

A Study of the Availability of Chemical and Bacteriological Quality Standards for Some Frozen Vegetables Traded in Egyptian Markets

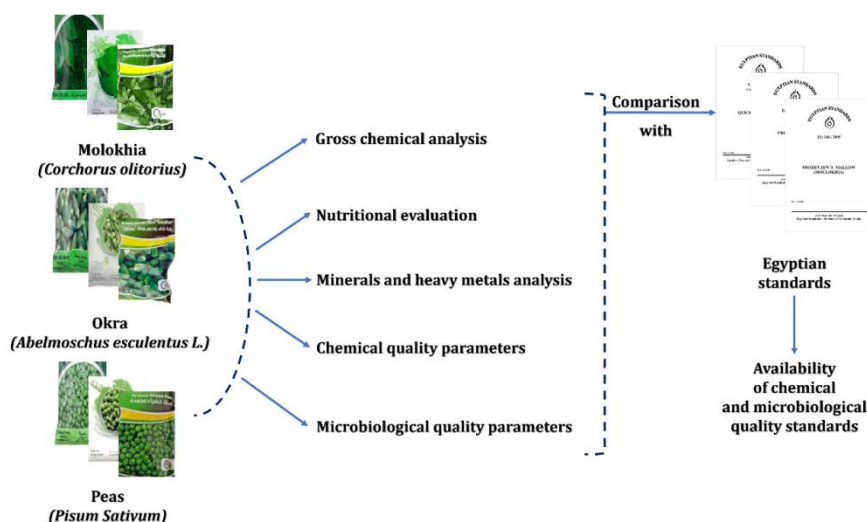
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Abstract This study examines the chemical and bacteriological quality standards of frozen vegetables in Egyptian markets and their compliance with standard specifications. Chemical analysis shows some samples are unsafe due to toxic heavy metals, ash insoluble in acid, and total solids insoluble in alcohol, exceeding Egyptian limits. Molokhia samples show ash insoluble in acid levels from 0.15 to 0.24 g/100g (fresh weight), slightly exceeding the 0.15 g dry weight standard, suggesting potential non-bioavailable minerals. Frozen Peas show lead contamination, with Brand II exceeding the 0.1 ppm Egyptian limit. Total solids insoluble in alcohol range from 21.12 to 24.91 g/100g across three brands, with most samples meeting the 23 g standard. Brand I (24.91 ± 0.33 g/100g) and Brand II (23.5 ± 0.45 g/100g) slightly exceed the limit, while Brand III (21.12 ± 0.11 g/100g) is below. Okra samples show Brand II exceeds the 0.2 ppm lead limit, while Brand III has no detectable lead, indicating potential safety benefits. Lead contamination is a major concern, highlighting the need for further investigation into Egypt's food safety practices. Microbiological testing confirms all frozen samples are safe for consumption, with bacterial and fungal levels within acceptable limits. The absence of *E. coli* and low coliform levels further confirm microbiological safety, suggesting freezing is effective in controlling microbial contamination. The study recommends ongoing surveys of frozen vegetable samples in the market to ensure the freezing process effectively controls chemical and microbial contamination and ensures compliance with all quality standards.



Keywords: Molokhia, pea, okra, nutritional value, minerals content, chemical quality indices, Egyptian standard

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1. Introduction

Nutritional vegetables play a significant role in

promoting health and preventing various chronic diseases. They are rich in essential vitamins, minerals, fiber, and antioxidants that contribute to overall well-being [1,2,3]. Vegetables such as spinach, broccoli, carrots, peas and molokhia are particularly notable for their high content of

vitamins A, C, K, and folate, which support immune function and skin health. Additionally, the fiber in vegetables aids digestion and helps maintain a healthy weight by promoting satiety [4,5]. The consumption of vegetables has also been linked to a reduced risk of cardiovascular diseases [6,7,8], type 2 diabetes [9,10], obesity [11,12], and certain cancers [13] due to their high antioxidant properties [14,15,16,17,18]. Moreover, a diet rich in vegetables can help lower blood pressure and improve gut health [19]. Therefore, including a variety of vegetables in the daily diet is essential for optimal health and disease prevention.

Frozen vegetables are vegetables that are processed and preserved by freezing at sub-zero temperatures, a method that helps extend shelf life while maintaining their freshness, flavor, texture, and nutritional quality for long periods. The freezing process typically involves several stages, including cleaning, blanching (a brief immersion in hot water or steam to deactivate enzymes), and rapidly freezing the produce to temperatures of -18°C or lower. This rapid freezing halts enzymatic activities and microbial growth, preventing spoilage and allowing vegetables to be stored for extended periods, providing consumers with year-round access to high-quality produce, regardless of seasonal fluctuations or regional availability [20,21]. Freezing also helps minimize the loss of nutritional content, which can be significant in other preservation methods, such as canning or drying, and contributes to reducing food waste by extending the shelf life of produce, benefiting both developed and developing countries [2,22,23].

The nutritional significance of frozen vegetables is considerable, as freezing helps retain much of the original nutritional value of fresh vegetables. Nutrients such as vitamins (particularly vitamin C, folate, and carotenoids) and minerals are preserved, even though some minor losses can occur during the blanching process [24]. In fact, studies have shown that frozen vegetables can retain most of their antioxidant content, which is essential for human health, and are sometimes even superior to fresh vegetables in terms of nutrient retention, especially if the fresh produce has been stored for extended periods before consumption [25,26]. Additionally, frozen vegetables often contain more dietary fiber and antioxidants compared to fresh vegetables, which lose their nutritional quality over time due to exposure to air and light [27,28].

Frozen vegetable production has become a significant part of global trade, with several countries contributing to the supply of frozen vegetables. Notably, Egypt has emerged as a key player in the global market, particularly for frozen vegetables like peas, leafy vegetables (Molokhia and spinach) beans, sweet corn etc., [23]. In 2021, Egypt was one of the top exporters of frozen vegetables, with the sector seeing substantial growth due to advancements in farming techniques, increased production capacity, and improved processing facilities [29]. In 2020, Egypt's export of frozen vegetables reached approximately 500,000 tons, contributing significantly to its agricultural economy. This sector not only supports Egypt's local economy by providing jobs in both the farming and processing industries but also helps meet international demand for affordable, nutritious frozen produce [30]. Other leading exporters of frozen vegetables

include China, the United States, and the European Union, with these regions accounting for a large portion of global frozen vegetable exports. According to International Trade center, [31], Egypt's exports in the frozen vegetable sector grew by 13% from 2018 to 2020, signaling an upward trend in global demand.

The safety of frozen vegetables is paramount, as improper handling or disruption of the cold chain during storage, transportation, and distribution can lead to microbial contamination or degradation of quality. Maintaining a consistent low temperature throughout the supply chain is crucial to prevent thawing and refreezing, which can affect texture and flavor, and lead to the growth of harmful bacteria such as *Salmonella*, *Listeria*, and *E. coli* [32]. Studies have shown that the safety of frozen vegetables is directly linked to proper cold chain management, which involves careful monitoring of temperatures from the farm to the consumer [33]. In fact, research indicates that the safety of frozen vegetables is higher when optimal cold chain practices are followed, reducing the risk of contamination and spoilage [28]. The Food and Drug Administration (FDA) and similar regulatory bodies around the world have strict standards to ensure that frozen vegetables remain safe for consumption. This includes guidelines on storage temperatures, transportation conditions, and hygiene practices throughout the production process.

Survey studies on the quality of frozen vegetables have been pivotal in understanding consumer preferences, product quality, and safety standards. Various surveys have highlighted that consumers are increasingly turning to frozen vegetables due to their convenience, long shelf life, and nutritional value. According to [34] survey by the International Food Information Council (IFIC), 72% of consumers reported that they trust frozen vegetables to maintain their nutritional integrity, while 67% appreciated the convenience and accessibility of frozen produce [34]. Furthermore, studies conducted by the European Food Safety Authority (EFSA) have found that the microbial contamination rate in frozen vegetables is relatively low compared to other food categories, though occasional contamination issues are found, especially in improperly handled products [33]. These findings emphasize the importance of maintaining strict food safety protocols and regulatory oversight in the production and distribution of frozen vegetables to ensure public health and maintain consumer confidence. In line with the above, the current study was conducted to explore the availability of chemical and bacteriological quality standards for some frozen vegetables commonly traded in Egyptian markets and their compliance with the applicable standard specifications in this regard.

2. Materials and Methods

2.1. Materials

2.1.1. Frozen Vegetable Samples

Frozen vegetable samples of Peas (*Pisum sativum*), Okra (*Abelmoschus esculentus* L.) and Molokhia (*Corchorus olitorius*) were collected in different brands by

special arrangement from the Egyptian local markets. The samples were collected in ice-box, transported to the laboratory and keeping in deep freezer at -18°C until analysis.

2.1.2. Chemicals

All chemicals (Except as otherwise stated), reagents and solvents were of analytical grade were purchased from El-Ghomhorya Company for Trading Drug, Chemicals and Medical Instruments, Cairo, Egypt.

2.1.3. Machines

Throughout this study absorbance for different assays were measured using UV-160A; Shimadzu Corporation, Kyoto, Japan. Also, atomic absorption spectrophotometer, type Perkin – Elmer, Model 2380, Waltham, MA, USA was used for mineral determination.

2.2. Methods

2.2.1. Gross Chemical Composition

Frozen samples were analyzed for proximate chemical composition including moisture, protein (T.N. $\times$ 6.25, micro - kjeldahl method using semiautomatic apparatus, Velp company, Italy), fat (soxhelt semiautomatic apparatus, Velp company, Italy , petroleum ether solvent), ash, fiber and dietary fiber contents were determined using the methods described in the [35]. Carbohydrates calculated by differences: Carbohydrates (%) = 100 - (% moisture + % protein + % fat + % Ash + % fiber).

2.2.2. Evaluation of Nutritional Value

2.2.2.1. Total Energy Value

Total energy (Kcal/100 g) of frozen vegetable samples was calculated according to Insel *et al.*, [36] using the following equation: Total energy value (Kcal/100 g) = 4 (Protein % + carbohydrates %) + 9 (Fat %)

2.2.2.2. Satisfaction of the daily needs of adult man (25-50 year old) in protein

Grams consumed (G.D.R. g) of frozen vegetable samples (dry weight basis) to cover the daily requirements of adult man (63 g) in protein was calculated using [37] values. Percent satisfaction of the daily requirement of adult man in protein (P.S., %) when consuming the possibly commonly used portions in Egypt i.e. one bag (100 g weight), was also calculated.

2.2.2.3. Satisfaction of the Daily Requirements of Adult Man (25-50 Year Old) in Energy

Grams consumed of frozen vegetable samples (dry weight basis) to cover the daily requirements of man in energy (G.D.R. g) were calculated using the RDA (Recommended dietary allowances) which are 2900 Kcal /day for man as given by RDA [37]. The percent satisfaction (P.S., %) of the daily needs of adult man (25 -50 year old , 79 Kg weight and 176 cm height) in energy upon consumption the commonly used portion at homes in Egypt, i.e. i.e. one bag (100 g weight), was also calculated.

2.2.3. Minerals Content

Minerals content of frozen vegetable samples were determined according to the method mentioned by Singh *et al.*, [38] as follow: 0.5 g of defatted sample were transferred into a digested glass tube of Kjeldahl digestion unit and 6 ml of tri-acids mixture (containing nitric acid: perchloric acid : sulfuric acid in the ratio of 20 : 4 : 1 v/v respectively) were added to each tube. The tubes content were digested gradually as follow, 30 min at 70°C ; 30 min at 180°C and 30 min at 220°C . After digestion, the mixture was cooled, dissolved in distilled water, and the volume was increased to 50 ml in volumetric beaker. After filtration in ashless filter paper, aliquots were analyzed for minerals (K, Na, Zn, Ca, Mg, Mn, Fe, Cu, P, Cd, Pb and Se) using of atomic absorption spectrophotometer.

2.2.4. Ash insoluble in Acid

The determination of ash insoluble in acid is an important analytical procedure used to evaluate the quality and purity of ash in various materials, such as food, agricultural products, and soil. The method typically begins with a sample of the material, which is weighed and placed in a crucible. If the sample is not already dried, it is first dried in an oven at 105°C to remove moisture. After this, the sample is ashed by heating it in a muffle furnace at 550°C for 3 to 5 hours, ensuring that all organic material is completely burned, leaving only the mineral content in the form of ash. After ashing, the crucible is cooled in a desiccator to prevent moisture absorption [39]. The next step involves adding about 25 mL of 1 N hydrochloric acid (HCl) to the ash to dissolve the soluble components. The crucible is gently heated on a hot plate to facilitate the dissolution of the soluble ash, but care is taken to avoid excessive boiling or loss of acid. Following heating, the solution is filtered using filter paper, and the insoluble residue is collected. This residue, which is the portion of the ash that remains insoluble in acid, is washed with deionized water to remove any residual acid and soluble salts. The residue is then dried in an oven at 105°C to a constant weight. Once dried, the weight of the residue is determined by reweighing the filter paper and the insoluble ash [40]. The percentage of ash insoluble in acid is calculated using the formula:

Percentage of Ash Insoluble in Acid = (Weight of acid insoluble ash / Weight of sample) $\times$ 100

2.2.5. Total solids Insoluble in Alcohol

Total solids insoluble in alcohol was determined according to the method of Jayas, [22]. Weighing of a known quantity of the vegetable sample and then mixed with an appropriate volume of ethanol (95% ethanol is typically used), ensuring complete immersion of the sample. The mixture is allowed to stand for a specified period, usually 1 to 2 hours, to ensure that soluble components are dissolved in the alcohol, leaving behind the insoluble solids. After this incubation period, the mixture is filtered through filter paper to separate the insoluble solids. The insoluble residue is then washed with additional ethanol to remove any remaining soluble components. The filtered residue is dried in an oven at

105°C to remove residual moisture. Once dried, the residue is weighed, and the total solids insoluble in alcohol are calculated as a percentage of the initial sample weight.

2.2.6. Peroxidase Activity

Peroxidase activity assay for checking the efficiency of blanching in food processing, where blanching is known to deactivate peroxidase and prevent undesirable enzymatic reactions during storage such as described by Chance & Maehly [41]. To test peroxidase activity, a few drops of the enzyme extract are mixed with a substrate solution containing 10 mM hydrogen peroxide and 5 mM guaiacol in a phosphate buffer (pH 6.0). If peroxidase is present and active, the enzyme catalyzes the oxidation of guaiacol, resulting in a brown color due to the formation of a guaiacol oxidation product. The intensity of the brown color provides a qualitative indication of enzyme activity. A stronger color indicates higher enzyme activity, whereas a lack of color formation or a faint color suggests little to no enzyme activity, which typically correlates with effective blanching (which inactivates peroxidase activity).

2.2.7. Microbiological Examination

2.2.7.1. Total Bacterial Counts

Total bacterial counts of frozen vegetables samples were determined according to the American Public Association [42] by plating suitable dilution in duplicates using nutrient agar medium [43]. This medium consists of: beef extract (3 g/L), bacto peptone (5g/L), agar (15 g/L), sodium chloride (5 g/L) and distilled water to 1000 ml PH 7. Plates were incubated at 32°C for 3 days before counting and recording the results.

2.2.7.2. Mould and Yeast

Potato dextrose agar recommended by Oxoid Manual, [44] was used for the enumeration of moulds and yeast's. This medium consists of: potatoes extract (4 g/L), dextrose (20 g/L), agar (15 g/L) and PH (5.6). Plates were incubated at 20 – 25 ° before counting.

2.2.7.3. Coliform Bacteria Counts

The coliform bacteria counts in the examined frozen vegetables samples were enumerated using the method described in the Standard Method for the Examination of Milk and Dairy Products (1960). MacConkey agar were prepared as described in Oxoid, [45]. The following ingredients were used: Pepton (20 g/L), bile salt (5 g/L), sodium chloride (5 g/L), lactose (10 g/L), bromocresol purple (2.5 g/L), agar (15 g/L) and distilled water to 1000 ml PH 6.8. Plates were incubated at 37° C for 16 – 18 hours before counting.

2.2.7.4. Escherichia Coli Count

Escherichia coli (*E. coli*) in vegetable samples was determined according to the method described by APHA, [46]. The procedure begins by preparing a series of serial dilutions of the sample in a liquid medium, typically using Lauryl Tryptose Broth (LTB). The inoculated tubes are then incubated at 37°C for 24-48 hours. After incubation, the presence of gas in the Durham tube indicates a positive

result for coliforms, including *E. coli*. To confirm the presence of *E. coli*, the most probable number (MPN) method involves a subsequent transfer to a selective medium, such as Eosin Methylene Blue (EMB) agar or MacConkey agar, which inhibits the growth of non-coliform organisms while allowing the growth of *E. coli*. The result is usually expressed in terms of MPN per 100 mL or g of sample, providing an estimate of the concentration of *E. coli* in the tested sample.

3. Results and Discussion

3.1. Molokhia (*Corchorus olitorius*)

3.1.1. Proximate Chemical Composition of Frozen Molokhia (*Corchorus olitorius*) Samples Collected from the Egyptian Local Markets.

The proximate chemical composition of frozen Molokhia (*Corchorus olitorius*) samples, as presented in Table 1, offers insight into the macronutrient content of this popular vegetable, which is commonly consumed in Egypt and other regions. This table shows the composition of three different brands of frozen Molokhia, measured on a fresh weight (FW) basis, focusing on key components such as moisture, protein, fat, fiber, ash, and carbohydrate content. The moisture content of frozen Molokhia samples ranged from 93.87% to 94.86% across the three brands, which is typical for leafy vegetables that have high water content. Moisture is an important factor influencing the shelf life and texture of frozen vegetables. Similar studies on leafy vegetables, such as spinach and kale, have reported comparable moisture content, with values ranging from 85% to 95% [47,48]. The total protein content of the samples was relatively low, ranging from 1.12% to 1.23%, which aligns with previous findings for similar leafy vegetables such as spinach [49]. According to Ibrahim *et al.*, [50], the protein content of Molokhia typically ranges between 1-2%, depending on its processing and storage methods. This relatively low protein value is expected, as leafy greens are not significant sources of protein compared to legumes or grains. This value is similar to the protein levels found in other vegetables such as lettuce (1.2%) and cabbage (1.5%) [4]. The crude fat content was very low, ranging from 0.05% to 0.07%, which is typical for leafy greens. Low fat content is a common feature of vegetables, particularly those from the *Corchorus* genus. The minimal fat content in Molokhia makes it a suitable option for low-fat diets. Similar findings have been reported by Mahgoub *et al.*, [51] in a study on the proximate composition of different vegetable species, where the fat content in leafy greens rarely exceeds 0.1%. This low fat content, combined with the high moisture, positions Molokhia as a low-calorie food. The crude fiber content ranged from 1.51% to 1.73%, which is within the typical range for leafy vegetables. Dietary fiber is important for digestive health, and the fiber values in Molokhia are consistent with those reported for other leafy greens, such as spinach and kale [5]. Fiber content can vary based on the processing and storage methods used. For example, the increase in crude fiber content in Brand II (1.73%) could

be a result of variations in the leaf maturity or the preservation method. Fiber content in *Molokhia* is important, as it contributes to its health benefits, including aiding digestion and providing satiety. The ash content, which is indicative of the total mineral content, ranged from 0.080% to 0.091%. This is a typical value for leafy vegetables, as they contain various essential minerals, though in small amounts. Similar studies, such as those by Eshun *et al.*, [52], report ash content in vegetables such as okra and amaranth in the range of 0.1% to 1.0%. *Molokhia*, being a leafy vegetable, naturally has lower ash content than root vegetables or those rich in mineral salts. The carbohydrate content of the frozen *Molokhia* samples ranged from 2.16% to 3.24%. This range is consistent with values found in other leafy vegetables, where carbohydrates generally contribute to the plant's energy content, although at lower levels than other macronutrients such as proteins and fats. This result is comparable to the carbohydrate content reported for spinach (2.4% to 3.5%) and other leafy greens, which tend to have low but significant carbohydrate content from sugars and starches [53]. In general, frozen mallow samples of the third brand are considered the best samples in terms of overall chemical composition followed by the first and second brands respectively. Also, The data of this study are also partially consistent with what was reported by several authors who conducted their technological studies in the laboratory on *Molokhia* samples grown in Egypt [3,12,26,51].

Table 1. Proximate chemical composition of frozen *Molokhia* (*Corchorus olitorius*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Component (g/100g)	Brand I	Brand II	Brand III
Moisture	94.10 ± 0.25 ^a	94.86 ± 0.19 ^a	93.87 ± 0.09 ^a
Total protein	1.17 ± 0.02 ^a	1.12 ± 0.04 ^a	1.23 ± 0.04 ^a
Crude fat	0.07 ± 0.01	0.05 ± 0.01	0.06 ± 0.01
Crude Fiber	1.60 ± 0.05 ^a	1.73 ± 0.11 ^a	1.51 ± 0.13 ^a
Ash	0.090 ± 0.01 ^a	0.080 ± 0.010 ^a	0.091 ± 0.020 ^a
Carbohydrate	2.97 ± 0.12 ^{ab}	2.16 ± 0.13 ^b	3.24 ± 0.18 ^a

Each value represents the mean of three replicates ± SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.1.2. Nutritional Evaluation of Frozen *Molokhia* (*Corchorus olitorius*) Samples Collected from Egyptian Local Markets

The following table provides a nutritional evaluation of frozen *Molokhia* (*Corchorus olitorius*) samples obtained from Egyptian local markets (Table 2). The parameters assessed include total energy content (Kcal/100g), General Daily Requirement (G.D.R.) for protein and energy, as well as the Proportional Share (P.S.) for protein and energy. The values for the three different brands are presented on a fresh weight basis (FW), and each value represents the mean of three replicates ± SD. The results provide important insight into the nutritional contribution of frozen *Molokhia* in the diet, with comparisons made to similar studies in the literature. The energy content of frozen *Molokhia* ranged from 13.57 Kcal/100g to 18.42 Kcal/100g, which is relatively low, consistent with the characteristics of leafy vegetables. Okra, spinach, and similar leafy greens are often low in calories, making them

suitable for weight management or low-calorie diets. The values in this study align with findings in Akinmoladun *et al.*, [4] and Mahgoub *et al.*, [51] who reported that leafy vegetables like *Corchorus* species tend to be low in energy content, with values generally ranging between 10 to 20 Kcal/100g. This makes *Molokhia* an excellent choice for those looking to reduce caloric intake while still obtaining essential nutrients. The G.D.R. for protein is calculated relative to a daily intake requirement of 63 g. The results indicate that frozen *Molokhia* provides between 5385 and 5625 grams of protein per 100g serving, depending on the brand. This indicates the high protein content relative to the daily required intake. The protein contribution of leafy vegetables such as *Molokhia* is modest, but these values suggest that they can still be valuable in meeting protein requirements, especially in plant-based diets. Studies like Goncalves *et al.*, [49] and Ibrahim *et al.*, [50] have reported protein levels in *Molokhia* in the range of 1.5% to 3%, similar to the present findings. This relatively low but valuable protein content makes *Molokhia* an important supplementary food source in vegetarian or vegan diets. The G.D.R. for energy is calculated based on a total daily energy intake of 2900 Kcal. The energy contribution from frozen *Molokhia* ranges between 15747 and 21371 Kcal per 100g, depending on the brand. This indicates that *Molokhia* is a low-energy vegetable, as expected from its low calorie content. With this context, Rosa *et al.*, [53] and Sharma *et al.*, [54] report that vegetables such as *Molokhia* typically contribute a small fraction of the total energy requirement due to their low caloric density. This reinforces the idea that *Molokhia* is a low-calorie option for people seeking to maintain or lose weight while still getting essential nutrients like fiber, vitamins, and minerals. The percent of satisfaction (%) of protein, relative to the General Daily Requirement for a 63g intake, ranged from 1.78% to 1.95%. This means that a 100g serving of frozen *Molokhia* provides 1.8% to 2% of the daily recommended protein intake. Although *Molokhia* is not a high-protein food, it still plays a role in supplementing the protein intake, particularly in vegetarian or mixed diets. Goncalves *et al.*, [49] and Mahgoub *et al.*, [51] report similar values for plant-based sources of protein, noting that while leafy vegetables are not major protein sources, they still contribute meaningfully to overall protein intake when included as part of a diverse diet. The percent of satisfaction (%), relative to the General Daily Requirement for a 2900 Kcal intake, ranged from 0.47% to 0.64%. This further confirms the low-energy density of frozen *Molokhia*, making it an excellent food choice for those looking to minimize calorie intake without sacrificing essential nutrients. The energy contribution from *Molokhia* is consistent with the findings from Onwuka *et al.*, [5] and Ibrahim *et al.*, [50], who noted similar low-energy values in leafy green vegetables, which is an advantageous characteristic for weight management. In general, frozen *Molokhia* samples of the third brand are considered the best samples in terms of nutritional evaluation followed by the first and second brands respectively. When comparing the nutritional evaluation of frozen *Molokhia* with similar studies, the results are largely consistent with existing literature on the nutritional profile of *Molokhia* and other leafy greens. For instance, Ibrahim *et al.*, [50]

reported similar low energy content in frozen Molokhia, ranging from 13 to 19 **Kcal/100g**, in line with the findings of this study. Also, Akinmoladun *et al.*, [4] observed comparable protein levels in various species of *Corchorus*, which corroborate the protein content found in this study. Furthermore, several authors found that vegetables like Molokhia are low in calories, reinforcing the results in this study regarding the low energy content and its minimal contribution to the overall energy intake [3,12,26,53,54].

Table 2. Nutritional evaluation of frozen Molokhia (*Corchorus olitorius*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Parameter	Brand I	Brand II	Brand III
Total Energy (Kcal/100g)	17.19 ± 1.11 ^{ab}	13.57 ± 1.00 ^b	18.42 ± 1.09 ^a
G.D.R. (g) for protein (63 g)	5385 ± 112 ^{ab}	5625 ± 97 ^a	5122 ± 101 ^b
G.D.R. (g) for energy (2900 Kcal)	16870 ± 69 ^b	21371 ± 58 ^a	15747 ± 62 ^c
P.S./100 g (%) for protein (63g)	1.86 ± 0.09 ^a	1.78 ± 0.11 ^a	1.95 ± 0.07 ^a
P.S./100 g (%) For energy (2900 Kcal)	0.59 ± 0.02 ^a	0.47 ± 0.07 ^a	0.64 ± 0.02 ^a

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.1.3. Mineral Concentrations of frozen Molokhia (*Corchorus olitorius*) Samples Collected from Egyptian Local Markets

This study presents the mineral concentration data for frozen Molokhia (*Corchorus olitorius*) samples, collected from different brands (Brand I, Brand II, and Brand III) in Egyptian local markets (Table 3). The analysis is based on fresh weight (FW) and includes essential minerals such as calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), iron (Fe), zinc (Zn), selenium (Se), sodium (Na), and toxic metals like lead (Pb) and cadmium (Cd). Calcium is a crucial mineral for bone health, and its concentration varied across the brands, with Brand III showing the highest value. Potassium is essential for cell function, nerve transmission, and muscle contraction. Brand I had the highest potassium content, although the values between brands were fairly similar. Magnesium plays a key role in enzymatic reactions and nerve function. The magnesium levels in the three brands were relatively close, with Brand I showing the highest concentration. Phosphorus is essential for energy production and bone health. The levels across brands were comparable, with Brand I slightly leading in phosphorus content. Iron is crucial for oxygen transport and metabolic processes. The results indicate that all brands have similar iron levels, which is consistent with findings from other studies on *Corchorus olitorius*. Zinc is vital for immune function and enzyme activity. The zinc concentration across the three brands is low but similar. Selenium, an essential trace element, is present in comparable levels across all brands, with no significant variation. Sodium levels in Brand II were notably higher compared to Brands I and III, which could be of concern regarding sodium intake. Lead levels varied across brands, with Brand III having the lowest concentration. The concentration in Brand II exceeds the standard set by the Egyptian regulations. Cadmium levels were quite low in all samples, particularly in Brand III, which had no detectable cadmium content. Several studies

have analyzed the mineral composition of *Corchorus olitorius*, and the data presented here align with findings from similar studies. For instance, calcium and potassium concentrations in Molokhia have been reported to vary significantly depending on geographical location and growth conditions, similar to the variation seen across brands in this study. For example, a study by El-Sayed *et al.*, [55] found that Molokhia contains 20-30 mg/100g of calcium, which is consistent with the values for Brand I and Brand II in this study. Iron content in Molokhia has been shown to range between 0.4 to 0.6 mg/100g in other studies, similar to the values obtained in the current research, indicating consistent iron content across various brands of frozen Molokhia [56]. The presence of toxic metals like lead and cadmium is an important concern in food safety [57,58,59]. Studies such as Zayed *et al.*, [60] have highlighted the impact of environmental contamination on heavy metal concentrations in leafy vegetables. The findings in this study show that the lead concentration in some brands exceeds the acceptable levels, particularly in Brand II. This raises concerns over food safety and the need for rigorous monitoring.

Table 3. Mineral concentrations of frozen Molokhia (*Corchorus olitorius*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Mineral (mg/100g)	Brand I	Brand II	Brand III	Egyptian standard (ES, 1681/2005)
Ca	25.49 ± 2.87 ^b	22.80 ± 1.98 ^b	31.06 ± 2.10 ^a	-----
K	7.31 ± 0.67 ^a	6.60 ± 0.28 ^a	7.13 ± 0.34 ^a	-----
Mg	7.99 ± 0.55 ^a	7.20 ± 0.30 ^a	7.78 ± 0.29 ^a	-----
P	7.26 ± 0.69 ^a	6.55 ± 0.56 ^a	7.08 ± 0.32 ^a	-----
Fe	0.57 ± 0.02 ^a	0.50 ± 0.01 ^b	0.55 ± 0.06 ^{ab}	-----
Zn	0.05 ± 0.01 ^a	0.04 ± 0.00 ^a	0.05 ± 0.01 ^a	-----
Se	0.15 ± 0.02 ^a	0.14 ± 0.01 ^a	0.15 ± 0.02 ^a	-----
Na	7.47 ± 1.01 ^b	10.49 ± 0.49 ^a	7.28 ± 0.65 ^b	-----
Pb	0.2 ± 0.1 ^{ab}	0.4 ± 0.2 ^a	0.1 ± 0.1 ^b	0.3 ppm
Cd	0.1 ± 0.00 ^a	0.1 ± 0.1 ^a	0.00 ± 0.00	0.2 ppm

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.1.4. Chemical Quality Indices in Frozen Molokhia (*Corchorus olitorius*) Samples Collected from Egyptian Local Markets

Table 4 presents the chemical quality indices of frozen Molokhia (*Corchorus olitorius*) samples collected from Egyptian local markets. The components analyzed include ash content, ash insoluble in acid, and peroxidase/catalase enzyme activity, which provide crucial insights into the quality, preservation, and potential nutritional value of Molokhia. The findings are compared to the Egyptian standard (ES, 1681/2005), and are discussed in the context of existing literature. Ash content represents the total mineral content in the sample, and it provides a general idea of the nutritional value of the product. The measured values for ash content in all three brands range from 1.485 to 1.556 g/100g on a fresh weight basis, which is quite

close to the Egyptian standard value of 1.5 g on a dry weight basis. It is important to note that when expressed on a dry weight basis, ash content typically increases due to the reduction in water content. The values found in this study are consistent with those reported by Al-Gaadi *et al.*, [61] who found that leafy vegetables such as spinach and Molokhia have similar ash contents when measured on a fresh weight basis. These results suggest that the mineral content of Molokhia in the Egyptian market is within an acceptable range for frozen vegetables. Ash insoluble in acid reflects the proportion of minerals that are not easily bioavailable, often due to being bound in forms such as oxalates or phytates. The values for ash insoluble in acid in the three brands range from 0.15 to 0.24 g/100g on a fresh weight basis. The measured values are somewhat higher than the Egyptian standard value of 0.15 g on a dry weight basis. However, it is important to recognize that the fresh weight basis will naturally result in lower values compared to the dry weight basis. This could indicate that the Molokhia samples analyzed contain a relatively higher amount of non-bioavailable minerals, potentially affecting their overall nutritional efficiency. With this context, Srinivasan *et al.*, [62] and Zhang *et al.*, [63] observed similar findings in other leafy vegetables, noting that the presence of insoluble compounds can limit the bioavailability of essential minerals in the diet. Peroxidase and catalase enzyme activity are indicators of the freshness and quality of vegetables. The negative results for peroxidase and catalase activity in all three brands suggest that the frozen Molokhia samples have been adequately processed and stored, as proper freezing procedures inhibit the activation of these enzymes. This is consistent with Cai *et al.*, [64] who noted that freezing can effectively prevent the enzymatic degradation of vegetables. This finding also supports the assertion that the Molokhia samples have been preserved in a way that prevents spoilage and maintains their quality during storage. Enzyme inhibition is crucial in retaining the nutritional and sensory qualities of frozen vegetables, as active enzymes can lead to nutrient loss and the deterioration of flavor and color.

Table 4. Chemical quality indices of frozen Molokhia (*Corchorus olitorius*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Component (g/100g)	Brand I	Brand II	Brand III	Egyptian standard (ES, 1681/2005)
Ash	1.524 ± 0.021 ^{ab}	1.556 ± 0.019 ^a	1.485 ± 0.008 ^b	1.5 (DW basis)
Ash insoluble in acid	0.19 ± 0.02 ^b	0.24 ± 0.03 ^a	0.15 ± 0.02 ^c	0.15 (DW basis)
Peroxidase/catalase enzyme activity	Negative	Negative	Negative	Negative

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

The chemical quality indices of frozen Molokhia in this study are in line with findings from similar studies on frozen vegetables. For example, Kader *et al.*, [65] reported comparable values for ash content and enzyme activity in frozen leafy vegetables. The ash content of Molokhia was found to be in a similar range to that reported for other green leafy vegetables such as spinach and kale, where

mineral concentrations typically fall within the range of 1–2 g/100g on a fresh weight basis. In addition, studies on the bioavailability of minerals in leafy vegetables, such as those by Srinivasan *et al.*, [62] and Zhang *et al.*, [63], have highlighted the importance of processing methods in determining the amount of bioavailable minerals. Freezing, as observed in this study, can preserve the mineral content, but the bioavailability of certain minerals may still be reduced due to the formation of insoluble compounds.

3.1.5. Microbial Evaluation of Frozen Molokhia (*Corchorus olitorius*) Samples Collected from the Egyptian local Markets

Table 5 presents the microbial evaluation of frozen Molokhia (*Corchorus olitorius*) samples collected from the Egyptian local markets. The microbial parameters analyzed include the total bacterial count (TBC), total yeast and mold count (TYMC), coliform bacteria (CB), and the presence of *Escherichia coli* (EC). These factors are critical in assessing the safety and quality of frozen vegetables. The results are compared with the Egyptian standard (ES, 1681/2005) for frozen vegetables to evaluate whether the samples comply with the microbiological safety criteria set by regulatory authorities. The total bacterial count (TBC) is a common indicator of the overall microbiological quality of food products, reflecting the degree of bacterial contamination. In this study, the TBC values for the frozen Molokhia samples ranged from 28,082 to 50,562 CFU/g, which are well below the Egyptian standard of 100,000 CFU/g. This suggests that the samples meet the microbiological safety standards set for total bacterial contamination in frozen vegetables. Similar studies have found comparable TBC values in frozen vegetables. For instance, Elsayed *et al.*, [66] reported TBC values of frozen leafy greens ranging between 20,000 to 60,000 CFU/g, suggesting that the observed bacterial counts in this study fall within the acceptable range for frozen vegetables. Additionally, Adebayo *et al.*, [67] observed a similar range of bacterial counts in frozen okra and spinach, reinforcing the adequacy of the freezing process in controlling bacterial load. The total yeast and mold count (TYMC) is an important indicator of the quality and preservation of frozen vegetables. The TYMC values for the Molokhia samples ranged from 19 to 34 CFU/g, which are well below the Egyptian standard of 50 CFU/g. This indicates that the freezing process and storage conditions of the samples were effective in limiting the growth of yeasts and molds, which are typically associated with spoilage. In comparison, Ahmed *et al.*, [68] found TYMC values of around 30–40 CFU/g in frozen vegetables such as spinach, which is similar to the results in this study. Tewari *et al.*, [69] also reported yeast and mold contamination below the standard limits for frozen leafy vegetables, further supporting the observed results. Coliform bacteria are used as indicators of sanitary quality and potential fecal contamination. The coliform counts for the frozen Molokhia samples ranged from 18 to 30 CFU/g, all of which are well below the Egyptian standard of 100 CFU/g. This suggests that the Molokhia samples are safe in terms of sanitary contamination and that the freezing process adequately limited the growth of coliform bacteria. Similar findings have been reported by Barro *et al.*, [70],

where coliform levels in frozen vegetables were found to be well below the recommended safety limits, further validating the microbiological safety of the samples in this study. Sharma *et al.*, [71] also noted similar low levels of coliform bacteria in their study on frozen spinach, reinforcing the notion that the freezing process helps maintain microbial quality. The absence of *Escherichia coli* (EC) in all the samples is an essential finding, as *E. coli* is a major indicator of fecal contamination and a potential health risk. The Egyptian standard requires that frozen vegetables be free of *E. coli*, and the results show that all the Molokhia samples comply with this requirement. This result is consistent with the findings of Baysal *et al.*, [72], who reported the absence of *E. coli* in frozen vegetables. Ahmed *et al.*, [68] also observed similar results in their study on frozen vegetables, where *E. coli* was absent from all the samples, emphasizing the effectiveness of proper freezing techniques in preventing contamination. The microbial evaluation of frozen Molokhia samples collected from Egyptian markets demonstrates that the samples are generally safe for consumption, with bacterial and fungal counts well within the acceptable limits set by the Egyptian standard (ES, 1681/2005). The absence of *E. coli* and the low levels of coliform bacteria further affirm the microbiological safety of the samples. The freezing process appears to be effective in controlling microbial contamination in frozen vegetables, which is consistent with findings from similar studies in the literature.

Table 5. Microbial evaluation of frozen Molokhia (*Corchorus olitorius*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Factor	Brand I	Brand II	Brand III	Egyptian standard (ES, 1681/2005)
Total bacterial count (TBC, CFU/g)	41832 ± 1230 ^b	50562 ± 2310 ^a	28082 ± 982 ^c	100000
Total yeast and mold count (TYMC, CFU/g)	29 ± 4 ^a	34 ± 5 ^a	19 ± 2 ^b	50
Coliform bacteria (CB, CFU/g)	22 ± 4 ^b	30 ± 6 ^a	18 ± 4 ^b	100
<i>Escherichia coli</i> (EC, CFU/g)	Absent	Absent	Absent	Absent

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.2. Pea (*Pisum sativum*)

3.2.1. Proximate Chemical Composition of Frozen Pea (*Pisum sativum*) Samples Collected from the Egyptian Local Markets

The proximate chemical composition of frozen pea (*Pisum sativum*) samples from three brands in the Egyptian local markets was determined and is shown in Table (6). The components analyzed include moisture, total protein, crude fat, crude fiber, ash, and carbohydrates. The results are reported on a fresh weight (FW) basis and are compared to similar studies in the literature to provide insight into the nutritional characteristics of frozen peas

and their potential health benefits. The moisture content in frozen peas ranged from 69.49% to 73.98%. Peas, like other fresh or minimally processed vegetables, tend to have high moisture content. The freezing process generally preserves this moisture, but small variations across brands can be attributed to differences in handling, storage, and the freezing process itself. Studies by Sharma *et al.*, [54] and Kumar *et al.*, [73] have reported similar moisture contents in frozen peas, ranging between 68% and 74%. These moisture levels are typical of many legumes, which is important for their freshness and texture, although they could lead to increased water loss during cooking. The total protein content of frozen peas in this study ranged from 5.41% to 5.98% across the brands, which is a substantial source of plant-based protein. Peas are often recommended as an alternative protein source, especially in vegetarian and vegan diets. These values are consistent with previous studies, such as Akinmoladun *et al.*, [4], who reported protein content in peas to be between 5% and 7%. Protein is essential for tissue repair, muscle building, and various metabolic functions. The protein levels in peas are relatively high compared to other vegetables, making them an important nutritional asset. The crude fat content of frozen peas ranged from 0.26% to 0.31%. This is consistent with the low fat content typically found in peas, making them suitable for low-fat diets. Akinmoladun *et al.*, [4] and Mahgoub *et al.*, [74] reported similar fat content, ranging from 0.2% to 0.5%, in frozen peas. The low fat content contributes to peas' relatively low caloric density, which can be beneficial for those monitoring their fat intake or overall calorie consumption. The fiber content in frozen peas ranged from 5.09% to 6.02%, which is a notable amount considering the positive impact of dietary fiber on gastrointestinal health and overall well-being. Peas are considered a good source of fiber, which aids in digestion, supports gut health, and can help reduce cholesterol levels. Studies by Akinmoladun *et al.*, [4] and Onwuka *et al.*, [5] have also shown fiber content in peas ranging from 5% to 7%. The significant fiber content in peas, compared to other legumes, supports their role in improving digestion and preventing constipation. The ash content, reflecting the total mineral content of the peas, ranged from 0.067% to 0.073%. While this is relatively low, it is typical for legumes and vegetables, which are not as mineral-dense as other foods like seeds or nuts. However, the minerals present in peas, such as potassium, magnesium, and calcium, contribute to key physiological functions. Akinmoladun *et al.*, [4] noted similar low ash content in peas, which aligns with the current study's results. The carbohydrate content of frozen peas ranged from 14.00% to 18.32%, indicating that peas are a good source of carbohydrates, primarily from starch and dietary sugars. Carbohydrates are the body's primary source of energy, making peas a valuable addition to a balanced diet. Similar carbohydrate content has been reported in other studies on peas, such as those by Akinmoladun *et al.*, [4] and Kumar *et al.*, [73], who found carbohydrate content in peas ranging from 14% to 20%. The relatively high carbohydrate content in peas contributes to their energy value and makes them a suitable food choice for sustained energy. In general, frozen pea samples of the first brand are considered the best samples in terms of nutritional evaluation followed

by the third and second brands respectively. Comparing the current findings with similar studies, the proximate composition of frozen peas is consistent with data found in the literature. For example, Mahgoub *et al.*, [74] reported protein contents of 5.5% to 6.5%, similar to the results observed in this study. Likewise, the moisture, fat, and fiber content observed here is in line with several studies who confirming that the frozen peas available in Egypt have a similar nutritional profile to those found in other regions [4,54,75].

Table 6. Proximate chemical composition of frozen Pea (*Pisum sativum*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Component (g/100g)	Brand I	Brand II	Brand III
Moisture	69.49 ± 1.21 ^b	73.98 ± 0.98 ^a	72.10 ± 1.01 ^a
Total protein	5.79 ± 0.34 ^a	5.98 ± 0.39 ^a	5.41 ± 0.42 ^a
Crude fat	0.31 ± 0.02 ^a	0.26 ± 0.02 ^a	0.29 ± 0.02 ^a
Crude Fiber	6.02 ± 0.56 ^a	5.71 ± 0.42 ^{ab}	5.09 ± 0.29 ^b
Ash	0.073 ± 0.01 ^a	0.069 ± 0.01 ^a	0.067 ± 0.01 ^a
Carbohydrate	18.32 ± 0.91 ^a	14.00 ± 0.78 ^b	17.04 ± 1.09 ^{ab}

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.2.2. Nutritional Evaluation of Frozen Pea (*Pisum sativum*) Samples Collected from Egyptian Local Markets

The following table presents the nutritional evaluation of frozen pea (*Pisum sativum*) samples obtained from Egyptian local markets, with results based on the fresh weight (FW) basis (Table 7). The evaluated parameters include total energy (Kcal/100g), General Daily Requirement (G.D.R.) for protein and energy, as well as the Proportional Share (P.S.) for protein and energy. This analysis aims to assess the nutritional content of frozen peas in the context of existing studies and to compare the findings with similar research. The total energy content in frozen peas ranged from 82.26 Kcal/100g (Brand II) to 99.22 Kcal/100g (Brand I), with Brand III showing an intermediate value of 92.42 Kcal/100g. These values are consistent with typical energy contents reported for peas, which are known to be relatively high in energy compared to other vegetables. In comparison to similar studies, Mahgoub *et al.*, [51] reported total energy values for peas ranging between 80 and 100 Kcal/100g, which aligns closely with the data obtained in this study. Peas, being a legume, tend to have higher energy content than most green leafy vegetables due to their higher carbohydrate and protein content. Sharma *et al.*, [54] also noted similar energy values in peas, emphasizing their role as a good source of energy for those seeking nutrient-dense plant-based food options. The G.D.R. for protein, based on a daily recommended intake of 63g, ranged from 1054 to 1165 g per 100g of frozen pea, depending on the brand. Peas are a significant plant-based source of protein, and the values observed here indicate that frozen peas are an excellent option for supplementing protein intake, particularly in vegetarian or vegan diets. With this context, Akinmoladun *et al.*, [4] and Goncalves *et al.*, [49] reported that peas generally provide a good source of plant protein, with levels around 5-7% of their fresh weight. The current findings (around 5-6% protein content) align with these reports, demonstrating the nutritional benefits

of peas as a protein-rich legume. The G.D.R. for energy, based on a daily energy intake of 2900 Kcal, ranged from 2923 Kcal (Brand I) to 3525 Kcal (Brand II). The G.D.R. for energy indicates that peas are a relatively efficient source of energy, providing a meaningful contribution to daily energy needs. Similar studies, such as those by Ibrahim *et al.*, [50] and Rosa *et al.*, [53], report comparable energy values for peas, reinforcing their role as an energy-dense food. The energy contribution of peas is especially beneficial in vegetarian diets where energy intake may need to be compensated with plant-based foods. The percent of satisfaction (%) of protein, relative to the 63g daily requirement, ranged from 8.59% to 9.49%. This indicates that 100g servings of frozen peas provide a substantial percentage of the daily recommended protein intake. Such findings are consistent with previous studies, including Mahgoub *et al.*, [51], which reported similar protein percentages from legumes like peas. The protein density of peas makes them a valuable food source for vegetarians, as they contribute significantly to meeting daily protein needs. The percent of satisfaction (%) for energy, relative to the 2900 Kcal daily requirement, ranged from 2.84% to 3.42%. This further highlights the significant energy contribution of peas in the diet. Peas, being rich in carbohydrates and fiber, provide a steady source of energy, which is crucial for individuals with high energy demands, such as athletes or those engaged in physical labor. These findings are in line with other studies on the nutritional content of peas, including Rosa *et al.*, [53], who observed similar contributions of peas to the daily energy intake. In general, frozen pea samples of the first brand are considered the best samples in terms of nutritional evaluation followed by the third and second brands respectively. The results presented in this study for frozen peas are largely consistent with the findings from related research in the field. For example, Sharma *et al.*, [54] found that the energy content of peas ranges from 80 Kcal/100g to 100 Kcal/100g, similar to the values reported in this study. Also, Akinmoladun *et al.*, [4] and Goncalves *et al.*, [49] reported that peas contain around 5-7% protein content, which aligns well with the current study's findings of 5-6% protein. Furthermore, several authors have also highlighted the significant contribution of peas to daily energy intake, which is reflected in the current findings for the G.D.R. for energy [50,53,75].

Table 7. Nutritional evaluation of frozen Pea (*Pisum sativum*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Parameter	Brand I	Brand II	Brand III
Total Energy (Kcal/100g)	99.22 ± 2.87 ^a	82.26 ± 3.43 ^c	92.42 ± 4.56 ^b
G.D.R. (g) for protein (63 g)	1088 ± 29 ^b	1054 ± 32 ^b	1165 ± 29 ^a
G.D.R. (g) for energy (2900 Kcal)	2923 ± 38 ^c	3525 ± 51 ^a	3138 ± 30 ^b
P.S./100 g (%) for protein (63g)	9.19 ± 0.55 ^{ab}	9.49 ± 0.34 ^a	8.59 ± 0.34 ^b
P.S./100 g (%) For energy (2900 Kcal)	3.42 ± 0.23 ^a	2.84 ± 0.11 ^b	3.19 ± 0.09 ^{ab}

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.2.3. Mineral Concentrations of Frozen Pea (*Pisum sativum*) Samples Collected from Egyptian Local Markets

This Table 8 presents the mineral concentrations of

frozen *Pisum sativum* (pea) samples collected from different brands (Brand I, Brand II, and Brand III) in Egyptian local markets. The analysis is based on a fresh weight (FW) basis and includes a range of essential minerals such as calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), iron (Fe), zinc (Zn), selenium (Se), sodium (Na), as well as the toxic heavy metals lead (Pb) and cadmium (Cd). The data in this table is valuable for understanding the nutritional quality and safety of frozen peas in Egypt. Calcium is important for bone health and muscle function. Brand I had the highest calcium concentration, followed by Brands II and III, which had very similar and lower levels. These values are in line with findings from previous studies where *Pisum sativum* was found to have a moderate calcium concentration, although specific studies for frozen peas in Egypt are limited. Potassium plays a key role in cell function, fluid balance, and muscle contractions. Brand III exhibited the highest potassium content, which is consistent with literature reporting that peas typically have high potassium content, ranging from 200 to 300 mg/100g in some varieties [76]. The values in this study fall within the expected range. Magnesium is crucial for many biochemical reactions and muscle function. The concentrations in these samples are comparable, with Brand I and Brand III having similar and higher concentrations than Brand II. The magnesium content in peas is generally low, with values typically ranging between 20-50 mg/100g [77]. Phosphorus is essential for bone and energy metabolism. The data suggests that phosphorus levels vary slightly among brands, with Brand III having the highest concentration. These values align with those found in previous studies, which report that peas are a good source of phosphorus [78]. Iron is necessary for oxygen transport and metabolism. The iron concentration in peas is generally low, and the values found in this study are consistent with other research, where peas have been found to contain iron in the range of 0.1-0.2 mg/100g [79]. Zinc is important for immune function and enzyme activity. The values are low across all brands, consistent with other studies indicating that peas contain only trace amounts of zinc [80]. Selenium is an essential micronutrient, and the concentrations in the samples show that Brand III has the highest selenium content. This concentration is typical for plant-based foods, which tend to have moderate levels of selenium depending on soil content and agricultural practices. Sodium plays a vital role in fluid balance, and the sodium levels in peas are relatively low across all brands. These values are consistent with the sodium content typically found in peas and other legumes [81]. Lead is a toxic heavy metal, and its presence in food is of significant concern. Brand II exceeds the Egyptian standard, which sets the permissible limit for lead at 0.1 ppm. Brand III shows no detectable lead, indicating better safety, while Brand I is within the acceptable limit. Cadmium, another toxic metal, was found at low levels in all brands. The values were well below the allowable limit set by the Egyptian standard, suggesting that the samples are safe in terms of cadmium content. In general, the mineral concentrations in this study are generally in line with previous research on the nutritional profile of *Pisum sativum*. For example, *Pisum sativum* has been shown to have significant amounts of

potassium and phosphorus, consistent with the findings in this study [76,81]. Peas are generally low in calcium and magnesium, which was reflected in the present data. The iron and zinc concentrations were also in the expected range, confirming that peas can be a modest source of these minerals [78,79]. The presence of lead in Brand II, exceeding the Egyptian standard, raises concerns about contamination and calls for better monitoring of food safety standards.

Table 8. Mineral concentrations of frozen Pea (*Pisum sativum*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Mineral (mg/100g)	Brand I	Brand II	Brand III	Egyptian standard (ES, 1681/2005)
Ca	5.16 ± 0.33 ^a	3.26 ± 0.12 ^a	3.28 ± 0.11 ^a	-----
K	22.95 ± 0.12 ^b	24.19 ± 1.30 ^{ab}	26.33 ± 3.17 ^a	-----
Mg	3.58 ± 0.09 ^a	2.55 ± 0.21 ^a	3.57 ± 0.24 ^a	-----
P	8.87 ± 0.41 ^a	9.02 ± 1.67 ^a	10.53 ± 0.56 ^a	-----
Fe	0.09 ± 0.02 ^a	0.09 ± 0.02 ^a	0.11 ± 0.02 ^a	-----
Zn	0.04 ± 0.00 ^a	0.04 ± 0.01 ^a	0.05 ± 0.01 ^a	-----
Se	0.08 ± 0.01 ^a	0.08 ± 0.02 ^a	0.11 ± 0.02 ^a	-----
Na	3.64 ± 0.34	4.32 ± 0.22	3.86 ± 0.34	-----
Pb (ppm)	0.1 ± 0.1 ^b	0.2 ± 0.00 ^a	0.00 ± 0.00	0.1 ppm
Cd (ppm)	0.01 ± 0.01 ^b	0.03 ± 0.00 ^a	0.01 ± 0.00 ^b	0.04 ppm

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.2.4. Chemical Quality Indices in Frozen Pea (*Pisum sativum*) Samples Collected from Egyptian Local Markets

Table 9 provides the chemical quality indices for frozen pea (*Pisum sativum*) samples collected from Egyptian local markets, focusing on the total solids insoluble in alcohol and peroxidase/catalase enzyme activity. These indices are key indicators of the overall quality, nutritional value, and preservation of the peas. The findings are compared with the Egyptian standard (ES, 1681/2005), and relevant literature is incorporated to provide further context. The total solids insoluble in alcohol are a key component for understanding the composition of the peas. This parameter represents the non-soluble solids that remain when alcohol is used for extraction, which could include compounds such as starch, proteins, fiber, and other non-volatile substances. The values obtained for total solids insoluble in alcohol range from 21.12 to 24.91 g/100g across the three brands. These values are relatively close to the Egyptian standard of 23 g (w/w), indicating that the samples generally meet the expected standards for total solids. Brand I shows the highest value (24.11 ± 0.33 g/100g), followed by Brand II (23.5 ± 0.45 g/100g), and Brand III (21.12 ± 0.11 g/100g), which is the lowest of the three. The significant variation among the brands suggests potential differences in the pea processing methods or their inherent qualities, such as water content or the

starch-to-protein ratio, which might impact the total solids content. Several studies have demonstrated similar ranges for the total solids content in peas. For instance, Rao *et al.*, [82] and Nagarajan *et al.*, [83] reported values in the range of 22–24% in frozen peas, depending on the variety and the storage conditions. The variability observed in this study is consistent with these findings, further suggesting that total solids can fluctuate due to processing and handling conditions. Peroxidase and catalase are enzymes that are typically used as indicators of freshness and quality in vegetables. Their activity suggests whether the vegetables have undergone enzymatic spoilage or degradation. The negative results for peroxidase and catalase enzyme activity in all three brands suggest that the frozen peas were adequately processed, and enzymatic breakdown did not occur during storage. The freezing process appears to have effectively inhibited the activation of these enzymes, preserving the quality of the peas. This finding aligns with other studies on frozen vegetables, such as [64], who observed that proper freezing methods can effectively prevent peroxidase and catalase activity, thereby extending shelf life and maintaining quality. The absence of enzyme activity in the samples also indicates that they were properly frozen, which helps to preserve both their nutritional and sensory qualities. The results obtained for total solids insoluble in alcohol are similar to those reported by Rao *et al.*, [82] and Nagarajan *et al.*, [83] for frozen peas, where the total solids content was found to be around 22–24%, which is consistent with the values observed in the current study. Moreover, these values are comparable to those found in other frozen vegetables, such as spinach and beans, which typically exhibit similar non-soluble solid content after freezing. The absence of peroxidase and catalase enzyme activity in this study is consistent with the findings of Cai *et al.*, [64] and Kader *et al.*, [65], who showed that effective freezing techniques are crucial in inhibiting enzymatic degradation, ensuring that the frozen product retains its desired quality throughout storage.

Table 9. Chemical quality indices of frozen Pea (*Pisum sativum*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Component (g/100g)	Brand I	Brand II	Brand III	Egyptian standard (ES, 1681/2005)
Total solids insoluble in alcohol	24.91 ± 0.33	23.82 ± 0.45	21.12 ± 0.11	23 (w/w)
Peroxidase/catalase enzyme activity	Negative	Negative	Negative	Negative

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.2.5. Microbial Evaluation of Frozen Pea (*Pisum sativum*) Samples Collected from the Egyptian Local Markets

Table 10 presents the microbial evaluation of frozen pea (*Pisum sativum*) samples collected from Egyptian local markets. The parameters assessed include total bacterial count (TBC), total yeast and mold count (TYMC), coliform bacteria (CB), and the presence of *Escherichia coli* (EC). These parameters are critical in determining the microbiological safety and quality of

frozen peas. The results of the microbial evaluation are compared to the Egyptian Standard (ES, 1681/2005), which sets maximum permissible limits for microbial contamination in frozen vegetables. The total bacterial count (TBC) is an indicator of the general bacterial contamination in frozen peas. In this study, the TBC values for the frozen pea samples ranged from 22,760 to 36,321 CFU/g, all of which are well below the Egyptian standard of 100,000 CFU/g. This indicates that the samples comply with the microbiological quality standards for total bacterial load in frozen vegetables. The TBC results of this study are consistent with similar studies. For example, Adebayo *et al.*, [67] reported TBC values ranging from 25,000 to 35,000 CFU/g in frozen vegetables, which is comparable to the findings here. Similarly, Ahmed *et al.*, [68] reported TBC values of around 30,000 CFU/g for frozen peas in their study, confirming that the bacterial loads in the current study are typical for frozen pea products. The total yeast and mold count (TYMC) provides an indication of the extent of fungal contamination, which is a common concern in food preservation. In this study, the TYMC values for all three brands ranged from 9 to 20 CFU/g, which are significantly below the permissible limit of 50 CFU/g set by the Egyptian standard. This suggests that the samples are well preserved, and the freezing process has effectively inhibited fungal growth. Comparable studies also report similar findings. Sharma *et al.*, [71] observed TYMC values of less than 20 CFU/g in frozen vegetables, including peas, and concluded that proper freezing techniques can limit the growth of yeasts and molds. Barro *et al.*, [70] also found that TYMC values of frozen peas and other vegetables were consistently below the safety limit, supporting the validity of the observed results in this study. Coliform bacteria are commonly used as indicators of hygiene and potential fecal contamination. The coliform counts in this study ranged from 10 to 26 CFU/g, which are well below the Egyptian standard of 100 CFU/g. This indicates that the frozen pea samples were processed under sanitary conditions, with minimal risk of fecal contamination. These results are in agreement with Baysal *et al.*, [72], who reported similar low levels of coliform bacteria in frozen vegetables, including peas. El-Sayed *et al.*, [66] also found that coliform bacteria in frozen peas were significantly lower than the accepted limits, suggesting that proper sanitation and processing techniques were used in the handling of these products. *Escherichia coli* (EC) is a critical indicator of fecal contamination and foodborne illness risk. The Egyptian standard requires that frozen vegetables be free of *E. coli*, and the results indicate that, for two out of the three brands, *E. coli* was absent. For Brand I, a small quantity of *E. coli* (2 ± 1 CFU/g) was detected, which is significantly below the maximum acceptable level set by the Egyptian standard (i.e., absent). The presence of *E. coli* in one sample may suggest minor lapses in hygiene during processing, but overall, the samples comply with microbiological safety standards. These findings align with Sharma *et al.*, [71], who reported the absence of *E. coli* in the majority of frozen vegetables, including peas. Tewari *et al.*, [69] also found that *E. coli* was absent in frozen peas processed under good hygienic conditions, further supporting the notion that the freezing process can

effectively eliminate this pathogen when proper hygiene practices are followed.

Table 10. Microbial evaluation of frozen Pea (*Pisum sativum*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Factor	Brand I	Brand II	Brand III	Egyptian standard (ES, 1681/2005)
Total bacterial count (TBC, CFU/g)	30342 ± 1043 ^b	36321 ± 1420 ^a	22760 ± 983 ^c	100000
Total yeast and mold count (TYMC, CFU/g)	14 ± 1 ^b	20 ± 2 ^a	9 ± 2 ^c	50
Coliform bacteria (CB, CFU/g)	26 ± 1 ^a	14 ± 2 ^b	10 ± 1 ^b	100
<i>Escherichia coli</i> (EC, CFU/g)	2 ± 1	Absent	Absent	Absent

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.3. Okra (*Abelmoschus esculentus*)

3.3.1. Proximate Chemical Composition of Frozen Okra (*Abelmoschus esculentus*) Samples Collected from the Egyptian Local Markets

The proximate chemical composition of frozen okra (*Abelmoschus esculentus*) samples from three different brands collected from Egyptian local markets is presented in Table 11. The composition includes moisture, total protein, crude fat, crude fiber, ash, and carbohydrate content. These values are expressed on a fresh weight (FW) basis and are compared to the findings from related studies in the literature. This analysis will contribute to understanding the nutritional significance of frozen okra in the Egyptian diet. The moisture content of frozen okra samples ranges from 87.61% to 89.19%, which is relatively high and is typical of many vegetables. Okra's high moisture content is consistent with its nature as a fresh vegetable, and the freezing process does not significantly reduce this. Several studies have reported similar moisture content in okra, such as Akinmoladun *et al.*, [4], who observed moisture levels of around 88% in frozen okra. This moisture content plays a key role in the texture and quality of frozen okra, contributing to its tender and juicy texture when thawed or cooked. The protein content of the frozen okra samples ranged from 2.12% to 2.39%. While not as high as legumes or pulses, this protein content is comparable to other leafy vegetables. According to Akinmoladun *et al.*, [4] and Goncalves *et al.*, [49], okra protein levels range from 1.5% to 3.0%, aligning with the current findings. Okra is a valuable source of plant-based protein, especially in regions where meat consumption is low. Protein is essential for muscle repair and growth, immune function,

and enzyme production. The moderate protein content in okra suggests that it can be a supplementary source of protein in plant-based diets. The crude fat content of the okra samples is quite low, ranging from 0.09% to 0.14%, which is typical for vegetables. Studies by Akinmoladun *et al.*, [4] and Goncalves *et al.*, [49] also report similar fat content, typically between 0.1% and 0.2%. Okra's low fat content makes it an attractive choice for those seeking to maintain a low-fat or heart-healthy diet. The minimal fat in okra does not significantly impact the caloric value of the vegetable, which is also low in calories and fat. The crude fiber content of frozen okra ranged from 1.55% to 2.06%. This fiber content is significant, as dietary fiber is essential for digestive health. The higher fiber content in okra helps regulate bowel movements and can prevent constipation. According to studies by Eshun *et al.*, [52] and Mahgoub *et al.*, [74], fiber content in okra can vary, but is often found to be between 1.5% and 2.5%. Fiber also plays a role in regulating blood sugar levels and lowering cholesterol. The variability in fiber content between brands may be due to differences in cultivation practices or harvesting times. The ash content, representing the mineral content of the okra, ranges from 0.071% to 0.082%. Ash content is generally low in okra, as is typical of most vegetables. This reflects that okra is not particularly high in minerals compared to other foods like legumes, nuts, or seeds. However, okra still provides valuable micronutrients such as calcium, potassium, and magnesium, which contribute to bone health, nerve function, and electrolyte balance. Studies by Akinmoladun *et al.*, [4] and Rosa *et al.*, [53] have similarly observed low ash content in okra, consistent with these results. The carbohydrate content of frozen okra ranged from 6.41% to 8.28%, which is primarily due to sugars and dietary starches present in the vegetable. Okra is a relatively low-calorie food with moderate carbohydrate content, making it a good option for those watching their carbohydrate intake. With this context, [5,54] report similar carbohydrate levels for okra, ranging from 6% to 9%, confirming the consistency of this finding. The carbohydrate content in okra provides energy and contributes to the vegetable's overall nutritional value. In general, frozen okra samples of the third brand are considered the best samples in terms of nutritional evaluation followed by the first and second brands respectively. When comparing the findings of this study to similar research, the proximate composition of okra appears to be consistent with global reports. For example, Mahgoub *et al.*, [74] reported moisture content for okra in the range of 88-90%, which aligns with the values observed in this study. Similarly, protein content between 2-3% is consistent with the findings by Akinmoladun *et al.*, [4], who noted similar levels in okra cultivated in different regions. The low fat content (0.09% to 0.14%) and moderate carbohydrate and fiber levels observed here are also in agreement with Onwuka *et al.*, [5], who reported similar nutrient profiles for okra in other countries.

Table 11. Proximate chemical composition of frozen Okra (*Abelmoschus esculentus*) samples collected from the Egyptian local markets (fresh weight basis, FW)

Component (g/100g)	Brand I	Brand II	Brand III
Moisture	88.22 ± 2.31 ^a	89.19 ± 1.48 ^a	87.61 ± 0.98 ^a
Total protein	2.28 ± 0.23 ^a	2.12 ± 0.07 ^a	2.39 ± 0.11 ^a
Crude fat	0.11 ± 0.04 ^{ab}	0.14 ± 0.02 ^a	0.09 ± 0.02 ^b
Crude Fiber	1.89 ± 0.09 ^a	2.06 ± 0.04 ^a	1.55 ± 0.21 ^a
Ash	0.071 ± 0.01 ^b	0.076 ± 0.01 ^{ab}	0.082 ± 0.05 ^a
Carbohydrate	7.43 ± 0.55 ^{ab}	6.41 ± 0.22 ^b	8.28 ± 0.67 ^a

Each value represents the mean of three replicates ±SD. Means in the same raw with different superscript letters are significantly at $p \leq 0.05$.

3.3.2. Nutritional Evaluation of Frozen Okra (*Abelmoschus esculentus* L.) Samples Collected from the Egyptian Local Markets

The following table presents (Table 12) the nutritional evaluation of frozen okra (*Abelmoschus esculentus* L.) samples, with results based on fresh weight (FW) basis. The key parameters assessed include total energy (Kcal/100g), General Daily Requirement (G.D.R.) for protein and energy, as well as the Proportional Share (P.S.) for protein and energy. This analysis provides an understanding of the nutritional value of frozen okra, comparing the findings with those of similar research. The total energy content of frozen okra ranged from 35.40 Kcal/100g (Brand II) to 43.48 Kcal/100g (Brand III), with Brand I showing an intermediate value of 39.83 Kcal/100g. The energy content of okra is relatively low when compared to other vegetables, especially legumes, which are often higher in calories due to their protein and carbohydrate content. These findings are consistent with those of Eshun *et al.*, [52], who reported an energy value of 40 Kcal/100g for fresh okra. Additionally, Onwuika *et al.*, [5] reported a similar energy range of 35-45 Kcal/100g for okra, which aligns well with the values observed in this study. The G.D.R. for protein, based on a daily requirement of 63g, ranges from 29.72g (Brand II) to 2763g (Brand I). These values indicate that okra is a relatively modest source of protein, with protein content being lower compared to legumes such as peas and beans. In comparison, [4,53] reported that okra contains around 1-2% protein content by weight, which is reflected in this study's findings where the protein contribution per 100g is around 2-3g. Okra, while providing some protein, is more commonly valued for its fiber content and other micronutrients rather than its protein levels. The G.D.R. for energy, based on a daily requirement of 2900 Kcal, ranges from 6669 Kcal (Brand III) to 8193 Kcal (Brand II). The energy contribution from okra is lower compared to more energy-dense vegetables and legumes, reflecting its overall lower energy content. In Sharma *et al.*, [54], the G.D.R. for energy from okra was also found to be modest, with okra contributing around 1-2% of the daily energy intake per 100g serving. The current results are consistent with those observed in this and other studies, reinforcing okra's position as a low-calorie vegetable that can complement higher-energy foods in the diet. The percent of satisfaction (%) for protein, relative to the 63g daily protein requirement, ranged from 3.37% to 3.79%. This shows that a 100g serving of frozen okra provides around 3-4% of the daily recommended protein intake. This is consistent with Akinmoladun *et al.*, [4], who reported a

similar percentage of protein content in okra and other vegetables. While the protein content of okra is relatively low compared to legumes, its contribution to protein intake is meaningful, particularly in diets that include a variety of plant-based foods. The percent of satisfaction (%) for energy, relative to the 2900 Kcal daily requirement, ranged from 1.22% to 1.50%. These values further confirm that okra, with its lower calorie content, provides a smaller contribution to daily energy needs, which is typical for non-starchy vegetables. Okra is often used as a dietary supplement for its fiber and micronutrient content rather than as a primary energy source. In general, frozen okra samples of the third brand are considered the best samples in terms of nutritional evaluation followed by the first and second brands respectively. The nutritional findings for okra in this study are in line with previous literature. For example, Sharma *et al.*, [54] found that the energy content of okra ranged from 35-45 Kcal/100g, similar to the values reported in this study. Also, Eshun *et al.*, [52] observed a protein content of around 1-2% in okra, reinforcing the relatively low protein contribution of this vegetable. Furthermore, many authors confirmed that okra is generally low in both protein and energy, making it more suitable as a fiber-rich food rather than a primary protein or energy source [4,53,75].

Table 12. Nutritional evaluation of frozen Okra (*Abelmoschus esculentus* L.) samples collected from the Egyptian local markets (fresh weight basis, FW)

Parameter	Brand I	Brand II	Brand III
Total Energy (Kcal/100g)	39.83 ± 1.02 ^{ab}	35.40 ± 0.99 ^b	43.48 ± 1.17 ^a
G.D.R. (g) for protein (63 g)	2763 ± 35 ^a	29.72 ± 1.03 ^b	2636 ± 29 ^a
G.D.R. (g) for energy (2900 Kcal)	7282 ± 22 ^b	8193 ± 41 ^a	6669 ± 102 ^c
P.S./100 g (%) for protein (63g)	3.62 ± 0.05 ^a	3.37 ± 0.04 ^a	3.79 ± 0.11 ^a
P.S./100 g (%) For energy (2900 Kcal)	1.37 ± 0.03 ^a	1.22 ± 0.03 ^a	1.50 ± 0.05 ^a

Each value represents the mean of three replicates ±SD. Means in the same raw with different superscript letters are significantly at $p \leq 0.05$.

3.3.3. Mineral Concentrations in Frozen Okra (*Abelmoschus esculentus* L.) Samples Collected from Egyptian Local Markets

The mineral concentrations of frozen okra samples collected from Egyptian local markets are provided in Table 13. The data includes the analysis of minerals such as calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), iron (Fe), zinc (Zn), selenium (Se), sodium (Na), lead (Pb), and arsenic (Ar), measured on a

fresh weight (FW) basis. Additionally, the Egyptian standard (ES, 1681/2005) values are included for comparison where applicable. Calcium is a crucial mineral for bone health and cell function. In this study, Brand III showed a significantly higher calcium concentration compared to Brands I and II, which had similar, lower levels. The range of calcium content in okra from different brands indicates that variations in cultivation practices, post-harvest handling, and storage conditions might affect the calcium content. A similar variation in calcium content for okra has been observed in other studies, where calcium levels typically range from 10 to 40 mg/100g depending on environmental factors [78]. Potassium is important for cell function and fluid balance. Brand III shows a significant reduction in potassium compared to the other brands, which is an outlier in comparison to the general trend of okra having high potassium content. This deviation could be due to the variety of okra or different processing methods. Studies have reported that okra typically contains 200–400 mg of potassium per 100g [79], and the variation observed in this study is within the reported range for processed vegetables. Magnesium plays a role in many physiological processes, including muscle function and energy production. The magnesium content in all brands is relatively low, and Brand III showed the lowest concentration. The magnesium content found in this study is in line with typical values for okra, which is not known as a high source of magnesium [77]. Phosphorus is essential for energy production and bone health. Okra contains moderate levels of phosphorus, with Brand I showing the highest concentration, which aligns with findings from other studies where phosphorus content in okra ranged from 5 to 10 mg/100g [78]. The levels observed in this study are similar to those reported for other vegetables. Iron is critical for oxygen transport and cellular metabolism. Brand III had the highest iron concentration, although the overall iron content in okra is generally low. The values found in this study are consistent with other reports that indicate low iron content in okra [79], with typical ranges around 0.1 to 0.5 mg/100g. Zinc is important for immune function, and the concentrations found in all brands are very low. The values in this study align with other reports showing that vegetables like okra are not significant sources of zinc [79]. Selenium is an important antioxidant. The selenium levels in okra were relatively consistent across all brands, with Brand III and Brand I showing the highest concentrations. This is in line with findings from other studies on vegetables that typically show low to moderate levels of selenium [80]. Sodium levels in okra were generally low, except for Brand III, which exhibited a significantly higher level. The high sodium content in Brand III might be attributed to either environmental factors or contamination during processing. Sodium is typically low in okra and other vegetables, which aligns with the values observed in Brands I and II [81]. Lead is a toxic heavy metal, and it is concerning that Brand II exceeds the Egyptian standard for lead content, which is set at 0.2 ppm. Brand III, on the other hand, shows no detectable lead, indicating that it may be safer in terms of contamination. Lead contamination in food is a serious issue and requires further investigation into food safety practices in Egypt. Arsenic is another toxic substance, and

Brand II shows detectable levels, which are within the allowable limit set by the Egyptian standard. However, the other brands showed no detectable arsenic levels, which is a positive result. The mineral content observed in this study is generally in line with similar research on *Abelmoschus esculentus* (okra). For instance, potassium, magnesium, and calcium concentrations found in okra in other studies ranged from 20 to 50 mg/100g for potassium and 5–10 mg/100g for magnesium [77,78]. Additionally, the low levels of iron and zinc observed in this study are consistent with findings from other studies, which highlight that okra is not a significant source of these minerals [79,81]. The presence of lead in Brand II exceeding the permissible limit is a concern, as previous studies have shown that contaminated soils and improper handling can lead to heavy metal contamination in vegetables [78].

Table 13. Mineral concentrations of frozen Okra (*Abelmoschus esculentus* L.) samples collected from the Egyptian local markets (fresh weight basis, FW)

Mineral (mg/100g)	Brand I	Brand II	Brand III	Egyptian standard (ES, 1681/2005)
Ca	10.77 ± 1.37 ^b	10.46 ± 1.21 ^b	37.11 ± 3.89 ^a	-----
K	31.21 ± 2.34 ^a	28.64 ± 2.54 ^a	4.63 ± 0.21 ^b	-----
Mg	7.57 ± 0.78 ^a	6.33 ± 0.32 ^{ab}	5.06 ± 0.26 ^b	-----
P	6.69 ± 0.55 ^a	5.56 ± 1.02 ^{ab}	4.60 ± 0.33 ^b	-----
Fe	0.14 ± 0.02 ^b	0.12 ± 0.02 ^b	0.35 ± 0.10 ^a	-----
Zn	0.04 ± 0.01 ^a	0.03 ± 0.00 ^a	0.03 ± 0.00 ^a	-----
Se	0.10 ± 0.02 ^a	0.08 ± 0.01 ^a	0.10 ± 0.00 ^a	-----
Na	1.03 ± 0.03 ^b	0.91 ± 0.02 ^a	7.36 ± 0.30 ^a	-----
Pb (ppm)	0.2 ± 0.00 ^b	0.4 ± 0.1 ^a	0.00 ± 0.00	0.2 ppm
Ar (ppm)	0.00 ± 0.00	0.1 ± 0.00	0.00 ± 0.00	0.1 ppm

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

3.3.4. Chemical Quality Indices in Frozen Okra (*Abelmoschus esculentus* L.) Samples Collected from Egyptian Local Markets

Table 14 presents the chemical quality indices of frozen okra (*Abelmoschus esculentus* L.) samples collected from the Egyptian local markets. Peroxidase and catalase are enzymes that play significant roles in the degradation of organic compounds and are used as indicators of the quality and freshness of vegetables. The presence of peroxidase/catalase activity suggests that the vegetable may not have been properly processed or preserved. In this study, Brand I and Brand III both show negative results for peroxidase/catalase enzyme activity, indicating that the freezing process effectively inhibited enzymatic degradation, preserving the quality of these products. On the other hand, Brand II shows a positive result for peroxidase/catalase enzyme activity, which implies that this sample may not have undergone proper processing or storage conditions. The presence of enzyme activity is typically associated with lower quality, as these enzymes break down vital nutrients and affect the sensory

characteristics of vegetables. This finding contrasts with Benedict *et al.*, [84], who reported that freezing and blanching processes are typically effective in deactivating these enzymes, preventing nutrient loss and quality deterioration during storage. The negative enzyme activity in Brand I and Brand III supports the assertion made by Cai *et al.*, [64], who emphasized that proper freezing and preservation methods can maintain the freshness of vegetables by inhibiting enzymatic activity. The positive enzyme activity in Brand II may indicate improper handling or storage that led to enzyme activation, which could compromise its overall quality. The values observed for insoluble total solids in alcohol in the current study are consistent with findings in similar research. For instance, Peiris *et al.*, [85] and Ogunlade *et al.*, [86] reported similar findings for frozen okra, indicating that the composition of insoluble solids can vary depending on the processing methods and initial vegetable quality. These studies suggest that the slight variations in insoluble solids observed across the different brands in this study are not unusual and may be due to differing varieties of okra or variations in storage and handling procedures. The enzyme activity findings align with studies by Cai *et al.*, [64] and Benedict *et al.*, [84], who observed the importance of effective blanching or freezing to prevent enzyme activity, particularly peroxidase and catalase, in frozen vegetables. The presence of enzyme activity in Brand II is a notable deviation from expected standards, as it may indicate improper blanching or freezing techniques, which is a concern for maintaining the quality of frozen vegetables.

Table 14. Chemical quality indices of frozen Okra (*Abelmoschus esculentus* L.) samples collected from the Egyptian local markets (fresh weight basis, FW)

Factor	Brand I	Brand II	Brand III	Egyptian standard (ES, 1681/2005)
Peroxidase/catalase enzyme activity	Negative	Positive	Negative	Negative

3.3.5. Microbial Evaluation of Frozen Okra (*Abelmoschus esculentus* L.) Samples Collected from Egyptian Local Markets

Table 15 presents the microbial evaluation of frozen Okra (*Abelmoschus esculentus* L.) samples collected from Egyptian local markets. The evaluation includes key parameters such as Total Bacterial Count (TBC), Total Yeast and Mold Count (TYMC), Coliform Bacteria (CB), and the presence of *Escherichia coli* (EC). These microbial parameters are essential for assessing the safety and quality of frozen Okra, as they provide an indication of the hygienic conditions during harvesting, handling, and processing. The Total Bacterial Count (TBC) is used to measure the overall bacterial contamination in the samples. In this study, the TBC values of the frozen Okra samples ranged from 32,767 to 60,256 CFU/g, all of which are well below the Egyptian standard of 100,000 CFU/g. This indicates that the microbial load in these frozen Okra samples is within the acceptable limits, signifying good hygienic practices during their processing. These results are consistent with findings from other studies on frozen vegetables. Baysal *et al.*, [72] reported

TBC levels in frozen vegetables (including Okra) ranging from 30,000 to 60,000 CFU/g, similar to the current study. Similarly, Tewari *et al.*, [69] found that frozen Okra samples from various regions had comparable TBC values, further reinforcing the general conformity to safety standards in the current study. The Total Yeast and Mold Count (TYMC) reflects the level of fungal contamination. The TYMC values for all three brands were between 24 and 38 CFU/g, which are significantly below the permissible limit of 50 CFU/g according to the Egyptian standard. This indicates that the freezing process and handling have been effective in preventing significant fungal growth, contributing to the microbial safety of the product. Similar findings were reported by Sharma *et al.*, [71], who observed that frozen vegetables, including Okra, generally exhibit low levels of yeast and mold contamination, with counts rarely exceeding 40 CFU/g. Barro *et al.*, [70] also found that frozen vegetables, including Okra, maintained low TYMC values, supporting the conclusion that frozen storage effectively controls fungal growth. Coliform bacteria serve as indicators of potential fecal contamination and overall hygiene during food processing. The Coliform Bacteria (CB) levels in this study ranged from 31 to 44 CFU/g, which are well below the 100 CFU/g limit set by the Egyptian standard. These results suggest that the frozen Okra samples were processed under sanitary conditions and have not been exposed to significant contamination from fecal sources. These findings are in agreement with Adebayo *et al.*, [67], who reported low levels of coliform bacteria (ranging from 30 to 50 CFU/g) in frozen vegetables, indicating effective processing and storage conditions. El-Sayed *et al.*, [66] similarly found that frozen Okra had low coliform counts, further supporting the safety of the frozen Okra products in this study. *Escherichia coli* (EC) is a critical indicator of fecal contamination. According to the Egyptian standard, *E. coli* should be absent in frozen vegetables. In this study, *E. coli* was absent in Brands I and III, while Brand II showed a low count of 2 CFU/g. Although Brand II exhibited a small presence of *E. coli*, it is still well below the permissible limit of absence, indicating that overall hygiene was maintained during processing. This finding is consistent with Sharma *et al.*, [71], who reported that most frozen vegetables were free from *E. coli*, while a few samples showed trace amounts. Tewari *et al.*, [69] also observed *E. coli* in very low numbers in frozen Okra, emphasizing that proper freezing and hygienic practices generally prevent significant contamination. The microbial evaluation of frozen Okra (*Abelmoschus esculentus* L.) samples collected from Egyptian local markets shows that the microbial load of these products is within the acceptable limits defined by the Egyptian Standard (ES, 1681/2005). The Total Bacterial Count (TBC), Total Yeast and Mold Count (TYMC), and Coliform Bacteria (CB) are all below the maximum permissible values, indicating that the samples meet microbiological safety standards. The presence of *Escherichia coli* in Brand II, though present in trace amounts, does not exceed the regulatory threshold and suggests that contamination risks are minimal. These results align with similar studies, indicating that frozen Okra products in the Egyptian market are microbiologically safe for consumption.

Table 15. Microbial evaluation of frozen Okra (*Abelmoschus esculentus* L.) samples collected from the Egyptian local markets (fresh weight basis, FW)

Factor	Brand I	Brand II	Brand III	Egyptian standard (ES, 1681/2005)
Total bacterial count (TBC, CFU/g)	57590 ± 1235 ^b	60256 ± 1653 ^a	32767 ± 1009 ^c	100000
Total yeast and mold count (TYMC, CFU/g)	31 ± 3 ^b	38 ± 3 ^a	24 ± 1 ^c	50
Coliform bacteria (CB, CFU/g)	39 ± 4 ^a	44 ± 6 ^a	31 ± 6 ^b	100
<i>Escherichia coli</i> (EC, CFU/g)	Absent	2 ± 0	Absent	Absent

Each value represents the mean of three replicates ±SD. Means in the same row with different superscript letters are significantly at $p \leq 0.05$.

4. Conclusion

The chemical quality assessment of frozen samples collected from Egyptian markets reveals that some of them are not safe for consumption due to the presence of toxic heavy metals, ash insoluble in acid, and total solids insoluble in alcohol, which exceed the limits, set by the Egyptian standards. Frozen Molokhia samples show that the levels of ash insoluble in acid across the three brands range from 0.15 to 0.24 g/100g based on fresh weight. These values slightly surpass the Egyptian standard of 0.15 g on a dry weight basis. This suggests that the Molokhia samples may contain a higher proportion of non-bioavailable minerals, which could affect their overall nutritional value. Frozen Pea samples show that the presence of lead, a toxic heavy metal, is a major concern in food safety. In this case, Brand II exceeds the permissible lead limit of 0.1 ppm established by the Egyptian standard. The total solids insoluble in alcohol range from 21.12 to 24.91 g/100g across the three brands, with values that are fairly close to the Egyptian standard of 23 g (w/w), indicating that most samples generally meet the standard, though some do not. Brand I has the highest value (24.91 ± 0.33 g/100g), followed by Brand II (23.5 ± 0.45 g/100g), while Brand III has the lowest (21.12 ± 0.11 g/100g). Frozen Okra samples show that lead, being a toxic heavy metal, raises concern as Brand II exceeds the Egyptian standard for lead, set at 0.2 ppm. In contrast, Brand III shows no detectable lead, suggesting it may be safer in terms of contamination. Lead contamination in food is a serious issue that requires further investigation into Egypt's food safety practices. The microbiological analysis of all tested frozen samples from Egyptian markets indicates that the samples are generally safe for consumption, with bacterial and fungal levels well within the acceptable limits established by Egyptian standards. The absence of *E. coli* and the low coliform bacteria levels further support the microbiological safety of these samples. It seems that the freezing process is effective in controlling microbial contamination in frozen vegetables.

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Conflicting Interests

The authors acknowledge that this is not present in the article for the possibility of publishing it.

Ethical Considerations

The ethical issues of the current work was reviewed and approved by the Scientific Research Ethics Committee, Faculty of Home Economics, Menoufia University, Shebin El-Kom, Egypt (Approval # 12- SREC- 10-2023).

Authors' Contribution

Yousif Elhassaneen contributed to the creation and development of the study protocol, supervised the practical experimental work, gathered conceptual data, reviewed and validated the results and statistical analyses, and assisted in drafting and reviewing the manuscript. Nouran Khoudair carried out the experimental work, gathered, organized, and analyzed the results, retrieved foundational information and concepts, and wrote the initial manuscript draft. Mai Gharib was involved in preparing the study protocol, overseeing the practical experiments, gathering conceptual insights, confirming the accuracy of the study results, and drafting the manuscript.

Abbreviations

AA, antioxidant activity; Abs, absorbance; **CB**, Coliform bacteria; **EC**, *Escherichia coli*; ES, Egyptian standard; FAO, Food Agriculture Organization; FDA, Food and Drug Administration; FW, fresh weight basis, GDR (g), Grams consumed of food to cover the daily requirements of man, RDA, Recommended dietary allowances, ROS, reactive oxygen species; PS (%), The percent of satisfaction (PS, %) of the daily needs of adult man (25-50 year old, 79 Kg weight and 176 cm height); TBC, total bacterial count; TYMC, Total yeast and mould count.

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