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Nutritional Valorization and Food Applications of Moringa oleifera Seeds: A Review of Processing Techniques, Functional Properties, and Health Implications

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Abstract

This paper evaluates the different processing techniques and applications of Moringa oleifera in the context of human nutrition. These seeds are particularly high in proteins (on average, 19%) and lipids (31%), and are therefore a valuable source of nutrition. In addition to their nutrition value, seeds and their oil have attracted interest in the food industry. For instance, the frying stability of Moringa oil has been proved to be higher than groundnut oil, and this when blended at relatively lower proportions used in snack products improved the taste and palatability. The seeds have been subjected to various processing techniques, including roasting, germination and boiling, for development of flours with good nutrient profiles. The defatted flours have been used in the formulation of different food products, such as cakes, cookies, burgers and infant porridge. Low incorporation amounts are generally well known, however, higher incorporation amounts can impart bitterness. Sold as superfood, yet defatted MSF and MO have not yet been appropriately used. This update underlines the significance of present treatment and describes the food uses of these constituents; also tapping into their potential to deliver nutritional requirements.

Keywords: Moringa oleifera, Defatted seed flour, Functional food ingredients, Thermal and biological processing, Nutritional enhancement, Food product fortification

1. Introduction

The species Moringa oleifera is the most popular and has 13 species within the Moringaceae family. Referred to by numerous names such as drumstick tree or horseradish tree, it is native to the Himalayan foothills which stretch from northwestern Pakistan, across northern India. It has spread over time to a wide range of tropical and subtropical areas as it can grow in diverse climatic conditions and on poor soils [1]. The tree may grow to as high as 15 meters; the seedpods are adapted for wind spread [1].

Traditionally and historically, M. oleifera was cultivated for its highly nutritious leaves, which have been used to alleviate hunger and malnutrition [2, 3]. These leaves are also known to have anti-hypercholesterolemic and antihypertensive properties [4], [5]. Nonetheless, its seeds have exhibited potential biological activities, such as antimicrobial, antitumor, anti-inflammatory, effects [6,7]. The majority of seed-based researches for this plant had been devoted for water treatment and oil recovery. Cooking oil was found to be stable and may also be used for different food-processing applications 8. However, studies on the nutritional and functional properties of defatted Moringa powder are scant. Although preliminary results indicate the potential of Moringa protein as protein supplement [10].

This work presents a concise review on the processing and utilization of M. oleifera seed for applications in food systems with emphasis on the defatted seed flour and oil. This sets the current work apart from previous reviews, which were largely focused on the bioactive compounds or the nutritional profiles of the seed without consideration of culinary use [11].

2. Nutritive Value of Moringa Seeds

Seeds of the moringa oleifera contain not only macronutrients proteins, fats, carbohydrates, but also micronutrients - vitamins, minerals. They are rich in vitamins A and B1, and also contain several bioactive agents, which includes flavonoids, saponins, sterols, phytates, and trypsin inhibitors. Seeds are rich (13-46%) in fat and due to higher fat content of seeds these were considered as oilseed in several studies. This abundant composition value highlighs their suitability as fats and protein, and also dietary fiber and bioactive compounds sources [12, 13].

2.1 Proteins

The proteins in Moringa seeds are the second most abundant macronutrient of Moringa seed, after lipids. The content varies from 18.6 to 37.2% in whole seeds. Defatted seed flour can have protein content from 32% up to 62.8% 14[16] after oil extraction. Nonetheless, although protein level is high the AA profile is not sufficient for all human essential AAs. Although it supplies amino acids such as histidine, threonine, tyrosine, leucine, isoleucine and phenylalanine, there ist a lack of methionine, lysine, valine, and tryptophan that are considered as the limiting amino acids [16].

The overall amino acid contents have been reported to increase in processing treatments such as germination and fermentation. Adding cereals such as rice, pearl millet, sweet corn and sorghum, the amino acid balance of Moringa seed flour is however improved. This alternative method could lead to more nutritionally rich proteins [16].

2.2 Carbohydrates

The carbohydrate content of the seeds varies greatly, from approximately 9.17% to 53.36%, depending on the variety and processing [12, 17]. Most part of carbohydrate profile is contributed by dietary fibers, which corresponds to around 24% in whole seeds and 3% in decorticated seeds [16]. The seeds are poor in simple sugars such as glucose, fructose, and sucrose, which make them suitable for diabetes patients. For instance, Moringa seeds contain far less glucose and fructose than the sweet pulp of Adansonia digitata or Parkia biglobosa [12, 13].

2.3 Vitamins and Minerals

Vitamins The seeds of M. oleifera are rich sources of provitamin A (β-carotene) and vitamin B1 (thiamine). These vitamins are important for vision, antioxidant defense, and metabolic regulation [18]. Moreover, the α-, γ-, and o-tocopherol forms of vitamin E has been detected in Moringa seed oil.

Mineral contentThe seeds are particularly high in calcium, potassium, phosphate, sodium, magnesium, and zinc. Interestingly, the seed of Moringa contains and calcium-to-phosphorus (Ca/P) ratio above 1, which is a favorable condition for bone health. But the Na/K ratio is often more than the recommended 0.6, indicating that some people prone to hypertension may be cautious in the consumption 17.

2.4 Lipids

Lipid in Moringa seed varies from 14-46% on dry weight basis [20]. These lipids are rich in polyunsaturated fatty acids, which account for 75–79% of total fatty acids [21]. With less saturated and monounsaturated fats, Moringa oil also offers beneficial minor compounds such as phytosterols and tocopherols. These attributes account for its resistance to oxidation and its nutritional importance as a culinary oil [22].

2.5 Biological Activity

While protein-targeted biological activity of Moringa seeds has been inadequately investigated, at least one study has reported safety concerns [23]. For instance, crude seed ingestion in Wistar rats negatively affected their health, which might have been related to lectins (hemagglutinins) [24]. At the same time, low doses of defatted seed flour have been found to benefit animal nutrition, but the higher doses may retard growth, due to the glucosinolate content [25]. In another study, rats fed with soaked seeds for 21 days showed adverse effects on liver function [26].

3. Structural and Functional Properties

The functional characteristics of Moringa oleifera seed flour that most impact its behaviour in food processing are key to assessing potential uses in the food industry. It has been reported that the physico-chemical properties such as bulk density, water absorption and emulsification properties can be modified by treatments including fermentation and germination [27].

For example, the BD of the flour, which relates to the space that flour occupies, is low and does not change much with fermentation or germination, a trend that correlates with other legumes such as Bambara groundnut [28]. This low density may affect packaging and product uniformity.

The foaming capacity, a property that affects their use for whipped toppings, cakes and baked goods among others, increased considerably by fermentation (from approximately 25.93% to 29.63%) and even more in germinated seeds (up to 37.70%) [28]. The swelling capacity, very important for texture in certain foods, also increases after fermentation, while germination shows little effect.

In raw Moringa seed flour of the water binding capacity (WAC) (ability of flour to retain water is low at first 80.3 g/ml). Fermentation increase it much more, to 141g/ml, germination almost none [29]. This implies that fermented Moringa flours may have a higher potential in moist food recipes.

Moreover, other distinguishing properties between full-fat and defatted Moringa flour are also noted. Defatting increases both water and fat absorption capacities, which improve the compatibility of flour with emulsified systems. For example, nitrogen solubility, which affects protein functionality, is greater at pH 6.0 for the two flours and enhanced in this regard for the defatted flour [30].

Foaming capacities are also greatly improved after defatting, with foam capacity and foam stability as 86.8% and 82.0 ml, respectively, in contrast to 20.6% and 18.5 ml in full-fat flour. On the same pattern, emulsifying capacity is much higher in defatted flour (97.2 ml/g) compared to the full-fat (66.0 ml/g) and, could therefore become a promising stabilizer in emulsified products [30].

Natural fermentation could improve several functional characteristics. W ater absorption capacity may rise (from 0.86 to 2.31 g/ml) and oil absorption capacity (from 0.87 to 1.91 g/ml) during 71 h of fermentation. Foaming and emulsifying activities are likewise enhanced greatly, whereas bulk density and dispersibility cut down and the flour tends to get denser but less able to be distributed in the liquid-based systems [31].

Furthermore, fermentation enhances pasting properties like peak viscosity, breakdown, and setback that determine the viscoelastic cooking properties of the flour. Taken altogether, the results demonstrate a higher potential of defatted, and fermented Moringas to be considered as ideal candidates for food emulsions, foams, and similar technological applications [31].

4. Treatments and Chemical Constituents of Moringa oleifera Seeds

Raw M. oleifera seeds have a characteristic bitter taste and possess several antinutritional factors which may limit digestibility and nutrient utilization. This has made them less desirable for ready as-consumed consumption. To reduce these undesirable compounds to improve their nutritional and sensory qualities for food applications, several treatments have been uséd in recent years [28].

4.1 Cooking and Roasting

4.1.1 Cooking

The seed composition of flax, carried out processing with cooking is influenced by thermal treatment. A single study reported that boiling for 10, 20, and 30 minutes decreased lipid and ash by 20% respectively, likely as a result of leaching into the cooking water. Protein content, however, was higher after boiling (32.0%) than before (26.7%), likely due to the concentration of solids in composed product after moisture reduction [18]. Likewise, at three different heating temperatures (100°C, 130°C and 150°C), the 30 min treatment gave the best oil yield of 33.7% compared to the control (28.9%). These treatments also had effects on oil chemistry: density, saponification index, free fatty acids, and acid value decreased, while specific weight did not significantly change [32].

4.1.2 Roasting

Roasted seeds are simply the seeds that are subjected to a heat treatment and as a result, there is a moisture reduction in them thus an increase in their mineral (Ca, Zn, Fe) and proximate (lipid, carbohydrate, fiber) contents [33]. Protein fraction also increased, particularly after microwave roasting for 20 min. Nevertheless, contents of vitamins A and B1 decreased remarkably revealing some loss of nutrients, while undergoing thermal treatments [18]. The antinutritional factors reciprocated the treatment effects—tannins reduced, saponins and phytates increased. Oxalate first increased, then subsided at a longer roasting time. Specifically, roasting for 15 min at 70°C was reported to diminish bitterness in Moringa seed flour enhancing its potential use in the preparation of infant porridges [34].

4.2 Biological Treatments

4.2.1 Fermentation

Natural fermentation and the nutritional profile of the seed. Protein content increased from 18.9% to 21.2% and carbohydrate levels went up from 53% to 61%. Lipid did not change significantly (13.4–14%), but varying changes occurred in fiber and ash [17]. However, there were remarkable mineral losses during fermentation, including calcium, phosphorus, iron and potassium [17]. Ratios such as the Na/K ratio increased while exceeding the safe level of 1, which could be a health concern for hypertensive people. On the contrary, the ratio of Ca/P was still acceptable, which is in favor of its potential use in child nutrition [35].

Fermentation enhanced the overall protein quality slightly, although did not compensate for lysine and methionine deficiencies. It also also changed fatty acid profile by increasing polyunsaturated fats from 58.8 to 62.1% and partially modifying saturated and monounsaturated ratios [17].

The microbial action reduced most of the secondary metabolites significantly. The levels of phytates, tannins, polyphenols, alkaloids, flavonoids, and saponins decreased and were found the terpenoid increased. This reduction of bitter and astringent compounds, particularly tannins, is a principal reason as to why fermentation generally improves the taste of Moringa foods [17, 34].

4.2.2 Germination

Germination induces endogenous enzyme activity, which changes the nutritional composition of seeds. It usually increases mineral accessibility, protein digestibility, inhibits antinutritionals. Protein and lipid in Moringa oleifera Seeds Progerminated protein content increased from 18.9% to 23.7% and lipid, from 13.4% to 14.6%. However, it affected ash, fiber and carbohydrates slightly [17].

At the same time, germination decreased tannins, phytates, polyphenols, alkaloids and saponins – all of which may interfere with digestion or nutrient absorption. Furthermore, controlled germination (e.g., water replacement every 2 h for 12 h, in order to avoid spontaneous fermentation) was very effective in reducing bitterness and enhancing the food-related characteristics [17].

5. Moringa oleifera Seed Flour and Oil in Food Systems

Moringa oleifera seed oils and flours are however emerging as valuable alternatives for multiple food uses. Their particular characteristics including high thermal stability and good nutritional features enable their addition to both traditional and fortified food matrices.

5.1 Oil

Ph 2Moringa seed oil has a superior oxidative, thermal and frying stability. After storing for 42 days under the same conditions, its peroxide value varied from 1.2 to 5.6 meq O_2/kg—a significantly weaker rise compared to groundnut oil, which was from 3 to 26.93 meq O_2/kg. This means that Moringa oil is relatively more resistant to oxidative conditions and it is probably because of its less amount of polyunsaturated fats [36].

Moringa oil during frying also stood superior in free fatty acid production than that of groundnut oil. One study demonstrated that frying Moringa oil led to 28.6% free fatty acids compared to 48.6% of groundnut oil. This reduced hydrolysis rate indicates its higher stability and that it is less reactive with water that is generated during frying [37].

The same test on fried foods such as potato chips was also performed with the moringa oil. Sensory scores of chips fried in Moringa oil were significantly higher than those fried in groundnut oil in terms of taste, texture and overall acceptability. Remarkably, chips fried in an equal proportion of Moringa and groundnut oil had the highest picture ratings indicating a beneficial synergy [38]. These results indicate the potential use of Moringa oil as a better option or complementary to traditional edible oil.

5.2 Flour

For bakery products, Moringa flour has been demonstrated to be nutritionally promising and moderately acceptable in taste. For instance, addition of 40% of the germinated Moringa seed flour to wheat flour for cake production reported an increment of the level of protein 13.14% to 23.10%. Other nutritional factors also increased, including fiber, iron, zinc, calcium, fat, and ash [35]. Higher Moringa ratio, however had negative effects on the pasting properties and organoleptic attributes of the end product. Moringa flour cakes up to 30% were still acceptable but dropped significantly in rating when Moringa inclusion level was increased to 40% because of strong bitter and astringent flavor [35].

At the level of cookies and bread, replacement of wheat flour with debittered Moringa flour (boiled at 100°C during 35 min) was satisfactory. Bread with a 90:10 wheat-to-Moringa ratio still had the effect of Moringa, but an 80:20 ratio was good for cookies, which had a nice nutty aftertaste. These products also had more protein, iron, and calcium [39].

Moringa flour has also been utilized in meat products. For example, the 2%, 4%, and 6% beef burgers with Moringa seed flour were found to have no significant sensory attribute difference in respect to color, taste, tenderness, and juiciness. Moreover, shelf life was also improved i.e., burgers developed with 0% and 2% Moringa flour observed 7 and 17 days of shelf life respectively whereas the product prepared with 4% and 6% flour, observed the 21 days of shelf life. This preservative effect was reported to be due to the antioxidant activity of Moringa flour [40].

It has also been introduced into infant formula. By a 15 minutes roasting at 70°C the seeds could be rid off bitterness, using the flour to formulate of mixtures cereal/ legumes that include sugar and fruit pulps. Examples are maize, rice, pumpkin, Parkia biglobosa, Adansonia digitata, and soybeans [13].

Fermented Moringa flour has been incorporated into maize based traditional Nigerian diets such as 'Ogi'. Blending with Moringa flour by 10%, 20%, and 30% increased the nutritional value but decreased some functional and textural properties and ultimately extended shelf life [41]. In like manner, snacks produced with

2, 5, and 7.5% Moringa flours had good sensory ratings from the evaluation panels and snacks with the highest incorporation level of Moringa were judged for their color, crispness, aroma and overall acceptability [42].

6. Conclusion and Future Work

Although the seeds of Moringa oleifera have been well researched for their nutritional and functional properties. High in proteins, lipids, vitamins, and antioxidants, these seeds have potential in the food and health industries. Their proteins, however, are lower in some of the essential amino acids, including lysine, sulphur amino acids, and tryptophan, requiring dietary complementation for balanced nutrition. The oil obtained from the seeds that is rich in oleic acid could be useful for frying and seasoning purposes owing to its high stability and oxidation resistance.

Beside the nutritional benefits, the seed and its products (particularly defatted flour and oil) exhibit potential for food preservation. Flour concentrations between 2% and 6% have been applied to improve the meat products shelf life, probably due to its antioxidant constituents as tocopherols, phytosterols, and carotenoids. But the inherent bitterness and antinutritional components in raw or soaked seeds restrict the use of these seeds directly in food without any suitable processing. Some debittering approaches— such as roasting and fermentation— have been proposed and look promising, particularly for flavor and toxicity reduction.

Investigations on the functional properties of Moringa flour have encouraged its utilization in various products, such as breads and infant porridge. However, the bitterness and possible toxicity of untreated flours are still of concern. In comparison, moringa seed oil has been found free from such toxicities and has been found to be more biologically and technologically appropriate than other commercial fuels.

Especially as food security and grain shortages continue to concern the world, notably in arid regions such as sub-Saharan Africa, Moringa oleifera provides an appealing option. xivae, grows under desert conditions and could possibly contribute to the diet and food preservation of marginal human populations.

In order to maximize this potential, more researches need to be conducted on the effects of the combination of processing methods, including e.g. roasting, cooking or germination, on the nutritive value and in vivo safety of Moringa seed flour and oil. Furthermore, the possibility of value-added products such as functional food ingredients with immune-modulatory and anti-inflammatory properties usage for Moringa derivatives exists. Human trials would provide a better understanding of the safety and efficacy of Moringa enriched foods for integration into public health nutrition programs.

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