Characterization of Partially Defatted Moringa Seed Flour Obtained at Different Temperatures

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Abstract

There is more and more interest in the search for new crops, which are well-adapted to climate change due to their low irrigation requirements and resistance to high temperatures. The plant, Moringa oleifera, is native to India and fulfills these characteristics. Moreover, each of its parts (leaves, pods, seeds, roots, flowers...) can be used for fodder, human food or pharmacological formulas due to the high levels in protein and antioxidants, among other components. This study focuses on the assessment of moringa defatted seeds (MDS) obtained after extracting oil from moringa seeds at different temperatures (from 70 to 220 ºC). Therefore, knowledge of their nutritional profile may offer up new possible uses in different food matrices, so contributing to the circular economy. The results showed that MDS had 50% proteins, 10% fats and 29% carbohydrates, the rest being water (4%) and ashes (7%). The highest temperature applied caused a significant reduction in the b* coordinate and luminosity, giving rise to MDS that were darker brown in color. This residue was rich in polyphenols (especially flavonols), which in some cases (p-coumaric acid, gallic acid, p-hydroxybenzoic acid and rutin) were enhanced at the highest temperature (220°C), as was the total antioxidant capacity.

Introduction

It is estimated that the global population will grow by nearly 2 billion over the next 30 years, going from the current 8 billion to 9.7 billion in 2050 and possibly reaching a peak of almost 10.4 billion halfway through 2080 (ONU 2022). Together with the inexorable advance of climate change, this makes it necessary to search for new drought and high-temperature resistant crops, which are also highly nutritious. Moringa oleifera, from the monogenic Moringaceae family, a tropical tree that is well-known and widely cultivated in the southern hemisphere may be an alternative to the traditional crops, one which meets these needs (F Anwar and Rashid 2007; Okuda et al. 2001). It grows in hot, dry countries, in relatively infertile soil and is not overly affected by drought, delivering a great deal of nutrients to the soil and so protecting it from external factors, such as erosion, desiccation and high temperatures (Moyo et al. 2011; Olson and Alvarado-Cárdenas 2016; Pérez et al. 2010). In addition, some Japanese research has revealed that the carbon dioxide (CO₂) absorbance rate of the moringa tree is twenty times greater than that of standard vegetation (Villafuerte and Villafurte-Abonal 2009).

Its fruits grow in very long (between 20 and 45 cm) fleshy, green, tricarpellary pods until they ripen and dry, turning browner in color (Radovich and Page 2011). Each pod can contain 15 to 20 seeds, each with an oil content of between 19 and 47%, and a maximum oil extraction percentage of 70% (Bhutada et al. 2016; Nadeem and Imran 2016). Some studies highlight the marked antioxidant activity of moringa seeds and have isolated some phytochemical compounds that may be used as nutraceutical bioactive molecules, with the capacity to lessen the oxidative stress associated with aging and cancer, while also acting as potential antitumor promoters (Guevara et al., 1999; Maiyo et al., 2015; Singh et al., 2009). In addition, its high oil content could be used in the production of biofuels (Fernandes et al. 2015).
The oil obtained from the moringa seed is an intense yellow in color, of low viscosity and rich in monounsaturated and saturated fatty acids, of which the main one is oleic acid (approximately 70%), which also makes it highly resistant to oxidation. It also contains other fatty acids, such as palmitic, estearic and behenic. It contains, in addition, a large quantity of tocopherols, such as vitamin E, so it may become an effective, complementary means of reducing cholesterol (Gómez-Mitjans et al., 2016). This oil may be used for cooking, in cosmetics or for medicinal purposes (Sandeep et al., 2019).

The cake left after the oil extraction process may also be put to many uses. Its high protein content (35-60%) makes it an interesting ingredient for use in animal feed (Godino, 2016; Saa et al., 2019). This subproduct can supply part of the proteins required for human consumption as it is a sustainable alternative source with a high biological value (Al-Kahtani 1995; F Anwar and Rashid 2007; McCarty et al. 2009). So, this cake can be used to obtain defatted moringa flours for use as a supplement in different formulations, including biscuits, cakes and baby food. However, the protein composition of the seeds only covers some of what humans require in terms of essential and semi-essential aminoacids; they contain histidine, threonine, tyrosine, leucine, isoleucine and phenylalanine but lack methionine, lysine, valine and tryptophan, which are considered to be limiting aminoacids (Saa et al. 2019). Moreover, the bitter taste of the cake of some species, such as Moringa peregrina, (Al-dabbas et al. 2010) together with its content in antinutritional components, such as phytic acid, an inhibitor of trypsin, tannins and chlorogenic acid (Al-Kahtani 1995) limit its use for human consumption (Saa et al., 2019). Some treatments, such as the boiling, fermentation or germination of the seeds, could reduce or inactivate the antinutritional factors or make the proteins more digestible (Aalim et al. 2021). The seed flour cake may also be used to purify water, thereby reducing the number of diseases transmitted through this medium, diseases which cause numerous deaths in developing countries (Zaku et al. 2015).

This all goes to show the great potential value of the residue of the oil extracted from the seeds and the wide variety of the uses it can be put to and the possibilities there are of introducing it into different food matrices and animal feeds. To this end, the aim of this study is to assess the physicochemical properties of defatted Moringa oleifera flour obtained at different oil extraction temperatures.

**Materials And Methods**

2.1 Raw material

Moringa seeds were obtained from trees grown in an experimental plot at the Universitat Politècnica de València (Spain) located at 39°29'02.2 "N 0°20'09.6 "W. The pods containing the seeds came from trees planted in 2016 and were harvested in March/April 2021 in a ripened stage. Then, they were dried at room temperature and were stored for approximately one month in a dry place before separating the seeds from the pods. After that, the seeds were shredded and shelled with an electric shredder (YT542 230 V) and were passed through a sieve with a mesh size of 4 mm to remove as many impurities as possible.
2.2 Oil extraction

An automatic press extractor (Cgoldenwall 350 W 3-6 kg/h), consisting of a worm screw operating with temperature control, was used to obtain the oil from the seeds. In this study, 70, 100, 130, 160, 190 and 220 °C were applied for oil extraction purposes. In this process, the moringa defatted seed residue (MDS) was collected and stored in glass jars in darkness until its analysis.

2.3 Analytical determinations

2.3.1 OPTICAL PROPERTIES

The CIEL*a*b* coordinates were determined by collecting the values of reflectance using a spectrophotometer ("Konica Minolta" Inc. Model CM - 3600d, Tokyo, Japan) with a reference illuminant D65 and a 10° observer. To that end, samples of MDS were placed in cuvettes with a volume of 50 mL. Six measurements were taken at each oil extraction temperature.

2.3.2. CENTESIMAL COMPOSITION OF MOISTURE, ASH, FAT AND PROTEIN CONTENT

The water content of the MDS extraction was determined by a gravimetric method (AOAC 2000) for the six temperatures considered. For this purpose, the samples were predried in an oven at 60°C for 24 h and then dried in a vacuum oven (J.P SELECTA, Conterm model) at 60 °C for 48 hours until a constant weight was reached.

The ash was also determined using a gravimetric method by measuring the inorganic MDS remaining after the ignition or complete oxidation of the organic matter in a food(Harris and Marshall 2017). For this purpose, the sample was weighed and preheated on a hotplate at 400 °C for 3 hours. It was then placed in the muffle (J.P SELECTA, model Select-Forn 1150 °C) at 550 °C for 6 hours, to record the final weight and obtain the mass variation that gives rise to the ash content.

The fat content was determined by a Soxhlet extraction (StarFish multi-experiment Workstation; Radleys, United Kingdom) following the methodology AOAC, 996.06 (AOAC 2005). To this end, 5 g of MDS extract was mixed with 20 mL of petroleum ether, heating this mixture at 40-70 °C for 5 hours to evaporate the ether. After the extraction process, the solvent was completely removed using a rotary vacuum evaporator (BÜCHI B-480) with a water bath at 4° C. The flasks were then placed in a forced circulation stove at 100 °C (OVF, Ibx instruments) for 15 minutes to evaporate the excess ether and, after cooling, the flasks were weighed.

Finally, the protein content was analyzed using the Kjeldhal method (AOAC 1990) based on the amount of nitrogen, by digestion, distillation, and titration (Block digest 6, J.P. Selecta Spain; Distillation unit UDK 127, Velp Cientifica, Italy). The nitrogen content was multiplied by a conversion factor to convert the value
of nitrogen equivalents into the protein percentage present in the sample. In this case, the factor chosen was 6.25, which is the standard value for plant foods (García Martínez and Fernández Segovia 2012).

All these analyses were performed in triplicate at every oil extraction temperature.

The carbohydrate content was calculated by difference up to 100 with respect to the percentage of the other components.

2.3.3 WATER ABSORPTION CAPACITY

The water absorption capacity (WHC) is defined by the amount of water that binds to the MDS or extraction cake without the application of any external force (except gravity and atmospheric pressure) (Martínez-Las Heras et al. 2017). For this purpose, 0.2 g of the MDS was weighed and placed in a graduated test tube. Then, 10 mL of water was added and the mixture was left for 18 h to hydrate. After this time, the supernatant was removed and the sample was frozen for 24 h at -20°C before freeze-drying in the Telstar Lyoquest at -40°C and a pressure of 0.8 mBar for a further 24 h. The result (g water/g dried residue) was obtained by applying this equation (equation 1).

\[
\text{WHC} = \frac{g_{\text{water}}}{g_{\text{dried residue}}} = \frac{\text{weight of hydrated residue (g)} - \text{weight of freeze-dried residue (g)}}{\text{weight of freeze-dried residue (g)}}
\]  

(\text{eq. 1})

2.3.3 ANTIOXIDANT CAPACITY

The total antioxidant capacity was determined by the DPPH (2,2-diphenyl-1-pyrrylhydrazyl) method, which consists of the reduction reaction of this radical due to the antioxidants present in the sample (Mishra et al. 2012) by analyzing the changes in absorbance in a spectrophotometer at a wavelength of 515 nm. To do this, first, a solution of DPPH with a concentration of 0.13 g/L was prepared. Then, 1 g of the MDS extraction dissolved in 10 mL of an 80% methanol solution was taken and centrifuged for 5 minutes at 1300 rpm. Then, 2.5 mL of 80% methanol solution, 0.6 mL of DPPH solution and 40 mL of supernatant of the centrifuged sample were placed in a cuvette and the absorbance was read both at time 0 \((A_0)\) and after 30 minutes \((A_{150})\) to obtain the percentage inhibition of DPPH with the following equation:

\[
\% \text{ Inhibition DPPH} = \frac{A_0 - A_{150}}{A_0} \quad (\text{ec. 2})
\]

The results were expressed as Trolox equivalents per 100 g of residue. The antioxidant activity was analyzed in triplicate at each extraction temperature.
2.3.4 PHENOLIC PROFILE

Firstly, the phenols were extracted from the MDS using a solution of methanol in water (80:20 w/w). For this purpose, 1 g of MDS was mixed with 10 mL of the methanol solution in an Ultraturrax T 25 digital-IKA. The mixture was then placed in an Eppendorf flask in an ultrasonic bath for 10 minutes and then centrifuged for 5 minutes at 1400 rpm. The supernatant was filtered through a PTFE syringe with a mesh size of 0.45 µm.

The phenols present in the sample were analyzed using an HPLC chromatograph (Alliance 2695 with Waters 2996 photodiode array detector, USA), separating the components using a C18 Column (150 x 4.6 mm) with a particle size of 5 µm and determined using Agilent MassHunter software. The binary mobile phase consisted of phase A (water and formic acid 95:5) and phase B (acetonitrile) (Jung et al. 2015; Xu et al. 2007).

The reference standard curve contained the following phenols: gallic acid, 4-O-caffeoylquinic acid, caffeic acid, rutin, p-coumaric acid, ferulic acid, quercitrin, apigenin 7-glucoside, quercetin, transcinnamic acid, naringenic acid, vanillin, 4-hydroxybenzoic acid, epicatechin, quercetin 3-glucoside, sinapic acid and kamferol.

The phenol content was analyzed in triplicate for each of the extraction temperatures at which the MDS was obtained.

2.4 Statistical analysis

Statgraphics Centurion software was used for the statistical analysis of the results. An ANOVA analysis of variance was performed, using the LSD (Least Significant Difference) test at a significance level of 95% (p-value ≤ 0.05).

Results and discussion

Table 1 shows the centesimal composition of MDS. In every case, the temperature factor had no relevant effect on most of the components, the mean values being: 4 ± 2 % water, 7 ± 2 % ash and 49 ± 5 % protein. However, at the highest extraction temperatures (190 and 220ºC), the remaining amount of fat in the MDS was higher (13.6 ± 0.9 %) than in the other cases, underlining the fact that it is recommendable to apply lower temperatures at which the mean value was 10.6±1.7% of fat. It is important to highlight that initial moringa seed had 33 ± 2 % of fat, which is coherent with the values reported by Gharsallah et al. (2021) (42 ± 4 %), by Anwar & Bhanger (2003), Dezfooli et al. (2016) and by Saleem et al. (2020) (38-42 %).

It should be noted that the reported protein content of moringa seeds is highly variable, ranging between 18.6 % (Kawo et al. 2009) and 37.2 % (Bridgemohan et al. 2014). When the fat is removed, the protein
content in moringa seeds ranges from 32% to 62.8% (Anwar & Rashid, 2007; Govardhan et al., 2011), which would cover the result obtained in this study. Therefore, depending on the conditions of the raw material (moringa seeds), the composition of the MDS after oil extraction could be different. Furthermore, the method to obtain the oil may also affect its composition. Thus, Bridgemohan et al. (2014) reported similar values to ours (45% protein, 7% water and 4% ash) when studying defatted moringa seed using a screw oil extraction system with a heater similar to the extractor used in this research, although they did not specify the temperature used. However, their fat content was higher (25%). On the other hand, when oil was obtained by extraction with hexane, the amounts of the components of the MDS were 29.4 ± 1.5 % protein, 6.6 ± 0.5 % ash and 5.7 ± 0.4 % water (Faroq Anwar and Bhanger 2003). In the case of press extraction (Komet press) and cake drying they obtained approximately 44% protein, 27% % fat, 5 % water and 4 % ash (Silva et al. 2018).

The average percentage of carbohydrates in these flours was 28.6%, whereas in another study into defatted moringa seeds carried out by Taiwo & Alikwe (2014), the value was significantly higher, 57.77 ± 0.12; this was probably due to the different extraction method (ether-petroleum) and the lower protein content 17.13 ± 0.13.

TABLE 1. Percentage of water, ash, protein, fat and carbohydrates in defatted moringa seeds (MDS)

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>% water</th>
<th>% ash</th>
<th>% protein</th>
<th>% fat</th>
<th>% carbohydrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>6 ± 2</td>
<td>7.3 ± 0.7ab</td>
<td>47 ± 7 a</td>
<td>10.4 ± 1.4bc</td>
<td>29.3</td>
</tr>
<tr>
<td>100</td>
<td>3.4 ± 1.2a</td>
<td>9 ± 3b</td>
<td>47 ± 3a</td>
<td>9.1 ± 0.7ab</td>
<td>31.5</td>
</tr>
<tr>
<td>130</td>
<td>2.4 ± 0.6a</td>
<td>6 ± 2 ab</td>
<td>49 ± 2a</td>
<td>11.2 ± 0.3c</td>
<td>31.3</td>
</tr>
<tr>
<td>160</td>
<td>6.5 ± 0.5a</td>
<td>5 ± 2a</td>
<td>46 ± 2a</td>
<td>8.8 ± 0.1a</td>
<td>33.5</td>
</tr>
<tr>
<td>190</td>
<td>3.7 ± 1.2a</td>
<td>6 ± 3a</td>
<td>52 ± 6a</td>
<td>13.0 ± 0.7d</td>
<td>25.3</td>
</tr>
<tr>
<td>220</td>
<td>3.9 ± 0.8a</td>
<td>7.8 ± 1.2ab</td>
<td>53.4 ± 0.7a</td>
<td>14.3d ± 0.7a</td>
<td>20.6</td>
</tr>
</tbody>
</table>

Identical letters indicate homogeneous groups obtained in the ANOVA with l.s.: 95% considering the temperature factor.

In comparison with other new vegetable sources of proteins, such as oilseeds or pseudocereals, this moringa flour contains a higher percentage of protein. In this regard, defatted chia seeds by crew press Komet Oil have a protein content of 27% (Ferreira et al. 2023). According to Bueno et al. (2008) whole chia seed has around 23.46 % protein. In flaxseed cake, this value ranged between 10.5-31 % (Oomah and Mazza 1993) when the oil was extracted with hexane. The oil content of other defatted oilseeds, such as soybean, was 45 % when extracted by pressing and milling at 6000 rpm, and 46 % when the extraction was carried out with organic solvent and milled at 6000 rpm (Xing et al. 2018).
The fat content of MDS is also higher than in defatted chia seed, which is 7 % (Ferreira et al., 2023), and similar to those obtained in defatted sesame seed (13.31-14.52 %) (Prakash et al. 2018) and linseed (13.52 %) (Krujl et al. 2021). In terms of carbohydrates, MDS has a greater content than defatted chia (21.29 ± 0.30 %) (Nassef et al. 2023), sesame (19-20 %) (Krujl et al., 2021) and especially defatted flaxseed flour (4.6 %) (Prakash et al., 2018). The ash content of MDS is slightly higher than that of defatted sesame seeds (3.41-3.62 %) or defatted flaxseed (5 %) (Krujl et al. 2021; Prakash et al. 2018). Finally, the moisture content of the MDS is lower than that of other defatted seeds (sesame: >7.3%, flaxseed: 8.6% and soy: 7-8%) (Krujl et al., 2021; Prakash et al., 2018; Xing et al., 2018), which could imply better storage conditions with a longer shelf life of this product.

Figure 1 shows the location of the a* and b* coordinates in the chromatic diagram (1A) and the values of luminosity (1B) of the moringa defatted seed at different oil extraction temperatures. The samples were in the first quadrant with b* values of between 7 and 20, while the mean values of the a* coordinate were between 2 and 6, coherent with their brown tones. Only the highest temperature applied caused significant reductions in both the b* coordinate and luminosity, giving rise to a darker brown color. This behavior may have been caused by Maillard reactions which take place at high temperatures and in the presence of aminoacids, in which this MDS is rich, and free sugars.

3.4 Water absorption capacity

Water absorption capacity is the amount of water absorbed by the food/flour in order to achieve the desired consistency and create a quality food product. Furthermore, it is related with water availability for gelatinization purposes. Therefore, WHC informs us about the optimum amount of water that should be added to a dough before it becomes too sticky to process (Godswill et al. 2019; Kulkarni et al. 1991). The process of defatting oilseed flours improves their WHC. This is due to the removal of oil film from the flour particles, allowing a better hydration of the polar molecules present in the flour (e.g. proteins, salts, fiber, and others) along with the entrapment of water molecules between the flour particles as a consequence of a better wetting of the flour particles (Joshi et al. 2015).

Figure 2 shows the water absorption capacity (WHC) values of MDS as a function of the temperature used in oil extraction. In almost every case, the WHC was above 0.8 g water/g MDS with few differences between the temperatures applied, but without a clear tendency. This water absorption capacity of the MDS would be linked to the high fiber content of the moringa seed and its proportions of polysaccharides. Thus, it has approximately 44 % cellulose and, to a lesser extent, lignin and hemicellulose (14 % and 12 %, respectively) (Bustamante 2015; Mateos et al. 2012). However, other defatted seeds such as soybean, sesame and wheat, have respectively 3.53, 2.75 and 1.92 g water/g dry matter (Joshi et al. 2015).

Therefore, this defatted moringa may be used in the reformulation of products with low-medium requirements of WHC. According to previous reports, a lower WHC may be desirable for making thinner gruels or porridges in which more flour can be added per unit volume of the gruel (Tenagashaw et al. 2016). in addition, the low WHC could allow the addition of more flour to help process nutrient-rich
products (Keyata et al. 2023). In this regard, MDS may be of great interest for the purposes of increasing the energy and nutrient density of infant foods due to its WHC characteristics (AIB International 2018). Moreover, the combination of MDS with other multigrain flours in various bakery products, such as biscuits, cookies and cakes, has a considerable effect on their nutritional values (Kumar 2019).

3.5 Total antioxidant capacity

Figure 3 shows the total antioxidant capacity, expressed as mg Trolox/g, of MDS. As can be seen in every case, the oil extraction temperature did not significantly affect this capacity, except at 220ºC at which temperature an increase in this parameter was registered. This behavior could be due to an increase in the bioavailability of antioxidants or an enhancement of the activity of natural antioxidants provoked by heating treatments which also involved the Maillard reaction (Chan et al. 2009; Yamaguchi et al. 2001).

The values of antioxidant capacity of dry moringa reported by other authors are expressed in different units and, therefore, the comparison with the results obtained in this research is quite difficult. Nevertheless, the units have been changed in some cases. Thus, 5.6 mg Trolox equivalent/ g dry weight (extraction by hydraulic press) was registered in *Moringa peregrina* (Sardabi et al. 2022); 0.547 ± 0.008 mg gallic acid/kg dry weight in *Moringa oleifera* whole grain (extracted by ether petroleum) (Boukandoul et al. 2020) and 9.20 ± 0.03 mg ascorbic acid equivalent/ g dry weight of *Moringa oleifera* seed meal (obtained by ultrasound-assisted extraction) (Sharma et al. 2020). In comparison with other defatted seeds, it seems that MSD has a higher antioxidant capacity, since 2.58 mg Trolox/g dry matter were found in partially defatted chia flour (Calvo-Lerma et al. 2020) and 0.78 ± 0.12 mg Trolox equivalent/ g were reported for defatted sesame seeds (Melo et al. 2021). In other cases, the antioxidant capacities of different oil seeds are expressed as % of DPPH inhibition and the value for each case is 17.20 ± 0.02 (hemp), 13.65 ± 0.02 (flax) and 34.15 ± 0.03 (canola) (Teh and Birch 2014).

3.6 Phenolic profile

Table 2 shows the content of the different types of polyphenols in the MDS after oil extraction at different temperatures. Table 2 also shows the values of the F-ratio coefficient and the p-value of the ANOVA applied in this analysis. The results obtained indicate that the main polyphenols present in the MDS are rutin and epicatechin, from the flavonoid group, followed by gallic acid and vanillin from the phenolic acid group. It should be noted that flavonols are the largest group of polyphenols in the MDSs analyzed. Their main characteristics are described below:

-Rutin: it is anti-inflammatory, neuroprotective and anticarcinogenic (Imani et al. 2021).

-Epicatechin: it has high antioxidant activity and its metabolites are found in plasma and accumulate in the brain, liver, heart, intestine, kidney and other organs (Actis-Goreta et al. 2012; Kosińska and Andlauer 2012).
Gallic acid: it has applications in various areas, mainly in that of pharmaceuticals, as it is a precursor in the manufacture of broad-spectrum antibiotics, such as trimethoprim. In addition, in the area of food, it has been used as an antioxidant in fats and oils, as well as an additive in some beverages and foods, preventing their oxidation (Hocman 1988).

Vanillin: this compound is mainly used in the food industry (approximately 80%) as a flavor enhancer and an agent that masks undesirable flavors, such as bitterness, as well as having antioxidant and anticarcinogenic properties (Babío et al. 2019).

Other published studies (Govardhan et al. 2013) indicate that moringa seed flour defatted by the Soxhlet method is rich in polyphenols, with almost all the major ones (gallic acid, epicatechin, caffeic acid, vanillin and p-coumaric acid) coinciding with those obtained in this analysis. However, due to differences in the extraction method and temperatures used, the concentrations were different.

In this sense, the incorporation of this MDS in food matrices could improve their nutritional profile. On the other hand, a significant increase in the concentration of p-coumaric acid, gallic acid, p-hydroxybenzoic acid and rutin was observed when working at the highest temperature (220ºC). In an experiment the purpose of which was to study the effect of different baking temperatures on the phenolic profile of bread, the gallic acid content increased up to values of between 1.7 and 6.1 mg/100 g in line with the temperature. Heat causes the disintegration of gallate derivatives and their conversion to gallic acid (Meral and Erim Köse 2019). This may also be related with the fact that the MDS extracted at 220 ºC is browner in color since phenolic compounds, such as p-coumaric acid, are responsible for the dark color of chia seed (Iglesias-Puig and Haros 2013).

TABLE 2. Average values of the concentrations of the polyphenols (mg/100 g MDS) identified in the oil seed MDS obtained at different extraction temperatures.
Conclusion

It is worth noting that the large amount of moringa defatted seeds (MDS) after oil extraction at different temperatures provides a great deal of protein (49 ± 5 %) and polyphenols (especially flavonols), with a low-medium water absorption capacity. Some of the polyphenols (p-coumaric acid, gallic acid, p-hydroxybenzoic acid and rutin) increased when working at the highest temperature (220ºC), as did the total antioxidant capacity, and the browner color became more intense. Therefore, further studies could be carried out into MDS as a possible component for the purposes of enriching different food matrices, such as cookies, pasta, bakery products and infant formulations, in order to enhance the diversification of the vegetable oil market.

Declarations

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Author's Contributions

S.P. and F.J.G-M obtained the moringa defatted flour and along with M.J-B. analysed all samples. M.D.S., M.D.O and M.L.C. processed data and they acquired the financial support for the project leading to this publication. All authors wrote the main manuscript and also, they prepared figures.

Data Availability

Data available on request from the authors

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

Not applicable

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could appear to influence the reported work.

References


**Figures**
Figure 1

Location in the chromatic plane of the coordinates $a^*$ and $b^*$ (A) and luminosity $L^*$ (B) of MDS when oil was extracted at different temperatures. Identical letters indicate homogeneous groups obtained in the ANOVA with n.s: 95% considering the temperature factor. In the chromatic plane, lower case letters represent homogeneous groups for coordinate $a^*$ and upper case letters represent homogeneous groups for coordinate $b^*$.

Figure 2

Water absorption capacity (WHC) of the MDS at different extraction temperatures expressed in (g water/g MDS). Identical letters indicate homogeneous groups obtained in the ANOVA with n.s: 95%, considering
the temperature factor.

**Figure 3**

Antioxidant capacity expressed in milliequivalents of TROLOX per gram of MDS. Identical letters indicate homogeneous groups obtained in the ANOVA with n.s: 95%, considering the temperature factor.