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MORPHOLOGICAL AND NUTRITIONAL VARIATION OF *MORINGA OLEIFERA* LAM GROWN IN DIFFERENT DISTRICTS OF BANGLADESH

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Abstract

Moringa, a multi-purpose and highly valued tree that possesses pharmacological properties which are widely used in medicine to treat a variety of diseases. The current study aimed to collect superior accessions from Bangladesh's key moringa-growing regions through *in-situ* evaluation and document them by using morphological (qualitative and quantitative) traits and nutritional value in order to conserve the best indigenous landraces. Four major moringa growing regions in Bangladesh were selected namely, Chapai Nawabganj, Rangpur, Lalmonirhat and Rangamati. Twelve moringa accessions were collected during 2019-2020 based on the farmer's preferences and morphological traits. The information on 35 quantitative and 16 qualitative aspects was analyzed using the International Plant Genetic Resource Institute (IPGRI), 2007 technique. The results demonstrated that flowering and fruiting occurred yearly in seasonal accession and three times per year in year-round accession. The flowers ranged in color from white to cream and year-round accession s MO8 and MO10 had corollas that were white with red spots. The seasonal accession's MO1 exhibited the highest pods (97.22 g) weight, while the year-round accession's MO12 had the lowest (45.16 g) pod weight. Leaves contained more than two times higher protein (23–34%) compared to pods (11–18%). As with nutrients, leaves had much higher levels of Ca and Fe (2137 to 3633 ppm and 252 to 424 ppm, respectively) than pods (2013 to 2875 ppm and 54-69 ppm, respectively). Overall, the findings imply that there were numerous changes in the most important qualitative and quantitative traits as well as nutrients available in different parts of moringa. The information and analysis from these investigations could contribute to the genetic development of the species.

Keywords: Accession, moringa, pod, nutritional value, morphological, seasonal.

Introduction

Moringa (*Moringa oleifera* Lam.) is one of the thirteen species that have been identified in the family Moringaceae, which consists of just one genus Moringa (Pareek *et al*., 2023). It is also known by the common names horse-radish tree, miracle tree, drumstick, moms best friend, Indian ben, benzolive, kelor, marango, mulangay, sajan among several other local and regional names (Islam *et al*., 2020). It is indigenous to the sub-Himalayan tracts of northern India, Pakistan, Asia, Africa, Soudi Arabia and is found all over the world in dry and semi-arid climates (Asghar *et al*., 2022). Moringa is a quickly-growing, drought-tolerant deciduous tree or shrub. It is a small

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with thin foliage, delicate and deciduous plant that can reach a height of up to 9-15m (Fahal *et al*., 2018). Every part of the moringa tree used as medicine and food commodity, which has received enormous attention as the 'natural nutrition of the tropic' (Wesonga and Kahane 2011). It is employed in a variety of ways to enhance both human and environmental well-being (Asghar *et al*., 2022). Some of these applications include alley farming, animal feed, vegetables, biogas, dye, honey clarifier, medicinal, ornamental, pulp, water purification, and edible oil (Foidl *et al*., 2001; Rajput *et al*., 2019; Islam *et al*., 2020). It has a twenty times higher CO_2 assimilation rate, requires very little water for cultivation and improves soil fertility (Gedefaw, 2015; Sahay *et al*., 2017). Moringa is rich in macronutrients and micronutrients, phytohormones, alkaloids, and flavonoids, which make this plant a multipurpose plant (Pareek *et al*., 2023). Recent research has shown that it's extract is also helpful in tolerance to abiotic and biotic stress under stressful environmental conditions (Arif *et al*., 2022). It is an excellent source of highly digestible protein, calcium, iron, antioxidants, vitamin C and carotenoids that are suitable for utilization in the developing regions of the world, where malnutrition is a major concern (Abbas *et al*., 2018). A number of pharmacological qualities, including antibacterial, anti-trypanosomal, hyposensitive, anti-spasmodic, anti-ulcer, anti-inflammatory, hypocholesterol and hypoglycemic action, have recently been reported from moringa formulations (Ma *et al*., 2020). Furthermore, plant growth promoters can be made from the leaf extracts. Moreover, the leaves can be fed to cattle as feed (Fatima and Ibrahim, 2013).

Oil contents in moringa seeds (35–40% of the total weight) and is used in the watch and cosmetic industries as well as for cooking (Nadeem and Imran, 2016). It is possible to use the seed oil's biodiesel characteristics as a renewable energy source. Moreover, it provides honey bees with a good amount of nectar and pollen (Kwaambwa and Maikokera, 2007; Rashid *et al*., 2008). The moringa tree has immense promise for enhancing nutrition, increasing food security, and promoting rural development (Pareek *et al*., 2023). There is growing focus in exploiting the nutritional advantages of moringa in many countries where it is not a native plant (Oduro *et al*., 2008). The nutritive values of the leaves of moringa which is available in Sudan and the results showed that, moisture content was 74.42%, protein 16.7% , fiber 3.5%, ash 8%, and oil 1.7%. In addition, the minerals content were determined and they found that the calcium content was 0.20 mg/100g, magnesium 0.13mg/100g, potassium 0.075mg/100g, and phosphorus 0.031 mg/100g (Elkhalif *et. al*., 2007).

The nutritional profile of moringa leaves, flowers, and pods from various species and regions has been discussed in certain articles. However, there is little information available on these traits of Bangladeshi moringa cultivars. Bangladesh is one of the possible hotspots for its richness of moringa tree (*Moringa oleifera*), which is growing in nearly every farmhouse. In Bangladesh, people are accustomed to eating both leaves and pods depending on their local customs. Major moringa growing regions in Bangladesh include Chapai Nawabganj, Rajshahi, Pabna, Jashore, Kushtia, Rangpur, Lalmonirhat, Natore, Bogra, and other districts with prolific growth along roadsides and in homesteads. Although it thrives in saline belt and drought-prone regions, but it struggles on soils that are heavily saturated with water. Moringa accession s with a variety of variations are available in Bangladesh and are referred to locally as sajna, lajna, raikhonjon, etc. The year-round and seasonal accession s differ from one other in their flowering and fruiting seasons. Recently, there has been attracted interest to established organization of standardized leaf cultivation for monitoring, standardization for increasing the nutritional security, and processing of leaves.

There are presently no assessments of the morphological and nutritional data of the many consumable parts of moringa in different locations of our country. Despite this, the goal of the current study was to collect seasonal and year-round accession s of moringa from four key growing regions in order to assess the nutritional value of the leaves and pods, which are the most commonly consumed by Bangladeshi people. Therefore, it will provide comparative overview of different accessions and a clear image of the abundant supplies of different micronutrients that can be found in either leaves or pods in Bangladeshi accession. Likewise, these findings could be used as a guide when selecting a accession and pro-ducing a moringa-based dietary supplement for human nutrition in Bangladesh.

Materials and Methods

The study was carried out during February 2019 to May 2020. Four major moringa growing regions in Bangla-desh were selected namely, Chapai Nawabganj, Rangpur, Lalmonirhat and Rangamati. Three locations are lo-cated in the North-Western parts belongs to Rajshahi and Rangpur divisions of Bangladesh. Rangamati is locat-ed south-eastern part of Bangladesh (Figure 1). Chapai Nawabganj is situated between 24°22’ N and 87°23’ E, Rangpur 25°44’ N and 89°15’ E, Lalmonirhat 25°54’ N and 89°27’ E and Rangamati 22°37’ N latitude and 92°11’ E longitude. Lalmonirhat, Rangpur, Chapai Nawabganj and Rangamati represent Active tista floodplain (AEZ2), Tista meander floodplain (AEZ3), High Ganges River Floodplain (AEZ11), Chittagong coastal plains (AEZ23), respectively.

We have collected superior accessions from these regions through in-situ evaluation and documentation of them utilizing their morphological features and nutritional value in order to conserve the best native landraces. Diver-sity was assessed from the farmers’ participatory survey using questionnaires in the fruiting season of 2019 in four different districts of Bangladesh. The questionnaires were designed to collect information from farmers to identify their preferred phenotype which identifies farmers’ varietal preferences, their problems associated with management and above all to obtain pointers to the genetic diversity. Such information permits initial selection of potentially useful germplasm. Afterwards, utilizing the descriptors provided by the IPGRI, 35 significant quantitative and 16 significant qualitative characterizations were made (IPGRI, 2007). Then members of the research team physically visited major moringa growing areas and talked to 100 farmers about the good acces-sions based on their experiences and a total of 47 sample trees, including year-round and seasonal cultivars, were chosen. From these collected accessions, finally, 12 accessions from four districts were selected based on a number of morphological characteristics and farmer preferences. Selected accessions were planted at the agro-forestry research field of the Bangabandhu Sheikh Mujibur Rahman Agricultural University (24° 09′ N; 90° 26′ E) in the month of July, 2020 for conservation purpose. Each accession was replicated three times by maintain-ing 4 m × 4 m distance from the plant to plant in order to grow lower story crops as an agroforestry system.

For qualitative characteristics, propagating material, tree shape, tree nature, tree height, trunk girth, canopy spread (east–west and north–south), bark color, young shoot color, leaf stalk color, foliage density, nature of branchlets, leaflet shape, leaflet apex, flowering start date, flowering end date, flower position on branchlets, shape of calyx, nature of calyx, color of calyx, shape of corolla, nature of corolla, color of corolla fruit development pattern, extent of fruit drop, fruit maturity group, fruit shape, fruit skin color, date of first fruit maturity, date of last fruit maturity, number of fruits/tree, fruit cracking, biotic stress susceptibility, resistant to hairy caterpillar were studied as tree characteristics.

For quantitative characteristics, the parameters considered for flower and fruit characterization using three flowering branch and three mature fruits, randomly taken from each selected tree were number of flowers/branchlets, length of fruit, fruit girth, individual fruit weight, number of longitudinal ridges/fruit, number of seeds/fruit, color of seed, shape of seed, diameter of the seed, seed weight, pulp color, taste of pulp, pulp flavor and pulp weight.

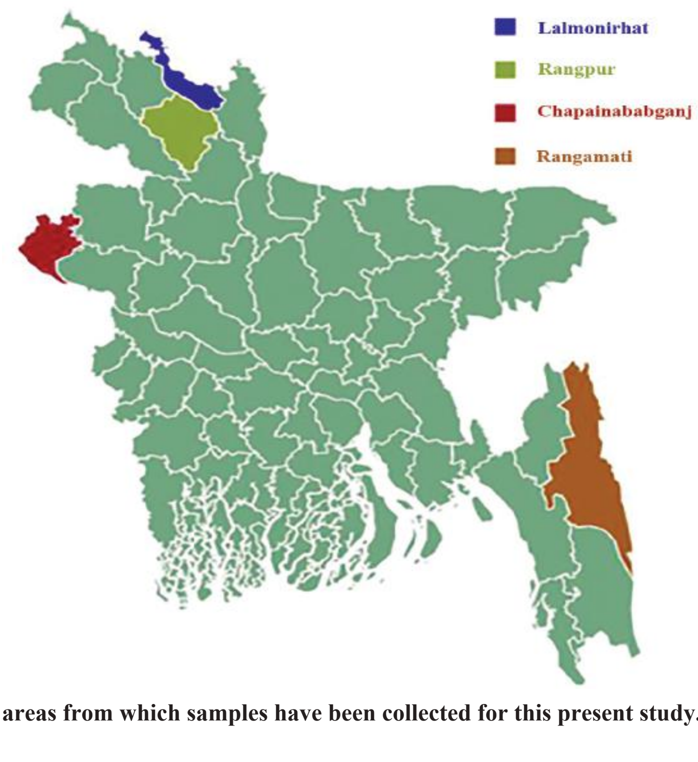


Fig. 1. Distribution areas from which samples have been collected for this present study.

Nutritional composition analysis

Nutritional analysis was carried out at the Agroforestry and Environment laboratory, BSMRAU. Nutrients content like protein, potassium (K), calcium (Ca), magnesium (Mg) and iron (Fe) were determined. The total protein content was determined by multiplying the nitrogen content by a conversion factor (6.25) (Islam *et al*., 2020). The contents of Ca, Mg and Fe were determined using the oven-dried leaves and pods sample that had been ground into powder and stored in a desiccator. We took 2 g of the finely ground powdered samples and digested them. To measure the ion contents using an atomic absorption spectrophotometer (Model No. PinAAcle 900H, Japan) and compared to a standard curve for each element (Roni *et al*., 2014). K contents in the digest were determined using flame emission spectrophotometer. The intensity of light emitted by potassium 589 nm was directly proportional to the concentration of K present in the sample. The percent emission for the elements was recorded and the K concentration was determined against standards (Knudsen *et. al*., 1982).

Statistical analysis

Data on different parameters were analyzed using Minitab version 17 (Minitab Inc., State College, PA, USA) by analysis of variance (General Linear Model procedure) and Tukey's pair wise comparison test ($p < 0.05$).

Results and Discussion

Qualitative and quantitative morphological study of moringa accessions

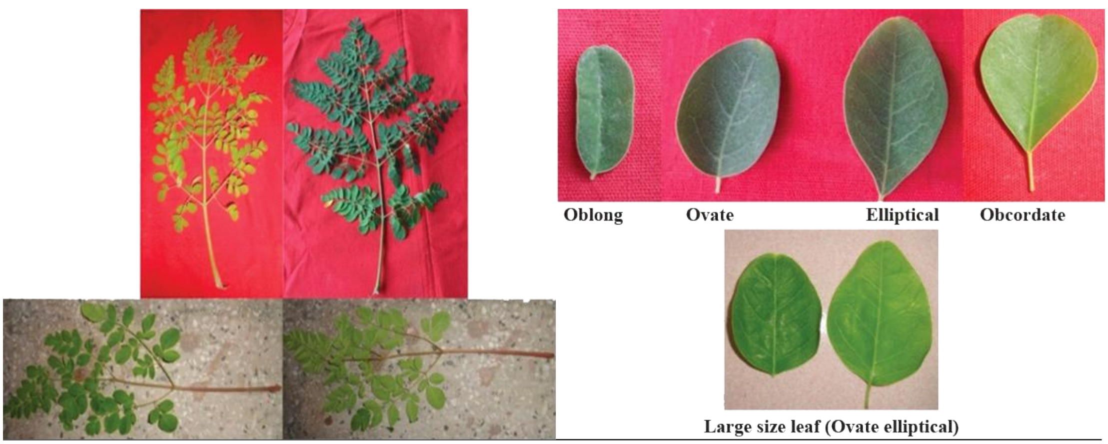
Twelve accessions of two cultivars (seasonal and year-round) of moringa from four different locations in the districts of Chapai Nawabganj, Rangpur, Lalmonirhat and Rangamati were examined morphologically (Table 2 and 3). Table 1 showed the information on accessions and the locations where samples were collected. It was noticed that all seasonal accessions had deciduous natures, whereas year-round MO8, MO9, and MO10 accessions

Table 1 Details of accessions taken for this study (2019-2020)

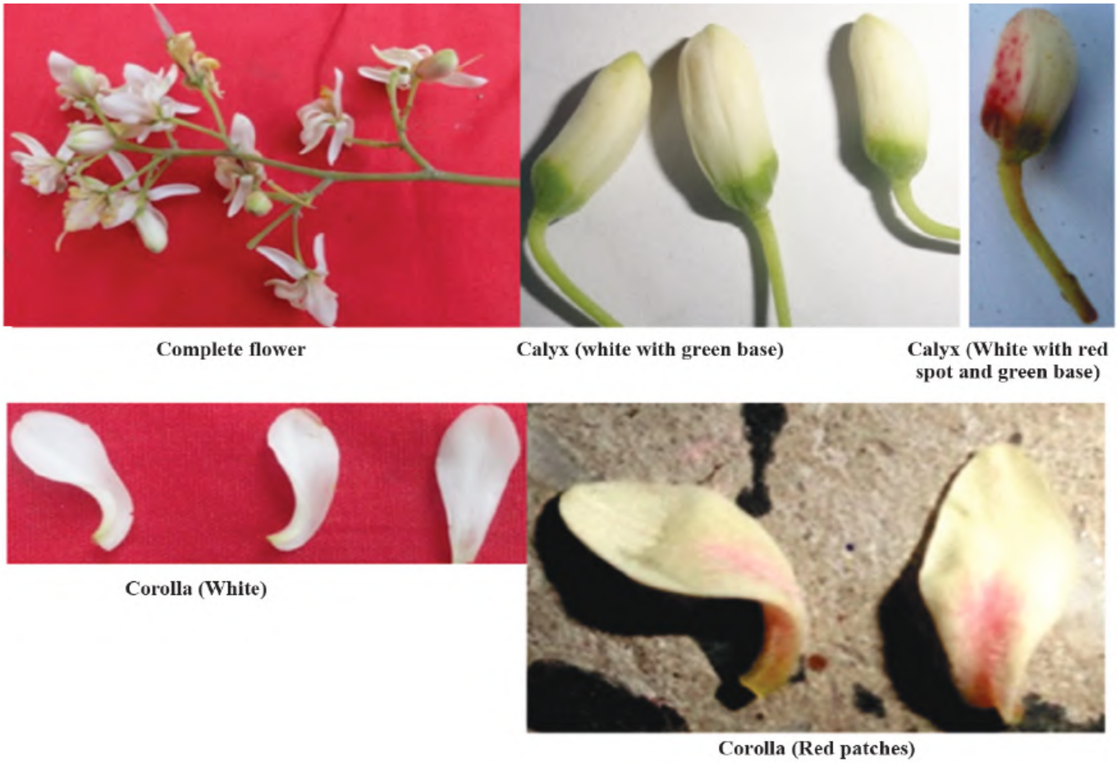
Accession	Cultivar	Location
MO. 1	Seasonal	Beltala, Sadar, Chapai Nawabganj
MO. 2	Seasonal	Habu, Gangachara, Rangpur
MO. 3	Seasonal	Haridebpur, Rangpur Sadar, Rangpur
MO. 4	Seasonal	Farmgath, Raikahli, Kaptai, Rangamati
MO. 5	Seasonal	Narayngiri, Raikhali bazaar, Kaptai, Rangamati.
MO. 6	Seasonal	Babupara, Lalmonirhat Sadar, Lalmonirhat.
MO. 7	Seasonal	Vatibari, Lalmonirhat Sadar, Lalmonirhat.
MO. 8	Year round	Uttar Gonessham, Kaliganj, Lalmonirhat
MO. 9	Year round	Dalalpara, Shibganj, Chapai Nawabganj
MO. 10	Year round	Barogachi, Bholahat, Chapai Nawabganj
MO. 11	Year round	Munsipara, Badargonj, Rangpur
MO. 12	Year round	Jagadishpur, Taraganj, Rangpur

had semi-deciduous natures. Different bark colors were observed in different accessions like, Red, light brown, brown and gray (Fig. 2a, Table 2). The majority of seasonal and year-round accessions were light brown to brown in color, although MO1 and MO12 had red and gray bark; respectively. The leaves were alternate and commonly pinnate compound leaves (imparipinnate) which were found tri-pinnate in both accessions (Fig. 2b). In both accession s, the leaflets are dark green or light green; and most of the cases dark green in the upper surface and light green in the lower surface. Apex is round and obtuse and leaflet shape was ovate, elliptical and oblong (Fig. 2b and Table 2). Some leaf stalks had red upper portions and pale green lower portions, while year-round accessions MO8, MO9, and MO10 featured both red portions (Fig. 2b and Table 2). Flowers varied in color from white

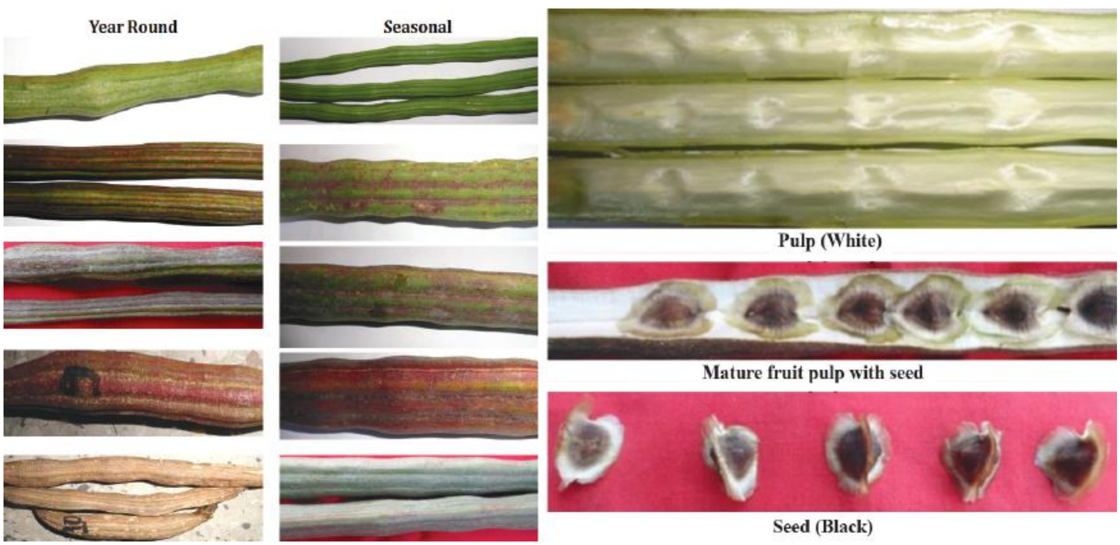
a) Variation in bark characters (Bark color and pattern)



b) Variation in leaf characters (shape, size, color and red colouration of petioles)



c) Variation in floral characters (color variation in petals)



d) Variation in fruit and seed characters (Fruit length, number and color of seeds)

Fig. 2. Variations of different parts of moringa plants (a, b, c and d)

to cream, and the corollas of the year-round accessions MO8 and MO10 were white with red spots (Fig. 3c and Table 2). The seasonal accession only has one flowering period (February to last February), while the year-round accession has three flowering periods (January, May, and September), and its fruits are available all year round with the exception of January and February. Details of further differentiation between the two accessions are presented in Table 2.

The green pod is ridged down its length and has a pendulous, beaked shape. Fruit length, pod color, yield, and the number of seeds per pod varied considerably between year-round and seasonal accessions (Fig. 2d and Table 3). The pods skin color were green, green with red spot, red, reddish green, brown and greenish ash with red strip (Fig. 2d and Table 2). In a seasonal accession, the MO1 accession's pod length was the highest (58.94 cm), whereas the lowest pod length was measured in MO10 accession (13.97cm) that was year round accession (Table 3), which were collected from Rangpur and Chapai Nawabganj, respectively. Every region has noticeable differences in fruit length between cultivars. When taking into account all ecological zones, the seasonal accession's range for pod length (45-58 cm) was greater than the range for the year-round accession (13-38 cm). Our results corroborated the findings of Islam *et al*. (2020). Pod length of different ecological zones of Saudi Arabia also found variation (Osman and Abohassan, 2012). The seasonal accession MO4 is collected from Rangamati district and has the largest pod girth of any year-round accession. The results for pod length and girth are consistent with the production of moringa when locations and accession s from this study are taken into account.

It has been observed that pod formation is less time consuming in the year round and a bit more time need in case of seasonal accession. The year-round accession's MO12 had the lowest pod weight (45.16 g), whereas the seasonal accession's MO1 had the highest pod weight (97.22 g). These samples were taken from the Rangpur and Chapai Nawabganj districts, respectively. After longitudinal section of green pod, seeds were found inside the pod. Seeds embedded in pith, parietal placentation, pale green seeds, whereas matured seeds become ivory-white to brownish with whitish papery and deciduous wings on the angles (Fig. 2d). It can be noticed that over matured seeds caused unacceptability of pod for human consumption. The seasonal accessions of Lalmonirhat district's MO6 and MO7 had the largest number of seeds per pod (22), while those of Chapai Nawabganj district's MO10 accession had the lowest number of seeds per pod (6) (Table 3). The seeds per pod are higher compared to the study of Osman and Abohassan, (2012) with an average range of 14–18. In our study, the number of seeds per pod varied significantly amongst accessions, but there was no significant variation among the seasonal accession s of the four locations. Different accessions of moringa were discovered to have varying pod lengths and seed densities (Stevens *et al*., 2019). Diameter of seed was statistically significant in MO12 and MO1 accessions than other accessions. Seed weight was found to be highest in MO1 followed by MO11 and MO4 accessions, while the lowest was in MO8. The accessions MO7, MO1, and MO4 from Lalmonirhat, Chapai Nawabganj, and Rangamati had the

Table 2. Qualitative morphological features of twelve accessions of moringa (12-15 years old, 2019-2020) in four different districts of Bangladesh

	Seasonal							Year round				
Character	MO1	MO2	MO3	MO4	MO5	MO6	MO7	MO8	MO9	MO10	MO11	MO12
Duration	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial
Tree shape	Semi spread	Upright	Upright	Upright	Upright	Upright	Semi spread	Upright	Semi spread	Upright	Semi spread	Upright
Tree nature	Deciduous	Deciduous	Deciduous	Deciduous	Deciduous	Deciduous	Deciduous	Partial deciduous	Partial Deciduous	Partial deciduous	Deciduous	Partial Deciduous
Bark color	Red	Light brown	Light brown	Brown	Brown	Brown	Brown	Brown	Light brown	Brown	Brown	Gray
Young shoot color	Pale green	Pale green	Pale green	Pale green	Pale green	Pale green	Pale green	Pale green,	Pale green	Pale green,	Pale green	Pale green
Leaf stalk color	Both part green	Both part green	Upper part red but lower part pale green	Both side green	Upper part red but lower part green. leaflet size was very big	Yellowish green (shoot color: upper part radish and lower part green)	upper and lower part red at mature stage)	both part red	Both part red	Both part red	Upper part red but lower part green	Leaf stalks both side green.
Foliage density	Low	Dense	Medium	Medium	Medium	Low	Medium	Low	Low	Medium	Dense	Low
Nature of branch-lets	Low	Medium	Medium	Medium	Medium	Low	Medium	Low	Low	Medium	Dense	Low
Leaflet shape	Elliptical	Elliptical	Ovate	Ovate-elliptical	Ovate-elliptical	Elliptical	Ovate-elliptical	Elliptical	Elliptical	Elliptical, Obcordate	Oblong	Elliptical,
Leaflet apex	Obtuse	Obtuse	Obtuse	Round, Obtuse	Round, Obtuse	Obtuse	Round, Obtuse	Obtuse	Obtuse	Obtuse, Retuse	Round	Obtuse
Beginning of flowering	January to February	January to February		January to February	January to February	January to February	January to February	3 times in a year(January, May, September)	3 times in a year(January, May, September)	3 times in a year(January, May, September)	3 times in a year(January, May, September)	3 times in a year(January, May, September)
Flowering period's end	Middle February to last February	Middle February to last February	Middle February to last February	Middle February to last February	Middle February to last February	Middle February to last February	Middle February to last February	20 days after each flowering date	20 days after each flowering date	20 days after each flowering date	20 days after each flowering date	20 days after each flowering date
Flower position on branchlets	Upper and Middle	Upper and Middle	Upper and Middle	Upper and Middle	Upper and Middle	Upper and Middle	Upper and Middle	Upper and Middle	Upper and Middle	Upper and Middle	Upper and Middle	Upper and Middle
Shape of calyx	Funnel	Funnel	Funnel	Funnel	Funnel	Funnel	Funnel	Funnel	Funnel	Funnel	Funnel	Funnel
Nature of calyx	Gamosepalous	Gamosepalous	Gamosepalous	Gamosepalous	Gamosepalous	Gamosepalous	Gamosepalous	Gamosepalous	Gamosepalous	Gamosepalous	Gamosepalous	Gamosepalous
Color of calyx	White with green base	White with green base	White with green base	White with green base	White with green base	White with green base	White with green base	White with green base	White with green base	White with green base	White with green base	White with green base

	Seasonal							Year round				
Character	MO1	MO2	MO3	MO4	MO5	MO6	MO7	MO8	MO9	MO10	MO11	MO12
Duration	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial	Perennial
Shape of corolla	Modified bell shaped	Modified bell shaped	Modified bell shaped	Modified bell shaped	Modified bell shaped	Modified bell shaped	Modified bell shaped	Modified bell shaped	Modified bell shaped	Modified bell shaped	Modified bell shaped	Modified bell shaped
Nature of corolla	Polypetalous	Polypetalous	Polypetalous	Polypetalous	Polypetalous	Polypetalous	Polypetalous	Polypetalous	Polypetalous	Polypetalous	Polypetalous	Polypetalous
Color of corolla	White	White	white	White	White	White	White	White with red spot	White	White with red spot	White	White
Fruit development pattern	Continuous growth after fruit set	Continuous growth after growth	Continuous growth after growth	Continuous growth after fruit set	Continuous growth after fruit set	Continuous growth after fruit set	Continuous growth after fruit set	Continuous growth after fruit set	Continuous growth after fruit set	Continuous growth after fruit set	Continuous growth after growth	Continuous growth after fruit set
Extent of fruit drop	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Fruit shape	Pendular	Pendular	Pendular	Pendular	Pendular	Pendular	Pendular	Pendular	Pendular	Pendular	Pendular	Pendular
Fruit skin color	Green with red spot	Dark green	Green	Green with red spot	Dark green with red spot	Dark green with red patches	Red	Reddish green	Red	Brown	Greenish ash with red strip	Dark green with brown patches
First fruit maturity	Mid April	Mid April	Mid April	Mid April	Mid April	Mid April	Mid April	February, June, October	February, June, October	February, June, October	February, June, October	February, June, October
Last fruit maturity	Last week of April	Last week of April	Last week of April	Last week of April	Last week of April	Last week of April	Last week of April	20-25 days later after fruit setting	20-25 days later after fruit setting	20-25 days later after fruit setting	20-25 days later after fruit setting	20-25 days later after fruit setting
Color of seed	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black
Shape of seed	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
Fruit cracking	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Pulp color	White	White	White	White	White	White	White	White	White	White	White	White
Taste of pulp	Palatable	Palatable	Palatable	Palatable	Palatable	Palatable	Palatable	Palatable	Palatable	Palatable	Palatable	Palatable
Pulp flavor	Strong	Strong	Strong	Mild	Normal	Moderate	Normal	Moderate	Strong	Moderate	Moderate	Moderate
Biotic stress susceptibility	High	High	High	High	High	High	High	High	High	High	High	High
Resistant to hairy caterpillar	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3. Quantitative morphological features of twelve accessions of moringa (12-15 years old, 2019-2020) in four different districts of Bangladesh

	Seasonal							Year round				
Character	MO1	MO2	MO3	MO4	MO5	MO6	MO7	MO8	MO9	MO10	MO11	MO12
Tree height (m)	3.81±0.53d	12.80±1.87a	7.62±0.97b	10.66±1.22a	8.33±0.99b	6.18±1.66c	8.53±1.87b	6.10±0.79c	4.57±0.77d	6.09±0.71c	8.53±1.22b	3.65±0.48d
Trunk girth (cm)	55.00±1.35d	143.00±2.55a	67.00±2.33c	94.00±3.23b	115.00±3.87a	70.00±2.76c	125.00±3.23a	100.00±0.99b	81.00±2.54c	61.00±1.23d	90.00±2.31b	51.00±1.44d
Tree (Canopy) spreading (m) (E-W)	5.10±0.24b	8.20±0.32a	8.40±0.66a	5.30±0.96b	5.80±0.76b	7.80±1.23a	4.20±0.75b	4.60±0.93b	2.20±0.78c	4.20±0.73	7.20±0.91a	3.70±0.67c
Tree spread (m) (N-S)	4.20±0.33c	9.80±0.55a	6.70±0.43b	3.80±0.37d	2.70±0.45d	4.10±0.88c	7.50±0.86b	7.40±1.45b	6.90±0.99b	4.30±0.49c	9.50±1.54a	5.20±0.62c
Number of flowers/ branchlets	15.00±0.98c	18.00±0.79b	15.00±1.22c	17.00±1.23b	17.00±1.22b	14.00±1.22c	16.00±1.34b	17.00±1.37b	16.00±1.98b	15.00±0.88c	37.00±1.28a	13.00±0.87d
Length of fruit (cm)	58.94±2.76a	58.42±1.24a	45.72±2.11b	55.11±2.34a	47.24±2.77a	54.61±3.55a	51.81±2.55a	25.65±2.87c	32.85±2.22c	13.97±1.22d	30.48±2.36c	38.10±2.77c
Fruit girth (cm)	1.73±0.21a	1.20±0.024c	1.46±0.22b	1.74±0.56a	1.43±0.66b	1.46±0.78b	1.63±0.67a	0.91±0.78d	1.40±0.82b	1.36±0.75b	0.90±0.29d	1.30±0.65c
Individual fruit weight (g)	97.22±3.14a	77.4±1.35b	66.50±2.44c	75.75±2.33b	67.00±1.89c	78.83±1.29b	78.00±2.85b	27±1.43e	41.73±2.71d	18.62±1.45e	39.4±2.81d	45.16±2.33d
Number of fruits/tree	252±3.78d	660±4.12a	437±3.22b	405±4.31b	649±3.98a	298±4.33d	374±5.25c	170±2.66e	114±2.52f	376±4.34c	576±3.74a	168±2.49e
Number of longitudinal ridges/fruit	9	9	9	9	9	9	9	9	9	9	9	9
Number of seeds/fruit	21±0.78a	21±0.90a	18±1.11a	19±1.25a	19±0.98a	22±1.35a	22±1.55a	14±1.23b	17±0.89b	6±0.79d	9±1.23c	9±0.99c
Diameter of the seed (mm)	10.00±0.88a	7.5±0.23b	8.5±0.73b	9.50±0.77a	9.00±0.56a	8.00±1.63b	7.00±0.98c	6.00±0.76c	9.00±1.55a	8.00±0.68b	9.00±0.73a	11.00±1.21a
Seed weight (no./g)	0.29±0.032a	0.19±0.044c	0.23±0.023b	0.25±0.056b	0.23±0.097b	0.21±0.071b	0.19±0.065c	0.12±0.036d	0.24±0.026b	0.19±0.035c	0.27±0.054a	0.33±0.029a
Pulp weight (g/ fruit)	51.73±1.25a	48.5±1.22a	43.8±4.21b	50.90±3.24a	46.22±2.78a	49.10±3.65a	53.80±2.54a	16.80±1.77d	29.55±1.32c	11.73±1.93d	27.23±1.66c	32.00±2.06c

Mean SE= standard error, followed by non-similar letters are significantly different at $p \leq 0.05$ according to Tukey's test.

highest pulp weights of moringa, whereas MO10 from Chapai Nawabganj had the lowest pulp weight. Also, we noted that the seasonal accession displayed the highest pulp weight compared to the year-round accession. The pulp favor of the MO1, MO2, MO3, and MO9 accession is stronger than that of other accessions.

Moringa leaves and pods contain nutrients and protein

The study demonstrated the presence of nutritive elements in moringa leaves and pods. Protein content in leaves and pods were significantly different in all accessions. The leaves contained more than twice as much protein as the pods. Notably, the leaves of the M12, MO9 and MO2 accessions had the highest protein content. However, the measurements revealed that the MO7, MO11 and MO2 accessions had the highest protein content in pods (Table 4). Pods showed an average protein level of 11–18% while leaves had an average protein content of 23–34%. This finding is comparable to that previously reported by Sanchez-Machado *et al*. (2010). A range of 19 to 29% protein was found in leaves from 11 agro-ecological zones in Thailand (Jongrungruangchok *et al*., 2010). Olson *et al*. (2016) also conducted study on the several taxa of moringa and they have got the highest amount of protein in moringa compared to others species. The average value of protein was found 29.1%. Chickpea, lentil, and dry pea contain about 22%, 28.6%, and 23.3% protein, respectively, which aren't much more protein than the protein composition of moringa leaves and pods (Sotelo and Adsule, 2012). Moringa has high-quality, easily digestible protein, which is impacted by the purity of its amino acids (Pareek *et al*., 2023). Noteworthy, the average crude protein concentration of 11-34.38% discovered in this study, even though it is lower than the crude protein level of sunflower seed cake (35.88%), which is primarily employed as a protein concentrate (Mapiye *et al*., 2010). Because of this, dry moringa leaves are a strong candidate for use as an additional source of protein in the diets of animals and human.

The analysis of micronutrients composition in 12 accessions of moringa leaves and pods showed remarkable concentrations in minerals and trace elements (Table 4). The results showed high concentrations in K, Ca and Fe in the leaves and pods of the 12 accessions. The K has been found in very high concentration in MO6 accession's leaves and pods. The leaves K content was the highest in MO6 which was statistically insignificant in MO9, MO7 and MO12 accessions (Table 4). In case of pods, K content was found to be lowest in MO2 accession. It was discovered that moringa cultivars from South Africa contain less K (1.50%) than those from Bangladesh (Moyo *et al*., 2011).

It's also intriguing that dried moringa leaves and pods have a significant mineral deposit. It was discovered that the Ca content was greater than that of other plant sources (Islam *et al*., 2020). Ca levels were found in the leaves to be 2137 to 3633 ppm, and 2013 to 2875 ppm in the pods (Table 4). The MO12 accession was revealed to have the highest Ca content and was strikingly identical to MO6, MO9, and MO2 accessions, which were collected from Rangpur, Lalmonirhat, Chapai Nawabganj, and Rangpur districts, respectively. In case of pods, M12 accession had the highest Ca

Table 4. Protein and nutrients content in the edible parts of twelve moringa accession's

Accessions	Protein (%)		K (%)		Ca (ppm)		Fe (ppm)	
	Leaves	Pods	Leaves	Pods	Leaves	Pods	Leaves	Pods
MO1	26.55 ± 2.15c	15.46 ± 1.15b	3.32 ± 0.23b	3.25 ± 0.21b	2354.31 ± 79.14d	2013.00 ± 72.32d	256.55 ± 21.13c	56.57 ± 6.44c
MO2	29.30 ± 1.43b	17.16 ± 0.97a	2.83 ± 0.29c	2.16 ± 0.27c	3425.30 ± 94.63a	2978.67 ± 79.23b	291.32 ± 18.22b	67.37 ± 8.36a
MO3	26.77 ± 2.19c	13.22 ± 2.11c	3.27 ± 0.63b	3.22 ± 0.18b	2137.17 ± 93.09d	2047.45 ± 67.98d	261.72 ± 13.19c	54.07 ± 6.19c
MO4	24.82 ± 2.22d	14.76 ± 1.13b	3.83 ± 0.82b	3.72 ± 0.86b	2267.60 ± 133.24d	2221.42 ± 74.21d	294.81 ± 12.22b	69.43 ± 8.12a
MO5	22.71 ± 2.13d	12.88 ± 2.05c	3.95 ± 1.22a	3.90 ± 1.01b	2384.74 ± 59.14d	2178.34 ± 58.66d	252.67 ± 20.33c	55.11 ± 5.33c
MO6	29.67 ± 2.47b	15.34 ± 0.88b	4.78 ± 0.32a	5.13 ± 1.38a	3543.39 ± 120.41a	3125.76 ± 121.56b	291.61 ± 18.43b	66.92 ± 8.37a
MO7	28.92 ± 2.75b	18.11 ± 2.02a	4.29 ± 0.56a	4.31 ± 0.97a	3186.20 ± 83.79b	2694.38 ± 111.34c	283.82 ± 20.29b	68.32 ± 6.15a
MO8	25.76 ± 1.25c	11.47 ± 1.95d	2.34 ± 0.23c	2.17 ± 0.25c	2584.50 ± 67.98c	2370.83 ± 78.56d	296.93 ± 17.24b	65.16 ± 7.75b
MO9	32.22 ± 2.79a	16.91 ± 2.52a	4.63 ± 0.73a	4.47 ± 0.62a	3484.39 ± 165.35a	3246.37 ± 97.05b	362.221± 20.71b	62.44 ± 8.35b
MO10	23.55 ± 1.79d	13.23 ± 0.76c	3.31 ± 0.25b	3.29 ± 0.28b	2902.60 ± 77.34b	2656.43 ± 45.33c	423.55 ± 22.54a	63.34 ± 7.19b
MO11	28.62 ± 1.98b	17.76 ± 3.10a	2.92 ± 0.32c	2.85 ± 0.39c	2386.02 ± 67.89d	2057.83 ± 77.19d	378.62 ± 19.28a	58.65 ± 6.91c
MO12	34.38 ± 2.32a	14.24 ± 1.12b	4.14 ± 0.63a	4.94 ± 1.03a	3633.12 ± 154.12a	3775.33 ± 162.32a	424.38 ± 22.33a	64.28 ± 7.31b

Note: Mean SE (standard error) followed by non-similar letters are significantly different at $p \leq 0.05$ according to Tukey's test.

content, which was then followed by MO2, MO6 and MO9 (Table 4). Milk is a fantastic source of Ca to prevent osteoporosis when it comes to human nutrition. It is also needed for normal blood clotting and nervous function. Cow milk with a concentration of 1021 to 1087 ppm Ca was examined by Soyeurt *et al*. (2009). Research suggests that the Ca content of moringa leaves and pods is as least two to three times higher than that of cow's milk (Cattan *et al*., 2022).

Leaves contain more than 3-4 times higher amounts of Fe compared to pods. Leaves contain 252 to 424 ppm, whereas pods contain 54 to 69 ppm, respectively (Table 4). The year-round cultivar MO12 had the maximum Fe contents (424.38 ppm), while MO5 accession, a seasonal cultivar, had the minimum Fe levels (252.67 ppm) in leaves. MO4 had greater pod Fe content (69.43 ppm), whereas MO3 had the lowest (54.07 ppm), although they both were seasonal cultivars and which were collected from Rangamati and Rangpur districts, respectively (Table 4). It was discovered that the various minerals and vitamin contents of 15 regularly consumed vegetables in Bangladesh and in which amaranth leaves had greater concentrations of Ca and Fe, at 430 and 26 ppm, respectively (Islam *et al*., 2020). Comparing the Ca and Fe content both in pods of leaves of moringa contain 78 to 134 times greater Ca than other green vegetables evidence is the eating of moringa leaves or pods can assure the nutrition security which can minimize the risk of cancer (Pareek *et al*., 2023). It's interesting to note that the leaves of this plant were rich in Fe, a mineral that is frequently low in diets that focus on plants. For the transportation of oxygen and the growth and division of cells, iron is an essential component of myoglobin and hemoglobin (Cattan *et al*., 2022). Moreover, iron is a necessary trace element for the oxidation of carbohydrates, proteins, and lipids as well as for the regular operation of the central nervous system. Iron has a part in energy metabolism as well because it makes it easier for electrons to move along the electron transport chain, which creates ATP (Kozat, 2007).

It has been reported that variations was occurred in morphological characteristics, protein and nutrients content of various moringa parts and similar parts from different regions (Anjorin *et al*., 2010). According to Jongrungruangchok *et al*. (2010), a variety of factors, including cultivation locations, growth circumstances, soil type, seasonal fluctuations, genetic differences, and storage conditions, might affect how nutritious a plant species. Overall, genetic, environmental, and agricultural factors can be blamed for variations in moringa accession s' nutritional values. Considering its nutritional and nutraceutical benefits, moringa is one of the most important industrial crops (Pareek *et al*., 2023). Besides, it has been documented that moringa consumers are found food and nutritionally secured; and food fortification through moringa leaves powder is another way to improve the nutritional security status.

Conclusion

The findings of the current study indicate that a large range of morphological variability has been found among the 12 accessions selected from the moringa-growing regions of Rangpur, Lalmonirhat, Chapai Nawabganj, and Rangamati districts in Bangladesh. Based on the qualitative characteristics all accession's corolla color was white except MO8 and MO10. Both pod length and protein content was found to be highest in MO2 accession. It was found that leaves were a better source of protein, calcium, and iron than pods. It implies that edible parts (leaves and pods), especially leaves, may be used as supplemental micronutrients in food products. These findings could be used as a reference when choosing a cultivar and creating a moringa-based dietary supplement for Bangladeshi consumers. Finally, to increase the cultivation of moringa in the country's arid regions, development strategies and regulations are needed.

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