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MEDICINAL CHEMISTRY RESEARCH

REVIEW ARTICLE

Nitrogenous phytoconstituents of genus *Moringa*: spectrophotometrical and pharmacological characteristics

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Abstract

Moringa Adans. (Moringaceae) is a multipurpose plant showing uncountable uses due to nutritional, folklore, and pharmacological worldwide applications. *Moringa* is rich in nitrogenous compounds, *viz*., glucosinolates, thiocarbamates, cyanogens, isothiocyanates, and alkaloids. Plants of this genus are a good source of vitamins, *β*-carotene, proteins, and various phenolics. This review focuses on spectrophotometrical characteristics of nitrogenous compounds along with their pharmacological properties. Aligning traditional usage with scientific assessment, *Moringa* have compounds with a great commercial potential especially nitrogenous compounds. We hope to support a new research on *Moringa*, especially on those species whose biological properties have not been studied to date moreover explore the mechanisms at the molecular level.

Keywords *Moringa* · Glucosinolates · Thiocarbamates · Cyanogens · Isothiocyanates

Introduction

Moringaceae is monogeneric plant family with valuable importance. *Moringa* (miracle tree) has 13 known species (*Moringa oleifera, M. peregrine, M. stenopetala, M. arborea, M. borziana, M. concanensis, M. drouhardii, M. hildebrandtii, M. longituba, M. ovalifolia, M. pygmaea, M. rivae*, and *M. ruspoliana*) located in Africa, Arabia, Southeast Asia, and South America, and cultivated in all tropical and subtropical parts of the world (Olson 2002). *Moringa* is deciduous, medium-sized (10 m) tree with a whitish bark (Taeckholm 1974). All parts of *Moringa* are edible except the bark. *Moringa* is commonly used in the Indian Ayurveda as a nutraceutical to improve health as well as antihyperglycemic. *M. oleifera* has been named "mother's best friend" as its leaves are fed to pregnant woman due to its high content of vital elements such as vitamin A, vitamin C, potassium, and calcium, moreover all essential amino acids. The leaves are used as a food supplements, the oil as a biofuel, and all of the plant parts can also be used for medicinal purposes (Bichi 2013). In many areas of Africa, seeds of *M. oleifera* are traditionally use for drinking water purifications as it possess strong coagulation properties of suspended mud and disinfecting effects on pathogens, hence it is called clarifying tree (Bichi 2013). The genus is well known for its multiple uses including healing skin infections, asthma, and fever, also it is used for treating anemia in the Philippines (Price 1985). *Moringa* is well known to have anti-inflammatory, antioxidant, anticancer, and antidiabetic activities. Recently, more research has been conducted on *M. oleifera, M. concanensis*, *M. stenopetala*, and *M. peregrina*. However, no researches on others have been found (Park et al. 2011). This review will primarily compile *Moringa* nitrogenous phytochemicals and their biological activities, aiming to encourage new research on activity of the isolated compounds.

Phytochemistry and nitrogenous phytoconstituents

Moringa species contain various phytoconstituents such as alkaloids, glucosinolates, saponins, tannins, steroids, terpenes, phenolics, and flavonoids. Numerous compounds (more than 110) were identified from the genus with various

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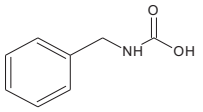
biological activities (Rani et al. 2018). *M. concanensis, M. peregrina, M. stenopetala, and M. oleifera* leaves were the most phytochemically studied. The high content of phenolics and flavonoids such as rutin, quercetin, kaempferol, and myricetin give *Moringa* a high antioxidant activity (Onyango et al. 2007). A significant amount (up to 53%) of ben oil is founded in *Moringa* seed kernels rich in oleic acid (73%) similar to olive oil. The ben oil was reported to be resistant to rancidity (Anwar and Rashid 2007). The ben oil has been added in salads, or as fine machine lubricant in industry and in perfume and hair care products (Baky and El-baroty 2013). *Moringa* is rich in glucosinolates, which are thiosaccharidic compounds (*β*-thioglucoside *N*-hydroxysulfate derivatives) with a sulfur-linked *β*-D-glucopyranose moiety (Fahey et al. 2001). Glucosinolates exhibit a broad biological activities such as fungicidal, bacteriocidal, nematocidal, and cancer chemoprotective (Fahey et al. 2001; Verhoeven et al. 1997). Glucosinolates toxicity is attributed to its hydrolytic products (Brown and Morra 2005). It is hydrolyzed thermally, by acids or enzymatically



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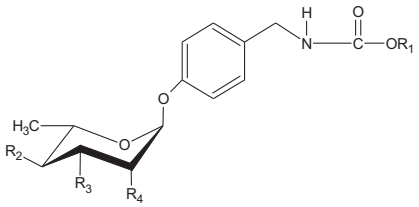
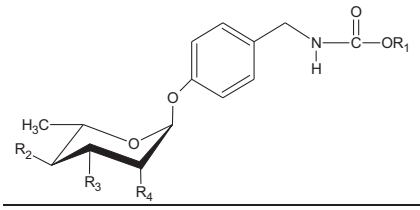
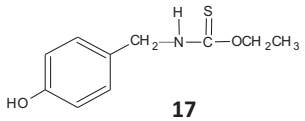


Carbamates				
	R1	**R2**	**R3**	**R4**
2	CH_3	OAc	OAc	OAc
5	CH_3	OAc	OH	OH
6	C_2H_5	OH	OH	OH
8	C_2H_5	OAc	OH	OH
9	C_2H_5	OAc	OH	OH
10	CH_3	OH	OH	OH



Carbamates				
	R1	**R2**	**R3**	**R4**
3	CH_3	OAc	OAc	OAc
4	C_2H_5	OAc	OAc	OAc
7	C_2H_5	OAc	OH	OH



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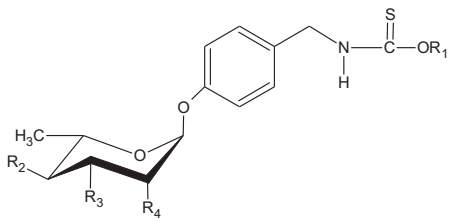
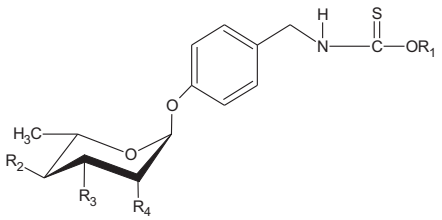
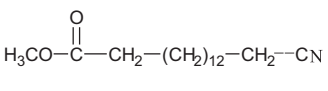


Thiocarbamates				
	R1	**R2**	**R3**	**R4**
11 (*Z*)	CH_3	OAc	OH	OH
12	CH_3	OAc	OH	OH
14	CH_3	OAc	OAc	OAc
15	C_2H_5	OAc	OAc	OAc
16	C_2H_5	OH	OH	OH
19	CH_3	OH	OH	OH
20	C_2H_5	OH	OH	OH
21	C_2H_5	OAc	OAc	OAc
23	C_2H_5	OAc	OH	OH



Thiocarbamates				
	R1	**R2**	**R3**	**R4**
11(*E*)	CH_3	OAc	OH	OH
13	CH_3	OAc	OAc	OAc
18	CH_3	OH	OH	OH
22	C_2H_5	OAc	OH	OH



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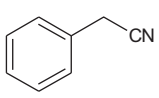

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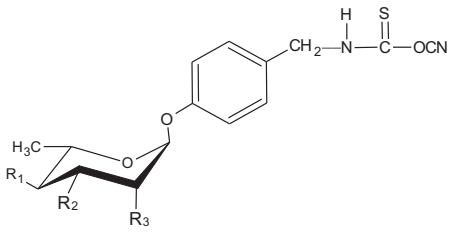
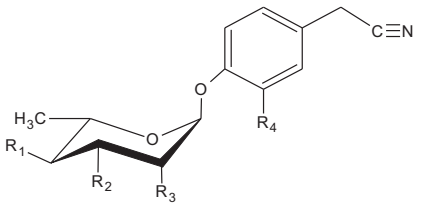
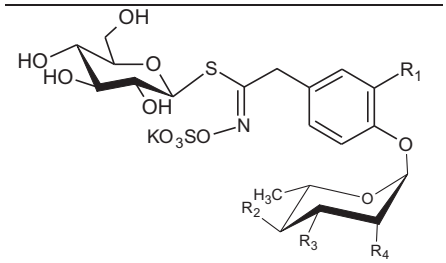
Fig. 1 Reported compounds from genus *Moringa*



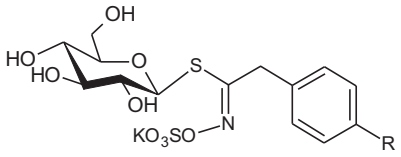
Nitriles			
	R_1	R_2	R_3
25	OH	OH	OH
26	OAc	OAc	OAc



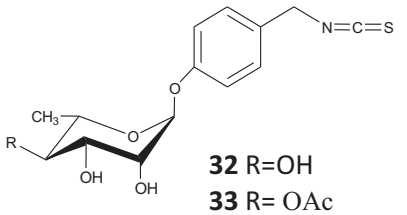
Nitriles				
	R_1	R_2	R_3	R_4
24	OAc	OAc	OAc	H
28	OH	OH	OH	H
29	OAc	OH	OH	H
30	OH	OH	OH	OH



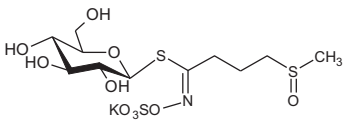
Glucosinolates				
	R_1	R_2	R_3	R_4
35	H	OH	OH	OH
36	H	OAc	OH	OH
38	OH	OH	OH	OH
39	OH	OH	OH	OAc
40	OH	OH	OAc	OH
41	OH	OAc	OH	OH

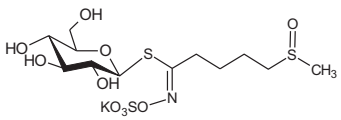


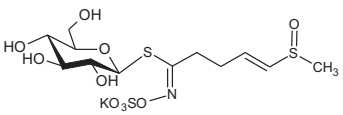
37 R=OH
34 R= OH

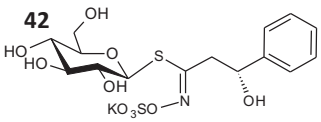


32 R=OH
33 R= OAc









43 **44** **45**

Fig. 1 Continued

with myrosinase. Depending on plant species, side-chain substitution, cell pH, and cell iron concentration, hydrolytic products may include substituted isothiocyanates (ITCs), nitriles, thiocyanates, and epithionitriles in addition to D-glucose, and hydrogen sulfate (Vaughn and Berhow 2005). ITCs have historically been considered the normal hydrolytic products of glucosinolates. They are often volatile with pungent flavors or odors. Nitrile formation is favored over ITC at low pH as it does not require rearrangement, but only loss sulfur. Epithionitriles formation requires the same conditions as for nitriles in the presence of an epithiospecifier protein (Brown and Morra 2005) (Fig. 1, Tables 1–6).

Glucomoringin {4-(α-L-rhamnopyranosyloxy) benzyl glucosinolate} (**35**) is predominant glucosinolate in *Moringa* (Brunelli et al. 2010). Simultaneous determination of glucosinolates in *M. oleifera* seeds was performed using LC coupled with tandem mass spectrometry (LC-MS/MS) (Maldini et al. 2014). Negative mass spectrum analysis of seeds extract revealed a major ion peak at m/z of 570, relative to the glucomoringin (**35**) with most intense

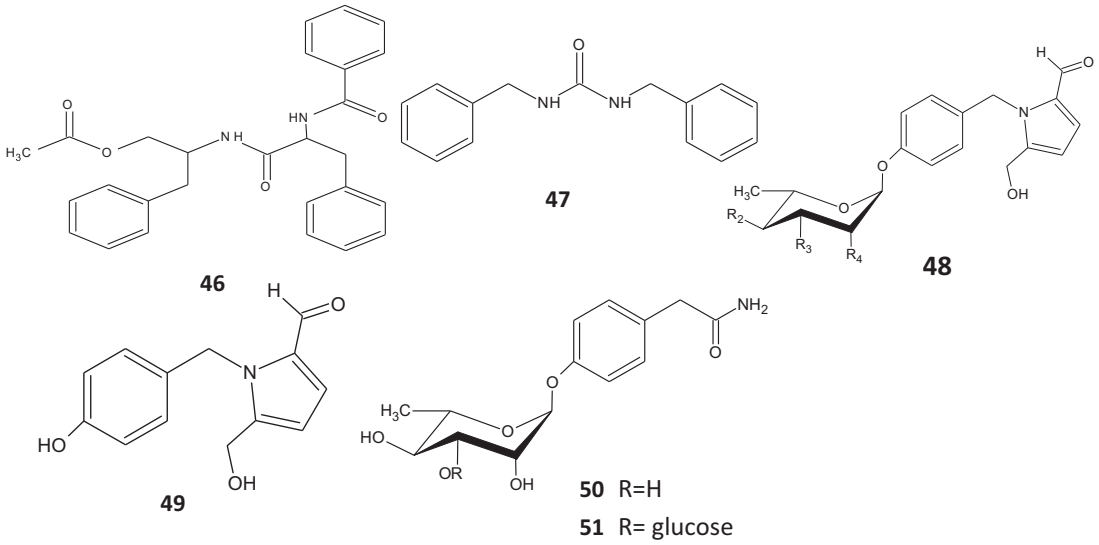


Fig. 1 Continued

fragment ions at m/z 424 and 328 presumably generated by the subsequent loss of a rhamnopyranosyloxyl moiety, followed by loss of sulfate ion. 3-hydroxy-4-(α-L-rhamnopyranosyloxy) benzyl glucosinolate (**38**) appear as a major ion peak at m/z 586, and other three C-2′, C-3′, and C-4′ α-L-rhamnopyranosyl acetylated glucosinolates (**39**–**41**) showed their ion peak at m/z 612. Other molecular ion peaks in mass spectrum appeared at m/z 424, 408, 422, 436, 434, and 438 were assigned for glucosinalbin (**34**), glucotropaeolin (**37**), glucoiberin (**42**), glucoraphanin (**43**), glucoraphenin (**44**), and glucobarbarin (**45**), respectively (Fig. 1, Table 1). The glucosinolates identity were verified by the comparison of each compound MS/MS spectra with those of the standards and/or with reported in the literature (Maldini et al. 2014).

Moringa is rich in thiocarbamates and carbamates glycosides, which usually contain nonacetylated, monoacetylated, or triacetylated rhamnose. These triacetylated glycosides were obtained in both *E*- and *Z*- forms. Niazinin (A and B), niazimicin, and niaziminins (A and B) thiocarbamates were reported to possess hypotensive activity (Faizi et al. 1992). Niazirin and niazirinin are nitrile glycosides that have been isolated from a myrosinase-treated seeds extract of *M. peregrine* (Faizi et al. 1994). Pyrrolemarumine 4′′-*O*-α-L-rhamnopyranoside (**48**) was the first pyrrole alkaloid isolated from *Moringa* with marumosides (A and B) (**50**–**51**) (Sahakitpichan et al. 2011) (Fig. 1, Tables 1, 5, 6). The daily use of this plant as a food supplement should be evaluated as studies reported that niazirin and its aglycone (4-hydroxyphenylacetonitrile) as well as 4′-hydroxyphenylethanamide (aglycone of marumosides A and B) have mutagenic effect (Villasenor et al. 1989).

Chemical–biological correlation of *Moringa* nitrogenous constituents

The anti-inflammatory and analgesic activities of *M. oleifera* root may have attributed to aurantiamide acetate (**46**) and 1,3-dibenzyl urea (**47**), which showed significant inhibition of cytokines TNF-α and IL-2 (Sashidhara et al. 2009). With other mechanism, 4-(α-L-rhamnosyloxy) benzyl isothiocyanate (**32**) and 4-(4′-*O*-acetyl-α-L-rhamnosyloxy) benzyl isothiocyanate (**33**) significantly displayed anti-inflammatory activity by regulating IL-1 and iNOS expression in addition to reducing the production of inflammatory markers in RAW macrophages (Waterman et al. 2014). The anti-inflammatory and antioxidant activities of 4-[(α-L-rhamnosyloxy) benzyl] isothiocyanate (**32**) were also evaluated against cerebral tissue damage induced by cerebral ischemia reperfusion in rats (Galuppo et al. 2015). A study also noted that 4-[(2′-*O*-acetyl-α-L-rhamnosyloxy) benzyl] isothiocyanate (**33**) suppressed COX-2 and iNOS activity (Park et al. 2011). 4-[(α-L-rhamnosyloxy) benzyl] isothiocyanate (**32**), and its acetylated derivatives inhibited the production of NO (Cheenpracha et al. 2010). 4-[(α-L-rhamnosyloxy) benzyl] isothiocyanate (**32**) and niazimicin (**20**) were responsible for the regulation of caspase-9 activity (Tiloke et al. 2013). 4-[(α-L-rhamnosyloxy) benzyl] isothiocyanate (**32**) delayed ALS development and reduced PARP-1 activity, in addition to promoting Nrf-2 activity by interfering with motor neuron degeneration and ALS development in rats (Galuppo et al. 2015).

4(α-L-rhamnosyloxy) benzyl isothiocyanate (**32**) exhibit antimicrobial activity with MIC = 40 and 56 μmol/L for *Mycobacterium phlei* and *Bacillus subtilis*, respectively (Eilert et al. 1981). The aglycone of deoxy-niazimicine

Table 1 Nitrogenous; carbamates, thiocarbamates, nitriles, isothiocyanates, glucosinolates, and alkaloids constituents of *M. oleifera*

No.	Compounds	Part	Ref.
	Carbamates		
1	*N*-benzylcarbamic acid	Root barks	(Chen et al. 2014)
2	*O*-Methyl-4-[(2′,3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy) benzyl] carbamate (*E*)	Leaves	(Faizi et al. 1995)
3	*O*-Methyl-4-[(2′,3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy) benzyl] carbamate (*Z*)	Leaves	(Faizi et al. 1995)
4	*O*-Ethyl-4-[(2′,3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy) benzyl] carbamate (*E*)	Leaves	(Faizi et al. 1995)
5	*O*-Methyl-4-[(4′-*O*-acetyl-α-L-rhamnosyloxy) benzyl] carbamate (*E*)	Leaves	(Faizi et al. 1995)
6	*O*-Ethyl-4-[α-L-rhamnosyloxy) benzyl] carbamate	Pods	(Faizi et al. 1998)
7	Niazimin A	Leaves	(Faizi et al. 1994)
8	Niazimin B	Leaves	(Faizi et al. 1994)
9	*O*-Ethyl-4-[(4′-*O*-acetyl-α-L-rhamnosyloxy) benzyl] carbamate	Leaves	(Sahakitpichan et al. 2011)
10	*O*-Methyl 4-(α-L-rhamnosyloxy) benzyl carbamate	Leaves	(Sahakitpichan et al. 2011)
	Thiocarbamates		
11	Niazicin A (*E*),(*Z*)	Leaves	(Faizi et al. 1994)
12	Niazicin B	Leaves	(Faizi et al. 1994)
13	*O*-Methyl-4-[2′,3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy) benzyl] thiocarbamate (*E*)	Leaves	(Faizi et al. 1995)
14	*O*-Methyl-4-[(2′,3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy) benzyl] thiocarbamate (*Z*)	Leaves	(Faizi et al. 1995)
15	*O*-Ethyl-4-[(2′, 3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy) benzyl] thiocarbamate (*Z*)	Leaves	(Faizi et al. 1995)
16	*O*-Ethyl-4-[(α-L-rhamnosyloxy) benzyl] thiocarbamate (*Z*)	Leaves	(Faizi et al. 1995)
17	*O*-Ethyl-*p*-hydroxy-benzenethiocarbamate	Pods	(Faizi et al. 1997)
18	Niazinin A	Leaves	(Faizi et al. 1992)
19	Niazinin B	Leaves	(Faizi et al. 1992)
20	Niazimicin	Leaves	(Faizi et al. 1992)
21	*O*-Ethyl-4-[(2′,3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy) benzyl] thiocarbamate	Leaves	(Faizi et al. 1992)
22	Niaziminin A	Leaves	(Faizi et al. 1992)
23	Niaziminin B	Leaves	(Faizi et al. 1992)
	Nitriles		
24	4-[(2′,3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy) benzyl] nitrile	Leaves	(Faizi et al. 1995)
25	Niazidin	Pods	(Faizi et al. 1997)
26	Triacetyl niazidin	Pods	(Faizi et al. 1997)
27	Methyl-15-cyanopentadecanoate	Pods	(Faizi et al. 1997)
28	Niazirin	Leaves	(Faizi et al. 1994)
29	Niazirinin	Leaves	(Faizi et al. 1994)
30	Niaziridin	Pods	(Gupta et al. 2005)
31	Phenylacetonitrile	Root barks	(Chen et al. 2014)
	Isothiocyanates		
32	4-[(α-L-rhamnosy1oxy) benzyl] isothiocyanate	Leaves	(Sahakitpichan et al. 2011)
33	4-[(4′-*O*-acetyl-α-L-rhamnosyloxy) benzyl] isothiocyanate	Leaves	(Faizi et al. 1994)
	Glucosinolates		
34	Glucosinalbin	Seeds	(Gueyrard et al. 2002)
35	Glucomoringin	Seeds	(Maldini et al. 2014)
36	4′-*O*-acetyl-α-L-rhamnosyl glucosinalbin	Seeds	(Gueyrard et al. 2002)
37	Glucotropaeolin	Seeds	(Maldini et al. 2014)
38	3-hydroxy-4-(α-L-rhamnosyloxy) benzyl glucosinolate	Seeds	(Maldini et al. 2014)
39	4-(2′-*O*-acetyl-α-L-rhamnosyloxy) benzyl glucosinolate	Seeds	(Maldini et al. 2014)
40	4-(3′-*O*-acetyl-α-L-rhamnosyloxy) benzyl glucosinolate	Seeds	(Maldini et al. 2014)
41	4-(4′-*O*-acetyl-α-L-rhamnosyloxy) benzyl glucosinolate	Seeds	(Maldini et al. 2014)
42	Glucoiberin	Seeds	(Maldini et al. 2014)
43	Glucoraphanin	Seeds	(Maldini et al. 2014)
44	Glucoraphenin	Seeds	(Maldini et al. 2014)
45	Glucobarbarin	Seeds	(Maldini et al. 2014)
	Alkaloids		
46	Aurantiamide acetate	Roots	(Sashidhara et al. 2009)
47	1, 3-dibenzyl urea	Roots	(Sashidhara et al. 2009)
48	Pyrrolemarumine 4′′-*O*-α-L-rhamnopyranoside	Leaves	(Sahakitpichan et al. 2011)
49	Pyrrolemarumine	Leaves	(Sahakitpichan et al. 2011)
50	Marumoside A	Leaves	(Sahakitpichan et al. 2011)
51	Marumoside B	Leaves	(Sahakitpichan et al. 2011)

(N-benzyl,S-ethyl thioformate) has antibacterial and antifungal activities (Nikkon et al. 2003). 4-[(α-L-rhamnosyloxy) benzyl] isothiocyanate (**32**) inhibited *Trypanosoma brucei rhodesiense* (IC_{50} of 0.1 μM) via irreversible inhibition of trypanothione reductase, which may have the potential to become an antitrypanosomal drug (Ayyari et al. 2014).

Table 2 [1]H-NMR of carbamates, nitriles, and isothiocyanates isolated from *Moringa*

Com-pounds	Carbamates						Nitriles					ITCs
H-position	2	3	4	5	7	8	24	25	26	28	29	33
2,6	7.07 d (8.8)	7.07 d (8.5)	7.00 d (8.7)	7.05 d (8.7)	6.97 d (8.7)	6.99 d (8.7)	7.08 d (8.5)	6.95 d (8.5)	7.03 (8.7)	7.05 d (8.9)	7.05 d (8.7)	7.05 d (8.8)
3,5	7.27 d (8.8)	7.27 d (8.5)	7.22 d (8.7)	7.27 d (8.7)	7.15 d (8.7)	7.17 d (8.7)	7.28 d (8.5)	7.19 d (8.5)	7.21 d (8.7)	7.25 d (8.9)	7.24 d (8.7)	7.25 d (8.8)
7	4.10 d (5.9)	4.09 d (6.1)	4.10 d (5.8)	4.10 d (6.1)	4.09 d (5.7)	4.01 d (5.8)	3.53 s	4.58 d (5.0) 4.16 d (5.2)	4.58 d (4.6) 4.82 d (4.8)	3.69 s	3.68 s	4.64 s
1′	5.39 d (1.5)	5.41 d (1.8)	5.39 d (1.9)	5.35 d (1.6)	5.37 d (1.7)	5.37 d (1.6)	5.45 d (1.6)	5.31 d (1.6)	5.42 d (1.8)	5.51 d (1.9)	5.55 d (1.6)	5.55 d (1.6)
2′	5.32 dd (3.9, 1.5)	5.02 dd (3.3, 1.8)	5.06 dd (3.6, 1.9)	3.88 m	3.87 m	3.88 m	5.07 dd (3.6, 1.6)	3.80 dd (3.3, 1.6)	5.42 m	4.14 dd (3.4, 1.9)	4.15 dd (3.5, 1.6)	4.14 dd (3.5, 1.6)
3′	5.14 dd (9.7, 3.9)	4.91 dd (9.6, 3.3)	4.91 dd (9.6, 3.6)	3.81 m	3.81 ddd (9.7, 6.1, 3.3)	3.81 ddd (9.6, 6.0, 3.3)	4.91 dd (9.3 3.3)	3.62 dd (9.2, 3.3)	5.48 dd (3.5, 9.9)	3.97 dd (9.1, 3.4)	4.09 dd (9.6, 3.5)	4.09 dd (9.4, 3.5)
4′	4.86 t (9.7)	4.86 t (9.6)	4.85 t (9.6)	4.86 t (9.8)	4.84 t (9.7)	4.86 t (9.6)	5.33 t (9.3)	3.26 t (9.2)	5.13 t (9.9)	3.54 t (9.1)	4.87 t (9.6)	4.85 t (9.4)
5′	3.87 m	3.70 m	3.87 m	3.59 m	3.63 qd (9.7, 6.2)	3.65 qd (9.6, 6.2)	3.97 m	3.46 qd (9.2, 6.2)	3.96 qd (6.2, 9.9)	3.75 rn	3.58 qd (9 6 6. 3	3.87 qd (9.4, 6.2)
6′	0.98 d (6.2)	1.09 d (6.0)	0.98 d (6.2)	0.98 d (6.2)	0.97 d (6.2)	0.98 d (6.2)	1.09 d (6.2)	1.08 d (6.2)	1.18 d (6.2)	1.27 d (6.2)	1.19 d (6.3)	1.19 d (6.2)
OCH_2Me	–	–	4.39 q (7.1) 4.38 q (7.1)	–	4.40 q (7.1)	4.40 q (7.1)	–	–	–	–	–	–
OCH_2Me	–	–	1.24 t (7.1) 1.22 t (7.1)	–	1.13 *t* (7.1)	1.15 t (7.1)	–	–	–	–	–	–
OMe	3.95 s	3.96 s	–	3.95 s	–	–	–	–	–	–	–	–
NH	4.53 t (5.9)	7.56 t (6.1)	4.53 t (5.8)	4.54 t (6.1)	7.52 t (5.7)	4.53 t (5.8)	–	7.95 t (5.0)	5.96 m	–	–	–
OCOMe	2.04, 2.06 2.07 s	2.04, 2.06 2.07 s	2.03, 2.06 2.07 s	2.04 s	2.03 s	2.04 s	2.04, 2.07 2.08 s	–	2.17, 2.03 2.01 s	–	2.13 s	2.13 s

Table 3 [1]H-NMR of thiocarbamates isolated from *Moringa*

Com-pounds	Thiocarbamates										
H-position	11	12	13	14	15	16	18	19	20	22	23
2,6	7.01 d (8.7)	7.05 d (8.8)	7.07 d (8.8) 7.00 d (8.7)	7.07 d (8.8) 7.01 d (8.6)	7.07 d (8.8) 6.99 d (8.6)	7.07 d (8.8) 6.96 d (8.8)	6.97 d (8.6)	6.98 d (8.7)	6.97 d (8.6)	7.00 d (8.7)	7.07 d (8.7)
3,5	7.21 d (8.7)	7.26 d (8.8)	7.28 d (8.8) 7.17 d (8.7)	7.17 d (8.5) 7.21 d (8.6)	7.21 d (8.7) 7.27 d (8.6)	7.21 d (8.6) 7.22 d (8.8)	7.21 d (8.6)	7.16 d (8.7)	7.21 d (8.6)	7.21 d (8.7)	7.27 d (8.7)
7	4.57 d (5.9) 4.25 d (6.1)	4.65 d (5.2) 4.10 d (5.3)	4.57 d (5.8) 4.10 d (6.1)	4.57 d (5.4) 4.20 d (6.0)	4.56 d (5.4) 4.23 d (5.9)	4.57 d (5.4) 4.20 d (6.0)	4.56 d (6.1)	4.54 d (6.1)	4.55 d (6.0)	4.56 d (6.0)	4.57 d (6.0)
1′	5.40 d (1.5)	5.44 d (1.8)	5.46 d (1.5)	5.39 d (1.8)	5.39 d (1.7)	5.33 d (1.9)	5.33 d (1-8)	5.33 d (1.8)	5.33 d (1-9)	5.43 d (1.7)	5.40 d (1 × 9)
2′	3.86 m	3.87 m	5.06 dd (3.3, 1.7)	5.36 dd (4.0, 1.8)	5.06 dd (3.4, 1.6)	3.81 m	3.81 ddd (3.9, 2.9, 1.8)	3.80 ddd (4.4, 3.6, 1.8)	3.80 ddd (4.3, 3.4, 1.9)	3.90 m	3.90 m
3′	3.81 ddd (9.6, 6.0, 3.3)	3.80 m	5.40 dd	5.31 dd	4.91 dd (9.4, 3.4)	3.64 m	3.63 ddd (9.2, 5.9,2.9)	3.62 ddd (9.3, 6.1, 3.6)	3.63 ddd (9.2, 5.9, 3.4)	3.83 m	3.83 >m
4′	4.86 t (9.6)	4.83 t (9.6)	4.86 t (9.7)	4.86 t (9.6)	4.86 t (9.4)	3.27 dt (9.1, 5.6)	3.26 dt (9.2, 5.6)	3.26 dt (9.3, 5.0)	3.27 dt (9.2, 5.6)	4.87 t	4.86 t
5′	3.65 qd (9.6, 6.2)	3.44 qd (9.6, 6.2)	3.99 m	3.89 qd (9.6, 6.2)	3.99 m	3.47 m	3.46 qd (9.2, 6.1)	3.42 qd (9.3, 6.2)	3.48 qd (9.2, 6.1)	3.66 qd (9.6, 6.2)	3.66 qd (9.6, 6.2)
6	0.99 d (6.2)	0.97 d (6.2)	0.89 d (6.2)	0.98 d (6.2)	1.09 d (5.9)	1.09 d (6.1)	1.09 d (6-1)	1.08 d (6.2)	1.09 d (6.1)	0.98 d (6.2)	0.98 d (6.2)
OCH_2Me	–	–	–	–	4.39 q (7.1) 4.38 q (7.1)	4.39 q (7.1) 4.38 q (7.1)	–		4.37 q (7.0)	4.39 q (7.1)	4.38 q (7.1)
OCH_2Me			–	–	1.24 t (7.1) 1.23 t (7.1)	1.24 t (7.1) 1.22 t (7.1)	–		1.24 t (7.0)	1.24 t (7.1)	1.20 t (7.1)
OMe	3.87 s 3.89 s	3.87 s 3.89 s	3.87 s	3.85 s	–	–	3.87 s 3.89 s	3.87 s 3.89 s			
NH	9.57 t (5.9)	4.52 t (5.2)	7.55 t (5.8)	4.53 t (5.4)	4.53 t (5.4)	4.53 t (5.4)	9.55 t (6-1)	4.56 t (5.8)	9.52 t (6.0)	9.53 t (6.0)	7.55 t (5.6)
OCOMe	2.04 s	2.02 s	2.04, 2.06, 2.07 s	2.04, 2.06, 2.07 s	2.03, 2.06, 2.07 s	–				2.03 s	2.03 s

Table 4 ^{13}C-NMR of carbamates, thiocarbamates, nitriles, and isothiocyanates isolated from *Moringa*

Compounds	Carbamate	Thiocarbamates							Nitriles				ITCs
H-position	5	13	14	18	19	20	22	23	25	26	28	29	33
1	155.3	153.1	154.2	155.01	155.26	155.00	154.71	155.25	155.14 154.94	155.37 155.61	156.03	156.00	155.65
2,6	116.3	116.7	116.7	116.29	116.33	116.08	116.38	117.05	116.36	116.96 116.83	116.65	116.87	116.80
3,5	128.7	128.8	128.4	128.80	128.75	128.46	128.79	129.40	128.61 128.31	129.40 129.17	129.23	129.25	128.81
4	131.7	131.0	131.8	132.29	131.36	131.18	130.51	131.75	132.66	131.31 130.81	132.64	131.70	131.68
7	47.4	47.9	47.0	47.40	47.44	47.96	47.41	47.14	46.48 42.28	42.18 42.20	22.90	22.91	47.50
8	191.0	190.1	190.3	190.72	191.00	189.84	190.13	190.13	182.88 182.90	184.62	123.72	123.70	128.60
9	–	–	–	–	–	–	–	–	110.05 110.06	112.00	–	–	–
1′	95.6	95.1	95.2	98.49	98.47	98.31	98.05	98.13	98.53	95.94	97.96	97.19	98.00
2′	68.4	68.7	68.4	70.14	69.44	69.96	69.97	69.97	70.22	69.82	70.87	70.65	67.94
3′	68.8	68.7	68.7	70.42	70.21	70.25	70.04	70.10	70.5	69.01	71.70	70.13	70.01
4′	70.1	69.9	69.9	71.78	70.45	71.60	73.56	73.56	71.88	71.11	73.48	75.49	73.48
5′	66.9	66.8	66.8	69.34	71.81	69.17	66.92	66.98	69.42	67.29	68.83	66.36	66.99
6′	17.8	17.2	17.2	–	–	–	–	–	17.89	17.44	17.49	17.46	17.42
OCH_2Me	–	–	64.2	–	–	65.06	65.39	65.39	–	–	–	–	–
OCH_2Me	–	–	14.6	–	–	13.97	14.24	14.24	–	–	–	–	–
OMe	56.5	58.9	–	56.43	56.53	–	–	–	–	–	–	–	–
OCOMe	170.2	169.7	169.7	–	–	–	170.04	170.04	–	169.91	–	172.01	169.98
OCOMe	21.6, 21.0, 21.8	20.5, 20.4, 20.6	20.5, 20.4, 20.6	–	–	–	20.89	20.89	–	20.79, 20.67, 20.64	–	21.05	20.87

Niazimicin (**20**) and niaziminins (A and B) (**22, 23**) are thiocarbamates, which are potent chemopreventive agents in chemical carcinogenesis (Guevara et al. 1999). Only one acetyl group should be present at 4′-position is an important structural activity requirement for niaziminins (**22, 23**) (Murakami et al. 1998). *O*-Ethyl-4-(α-L-rhamnosyloxy) benzyl carbamate (**6**), 4 (α-L-rhamnosyloxy) benzyl isothiocyanates (**32**), and niazimicin (**20**) showed significant in vitro inhibitory effects on Epstein–Barr virus early antigen (Murakami et al. 1998). Niaziminins (A and B) (**22, 23**) and 4-[(4′-*O*-acetyl-α-L-rhamnosyloxy) benzyl] isothiocyanate (**32**) exhibit inhibition of tumor-promoter-induced Epstein–Barr virus (Murakami et al. 1998). Only one acetyl group should be present compulsorily at the 4′-position for that activity and yet no further acetyl groups should be attached to the sugar moiety (Murakami et al. 1998). Aurantiamide acetate (**46**) showed cytotoxicity against doxorubicin-resistant human breast cancer cell lines with inhibition percent 27.33 ± 2.89 at 20 μM (Chen et al. 2014).

Niaziminins (A and B) (**22, 23**) and 4-(4′-*O*-acetyl-α-L-rhamnosyloxy) benzyl isothiocyanate (**33**) (3 mg/kg) were found to lower the arterial blood pressure, whereas the nitriles, niazirin (**28**) and niazirinin (**29**), were devoid of any activity at dose levels up to 5 mg/kg. The amide or –N=C– group and/or sulfur atom may be essential for the hypotensive activity illustrated by hypotensive potency of ITCs and thiocarbamates, coupled with the absence of activity in the nitriles (Faizi et al. 1994). Niazinin (A and B) (**18, 19**), niazimicin (**20**), and niaziminins (A and B) (**22, 23**) (1–10 mg/kg) are active thiocarbamates, which showed a hypotensive and bradycardiac effect in rats mediated possibly through a calcium antagonist effect (Gilani et al. 1994; Faizi et al. 1992). Intravenous administration of *O*-Methyl-4-[(2′,3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy)] benzyl thiocarbamate (*E, Z*) (**13, 14**), *O*-Ethyl-4-[(α-L-rhamnosyloxy) benzyl] thiocarbamate (**15**), and *O*-Ethyl-4-[(2′,3′,4′-tri-*O*-acetyl-α-L-rhamnosyloxy) benzyl] thiocarbamate (**16**) caused a fall in systolic, diastolic, and mean arterial blood pressure in normotensive anaesthetized rats (Faizi et al. 1995). The bioactive nitriles, niazirin (**28**) and niaziridin (**30**), reduced pulmonary arterial blood pressure

Table 5 NMR data of pyrrole alkaloids isolated from *Moringa*

Compounds	48		49	
Position	^{13}C	^{1}H	^{13}C	^{1}H
2	132.1	–	132.1	–
3	124.6	7.04 (d, 3.9)	124	7.02 (d, 4)
4	110.3	6.28 (d, 3.9)	110.2	6.25 (d, 4)
5	144.3	–	144.3	–
6	55.4	4.42 s	55.4	4.41 s
7	179.9	9.45 s	179.8	9.47 s
1′	47.5	5.56 s	47.5	5.50 s
1″	131.8	–	128.6	–
2″, 6″	127.9	6.95 s	128	6.83 (d, 8.5)
3″, 5″	116.9	–	115.6	6.67 (d, 8.5)
4″	155.6	–	156.9	–
Sugar				
1‴	98.9	5.32 s	–	–
2‴	70.8	3.8 s	–	–
3‴	70.6	3.63 (d, 9)	–	–
4‴	72.2	3.28 (dd, 9, 8.9)	–	–
5‴	69.9	3.42 m	–	–
6‴	18.3	1.08 (d, 6.2)	–	–

Table 6 NMR data of amide alkaloids isolated from *Moringa*

Compounds	50		51	
Position	^{13}C	^{1}H	^{13}C	^{1}H
1	172.8	–	173.2	–
2	41.5	3.30 s	41.7	3.30 s
1′	129.9		130.4	
2′,6′	130.2	7.17 (d, 8.2)	130.5	7.17 (d, 8.2)
3′,5′	116.3	6.94 (d, 8.2)	116.9	6.94 (d, 8.2)
4′	154.8	–	154.9	
NH_2	–	7.46 s 6.86 s	–	7.46 s 6.86 s
Sugar				
1″	98.6	5.32 s	98.9	5.32 s
2″	70.5	3.82 s	69.3	3.82 s
3″	70.3	3.63 (dd, 9, 3.2)	81.4	3.63 (dd, 9, 3.2)
4″	71.9	3.28 (dd, 9.4, 9)	71.1	3.28 (dd, 9.4, 9)
5″	69.5	3.45 m	69.8	3.45 m
6″	18.3	1.09 (d, 6)	18.2	1.09 (d, 6)
1‴	–	–	104.9	4.48 (d, 7.7)
2‴	–	–	74.4	3.1 (dd, 8.7, 7.7)
3‴	–	–	77	3.18
4‴	–	–	70.2	3.13
5‴	–	–	76.6	3.21
6‴	–	–	61.3	3.67 (d, 11.3)

immediately after administration of monocrotaline to rats (Chen et al. 2012). *O*-Ethyl-4-(α-L-rhamnosyloxy) benzyl carbamate (**6**) showed promising hypotensive effect (Faizi et al. 1998). Carbamates as niazimin A (**7**), niazimin B (**8**), and thiocarbamates as niazicin A (**11**) and niazicin B (**12**) are hypotensive glycosides (Faizi et al. 1994). Isothiocyanates (**32, 33**) and its acetylated derivatives had also been reported to show antidiabetic activity (Waterman et al. 2015).

Conclusion

Genus *Moringa* is widely distributed all over the world. Numerous studies have corroborated its effectiveness as a natural source of new therapeutical applications. The diversity of metabolites clearly indicate that the genus *Moringa* could afford new bioactive molecules. Further studies to identify other phytoconstituents and explore the mode of action at the molecular level are necessary.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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