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Allelopathic Plants: 27. *Moringa* species

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ABSTRACT

Moringa is a medicinal plant used to treat numerous diseases. It is rich in allelochemicals [amino acids **(**Threonine, methionine and phenylalanine)**,** fatty acids (Palmitic, oleic and linoleic), phenols (Gallic acid, p-coumaric acid and ferulic acid) flavonoids (Catechin, quercetin, kaempferol and niazimicin) and other bioactive compounds, vitamins (B, A, C, D and K)], zeatin and essential macro (Potassium, magnesium and phosphorus) and microelements (Iron and zinc). These elements accelerate the plant's growth, improves the plant's resistance against pests and diseases and tolerance to biotic and abiotic stresses.

Keywords: Allelochemicals, allelopathic plants, allelopathy effects, chemical composition, economic importance, geographical distribution, morphology, *Moringa* species, plants nutrients.

1. INTRODUCTION

The Allelopathy affects the neighbouring plant's growth through the release of plant-produced bioactive secondary metabolites called allelochemicals in the environment (46). The moringa plants affect the germination and growth of wheat, faba bean, maize and wild mustard (71). The high doses of moringa extract are inhibitory and thus decreased the germination and growth of recipient's plants such as wheat, barley and weeds (82).

The moringa leaves contain several types of compounds, which have pharmaceutical, industrial and allelopathic properties. The moringa plants are rich in macro and micronutrients and contain methionine, cysteine, tryptophan, lysine, vitamin C,

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vitamin B1, vitamin B2, vitamin B3, iron, potassium, calcium, zinc, sodium (7). Besides, it is a potential source of natural antioxidants, flavonoids, anthocyanin, cinnamates and proanthocyanidins, 4-hydroxymellein, ß-sitosterol, vanillin, essential oils and fatty acids. Moringa plants also contain several allelochemicals (phenolics compounds (benzoic acid, vanillic acid, coumaric acid, gallic acid, caffeic acid, ferulic acid and chlorogenic acid) and fatty acids (linoleic, oleic and 9-octadecenoic). These allelochemicals at high concentrations may be used as natural pesticides (37,74). This review describes the classification, distribution and economical importance of *Moringa* species, the effects of its phytotoxic compounds on other organisms and allelochemicals involved in these interactions.

2. GEOGRAPHICAL DISTRIBUTION AND MORPHOLOGY

Moringa species are native to parts of Africa, Asia (sub-Himalayan tracts of India, Pakistan and Bangladesh), tropical and sub-tropical areas of the World (34) (Figure 1). It belongs to the family *Moringaceae*, that includes 13 species of various sizes from small plants (*M. oleifera*) to huge trees (*M. stenopetala)* (1-15 m height) (1,26,56). The most commonly cultivated commercial specie is *M. oleifera* Lam. (horseradish and drumstick tree) native to dry tropical areas in north-western India (34) but is widely cultivated in tropics. It is grown in India, Philippines Africa (Ethiopia, Sudan, East, West and South Africa), Latin America, Pacific Islands, Caribbean and Florida (66). Its 9-species (*M. arborea*, *M. borziana*, *M. longituba*, *M. ovalifolia*, *M. peregrine*, *M. pygmaea*, *M. rivae*, *M. ruspoliana*, and *M. stenopetala*) occur in eastern Ethiopia, northern Kenya, and Somalia, of which 8, are endemic to Africa (Table 1).

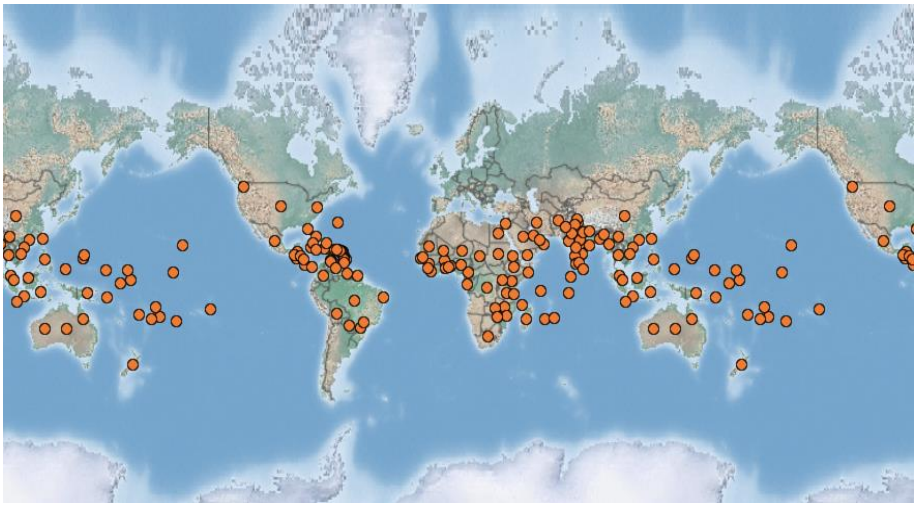

Figure 1. Distribution of *Moringa* species on the planet.

(Source: https://www.cabi.org/isc/datasheet/34868#toDistributionMaps).

Table 1. Distribution of *Moringa* species in different countries (1).

Species No.	*Moringa* species	Countries
1	*M. arborea*	Kenya
2	*M. borziana*	Somalia and Kenya
3	*M. concanensis*	Sub-Himalayan tracts of Northern India
4	*M. drouhardii*	Madagascar
5	*M. hildebrandi*	Madagascar
6	*M. longituba*	Kenya, Ethiopia and Somalia
7	*M. oleifera*	Sub-Himalayan tracts of Northern India
8	*M. ovalifolia*	Namibia and Angola
9	*M. peregrine*	Red sea and Africa
10	*M. pygmaea*	Somalia
11	*M. rivae*	Kenya and Ethiopia
12	*M. ruspoliana*	Ethiopia
13	*M. stenopetala*	Kenya and Ethiopia

Morphology: *Moringa* spp plants vary in morphological characters (Table 2). Some *Moringa* species are perennial, 5-10 m tall, stem diameter (20 to 100 cm). The stem bark is thick cork and whitish-grey in colour. The leaves are of different shapes (imparipinnate, pinnate and droop). The stomata are present in epidermal cells in the lower and upper layers. The flowers are asexual and fragrant with yellowish-white petals (1-2 cm long and 1.50-2.00 cm wide). In cool areas, flowering occurs once a year (April to June), while all year-round in some regions. Its seeds are brown, white and yellow, angled or winged or round (Figure 2).

Figure 2. Some parts of *M. oleifera.* A. Leaves, B. Flowers, C. Pods and D. Seeds.

Table 2. Botanical descriptions of some *Moringa* species.

Botanical description	***M. oleifera***	***M. stenopetala***	***M. peregrina***	***M. concanesis***	***M. ovalifolia***
Leaf shape	Imparipinnate	Imparipinnate	Pinnate	Pinnate	Droop
Leaflets number	9	7	3	3	9
Leaflet shape	Oboordate	Elliptic	Linear	Linear	Oval
Stomata shape	Actinocytic	Anomocytic	Anomocytic	Anomocytic	Actinocytic
Seed color	Brown	Brown	White	White or Yellow	Brown
Seed shape	Round	Like almonds	Angled	Angled	Winged
Epidermal cell shape	Reticulate	Reticulate-foveate	Periclinal	Periclinal	Reticulate
References	16,42	16,42	16,42	10	40

3. ECONOMIC IMPORTANCE

Moringa is a miracle plant, among the medicinal, agricultural and horticultural crops. It grows quickly in tropical and subtropical environments. The global market demand for Moringa products is estimated > US$ 4.6 billion. India is the largest producer (41% of world production, followed by Africa (33%), Malaysia and Philippines (12%), China (8%) and Venezuela (6%), It easily propagates, very fast-growing, hence, the cost of production is low. It is resistant to drought, pests and grows in poor soil (15,82). All parts (root, leaf, stem, bark, flower, pod, and seed) have agricultural and industrial uses. It can be used to stimulate the wheat seeds germination (73), bio-control of weeds [decreased the seeds germination of wild mustard weed (73)], and to improve the soil fertility (3).

4. ALLELOCHEMICALS IN MORINGA SPECIES

Moringa plant parts contain numerous phytochemical constituents (Tables 3, 4 and 5) from various parts and some of these have allelopathic effects (17,18,23,53,57,64,73).

4.1. Essential oils

M. oleifera leaves are rich in essential oils and include several compounds (Table 3) viz., hexacosane, hexanoic acid, pentacosane, phytol, thymol, nonacosane, 1,2,4-trimethyl-benzene, heptacosane and nonacosane (53,57,73). Pantolactone and squalene are vital constituents in the leaf and bark of *M. concanensis* (17). The major compounds in flowers are (*E*)-nerolidol, α-terpineol and benzyl isothiocyanate, octadecane and hexadecanoic acid (18,64). Tahir *et al*. (73) reported that flower extracts of *M. oleifera* were rich in nonacosane, methyl linoleate and methyl palmitate. The seeds are rich in several volatile compounds such as nonane, 3-methyl-5-propyl-, octane, 3,5-dimethyl-, and tetradecane (73) and fruits comprise tetracosane (23). The pentacosane allelochemical acts as a repellent against aphids (39).

Table 3. Chemical components in essential oils of *Moringa* species.

Plant part	***Moringa* species**	**Chemical constitutes**	**References**
Leaves	*M. oleifera*	Hexacosane, hexanoic acid, pentacosane, phytol, thymol, nonacosane, 1,2,4-trimethyl-benzene, heptacosane, nonacosane, benzaldehyde, 2-hexanal and phnethyl alcohol	52,56,57,73
Flowers	*M. oleifera*	(E)-nerolidol, α-terpineol and benzyl isothiocyanate, octadecane and hexadecanoic acid, Nonacosane, methyl linoleate and methyl palmitate	18,64,73
Barks	*M. oleifera*	Pantolactone and squalene	17
Seeds	*M. oleifera* and *M. stenopetala*	Nonane, 3-methyl-5-propyl-, octane, 3,5-dimethyl-, and tetradecane, benzyl isothiocyanate and isobutyl isothiocyanate	30,69,73
Fruits	*M. oleifera*	Tetracosane	23

4.2. Phenolics and flavonoid compounds

Moringa contains various bioactive compounds: simple and polyphenol components, good for health (77) (Table 4). Several allelochemicals were also found in different parts of *Moringa* species. For instance, 4-(R-L-rhamnopyranosyloxy)-benzylglucosinolate was isolated from the moringa seeds, whereas two compounds: 4-(R-L-rhamnopyranosyloxy)-benzylglucosinolate and benzyl glucosinolate were isolated from the moringa roots. Moringa leaves are rich in 4-(R-L-rhamnopyranosyloxy)- benzylglucosinolate, 3-caffeoylquinic acid, 5-caffeoylquinic acid, and three monoacetyl isomers of this glucosinolate, whereas, 4-(R-L-rhamnopyranosyloxy)-benzylglucosinolate was detected in its bark (21). Faizi *et al.* (32,33) reported several allelochemicals in *Moringa* species, including isothiocyanates and nitriles; whereas, Eilert *et al.* (29) detected 4-(RL-rhamnopyranosyloxy)-benzyl in its seeds. Results of chromatography identified some flavonoid compounds in moringa extracts including flavonols, flavones, biflavonyl, kaempferol, delphinidin, triglycerides, and glycosylflavones (27,69,72). *M. peregrina* plants are rich in many allelochemicals (quercetin, quercetin-3-orutinoside, chryseriol-7-O-rhamnoside, and 6, 8, 3', 5'-tetra methoxy apigenin, lupeol acetate, β-amyrin, α-amyrin, β-sitosterol-3-O-β-D-glucoside and rhamnetin, caffeoylquinic acid, quercetin, caffeoylquinic acid, and β-amyrin) (28,79).

Table 4. Phenols and favonoids compounds found in *Moringa* species.

Plant part	***Moringa* species**	**Chemical constitutes**	**References**
Leaves	*M. oleifera*, *M. stenopetala* and *M. Peregrine*	4-(R-L-rhamnopyranosyloxy)-benzylglucosinolate, 3-caffeoylquinic acid, 5-caffeoylquinic acid, and flavonoid compounds	21,27,69,72
Flowers	*M. oleifera*	Flavonoid compounds	69
Barks	*M. oleifera*	4-(R-L-rhamnopyranosyloxy)-benzylglucosinolate	21
Seeds	*M. oleifera* and *M. stenopetala*	4-(R-L-rhamnopyranosyloxy)-benzylglucosinolate	21,29
Roots	*M. oleifera* and *M. stenopetala*	4-(R-L-rhamnopyranosyloxy)-benzylglucosinolate and benzyl glucosinolate	21

4.3. Fatty acids

Moringa oleifera organs are rich in unsaturated fatty acids including octadec-9-enoic acid (in leaf), methyl 12,15-octadecadienoate (in flower) and oleic acid (in seeds) (9,50,51,73) (Table 5). Cheikhyoussif *et al*. (25) found that *M. ovalifolia* seeds contained large amounts of monounsaturated fatty acids such as oleic acid in addition to tocopherol (25). *M. concanensis* seed oil was hydrolysed and the fatty acids profile showed high amounts of saturated fatty acids with oleic acid (71). Some of these fatty acids have allelopathic effects (73,74), they reported that l-(+)-ascorbic acid 2,6-dihexadecanoate and octadecanoic acid were allelopathic to the germination and seedlings elongations of wild mustard weed.

Table 5. Fatty acids identified in different parts of *Moringa* species.

Plant part	***Moringa* species**	**Chemical constitutes**	**References**
Leaves	*M. oleifera*	Octadec-9-enoic acid	73
Flowers	*M. oleifera*	Methyl 12,15-octadecadienoate	73
Seeds	*M. oleifera*, *M. ovalifolia* and *M. concanensis*	Oleic acid and stearic acid	9,25,50,51,71,73

5. ALLELOPATHY OF MORINGA SPECIES

The allelopathic plants produce secondary metabolites with allelopathic effects during the various physiological processes. The allelopathic plants may Improve the (i) productivity of agricultural systems, (ii) tolerance to biotic and abiotic stresses and (iii) ecologically manage agricultural pests (22,34). The allelochemicals bioactivity depends on the concentration, the high concentrations inhibit the plant growth, while the low concentration promotes the growth (22,36).

5.1. Inhibitory effects

I. Crops: The *M. oleifera* extracts influence the growth and development of wheat, maize and weeds (Table 6). The water extracts of different parts of *M. oleifera* are inhibitory to various plants (14,31,43,44,55). Moringa leaf, flower and seed extracts at higher concentrations inhibited the seeds germination and seedlings growth of broad bean, mung bean and lettuce. Phiri and Mbewe (62) demonstrated that the application of moringa leaf extracts delayed the emergence of the seedling, decreased the root growth and field survival of beans, groundnut and cowpea. Piyatida and Kato-Noguchi (63) stated that leaf, stem and root extracts of *M. oleifera* Lam inhibited the seedling growth of cress, lettuce, alfalfa, and crabgrass seedling and the allelopathic effects differed with plant species. Hanan and Salama (41) and Sarmin (70) studied the allelopathic potential of *M. oleifera* Lam. on growth and physiological characters of *Vicia faba* L., *Zea mays* L., and *Triticum aestivum* L. and they found that leaves extracts of *M. oleifera* Lam adversely affected the seeds germination in all test crops. The leaves extracts of *M. oleifera* at lower doses slightly affected the seed germination, radicle growth and biochemical components of *Cicer arietinum* L. and *Raphanus sativus*, whereas, the higher doses are inhibitory to the growth of chickpea plants (49,53). The *M. oleifera* leaves aqueous extracts (2.5, 5, 7.5 and 10%) decreased the seeds germination and plumule length of *Citrullus lanatus* at 7 days after application. (5).

II. Weeds: Tahir *et al.* (73) reported that higher concentration of ethanolic extracts from bark, leaf, and flower of *M. oleifera* inhibited the germination of wild mustard in laboratory conditions than the lower concentration (Table 6). They showed that phenols, flavonoids and/or alkaloids allelochemicals were present in the extracts of *M. oleifera*, which might have caused the allelopathic inhibition in test plant. Leaf and seed aqueous extracts of *M. oleifera* reduced the growth of broad-leaved and grassy weeds but increased the dry weights in the leaves and bulbs of *Narcissus tazetta* L (31,49).

Table 6. Allelopathic effects of *M. oleifera* organs on germination and seedling growth of some test plants.

Moringa organ	**Test plant species**	**Effects**			**References**
		Germination	**Root length**	**Shoot length**	
Leaves	Wheat, wild mustard, maize, sorghum, spiny amaranth and faba bean	Inhibition	Inhibition	Inhibition	13,55,59, 70,73
Flowers	Wheat and wild mustard	Inhibition	Inhibition	Inhibition	73
Barks	Wheat	Inhibition	Inhibition	Inhibition	70
Seeds	Wheat, and wild mustard	Inhibition	Inhibition	Inhibition	73
Roots	Wheat	Inhibition	Inhibition	Inhibition	70

III. Pests: The aqueous extracts of *M. oleifera* leaves controlled the damping-off and stem rot diseases of cowpea caused by *Sclerotium* (2). The effects of the coagulant lectin of *M. oleifera* on moth flour (*Anagasta kuehniella*) were reported by mixing this protein in the artificial diet at levels of 0.5, 1 and 2%, respectively. The insecticidal effects of the lectin of *M. oleifera* were dose-dependent on the larval mass of *Anagasta kuehniella*. Besides, the group fed at 1% of coagulant lectin of *M. oleifera* caused 27.6% pupal mortality (56).

IV. Biochemical processes: The *M. oleifera* leaf leachates decreased the enzymatic activities of α-amylase and invertase enzymes and decreased the amount of reducing and non-reducing carbohydrates such as sucrose in *Sorghum bicolor* (61). Fahey and co-workers (35) reported the potent chemoprotective properties in most *Moringa* species due to the presence of glucosinolates.

5.2 Stimulatory effects

The stimulatory impacts of the moringa plant depend on the extract concentration. The low concentration of extract stimulated the seedling growth. Zeatin is a group of cytokinin found in *Moringa* plant, it increases the growth and yield of tomato and maize by 25-30% (7,19,20,45). On the other hand, the *M. oleifera* leaf extracts improve the seeds germination and plant vigour of *Cenchrus ciliaris*, *Panicum antidotale* and *Echinochloa crusgalli* (58). Foliar application of moringa leaf extracts significantly increase the oil content and yield of sunflower (48). Moreover, mixed foliar spray of water extract of moringa + sorghum improves the plant height, number of grains, 100-grains weight, grain yield and protein, starch, oil and chlorophyll contents and leaf chlorophyll contents of maize (48). Foliar spray of *M. oleifera* leaf extract delays the plant maturity by prolonging

the leaf area and grain-filling duration in wheat (79). The Plums (*Prunus*) treated with 6% moringa leaf aqueous extract significantly increased the yield and fruit weight (75). An experiment was conducted to study the effect of moringa leaf extracts and humic acid foliar application on cucumber growth, yields and physico-chemical components. Results showed that the maximum vine length, single fruit weight, fruit diameters, total yield, titrable acidity and ascorbic acid content were increased by foliar application of moringa extract at 50 g/L (67). Bose *et al.* (23) soaked the seeds of *Vigna mungo* in the ethanolic extracts of *M. oleifera* and found to be beneficial for nodulation and nitrogenase activity. The efficacy and quality of two cotton cultivars were studied by the exogenously applied *M. oleifera* (MLE), nitrogen, and potassium and conventional cotton cultivar (CIM 573) interacts with the exogenous application of moringa leaves + nitrogen and potassium, increases the plant height, cotton yield, staple length, fiber maturity and fiber strength (13).

6. ROLE OF MORINGA ALLELOCHEMICALS IN HUMAN MEDICINE

The *M. oleifera* is called miracle medicinal plant as it is used to treat many diseases and disorders in Human beings. *M. oleifera* different parts extracts in various solvents contain antioxidant properties (1) due to inhibition of lipid peroxidation by phytochemical antioxidants like polyphenols present in its leaves. Moringa seeds and pods have beneficial anti-inflammatory effects (11,24,32). Experimental animal models indicate that *M. oleifera* was given orally and its leaf extract decreases the development of fructose-induced diabetes. The *M. oleifera* leaf powder enhances the alloxan-induced hyperglycemia, showing the ability to treat diabetes (51,78). In lung cancer cells, an aqueous fraction of *M. oleifera* leaf extract caused an apoptotic in HepG2 cells. Leaf extracts given orally substantially reduced the development of HepG2 cells and lung cancer cells (47).

7. FUTURE RESEARCH AREAS

Future researches on *Moringa* species may be done on the following aspects:

I. Understanding the primary mechanisms of moringa extracts as inhibitory and stimulatory effects on plants.
II. Effects of biotic and abiotic factors on the bioactive component levels in various parts of the moringa plant.
III. Allelopathic potential of *Moringa* species should be tested as a growth regulator and biofertilizer.
IV. Development of bioactive molecules of moringa as growth promotor and pesticides (Insecticides, nematicides and fungicides).
IV. Allelopathic properties of *Moringa* species for use in biocontrol of agricultural pests (Insects, nematodes and pathogens).
V. Develop bioactive molecules of moringa as growth inducer and pesticides (Insecticides, nematicides and fungicides).

8. CONCLUSIONS

Moringa species are rich in various nutritional elements and bioactive compounds [1-(+)-ascorbic acid, 2,6-dihexadecanoate, hexadecanoic acid, methyl ester and benzyl isothiocyanate), which after further research could be useful as bio-fertilizer and bio-control of crop pests. High doses of moringa extracts inhibit the seeds germination and seedling growth, while, low concentrations are stimulatory to test plants.

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