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Physicochemical and Sensory Characteristics of a New Milk Substitute from Dry White Kidney Bean

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Abstract In the last few years, there has been a proliferation of non-dairy milk substitutes derived from various plant-based milk. This study focused on the production of a newly developed plant-based milk alternative from white kidney bean *seeds (Phaseolus vulgaris L.*) and analyzed their physicochemical and sensory characteristics, using commercial soymilk as a comparison control. The nutrient composition of the raw material used in the production of the proposed plant-based milk worked out. Protein, ash, fat, carbohydrate, moisture, and total solids contents were 23.61%, 4.57%, 1.23%, 47.8%, 9.2%, and 90.78%, respectively. The developed milk-based product derived from white kidney beans and the soymilk used as a control contained 12.19-8.06% total solids, 3.71-3.05% protein, 0.79-1.69% fat, 6.41-2.51% carbohydrate 1.19-0.5% ash, 0.8-0.54% fiber, and 87.78-92% for moisture, respectively, and 6.64-6.87 and 2.19-2.34% for pH and acidity (as a citric acid), respectively for white kidney bean and soymilk. The total energy was 47.4 kcal, and it was significantly higher ($p<0.05$) in nutritional value as compared to the soymilk used as a control, which was 39.22 kcal. In the sensory evaluation, the white kidney bean milk was slightly less acceptable than the commercial soymilk in terms of overall acceptability. These results give us a nutritious and low-fat milk alternative and give consumers more choices. It is expected that improvement in the production steps and the addition of flavor enhancers could increase the acceptance of white kidney bean milk by the consumer.

Keywords Plant-Based Milk Alternatives, White Kidney Bean Milk, Soymilk, Proximate Analysis, Sensory Evaluation

1. Introduction

In recent years, there has been a significant rise in the consumption of non-dairy plant-based beverages, commonly known as "vegetable milks". The increasing popularity of plant-based milk can be attributed to various factors such as the growing prevalence of dietary lifestyles such as veganism and vegetarianism [1], owing to vegans and vegetarians often associated with a resolute political position against modern agricultural methods and the mistreatment of animals [2]. Also, concerns related to health such as lactose intolerance, and the elevated risk of hypercholesterolemia[3]. Furthermore, the production of plant-based milk exhibits a reduced carbon footprint in comparison to that of cow's milk, which promotes the achievement of both food security goals and environmental objectives [4].

According to the Food Institute [5], sales of non-dairy milk products increased by 6% in 2022 and reached a value of 19.1 billion $ per Euromonitor. This consumption of milk substitutes will only grow further in the future according to the forecasts of Statista Research Department [6].

Although Plant-based substitute consumption is growing due to the inclusion of bioactive components that possess health-promoting characteristics, the alternatives still face significant challenges to their market position when compared to cow's milk caused by the diminished nutritional composition and sensory palatability of plant-based beverages, including factors such as flavor, taste, and solubility. Nevertheless, innovative food processing technologies are used to improve and solve these issues by tackling physicochemical and nutritional properties as well as shelf life and sensory evaluation [7].

The process of manufacturing plant-based milk alternatives entails the dispersion of plant matter, resulting in the formation of dispersed particles of varying compositions and sizes. The physical properties of the particles and the durability of the final product are dependent upon the characteristics of the source material, the method of disintegration employed, and the conditions of storage [8]. These substitutes are derived from legumes (such as soybeans), cereals (such as rice and oats), or nuts (such as almonds and hazelnuts) which are completely free of animal-derived components. Out of these sources, legumes are the second-largest food crop worldwide in terms of production and consumption. Legumes are an important source of dietary protein in various regions of the world and are considered an essential part of the Mediterranean diet; these foods are an economically feasible and highly nutritious source of protein, complex carbohydrates, and dietary fiber while being low in fat. Furthermore, they have additional health benefits related to their micronutrient content, which includes minerals and vitamins in addition to bioactive components such as oligosaccharides, saponins, lectins, and phenolic compounds [9].

Phaseolus vulgaris L., commonly referred to as common beans, includes various species, such as the white kidney beans that fall under the category of legumes. This particular species is believed to have originated in South American nations such as Mexico and Argentina. In 2012, the global production of this commodity amounted to approximately 23 million tons. According to He et al. [10], Legumes are consumed by more than 500 million people and South America represents the primary consuming region [11]. Furthermore, the seeds are considered a valuable food source due to their high protein content, which ranges from 22% to 27% of their weight, as well as their significant carbohydrate content. Accordingly, because of the scarcity of studies on it as an alternative beverage, we have studied to provide a novel plant-based milk alternative derived from dry white kidney beans for the enhancement of consumer options and for future research activities that may be conducted to generate high-quality plant-based milk replacements. Additionally, consumer nutrition may be improved by studying this novel product, and the sensory assessment test helps us evaluate consumer acceptance of new products using soymilk as a benchmark.

2. Material and Methods

2.1. Sample Collection

White kidney beans (*Phaseolus vulgaris L.)* were purchased from the local market in Amman, Jordan in the form of a 25 kg bag originating from Egypt from a supplier that had been certified to the ISO 9001 the international standards of quality management system.

2.2. Proximate Analysis

The analysis of moisture, protein, fat, ash, and crude fiber was conducted using the Official Methods 925.09, 979.09, 920.39, 923.03, and 962.09, respectively, described by the [12]. The estimation of total carbohydrates was achieved through a calculation by subtracting the cumulative value of the principal components from a constant value of one hundred. To minimize errors, the experiments were conducted in triplicate.

2.3. Sample Preparation

First, we spread the beans on an area above the table to remove impurities and broken grains, and take half a kg initially, then we divide the quantity and take 100 g to grind it with a mill until it almost becomes a powder. Then we store it in the box for the proximate analysis. Furthermore, we take 400 g of the quantity to soak it for the production of milk substitute.

2.4. Procedure of Preparation of White Kidney Bean Milk

To produce white bean milk, the steps shown in Figure 1 were followed; these are based on the Illinois process for soymilk production [13]. First, the beans were purified and sorted for impurities, then 150 g were taken and soaked in 450 ml boiled water for overnight soaking, after which, the water was discarded, and new boiled water (90 ℃) was added to the beans for blanching for around 20 minutes. This was followed by grinding the beans and then putting the slurry in the steam-jacketed vessel. Furthermore, the blanched beans were weighed to estimate the water uptake and the amount of water to be added to the blender to obtain the desired level of TSS, as well as the beans put in the blender with the estimated tap water for the homogenization. Then blend the mixture well until it reaches the desired consistency. Then the pH of the milk was adjusted with 0.1N HCL to the desired level. Finally, the bean milk produced was put in bottles and heated to 83 ℃ for 5 minutes, then cooled and stored in refrigeration <5 ℃.

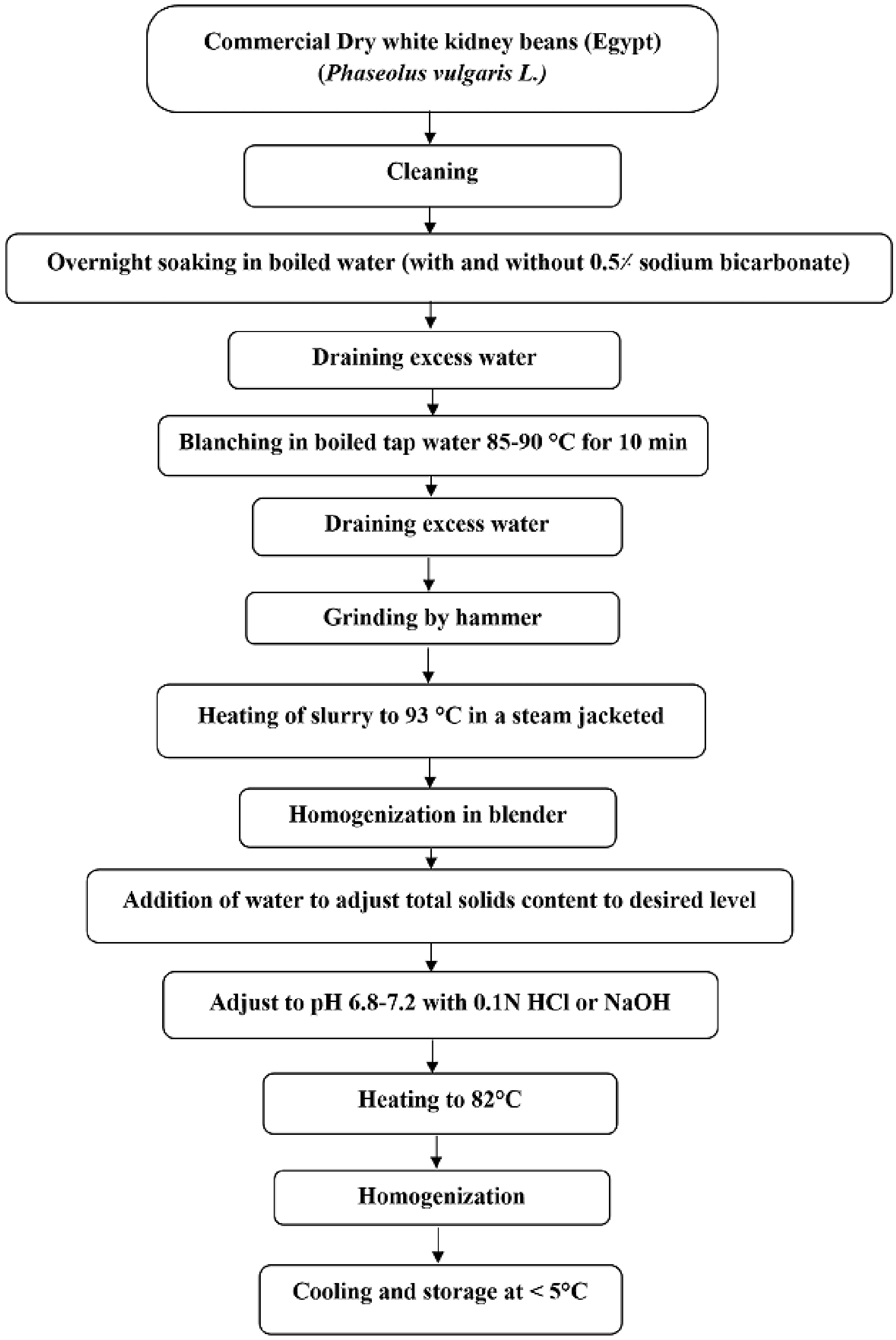


Figure 1. Steps of the production of plant milk from dry white kidney bean[13]

2.5. Determination of pH

pH was measured using the GOnDO PP-203 portable pH meter made in Taiwan. The electrode was dipped in the sample to a sufficient depth that it should not touch the bottom of the beaker. The readings were recorded and displayed constantly.

2.6. Determination of Titratable Acidity%

A 10 mL sample of white bean milk was subjected to a titration process using sodium hydroxide, with phenolphthalein serving as the indicator. The sample was collected inside a conical flask containing 10 milliliters of distilled water and 3-4 drops of a 1% phenolphthalein indicator solution. The solution underwent titration with a 0.1 N NaOH solution until a noticeable change in color to pink was seen. Subsequently, the measurement obtained from the burette was duly documented [14].

$$\text{Acidity\%}= \frac{N \times Vn \times 64{,}4 \times 100}{Vs} \quad (1)$$

Vn= volume of 0.1N NaOH, N= concentration of NaOH, 64,4=equivalent weight of citric acid, and Vs= volume of sample.

2.7. Total Soluble Solids (TSS)

The amount of total soluble solids (TSS) in the milk produced from white kidney beans was measured using a handheld refractometer (RHB-32) with a range of 0-32 °Brix [15]. The refractometer reading was calibrated to zero using a tiny revolving calibration screw. A small quantity of white bean milk was spread over the sensor to conduct a measurement, and the resulting refractometer reading was appropriately recorded.

2.8. Energy Determination

The calculation of the overall energy content of the food samples was performed by applying a conversion factor specific to each energy-yielding substrate present in the samples. According to the [1], the energy (kcal)= 4 × (carbohydrate(g) + protein (g)) + 9 × (fat (g)).

2.9. Sensory Evaluation

The sensory quality of the newly developed products was evaluated by 41 panelists selected from a lab at the University of Jordan. The two samples were in bottles, which were assigned a 3-digit random code presented in the session, which have been carefully pre-disinfected and covered to ensure the safety of the products and to avoid any contamination. The panelists (students from the Department of Nutrition, Food Science and Technology, University of Jordan) were handed the food sample as well as a bottle of water so that they could cleanse their mouths between each tasting. Samples were served in plastic cups at refrigerator temperature (4 °C). Furthermore, the panelists were asked to evaluate the acceptance of the product and evaluated five attributes: overall like, appearance, viscosity, flavor, smell, and color of each sample on a 9-point hedonic scale (1 = extremely dislike, 5 = neither like nor dislike and 9 = extremely like. The sensory analysis was performed at the dairy and cheese factory in the department.

2.10. Statistical Analysis of the Experiment

The software JMP was utilized for the objective of carrying out data analysis. The analysis of variance (ANOVA) T-test was performed to compare the results of our produced samples with the control, and the least significant difference (LSD) test was undertaken at a = 0.05 to assess if there is a significant difference between the samples, to obtain the mean and standard deviations (SD).

3. Results and Discussions

3.1. Proximate Chemical Composition Analysis

The figures below show the results of the proximate analysis of raw and milk substitutes from dry white kidney beans.

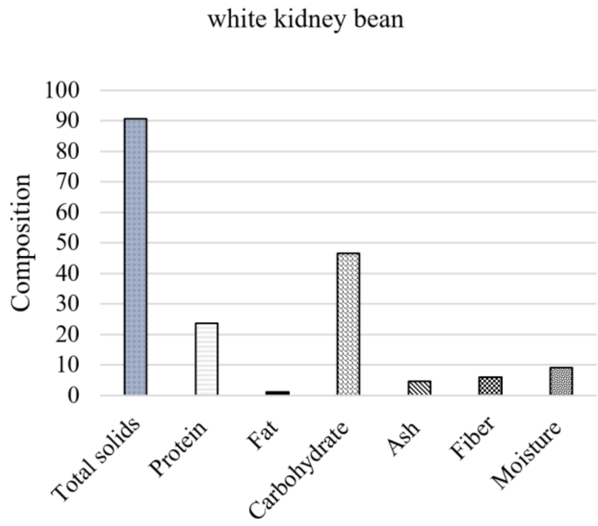
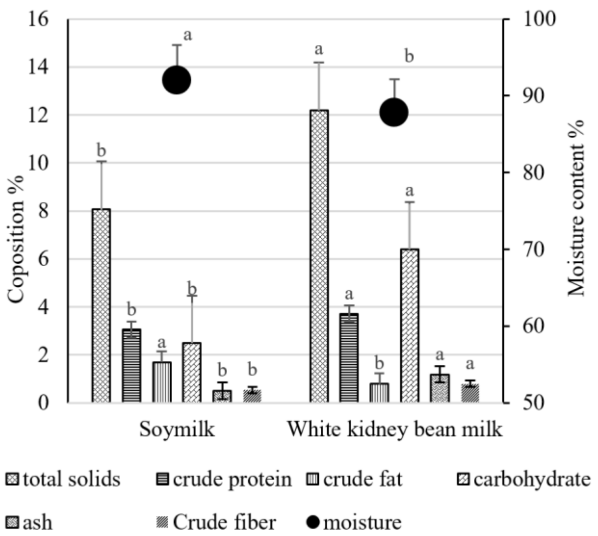


Figure 2. Proximate analysis of white kidney beans used for the production of the plant milk

The protein content of white kidney beans in our experiment was observed to be 23.61%. These results agree with those found by Vargas et al. [16] in their work; the protein content of the dried white kidney beans was found to fall within the previously reported range of 18.9–24.2%, which includes several common bean varieties. In addition, the ash and total solids content in our kidney beans were determined to be 4.57% and 90.78%, respectively. This ratio is almost equal to the range provided in the study by Wang et al. [17] in which the ash content varied from 32.4 to 44.0 % and 93.4 % for total solids slightly higher than our experiment. Another study by Kouakou et al. [18] found the total solids of white bean seeds *(Phaseolus vulgaris L)* produced in Côte d'Ivoire 90.59%, which agrees with our results of 90.78%. Furthermore, the carbohydrate content was 46.51%, which results slightly less than the previous study demonstrated by Rehman et al. [19] which found the total carbohydrate of white kidney beans 47.8%. In addition, this result agrees with the majority of the literature on the subject that white kidney beans composition is mostly carbohydrates.

The results of the moisture content of this study 9.2%, can be considered nearly similar to that obtained by Marilyn-Josephine et al. [20] which ranged between 7.93 and 9.74 % in six samples. For the fat content, the study of Shimelis et al., [21] indicated a range of fat and fiber content from varieties of dry beans between 1.2–2.4 and 4.6–5.7 g/100g, respectively. The results found in our experiment showed 1.23% for fat, and as such, we agree with their results. On the other hand, our results on fiber content were measured to be 5.98%, and as such, our results show a slightly higher presence of crude fiber in our beans compared to the previous study.



Levels not connected by the same letter are significantly different ($p \leq 0.05$) ±SD

Figure 3. Proximate analysis of white kidney bean milk and soymilk as a control

Until now, there have been no global standards or Codex Alimentarius commission for all the plant-based milk alternatives that regulate the percentage of the nutrients in each alternative except for a few beverages like an aqueous coconut product [22-23]. However, there is no determination of the percentage of nutritional value or the percentage of moisture. However, there are many published studies dealing with the physicochemical and rheological properties of milk alternatives. Reyes-Jurado et al. [24] summarized much of the research on the physicochemical properties of selected plant-based milk alternatives (soy, peanut, rice, almond, cashew, chickpea, lentil, hazelnut, tiger nut, and colocynth seed alternatives). A significant difference in ash and total solids content ($p \leq 0.05$) was noticed between our product and commercial soymilk used as a control. The result of the study was 12.20% for total solids and 1.20% for ash. The results agree with the experiment aforementioned, concerning the total solids and ash ranging between 4.80- 27.96% and 0.16- 3.02%, respectively. Also, that difference may be due to the amount of water added to the beans. the water absorbed during the soaking process, and the method of preparation.

Furthermore, there was a significant difference in the percentage of carbohydrates ($p \leq 0.05$) in the white kidney bean milk and the control soymilk. It was 6.41% and 2.51%, also higher than the study of Kundu et al., [25] which reported 4.92% in soy milk with 10% total solids. That difference was because the white kidney bean has a greater amount of carbohydrates than soybean, according to Rebello CJ et al. [26]. Furthermore, the result was less than a brown rice milk alternative according to Latifa et al. [27], and Belewu et al. [28] in the case of white rice, which reported a range of 38.21% to 40.211% with the treatment of alginate of 0.05–0.1–0.2% and 57.30%, respectively.

Another study by Lu et al[29] found the carbohydrate of coconut milk was 6.6% and that result was higher than our result 6.41%. Moreover, in a study of the nutritional and sensory properties of cashew seed *(Anacardium occidentale)* milk Manzoor et al. [30]. Carbohydrate content was 4.38%, which was less than our results. As for the fat content, there was a significant difference in the fat content ($p \leq 0.05$) between the sample and the soymilk as a control. The white kidney bean has a low amount of fat, as we discussed before in the proximate analysis of raw white kidney beans. Consequently, the fat result in our milk alternative was 0.79%, which is less than the soymilk as a control and those reported by Kundu P et al. [25], 8.25% for almond milk, and 2.35% for soymilk, and more than the result reported by El Tahir., [31] which was 0.88%. We also agreed with the results of another study by Belewu et al. [28] on rice milk, which reported 0.79%.

Figure 3 shows the results of protein analysis, a significant difference between our product and the control ($p \leq 0.05$). The protein content in our white kidney bean milk was 3.77% and 3.05% for the soymilk, which is higher than that reported by El Tahir [31], which was 1.87% and Kundu et al., [25] which was 3.24%, and less than that reported by Belewu et al., [28]. which was 15.55%.

Dietary fiber is an indigestible constituent derived from plants that do not undergo digestion in the human small intestine. There exist two distinct categories of fibers, namely soluble fibers such as pectin and gums, and insoluble fibers such as cellulose, hemicellulose, and lignin. Soluble fiber is beneficial for regulating weight and reducing cholesterol levels, particularly for individuals with diabetes and heart disease. On the other hand, insoluble fiber has been observed to aid in digestion [32]. There was noticeably a significant difference in fiber content between our product and soymilk used as control, 0.8% and 0.55% respectively. This was generally consistent with that found by Manzoor et al. [30] who reported 1.15% fiber content in cashew milk. Additionally, the findings agree with those reported by Bernat et al., [33] and Kundu et al., [25] in which the fiber content ranged between 0.58 and 1.25%. Furthermore, the findings were higher than those obtained by Bernat et al., [33] and Gul et al., [34]. who reported that the fiber content was 0.4% in the hazelnut milk substitute.

3.2. Titratable Acidity and pH

A significant difference was noticed in the pH of the white kidney bean milk and the control. It was 6.65±0.013 and the titratable acidity was 2.18±0.1 mg/for our milk alternative and 6.87±0.13 and 2.34±0.1mg/g for the control. This agrees with the results reported by Liu et al. [35]. pH of 37 soybean samples ranged between 6.55 and 6.72, and the titratable acidity ranged between 1.42 and 2.38 mg/g.

3.3. Energy Determination

The energy content of the samples was significantly different between the samples by 39.2 and 47.4 Kcal for the soymilk used as a control and white kidney bean milk substitutes respectively. These could be due to the differences between the fat, carbohydrate, and protein content of the product. According to Akinyel and Abudu [36], the energy content of milk substitutes from four cultivars of cowpeas *(Vigna unguiculata)* ranged between 17.9 and 42.4 Kcal, which almost agrees with our results. In another study by Chalupa-Krebzdak et al. [37], the value of energy content of the coconut-based milk substitute varied between 50 and 92 kcal, while the soy-based milk substitutes ranged from 33 to 58 kcal. In general, the observed alternatives to dairy milk derived from plant sources exhibited a variation in caloric content, spanning from 12 to 92 kcal, which agrees with our results.

3.4. Sensory Evaluation

Figure 4 shows the spider plot of the viscosity, appearance, taste, and overall acceptability testing of white kidney bean milk. The most notable distinctions were noticed in the taste and viscosity characteristics, where the scores of soy milk were higher than those of white kidney bean milk. This distinction could be due to differences in total solids (8% in soymilk and 12.2% in white kidney bean milk), the manufacturing method and equipment used in thermal processing as well as non-thermal processing (such as ultra-high-pressure homogenization, pulsed electric field, and ultra-sonication), which contributes positively to the viscosity and taste. Furthermore, the impact of soluble fibers found in plants on the texture of milk substitutes can be observed, as they may impart a gritty and fluffy consistency due to the existence of insoluble particles [8].

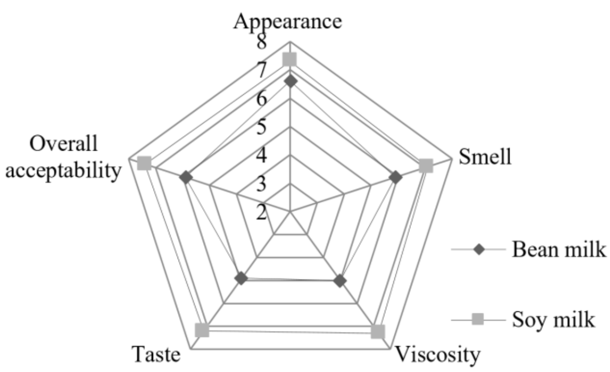


Figure 4. Spider plots of sensory evaluation of white kidney bean milk as compared with soymilk, representing means for n = 41, where score 1 refers to dislike extremely and 9 to like extremely in the nine-point hedonic scale

Zhang et al., [38] reported that high-pressure treatment can increase the viscosity of soy milk. Furthermore, the relatively low score of taste could be attributed to the grainy feeling of the white kidney bean milk and its very low-fat content. On the other hand, the use of salt, gam, and natural soy flavor as enhancers in the commercial soymilk used as control could result in higher scores. In general, consumers tend to evaluate the taste of plant-based milk alternatives in comparison to that of bovine milk and often perceive them to possess unfavorable attributes. Legume-based milk substitutes may face consumer rejection due to their characteristic beany and earthy aroma, which is attributed to the presence of hexanol resulting from plant lipid oxidation. Additionally, consumers may not be accustomed to the taste of these alternatives. The decreased acceptability of soy and peanut milk alternatives was due to their beany taste and flavor, which resulted in scores of "slightly/moderately liked." Conversely, attributes such as appearance, and texture, may receive high scores. Abou-Dobara [39] also found in the study that the appearance of the samples was moderate as compared to other attributes. Additionally, there was a slight difference in the overall acceptability between the samples (like slightly) for the white bean milk and (like moderately) for the soymilk used as a control. This was due to the panelist's knowledge of the marketed soymilk used as a control from its attributes. In a study by Kundu et al. [25], a sensory evaluation was performed on almond milk as a dairy alternative. The researchers found that the high-fat content of the drink contributed to its favorable mouthfeel, and it received a positive overall acceptance score. Furthermore, the researchers assessed combinations of almond milk substitute and soymilk in varying proportions of 50:50, 40:60, and 60:40. Notably, the third mixture received the highest rating, which can be attributed to the inclusion of almonds in its composition. The blend exhibited noteworthy enhancements in its color, taste, and mouthfeel. It was also noted by the researchers that the overall appeal of the non-dairy milk substitute was comparable to that of bovine milk. It is worth mentioning that the white kidney bean milk substitute with its relatively high content of good quality protein, carbohydrates, and available energy has an obvious nutritional advantage.

4. Conclusions

The article focuses mainly on the physicochemical and sensory properties, about the nutritional characteristics, of a newly plant-based milk alternative produced from white kidney beans. So, it could be concluded from the findings white kidney milk alternative was more in carbohydrates and slightly low in protein and low in fat but due to the difference between the solid matter and the water added during the preparation process of the substitutes, the total energy of the produced kidney bean milk was slightly higher than the soymilk. Furthermore, the sensory characteristics of the product that were slightly lower in overall acceptability and the ranking test after the sensory evaluation than that of the soymilk could be improved by adding flavor enhancers, such as honey and fruit concentrates.

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