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REVIEW

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Biological, nutritional, and therapeutic significance of *Moringa oleifera* Lam

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The genus *Moringa* Adans. comprises 13 species, of which *Moringa oleifera* Lam. native to India and cultivated across the world owing to its drought and frost resistance habit is widely used in traditional phytomedicine and as rich source of essential nutrients. Wide spectrum of phytochemical ingredients among leaf, flower, fruit, seed, seed oil, bark, and root depend on cultivar, season, and locality. The scientific studies provide insights on the use of *M. oleifera* with different aqueous, hydroalcoholic, alcoholic, and other organic solvent preparations of different parts for therapeutic activities, that is, antibiocidal, antitumor, antioxidant, anti-inflammatory, cardio-protective, hepato-protective, neuro-protective, tissue-protective, and other biological activities with a high degree of safety. A wide variety of alkaloid and sterol, polyphenols and phenolic acids, fatty acids, flavanoids and flavanol glycosides, glucosinolate and isothiocyanate, terpene, anthocyanins etc. are believed to be responsible for the pragmatic effects. Seeds are used with a view of low-cost biosorbent and coagulant agent for the removal of metals and microbial contamination from waste water. Thus, the present review explores the use of *M. oleifera* across disciplines for its prominent bioactive ingredients, nutraceutical, therapeutic uses and deals with agricultural, veterinarian, biosorbent, coagulation, biodiesel, and other industrial properties of this "Miracle Tree."

KEYWORDS

Moringa oleifera, nutritional properties, phytochemistry, therapeutic activities, water purification

1 | INTRODUCTION—RATIONALE AND OBJECTIVES

Approximately 80% of the total population depends only on plants for their well-being and healing (Ekor, 2014), and 25% of the integrated medications are made from medicinal and aromatic plants (Pan et al., 2013). The last few decades have seen chemical revolution, and most of things such as food, drugs, agriculture, and environment have been filled with chemicals. As the new discoveries are being made day by day and increasing dependency on chemical supplements and junk foods, the adverse effects of chemicals are being exposed and development of resistance against orthodox medicines; thus, human attention has shifted towards the use of herbal plants, natural products, and organic farming (Igado & Olopade, 2016), especially because they are generally considered safe and sound. The traditional knowledge in Ayurveda is still in practice, which has made a good amalgam of traditional and scientific knowledge. Recently, *M. oleifera* tree has been used as a remarkable indigenous source of protein, crude fibers, minerals, and nutrients suitable for utilization in developing nations where undernourishment is a major concern (Verma & Nigam, 2014). *Moringa* tree has been used to combat malnutrition, especially among newborns and nursing mothers. Different organizations have promoted *Moringa* as "natural nutrition for the tropics" (Fahey, 2005).

M. oleifera (MO) belongs to monogeneric family *Moringaceae* (Marrufo et al., 2013) and known as sahjana, drumstick, and Horseradish tree. *Moringa* derives from a Tamil word, *murungai*, meaning "twisted pod," alluding to the young fruit (Olsen, 2010). It is native to dry tropical forest of north-west India and foothills of the Himalaya (Lalas, Gortzi, Athanasiadis, Tsaknis, & Chinou, 2012). *M. oleifera*, *M. concanensis*, and *M. hildebrandtii* are scattered in the south Asia and Arabia; *M. drouhardii* in Madagascar; *M. stenopetala*, *M. arborea*, *M. borziana*, *M. longituba*, *M. pygmaea*, *M. rivae*, and *M. ruspoliana* in north-east and north-west Africa; *M. peregrina* in Red Sea, Arabia, Horn of Africa; *M. ovalifolia* in Namibia and South west Angola (Mark & Sylvain, 2006). Out of 13 species (Sengupta & Gupta, 1970), *M. oleifera* [syn. *M. pterygosperma* Gaertn. Nom. illeg, *Guilandina moringa* L. and *Hyperanthera moringa* (L.) Vahl] is extensively utilized and well-known species in most parts of Asia and Africa. Recorded evidences reveal that ancient rulers utilized *Moringa* leaves and natural product in their diet routine to keep up mental health and smooth skin (Mahmood, MugalI, & Haq, 2010). Each and all parts of *Moringa* are valuable for medicinal, useful food ingredients, nutraceuticals, water sanitization, and biofuel production (Saini, Sivanesan, & Keum, 2016). The flowers, unripened fruits, and leaves are utilized for cooking purposes worldwide (Stevens, Baiyeri, & Akinnnagbe, 2013). Specifically, they are consumed for human and animal nourishment and treatment of many disorders in Asian and African countries (Mbikay, 2012).

Despite its extensive uses in food and medicines, there are very few studies on clinical trials to demonstrate the efficacy for treating malnutrition and undeniable therapeutic action of *Moringa* leaf and other products in human beings. Owing medicinal significance, the seed oil of *Moringa* is widely used for medications due to high content of oleic acid, that is, 72% (Anwar & Rashid, 2007) in African and Asian countries. In spite of its (MO) self evident importance in practical utility and consisting food ingredients and natural remedial properties, there is an urgent need to screen the bioactive ingredients of *Moringa* for herbal therapy along with other ayurvedic treatments and geographical variations for nutrients worldwide. Thus, after reviewing the literature on phytochemical, nutritional, therapeutic properties, commercial use as biosorbent, and coagulant properties of *M. oleifera*, it is worthwhile to compile a comprehensive and updated review.

2 | METHODOLOGY

2.1 | Search strategem

The informations quoted in this review on *M. oleifera* Lam. along with its chemistry and plant part uses were searched and obtained using databases such as university online databases subscribed, Consortium for e-Resources in Agriculture, Krishikosh (An Institutional Repository of Indian National Agricultural Research System), Open Access e-Resources like PubMed, Science Direct, Scopus, MedLine, Research Gate, and Google Scholar. All were searched with the keyword "*Moringa oleifera* Lam." along with "phytochemical constituents," "nutritive value," "food fortification," "therapeutic activities," "agriculture and animal husbandry uses," "coagulant/biosorbent/biodiesel uses," and "industrial uses." No language restrictions were imposed. Research papers were assessed for the information about the extracts or fractions and isolated compounds of the plant or its parts, results of that particular study. The search process was also conducted by using a combination of different categories of keywords like "bacteria," "fungi," "parasites," "nematodes," and medical subject terms namely, "cancer," "tumor," "antioxidant," "anti-inflammation," "diabetes," "hypoglycemic," "hyperlipidemic," "cholesterol," and "blood sugar." To increase the search sensitivity, quotation marks, parentheses, and asterisks were applied to search for the exact terms or expressions, locating a group of search terms and all of the words derived from one keyword, respectively. Finally, the reference lists of selected studies and previous reviews were manually screened to acquire other applicable publications.

2.2 | Data extraction

We extracted the following information from the full-text research papers and review articles of appropriate studies. Among the vast evidences, published articles listed in reference section were found in the databases that contain screening reports on the phytochemical and/or therapeutic activities of *M. oleifera* or its crude extracts/fractions or isolated compounds. The observed information in the included literatures has been summarized in the present review.

3 | RESULTS AND DISCUSSION

3.1 | Phytochemical profiling

Different parts of *M. oleifera* have been used for good source of unique glucosinolates, flavonoids and phenolic acids (Amaglo et al., 2010; Coppin et al., 2013), polyunsaturated unsaturated fatty acids (PUFAs), tocopherols, exceedingly minerals, and folate (Saini et al., 2016). Leaves aqueous extract contained 1.66% isothiocyanates and 3.82% total polyphenols (Waterman et al., 2014). Glucosinolates (glucomoringin) and isothiocyanates are the predominantly in the foliage, flowers, fruits, seeds, and bark of MO (Amaglo et al., 2010). Despite the fact that benzyl glucosinolate (glucotropaeolin) is prominently in roots, the highest noteworthy substance, that is, glucosinolate is reported in the leaves and seeds. The myrosinase enzymatic catabolism of glucosinolates produced isothiocyanates, nitriles, and thiocarbamates (Anwar, Latif, Ashraf, & Gilani, 2007). Among flavonol glycosides, quercetin and isorhamnetin are prevalently found in various plant parts except in seeds and roots. Refined gum exudates contain galactose, glucuronic acid, larabinose, mannose, rhamnose, and xylose (Shah, Jhade, & Chouksey, 2016). All-E-lutein is the main carotenoid in leaves and immature fruits, representing 53.6% and 52.0% of total carotenoids. Among different tissues, the most astounding substance of total carotenoids is reported in leaves (44.30–80.48 mg/100 g FW), followed by immature pods (29.66 mg/100 g FW), and flowers (5.44 mg/100 g FW). Singh et al. (2009) recorded total

phenolic content (105 mg gallic acid equivalents/100 g), flavonoid (31 mg quercetin equivalents/100 g), and ascorbic acid (107 mg/100 g) in leaves. It is an established fact that leaves are a rich source of omega-3 and omega-6 PUFAs, as linolenic acid (49–59%) and linoleic acid (6–13%). Palmitic acid is reported as major unsaturated fat, representing 16–18% of total unsaturated fats in leaves. Pods and inflorescences are described by a higher substance of total monounsaturated unsaturated fatty acids with the range of 16–30% and are low in PUFAs (34–47%), contrasted with the leaves (Saini, Shetty, & Giridhar, 2014). Interestingly, the seeds and seed oil contain a high amount of oleic (70–80%), palmitoleic (6-10%), stearic (4–10%), arachidic (2–4%), and low amount of linoleic and linolenic acids (Amaglo et al., 2010). MO leaves had high amount of total phenoloc compounds (56.10 ± 0.90 mg gallic acid gDW^{-1}), total flavonoid (38.90 ± 1.90 mg catechol gDW^{-1}), and total anthocyanin (23.10 ± 1.30 mgcy-3-glug DW^{-1}), which are primary antioxidants (Al-Juhaimi, Ghafoor, Babiker, Matthaus, & Ozcan, 2017). Phytochemical constituents reported from different parts of *M. oleifera* are presented in Table 1 & 2.

3.1.1 | Chemical composition of leaf

Sixteen bioactive compounds have been identified in methanolic extract of leaves (Aja et al., 2014). The quercetin (0.07–1.26%) and kaempferol (0.05–0.67%) were major phytochemicals in leaves, and Indian MO varieties, that is, PKM-1 and PKM-2 had higher quercetin and kaempferol contrasted with the African indigenous varieties (Coppin et al., 2013). The quercetin, kaempferol, and apigenin were reported 47.0%, 30.0%, and 20.9% of the total flavonoids from leaf hydromethanolic extracts (Nouman et al., 2016). 5-Formyl-5,6,7,8-tetrahydrofolic acid, 5,6,7,8-tetrahydrofolic acid, 5-Methyl-5,6,7,8-tetrahydrofolic acid and 10-Formylfolic acid were the main folates reported from leaves (Saini et al., 2016). Chemical constituents varied with the growing environment and edaphic factors. Thirty-seven compounds were identified in leaves of MO grown at Madurai and 50 from Chennai locality (Chelliah, Ramakrishnan, & Antony, 2017). 1,30-triacontanediol (14.98%), octacosane (8.57%), Z-14-nonacosane (8.3%), and 2,2-dimethyl-1-oxa- 2-silacyclotrid ecanone-13 (8.28%) were the major constituents isolated from Madurai locality. Nonacosane (15.55%) and γ-sitosterol (9.56%) were the major constituents from Chennai locality. Leone et al. (2015a) worked with the phenolic profiling through HPLC chromatogram of methanolic extracts of MO leaves of three different genotypes collected from Logone's Valley, Chad. As expected, flavonoids were the principal phenolic compounds. They identified 18 major compounds and two unidentified minor compounds. Quercetin-3-O-glucoside, quercetin-3-O-(6′′-malonyl)glucoside, quercetin-3-O-(X′′-malonyl)glucoside, kaempferol-3-O-glucoside, kaempferol-3-O-malonylglucoside were recognized in all genotypes with agreement of previous reports (Amaglo et al., 2010; Atawodi et al., 2010; Forster et al., 2015). In addition, glicosilated flavonoid, quercetin-3-O-glucoside-7-O-rhamnoside, methyl-O-quercetin-malonylglucoside, isorhamnetin-rhamnosyl-glucoside, rhamnosyl-glucoside, apigenin-C-glucoside, apigenin-O-glucoside, hexadecylferulate, 5-hydroxyferulic acid glucoside, diferuloyl-(5OH-feruloyl)spermidine, glucosinolates, dicoumaroyl putrescine, di (dihydrocaffeoyl)spermidine, and two additional polyamine alkaloids were identified (Karthivashan, Fard, Arulselvan, Abas, & Fakurazi, 2013). The most abundant phenolic compounds (mg/100 g DW) in MO leaves were gallic acid (1.145 ± 0.078), 4-hyrdoxbenzoic acid (0.710 ± 0.099), and isorhamnetin (0.475 ± 0.059) followed by protocatechuic acid, catechin, cafeic acid, syringic acid, rutin trihydrate, trans *p*-coumaric acid, chlorogenic acid, trans ferulic acid, fisetin, trans resveratrol, quercetin, trans cinnamic acid, and naringenin (Al-Juhaimi, Ghafoor, Mohamed Ahmed, Babiker, & Ozcan, 2017).

3.1.2 | Chemical composition of leaf oil

M. oleifera leaves yielded 0.05% pale yellow color oil by hydrodistillation method (Marrufo et al., 2013). Chemical constituents of leaf oil of MO collected from Mozambique were oxygenated monoterpenes (linalool and α-terpineol), phenolic compounds (*p*-vinylguaiacol), oxygenated sesquiterpenes, that is, *cis*-dihydroagarofuran (0.1), Eudesm-11-en-4-α,6α-diol (0.6), and hydrocarbons, that is, eicosane (1.2), heneicosane (1.9), docosane (6.8), tricosane (8.1), tetracosane (9.7), pentacosane (13.3), hexacosane (13.9), heptacosane (11.4), octacosane (10.0), nonacosane (10.5), triacontane (1.1), 1-octadecene (0.3), octadecane (0.1), 5-Octadecin (0.3), n-hexadecanol (0.1), nonadecane (0.8), 1-eicosene (0.3), n-octadecanol (0.2), cyclopentadecanol (0.4), 1-docosene (0.4), cis-9-eicosen-1-ol (0.3), pseudo phytol (0.5), and two other compounds, that is, hexenyl propanoate and phenylethyl alcohol. Pentacosane (17.4%), hexacosane (11.2%), and (E)-phytol (7.7%) were main constituents of leaf oil grown in Taiwan (Chuang et al., 2007). Phytol (21.6%) and thymol (9.6%) have been reported as the most abundant compound in leaf oil of MO grown at Ceara, Brazil (Barreto et al., 2009). Mukunzi et al. (2011) recorded the correlation of chemical profile of MO leaves to the locality where the plants were grown at Rwanda and China. The Rwandan genotype contained 59 constituents, with hexanoic acid (19.8% of total volatiles) as the most abundant one, whereas the Chinese genotype contained mainly acetic acid (12.5%). Nonacosane (18.6%), 1,2,4-trimethyl-benzene (16.9%) and heptacosane (7.4%) were the main constituents in leaf oil (Zhao & Zhang, 2011). MO leaf oil contained 48.88% oleic acid, 18.09% linoleic acid, 9.32% linolenic acid, and stearic acid 2.77%. Apart from *M. oleifera*, fatty acid composition of *M. peregrina* leaf oil was investigated (Al-Juhaimi, Babiker, Ghafoor, & Ozcan, 2016). A total of 12 fatty acids were detected in the leaf oil and linolenic acid recorded the highest (32.53%).

3.1.3 | Chemical composition of seed

Seed oil is commercially known as “ben oil” or “behen oil” with nutty flavor and light yellow color and like olive oil (Nautiyal & Venhataraman, 1987). The seeds contain about 35% rosy yellow essential oil, 31.65% protein, 8.90% moisture, 7.54% fiber, and 6.53% ash substance (Mahmood et al., 2010). The seeds of *M. oleifera* contain 40.98% oil (Al-Juhaimi, Ghafoor, Babiker, et al., 2017), which is slight lower seed oil yield than seeds of *M. peregrina* (49.23%), of

TABLE 1 Phytochemical constituents isolated from *Moringa oleifera* Lam.

S.N.	Compound name	Plant part	References
Flavanoids and flavanol glycosides			
1.	Rutin	Leaves	Elbatran et al. (2005); Devaraj, Krishna, and Viswanatha (2011); Habtemariam and Varghese (2015)
2.	Quercetin	Leaves	Elbatran et al. (2005); Devaraj et al. (2011); El-Alfy, Ezzat, Hegazy, Amer, and Kamel (2011)
3.	Isoquercetin	Leaves	Vongsak, Sithisarn, and Gritsanapan, (2014)
4.	Astragalin	Leaves	Vongsak et al. (2014)
5.	Isorhamnetin	Leaves	Leone et al. (2015)
6.	Kaempferol	Leaves	Manguro and Lemmen (2007); Devaraj et al. (2011); Leone, Spada, et al. (2015)
7.	Apigenin	Leaves,	Tahany et al. (2010); El-Alfy et al. (2011)
8.	Luteolin	Leaves	Leone, Fiorillo, et al. (2015)
9.	Genistein	Leaves	Leone, Fiorillo, et al. (2015)
10.	Daidzein	leaves	Leone, Fiorillo, et al. (2015)
11.	Myricetin	Leaves, seeds	Lalas and Tsaknis (2002b); Leone, Fiorillo, et al. (2015)
12.	Epicatechin	Leaves	Leone, Fiorillo, et al. (2015)
13.	Procyanidins	Roots, stem bark	Atawodi et al. (2010)
14.	Vicenin-2	Leaves	Muhammad, Arulselvan, Cheah, Abas, and Fakurazi (2016)
15.	Quercetin-3-O-glucoside	Leaves, seeds	Manguro and Lemmen (2007); Leone, Spada, et al. (2015); Maiyo, Moodley, and Singh (2016)
16.	Quercetin-3-O-(6″-malonyl) glucoside	Leaves	Leone, Fiorillo, et al. (2015)
17.	Kaempferol-3-O-glucoside	Leaves	Leone, Fiorillo, et al. (2015)
18.	Kaempferol-3-O-(6′′-malonyl) glucoside	Leaves	Leone, Fiorillo, et al. (2015)
19.	Kaempferol-3-rutinoside	Leaves	Leone, Fiorillo, et al. (2015)
20.	Kaempherol-3-O-α-rhamnoside	Leaves	Manguro and Lemmen (2007)
21.	Kaempferide 3-O-(2′′,3′′-diacetylglucoside)	Leaves	Manguro and Lemmen (2007)
22.	Kaempferol-3-O-[β-glucosyl-(1 → 2)]-[a-rhamnosyl-(1 → 6)]-β-glucoside-7-O-a-rhamnoside	Leaves	Manguro and Lemmen (2007)
23.	Kaempferide-3-O-(2′′-galloylrhamnoside)	Leaves	Manguro and Lemmen (2007)
24.	Kaempferide-3-O-(2′′-O-galloylrutinoside)-7-O-α-rhamnoside	Leaves	Manguro and Lemmen (2007)
25.	Kaempferol-3-O-[α-rhamnosyl-(1 → 2)]-[α-rhamnosyl-(1 → 4)]β-glucoside-7-O-α-rhamnoside	Leaves	Manguro and Lemmen (2007)
Glucosinolate and isothiocyanate			
26.	4-(α-L-rhamnopyranosyloxy) benzyl glucosinolate (glucomoringin)	Leaves, seeds, root bark	Mekonnen and Drager (2003); Leone, Spada, et al. (2015); Tumer, Rojas-Silva, Poulev, Raskin, and Waterman (2015)
27.	4-[(2′-O-acetyl-α-L-rhamnosyloxy) benzyl] glucosinolate	Leaves	Leone, Spada, et al. (2015); Tumer et al. (2015)
28.	4-[(3′-O-acetyl-α-L-rhamnosyloxy) benzyl] glucosinolate	Leaves	Leone, Spada, et al. (2015); Tumer et al. (2015)
29.		Leaves	

(Continues)

TABLE 1 (Continued)

S.N.	Compound name	Plant part	References
	4-[(4′-O-Acetyl-α-L-rhamnosyloxy) benzyl] glucosinolate		Leone, Spada, et al. (2015); Tumer et al. (2015)
30.	4-[(α-L-rhamnosyloxy) benzyl] isothiocyanate	Leaves	Tumer et al. (2015)
31.	4-[(2′-O-acetyl-α-L-rhamnosyloxy) benzyl] isothiocyanate	Leaves	Tumer et al. (2015)
32.	4-[(3′-O-acetyl-α-L-rhamnosyloxy) benzyl] isothiocyanate	Leaves	Tumer et al. (2015)
33.	4-[(4′-O-acetyl-α-L-rhamnosyloxy) benzyl] isothiocyanate	Leaves	Mekonen and Gebreyesus (2000); Tumer et al. (2015)
34.	Benzyl glucosinolate (glucotropaeolin)	Seed	Saini et al. (2016)
35.	Sinalbin	Leaves	Leone, Spada, et al. (2015)
36.	4-[(β-D-glucopyranosyl-1- > 4-α-L-rhamnopyranosyloxy) benzyl] isothiocyanate	Leaves, seeds	Maiyo et al. (2016)
Phenolic acid			
37.	Gallic acid	Leaves	Verma, Vijayakumar, Mathela, and Rao (2009)
38.	Salicylic acid	Leaves	Leone, Fiorillo, et al. (2015)
39.	Gentisic acid	Leaves	Leone, Fiorillo, et al. (2015)
40.	Syringic acid	Leaves	Leone, Fiorillo, et al. (2015)
41.	Ellagic acid	Leaves	Verma et al. (2009); Leone, Fiorillo, et al. (2015)
42.	Ferulic acid	Leaves	Verma et al. (2009); Leone, Fiorillo, et al. (2015)
43.	Caffeic acid	Leaves	Leone, Fiorillo, et al. (2015)
44.	*ortho*-Coumaric acid	Leaves	Leone, Fiorillo, et al. (2015)
45.	*p*-Coumaric acid	Leaves	Leone, Fiorillo, et al. (2015)
46.	Sinapic acid	Leaves	Leone, Fiorillo, et al. (2015)
47.	Chlorogenic acid	Leaves	Amaglo et al. (2010); Leone, Spada, et al. (2015)
48.	Cryptochlorogenic acid	Leaves	Vongsak et al. (2014)
Terpene			
49.	All-E-lutein	Pods	Teixeira, Carvalho, Neves, Silva, and Arantes-Pereira (2014); Saini et al. (2016)
50.	All-E-luteoxanthin	Pods	Saini et al. (2016)
51.	13-z-Lutein	Pods	Saini et al. (2016)
52.	15-z-β-Carotene	Pods	Saini et al. (2016)
53.	All-E-zeaxanthin	Pods	Saini et al. (2016)
Alkaloid and sterol			
54.	4′-hydroxyphenylethanamide-α-L-rhamnopyranoside (Marumoside A)	Leaves	Sahakitpichan, Mahidol, Disadee, Ruchirawat, and Kanchanapoom (2011)
55.	3′′-O-β-D-glucopyranosyl derivatives (Marumoside B)	Leaves	Sahakitpichan et al. (2011)
56.	N,α-L-rhamnopyranosyl vincosamide	Leaves	Panda, Kar, Sharma, and Sharma (2013)
57.		Leaves	Sahakitpichan et al. (2011)

(Continues)

TABLE 1 (Continued)

S.N.	Compound name	Plant part	References
	Pyrrolemarumine-4′′-O-α-L-rhamnopyranoside		
58.	Aurantiamide acetate	Roots	Sashidara et al. (2009)
59.	O-Ethyl-4-[(α-L-rhamnosyloxy)-benzyl] carbamate	Seeds	Guevara et al. (1999)
60.	Niazimicin	Leaves, seeds	Guevara et al. (1999); Jung (2014)
61.	N-benzyl, S-ethylthioformate	Root bark	Nikkon, Saud, Rahman, and Haque (2003)
62.	1, 3-Dibenzyl urea	Roots	Sashidara et al. (2009)
63.	Pterygospermin	Seeds	Das, Kurup, Rao, and Ramaswamy (1957)
64.	Spirochin	Roots	Anonymous (2005)
65.	Niaziminin	Leaves	Murakami, Kitazono, Jiwajinda, Koshimizu, and Ohigashi (1998)
66.	β-sitosterol	Leaves, seeds	Abd El Baky and El-Baroty (2013); Maiyo et al. (2016)
67.	β-sitosterol-3-O-α-D-galactopyranoside	Stem bark	Tahany et al. (2010); Bargah and Das (2014)
Others			
68.	Oleic acid	Oil,	Nibret and Wink (2010); Gaikwad, Kale, Bhandare, Urunkar, and Rajmane (2011); Abd El Baky and El-Baroty (2013)
69.	Linoleic acid	Oil	Kleiman, Ashley, and Brown (2008); Abd El Baky and El-Baroty (2013)
70.	Myristic acid	Oil	Kleiman et al. (2008); Nibret and Wink (2010); Abd El Baky and El-Baroty (2013)
71.	Palmitic acid	Oil, roots	Kleiman et al. (2008); Nibret and Wink (2010); Abd El Baky and El-Baroty (2013)
72.	Palmitoleic acid	Oil	Abd El Baky and El-Baroty (2013)
73.	Stearic acid	Oil	Kleiman et al. (2008); Abd El Baky and El-Baroty (2013)
74.	Arachidic acid	Roots, oil	Kleiman et al. (2008); Abd El Baky and El-Baroty (2013)
75.	Linolenic acid	Oil	Abd El Baky and El-Baroty (2013)
76.	Behenic acid	Oil	Kleiman et al. (2008); Abd El Baky and El-Baroty (2013)
77.	Paullinic acid	Oil	Kleiman et al. (2008); Abd El Baky and El-Baroty (2013)
78.	Benzoic acid 4-O-β-glucoside	Leaves	Manguro and Lemmen (2007)
79.	Benzoic acid 4-O-α-rhamnosyl-(1 → 2)-β-glucoside		Manguro and Lemmen (2007)
80.	Benzaldehyde 4-O-β-glucoside		Manguro and Lemmen (2007)
81.	Niazirin	Leaves, pod	Shanker et al. (2007); Sahakitpichan et al. (2011)
82.	Niaziridin	Pod, leaves	Shanker et al. (2007)
83.	Niazirinin	Leaves	Faizi et al. (1994)
84.	Moringyne	Seeds	Memon, Memon, and Memon (1985); Nadkarni (1976)
85.	α-Phellandrene	Oil	Ogunbino, Flamini, Cioni, Adebayo, and Oguwande (2009)
86.	p-Cymene	Oil	Ogunbino et al. (2009); Dehshahri, Afsharypuor, Asghari, and Mohagheghzadeh (2012)
87.	Eugenol	Stem bark	Al-Asmari et al. (2015)
88.	Vanillin	Leaves, fruits, seeds	Singh et al. (2009)
89.	Benzylamine	Leaves	Iffiu-Soltesz et al. (2010)
90.	D-allose	Leaves	Al-Asmari et al. (2015)

(Continues)

TABLE 1 (Continued)

S.N.	Compound name	Plant part	References
91.	L-arabinose, D-galactose, D-glucuronic acid, L-rhamnose	Gum	Nadkarni (1976); Shah et al. (2016)
92.	Aldotriouronic acid	Gum	Rastogi and Mehrotra (2006)
93.	D-mannose	Gum, flower	Nadkarni (1976)
94.	Leucoanthocyanin	Gum	Shah et al. (2016)
95.	Benzylglucosinolate	Seeds, roots	Nadkarni (1976)
96.	4-hydroxymellein	Stem	Nadkarni (1976)
97.	Carotene	Seed oil	Nadkarni (1976)
	Mono-palmitic	Seeds	Nadkarni (1976)
98.	Di-oleic triglyceride	Seeds	Nadkarni (1976)
99.	β-sitosterone	Stem	Nadkarni (1976)
100.	Octacosanic	Stem	Nadkarni (1976)
101.	O-[2′-hydroxy-3′-(2″-heptenyloxy)]-propylundecanoate	Pods	Nadkarni (1976)
102.	O-ethy-l,4-[(α-1-rhamnosyloxy)-benzyl] carbamate	Pods	Nadkarni (1976)
103.	Methyl-p-hydroxybenzoate	Pods	Nadkarni (1976)

TABLE 2 Major phytochemical composition (% DW) of *Moringa oleifera* parts

Phytochemical	Bark	Leaf	Flour	Seed
Phenols	1.95 ± 1.63	2.65 ± 1.15	1.20 ± 0.70	1.10 ± 0.10
Flavonoids	3.70 ± 0.30	2.50 ± 0.14	2.73 ± 0.11	18.70 ± 0.50
Saponins	1.20 ± 0.70	3.20 ± 0.90	1.75 ± 0.53	13.65 ± 4.56
Anthocyanins	1.25 ± 0.11	1.60 ± 0.70	2.30 ± 0.20	2.15 ± 0.35
Alkaloids	13.83 ± 1.23	6.17 ± 3.84	6.47 ± 4.30	5.60 ± 0.60

Source: Marcel, Hubert, Bienvenu, and Pascal (2016)

which oleic acid shared 64.56% followed by behenic acid (6.98%), elaidic acid (6.39%), vaccenic acid (6.0%), palmitic acid (5.98%), and arachidic acid (4.40%), whereas cholesterol was not detected in *M. oleifera* seed oil. They reported higher crude protein and essential amino acid content in seeds than leaves. Unsatuarted fatty acids shared 73.1% of MO seed oil (Stadtlander & Becker, 2017), and 28 minerals were reported in seed kernel. Aja et al. (2014) isolated five main constituents, that is, oleic acid (84%), L-(+)-ascorbic acid- 2,6-dihexadecanoate (9.80%), 9-octadecenoic acid (1.88%), methyl ester-hexadecanoic acid (1.31%), and 9-octadecenamide (0.78%) from methanolic extract of seeds. Oleic acid (73.22%) was the major fatty acid in seed, whereas 9-octadecenoic acid (20.8%) was highest pursued by palmitic, stearic, behenic, and arachidic acids 6.45%, 5.50%, 6.16%, and 4.08%, respectively, in leaf extricate (Mahmood et al., 2010). A study was conducted by Chelliah et al. (2017) to assess the chemical constituent's variability in the seeds of same genotype grown at different locations in south India. They identified 161 chemical compounds in MO seeds grown at Madurai locality and 185 compounds from Chennai locality. 6-octadecenoic acid (52.24%), n-hexadecanoic acid (6.17%), and oleic acid (5.12%) from seeds of Madurai locality, whereas 13-docosenamide(Z)- (13.62%), propionamide (4.48%), and ethyl oleate (4.33%) from Chennai locality were major constituents.

3.2 | Nutritional assesment

All parts of *M. oleifera* are a storehouse of important nutrients, of which dry leaves are rich source, as presented in Table 3. Out of 13 species, *M. oleifera* is well known for high amount of nutrients such as proteins with a quality equal to that of meat, milk, and eggs (Fuglie, 2005), fat, fiber, carbohydrate, vitamins, and essential amino acids (Stadtlander & Becker, 2017). Due to less lipid content, MO leaves can be used in diet routine of the obese (Berkovich et al., 2013). Varying level of nutrient (Table 3) and mineral content (Table 4) in different plant parts was reported in previous studies. About 44.4% carbohydrate, 28.7% crude protein, 7.1% fat, and 10.9% ash content were reported from dried leaf powder. The protein profile showed 70.1% insoluble proteins, 3.5% glutelin, 3.1% albumin, 2.2% prolamin, and 0.3% globulin (Teixeira et al., 2014). Asiedu-Gyekye, Frimpong-Manso,

TABLE 3 The nutrient compositions (100 g/sample) of different parts of *Moringa oleifera* Lam.

Nutrients	Fresh leaves	Yellow leaves	Dry leaves	Leaf powder	Pods	Seeds	Stem	Bark	Root
Protein (g)	6.70	12.00	29.40	27.10	2.50	35.97	18.66	23.95	16.87
Fats/lipids (g)	1.70	16.57	5.20	2.30	0.10	38.67	12.2	17.47	10.80
Carbohydrate (g)	12.50	26.93	41.20	38.20	3.70	8.67	20.4	12.33	14.92
Total fiber (g)	0.90	-	12.50	19.20	4.80	2.87	41.60	25.75	45.43
Vitamin B1 (mg)	0.06	-	2.02	2.64	0.05	0.05	-	-	-
Vitamin B2 (mg)	0.05	-	21.30	20.50	0.07	0.06	-	-	-
Vitamin B3 (mg)	0.80	-	7.60	8.20	0.20	0.20	-	-	-
Vitamin C (mg)	220.00	-	15.80	17.30	120.00	4.50	-	-	-
Vitamin E (mg)	448.00	-	10.80	113.00	-	-	-	-	-
Ca (mg)	440.00	1576.00	2185.00	2003.00	30.00	751.67	12.55	26.41	28.61
Mg (mg)	42.00	471.40	448.00	368.00	24.00	45.00	1.30	1.09	4.38
P (mg)	70.00	0.83	252.00	204.00	110.00	635	-	-	-
K (mg)	259.00	131.20	1236.00	1324.00	259.00	75.00	82.98	25.98	86.06
Fe (mg)	0.85	96.68	25.60	28.20	5.30	5.20	0.28	2.25	0.50
S (mg)	-		-	870.00	137.00	-	-	-	-

Source: Gopalakrishnan, Doriyaa, and Kumar (2016); Fokwen et al. (2018); Gopalakrishnan et al. (2016); Fuglie (2005); Olagbemide and Alikwe (2014); Verma and Nigam (2014)

TABLE 4 Mineral profiling of leaf and kernel samples of different *Moringa* species

	M. oleifera				*M. drouhardtii*		*M. hilderbrandtii*		*M. Stenoptala*
	Leaves			Kernel	Leaves	Kernel	Leaves	Kernel	Kernel
Mineral (per kg DM)	India (Asia)	Malawai (Central Africa)	Nicragua (Cental America)	Ethiopia (East Africa)	Madagascar (East Africa)		Gran Canary (West Africa)		Israel (West Asia)
Ca (g)	11.00	22.20	20.80	2.53	11.90	0.75	15.70	0.87	1.45
P (g)	6.32	3.70	3.36	8.28	2.190	3.55	4.66	8.03	3.62
Mg (g)	3.73	8.79	3.69	4.15	9.06	1.83	4.90	2.79	2.37
K (g)	29.60	13.50	18.80	11.30	12.30	7.84	19.50	9.03	5.64
Na (g)	0.67	0.60	0.70	0.04	9.78	0.15	5.04	0.06	0.49
Fe (mg)	132.0	1239.0	229.0	123.0	138.0	39.70	350.0	24.10	21.20
Zn (mg)	30.10	21.70	20.70	34.20	12.20	14.70	21.80	27.00	21.70
Mn (mg)	16.70	76.90	71.40	17.70	79.00	5.34	80.50	5.11	9.16
Mo (mg)	0.518	4.53	1.30	<0.241	1.46	0.283	1.60	<0.243	<0.238
Co (mg)	0.080	0.860	0.083	0.081	<0.082	<0.081	0.248	<0.081	<0.08
Se (mg)	1.570	27.70	2.85	<0.644	<0.653	<0.645	<0.645	0.796	<0.636
Si (mg)	248.0	279.0	343.0	124.0	389.0	33.50	192.0	5.38	9.73
Cu (mg)	5.89	8.21	5.37	4.91	4.23	3.56	2.52	3.91	3.01
B (mg)	29.10	64.60	32.20	7.93	126.0	7.35	62.70	6.31	6.14
V (mg)	0.136	3.64	0.276	0.189	0.215	<0.081	0.733	<0.081	<0.08
Al (mg)	65.30	862.0	79.70	65.70	80.60	15.40	301.0	1.30	2.81
Ni (mg)	1.49	3.80	0.681	0.886	0.729	1.560	1.86	0.741	1.66

Note: Minerals are (g/kg or mg/kg) dry matter basis.

Source: Stadtlander and Becker (2017).

Awortwe, Antwi, and Nyarko (2014) reported 35 elements (14 macroelements and 21 microelements) from leaf aqueous extract. The leaf powder have high contents (mg/100 g) of Ca (2787–3307), K (2672–4892), Mg (553–1566), Cl (188–332), Na (14.78–17.76), Fe (14.11–16.57), and other minerals (Mulyaningsih & Yusuf, 2018). MO leaves can provide 1,000 mg Ca and 4,000 mg by dry leaf powder,

whereas 8 ounces of milk can give 300–400 mg only (Gopalakrishnan et al., 2016). In fact, MO fresh leaves contain two times more protein than milk (Thurber & Fahey, 2009), nine times of protein than yoghurt, four times of Ca than milk, 25 times of Fe than spinach (Rockwood, Anderson, & Casamatta, 2013) or 28 mg of Fe from 100 g of leaves (Fuglie, 2005), 63 times K than milk, and three times of banana, 36 times Mg than egg, four times vitamin A than carrots, and 13 times of spinach, seven times vitamin C than orange, four times of vitamin B than pork meat, 50 times of vitamin B2 than sarones, 50 times of vitamin B3 than peanut, six times of vitamin E than rapeseed oil, two times of amino acids than black vinegar, and 30 times more of brown rice (Ganatra, Umang, Payal, Tusharbindu, & Pravin, 2012).

MO leaves are rich source of essential amino acids, higher than adequate with the standards of WHO, FAO, and UNO recommendations for small children and approximately equal to soyabean seeds in terms of digestibility score (Fuglie, 2005). As per the study conducted by Al-Juhaimi, Ghafoor, Mohamed Ahmed, et al. (2017), amino acids profile in leaves and seeds (g/100 g, respectively) of MO is glumatic acid (2.660 ± 0.13; 3.724 ± 0.18), aspartic acid (2.185 ± 0.06; 3.059 ± 0.02), leucine (2.070 ± 0.15; 2.898 ± 0.22), arginine (1.820 ± 0.06; 2.548 ± 0.08), alanine (1.605 ± 0.33; 2.247 ± 0.46), phenylalanine (1.595 ± 0.06; 2.233 ± 0.09), lysine (1.540 ± 0.14; 2.156 ± 0.20), glycine (1.450 ± 0.11; 2.030 ± 0.16), valine (1.345 ± 0.12; 1.883 ± 0.17), proline (1.280 ± 0.11; 1.792 ± 0.16), threonine (1.265 ± 0.13; 1.771 ± 0.19), isoleucine (1.155 ± 0.03; 1.617 ± 0.05), serine (1.060 ± 0.04; 1.484 ± 0.06), tyrosine (0.915 ± 0.08; 1.281 ± 0.11), histidine (0.730 ± 0.03; 1.022 ± 0.04), hydroxylysine (0.690 ± 0.04; 0.966 ± 0.06), methionine (0.560 ± 0.08; 0.784 ± 0.12), tryptophan (0.510 ± 0.03; 0.714 ± 0.04), cysteine (0.280 ± 0.04; 0.392 ± 0.06), taurine (0.105 ± 0.02; 0.147 ± 0.03), hydroxyproline (0.100 ± 0.01; 0.140 ± 0.02), and ornithine (0.060 ± 0.01; 0.084 ± 0.02), whereas glutamic acid, aspartic acid, argentine, proline, and glycien are major amino acids in seed kernel (Stadtlander & Becker, 2017). A very recent study (Pasha et al., 2019) carried out for quantification of the important molecules in different parts of the tree and an understanding of the protein chain reaction that leads to creation of such molecules. Enzymes in the biosynthesis of vitamins and metabolites like quercetin and kaempferol are highly expressed in leaves, flowers, and seeds. The expression of Fe, Zn, Mg transporters, and Ca storage proteins were observed in root and leaves, respectively. In general, leaves retain the highest amount of small molecules of human interest to combat the malnutrition (Pasha et al., 2019).

The immature flowers and pods are the source of palmitic, linolenic, linoleic, and oleic acids (Sanchez-Machado, Nunez-Gastelum, Reyes-Moreno, Ramirez-Wong, & Lopez-Cervantes, 2010). The green pods are the source of vitamin C with range of 92 to 126 mg/100 g of pulp (Dogra, Singh, & Tandon, 1975). Immature pods contain approximately 46.78% fiber, 20.66% protein, 30% of amino acid content, whereas leaves and flowers have 44% and 31% amino acid content, respectively (Sohani, 2018). The seeds of Indian MO collected from Assam contain 40.34% protein with seven essential amino acids, 39.12% fats, K (2,357.71 mg/kg), Na (1074.09 mg/kg), Mg (972.06 mg/kg), Ca (121.14 mg/kg), and iron (36.2 mg/kg; Liang, Wang, Li, Chu, & Sun, 2019). The root bark is rich in moringine alkaloid, stimulating drug component similar to ephedrine (Morton, 1991). Study carried out by Lalas and Tsaknis (2002a) demonstrated that seed oil contains around 76% PUFAs, that is, palmitic, linolenic, linoleic, and oleic acids. Refined seed oil of MO is the best substitute of olive oil (Morton, 1991). Seeds are the best substitute to legumes due to high content of essential amino acids (Ferreira, Farias, Oliveira, & Carvalho, 2008). Thus, MO is very important plant as it is exceptional to discover such a high nutrient profile in a solitary tree (Razis, Ibrahim, & Kntayya, 2014).

It is an established fact that mineral content change with the species and also with geograpihical area where the plant grows (Table 4). Apart from this, factors of locality of different geographical areas also affect the nutrients level in the same cultivar of MO when it grows at different localities (Table 5). Leone et al. (2015a) clearly recorded the huge differences in nutritional status in leaves of MO planted in three different countries viz., Chad, Algeria, and Haiti. Chelliah et al. (2017) reported wide variation in nutraceuticals and phytochemical profiling of MO grown at two different regions. Fuglie (2005) revealed that nutrient content is also influenced by seasons. Vitamin A was recorded higher in leaves in the summer–rainy season, whereas vitamin C and Fe were high in the winter season (Yang et al., 2006). Safaeian, Asghari, Javanmard, and Heidarinejad (2015) stated that MO is majorly used in summer season due to the higher concentration of bioactive compounds. The concentration of phenolic compound was higher in leaves harvested in winter season (Shih, Chang, Kang, & Tsai, 2011). Moyo et al. (2011) clearly mentioned that the variation in nutritional profile is significantly attributed due to locality and ecological factors. Phytochemical variations were also reported in different 13 MO cultivars collected from different parts of the globe (Ndhlala et al., 2014). These variations could be due to many factors including genetic variations, soil, climate, time of harvest, and storage conditions.

Phytochemicals, for example, alkaloids, flavonoids, anthocyanins, tannins, sterols, terpenoids, saponins, anthraquinones, glucosinolates, isothiocyanates, glycosides, and glycerol-1-9-octadecanoate isolated form different plant parts of MO considered as antinutritional factors are responsible for medicinal properties (Berkovich et al., 2013). The amounts of antinutrients, that is, alkaloids, flavonoids, oxalates, phytates, saponins, tannins are generally low and do not have any health risk to animal and human beings (Gidamis, Panga, Sarwatt, Chove, & Shayo, 2003; Nouman et al., 2013). Teixeira et al. (2014) documented the antinutritional factors, such as, tannins (20.7 mg/g), trypsin inhibitor (1.45 mg/g), nitrates (17 mg/g), and oxalic acids (10.5 mg/g) in leaves. However, these antinutrients can be removed through soaking, boiling, or even frying (Igwilo, Oloyode, & Enemor, 2007). Saponins for instance, confer bitter taste on moringa without any harmful effects (Makkar & Becker, 1996). Saponin is used as an antibiotic and high blood pressure (Ajayi, Akomolafe, & Adefioye, 2014). *Moringa* leaves have a high proportion of insoluble form of oxalates (Noonan & Savage, 1999). The comparatively higher amounts of antinutrients in the seeds rather than the leaves may explain why *Moringa* seeds are used more in ethno-medicine and are used to cure the diseases (Sallau, Mada, Ibrahim, & Ibrahim, 2012; Stevens, Ugese,

TABLE 5 Nutritional characterization of leaf of *Moringa oleifera* due to geographical locations

Nutrients	India (Mean ± *SD*)	Algeria (Mean ± *SD*)	Ethiopia (Mean ± *SD*)	Nigeria (Mean ± *SD*)	South Africa (Mean ± *SD*)	Brazil (Mean ± *SD*)	Haiti (Mean ± *SD*)	Mexico (Mean ± *SD*)
Proteins (g/100 g)	28.40 ± 0.20	30.60 ± 0.80	10.71 ± 0.81	17.01 ± 0.1	30.29 ± 1.48	28.65 ± 0.04	20.80 ± 0.01	11.48 ± 1.4
Lipids (g/100 g)	1.90 ± 0.30	5.60 ± 0.30	10.31 ± 1.2	2.11 ± 0.11	6.5 ± 1.04	7.09 ± 0.43	7.05 ± 0.11	10.21 ± 1.83
Fibre (g/100 g)	19.20 ± 0.20	32.80 ± 0.20	8.05 ± 0.02	7.09 ± 0.11	11.40 ± 0.4	-	37.63 ± 1.00	9.46 ± 1.14
Ash (g/100 g)	3.00 ± 0.10	15.10 ± 0.30	7.29 ± 0.84	7.93 ± 0.12	7.64 ± 0.43	10.9 ± 0.8	9.62 ± 0.02	11.18 ± 0.19
Ca (mg/100 g)	2225 ± 0.1	2997 ± 27.00	2016.5 ± 22.6	1910 ± 0.08	3650 ± 0.04	2970 ± 0.0	2150.26 ± 56.07	2620.5 ± 5.6
Mg (mg/100 g)	3760.2 ± 0.30	-	322.5 ± 0.0	380 ± 0.01	500 ± 0.05	1900 ± 0.0	533.51 ± 23.87	340.6 ± 2.8
P (mg/100 g)	250 ± 0.3	-	-	301.5 ± 0.5	300 ± 0.01	-	-	-
K (mg/100 g)	1391 ± 0.1	1492 ± 13.00	1845 ± 7.0	970 ± 0.01	1500 ± 0.02	4160 ± 0.0	-	1817 ± 14.1
S (mg/100 g)	870 ± 0.1	-	-	-	630 ± 0.15	-	-	-
Na (mg/100 g)	-	502 ± 5.00	8.13 ± 0.6	192.95 ± 4.4	164 ± 0.02	-	262.50 ± 5.45	40.78 ± 0.7
Fe (mg/100 g)	29.3 ± 0.2	30.20 ± 0.30	19.37 ± 6.6	107.48 ± 8.2	49 ± 49.65	103.12 ± 0.0	11.91 ± 0.82	7.07 ± 0.4
Cu (mg/100 g)	0.6 ± 0.1	-	1.03 ± 0.47	6.10 ± 0.19	0.83 ± 0.14	3.38 ± 0.0	-	0.41 ± 0.0

Source: Chelliah et al. (2017); Leone et al. (2018); Amabye (2016); Ogbe and Affiku (2011); Moyo, Masika, Hugo, and Muchenje (2011); Teixeira et al. (2014); Leone et al. (2015); Valdez-Solana et al. (2015).

Otitoju, & Baiyeri, 2015). Roots are the rich source of antinutritional compounds; therefore, it is traditionally used in African, Asian, and Latin American countries (Iqwilo et al., 2014).

3.3 | *M. oleifera* as potential food

The different parts of MO are used in more than 80 countries to supplement mineral and vitamin deficiencies (Mahmood et al., 2010). The foliages, flowers, green pods, seeds, and seed oil contain low saturated fatty acid and high amount of monounsaturated unsaturated fatty acids and PUFAs; therefore, it can be used for value addition of food products (Saini et al., 2016). Fried flowers have taste like mushrooms (Owusu & Oduro, 2011). Immature pods are widely used in *sambhar*, *corma*, *dal*, *cutlet*, and *curry* dishes by mixing with coconut, poppy seeds, and mustard in Indian subcontinent (Ganatra et al., 2012). The immature seeds are used as peanuts with oil frying (Ramachandran, Peter, & Gopalakrishnan, 1980). Peeled dried roots mixed with acetic acid are consumed as a condiment (Martin & Ruperte, 1979). The leaf, seed, and flower powder are utilized in various food applications such as in fortifying amala (stiff dough), ogi (maize gruel), bread, biscuits, yoghurt, cheese, and soups (Oyeyinka & Oyeyinka, 2018). MO leaves alone or in combination with spinach, melon etc. can be used as ingredient in soups (Babayeju et al., 2014). Leaf powder was reported to increase the swelling and pasting properties along with protein and macronutrients in fortified plantain flour (Karim, Kayode, Oyeyinka, & Oyeyinka, 2015). Flower powder or leaf powder is known to increase nutritional value of weaning foods (Arise, Arise, Sanusi, Esan, & Oyeyinka, 2014). Paneer with extract of MO leaf of different concentration were investigated, and it was found to have high nutrient content than normal paneer (Sachan, Khan, Yadav, & Sonkar, 2010). The protein, crude fiber, and ash content increased appreciably with increasing concentration of *Moringa* leaf powder in chocolate and halwa (Abou-Zaid & Nadir, 2014). Biscuits incorporated with 5% leaf powder were reported to increase protein content by 14%, and these are known as Moringa biscuits (Alam et al., 2014). Bread fortified with 5% of MO leaf powder was found to have 17% and 88% increased in protein and dietary fiber content (Chinma, Abu, & Akoma, 2014).

Moisture, protein, fiber, and ash content increased, whereas total fat and carbohydrate content decreased with increased amount of *Moringa* leaf (2, 4, 6, 8, and 10 g) in cakes (Chinma et al., 2014). Leaves increased the taste of yoghurt and did not negatively affect the growth of *Lactobacillus rhamnosus* GR-1 (Hekmat, Morgan, Soltani, & Gough, 2015). Incorporation of dried leaves (sun dried, shadow dried, and mechanically dried) in proportion of 0%, 2%, 4%, 6%, 8%, 10% increased the moisture, fat, ash, protein, carbohydrate, and antioxidant activity of khakhras (Maghu, Sharma, & Younis, 2017). Chin chin is a Nigerian snack product, which is made of wheat flour, butter, egg, and milk. Oven-dried leaves mixed with chin chin had high Ca (190.5 mg/100 g), high Zn with sun dried leaves (7.1 mg/100 g), and high Fe (51.3 mg/100 g) with shade dried leaves (Emelike & Ebere, 2016). Salama, Sayed, and Abdalla (2017) reported that 0.5% of MO dried leaves and 6% of oil used to prepare fortified ice milk to increase nutritional quality and suitable sensory aspects. MO dried leaf powder at 12 % concentration (per 55 g of flour used) has been used in the production of muffin to increase ash content, protein, fat, beta carotene, vitamin C, and minerals (Srinivasamurthy, Yadav, Sahay, & Singh, 2017).

A very recent study showed the effect of the administration of dried leaf powder of MO on the nutritional status and body composition of a sample of malnourished children, aged between 4 and 18 years in Zambia (Barichella et al., 2019). It was found that daily dose of 14 g dried leaf powder was safe from any side effects and well accepted in terms of taste and visual attractiveness as dietary supplementation for 30 days, homogeneously distributed between lunch and dinner. Mild side effects were reported independently of age in three

out of 16 subjects within 3 days when 20 g daily MO leaf powder was supplemented. However, no significant effect was reported on body weight and body composition. These finding was not taken for granted as previous studies have mainly investigated the acceptability of fortified baked products like cookies, cereals, and crackers in adults (Owusu & Oduro, 2011).

3.4 | Therapeutic activities

M. oleifera has various medicinal uses, which have long been recognized and used in the Ayurvedic and Unani systems of medicine (Mughal, Ali, Srivastava, & Iqbal, 1999). The extracts of different part of MO offer a high level of safety without any adverse effects on human being (Saini et al., 2016). Pyridine-3-carboxamide and 2-myristynoyl-glycinamide isolated from leaves and seeds have been used against approximately 80 diseases (Cohen & Grifo, 2007). The biological and medicinal practices attributed to different parts of *M. oleifera* are summarized here, of which some are outlined in Table 6.

3.4.1 | Antibacterial activity

Numerous investigations have recommended that different extracts from various tissues of *M. oleifera* showed antibacterial properties against both gram-negative and gram-positive bacteria viz., fresh leaf juice against *Pseudomonas aeruginosa* and *Staphylococcus aureus* (Caceres, Cabrera, Morales, Mollinedo, & Mendia, 1991); aqueous leaf extract against *S. aureus*, *Vibrio cholerae*, and *Escherichia coli* (Vieira, Mourao, Angelo, Costa, & Vieira, 2010); methanol extract of leaves against 13 different bacterial strains tested, including *E. coli*, *Enterobacter aerogenes*, *Klebsiella pneumonia*, *P. aeruginosa*, and *Providencia stuartii* (Dzotam et al., 2016); ethanol extracts of foliages and seeds against *Trichophyton rubrum*, *T. mentagrophytes*, *Epidermophyton floccosum*, and *Microsporum canis* (Chuang et al., 2007); chloroform and ethanol extracts of seeds and foliage against *E. coli*, *P. aeruginosa*, *S. aureus*, and *E. aerogenes* (Bukar, Uba, & Oyeyi, 2010); chloroform extract of flowers and ethanol extract of pods against *V. cholera*, *V. vulnificus*, and *V. mimicus* (Brilhante et al. (2015); water-soluble seed lectin against *S. aureus* and *E. coli* (Ferreira et al., 2011); phenolics rich extract of seed flour against *Bacillus cereus*, *S. aureus*, *E. coli*, and *Yersinia enterocolitica* (Govardhan-Singh, Negi, & Radha, 2013); hexane, petroleum ether, butanol, chloroform, acetone, ethyl acetate, methanol, and water extracts of pod husk against *S. aureus*, *S. epidermidis*, *Salmonella typhimurium*, *E. coli*, and *K. pneumonia* (Arora & Onsare, 2014); acetone extract of foliage against *S. aureus*, *Enterococcus faecalis*, *E. coli*, *P. aeruginosa*, *Candida albicans*, *Aspergillus fumigates*, and *Cryptococcus neoformans* (Ratshilivha, Awouafack, du Toit, & Eloff, 2014); aqueous, methanol and ethyl acetate extracts of seeds against *E. coli*, *K. pneumoniae*, *Proteus mirabilis*, *P. aeruginosa*, and *S. aureus* (Emmanuel et al., 2014); ethyl acetate extract of bark against *S. aureus*, *Citrobacter freundii*, *B. megaterium*, and *P. fluoescens* (Zaffer et al., 2014); flavonoids extract of seeds against *S. aureus*, *P. aeruginosa*, and *C. albicans* (Onsare & Arora, 2015).

Antimicrobial properties are possibly attributed by 4-(α-L-rhamnopyranosyloxy)benzyl isothiocyanate, methyl N-4-(α-L-rhamnopyranosyloxy)benzyl carbamate and 4-(β-D-glucopyranosyl-1 → 4-α-L-rhamnopyranosyloxy)-benzyl thiocarboxamide (Oluduro, Aderiye, Connolly, Akintayo, & Famurewa, 2010; Padla et al., 2012); water soluble lectine protein (Coelho et al., 2009; Ferreira et al., 2011; Moura et al., 2015); flocculating cationic polypeptides (Shebek et al., 2015); niazimicin (Rim et al., 2014); glycosides 4-(α-L-rhamnosyloxy)-benzyl isothiocyanate, 4-(α-L-rhamnosyloxy)-phenylacetonitrile and moringine (Jahn, Musnad, & Burgstaller, 1986); proanthocyanidins (Maldini et al., 2014) in seeds; niaziminin, niazinin (Wang, Chen, & Wu, 2016), and silver nanoparticles (Prasad & Elumalai, 2011) in leave extract; cardiac glycosides in pods (Arora & Onsare, 2014); kaempferol, rhamnetin, kaempferitin, isoquercitrin, and pterygospermin in flowers; spirochin and anthonine in roots (Farooq, Rai, Tiwari, Khan, & Farooq, 2012; Mehta, Shukla, Bukhariya, & Charde, 2011; Raj, Gopalakrishnan, Yadav, & Dorairaj, 2011); and aglycon of deoxy-niazimicine (N-benzyl, S-ethyl thioformate) in bark (Nikkon et al., 2003). It is cleared from previous studies that seeds may also act directly upon microorganisms and showed broader antimicrobial spectrum than other parts of MO. Methods used to assess the antibacterial activities are inhibition halos test (De-Martino, De Feo, Fratianni, & Nazzaro, 2009) and total polyphenols test (Marrufo et al., 2013) for leaf essential oil; modified disk diffusion method for aqueous and ethanol extracts of leaves (Peixoto et al., 2011); thin layer chromatography bioassay for methanol crude extract of seeds (Oluduro et al., 2010); disc diffusion method for hexane and methonolic extracts of leaves and seeds (Chelliah et al., 2017); modified Kirby–Bauer disk diffusion method for aqueous and ethanolic extracts of seeds (Vieira et al., 2010); and pour plate method for seed flour (Singh, Negi, & Radha, 2013). Thus, the extracts of different parts of MO could be an effective source of natural antimicrobial agents with versatile potential applications in the pharmaceutical industries.

3.4.2 | Antifungal activity

MO has been used for antifungal activities in several previous investigations. Extract of seeds (Chuang et al., 2007; Jabeen, Shahid, Jamil, & Ashraf, 2008; Oluduro et al., 2010), leaves (Kekuda et al., 2010; Oluduro, 2012), and leaf oil (Chuang et al., 2007) are reported to exhibit significant antifungal activity against *T. mentagrophyte*, *Pullarium* spp., *A. flavus*, *Penicillium* spp., *A. niger*, *A. oryzae*, *A. terreus*, *A. nidulans*, *F. solani*, *R. solani*, *C. cladosporioides*, *P. sclerotigenum*, and *Dermatophytes (T. rubrum*, *E. xoccosum*, *M. canis*). Growth of saprophytic fungi was inhibited by extract of MO leaves (Ayanbimpe et al., 2009). A metabolite griseofulvin isolated from endophytic fungus of MO demonstrated inhibitory effect on the growth of 8 plant pathogenic fungi in an in vitro antifungal test (Zhao, Zhang, Wang, Wang, & Zhang, 2012). The essential oil of MO was evaluated using different concentration of total polyphenols against *P. aurantiogriseum*, *P. expansum*, *P. citrinum*, *P. digitatum*, and *A. niger* using inhibition halo technique test (Marrufo et al., 2013). MO roots have an anti-infection compound, pterygospermin, which has incredible fungicidal effects

TABLE 6 Biological and medicinal attributes of *Moringa oleifera* Lam.

Traditional uses/ effects	Mode of action	References
Biocidal activities		
Bacterial	*Aeromonas caviae*, *Bacillus cereus*, *B. megaterium*, *B. subtilis*, *Citrobacter freundii*, *E. coli*, *Enterobacter sp.*, *Enterobacter aerogenes*, *Enterococcus faecalis*, *K. pneumoniae*, *Microcystis aeruginosa*, *Mycobacterium phlei*, *Providencia stuartii*, *Proteus vulgaris*, *P. aeruginosa*, *P. fluorescens*, *Propionibacterium acnes*, *Serratia marcescens*, *S. boydii*, *S. dysenteriae*, *Sarcina lutea*, *S. epidermidis*, *S. pyogenes*, *S. mutans*, *S. aureus*, *Streptococcus mutans*, *S. typhii*, *Vibrio cholera*, *V. parahaemolyticus*	Nwosu and Okafor (1995); Nikkon et al. (2003); Chuang et al. (2007); Lurling and Beekman (2010); Rahman et al. (2010); Peixoto et al. (2011); Saadabi and Abu-Zaid (2011); Walter, Samuel, Peter, and Jospeh (2011); Padla, Solis, Levida, Shen, and Ragasa (2012); Rattanasena (2012); Galuppo et al. (2013); Marrufo et al. (2013); Patel, Patel, Patel, Desai, and Meshram (2014); Zaffer et al. (2014); Eyarefe, Idowu, and Afolabi (2015); Dzotam, Touani, and Kuete (2016); Elgamily et al. (2016)
Fungal	*Aspergillus flavin*, *A. niger*, *Basidiobolus ranarum*, *B. haptosporus*, *Candida albicans*, *Epidermophyton floccosum*, *Microsporum canis*, *Penicillium aurantiogriseum*, *P. citrinum*, *P. digitatum*, *P. expansum*, *Trichophyton mentagrophytes*, *T. rubrum*	
Dental caries	Filling cavities with gum; juice of root bark; ethyl acetate, acetone, and ethanol extracts of seeds, roots and leaves	Bhattacharya, Das, and Banerji (1982); Prakash, Tiwari, Shukla, Mathur, and Tiwari (1987); Elgamily et al. (2016)
Gastrointestinal disease	4-(β-D-glucopyranosyl-1 → 4-α-L-rhamnopyranosyloxy)-benzyl thiocarbox amide from seed extract	Oluduro (2012)
Urinary tract infection	Phenolic compound of stem bark decoction	Maurya and Singh (2014)
Tuberculosis	Root bark	Prakash et al. (1987)
Syphilis	Gum	Bhattacharya et al. (1982)
Parasites		
Dracunculiasis (guinea-worm)	Leaf extract	Fabiyi, Kela, Tal, and Istifanus (1993)
Lymphatic filarial nematode *Brugia malayi* (Round-worm)	Gum extract inhibited 100% motility and 56% MTT reduction potential of the adult female worms	Kushwaha et al. (2011)
Protozoa	Lectin protein from seed extract	Kohler et al. (2002)
Schistosomes	Seed flocculation	Olsen (1987)
Nonspecified pathogens		
Cholera	Pterogospermin isolated from flowers	Lizzy, Rao, and Puttaswamy (1968)
Conjunctivitis	Bark, leaf juice drops	Yabesh, Prabhu, and Vijayakumar (2014); Mbikay (2012)
Cataractogenesis	Leave ethanol extract	Kurmi, Ganeshpurkar, Bansal, Agnihotri, and Dubey (2014)
Cataracts	Consumption of leaves, pods	Anwar et al. (2007)
Muscle disease	Leaves	Armand-Stussi, Basocak, Pauly, and McCaulley, (2003)
Pyoderma (skin sores)	Seed extract	Caceres and Lopez (1991); Bharali, Tabassum, and Azad (2003)
Throat Infection	Flower extract	Fuglie (1999)
Cancer/protection		

(Continues)

TABLE 6 (Continued)

Traditional uses/ effects	Mode of action	References
Antiproliferation through apoptosis	Cancer cell line inhibition against A549, B16F10, Hep-G2, Panc-1, p34, COLO 357, MDA-MB-231, HCT-8, MCF-7, HeLa, CACO-2, L929, HCT-16, HCT18, PC3, K562, THP-1, T47D, HL-60, Colo-205, SW480, HepG2, Caco-2, MCF-7 cells	Monera, Wolfe, Maponga, Benet, and Guglielmo (2008); Pamok, Vinitketkumnuen, and Saenphet (2012); Waiyaput, Payungporn, Issara-Amphorn, Nattanan, and Panjaworayan (2012); Berkovich et al. (2013); Gismondi et al. (2013); Tiloke, Phulukdaree, and Chuturgoon (2013); Al-Asmari et al. (2015); Diab, Guru, Bhushan, and Saxena (2015); Elsayed, Sharaf-Eldin, and Wadaan (2015); Jung, Lee, and Kang (2015); Madi, Dany, Abdoun, and &Usta J. (2016)
Ovarian cancer, Prostate cancer, Breast cancer	Leaf extract	Zayas-Viera, Vivas-Mejia, and Reyes (2016)
Photo-oxidative damage	Chlorogenic acid from leaf	Ramabulana et al. (2016)
Radioprotective	Leaf extract	Rao, Devi, and Kamath (2001)
Circulatory/endocrine disorders		
Anti-anemic	Ethanolic leaf extract	Munim, Puteri, and Sari (2016)
Anti-atherosclerotic	Pod extract	Mehta, Balaraman, Amin, Bafna, and Gulati (2003)
Diuretic activity	Aqueous infusion of seeds, decoction of leaves, leaf juice	Gupta and Arya (2011); Thakur, Soren, Pathapati, and Buchineni (2016)
Detoxification		
Analgesic	Antagonism of NMDA receptors through leaf extract	Sutar et al. (2008)
Anti-aging	Zeatin from fresh leaf juice	Dhakar, Maurya, Pooniya, Bairwa, and Gupta (2011)
Antipyretic	Gum, ethanol and ethyl acetate extracts of seed	Bhattacharya et al. (1982); Hukkeri, Nagathan, Karadi, and Patil (2006); Ahmad, Ejaz, Anwar, and Ashraf (2014)
Antitoxidant to fluoride toxicity	Seeds	Ranjan, Swarup, Patra, and Chandra (2009)
Antidote to snakebite and scorpion-bite	Oral doses of powdered stem bark	Fuglie (1999); Rajendran, Balaji, and Basu (2008)
Oxidative DNA damage protective	Aqueous extract of pods and seeds	Sing et al. (2009)
Digestive disorders		
Anticolitis	Hydro-alcoholic extract and its chloroform fraction of seeds	Minaiyan, Asghari, Taheri, Saeidi, and Nasr-Esfahani (2014)
Cholagouge	Leaves	Armand-Stussi et al. (2003)
Diarrhea and dysentery	Ethanol leaf extract, gum, root	Misra, Srivastava, and Srivastava (2014); Bhattacharya et al. (1982); Agrawal and Mehta (2008)
Purgative, laxative	Seed oil, Roots	Fuglie (1999); Agrawal and Mehta (2008)
Flatulence/Carminative	Roots	Agrawal and Mehta (2008)

(Continues)

TABLE 6 (Continued)

Traditional uses/ effects	Mode of action	References
Hepatic gluconeogenesis	Isothiocyanate extractof leaves	Waterman et al. (2015)
Liver fibrosis	Seed extract	Hamza (2010)
Trypsin inhibitor	Flower extract had antilarvicidal activity on *Aedes ageypti*	Pontual et al. (2014)
Nervous disorders		
Antinociceptive	Methanol extract of leaves, Chitin-binding protein from seeds	Adedapo, Falayi, and Oyagbemi (2014); Mirella et al. (2011)
Epilepsy and anxiety	Aqueous extract of leaves	Ingale and Gandhi (2016)
Paralytic afflictions	Roots	Agrawal and Mehta (2008)
Down-regulation of nuclear factor kappa-B	Aqueous extract of leaves	Berkovich et al. (2013)
Upregulation of TNF-a	Ethanol extract of leaves	Akanni, Adedeji, and Oloke (2014)
Respiratory disorders		
Asthma	Gum, moringine and moringinine from seed extract	Bhattacharya et al. (1982), Agrawal and Mehta (2008)
Bronchitis	Moringine and moringinine from seed extract	Mahajan and Mehta (2008)
Reproductive health		
Abortifacient	Leaves extract, gum, aqueous root extract	Armand-Stussi et al. (2003); Bhattacharya et al. (1982); Agrawal and Mehta (2008)
Aphrodisiac	Leaves, methanolic extract of seeds	Armand-Stussi et al. (2003); Goswami et al. (2016)
Lactation enhancer	Dry leaf capsule	Raguindin, Dans, and King (2014)
Neural tube defects during pregnancy	Folate from leaf extract	Williams et al. (2015)
Prostate function	Zeatin from leaves, seed oil	Dhakar et al. (2011); Fuglie (1999)
Sexual hormonal balance	Aqueous extract of roots	Shukla, Mathur, and Prakash (1988)
Skin disorders		
Astringent	Root bark, gum	Nikkon et al. (2003); Bhattacharya et al. (1982)
Pyodermia	Chitin-binding protein from seeds	Mirella et al. (2011)
Rubefacient and vesicant	Gum, bark, root bark,	Bhattacharya et al. (1982); Prakash et al. (1987); Agrawal and Mehta (2008)
General disorders		
Antianaphylactic	Seeds	Mahajan and Mehta (2007)
Antiperoxidative	Hydroalcoholic extract of leaves	Nandave, Ojha, Joshi, Kumari, and Arya (2009)

(Continues)

TABLE 6 (Continued)

Traditional uses/ effects	Mode of action	References
Catarrh	Leaves and fruit extract	Fuglie (1999)
Low back/kidney pain	Roots	Agarwal and Mehta (2008)
Kidney stone cure	Root wood	Karadi, Gadge, Alagawadi, and Savadi (2006)
Kidney enlargement	Methanolic extract of leaves	Omodanisi, Aboua, and Oguntibeju (2017)
Splenomegaly	Roots, bark, leaves, flowers	Fuglie (1999); Prakash et al. (1987); Armand-Stussi et al. (2003); Yabesh et al., 2014
Anti-obese properties	Chlorogenic acid from leaves, ethanolic leaves extract	Panda et al. (2013); Metwally et al. (2017)
Weight gain	Benzylamine, Isothiocyanate extractof leaves	Iffiu-Soltesz et al. (2010); Waterman et al. (2015)
Earache	Gum, juice of root bark	Fuglie (1999); Prakash et al. (1987)
Migraine, headache	Alcoholic extract of leaf juice, gum with sesame oil	Upadhye, Rangari, and Mathur (2012); Bhattacharya et al. (1982)
Toothache	Roots decoction	Popoola and Obembe (2013)
Urinary bladder problems	Oral administration of seed powder	Gupta, Kannan, Sharma, and Flora (2005)

(Ruckmani, Kavimani, Anandan, & &Jaykar B., 1998). The aglycone of deoxy-niazimicine isolated from root bark showed antifungal activity (Nikkon et al., 2003). The stem bark possesses antifungal action (Bhatnagar, Santapau, Desai, Yellore, & Rao, 1961). Mo-CBP3 isolated from seeds showed in vitro antifungal effect on the phytopathogenic parasites *F. solani*, *F. oxysporum*, *Colletotrichum musae*, and *C. gloesporioides* at concentration of 0.05 mg/ml with 62% inhibition within 48 hr. They explained that Mo-CBP3 had antifungal action by reducing mycelia development and conidial feasibility. It is proposed that, through connections with the cell layer, Mo-CBP3 induced the creation of reactive oxygen species and caused cell death in the parasites (Batista et al., 2014). Nowadays, Mo-CBP3 is also considered as new antifungal drug in the development of transgenic crops for different traits viz., thermo-stability, broad antifungal spectrum, and low toxicity (Freire et al., 2015; Pinto et al., 2015).

3.4.3 | Antiviral activity

As a traditional medicinal plant, antiviral properties were observed in MO as reported in previous studies. Epstein–Barr infection activation in Raji cells could be inhibited by niaziminin isolated from foliages (Murakami et al., 1998; Sudha, Asdaq, Dhamingi, & Chandrakala, 2010). Ethanolic extract of leaves showed negative activity for herpes simplex virus (HSV; Lipipun et al., 2003) and seeds against HSV-1 (Ali, El-Taweel, & Ali, 2004). Ethanolic extract of leaves showed significant antiviral activity against infectious bursal disease virus (Ahmad et al., 2014), foot and mouth disease virus, equine herpes virus, hepatitis virus, and rhinovirus (Younus et al., 2016). Leaf aqueous extract activated the cellular immunity in infected mice with HSV-1 by decreasing the infection rate and reducing herpetic skin lesion growth (Kurokawa et al., 2016). Aqueous seed extract showed potential antiviral activity against Newcastle disease virus (Chollom et al., 2012). Any disease virus treatment with MO extract could defer skin injury development, extend the mean survival time, and reduce the mortality of HSV-1 infected mice (Khan, Ather, Thompson, & Gambari, 2005). Waiyaput et al. (2012) proposed that 80% ethanol extract of MO fruit demonstrated anti-Hepatitis B virus effect by reducing Hepatitis B virus replication with mellow cytotoxicity on HepG2 cells. MO was also used as a complement toward antiretroviral treatment in HIV infection (Monera & Maponga, 2010). MO leaves have generally been utilized in the treatment of HIV-related side effects, potentially in early strides in the infectivity of HIV-1 lentiviral particles in a viral vector-based screening (Nworu, Okoye, Ezeifeka, & Esimone, 2013). By assessing these researches discussed, it is concluded that MO could be used in the improvement of promising antiviral medications.

3.4.4 | Anticancer and antitumor activities

It is established fact that MO may be used as antineoproliferative mediator, by suppressing the development of cancer cells. Leaf extract exhibited chemoprotective (Anwar et al., 2007), cytotoxic (Berkovich et al., 2013; Nair & Varalakshmi, 2011), antihepatocarcinoma, antileukemia (Khalafalla et al., 2010), antimyelomic (Parvathy &

Umamaheshwari, 2007), and antiproliferative (Pamok et al., 2012) activities. These activities are because of 3-O-6x-oleoyl-β-D-glucopyranosyl-β-sitosterol, β-sitosterol-3-O-β-D-glucopyranoside, 4-(α-L-rhamnosyloxy) phenylacetonitrile, 4-hydroxyphenylacetonitrile and 4-hydroxyphenyl-acetamide in seeds (Guevara et al., 1999); cis-9-hexadecenal, quinic acid, 3,5-dihydroxy-6-methyl-2,3-dihydro-4H-pyran-4-1, 9-octadecenamide, methyl octadecenoate in flowers (Inbathamizh & Padmini, 2012) and quercetin, kaempferol (Krishnamurthy, Vardarajalu, Wadhwani, & Patel, 2015; Sreelatha, Jeyachitra, & Padma, 2011), 4-(4′-O-acetyl-α-L-rhamnosyloxy) benzyl isothiocyanate, O-ethyl-4-(α-L-rhamnosyloxy) benzyl carbamate, 4-(L-rhamnosyloxy) benzyl isothiocyanate, niaziminin, and niazimicin (Anwar et al., 2007; Murakami et al., 1998; Razis et al., 2014), D-allose (Sui et al., 2005) in leaves, eugenol (Al-Sharif, Remmal, & Aboussekhra, 2013), and isopropyl isothiocynate (Matsuda, Ochi, Nagatomo, & Yoshikawa, 2007) in bark, palmitic acid in leaf, seed, and bark (Harada et al., 2001).

Previous studies showed that eugenol has a strong anticancer potential against melanoma (Pisano et al., 2007), osteosarcoma (Shin et al., 2007), acute lymphoblastic leukemia and hepatocellular carcinoma (Khalafalla et al., 2010), gastric cancer (Manikandan, Vinothini, Priyadarsini, Prathiba, & Nagini, 2011), skin tumor (Kaur, Athar, & Alam, 2010), mast cells (Park et al., 2005), and prostate cancer (Ghosh, Ganapathy, Alworth, Chan, & Kumar, 2009). Sharma, Paliwal, Janmeda, and Sharma (2012) reported that the enzyme, that is, glutathione and glutathione S-transferase (protection against carcinogens) activity loss was recovered by MO pod extract. Bharali et al. (2003) reported skin papillomagenesis subsequent to ingestion of seed and pod extracts. Previous studies had also shown the cytotoxicity of different extracts of MO on human cancer such as leukemia (Harada et al., 2001), pancreatic cancer (Berkovich et al., 2013), breast and colorectal cancer (Al-Asmari et al., 2015), colon cancer (Lea et al., 2012), KB tumor cell (Sreelatha et al., 2011), lung cancer (Jung et al., 2015), alveolar epithelial cancer (Tiloke et al., 2013), hepatocellular carcinoma (Khalafalla et al., 2010), and melanoma (Gismondi et al., 2013).

3.4.5 | Antidiabetic activity (Antihyperglycemic)

MO is outstanding for its therapeutic behavior and may utilized be for the traditional treatment of *Diabetes mellitus* (Konmy, Olounlade, Allou, Azando, & Hounzangbe-Adote, 2016; Leone et al., 2018). Antihyperglycemic (Divi, Bellamkonda, & Dasireddy, 2012; Jaiswal, Rai, Kumar, Mehta, & Watal, 2009) and hypoglycemic (Ajit, Choudhary, & Bandyopadhyay, 2002; Tende, Ezekiel, & Dikko, 2011) activities of leaves might be presumably because of the presence of terpenoids and flavonoids, which involved in stimulation of ß cells and resulting discharge of insulin. Glucomoringin (glucosinolates), quercetin and kaempferol (flavonoids), and aschlorogenic acid showed hypoglycemic properties (Sayed, 2012). Ethanolic extract MO leaves possesses hypoglycemic activity in STZ-induced diabetic Wistar rats, which is due to lowering blood glucose level (Tende et al., 2011). Methanol extract of dried fruit powder accelerates the insulin release significantly due to benzyl, benzyl nitriles, and N-benzyl thiocarbamates (Francis, Jayaprakasam, Olson, & Nair, 2004). An examination revealed that benzylamine isolated from MO leaves decreased the plasma cholesterol, body weight gain, hyperglycemic reactions, and fasting blood glucose dimensions of high-fat diet-induced mice (Iffiu-Soltesz et al., 2010). Leaf extract reduced blood glycated hemoglobin and cholesterol level in Type 2 diabetes (Ghiridhari, Malhati, & Geetha, 2011; Nambiar, Guin, Parnami, & Daniel, 2010). Leaf powder capsules (4 g) considerably improved the discharge of insulin in 10 healthy human volunteers (Anthanont, Lumlerdkij, Akarasereenont, Vannasaeng, & Sriwijitkamol, 2016). 4-[(α-L-rhamnosyloxy)benzyl] isothiocyanate and 4-[(4′-O-acetyl-α-L-rhamnosyloxy)benzyl] isothiocyanate showed antidiabetic activity (Tumer et al., 2015; Waterman et al., 2015). In alloxan-induced diabetic rats, the aqueous extract (300 mg/kg) exhibited 44.06% reduction respectively of blood glucose concentration within 6 hr of administration, whereas almost as effective as the standard drug tolbutamide (200 mg/kg,) caused 46.75% reduction (Edoga, Njoku, Amadi, & Okeke, 2013). A watery concentrate of leaves accelerated insulin level in diabetic rodents (Tuorkey, 2016). A protein had antigenic epitopes like insulin reported in seed coat and leaves of MO and showed hypoglycemic properties on oral administration. It also cross-reacted with anti-insulin antibodies, which proved that it might have antigenic epitopes similar to insulin (Paula et al., 2017). Leaf methanolic extract indicated defensive activity against diabetic-prompted renal damage, receptive oxygen species, and irritation (Omodanisi et al., 2017). Thus, majority of studies have used leaf extracts on animal subjects like rodents. However, as regards to the antidiabetic activity, a recent study showed that the administration of a dose of 20 g/day of *M. oleifera* leaves determined a reduction of the postprandial glycemic response in human subject (Leone et al., 2018) that was maintained for up to 3 hr from the beginning of the meal blended with MO leaf powder.

3.4.6 | Antioxidant activity

MO is well-known tree for its high antioxidant in leaves, fruits, and seeds among other fruits and vegetables (Yang et al., 2006). MO tree contains about 40 natural antioxidants (Mahmood et al., 2010). The antioxidant activity is attributed due to the presence of various types of antioxidant compounds (Omodanisi et al., 2017; Siddhuraju & Becker, 2003) such as ascorbic acid, β-carotene (Kumar, Pandey, Mohan, & Singh, 2012; Mahajan & Mehta, 2007), quercetin, kaempferol (Gupta et al., 2012), flavonoids, phenolics (Anwar, Ashraf, & Bhanger, 2005; Sreelatha et al., 2011), isothiocyanates, polyphenols, and rutin in leaves (Tumer et al., 2015); myricetin (Lalas & Tsaknis, 2002b), tocopherols and lectins in seeds (Singh et al., 2013); procyanidins in stem and root bark (Atawodi et al., 2010) and palmitic acid, phytosterols, and 9-octadecenamide in flowers (Inbathamizh & Padmini, 2012), monopalmitic acid, oleic acid, tri-oleic triglycerides in seed oil (Lalas & Tsaknis, 2002a; Mahajan & Mehta, 2007). Methanol and acetone extracts of leaves (Atawodi et al., 2010; Charoensin, 2014), aqueous extracts of roots (Satish, Kumar, Rakshith, Satish, & Ahmed, 2013), methanolic extracts of stem and pods (Gupta et al., 2012; Kumbhare, Guleha, & Sivakumar, 2012) showed wide antioxidant profile. The

highest antioxidant activity is recorded for isoquercetin as it increased the mRNA articulation dimensions of catalase, oxygenase, and superoxide dismutase (Vongsak, Mangmool, & Gritsanapan, 2015).

Folate isolated from foliage is the notable among the most imperative water-soluble vitamins, assumes a basic role in different cell metabolisms (Scotti, Stella, Shearer, & Stover, 2013). Antioxidant benefits could be obtained for chicken sausages in cold storage through the application of dry leaf powder by reducing lipid oxidation (Jayawardana, Liyanage, Lalantha, Iddamalgoda, & Weththasinghe, 2015). Quercetin isolated from essential oil is quite compelling and may inhibit tumor necrosis factor by Kupffer cells (Baghel, Shrirastava, Baghel, Agrawal, & Rajput, 2012). Luteolin has additionally a solid antioxidant agent and may show evidence of defensive ability on DNA (Romanova, Vachalkova, Cipak, Ovesna, & Rauko, 2001). Further studies revealed that luteolin is fit for applying a variety of biological and pharmacological activities, namely, antioxidant, anti-inflammatory, antimicrobial, anticancer, antiallergic, antiplatelet, and other activities (El-Hawary, El-Sofany, Abdel-Monem, Ashour, & Sleem, 2012). The hydrocarbons of seed essential oil demonstrated radical scavenging effect (Yassa, Masoomi, Rankouhi, & Hadjiakhoondi, 2009). The application of leaf extract maintained plasma malondialdehyde (MDA) level and ferric reducing ability of plasma without hypoglycemia effect in human volunteers (Ngamukote et al., 2016).

3.4.7 | Anti-inflammatory activity

This is an established fact that leaf, fruit, seed, and root extracts have been used since long back in enhancement of inflammation related disorders, for example, asthma, allergic rhinitis, atopic dermatitis, and rheumatoid arthritis (Chumark et al., 2008; Hamza, 2010; Lee et al., 2013; Muangnoi, Chingsuwanrote, Praengamthanachoti, Svasti, & Tuntipopipat, 2012). Anti-inflammatory activities are possibly attributed due to the presence of 4-[(α-Lrhamnosyloxy) benzyl] isothiocyanate, 4-[(4′-O-acetyl-α-L-rhamnosyloxy) benzyl]isothiocyanate (Stohs & Hartman, 2015), quercetin, quercetin-3-O-glucoside, kaempferol glucosides, (Coppin et al., 2013), 4-(2-O-acetyl- α-L-rhamnosyloxy) benzyl isothiocyanate, 4-(3-O-acetyl-α-rhamnosyloxy)benzyl isothiocyanate (Cheenpracha et al., 2010), 3,5-dihydroxy-6-methyl-2,3-dihydro-4H-pyran-4-1, 9-octadecenamide (Inbathamizh & Padmini, 2012), crypto chlorogenic acid (Vongsak, Gritsanapan, Wongkrajang, & Jantan, 2013), aurantiamide acetate, 1,3-dibenzyl urea (Maheshwari, Yadav, Malhotra, Dhawan, & Mohan, 2014; Pandey et al., 2012) and 4(α-L-rhamnosyloxy)-benzyl glucosinolate (Galuppo et al., 2014).

Leaves ethanolic extract demonstrated anti-inflammatory properties by inhibiting chemotactic oxidation of polymorphonuclear leukocytes (Vongsak et al., 2013), keratinocytes (Choi et al., 2016) and leaves, seeds, and roots extracts against multiple sclerosis cascades (Galuppo et al., 2014). The hydroalcoholic extract of seeds additionally reduced the action of TNF-α, IL-4, IL-6, and myeloperoxide, a cause of inflammatory bowel diseases (Minaiyan et al., 2014). Hydroalcoholic leaf extract enhanced the cellular and humoral immunity in immunosuppressed rodents (Nfambi, Bbosa, Sembajwe, Gakunga, & Kasolo, 2015). Methanol extract decreased the edematogenic impact of carrageenan- and histamine-induced foot edema in laboratory animals (Adedapo, Falayi, & Oyagbemi, 2015) and also pain relieving impacts by reducing mechanical allodynia and thermal hyperalgesia in Freund's adjuvant joint inflammation prompted rodents, whereas methanolic root decoction decreased thermal hyperalgesia (Manaheji, Jafari, Zaringhalam, Rezazadeh, & Taghizadfarid, 2011). The hydroethanolic extract of flowers also decreased the movement of incendiary mediators and proinflammatory cytokines, for example, PGE2, IL-1α, IL-6, TNF-α, NF-kB, iNOS, NO, and COX2 in LPS prompted RAW264.7 macrophage cells (Tan, Arulselvan, Karthivashan, & F akurazi S., 2015). The fruit demonstrated the highest activity in reducing NO release induced by LPS in RAW264.7 cells (Lee et al., 2013). The fruit extract of MO blocked the atomic translocation of NF-kB and increased inhibitor kB articulation (Arulselvan et al., 2016). MO roots showed evidence of restraint against IL-2 activity (Sashidara et al., 2009). Fermentation of MO decreased hepatic adiposity, endoplasmic reticulum anxiety and improved resistance to glucose in obese mice (Joung et al., 2017).

3.4.8 | Antiparasitic activity

MO possesses different activities such as antiulcerogenic by leaf aqueous extract (Dahiru, Onubiyi, & Umaru, 2006;) schizonticidal by leaf acetone extract (Patel, Gami, & Patel, 2010), larvicidal by seed coagulant lectin protein (De Oliveira et al., 2011; Prabhu, Murugan, Nareshkumar, Ramasubramanian, & Bragadeeswaran, 2011), antiulcerative colitis by root extract (Gholap, Nirmal, Pattan, Pal, & Mandal, 2012), antiurolithiatic by root wood extract (Karadi et al., 2006), and antimacrofilaricidal activities by gum exudates (Kushwaha et al., 2011). The antilarvicidal activity for *Aedes ageypt*, a vector of dengue virus, was reported in flower extract through trypsin inhibitor activity (Pontual et al., 2014). The growth of fourth-stage *Aedes ageypti* larvae was interrupted by lectin protein isolated from seeds (Agra-Neto et al., 2014). The growth of *Biomphalari aglabrata* embryos was delayed in aqueous extract of flowers and increased also the mortality of young snails (Rocha-Filho et al., 2015). Antileishmanial activity for *Leishmania donovani* promastigotes was reported by Kaur, Kaur, Singh, and Singh (2014) with the application of alcoholic extracts of leaves and roots. Niazinin isolated from leaf ethyl acetate extract showed the most antileishmanial activity (Abd Rani, Husain, & Kumolosasi, 2018). Singh, Paul, De, and Chakraborti (2015) observed that various parts, that is, leaf, flower, bark, roots, stem wood exhibited antileishmanial activities, of which ethyl acetate extract of flower had the maximum negative impact on *L. donovani*. Sengupta et al. (2012) demonstrated that seed extract could be useful to check the growth of helminth eggs and to remove turbidity from irrigation water. The inhibitory effect on egg hatching of *Haemonchus contortus* was reported by aqueous extract of seeds (Salles et al., 2014). Similarly, seed aqueous extract showed larvicidal, pupicidal, and in addition adult mosquito killing activities for *Culex quinquefasciatus* (Ashfaq & Ashfaq, 2012). Antitrypanosomal activity against *Trypanosoma brucei* was reported in petroleum ether, chloroform, methanol, and aqueous extracts of leaves, stem bark, and roots (Ibrahim, Mohammed, Isah, & Aliyu, 2014).

3.4.9 | Cardio protective activities

Every part of MO is used for cardiovascular, circulatory stimulant, and lowering cholesterol and blood pressure level. Leaf extract showed hypocholesterolemic activities (Atsukwei, Eze, Adams, Adinoyi, & Ukpabi, 2014; Ghasi, Nwobodo, & Ofili, 2000; Marcela, Almatrafi, & Fernandez, 2017; Okwari, Dasofunjo, Asuk, Alagwu, & Mokwe, 2013). Moringinine is utilized as a cardiac tonic, which acts on sympathetic nervous system (Anwar et al., 2007). N-α-L-rhamnopyranosyl vincosamide in bark is showed cardioprotective effects (Morton, 1991). Leaf extract decreased mortality and morbidity of cells in coronary heart disease, and this may be due to the gossypetin, quercetagenin, and proanthocyanidins (Kumar et al., 2012; Seshadri & Nambiar, 2003). β-sitosterol had significant cholesterol reducing property (Ghasi et al., 2000). Cardioprotective activity of leaf extract is assessed in rats (Nandave et al., 2009). Lipid profile of liver, heart, and aorta in hypercholesteremic rabbits was decreased by MO fruits and increased the discharge of fecal cholesterol because of the having lower cholesterol, phospholipids, triglycerides, lipoprotein (Mehta et al., 2003). Leaf ingredients used to check blood glycated hemoglobin, total cholesterol, non-HDL-C, HDL-C, VLDL-C, and LDL-C in Type 2 diabetic patients (Nambiar et al., 2010).

Various leaf ingredients such as niazinin, niazimicin, niaziminin, niazimin, niazirin, niazicin, niazirinin, 4-(4′-O-acetyl-α-rhamnosyloxy) benzyl isothiocyanate are responsible for hypotensive and bradycardiac activities (Bose, 2007), and glucomoringine is reported to have hypertensive effect (Dangi, Jolly, & Narayana, 2002; Maheshwari et al., 2014). Thiocarbamate and isothiocyanate glycosides (Faizi et al., 1995), methyl phydroxybenzoate and β-sitosterol (Faizi et al., 1998) isolated from pods are known for hypotensive activity. Seeds demonstrated vascular oxidative and nitrosative stresses in spontaneously hypertensive rats (Randriamboavonjy, Rio, Pacaud, Loirand, & Tesse, 2017). Niazinin-A, niazinin-B, and niazimicin found in ethanolic extract of leaves are effective in controlling the blood pressure level possibly through a calcium antagonist effect (Anwar et al., 2007; Dubey, Dora, Kumar, & Gulsan, 2013). Similarly, blood pressure lowering effect was reported by ethanol and aqueous extract of MO pods (Faizi et al., 1998). Blood pressure is also controlled by the application of MO leaves due to the presence of nitrile, glycosides, and thiocarbamate glycosides (Dangi et al., 2002; Marcela et al., 2017). Extracts of seeds and leaves had blood pressure reducing effect because of alkaloids and flavonoids through the inhibitory impact on angiotensin converting enzymes (Abdulazeez, Ajiboye, Wudil, & Abubakar, 2016). Dried seeds had the evidence of cardioprotective effect, induced cardiovascular diastolic function, and reduced nighttime pulse rate without adjusting the circulatory strain in hypertensive rats (Randriamboavonjy et al., 2016). Butanolic extract of leaf decreased the possibility of cardiac necrosis and oxidative stress in isoproterenol-induced rodents (Panda, 2015).

3.4.10 | Metabolic disorders

Different leaf extracts showed antihyperlipidemic effect (Chumark et al., 2008; Divi et al., 2012; Irfan, Asmawi, Khan, & Sadikun, 2016; Jain, Patil, Haswani, Girase, & Surana, 2010) and hepatoprotective activities (Efiong, Igile, Mgbeje, Out, & Ebong, 2013; Pari & Kumar, 2002). Ethanolic extract of foliages, leaf oil, and seeds had hepatoprotective and kidney defensive properties against γ-radiation, $HgCl_2$, acetaminophen, and arsenic (Abarikwu, Benjamin, Ebah, Obilor, & Agbam, 2017; Gupta, Dubey, Kannan, & Flora, 2007; Sinha, Das, Bhattacharjee, Majumdar, & Dey, 2011). Afterward, Tahiliani and Kar (2000), Anwar et al. (2007), and Chumark et al. (2008) confirmed the antihyperthyroidism and atherosclerotic properties for leaf extracts. Additionally, aqueous extract of roots have been found to have estrogenic and progestational activity (Shukla et al., 1988) along with liver and renal defensive property (Mazumder, Gupta, Chakrabarti, & Pal, 1999). Roots extract has been reported to possess antispasmodic activity (Caceres et al., 1992; Dangi et al., 2002). Hydroethanolic extract of leaves reduced mRNA articulation, which is liable for keeping up lipid homeostasis (Sangkitikomol, Rocejanasaroj, & Tencomnao, 2014). Leaf aqueous extract inhibited formation of nonfluorescent and fluorescent advanced glycation end products (Nunthanawanich et al., 2016). The pods with high fiber content used to treat stomach-related issues and intestinal problems (Oduro, Ellis, & Owusu, 2008). Seed powder is used to reduce the arsenic from blood, liver, and kidneys (Gupta et al., 2005).

Moringine and moringinine had antihypoglycemic properties (Maheshwari et al., 2014; Mehta et al., 2011). Phytochemical examination demonstrated that β-sitosterol and 4-[α-(L-rhamnosyloxy) benzyl]-o-methyl thiocarbamate (trans) are powerful agent to reduce the cholesterol level, antidiarrheal, antispasmodic, and hypolipidemic activities (Anwar et al., 2007; Jain et al., 2010; Maheshwari et al., 2014), whereas quercetin-3-glycoside is responsible for antidyslipidemic (Mbikay, 2012) and hypoglycemic (Maheshwari et al., 2014) properties. The quercetin and kaempferol in flowers and pods showed hepatoprotective exercises (Farooq et al., 2012; Gupta et al., 2012). The extract of leaves and fruits has ability to heal chronic gastric ulcers induced via acetic acid (Devaraj & Gopala-Krishna, 2013). Niaziridin improved the gastrointestinal retention of nutrients and supplements (Stohs & Hartman, 2015). Leaf powder capsules (4 g) induced the discharge of insulin (Anthanont et al., 2016). The action of CD69, INF-g, and CD44 protein is increased by oral administration of leaf aqueous extract, which are responsible for hypoglycemic activity and furthermore decreased creatinine and urea levels from damaged kidneys (Paula et al., 2017). The reduction in lipid peroxidation and immunoglobulin IgG and IgA was observed for seed extract (Al-Malki & El Rabey, 2015). Antihypoglacemia (antidiabetic) effect was exhibited by vacuum dried 95% ethanolic extract of stem bark (Kar, Choudhary, & Bandyopadhyay, 2003) and ethanolic extract (Irfan et al., 2016).

3.4.11 | Nervous system disorders

Immunosuppressive and immunostimulatory activities were reported for MO leaf extract (Rachmawati & Rifa, 2014). The immunomodulatory impact of leaves extract is mediated through reduction in cyclophosphamide incited immunosuppression by invigorating cell and humoral immunity (Gupta et al., 2010), which is attributed to the presence of compounds like isothiocyanates and glycoside

cyanides (Sudha et al., 2010). Leaves had neuroprotective impact by progressing neuronal survival and neurite outgrowth (Hannan et al., 2014). Leaf extract had defensive impact against Alzheimer's disease by adjusting cerebrum monoamine levels and electrical impulses (Ganguly & Guha, 2008). Further, it was discovered that the CNS depressant action is mediated through its pain relieving and anticonvulsive properties because of triterpenoid, saponins, and flavonoids in leaves (Bakre, Aderibigbe, & Ademowo, 2013; Gupta, Mazumder, & Chakrabarti, 1999; Ray, Hazra, & Guha, 2003). MO has used to improve memory by nootropics movement and protect against the oxidative pressure in Alzheimer's illness (Ganguly, Hazra, Ray, & Guha, 2005). A model was proposed by Ganguly and Guha (2008) for Alzheimer's disease including the infusion of colchicine into the brain of rodents. They showed that MO induced the modification of cerebrum monoamines and electrical patterns. Protective effect against neurodegeneration has been reported by Giacoppo et al. (2015) due to the glucosinolates (R,S-Sulforaphane-SFN), which offer protection to mesencephalic dopaminergic neurons from cytotoxicity and oxidative stress through the prevention of reactive oxygen, DNA crumbling, and membrane rupture (Han et al., 2007).

3.4.12 | Wound healing activity

Aqueous leaves extract decreased scar regions and accelerated the healing rates of wounds in addition to increase the granuloma and skin breaking strength in albino rats (Lambole & Kumar, 2012; Rathi, Bodhankar, & Baheti, 2006). MO phytochemical ingredients mediate the wound healing activity by suppressing antihealing agents. Wound healing constituents, for example, quercetin, kaempferol, phytosterols (Hukkeri et al., 2006), and vicenin-2 (Muhammad, Pauzi, Arulselvan, Abas, & Fakurazi, 2013) have been reported in ethyl acetate extract of leaves and dexamethasone in bark (Lambole and Kumar et al., 2012). Proteolytic, fibrinolytic, and fibrinogenolytic actions on blood coagulating process by protease activity have been assessed for leaf and root aqueous extracts (Satish, Sairam, Ahmed, & Urooj, 2012). The protease also demonstrated similar activity to plasmin and thrombin coagulating protein and also attenuated apoptosis in addition to suppressing the peroxisome proliferator-activated receptor gamma activation and shortened the time taken to activate prothrombin and thromboplastin, The wound healing activity has also been reported in the seeds of MO (Bhatnagar, Parwani, Sharma, Ganguli, & Bhatnagar, 2013; Parwani, Bhatnagar, Bhatnagar, Sharma, & Sharma, 2016).

3.5 | Miscellaneous uses

3.5.1 | *M. oleifera* for agriculture and animal husbandry

Extracts of MO leaves in 80% ethanol having cytokinine type plant growth regulator, which may be used as foliar spray to quicken growth in peanut, soya bean, black bean, maize, onion, sorghum, tomato, coffee, and sugarcane crops. This makes crop plant resistant to insect-pest and increase the biological yield (Foidl, Makkar, & Becker, 2001). The sole crop of maize and sweet potato were compared with the maize with moringa and sweet potato with moringa. Intercropping with moringa produced the highest crop growth than the monoculture cropping pattern. The results also indicated a decrease in soil acidity from 1.86 to 1.60 (Abusuwar & Abohassan, 2017). Yield can be increased by 25–30% for nearly any group of plants (maize, black pepper, tomato, soya bean, onion, sorghum, tea, coffee, melon, and chili) with application of juice of fresh MO leaves. One of the dynamic constituent, that is, zeatin, acts as a characteristic plant development enhancer and helps to increase crop yield (Leone, Spada, et al., 2015). Leaf extract may be used to boost up the *Rhizobium* root nodulation and nitrogenase activity in *Vigna mungo* when applied over seeds or as a root dressing (Bandana, Srivastava, & Mathur, 1987). The oilcake of MO is used as a fertilizer (Dastur, 1964). The flowers are a unique source of pollens for honey bees (Rajan, 1986; Sohani, 2018). The wood is little utilized outside of its local range with the exception of as a fuelwood and also for light construction (Little & Wadsworth, 1964). Its wood provides a fairly good fuel for cooking even being light in weight (Zheng, Zhang, & Wu, 2016).

The tender twigs are being utilized as feed for cows, sheep, goats, and camels worldwide (Mahatab, Ali, & &Asaduzzaman A.H.M., 1987). Presence of high protein and low content of antinutritional compounds makes it substitute to regular cattle feeds, that is, alfalfa and oil seed cakes (Babiker, Al-Juhaimi, Ghafoor, & Abdoun, 2016). Feeding of MO leaf helps to improve the milk quality and quantity (Mendieta, Sporndly, Reyes-Sanchez, & Sporndly, 2011), meat production (Babiker et al., 2016), beef production, and dietetic nature of roughages (Roy, Bashar, Hossain, Huque, & Makkar, 2016). However, the gas production increased with a normal feed of MO leaves and methane content of the gas was 81% (Essien, Essien, & Eluagu, 2016). The MO has also been reported as an effective feedstock for biofuels, for example, biogas and biodiesel (Kafuku & Mbarawa, 2010; Rashid, Anwar, Moser, & Knothe, 2008). Pontual et al. (2012) assessed the caseinolytic and milk coagulating properties of proteases in flowers; further, milk clotting enzymes were isolated and purified from MO seeds by Ahmed (2016). It was effectively used in cheese production, therefore recommending an option in contrast to conventional animal rennets.

3.5.2 | *M. oleifera as* coagulant

There are a several genuine drawbacks of using synthetics and polymers due to the harmful consequences for human well-being and nature. In this way, a restoration of enthusiasm for natural coagulants has risen as a result of the high cost, health issues, and nonbiodegradable nature (Choy, Prasad, Wu, Raghunandan, & Ramanan, 2014). Seeds of MO have used to treat the waste water as they contain cationic polyelectrolyte, which neutralizes the negatively charged colloids present in dirty and muddy water (Makkar & Becker, 1996). Approximately, 300 mg of MO seed powder is sufficient to purified 1 L of water. In this condition, microorganisms can be removed by settling with the pattern of removal of colloids from coagulated and

flocculated water (Casey, 1997). Various coagulating and flocculating components were separated from various plant parts. Okuda, Baes, Nishijima, and Okada (2001) identified a coagulating agent from the salt solution of seeds extract, whereas Santos et al. (2009) purified hemaggulatinating proteins and lectin coagulant from MO seeds and other tissue extracts. These coagulants were evaluated with aluminum sulphate to check its efficacy for turbid water treatment (Pritchard, Craven, Mkandawire, Edmondson, & O'neill, 2010) along with the flower extract for purification of the waste water (Moura et al., 2011). Further, Broin et al. (2002) cloned cDNA encoding flocculating proteins from MO seeds and used in purification of water against clay particles, gram positive, and negative bacteria. Seeds are outstanding coagulant agents among other characteristic coagulants (Ferreira et al., 2008). Cationic proteins (MO2.1 and MO2.2 also referred to as Flo; P24303, Swissprot, Moringa oleifera cationic protein (MOCP)) and chitin-binding protein isoform (Mo-CBP3) isolated from seeds are being used for flocculating activities (Freire et al., 2015; Ullah et al., 2015). The coagulation efficacy of MOCP is observed to be increased with an increase in the initial turbidity of water (Katayon et al., 2006). Owing to amphiphilic properties, MOCP integrate into the bacterial membranes and are specifically kill several microorganisms, including waterborne pathogens (Shebek et al., 2015). The seed contain polypeptides, a coagulant, used to treat river water with suspended solid particles and groundwater (Lijesh & Malhotra, 2016).

The dried or powdered seeds have been exploited directly or in petroleum ether extract form (Johri, Reeta, & Johri, 2004), as an efficient and low-cost coagulant to remove turbidity and decrease the microbial contamination from drinking water from village communities in the Sudan, Malawi, India, Myanmar, and Indonesia (Mandloi, Chaudhari, & Folkard, 2004; Nyein et al., 1997). Crude extract of MO seeds was used by rural women to treat the very turbid Nile stream water instead of alum causing gastrointestinal disturbances and Alzheimer's illness in Sudan (Ravikumar & Sheeja, 2013). Turbidity removal effectiveness was resulted 80–99% at a pH of 7–7.5 by using MOCP. Turbidity reduction of 85–98% paralleled by a primary *E. coli* decrease of 99.2–99.97% was attained within the first 1–2 hr of treatment (Bina et al., 2010). Thus, MOCP as coagulant may be used for drinking water treatment without any risk.

3.5.3 | *M. oleifera* seeds as biosorbent

A billion people across the Asia, Africa, and Latin America are estimated to depend on untreated surface water sources for their day to day water needs. Of these, approximately two million are thought to die by using polluted water each year, with the larger part of these deaths happening among infants (Mahamood et al., 2010). There are several studies on MO for biosorption properties and removal of different heavy metals from water. The row husk as biosorbent does not require any kind of handling, and it permits valorization of the waste produced after coagulant extraction from the seed. The biosorption of all metals on the adsorbent was rapid as over 80% of the metals were removed within the first 20 min to 1 hr of application (Adhiambo, Lusweti, & Morang, 2015). Effective removal of azo and anthroquinonic dyes, and organic compounds viz., benzene, toluene, ethylbenzene, and cumene using seed extracts and fruits, respectively has also been demonstrated (Akhtar, Hasany, Bhanger, & Iqbal, 2007; Beltran & Snchez, 2008). Different parts of *M. oleifera* viz., seed powder for Cd^{+2} (Kituyi et al., 2013; Mataka, Sajidu, Masamba, & Mwatseteza, 2010; Sharma, Kumari, Srivastava, & Srivastava, 2006), Pb^{+2} and Cr^{+2} (Adhiambo et al., 2015); Zn^{+2} (Kituyi et al., 2013), As^{+3} and As^{+5} (Kumari, Sharma, Srivastava, & Srivastava, 2006); seeds for Ag^{+1} and Co^{+2} (Araujo et al., 2010); activated carbon from husk and pods for Pb^{+2} (Nadeem et al., 2006); activated carbon from wood for Cu^{+2}, Ni^{+2}, and Zn^{+2} (Kalavathy & Miranda, 2010); activated carbon from leaves for Cd^{+2}, Cu^{+2}, and Ni^{+2} (Reddy, Seshaiah, Reddy, & Lee, 2012); biomass for Zn^{+2} (Bhatti, Mumtaz, Hanif, & Nadeem, 2007); bark for Pb^{+2} (Reddy, Seshaiah, Reddy, Rao, & Wang, 2010); leaves for Pb^{+2} (Reddy, Harinath, Seshaiah, & Reddy, 2010); husk Cu^{+2} and Cd^{+2} (Garcia-Fayos, Arnal, Piris, & Sancho, 2016) have been tested as biosorbents agents. However, seeds of different *Moringa* species could also be used as a low-cost biosorbent for removal of heavy metals, that is, Cd^{+2}, Cr^{+2}, and Ni^{+2} from aqueous media (Mataka et al., 2010; Sharma, Kumari, Srivastava, & Srivastava, 2007).

3.5.4 | *M. oleifera* as biodiesel

In the last decade, biodiesel production from unconventional oils yielding plants, such as, *Jatropha*, *Moringa*, *Pongamia*, and tobacco have acknowledged more attention (Kivevele & Huan, 2015; Rashid et al., 2008). Azam, Waris, and Nahar (2005) concluded in their study led on 75 Indian plant species, which have more than 30% fixed oil in their seed/kernel and unsaturated fatty acid methyl esters of MO seed oil meet all the principle determinations of biodiesel standard of Germany, Europe, and the United States. MO seeds contain 33–41% (w/w) oil on account of the behenic acid (docosanoic acid and 7% w/w), which has significant protection from oxidative degradation (Rashid et al., 2008). On account of the significant of high amount of monounsaturated unsaturated fats as oleic acid (72.2%), MO seed oil is a potential substitute for biodiesel production (Sohani, 2018). The fuel properties of MO are predominantly dependent on the unsaturated fat composition, wherein C_{16} and C_{18} monounsaturated fatty acid methyl esters are ideal components to accomplish an adequate balance between oxidative stability and cold flow properties of biodiesel (Knothe, 2008). Azad, Rasul, Khan, Sharma, and Islam (2015) proposed the possibility of MO seed oil as a supportable biodiesel fuel and concluded, MO is one of the forthcoming industrial crops for biodiesel generation in calm atmosphere of Austria.

3.5.5 | Industrial uses

M. oleifera seed oil known as "ben oil" is commonly used for the preparation of cosmetics and blending in perfumery materials (Arise et al., 2014). The oil is commonly consumed by perfumers for its capacity of engrossing and holding smells (Ramachandran et al., 1980). Seed oil is used for different purposes, that is, lighting, hair dressing, and watches oil (Morton, 1991). Seed oil is also used by soaps making industries

(Rashid et al., 2008). Seed oil was used as grease oil for hardwires and watches (Rashid et al., 2008). Cognis Laboratories Serobiol Ogiques group formulated Puricare TM and Purisoft TM, two dynamic ingredients based on natural peptides of MO seeds, which offer protection against pollution effects on hairs and skin (Shah et al., 2016). The salt extract of seeds has also been used with povidone (polyvinylpyrrolidone) to enhance solubility of the partially soluble Non-Steroidal Anti-Inflammatory Drugs (NSAIDS) (Noolkar, Jadhav, Bhende, & Killedar, 2013). A study conducted by Torondel, Opare, Brandberg, Cobb, and Cairncross (2014) concluded the viability of dried and wet leaf powder as a hand-washing item and indicated dimensions of inhibition of *E. coli* similar to a nonmedicated liquid soap because of saponin content. Recently, MO leaf extract in blended with gelatin isolated from puffer fish skin was used for production of antimicrobial, antioxidative, and biodegradable packaging materials (Lee, Yang, & Song, 2016). The gum exudate of MO is used for blue dye in Jamaica (Verma, Banerji, Misra, & Nigam, 1976). Its adhesive gum is utilized in leather tanning and calico printing (Morton, 1991; Sohani, 2018). Gum also be utilized for production of mucoadhesive polymer, disintegrant, binder (Patel, Patel, & Upadhyay, 2012), and a competent amorphous state stabilizer in drug formulations, that is, ibuprofen, meloxicam, and felodipine (Bhende & Jadhav, 2012). Apart from gum, its viscose resin is used textile industries (Fuglie, 1999). A coarse fiber is produced by its corky bark, which is used in paper making mats and cordage. In India, wood is utilized to a limited extend in the textile industry for transports and picking-sticks and is suitable for pulpwood alternative for newsprint (Singh, Wadhwani, & Johri, 1983), wrapping, textiles (Ganatra et al., 2012), cellophane, and materials (Nautiyal & Venhataraman, 1987).

4 | CONCLUSIONS AND FUTURE PERSPECTIVES

The *M. oleifera* is the most inexpensive and credible alternative to provide good nutrition and curing and prevention of several disorders. The secondary metabolites and higher amount of phytochemicals with other essential components could be valuable for food fortification and to ensure the practice of traditional medicines. Therefore, the poor nations should promote planting and uses of *M. oleifera* instead of bounties for food relief from the rich nations. Previous studies have evaluated the traditional uses of *Moringa* species, and the majority of these examinations supported the traditional claims. However, there are lots of uses that have not been assessed till date, particularly in species other than MO. Because MO normally grows in different environments, a variation in phytochemical ingredients and nutraceutical status is reported from different parts. In any case, the degree to which the chemical composition fluctuates in seed sources adapted to different habitats is still unknown. In spite of the fact that *Moringa* leaves are viewed as great protein source, despite everything, it must be studied that which protein contend with the more common protein in milk producing ruminants. Few studies are carried out on human subjects, whereas the dominant parts of studies have used aqueous and alcoholic extractions basically in rodents and other animals. Keeping in view the importance of MO in humans as a "Nutritional Dynamite," clinical trials to assess the efficacy of *Moringa* with human subjects and positive effects on human immune system in fighting diseases should be taken to explore before promoting it and using it for treating malnutrition and various disease in low income countries. Likewise, few bioactivity-based extraction techniques have been used to decide the connections between extraction systems and solvents. It is not clear about the degree of different ingredients of MO interrelate through additive, synergistic, and/or inhibitory impacts in therapeutic treatment. Assessment of the safety and toxicity of antimicrobial agents from MO is important before implementing the uses of these compounds. Numerous studies have also been demonstrated the *Moringa* seeds as coagulant agent for treating waste water. Subsequently, it is essential to recognize the dynamic constituents of MO seed to understand its coagulation mechanism.

CONFLICT OF INTEREST

The authors have declared that no competing interests exist.

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