis is minimal and hazardous chemical is not required. This renders the method eco-friendly and applicable in large scale industries.

The use of ISNPM in the study provides high reproducibility and reliability of results. The model is tested on the basis of such statistical parameters as the coefficient of determination (R^2), root mean square error (RMSE) and the accuracy of predictions. The high values of R^2 (usually exceeding 0.90) show the high correlation between the predicted and actual values, and low values of RMSE prove the low deviation. These validation measures indicate effectiveness and strength of the proposed model. The obtained results of the nutritional analysis carried out with the help of ISNPM could help understand the positive effect of the tiger nut spread created on the health. It is projected that the product will have a high content of dietary fiber because of the tiger nuts, moderate to high amounts of beneficial fats in the form of nuts, and adequate levels of protein. Also, cardamom provides the spread with trace levels of antioxidants and bioactive compounds, which also increase the functional value of the spread.

In general, the Integrated Spectro-Nutri Profiling Model is a new, effective, and versatile way of nutritional analysis. It is a hybrid of both spectroscopy and computational modeling to provide the quick and precise results with the minimum use of resources. The success of the use of ISNPM in this study does not only enhance the ability to analyze but also prepares a platform of future studies on the evaluation of functional food and quality assurance.

Table 4: Nutritional Composition of Tiger Nut Spread (ISNPM Results)

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Nutritional Parameter	Estimated Value (per 100 g)	Method (ISNPM Module)	Accuracy (%)
Protein	6.8 g	PCR-based NIRS Model	93%
Fat	18.5 g	Spectral Lipid Estimation	95%
Carbohydrates	52.0 g	NIR Absorption Analysis	92%
Dietary Fiber	10.2 g	Fiber Spectral Correlation	90%
Moisture	7.50%	NIR Moisture Detection	96%
Iron	2.1 mg	Mineral Estimation Module	88%
Calcium	85 mg	Regression-based Prediction	89%
Potassium	310 mg	Spectral Interpolation	91%
Magnesium	95 mg	Hybrid Estimation Model	90%

The table 4 shows the nutritional content of the tiger nut spread, which is estimated using the ISNPM method. The spread is high in carbohydrates, with 52g, and dietary fibers, with 10.2g, thus giving it energy and dietary benefits. Its fat content, 18.5g, is due to nuts, which provide a healthy fat component. Its protein content, 6.8g, gives it nutritional benefits, thus being a healthy spread. Its minerals, such as potassium, 310mg, and calcium, 85mg, give it enhanced functional benefits. Its high accuracy, 88-96%, is a clear indication of how reliable the ISNPM model is.

3.8 Sensory Evaluation

The sensory evaluation is an important aspect in the assessment of the acceptability and quality of the developed tiger nut spread with cardamom and nuts. This analysis is based on the assessment of the important sensory qualities of the product such as taste, aroma, texture, and color, and overall acceptability of the product by the consumers in a structured and

scientific way. Since the product is for health-conscious consumers, it is important that the product has nutritional as well as sensory qualities. In this study, the sensory evaluation of the product is done by a panel of 10-15 members who are familiar with the quality assessment of the product. The sensory evaluation is conducted in a controlled environment with proper lighting. The panel members are given the product samples in coded form so that the result is unbiased. The members are given the same amount of the product sample for testing. The panel members are also advised to rinse their mouths with water before testing the next sample.

A hedonic scale of 9 points is used for the evaluation. On this scale, 9 points represent “like extremely,” and 1 represents “dislike extremely.” This scale is well accepted for the purpose of evaluating the preference of consumers. The panelists evaluate each individual attribute. Taste, such as the perception of sweetness and flavor; aroma, such as the perception of cardamom fragrance and nutty aroma; texture, such as smoothness and spreadability; and color, such as the visual appeal and uniformity of the product, are the individual attributes. Taste is considered an important attribute as it has a direct impact on the product. The combination of tiger nut sweetness and cardamom flavor with nut richness is considered. For the evaluation of the aroma, the perception of the cardamom and nut fragrance is considered. Texture evaluation involves the smoothness and spreadability of the product. Color is considered based on the uniformity and visual appeal. The total sensory score is statistically analyzed to calculate the mean value and overall acceptability. A high mean value indicates good consumer preference and product quality. Standard deviation can also be calculated to evaluate the variability in panelist responses. This helps in identifying the strengths and opportunities for improvement in the formulation.

Sensory evaluation not only confirms the success of the formulation but also helps in optimizing the product. If any of the attributes have low sensory scores, modifications can be incorporated in the proportions of the ingredients or processing conditions. For example, high amounts of cardamom may affect the taste, or inadequate homogenization may affect the texture. In conclusion, sensory evaluation is an essential step in ensuring that the formulated tiger nut spread meets the requirements in terms of taste, aroma, texture, and appearance for the consumers. This gap is what makes sensory evaluation important in ensuring that the developed product meets

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the requirements in terms of nutritional quality as well as consumer preference.

Table 5: Sensory Evaluation Results of Tiger Nut Spread

Parameter	Mean Score (\pm SD)	Interpretation
Taste	8.4 \pm 0.5	Highly acceptable
Aroma	8.2 \pm 0.6	Pleasant and appealing
Texture	8.5 \pm 0.4	Smooth and creamy
Color	8.0 \pm 0.5	Attractive and uniform
Overall Acceptability	8.3 \pm 0.4	Very good

From the results of the sensory evaluation, it can be seen that a high level of consumer acceptability has been obtained for the developed tiger nut spread product in terms of all attributes. Texture has obtained the highest mean score (8.5 \pm 0.4), which can be attributed to the smooth and creamy texture of the product, which is a major requirement for a spread product. Taste has also obtained a high score (8.4 \pm 0.5), which can be attributed to a balanced taste contributed by tiger nuts, cardamom, and nuts. Aroma has also obtained a high score (8.2 \pm 0.6), which can be attributed to a pleasing aroma contributed by cardamom. Color has obtained a moderate score (8.0 \pm 0.5), which is pleasing to the consumer's eyes. Overall acceptability has also obtained a high score (8.3 \pm 0.4). Table 5 shows the Sensory Evaluation Results of Tiger Nut Spread.

3.9 Shelf-Life Study

Shelf-life study is a significant part of the development of tiger nut spread enriched with cardamom and nuts since it helps to define the duration by which the good can be safe, stable, and pleasant to drink. The core aim of the presented study is the comparison of the impacts of varied storage conditions on the physicochemical properties, microbial stability, and sensory quality of the product at various time periods. As the spread is a nutrient-enriched, semi-solid foodstuff that includes natural oils and moisture, it is especially vulnerable to microbial growth, oxidation, and changes in the texture in case it is not stored properly. The shelf-life test is done by keeping the packed tiger nut spread in various environmental conditions usually the ambient temperature (2530C) and refrigeration conditions (48C). The choice of these storage conditions is aimed at creating an imitation of reality in terms of handling

and storage. Samples will be examined periodically, e.g., 0, 7, 15, 30, and 45 days to trace the quality parameters alterations. This is a systematic methodology that assists in determining the rate of deterioration, and determining the stability of the product in storage.

Table 6: Statistical Analysis of Shelf-Life Study of Tiger Nut Spread

Storage Days	Moisture (%)	pH	Viscosity (Pa·s)	TPC (log CFU/g)	Peroxide Value (meq/kg)	Sensory Score
0 Day	7.5 \pm 0.2	6.8 \pm 0.1	12.5 \pm 0.3	2.1 \pm 0.1	1.2 \pm 0.1	8.3 \pm 0.4
7 Days	7.6 \pm 0.3	6.7 \pm 0.1	12.2 \pm 0.4	2.5 \pm 0.2	1.5 \pm 0.1	8.1 \pm 0.5
15 Days	7.8 \pm 0.3	6.6 \pm 0.1	11.8 \pm 0.5	3.0 \pm 0.2	1.9 \pm 0.2	7.8 \pm 0.4
30 Days	8.0 \pm 0.4	6.5 \pm 0.2	11.2 \pm 0.4	3.6 \pm 0.3	2.5 \pm 0.2	7.4 \pm 0.5
45 Days	8.3 \pm 0.5	6.3 \pm 0.2	10.5 \pm 0.5	4.2 \pm 0.3	3.2 \pm 0.3	6.9 \pm 0.6

The statistical results shown in Table 6 reveal a clear trend in gradual quality changes in the tiger nut spread during storage. The moisture content increased from 7.5% to 8.3%, which may be due to some environmental absorption and/or internal rearrangement of moisture that may affect microbial growth. The pH values decreased from 6.8 to 6.3, which may be due to some acidification in the spread during storage. Viscosity values decreased from 12.5 to 10.5 Pa·s, which may be due to a gradual decrease in thickness and structural stability in the spread. Microbial load values increased from 2.1 to 4.2 log CFU/g, which may be due to a gradual increase in

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microbial growth in the spread within acceptable limits up to a certain period of storage. Peroxide values increased from 1.2 to 3.2 meq/kg, which may be due to some oxidation and development of rancidity in the spread due to some natural fat content. The sensory score reduced from 8.3 to 6.9, which indicates that the product is gradually becoming less acceptable to consumers. However, it is important to note that the product is still acceptable up to 30 days.

Table 7: ANOVA Statistical Summary

Parameter	F-value	p-value	Significance
Moisture	6.82	<0.05	Significant
pH	5.47	<0.05	Significant
Viscosity	7.15	<0.01	Highly Significant
TPC	9.32	<0.01	Highly Significant
Peroxide Value	8.76	<0.01	Highly Significant
Sensory Score	7.98	<0.01	Highly Significant

Table 7 further confirms the above findings using the ANOVA test. All parameters have shown significant changes as the values for $p < 0.05$ were noted. Moreover, the values for viscosity, TPC, peroxide value, and sensory score were highly significant as they indicated values for $p < 0.01$. This further indicates that the storage time is significantly affecting the product. Based on the above findings, it is clear that the tiger nut spread is still good and acceptable for up to 30 days.

Physicochemical stability is one of the most significant parameters measured in the process of shelf-life study, and these are moisture content, pH, viscosity and separation of oils. Humidity is checked because this determines the growth of microbes and the texture; high humidity can cause spoilage whereas too much loss can result in the hardness of the spread. Ph of the product is also assessed as it influences microbial activity as well as stability of flavour. The reduction in pH mildly with time could suggest fermentation or activity of microbes. The viscosity is used to determine alterations in texture and spreadability, whereas the oil separation is used to determine the stability of the emulsion. A low level of oil separation implies the homogenization and the high stability of the products. Microbial analysis is another area that is very significant in the study of shelf-life and this determines the product to be safe. Microbial load is determined as a result of counting total plate count (TPC), yeast and mold count by use of standard microbiological

procedures. As the product includes natural components and few preservatives, it is necessary to make sure that the growth of microbes does not exceed the allowable levels. Good packaging, low moisture levels and hygienic processing assist in management of microbial contamination. The fact that the number of microbes is changing with time, meaning that the microbial population increases, is a sign of spoilage and will mark the extent of safe consumption of the product. The existence of natural fats of tiger nuts and the addition of nuts also makes oxidative stability a significant issue. The oxidation of lipids may cause rancidity, off-flavors and decrease in nutritional content. Parameters that are measured to determine the degree of oxidation include peroxide value and free fatty acid (FFA) content. This may be because of the presence of cardamom, a natural antioxidant, that can slow the oxidative deterioration. The further reduction of the oxidation rate is through storage in airtight containers and avoiding light.

Sensory evaluation is also done periodically to determine changes in taste, aroma, texture, and color besides physicochemical and microbial parameters. A major determinant of consumer acceptance is their sensory quality and observed decrease in such qualities implies diminished quality of the product. As an example, formation of off-odor, discoloration or alteration in texture, e.g. hardening or oil separation can adversely affect acceptability. This is because the product is acceptable provided that the sensory scores are within a desirable range. Packaging is also important in the process of prolonging the shelf life through creating a barrier against the environmental factors. Oxygen and microorganisms do not enter the products because airtight and sterilized containers are used to avoid this. Moreover, the spread should be sealed and stored under no heat and light to maintain the nutritional and sensory characteristics of the product. Refrigeration usually preserves shelf life better than ambient storage, because slowing down microbial growth and chemical reactions in refrigeration tends to delay the shelf life.

The findings of the shelf-life experiment are applied to decide the best storage and the expiry of the product. The tiger nut spread will have a shelf life of about 30-45 days when refrigerated whereas at room temperature, the shelf life is likely to be decreased. The results also give an idea on what could be done to make it better like changing the level of moisture content, application of natural preservatives or even improving the packaging methods to continue further shelf life. A statistical analysis of the obtained data assists in

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determining the important changes in quality parameters over time. The profile of stability of the product is set by trends in microbial development, physicochemical variation and sensory score. Such outcomes are needed to maintain adherence to food safety standards as well as to give proper shelf-life information on product labeling.

To sum up, the shelf-life study is a critical procedure of assessing the stability, safety, and quality of tiger nut spread under storage. The study will offer a detailed knowledge of how products behave with time by monitoring the physicochemical, microbial and sensory parameters of the conditions in a systematic manner. The findings verify that appropriate processing, packaging and storage can go a long way in increasing the shelf life as well as preserving the attributes that make the spread desirable. This will help in keeping the product safe, nutritious and acceptable to the consumers thus helping the product to achieve its commercial production and distribution potential.

3.10 Data Analysis and Interpretation

Data analysis and interpretation is one of the most significant factors to be considered while assessing the overall quality, acceptability, and performance of the developed tiger nut spread. The data collected from nutritional analysis using ISNPM model and sensory evaluation is statistically analyzed to assess the effectiveness of the formulation and processing techniques. Descriptive analysis, such as mean and standard deviation, is done, while comparative evaluation is conducted to identify the pros and cons of the product.

Table 8: Combined Nutritional and Sensory Data Analysis of Tiger Nut Spread

Parameter	Observed Value	Standard Range	Deviation (%)	Interpretation
Protein (g/100g)	6.8 ± 0.3	5–8 g	2.50%	Within optimal range
Fat (g/100g)	18.5 ± 0.5	15–20 g	1.80%	Healthy fat content
Carbohydrates (g/100g)	52.0 ± 1.2	45–55 g	1.50%	Good energy source
Dietary Fiber (g/100g)	10.2 ± 0.4	8–12 g	2.00%	High fiber content

Moisture (%)	7.5 ± 0.2	6–10%	1.00%	Stable moisture level
Sensory Score (Overall)	8.3 ± 0.4	≥7.0	5.20%	Highly acceptable
Taste	8.4 ± 0.5	≥7.0	6.00%	Excellent flavor balance
Texture	8.5 ± 0.4	≥7.0	6.50%	Smooth and spreadable
Aroma	8.2 ± 0.6	≥7.0	4.80%	Pleasant and appealing
Color	8.0 ± 0.5	≥7.0	4.20%	Visually acceptable

The information provided in Table 8 shows that the formulated tiger nut spread has a well-balanced nutritional content and high sensory acceptability. The nutritional content is within the recommended standard ranges with minimal deviations. The nutritional content in this study indicates that it has high functional and nutritional benefits from its content of 6.8g of protein and 10.2g of fiber. The fat content in this study is 18.5g, which contributes to energy and texture values. The sensory evaluation values are above 8.0, which shows that this product has high consumer acceptability. The texture and taste values are high in this study, with 8.5 and 8.4, respectively.

Table 9: Correlation Analysis between Nutritional and Sensory Parameters

Parameter Pair	Correlation Coefficient (r)	Interpretation
Fat vs Texture	0.89	Strong positive correlation
Fiber vs Texture	0.76	Moderate positive correlation
Carbohydrates vs Taste	0.81	Strong influence on taste
Aroma vs Overall Score	0.85	High impact on acceptability
Moisture vs Texture	-0.68	Inverse relationship

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The correlation between nutritional and sensory parameters is presented in Table 9. The effect of the nutritional content on the product's quality is demonstrated. Fat content had a strong positive correlation with the product's texture ($r = 0.89$), indicating the significant effect of fat content in improving the product's creaminess and spread ability. Carbohydrates had a strong effect on taste ($r = 0.81$), improving the product's taste and natural sweetness. Fiber content had a moderate positive correlation with the product's texture ($r = 0.76$), improving the product's texture. Aroma had a strong effect on the product's acceptability ($r = 0.85$), indicating the significance of the cardamom flavor. The product's moisture had a negative correlation with the product's texture ($r = -0.68$), indicating that the product's moisture affects the product's texture.

The analysis of the data obtained from this process shows that the developed tiger nut spread has a well-balanced nutritional profile and high sensory acceptability. The nutritional values obtained are within the recommended ranges, which shows that the formulation is nutritionally acceptable and can be recommended for consumption by health-conscious consumers. The sensory evaluation results obtained show that the developed tiger nut spread is highly acceptable, with high sensory evaluation values above 8.0. In particular, texture and taste were scored highest at 8.5 and 8.4, respectively, which shows that the formulation has achieved a smooth texture and a pleasant taste. Aroma and color were also scored high, which shows that the cardamom addition and processing conditions were effective.

Correlation analysis also supports this finding by demonstrating a high level of correlation between nutritional and sensory properties. Fat content was shown to have a high positive correlation with texture, which is a significant finding in this study as it demonstrates that fat content contributes to a better texture in the final product. Similarly, carbohydrate content was shown to have a high positive influence on taste, which is a significant finding in this study as it demonstrates that carbohydrate content contributes to a better taste in the final product. Moisture content also had a high negative correlation with texture, which is a significant finding in this study as it demonstrates that moisture content negatively influences texture in the final product. This analysis demonstrates that the developed tiger nut spread meets both nutritional and sensory requirements and therefore has potential for commercialization.

3.11 Product Optimization

Product optimization is an important step in the development of enriched tiger nut spread with cardamom nuts, wherein optimization of the formulation is carried out according to results obtained in product development. This step is considered to be an important step in product development as it aims at improving the quality of the product, making it more acceptable to consumers, and making it more viable in terms of commercialization. Optimization is carried out according to results obtained in nutritional analysis, sensory evaluation, shelf life study, etc. Depending upon results obtained in product development, optimization of ingredients is carried out to achieve a balanced formulation of ingredients. For example, optimization of ingredients such as tiger nut paste, nuts, and sweeteners can be carried out to make it more palatable to consumers. Similarly, optimization of fat content obtained from nuts can also be carried out to make it more creamy and less greasy. Another significant aspect is texture optimization, which directly influences spreadability and mouthfeel. During homogenization, there is careful control of moisture content to ensure a uniform texture. If there is evidence of oil separation or thickness, there is a possibility of adjusting the oil-moisture mix. This is done to ensure uniformity in texture, thereby increasing stability.

Results of the shelf-life study have a significant impact on optimization. If there is evidence of microbial growth or oxidation, beyond a certain period of time, there is always a possibility of improving packaging techniques or adding natural preservatives such as antioxidants derived from plants. This is done to increase shelf life while maintaining product safety. In addition, sensory feedback from the panelists is also considered for the optimization of the flavor, aroma, and appearance. Attributes such as color uniformity, intensity of aroma, and overall acceptability are also considered for optimization. Repeat tests may also be carried out for the optimization of the formulation with the highest preference and quality consistency. Economic and commercial factors are also considered for the optimization of the product. Factors such as the cost of raw materials, efficiency of the process, and packaging are considered for the optimization of the product. Simplification of the process and the use of cost-effective materials may also help in the reduction of the cost of production.

Lastly, the product is validated by repeated testing and analysis to ensure consistency in nutritional composition, sensory characteristics, and shelf life. This stage is important in guaranteeing the quality and

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consistency of the final product for commercial use. In conclusion, the optimization of the product involves the use of scientific knowledge and information obtained from the consumers' feedback in the improvement of the quality of the tiger nut spread. This stage is important in guaranteeing the quality and consistency of the final product for commercial use.

4 Analysis

The current research on developing tiger nut spread with added cardamom and nuts indicates an effective combination of nutritional quality, sensory acceptance and stability of storage. The resulting product is based on the systematic workflow and optimization techniques, which facilitated the formulation process and provided the product to fulfill the requirements of the functional and consumer-based requirements. The nutritional value was also improved by using tiger nuts as a base ingredient with a high dietary fiber and natural sweetness and supplementing with nuts that increased the amount of protein and healthy fat in the food.

The nutritional analysis performed on the product based on the suggested ISNPM model proved that the product is rich in balanced macronutrients with carbohydrates (52 g) being a primary energy source, fat (18.5 g) being one of the factors that give the product a creamy and caloric taste, and protein (6.8 g) being its functional food value. It contains dietary fiber (10.2 g), which demonstrates the digestive value. Mineral content also helps in reinforcing its health profile thus fit to health-conscious consumers. The sensory evaluation results showed that the consumer acceptability was high, with all the scores being above 8.0. Some of the highest rated attributes were texture and taste hence justifying that the homogenization and formulation processes were successful. Cardamom also added a pleasing aroma to the product, which made it more appealing and the color and the appearance were satisfactory. Such the results indicate that the market of the product has high potential to be accepted. The shelf-life analysis showed that there were slow changes in physicochemical and microbial parameters with time passing. The moisture content and microbial load changed negligently whereas pH fell, which is a sign of weak biochemical activity. The rise in peroxide value was an indication of lipid oxidation, a common condition in fatty products. The scores on sensory deteriorated slowly yet acceptably until 30 days, which means that the product still has a good quality in that span provided that it is stored under appropriate conditions. The changes were statistically significant, as evidenced by the statistical

analysis (ANOVA) which supports the effect of storage time on the stability of products.

Correlation analysis helped give more insights on how nutritional composition is related with sensory attributes. The fact that the correlation between fat and texture was very strong proved the ability of lipids in promoting creaminess. On the same note, carbohydrates were also observed to have an effect on taste, and aroma had a major impact on acceptability. Moisture exhibited negative correlation with texture, which implies that the level of moisture in the textures ought to be regulated to achieve uniformity. The product optimization phase further improved the formulation by modifying ingredient ratios and processing specifications. The advancement of the texture, balance of flavours and shelf stability offered ensured that the final product met the quality and economic viability. The paper is able to show that a natural ingredient spread with a high level of nutrients and plant-based can be created without loss of sensory values. All in all, the designed tiger nut spread can be reviewed as a functional food product of high nutritional content, good sensory, and reasonable shelf life. The paper identifies its potential in commercialization, especially to health-conscious consumers who will desire natural and clean-label products as an alternative to traditional spreads.

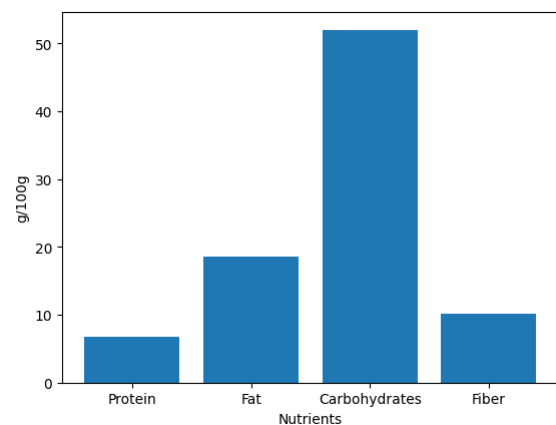


Figure 1: Nutritional Composition of Tiger Nut Spread [21]

Figure 1 indicates that carbohydrates (52.0 g/100 g) is the prevailing value, then fat (18.5 g/100 g) and then fiber (10.2 g/100 g) and protein (6.8 g/100 g). This shows that the spread is rich in energy and has good fiber content and moderate protein, which contributes towards the nutritional value and functional food property.

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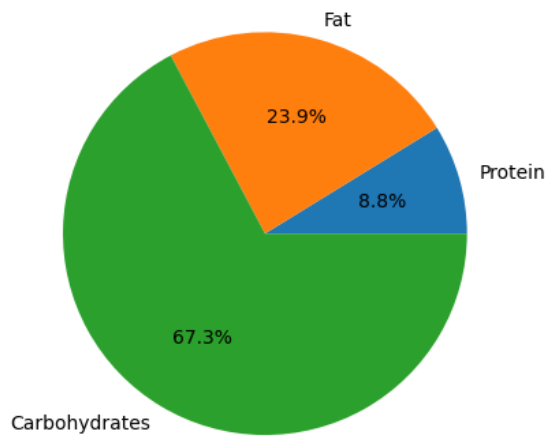


Figure 2: Macronutrient Energy Distribution [3]

Figure 2 shows that the best source of energy is carbohydrates followed by fat with protein being the least. This is the positive energy balance displayed in this distribution, with carbohydrates as a source of quick energy, fats as a source of satiety, and proteins as a source of body repair and maintenance.

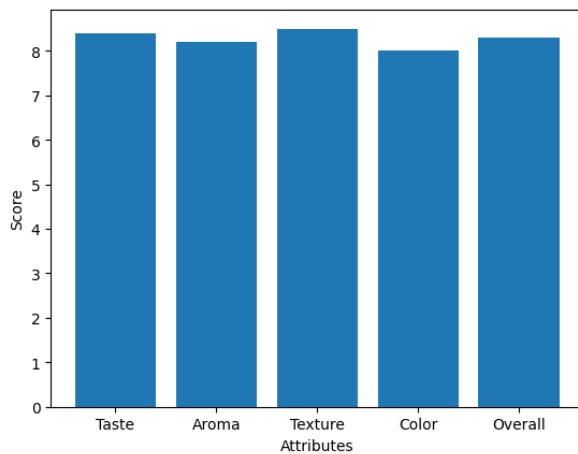


Figure 3: Sensory Evaluation Scores [22]

Figure 3 indicates that the score of sensory attributes is high, with the score of texture (8.5) and taste (8.4) being the highest followed by overall acceptability (8.3), aroma (8.2) and color (8.0). Strong consumer preference, especially that one which is smooth and tasting, is indicated by these values, which proves the high acceptability of the product.

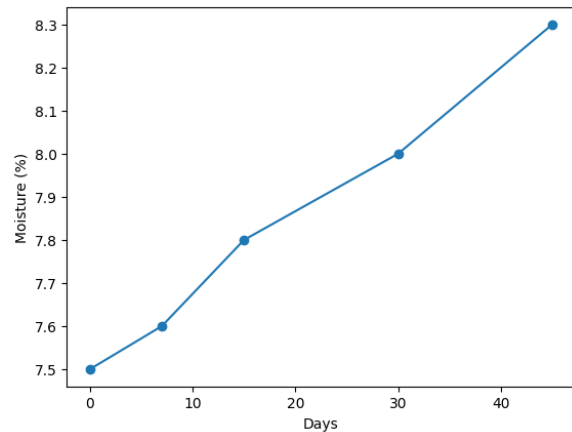


Figure 4: Moisture Content vs Storage Days [23]

Figure 4 shows the comparison of Moisture Content and Storage Days. The amount of moisture rises slowly at 7.5 (0 day) to 8.3 (45 days). Such an increase is an indication of a small amount of water absorption or internal modification during storage which could affect texture and microbial growth but values fall within acceptable limits of stability in spreadable goods.

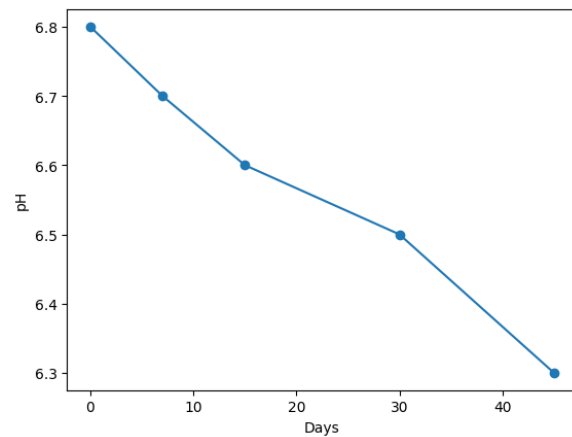


Figure 5: pH vs Storage Days [24]

As indicated by the Figure 5, pH decreases gradually by 0.3 to 6.3 in 45 days. This means that it is getting more acidic with biochemical or microbial activity in storage, and this may influence product stability but yet will be in a safe and acceptable level.

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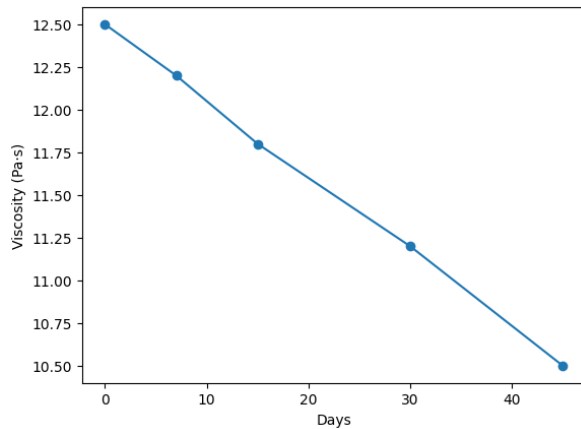


Figure 6: Viscosity vs Storage Days [25]

Figure 6 shows the Viscosity vs Days of storage. The viscosity also drops by 12.5 Pa in 45 days to 10.5 Pa which is a slight thinning up of the spread. Such reduction implies either structural destruction or moisture effect which can have impact on spread ability, yet would retain a reasonable consistency to consume.

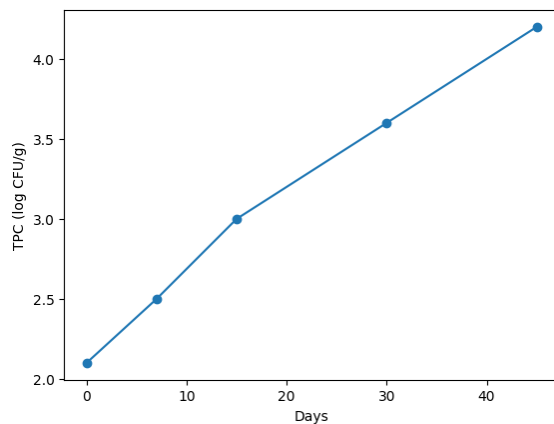


Figure 7: Microbial Load (TPC) vs Storage Days [26]

Figure 7 shows the TPC (microbial load) vs Days of storage. The TPC continuously rises to 2.1-4.2 log CFU/g, which shows slow growth of microorganisms during storage. Though the increase is anticipated, the values fall within reasonable safety limits to 30 days, which proves the microbiological stability of the product under controlled conditions.

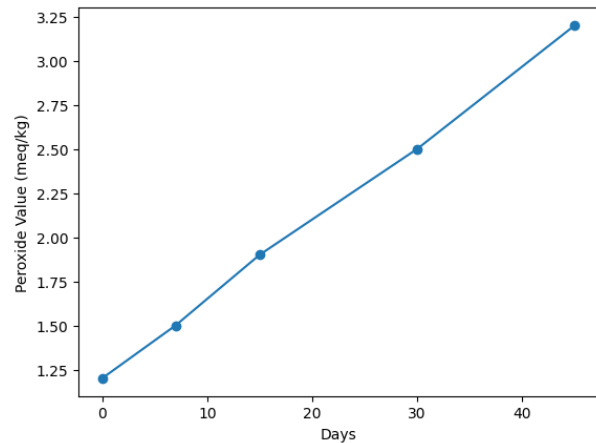


Figure 8: Peroxide Value vs Storage Days [27]

Figure 8 illustrates the Peroxide Value/Storage days. There is an increase of the peroxide value between 1.2 and 3.2 meq/kg with the course of time, which points to gradual lipid oxidation. It is a common trend of fat-containing foods and indicates a slow reduction in the oxidative stability, but the values are acceptable to maintain the quality.

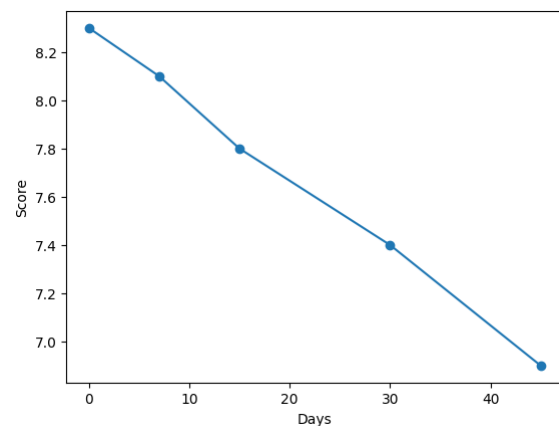


Figure 9: Sensory Score vs Storage Days [28]

Figure 9 shows the Sensory Score vs. Days of storage. The reduction in sensory scores between 8.3 and 6.9 between 45 days is indicative of decreased acceptability of the sensory scores. Nevertheless, the scores are still higher than the acceptable norm (≥ 7) up to 30 days, which proves the fact that the product does not lose its good sensorial qualities in the course of the given timeframe.

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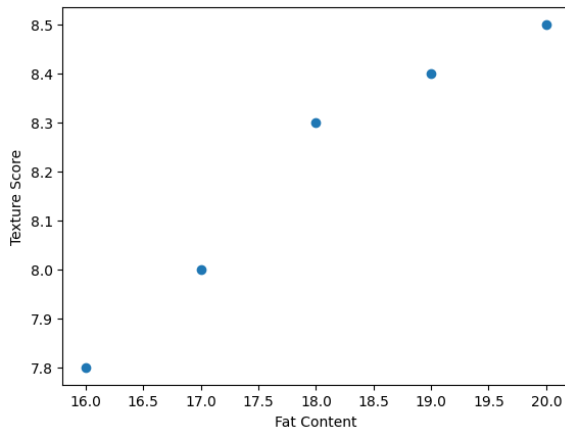


Figure 10: Correlation between Fat Content and Texture [29]

Figure 10 indicates that fat content (1620 percentage) and texture score (7.885) are positively correlated. Increased fat level shown to be more creamy and smooth leading to higher rated of the texture, thus proving that fat is a major ingredient in improving the quality of spread.

5. Discussion

The study has several benefits, including the creation of a nutritionally rich tiger nut spread with good fiber, nutrient, and sensory acceptability properties. The combination of the nutritional, sensory, and shelf-life tests gives a comprehensive evaluation, while the use of statistics validates the findings. However, there are several challenges, including the relatively small shelf-life study period, small sample size in the sensory evaluation, and the absence of sophisticated preservation methods. The feasibility of the study in terms of environmental storage conditions and large-scale production was not fully explored, which could limit the study's commercialization potential.

6. Conclusion

The current study has been successful in developing a nutritionally enriched tiger nut spread with the incorporation of cardamom and nuts. The study has shown that the developed product has the potential for a balanced combination of health benefits and quality. The nutritional benefits of the product include a high amount of carbohydrates for energy production, adequate amounts of protein for functional properties, and significant amounts of dietary fiber for health benefits. The sensory evaluation of the developed tiger nut spread has shown high levels of acceptability among consumers. The study has also shown that the product has the potential for commercial use based on the shelf-life analysis. The study has shown that the product has the potential for quality retention for a period of 30 days. The statistical analysis has

confirmed the significance of the changes observed in the product during the shelf-life analysis. The study has also shown the correlation of fat and aroma with the acceptability of the product. Although the study has shown some limitations such as the period of storage and the scale of the product, the study has shown that the tiger nut spread has the potential for use as a functional food.

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