Progress in research and development of moringa at the World Vegetable Center

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Abstract

The World Vegetable Center has a collection of over 50 moringa accessions, majority of which belong to *M. oleifera*. The planting of this species in southern Taiwan started some 35 years ago. The World Vegetable Center initiated research on moringa in 2001. A small project was established to introduce and evaluate a number of moringa accessions collected from Asia, Africa and USA. The accessions were evaluated for growth characteristics and horticultural traits, aiming at high leaf production and nutritional value. A total of 50 accessions were collected and from this collection, seeds of 42 accessions representing four species (*Moringa oleifera, M. stenopetala, M. drouhardii* and *M. peregrina*) were germinated and transplanted to the field for seed multiplication, characterization and evaluation. Twenty-two accessions produced sufficient seeds for replicated evaluation trials and seed distribution. Ten promising accessions were selected and evaluated in replicated trials over a two-year period. Among those, three accessions showed fresh young shoot yield averaging 20-40 t ha^{-1}. The effects of leaf type (age), harvest season and variety on nutrient content were investigated as a component of this study. Results showed no significant differences for most nutrient contents among accessions. Mature leaves are more nutritious than young leaves or shoots. Nutrient content varied with harvest season. Calcium, vitamins A and E were higher in hot-wet season in southern Taiwan than during winter, whereas Fe and vitamin C were higher in cool-dry season than in summer. Subsequent field evaluation studies revealed the variability of *Moringa* accessions in terms of horticultural traits. The accessions varied significantly in plant height, stem diameter, leaf and stem biomass, number of side shoots, tolerance to flooding and survival after heavy rainfall and strong wind brought about by tropical typhoons. Superior and promising accessions are being multiplied to meet the increasing demand for seed and planting materials of moringa. During the last ten years, the World Vegetable Center has distributed moringa germplasm to universities, government organizations, non-governmental organizations and private companies in 15 countries. The Philippines, Malaysia, Thailand, Germany, Vietnam, Egypt, The Netherlands, and Pakistan were the top recipient countries. Moringa is also distributed in seed kits for home garden projects in Asia and Africa.

Keywords: drumstick tree, *Moringa oleifera*, indigenous vegetables, plant introduction, varietal screening, horticultural traits, nutrients and anti-nutrients

INTRODUCTION

For the past 10 to 20 years new developments and studies in the fields of agronomy, horticulture, biotechnology, biochemistry, engineering, nutrition, natural medicine and industry have intensified and progressed indicating the importance of moringa as one of the most useful plants (Palada and Ebert, 2014). At the World Vegetable Center, a research and development initiative on moringa only started in the early 2000s (Palada et al., 2007).

Moringa was first grown at the World Vegetable Center home garden, southern Taiwan some 30 years back. The tree is adapted to the growing conditions of southern Taiwan with mild winters and warm summers. In spite of its increasing popularity and nutritional value

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not much research has been done at the World Vegetable Center. As an indigenous vegetable, moringa has potential as leafy vegetable for specialty markets in Taiwan. As a health food, moringa can be processed into herb teas, snacks, and herbal food supplements (Ebert and Palada, 2017).

The Genetic Resources and Seed Unit (GRSU) at the World Vegetable Center has a collection of 70 moringa accessions but less than 50% have been evaluated under field conditions. Over the past 15 years, research and development efforts on moringa at the World Vegetable Center has been focused on four major objectives: 1) germplasm collection, conservation and seed distribution, 2) varietal screening for horticultural traits, 3) nutritional quality, and 4) improved crop management practices. This paper summarizes the results and progress of the studies conducted under objectives 1 to 3.

GERMPLASM COLLECTION OF THE WORLD VEGETABLE CENTER

The moringa germplasm collection at the World Vegetable Center consists of four species: *M. oleifera*, *M. stenopetala*, *M. peregrina* and *M. drouhardii* (Figure 1). Moringa germplasm was obtained from 12 countries, reaching a total of 70 accessions (Table 1). The largest number of accessions (57) is represented by *M. oleifera*. Only one accession each represented the other three species. Most of the *M. oleifera* accessions originated from Thailand (Table 1). These accessions are presently maintained at the World Vegetable Center's headquarters in Taiwan. Of the four species, only *M. oleifera* produces seed pods. Small seed quantities of this species are made available for distribution to recipients worldwide based on seed requests received by GRSU.

Table 1. Moringa germplasm collection of the World Vegetable Center, 2015.

Origin	Species	Number of accessions
Cambodia	*M. oleifera*	2
India	*M. oleifera*	6
Indonesia	*M. oleifera*	1
Lao PDR	*M. oleifera*	1
Malaysia	*M. oleifera*	3
Nigeria	*M. oleifera*	1
Philippines	*M. oleifera*	6
Taiwan	*M. oleifera*	4
Thailand	*M. oleifera*	33
Tanzania	*M. oleifera*	5
USA	*M. oleifera*	1
USA	*M. peregrina*	1
Unknown	*M. stenopetala*	1
Unknown	*M. drouhardii*	1
Unknown	*M. oleifera*	4

Moringa oleifera

The best known member of the family *Moringaceae*, *M. oleifera* is a fast growing tree native to the sub-Himalayan tracts of Northern India (Figure 1a). It is now distributed worldwide in the tropics and sub-tropics for its multiple uses. *M. oleifera* is the most popular species of the 13 known species of the genus *Moringa*. Collected from 12 countries, *M. oleifera* has the largest number of accessions at GRSU of the World Vegetable Center. The collection consists of 13 accessions from Thailand, six from India and the Philippines, respectively; five from Tanzania, four from Taiwan, three from Malaysia, two from Cambodia and one each from Lao PDR and USA (Table 1). Four accessions originated from unknown sources. Most of the World Vegetable Center studies are focused on this species because of its popularity and adaptability.

a) Moringa oleifera

b) Moringa peregrina

c) Moringa stenopetala

d) Moringa drouhardii

Figure 1. The four moringa species at the World Vegetable Center: a) *M. oleifera*; b) *M. peregrina*; c) *M. stenopetala*; and d) *M. drouhardii.*

Moringa drouhardii

This species belongs to a group in the *Moringaceae* family known as "bottle trees" because the shape of the stem resembles the form of a bottle. Bottle trees are massive trees with bloated water-storing trunks and small symmetrical flowers of cream color (Olson, 1999, 2001). *M. drouhardii* originated in East Africa and is native to the southern Malagasy dry forest. The tree grows extremely fast, surpassing 3 m during the first year. Only one accession is maintained at the World Vegetable Center fields and the trees were planted in 2002 (Figure 1d). The trees bear flowers but these do not develop into seed pods. The strongly scented bark and wood are used for treatment of colds and coughs.

Moringa peregrina

Moringa peregrina has the widest range of any *Moringa* species, and is the only one of the slender trees to extend out of Asia. It occurs from the Musandam Peninsula on the eastern part of the Arabian Peninsula around the southern part of the peninsula, on both sides of the Red Sea and into northern Somalia, north to the hot lowlands of the Dead Sea (Olson, 2001). *M. peregrina* is related to *M. oleifera* as both belong to slender trees (Figure 1b). The young seeds are eaten like peas and mature seeds are fried or roasted like peanuts. Like *M. oleifera*, this species has some medicinal value. The original seed was brought to the World Vegetable Center from the US Virgin Islands and later some seeds were obtained from

India. The trees were planted in 2001 at the World Vegetable Center fields. Flowers are abundant but generally only few seed pods develop.

Moringa stenopetala

M. stenopetala is the economically most important species after *M. oleifera*. It is reported to be an important food plant in southwestern Ethiopia and northern Kenya where the leaves are eaten as a vegetable (Jahn, 1991; Förch, 2003). However, it has only been documented from five wild localities in northwestern Kenya and southwestern Ethiopia: at Lake Baringo and in the vicinity of Lake Turkana (Olson, 2001). *M. stenopetala* is a massive spreading tree that often branches near the base (Figure 1c). The leaf glands of this species are among the most active of the genus, and often make the leaves glisten with drops of clear, sticky exudate that attracts ants. *M. stenopetala* has attracted interest because its larger size seems to make it more drought resistant than *M. oleifera*. This drought resistance makes it an important "famine food", that is, a food that is available even in very bad drought years (Balemie and Kebebew, 2006). Its leaves are more fibrous but apparently are nutritious, although it is not clear whether they have antioxidant activity similar to *M. oleifera.* The original seed was brought from US Virgin Islands to the World Vegetable Center in 2001 and the trees are maintained since then. *M. stenopetala* belongs to the group of bottle trees and is relative of *M. drouhardii*. Although trees bear abundant flowers, none of these developed into seed pods.

Varietal screening

Greenhouse and field evaluation of moringa accessions was initiated in 2001. The initial studies were mainly observational and non-replicated due to shortage of seed. Replicated field trials were conducted in 2004 to 2009.

Introduction and varietal evaluation

In 2001, seeds of four groups of different *Moringa* species were sown to develop seedling establishment methods and to evaluate the growth potential of different accessions. Group 1 consisted of 26 *M. oleifera* accessions (23 from Thailand, and one each from Luzon Islands, Philippines, Virgin Islands, USA, and the World Vegetable Center). Seeds were sown on April 12, 2001, using a standard seed germination procedure. Group 2 consisted of three accessions from the US Virgin Islands. Seeds were sown on June 22 in pots containing a standard medium for seedlings. Group 3 consisted of four accessions. Seeds were first sorted by their health status and sown on September 13. Group 4 consisted of three accessions and a duplicated accession from another group. Seeds were sown on November 21, 2001. Promising accessions from observational studies were field planted for seed multiplication in 2002 and 2003. Additional new accessions were field evaluated in 2004 in non-replicated plots. Results of this study were reported by Palada et al. (2007). Seedlings from these studies were found to grow rapidly especially under warm conditions in plastic nethouse. Seedlings grew an average of 50 cm in one month, 100 cm in two months and 200 cm in three months. Accession Mo02, introduced from the US Virgin Islands was the most vigorous one (data not shown).

Of the four moringa species, *M. oleifera* was the most adapted to the growing conditions of southern Taiwan. *M. stenopetala* produced flowers but these did not develop into pods/fruits. *M. drouhardii* and *M. peregrina* produced very few seeds. Therefore, vegetative propagation by stem cuttings is the only method by which species with few seeds or inexistent seed production can be multiplied and conserved. Results from preliminary observations and harvest data indicated that seven *M. oleifera* accessions (Mo01, Mo02, Mo07, Mo08, Mo09, Mo16 and Mo17) have potential for use as leafy vegetable based on their growth rate (200 cm plant height 100 days after sowing). Accessions Mo03 and Mo07 from Thailand blossomed early (77 days and 83 days after sowing, respectively) and these accessions have potential for young pod production (Palada et al., 2007).

Advanced yield trial

From the results of initial screening, ten promising accessions of *M. oleifera* were selected for a study evaluating horticultural traits and young shoot production in 2004 and 2005 replicated trials. In the first trial, seeds of 10 accessions were sown on March 30, 2004 and transplanted on April 26, 2004 (27 days after sowing). In the second trial, seeds were sown on February 24, 2005 and transplanted on April 7, 2005 (32 days after sowing). In both trials, plants were grown in double rows per bed with plant density of 44,444 plants ha^{-1}. Crop management practices were followed using the guides suggested by Palada and Chang (2003). At harvest, samples of mature leaves and young shoots were collected to determine the nutritional qualities (dry matter, protein, vitamins, minerals and phenolics) as affected by genotype (accession), leaf type (age) and harvest season.

As reported by Palada et al. (2007), significant differences in young shoot production were observed among accessions and between planting and harvest season (Table 2). In 2004, harvesting conducted from June 30 to December 7, resulted in young shoot yield ranging from 14.4 t ha^{-1} (Mo04) to 21.9 t ha^{-1} (Mo35). Two accessions (Mo29 and Mo35) surpassed the 20 t ha^{-1} yield. Shoot yield from harvests conducted in 2005 (April 25 to December 15) was generally greater than those in 2004 (Table 2). Yield ranged from 25.3 t ha^{-1} (Mo04) to 41.8 t ha (Mo35).

Table 2. Young shoot yield of moringa accessions as affected by planting and harvesting dates at the World Vegetable Center, 2001-2005. Source: Palada et al. (2007).

Accession number	Code name	Country of origin	Young shoot yield (t ha^{-1})		
			2004[1]	2005[2]	2005[3]
Mo02	TOT4880	USA	18.3 bc	39.1 a	22.7 a
Mo03	TOT4100	Taiwan	18.2 bc	34.5 d	15.8 bc
Mo04	TOT4893	Thailand	14.4 d	25.3 d	11.9 c
Mo06	TOT4951	Thailand	15.9 d	27.6 cd	13.5 c
Mo07	TOT4977	Thailand	15.4 d	34.0 b	14.8 bc
Mo29	TNAU-1	India	20.5 ab	40.1 a	24.0 a
Mo33	Davao	Philippines	15.5 d	29.2 c	18.2 b
Mo34	La-Mu E	India	19.8 ab	40.8 a	25.3 a
Mo35	RCA	Tanzania	21.9 a	41.8 a	25.0 a
Mo38	Ma Rum C	Thailand	16.7 cd	32.7 b	22.7 a

[1]Date sown: March 30, 2004, Date transplanted: April 26, 2004; Harvest: June 30 to December 7, 2004
[2]Date sown: March 30, 2004; Date transplanted: April 26, 2014; Harvest: April 25 to December 15, 2005.
[3]Date of sowing: February 24, 2005; Date transplanted: April 7, 2005; Harvest: May 30 to December 15, 2005.
Mean separation in columns by Duncan's Multiple Range Test (5%).

Three accessions (Mo29, Mo34 and Mo35) produced shoot yield of >40 t ha^{-1} and was significantly higher than yield of most accessions. Shoot yield of accessions planted in 2005 was almost similar with first harvest of those planted in 2004, however, five accessions (Mo02, Mo29, Mo34, Mo35 and Mo38) produced over 20 t ha^{-1} and were significantly higher than other accessions. The data suggest that maximum shoot production can be attained during the second season (second harvest). Young shoot yield and production obtained from this study is comparable or greater than other indigenous leafy vegetables and moringa can provide year-round supply of fresh leaves. Results of nutritional qualities are discussed in the following section under nutritional quality.

Varietal evaluation for horticultural traits

The major objective of this study was to evaluate a sub-set of the World Vegetable Center *Moringa oleifera* Lam. germplasm collection for important horticultural traits. The 18 World Vegetable Center moringa accessions originated from India, Laos, Philippines, Taiwan, Tanzania, Thailand and USA. Three-month-old seedlings were transplanted onto single-row raised beds, spaced 1.5 m apart. Plants were arranged in a randomized block design with

three replications. Data were collected on stand establishment (survival), plant height, number of branches, canopy width, fresh biomass (stems and leaves), days to flowering, pod/seed yield and incidence of pests and diseases. Results from this study were reported by Palada et al. (2015). One month after transplanting, four accessions attained a plant height of above 1 m (Table 3). Number of side branches ranged from 9 to 14 plant^{-1}. Differences in plant height and stem diameter were significant at 70 days after transplanting (DAT). Tallest plants (2.9 m) were observed in Mo-35 from Tanzania while Mo-8 from Thailand produced the largest stem diameter (36 cm). Leaf fresh weight and dry weight was highest (15.8 and 9.2 t ha^{-1}, respectively) for 'Mo-35' at 70 DAT, survival and stand count decreased after two strong typhoons and severe flooding in 2009 and 2010 (Palada et al., 2015).

Table 3. Plant height, stem diameter, number of side shoots, leaf biomass and plant survival of moringa accessions at the World Vegetable Center, Taiwan. Source: Palada et al. (2015).

Accession	Country	Plant height[1] (m)	No. of side shoots[2]	Stem diameter[1] (cm)	Leaf biomass[1] (t ha^{-1})		Plant survival[3] (%)
					Fresh	Dry	
Mo-2	USA	2.7 a-e	13	32.3 a-d	8.8 b	5.5 abc	67
Mo-3	Taiwan	2.6 a-e	10	31.7 a-d	8.6 b	5.9 abc	73
Mo-4	Thailand	2.4 d-e	9	30.0 a-d	12.1 ab	7.2 abc	60
Mo-6	Thailand	2.3 d-e	12	25.7 d	8.7 b	5.8 abc	47
Mo-7	Thailand	2.8 abc	14	34.7 ab	12.7 ab	6.9 abc	13
Mo-8	Thailand	2.8 abc	12	36.0 a	12.7 ab	8.3 ab	60
Mo-9	Thailand	2.6 a-e	14	29.7 a-d	10.4 ab	6.9 abc	27
Mo-12	Thailand	2.3 d-e	11	26.3 cd	7.0 b	4.6 c	67
Mo-14	Thailand	2.5 b-e	10	27.3 bcd	7.7 b	4.9 c	33
Mo-15	Thailand	2.5 b-e	11	30.7 a-d	9.1 b	5.7 abc	53
Mo-20	Thailand	2.7 a-e	9	28.3 a-d	8.8 b	6.1 abc	20
Mo-29	India	2.7 a-e	11	31.3 a-d	12.5 ab	8.7 a	60
Mo-33	Philippines	2.5 a-e	12	32.0 a-d	8.0 b	6.3 abc	27
Mo-34	India	2.9 a	12	33.3 a-d	10.8 ab	7.7 abc	27
Mo-35	Tanzania	2.9 a	14	34.3 abc	15.8 a	9.2 a	60
Mo-37	Lao PDR	2.8 abc	11	32.7 a	12.0 ab	7.9 ab	73
Mo-38	Thailand	2.7 a-e	13	30.3 a-d	10.2 ab	6.9 abc	100
Mo-40	India	2.7 a-e	12	32.7 a-d	9.4 b	6.2 abc	0

[1]Measured 70 days after transplanting.
[2]Measured 30 days after transplanting.
[3]Determined August 8, 2011, two years after intense waterlogging for a period of 3 days in 2009.
Mean separation in columns by Duncan's Multiple Range Test (5%).

This field evaluation study demonstrated the variability of moringa accessions in terms of horticultural traits. The accessions varied significantly in plant height, stem diameter, leaf and stem biomass, number of side shoots, tolerance to flooding and survival after heavy rainfall and strong wind brought about by tropical typhoons. In terms of plant height and canopy cover, accessions from Tanzania and Thailand are promising. Mo-35 from Tanzania was the most promising accession in terms of growth rate and leaf fresh and dry biomass production which is ideal for processing into moringa by-products for commercial markets. In terms of plant tolerance to waterlogged conditions (flooding), Mo-38 from Thailand was the most outstanding accession with 100% survival followed by Mo-37 from Lao PDR with 93% survival, two years after plant establishment.

Nutritional quality

A survey conducted by the World Vegetable Center of over 120 species of tropical and

subtropical edible plants for nutrient content, antioxidant activity (AOA), and crop traits indicated that *M. oleifera* is one of the promising crops which could contribute to increased intake of micronutrients and antioxidants. Two studies on nutritional quality of moringa have been published by Yang et al. (2006). These studies compared the nutritional quality of four moringa species and the effect of variety (accession), leaf age and growing (harvest) season on nutrient and phytochemical contents of moringa leaves.

Nutritional quality of the four moringa species

Among the four species, *M. oleifera* contained the highest amounts of β-carotene, ascorbate (vitamin C), α-tocopherol (vitamin E) and iron, and was the second highest in protein content (data not shown). *M. oleifera* grows faster than the other three species under the subtropical lowlands in southern Taiwan, and this species is commonly consumed as a vegetable in South Asia and Africa. Oligosaccharides and oxalate were reported as anti-nutrient factors in moringa leaves (Freiberger et al., 1998). In this study, stachyose and raffinose were not found in mature leaves, but detected in young leaves (0-14 mg g^{-1} dry weight) and in seeds (22-98 mg g^{-1} dw). Moringa mature leaves contained very low levels of oxalate (0.99±0.21 mg g^{-1} dw) compared to spinach (25-45 mg g^{-1} dw). The data indicated that oxalate and oligosaccharides are not significant anti-nutrient factors in moringa (Yang et al., 2007).

Concentrations of four natural antioxidants (total phenolics and antioxidant vitamins A, C and E) were measured for the four species. The content ranges on a dry weight basis were 74-210 μmol g^{-1} for phenolics, 70-100 μmol g^{-1} for ascorbate (vitamin C), 1.1-2.8 μmol g^{-1} for β-carotene and 0.7-1.1 μmol g^{-1} for α-tocopherol (vitamin E) (data not shown). The antioxidant content of moringa is high when compared to vegetables and fruits known for their high antioxidant content such as strawberries. The content of phenolics in moringa is 330 mg gallic acid (GA) 100 g^{-1} FW or ~190 μmol GA g^{-1} DW; hot pepper high in ascorbate (200 mg 100 g^{-1} fw, or ~110 μmol g^{-1} dw, carrot high in β-carotene (10 mg 100 g^{-1} fw, or ~1.8 μmol g^{-1} dw) and soybean which is high in α-tocopherol (0.85 mg 100 g^{-1} fw, or ~1.8 μmol g^{-1} dw). Moringa is an excellent source of a wide spectrum of dietary antioxidants. This study indicated that: (1) high levels of nutrients, antioxidants and glucosinolates, and low oxalate contents are common features of the four moringa species; and (2) *M. peregrina* was the uppermost for antioxidant content, while *M. oleifera* has the highest nutrient values among the four species (Yang et al., 2007).

Effect of cultivar, leaf age and harvest season on nutrient and phytochemical contents of moringa leaves

This study used plant samples of moringa listed above under advanced yield trial. At harvest, samples of mature leaves and young shoots were collected to determine the nutritional qualities (dry matter, protein, vitamins, minerals and phenolics) as affected by cultivar (accession), leaf type (age) and harvest season. Results of this study are reported by Yang et al. (2006). Variations among 10 *M. oleifera* accessions for nutrient contents were small (data not shown) so breeding for higher nutrient content is not worthwhile. Varietal selection should focus on important horticultural traits. Mature leaves were more nutritious than young shoots and could be quickly dried with minimum nutrient loss; however, young shoots exhibited better eating quality and were more acceptable for the fresh market (Table 4). Seasonal effects caused variation in the content of vitamin A, iron and antioxidants in moringa leaves by a factor of 1.5 to 3 times. Higher vitamin A levels were obtained during the hot-wet summer season, while higher iron and vitamin C content were found during the cool-dry winter season (Yang et al., 2006).

Table 4. Means of nutrient values of 10 *M. oleifera* accessions and three harvests. Source: Yang et al., 2007.

Nutrients	Nutrient values 100 g^{-1} fresh weight[1]	
	Mature leaves	Young shoots
Dry matter (g)	55.2±1.6	15.1±2.7
Protein (g)	6.9±0.8	4.3±0.9
Fiber (g)	1.8±0.2	1.5±0.7
Sugar (g)	2.9±0.4	2.2±0.4
Calcium (mg)	454±63	82±31
Iron (mg)	6.7±2.8	2.9±1.5
B-carotene (mg)	13.9±5.2	4.1±2.2
Vitamin C (mg)	257±53	244±54
Vitamin E (mg)	16.7±3.2	4.3±1.9
TEAC[2] (µmol TE)	3628±1257	23.4±926
Total phenolics (mg)	680±116	581±134

[1]Values are given as mean±SD; *n*=90 including 10 accessions, 3 replications and 3 harvests (June 2004, and January and April 2005).

[2]TEAC: Trolox equivalent antioxidant capacity, an antioxidant assay using ABTS radicals; TE: trolox equivalent.

SUMMARY

After more than a decade, considerable progress in research and development for moringa has been achieved in the areas of germplasm collection and conservation, variety evaluation, and nutrition value at the World Vegetable Center. The Center has now 70 accessions of moringa collected mostly from South and Southeast Asia, Africa and the USA representing four species (*M. oleifera, M. peregrina, M. stenopetala and M. drouhardii*). *M. oleifera* constitutes by far the largest group of accessions (97%). Field variety evaluation studies identified 10 promising accessions in terms of important horticultural traits such as leaf and young shoot biomass yield, stem diameter and number of side branches. Nutritional studies indicated that high levels of nutrients, antioxidants and glucosinolates, and low oxalate contents are common features of the four moringa species. While *M. oleifera* has the highest nutrient content, *M. peregrina* has the highest antioxidant content among the four species. Growing and harvest season influenced the nutritional quality of leaves. Vitamin A content increased during the hot-wet season while iron and vitamin C were highest during the cool-dry season. Promising accessions are being multiplied to meet the increasing demand for seed and planting materials of moringa. Future research will be focusing on improved crop management and propagation methods.

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