Review [Revisión]

Moringa oleifera LAM.: A REVIEW OF ENVIRONMENTAL AND MANAGEMENT FACTORS THAT INFLUENCE THE NUTRITIONAL CONTENT OF LEAVES †

[*Moringa oleifera LAM.*: UNA REVISIÓN DE LOS FACTORES AMBIENTALES Y DE MANEJO QUE INFLUYEN EN EL CONTENIDO NUTRICIONAL DE LAS HOJAS]

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SUMMARY

Background. *Moringa oleifera* Lam. It is a species native to India with an excellent capacity for acclimatization and is distributed in tropical, subtropical, and semi-arid climates. This plant is of economic importance due to its nutritional content and uses food, forage, medicinal and industrial. All plant parts can be used, but the leaves are characterized by their high nutritional content and low antinutritional compounds. Significant variation in the nutritional content of the leaves has been identified, and, therefore, a generalization or recommendation about their nutritional content is impossible. **Objective.** To identify the environmental and management factors that influence the nutritional content of *M. oleifera* leaves. **Methodology.** A bibliographic review on *M. oleifera* present in the databases of Scopus, NCBI, Science direct, and other repositories was carried out. The keywords for the search were: *M. oleifera*, chemical composition, nutritional content, environmental factors, phenology, agronomic management, postharvest management, type of dehydration, and methods of analysis. **Results.** The results obtained show that genetic, edaphoclimatic, agronomic, phenological factors, postharvest handling, type of dehydration, storage before and after dehydration, and type of analysis influence the nutritional content of moringa leaves. **Implications.** Identifying the factors and processes that affect the nutritional content allows a better understanding of the chemical content of moringa leaves under specific conditions. **Conclusions.** Fertilization is the factor that most influences the protein content when agronomic management is carried out. Temperature and dehydration type are the factors that showed the most significant influence on the decrease in the nutritional content of the leaves in postharvest management.
Key words: protein; fat; type of dehydration; temperature.

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RESUMEN

Antecedentes. *Moringa oleifera* Lam. es una especie originaria de la India que presenta gran capacidad de aclimatación y se distribuye en climas tropicales, subtropicales y semiáridos. Esta planta es de importancia económica debido a su contenido nutricional y usos alimenticios, forrajeros, medicinales e industriales. Todas las partes de la planta pueden ser aprovechadas, pero las hojas destacan por su alto contenido nutricional y baja concentración de compuestos antinutricionales. Se ha identificado gran variación en el contenido nutricional de las hojas y, por tanto, es imposible una generalización o recomendación acerca de su contenido nutricional. **Objetivo.** Identificar los factores ambientales y de manejo que influyen en el contenido nutricional de las hojas de *M. oleifera*. **Metodología.** Se realizó una revisión bibliográfica sobre *M. oleifera* presente en las bases de datos de Scopus, NCBI, Science direct y otros repositorios. Las palabras clave para la búsqueda fueron: *M. oleifera*, composición química, contenido nutricional, factores ambientales, fenología, manejo agronómico, manejo poscosecha, tipo de deshidratación y métodos de análisis. **Resultados**. Los resultados obtenidos demuestran que los factores genéticos, edafoclimáticos, agronómicos, fenológicos, manejo postcosecha, tipo de deshidratado, almacenamiento previo y posterior al deshidratado y tipo de análisis influyen en el contenido nutricional de las hojas de moringa. **Implicaciones**. La identificación de los factores y procesos que afectan el contenido nutricional permite una mayor comprensión acerca del contenido químico de las hojas de moringa bajo condiciones específicas. **Conclusiones.** La fertilización es el factor que más influye en el contenido de proteínas cuando se realiza el manejo agronómico. La temperatura y el tipo de deshidratación son los factores que mostraron mayor influencia en la disminución del contenido nutricional de las hojas en el manejo postcosecha.

Palabras clave: proteína; grasas; tipo de deshidratado; temperatura.

INTRODUCTION

Moringa oleifera Lam. is a species native to the lower parts of the Himalayas in northern India (Korsor *et al*., 2017). It belongs to the Moringaceae family and is the most investigated species out of 13 Moringa. Their common names are white paradise, mom's best friend, tree of life, and moringa, the latter being the most frequent (Rajput *et al*., 2017).

It is mainly distributed in tropical, subtropical, and arid zones (He *et al*., 2020) and presents good development at altitudes below 700 m. However, some crops have been observed at altitudes close to 2,000 m (Velázquez-Zavala *et al*., 2016). Moringa can grow in all types of soils, but loam and clay loam soils are optimal for its cultivation (Dania *et al*., 2014). This tree tolerates a pH range of 6 to 8 and rainfall of 250 to 2000 mm per year (Basra *et al*., 2015). It can be established like a crop, living fence, continuous windbreaker, and agroforestry system. It tolerates extreme pruning and has excellent regrowth capacity (Nouman *et al*., 2014).

Moringa cultivation can be used as forage, adsorbent, bioenergetic, industrial, flocculant, biofertilizer, food, and medicinal plant (Dania *et al*., 2014). The last two are the most economically important in developing countries (Kshirsagar *et al*., 2017). Moringa leaves contain large amounts of nutrients, and being a perennial species, they are available throughout the year (Mendieta-Araica *et al*., 2013). The number of antinutrients such as tannins, saponins, phytates, and alkaloids is low that they do not represent a threat to human or animal consumption (Oladeji *et al*., 2017). It can be consumed as tea, fresh, dry, tablets, capsules, or a vegetable that can be added to the typical foods of each region (Rajput *et al*., 2017). The nutritional value of the leaves can be used to complement the nutrition of people and animals (Melesse, 2011). The nutritional content gives it great nutritional and medicinal potential that can be used to treat or prevent different types of diseases (Gopalakrishnan *et al*., 2016). For this reason, organizations such as FAO, Tree for Life, Church World Service, and Educational Concerns for Hunger Organization promote its cultivation and consumption (Ganatra *et al*., 2012; FAO, 2014).

The nutritional and functional qualities are affected by multiple factors, and when ignored, they limit the maximum nutritional use of the leaves (Reyes *et al*., 2006; Amabye *et al*., 2015); as far as we know, there is little scientific literature about the multiple factors that affect the nutritional quality of moringa leaves. Therefore, the objective of this review was to identify the environmental and management factors that influence the nutritional content of *M. oleifera* leaves.

METHODOLOGY

A bibliographic review on *M. oleifera* present in the databases of Scopus, NCBI, Science direct, and other repositories was carried out. The search period was from 2010 to 2021. The investigations prior to the contemplated period were included because they provided relevant information for this investigation. The keywords for the search were: *M. oleifera*, chemical composition, nutritional content, environmental factors, phenology, agronomic management, postharvest management, type of dehydration, and methods of analysis. Based on the results obtained, each factor or process and its effect on the nutritional content of the moringa leaves were discussed.

CHEMICAL COMPOUNDS PRESENT IN THE LEAVES AND FACTORS THAT INFLUENCE THE NUTRITIONAL CONTENT OF MORINGA

Moringa leaves can be used as a food supplement, functional food, or nutraceutical due to their high content of nutrients (Mumtaz and Sumia, 2017). The diversity of chemical compounds highlights their medicinal importance, and their consumption can improve people's nutritional status (Umerah *et al*., 2019). Anemia and malnutrition are some diseases that can be prevented through moringa consumption (Madukwe *et al*., 2013).

Moringa leaves contain fat, carbohydrates, fiber, protein, and 18 amino acids (Massry *et al*., 2013). Carbohydrates represent an energy source, and the ash content represents the total mineral content (Amabye *et al*., 2015). Fiber improves gastrointestinal function, removes carcinogens, regulates cholesterol absorption, and reduces metabolic diseases, and minerals contribute to proper physiological function (Aja *et al*., 2013; Mumtaz and Sumia 2017). Fats are sources of energy, transport fat-soluble vitamins, participate in cellular processes, and protect and isolate internal tissues (Isitua *et al*., 2015).

The leaves contain vitamins such as β-carotene, B1, B2, B3, C, and E. Minerals such as calcium, magnesium, phosphorus, potassium, copper, iron, sodium, iron, sulfur, selenium, and zinc (Moyo *et al*., 2011). Vitamins and minerals contribute to human nutrition and participate in fundamental biological processes such as nutrient absorption, chemical reactions, oxygen transport, immunity, reproduction, the transmission of nerve impulses, growth, and development (Ilyas *et al*., 2015).

Moringa contains essential amino acids (tryptophan, phenylalanine, histidine, isoleucine, leucine, lysine, methionine, tyrosine, threonine, and valine) and non-essential (aspartic acid, glutamic acid, alanine, arginine, cysteine, glycine, proline, and serine) (Olaofe *et al*., 2013; Stadtlander and Becker, 2017). According to the FAO/OMS (1991), moringa contains all the essential amino acids, and the amount of these compounds in the leaves is greater than the recommended daily intake (Mune *et al*., 2016).

Phenolic compounds such as gallic acid, 3,4-dihydroxybenzoic acid, pyrogallol, esculetin, catechin, chlorogenic acid, p-coumaric acid, gallocatechin, caffeic, ellagic, salicylic, ferulic, glucosinolates, and isothiocyanates can be found in the leaves (Moyo *et al*.., 2011; Nambiar *et al*., 2013; Leone *et al*., 2015; El-Sohaimy *et al*., 2015; Gopalakrishnan *et al*., 2016) and flavonoids (quercetin, rutin, luteolin, apigenin, kaempferol) (Valdez-Solana *et al*., 2015). Moringa leaves represent an essential source of antioxidants that are of great importance in the pharmaceutical industry by eliminating free radicals and reactive oxygen species (Shih *et al*., 2011).

The fatty acids contained in moringa leaves are saturated (caproic, lauric, myristic, palmitic, margaric, stearic, arachidic, behenic, lignoceric, monounsaturated (palmitoleic, oleic, erucic), diunsaturated (Linoleic), triunsaturated (α-linolenic), and tetraunsaturated (arachidonic) (Olaofe *et al*., 2013).

Due to all the chemical compounds present in the leaves, it has been used for the prevention of diseases such as osteoporosis, obesity, dementia, asthma, cholera, diabetes, malnutrition, paralysis, cancer, ulcers, liver lesions, and Alzheimer's (Velázquez-Zavala *et al*., 2016; Sultana, 2020). Its neuroprotective, antibacterial, anti-inflammatory, antiviral, antifungal, and chemopreventive properties can be exploited by consuming its leaves (Aja *et al*., 2013; Gopalakrishnan *et al*., 2016).

Analysis of nutritional content

The nutritional composition in moringa leaves highlights its nutritional importance and supports its use when the availability of other foods is low or absent (Valdez-Solana *et al.*, 2015). Proximal analyses allow determining the amount of protein, fiber, fat, ash, and carbohydrates under given conditions. The results obtained are used to prepare food supplements or formulate low-cost diets with unconventional ingredients (Ajantha *et al*., 2018).

Mature and compound leaves in a fresh stage

The fresh leaves are consumed as vegetables in several developing countries and prevent malnutrition and gastric ulcers; protein and fat concentrations in fresh leaves are low because moisture can occupy from 65.10 to 80.56% of the weight (Sanchinelli, 2004; Tijani *et al*., 2016). The moisture content in the leaves favors the absorption rate of the food (Table 1). However, one of the disadvantages of the high moisture content in the leaves is the vulnerability to microbial decay (Sultana, 2020).

Dolma *et al*. (2020) recommend the consumption of mature leaves or those older than 30 days of development because they contain a significant amount of nutrients. These chemical compounds contribute to the elimination of free radicals (Sreelatha and Padma, 2009). The fresh consumption of moringa leaves reduces protein-energy malnutrition in underdeveloped and developing countries (El-Sohaimy *et al*., 2015). Its production contributes to food security through access to fresh, healthy foods with a high soluble protein content (Olson *et al*., 2016).

Table 1. The nutritional content of 100 g of fresh leaves of *M. oleifera.*

Humidity (%)	Ash (%)	Fat (%)	Fiber (%)	Protein (%)	Carbohydrates (%)	AOAC Method	Source
80.56	NR*	NR	NR	4.62	NR	(2000)	Sanchinelli, 2004
75.90	4.66	1.50	10.67	13.13	2.18	(2000)	Foline *et al*., 2011
75.90	NR	1.70	0.90	6.70	12.50	(2004)	Chandramouli *et al*., 2012
65.10	3.80	1.80	1.20	6.70	NR	(2012)	Tijani *et al*., 2016
72.83	NR	6.72	5.75	5.29	10.57	(1990)	Rajput *et al*., 2017
70.10	1.30	1.50	0.80	6.20	11.70	(2005)	Kshirsagar *et al*., 2017
75.33	2.46	0.78	3.41	6.01	12.28	(2000)	Umerah *et al*., 2019

NR: no report

Fresh moringa leaves contain protein, fat, and vitamins. However, these compounds decrease after the harvest of the leaves (Valdez-Solana *et al*., 2015).

Dehydration methods and their effect on nutritional content

There are several dehydration methods, of which freeze-drying is the one that manages to conserve the most outstanding amount of nutrients in moringa leaves (Alí *et al*., 2017). However, its high cost limits its use, making it a limited technique for small-scale producers and farmers in rural areas. Therefore, it is necessary to know the low-cost techniques that allow optimal dehydration of moringa leaves. Dehydration improves nutritional quality, bioavailability, promotes digestibility, eliminates microorganisms and antinutrients, and prolongs the shelf life of moringa leaves (Umerah *et al*., 2019). Authors such as Basra *et al*. (2015) and Dolma *et al*. (2020) indicated that the collected leaves must be healthy, mature, and intense green color, avoiding those that present yellowing or some disease (Fokwen *et al*., 2018).

Shade dehydration

Shade dehydration is one of the most common techniques used on moringa leaves. This technique is inexpensive and can be performed under any structure. However, ambient temperature, relative humidity, and dehydration time affect the chemical composition (Foline *et al*., 2011). The temperature variation rehydrates

Table 2. The nutritional content of 100 g of *M. oleifera* leaves dehydrated in the shade.

Humidity (%)	Ash (%)	Fat (%)	Fiber (%)	Protein (%)	Carbohydrates (%)	Temperature (°C)	Time (days)	AOAC Method	Source
6.55	NR*	NR	NR	23.8	NR	NR	12 h	(2000)	Sanchinelli, 2004
11.40	7.6	6.5	NR	30.2	NR	NR	NR	(2005)	Moyo *et al*., 2011
4.80	16.0	16.9	15.7	26.2	35.7	25	14	(1990)	Yaméogo *et al*., 2011
NR	13.2	6.7	8.5	28.9	NR	NR	NR	(1990)	Melesse, 2011
3.21	7.9	2.1	7.1	17.0	63.1	35	3-5	(1990)	Ogbe y Affiku, 2011
6.93	10.1	5.4	8.9	29.9	45.5	ambient	3	(2005)	Ijarotimi *et al*., 2013
7.05	7.6	2.1	7.5	26.2	49.3	NR	4	(1995)	Madukwe *et al*., 2013
10.74	4.5	7.7	11.2	9.3	56.3	NR	3	(1995)	El-Sohaimy *et al*., 2015
6.12	11.5	9.2	10.2	24.3	55.9	NR	7-10	(2010)	Isitua *et al*., 2015
8.07	8.0	2.8	19.6	28.1	NR	NR	7	AACC (2000)	Ilyas *et al*., 2015
6.40	7.9	3.4	10.1	22.6	NR	NR	4	(2012)	Tijani *et al*., 2016
NR	NR	NR	NR	30.7	NR	30	4	(1990)	Clement *et al*., 2017
6.20	11.3	5.8	8.4	28.6	NR	NR	14	(2006)	Korsor *et al*., 2017
7.60	12.5	10.2	11.2	25.0	60.9	NR	7-10	(2000)	Mumtaz and Sumia, 2017
4.20	8.6	8.6	8.2	26.2	NR	35	7	(1995)	Ajantha *et al*., 2018
7.60	11.1	6.8	NR	26.9	NR	NR	NR	(2005)	Ahmad *et al*., 2018
6.38	7.4	9.1	9.0	30.0	38.0	NR	NR	(1984)	Samia *et al*., 2018
4.42	8.8	2.4	9.2	15.2	59.8	NR	14	(1990)	Ali *et al*., 2019
NR	2.3	8.1	8.8	33.4	47.4	NR	NR	(2000)	Fuentes *et al*., 2019
7.94	10.3	4.0	6.0	25.5	54.1	NR	3	(1984 and 2010)	Sultana, 2020

NR: no report

Table 3. The nutritional content of 100 g of *M. oleifera* leaves dried in the oven.

Humidity (%)	Ash (%)	Fat (%)	Fiber (%)	Protein (%)	Carbohydrates (%)	Temperature (°C)	Time (h)	Method AOAC	Source
NR*	13.12	20.64	5.95	25.72	NR*	NR	NR	(1984)	Nag y Matai, 2000
NR	8.89	NR	30.81	23.01	NR	65	48	Kjeldahl	Reyes *et al*., 2006
13.53	6.78	2.16	16.39	28.8	NR	65	NR	(1990)	Jongrungruangchok *et al*., 2010
NR	14.6	4.96	30.97	22.42	NR	60	8	(1984)	Sánchez-Machado *et al*., 2010
NR	13.2	NR	9.9	28.7	37.6	65	48	VDLUFA (2006)	Melesse *et al*., 2012
6	NR	7.01	11.8	23.78	28.32	60	4-5	(2004)	Chandramouli *et al*., 2012
NR	10.26	NR	23.21	27.27	NR	65	48	(1990)	Mendieta-Araica *et al*., 2013
5.48	7.92	4.98	18.67	26.79	35.9	45	6	(2000)	Massry *et al*., 2013
NR	NR	NR	NR	27.87	NR	60	NR	NR	Okereke y Akaninwor, 2013
NR	NR	NR	NR	9.83	NR	105	4	(1990)	Clement *et al*., 2017
NR	NR	NR	NR	32.24	NR	60	8	(1990)	
7.43	NR	12.47	20.03	20.42	50.16	60-70	6-8	(1990)	Rajput *et al*., 2017
6.17	7.27	1.79	8.45	20.28	50.25	45	constant wight	(2000)	Oladeji *et al*., 2017
34.95	9.59	11.83	12.42	27.64	38.51	NR	NR	(2005)	Lamidi *et al*., 2017
NR	8.76	1.79	25	20.66	27.37	NR	NR	(1990)	Mouchili *et al*., 2018
NR	6.36	5.01	26.08	16.67	28.33	NR	NR	(2000)	Mouchili *et al*., 2019
5.4	11.24	14.24	9.19	34.12	25.81	50	4	Protocol CNR	Dolma and Tashi, 2020
6.94	9.08	6.09	12.44	30.36	40.02	60	48	(2005)	Pérez-Ángel *et al*., 2020
NR	6.83	6.95	16.46	21.79	48.45	60	NR	(2000)	Guzmán-Maldonado *et al*., 2020

NR: no report

the leaf and prolongs its dehydration (Sani, 2015), so this process can cause contamination by fungi or an undesirable enzymatic process.

The main carbohydrates present in the moringa leaf are fructose, glucose, raffinose, and sucrose (Tesfay *et al*., 2011). The carbohydrate content obtained through dehydration in the shade can improve the nervous, circulatory, digestive, and immune systems (Isitua *et al*., 2015). Table 2 shows a significant variation in protein, fat, fiber, and moisture content under dehydration in the shade. This variation can be attributed to the ambient temperature in which the sample was dehydrated.

Dehydration in oven

Dehydration allows a higher protein content to be concentrated due to the elimination of moisture (Osum *et al*., 2013). In the case of moringa, oven dehydration allows a reduction in volume, a higher concentration of nutrients and reduces production costs by facilitating its storage and distribution (Kshirsagar *et al*., 2017). However, high temperatures and prolonged periods of dehydration decrease the nutrient content of the leaves (Dolma *et al*., 2020).

The control of the dehydration temperature allows the reduction of the moisture content and increases the proper life period of the dry leaf (Dolma *et al*., 2020). As the temperature increases, the crude protein and fat content decrease significantly, and the ash, fiber, and carbohydrate contents increase (Alakali *et al*., 2015).

Clement *et al*. (2017) obtained 32.24% and 9.83% crude protein when dehydrating the leaves at 60° C and 105° C, respectively. Temperature above 41° C breaks the protein bonds and denatures them, reducing the crude protein content (Branden y Tooze, 1998). Therefore, there is a negative relationship between the increase in temperature and the protein content.

Dolma and Tashi (2020) mentioned that the temperature of 50° C for four hours allowed 34.12% of protein and that the temperature of 60° C for six hours lowered the protein content to 27.65%. Olson *et al*. (2016) obtained an average of 29.10% of protein from 23 moringa accessions, of which 25.9% corresponded to soluble protein. The above guarantees moringa leaves as a low-cost protein source. Table 3 shows significant variation in the nutritional content of moringa under different temperatures and dehydration times in the oven.

Table 4. The nutritional content of 100 g of *M. oleifera* leaves under different dehydration techniques.

Humidity (%)	Ash (%)	Fat (%)	Fiber (%)	Protein (%)	Carbohydrates (%)	Dehaydration method	Temperature (°C)	Time (days)	Method AOAC	Source
75.90	NR*	1.70	0.90	6.70	12.50	Fresh leaves	NR	NR	(2004)	Joshi and Mehta, 2010
6.00	NR	6.99	11.30	23.42	27.98	Solar drying	NR	4		
6.00	NR	7.03	12.10	23.66	28.48	Shade drying	NR	6		
6.00	NR	7.01	11.80	23.78	28.32	Oven	60	1 h		
75.90	4.66	1.50	10.67	13.13	2.18	Fresh leaves	NR	NR	(2000)	Foline *et al.*, 2011
5.50	7.33	3.25	10.12	27.26	39.90	Mixture	50	NR		
4.70	8.00	3.25	9.80	26.20	41.03	Solar drying	NR	NR		
5.10	7.83	6.00	10.30	35.60	29.08	Ambient	Ambient	NR		
75.90	NR	1.70	0.90	6.70	12.50	Fresh leaves	NR	NR	(2004)	Chandramouli *et al.* 2012
6.00	NR	6.98	11.30	23.42	27.98	Solar drying	NR	4		
6.00	NR	7.03	12.10	23.66	28.47	Shade drying	NR	6		
6.00	NR	7.01	11.80	23.78	28.32	Oven	60	4-5 h		
13.67	9.33	2.33	3.00	28.50	56.50	Shade drying	23 – 27	6	(1990)	Sani, 2015
2.67	12.00	6.00	7.17	3.20	71.67	Solar drying	Variable	NR		
5.67	9.50	4.83	10.50	6.80	68.37	Oven	60	24 h		
8.50	9.17	6.50	3.00	14.30	67.03	Solar drying	NR	NR		
5.10	8.30	9.70	11.50	31.90	37.50	Oven	60	4 h	(2005)	Kshirsagar *et al*., 2017
5.90	8.50	8.70	10.90	29.70	42.70	Shade drying	NR	6		
5.70	5.30	8.90	11.30	26.20	43.30	Solar drying	NR	4		
5.91	0.12	NR	NR	30.87	NR	Solar drying	NR	6 h		Setiaboma *et al.*, 2019
10.74	0.11	NR	NR	30.85	NR	Shade drying	29	42 h		
4.80	0.11	NR	NR	30.16	NR	Shade drying	50	6 h		
75.33	2.46	0.78	3.41	6.01	12.28	Fresh leaves	NR	NR	(2000)	Umerah *et al*., 2019
8.99	13.21	3.06	11.96	14.26	48.58	Solar drying	NR	NR		
11.04	15.22	3.81	13.14	17.68	39.11	Shade drying	NR	NR		

NR: no report

One of the disadvantages of high oven dehydration temperatures is the Maillard reaction that causes a reaction between proteins and carbohydrates, reducing the nutritional content in moringa leaves (Clement *et al*., 2017).

Combination of dehydration methods

The correct use of dehydration techniques allows more nutrients to be concentrated in the dried moringa leaves and prolongs their shelf life (Kshirsagar *et al*., 2017). Foline *et al*. (2011) mentioned that dehydration in the sun decreased the protein and fat content and identified a higher incidence of bacteria and fungi than dehydrated in mixed dehydration (shade + oven). In addition, the latter retains a significant amount of nutrients due to time and temperature control. Direct sun dehydration denatures amino acids and affects the crude protein content in moringa leaves. Regarding the ash and fiber content, these are little affected by the temperature or type of dehydration (Foline *et al*., 2011).

Umerah *et al*. (2019) studied fresh leaves and two types of dehydration methods (shade, direct sun) and identified that the highest amount of protein, fat, ash, and fiber was found in leaves dehydrated in the shade. Dehydration in the shade and indirect sun are the most frequent. However, it has many disadvantages, such as the risk of contamination, the quality is not constant, the volume obtained is low, and the dehydration time is long (Alakali *et al*., 2015). The high moisture content in the leaves dehydrated in the shade negatively affected the conservation time (Madukwe *et al*., 2013). Kshirsagar *et al*. (2017) showed statistical differences in protein, fiber, and fat content when applying different dehydration methods to moringa leaves, and they point to oven dehydration as the most appropriate technique. Table 4 shows the results of the effect of different dehydration methods on the nutritional content of moringa leaves.

The control of the temperature and the dehydration time allows obtaining a greater quantity of nutrients and more significant volumes of dry leaf or flour in less time. Lamidi *et al*. (2017) mentioned that adequate drying must be applied to obtain high protein levels.

Genetic factors

Rajput *et al*. (2017) mention that the fresh and dried leaves of the PKM-1 variety of moringa present many minerals, protein, crude fiber, fats, and carbohydrates. Miten *et al*. (2017) evaluated four genetic variants of moringa grown in the same area, and they determined that the content of protein and essential amino acids was higher in the odorous green variant compared to the green, red and reddish-green variants, while

Sultana (2020) identified differences in the nutritional content of leaves of five cultivars evaluated. Moyo *et al*. (2011) reported the chemical content of the African ecotype and El-Sohaimy *et al*. (2015) of the Egyptian ecotype, both with high nutritional content. In Mexico, Pérez-Ángel *et al*. (2020) identified statistical variation in the nutritional content of six moringa ecotypes introduced to the state of Sinaloa (Table 5). These investigations show that genetic variants present differences in their nutritional content. However, little research mentions the variety, ecotype, line, or cultivar used during the nutritional evaluation. This lack of information limits the maximum use of the nutritional content of moringa leaves from local crops (Leone *et al*., 2015).

Edaphoclimatic factors

Tables 3 and 4 show a significant difference in nutritional content, and this variation may also be due to factors such as temperature (minimum and maximum), precipitation (250-3000 mm), altitude, plant community, soil texture, pH, and organic matter content (Melesse, 2011). Variation in environmental factors affects plant phenology and physiology and alters nutrient synthesis. Aja *et al*. (2013) and Korsor *et al*. (2017) mentioned that the protein, fat, ash, and fiber contents presented significant variation due to the geographical location of the crop and the sampling season. Lamidi *et al*. (2017) identified statistical differences in the content of moisture, fat, fiber, ash,

Table 5. The nutritional content of 100 g of dried leaves of varieties or ecotypes of *M. oleifera*.

Varieties or ecotypes	Humidity (%)	Ash (%)	Fat (%)	Fiber (%)	Protein (%)	Carbohydrates (%)	Source
Green	NR*	10.9	7.42	6.84	33.9	NR	Miten *et al*., 2017
Green-redish	NR	9.92	9.99	8.73	27.5	NR	
Red	NR	8.7	8.99	7.14	28.4	NR	
Aromatic green	NR	11.7	6.97	7.74	36.5	NR	
Chaitali Joy	8.29^{ab}	10.38^{a}	9.51^{a}	9.60^{a}	23.26^{d}	47.25^{d}	Sultana, 2020
Barsali Joy	7.55^{c}	9.22^{b}	4.45^{c}	8.00^{b}	29.36^{a}	48.97^{c}	
Baromashi Joy	8.22^{ab}	8.05^{c}	5.25^{b}	6.40^{c}	24.05^{c}	56.25^{a}	
Chaitali Mym	8.65^{a}	8.79^{b}	5.52^{b}	6.70^{c}	22.99^{d}	56.00^{a}	
Baromashi Mym	7.94^{bc}	10.29^{a}	4.03^{d}	6.00^{c}	25.56^{b}	54.12^{b}	
Culiacán	8.67^{a}	8.6^{bc}	8.74^{ab}	13.18^{a}	29.24^{a}	40.24^{ab}	Pérez-Ángel *et al*., 2020
Elota	6.94^{b}	9.08^{ab}	6.09^{d}	12.44^{ab}	30.36^{a}	40.02^{ab}	
Guerrero	7.41^{ab}	9.17^{ab}	8.28^{bc}	9.46^{bc}	28.93^{a}	44.16^{bc}	
Mojolo	8.22^{ab}	9.62^{a}	9.17^{a}	12.6^{ab}	29.54^{a}	39.07^{c}	
Sinaloa	7.23^{ab}	8.97^{ab}	8.74^{ab}	12.65^{ab}	29.87^{a}	39.77^{c}	
Sonora	8.14^{ab}	7.98^{c}	7.62^{c}	11.52^{b}	24.9^{b}	47.99^{a}	

NR: no report

Table 6. The nutritional content of 100 g of dried leaves of *M. oleifera* from different geographical locations.

Population	Ash (%)	Fat (%)	Fiber (%)	Protein (%)	Carbohydrates (%)	Source
Chaiyaphum	7.86	2.47	18.3	19.15	NR*	Jongrungruangchok *et al.*, 2010
Nakhonsawan	6.78	2.16	16.39	28.8	NR	
Nongbualumphu	7.05	2.20	22.25	23.05	NR	
Chad	10.79	6.65	33.29	31.47	12.41	Leone *et al.*, 2015
Sahrawi camps	13.38	4.85	31.88	27.98	11.37	
Haití	9.62	7.05	37.63	20.80	13.75	
Malawi	NR	NR	NR	27.70	NR	Stadtlander y Becker, 2017
Nicaragua	NR	37.40	NR	36.70	NR	
India	NR	37.00	NR	37.50	NR	
Ethiopia	NR	28.50	NR	34.70	NR	
Sonora	13.38	10.76	15.97	18.34	41.58	Guzmán-Maldonado *et al.*, 2020
Guerrero	6.83	6.95	16.46	21.79	48.45	

NR: no report

and carbohydrates of four crops with different geographical locations and attributed the effect of soil type to the nutritional content of the leaves. The protein, fat, and fiber contents present high levels of variation in samples obtained under different edaphoclimatic conditions (Leone *et al*., 2015) (Table 6). This variation in edaphoclimatic conditions is also reflected in the protein and fat content of samples collected in Malawi, Nicaragua, India, and Ethiopia (Stadtlander and Becker, 2017).

Crops located in warm climates affect the nutritional content of the leaves because high temperatures denature proteins (Asante *et al*., 2014). Melesse (2011) and Lamidi *et al*. (2017) mentioned the importance of knowing the environmental conditions since they determine the properties of the soil and, in turn, influence the nutritional content in moringa. Environmental variation influences genetic materials and originates different phenotypes with differences in their nutritional composition (Miten *et al*., 2017).

Regarding the year's season, Shih *et al*. (2011) identified that the ash content is higher in winter than in summer. Furthermore, Valdez-Solana *et al*. (2015) mentioned that seasonal variations could influence the results obtained from nutritional analyzes. Melesse *et al*. (2012) mentioned a variation in fiber and mineral content due to altitude and season of the year (Table 7). Their work observed higher nutritional yields at altitudes of 1 700 m., while Yang *et al*. (2006) identified that more protein is concentrated in the warm-humid season than in the cold-dry season. The above mentioned is because the moisture in the soil contributes to the absorption of nutrients and promotes better leaf development (Asante *et al*., 2014). Yaméogo *et al*. (2011) identified a significant variation in the nutritional content of moringa leaves collected in three different sectors of Ouagadougou city, Burkina Faso. The authors pointed out that the three sectors showed the same climate and mentioned that the only source of variation was soil type that affected the mineral absorption process. However, they do not mention the soil type of each geographic point sampled.

Agronomic management factors

Reyes *et al*. (2006) mention that the frequency of harvesting of moringa leaves has a significant effect on the content of fiber, ash, and dry matter. These same authors indicated that the 75-day cutting frequency presented a better use of the nutrients (Table 8). Basra *et al*. (2015) determined that the sowing density and the harvest period influence the nutritional composition of the leaves since the plants compete for the soil's nutrients and mention that 30-day periods are adequate for the collection of leaves.

Table 7. The nutritional content of 100 g of dry leaflets of *M. oleifera* under different climatic conditions (six years old).

Climate	T Min (°C)	T Max (°C)	RH (%)	Precipitation (mm)	Sampling season	Altitude (m)	Ash (%)	Fiber (%)	Protein (%)	Carbohydrates (%)
Warm	13.3	27.5	62.1	957	Rainy season	1 700	13.1	10.4	28.6	35.2
	13.3	27.5	62.1	957	Dry season	1 700	13.2	9.9	28.7	37.6
Warm subhumid	16.8	29.9	54.6	886	Rainy season	1 100	13.2	8.0	29.0	33.9
	16.8	29.9	54.6	886	Dry season	1 100	13.3	9.0	28.9	35.0

Source: Melesse *et al*. (2012)

Table 8. The nutritional content of 100 g of dry leaves of *M. oleifera* under different harvest frequencies and crop ages.

Harvest frequency (days)	Crude Protein (%)	Neutral detergent fiber (%)	Acid detergent fiber (%)	Ash (%)	Crop age (years)
45	22.63^{a}	32.12^{b}	22.76^{a}	8.58^{b}	1
60	22.89^{a}	28.9^{a}	20.31^{a}	9.06^{a}	
75	22.25^{a}	30.75^{ab}	22.51^{a}	9.14^{a}	
45	21.11^{a}	39.68^{a}	26.61^{a}	9.67^{a}	2
60	21.38^{a}	36.30^{b}	23.41^{b}	9.08^{b}	
75	21.57^{a}	38.07^{ab}	25.31^{a}	9.71^{a}	

Source: Reyes *et al*. (2006)

Table 9. The nutritional content of 100 g of dried leaves of *M. oleifera* under different nitrogen levels (N).

Treatment (kg N ha^{-1})	Ash (%)	Fat (%)	Crude Fiber (%)	Crude Protein (%)	Carbohydrates (%)	DM* (%)
0	6.36^{a}	5.01^{c}	26.08^{a}	16.67^{a}	28.33^{c}	87.44^{b}
50	6.87^{bc}	2.56^{b}	31.00^{a}	21.63^{b}	27.72^{c}	87.97^{b}
100	7.05^{bc}	1.09^{a}	25.57^{a}	25.40^{c}	26.83^{c}	87.43^{b}
150	6.74^{ab}	2.39^{b}	28.94^{a}	29.11^{d}	24.92^{b}	87.85^{b}
200	7.29^{a}	1.11^{a}	29.30^{a}	32.99^{e}	22.56^{a}	87.51^{b}
250	8.33^{d}	1.77^{ab}	29.65^{a}	32.69^{e}	20.95^{a}	83.28^{a}

DM: dry matter; Source: Mouchili *et al*. (2019).

Table 10. The nutritional content of 100 g of dry leaves of different colors and degrees of maturity of *M. oleifera* leaves.

Characteristic	Variable	Humidity (%)	Crude Protein (%)	Carbohydrates (%)	Fiber (%)	Ash (%)	Fat (%)	Source
Leaves color	Green	9.86	16.00	22.00	NR*	35.81	16.33	Fokwen *et al*., 2018
	Yellow	10.56	12.00	26.93	NR	33.94	16.56	
Leaves maturity	Early	6.0^{a}	27.61^{ab}	55.14^{c}	9.80^{a}	5.75^{a}	1.5^{a}	Bamishaiye *et al*., 2011
	Medium	6.3^{a}	23.7^{b}	53.53^{b}	8.20^{b}	8.0^{b}	2.0^{a}	
	Late	6.1^{a}	28.08^{a}	47.09^{a}	10.11^{a}	9.25^{b}	2.5^{a}	

NR: No report

The nutritional composition in moringa leaves shows a decrease due to the lack of a fertilization plan (Reyes *et al*., 2006), and this is aggravated when there are high planting densities. Fertilizations of 521 kg N ha^{-1} $year^{-1}$ significantly increase the crude protein content in dried moringa leaves, and high doses of N can decrease the fiber content (Mendieta-Araica *et al*., 2013; Korsor *et al*., 2017). He *et al*. (2020) mentioned that the full content of N at the tissue level is reached by applying 1 400 kg N ha^{-1}, while Mouchili *et al*. (2018) identified that fertilization increases the protein and fat contents in the leaves and that high amounts of N can reduce the carbohydrate content by half (Table 9). Regarding organic fertilization, the use of poultry manure significantly increases N content in moringa leaves (Dania *et al*., 2014).

Phenological factors

Phenological factors influence the nutritional content of moringa leaves. Research by Yang *et al*. (2006) and Dolma and Tashi (2020) reported that the mature leaves and sprouts of 3-year-old trees contain a higher content of nutrients and have a high dehydration speed. Joshi and Mehta (2010), Melesse *et al*. (2012), and Setiaboma *et al*. (2019) reported the nutritional content of leaflets and not the entire leaves. The latter is because there is a consumer preference for the leaflets and not for the fibrous rachis of the leaves (Olson *et al*., 2016). Regarding the color of the leaf, Fokwen *et al*. (2018) identified that green leaves had a higher content of minerals (P, K, Na, Ca, and Mg) and a higher antioxidant capacity (Table 10).

Other factors that can influence the nutritional content of the leaves are the age of the plant, the origin of the plant (crop, wild population, or genetically improved population) and maturity of the leaves (Isitua *et al*., 2015), harvest time, material, temperature, and storage time before and after dehydration (Miten *et al*., 2017; Sultana, 2020). These factors influence the nutritional content due to the accumulation and conservation of nutrients in the field and postharvest phase.

Storage before and after dehydration

After harvesting, the fresh leaves must be washed and disinfected. Subsequently, they should be stored in polyethylene bags, airtight bags, or aluminum inside containers with ice bags or frozen gels (Sanchinelli, 2004; Miten *et al*., 2017). Lowering the temperature in the container reduces the enzymatic activity and prevents the loss of protein (Asante *et al*., 2014). If dehydration will not occur immediately, it is recommended to store the leaves at -18 °C (Massry *et al*., 2013).

After dehydration, the leaves should be stored in airtight or opaque jars, clean, dry, and at a low temperature (-20 or 4-6 °C) to preserve the chemical composition. The maximum moisture content in the flour should not be more than 4.8% (Leone *et al*., 2015; Rajput *et al*., 2017). Samples obtained through commercialized products must be kept in low temperature and low light conditions (Amabye *et al*., 2015).

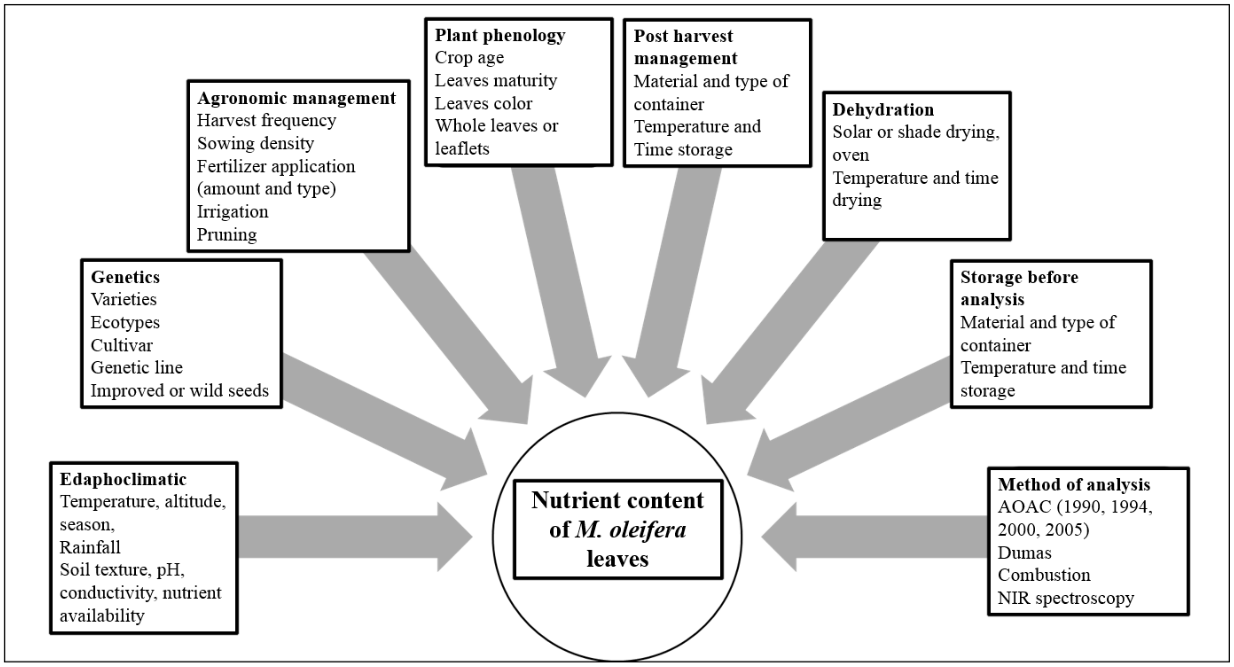

Figure 1. Main factors that influence the nutritional content of dried *M. oleifera* leaves.

Regarding the analysis of nutritional content, a high frequency of the AOAC methodology, 1990, 2000, 2004, and 2005 was observed and, in a few cases, the Weende method for the determination of fiber. The Kjeldahl method was the most used to determine the protein content, and the Dumas or combustion method was the least frequently used (Olson *et al*., 2016; Korsor *et al*., 2017). The fat quantification was mainly done by the AOAC protocol and the method of Folch *et al*. (1957). Figure 1 shows the summary of factors that influence the nutritional content of dried moringa leaves.

CONCLUSIONS

The significant variation in the nutritional content of *M. oleifera* is due to the interaction of multiple factors that have a positive or negative effect on the chemical composition of the leaves. Fertilization is the factor that most influences the protein content when agronomic management is carried out. The temperature and dehydration type are the factors that showed the most significant influence on the decrease in the nutritional content of the leaves in postharvest management. Identifying the factors that affect the nutritional content allows a better understanding of the protein, fat, ash, fiber, and carbohydrate content in *M. oleifera* leaves under specific geographic conditions. Controlling or minimizing the effect of each factor (agronomic, phenological, postharvest, and dehydration) facilitates standardization in the sowing, harvesting, and laboratory processes. The high content of nutrients in *M. oleifera* leaves can be used for human and animal nutrition. The frequent consumption of the leaves prevents diseases associated with deficiency of nutrients. Moringa leaves serve as food to reduce protein-energy malnutrition in populations with scarce food.

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