Rheedea
Vol. 25(1)
14-30
2015
ISSN: 0971 - 2313

A systematic review of the genus *Abelmoschus* (Malvaceae)

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Abstract

The diverse agro-climatic conditions encompassing variable farming systems, rainfall and soil regimes have promoted diversification of the crops in the Southeast Asia. India is a rich treasure house of various species of *Abelmoschus* and all 11 species are found either in the wild, semi-wild or under cultivation. The genus *Abelmoschus* has a tortured systematic history. The ambiguity in nomenclature and lack of strong morphological characters for the delimitation of species has made the circumscription the genus rather controversial and created problems in breeder's selection efforts. In the present review updated information on its taxonomy, genetic diversity, cytology and interspecific hybridization is discussed.

Keywords: *Abelmoschus*, distribution, Malvaceae, okra, review, systematics

Introduction

The word *Abelmoschus* probably originated from Arabian *abul-l-mosk* meaning "father of musk, source of musk" referring to the seeds of the genus (Don, 1831; Jaeger, 1950; Nayar, 1985; Quattrocchi, 2000). Genus *Abelmoschus* is important and well known because of its cultivated species, viz., *A. esculentus* and *A. caillei.* They are grown in many parts of the world, especially in tropical and subtropical countries (Borssum Waalkes, 1966; Velayudhan *et al.*, 1996).

The genus *Abelmoschus* has a tortured systematic history and it still pose problems in the delimitation of species and other infraspecific categories. It is mainly due to the polyploid nature of genome, morphological plasticity, intermediate breeding system, long history of cultivation and dispersion (IBPGR, 1991). Remarkably little attention has been paid to the wide spread taxa of *Abelmoschus* in India (Borssum Waalkes, 1966; Paul & Nair, 1988; IBPGR, 1991; Sivarajan & Pradeep, 1996; Velayudhan *et al.*, 1996; Bhat, 1996).

The main objective of this review is to provide an overview of the existing information about origin, distribution, taxonomy, cytology, genetic diversity, interspecific hybridization and economic importance of genus *Abelmoschus* to confer the needs of those engaged in research on breeding and crop improvement.

Taxonomical scenario of Abelmoschus

Hibiscus-Abelmoschus complex

Abelmoschus was originally included in the genus *Hibiscus* under Monadelphia - Polyandria by Linnaeus (1753). On the basis of capsule features, Medikus (1787) proposed to raise this section to the rank of a distinct genus. This was accepted by Gaertner (1791), Moench (1794) and Schumann (1890). On the contrary, authors like Masters (1874), Prain (1903) and Dunn (1915) did not accept the Medikus view and followed the view of de Candolle (1824). Hence, they treated *Abelmoschus* as section of *Hibiscus*. Later, Hochreutiner (1924) distinguished the genus *Abelmoschus* from *Hibiscus* mainly based on its peculiar spathaceous calyx splitting to one-side. This was subsequently followed in the taxonomic and contemporary

literature (Borssum Waalkes, 1966; Terrell & Winters, 1974; Paul & Nair, 1988; IBPGR, 1991; Vredebregt, 1991; Sivarajan & Pradeep, 1996; Bhat, 1996; Bisht & Bhat, 2006; John *et al.*, 2012; Sutar *et al.* 2013).

Species circumscription

The number of species included in the genus *Abelmoschus* by various authors (Hochreutiner, 1924; Borsssum Waalkes 1966; Sivarajan & Pradeep, 1996; Sutar *et al.,* 2013) are provided in Table 1. Nevertheless, authentic number of species included in the genus *Abelmoschus* is still uncertain, as they have not been studied in detail with respect to their taxonomic delimitation. Over fifty species were described from the world (Charrier, 1984) that comprised many synonyms and misidentifications (Vredebregt, 1991).

Hochreutiner (1924) described 14 species, of which *A. moschatus* Medik. and *A. manihot* (L.) Medik. comprises several varieties. However, only six species viz., *A. esculentus* (L.) Moench, *A. moschatus* Medik., *A. ficulneus* (Linn.) Wight & Arn., *A. manihot* (L.) Medik., *A. crinitus* Wall. and *A. angulosus* Wall. ex Wight & Arn. were maintained by Borssum Waalkes (1966). Further, *A. manihot* has been divided into two subspecies, namely subsp. *manihot* and subsp. *tetraphyllus* (Roxb. ex Hornem.) Borss. whereas, *A. moschatus* with three subspecies, namely subsp. *moschatus*, subsp. *tuberosus* (Span.) Borss. and subsp. *biakensis* (Hochr.) Borss. Later, this classification was adopted by International Okra workshop held at NBPGR, Delhi (IBPGR, 1991) with some minor changes. In this modified treatment *A. manihot* subsp. *tetraphyllus* was raised to the specific rank and two more species viz., *A. tuberculatus* Pal & Singh and *A. caillei* (A. Chev.) Stevels were included. Three varieties of *A. angulosus* Wall. ex Wight & Arn., viz., var. *angulosus*, var. *grandiflorus* Thwaites and var. *purpureus* Thwaites are reported from India (Sivarajan *et al*., 1994; Sivarajan & Pradeep, 1996). Recently, John *et al.* (2012) described a new species, *A. enbeepeegearense* from the Western Ghats and Sutar *et al.* (2013) described *A. palianus* from Chhattisgarh, India. Thus presently there are 11 species, 3 subspecies and 4 varieties in India as well as for the world (Sutar *et al.*, 2013).

However, the taxonomic treatment for some species of *Abelmoschus* is not consistent. *A. manihot* and *A. moschatus* are the most polymorphic species (Hamon & Charrier, 1983). Sivarajan and Pradeep (1996) have provided detailed morphological features and ecological distribution for wild species. However, they did not consider infraspecific classification of *A. manihot* produced by Borssum Waalkes (1966). Paul and Nayar (1988) and Paul (1993) since then used characters for separation, but these seem to be too feeble and highly inconsistent. Therefore, Sivarajan and Pradeep (1996) treated *A. manihot* as a single variable species and not attempted for recognising any infraspecific categories. Bates (1968) also suggested that all subspecies and varieties of *A. manihot* should be merged under the species. Later, Hamon *et al.* (1987) and Vredebregt (1991) pointed out that *A. manihot* subsp. *manihot*, *A. manihot* subsp. *tetraphyllus* var. *tetraphyllus* and *A. manihot* subsp. *tetraphyllus* var. *pungens* (Roxb.) Hochr. complex lack discrete species boundaries among them, which further contradicts Hochreutiner (1900), Borssum Waalkes (1966), Paul and Nayar (1988) and Paul (1993). Intraspecific taxonomy of *A. moschatus* is also a matter of debate as many subspecies and varieties have been recognized by Masters (1874), Hochreutiner (1900) and Borssum Waalkes (1966).

Initially, *A. caillei* has been considered as a species resembling to *A. esculentus* (Chevalier, 1940) and therefore, with restrictive approach Borssum Waalkes (1966) ignored this species in his revision of Malesian Malvaceae. Later, *A. caillei* was elevated to a distinct species by Stevels (1988) and this was further supported by Martin and Rhodes (1983) and Sunday *et al*. (2008). However, *A. esculentus* (Asian genotype) and *A. caillei* (West African genotype) generally pose problems as to their determination.

The recognition of *A. tuberculatus* as the closest progenitor of *A. esculentus* has been widely accepted, but Bates (1968) in his description of *Abelmoschus*, suggested that *A. tuberculatus* should be included under *A. esculentus*. However, his argument for this is questionable since *A. tuberculatus* has already been recognized as a distinct species by Pal *et al*. (1952). The sequence information based on internal transcribed spacer (ITS) gene also confirms the species status of *A. tuberculatus* (authors unpublished data). Sterility of direct and reciprocal F1 hybrids of *A. esculentus* and *A. tuberculatus* give additional evidence to their distinctiveness as two different biological species.

Table 1. Systematic treatment of the genus *Abelmoschus* by various authors.

Hochreutiner (1924)	Borssum Waalkes (1966)	Paul & Nayar (1988)	IBPGR (1991)	Sivarajan & Pradeep (1996)	Sutar *et al.* (2013)
A. crinitus	*A. crinitus*	*A. crinitus*	*A. crinitus*	*A. crinitus*	*A. crinitus*
A. ficulneus	*A. ficulneus*	*A. ficulneus*	*A. ficulneus*	*A. ficulneus*	*A. ficulneus*
A. angulosus	*A. angulosus*	*A. angulosus*	*A. angulosus*	*A. angulosus*	*A. angulosus*
				var. *grandiflorus*	var. *grandiflorus*
				var. *angulosus*	var. *angulosus*
				var. *purpureus*	var. *purpureus*
A. haenkeanus					
A. moschatus	*A. moschatus*	*A. moschatus*	*A. moschatus*	*A. moschatus*	*A. moschatus*
var. *genuinus*	subsp. *moschatus*		subsp. *moschatus*		
	var. *moschatus*		var. *moschatus*		
var. *betulifolius*	var. *betulifolius*		var. *betulifolius*		
var. *multiformis*					
var. *rugosus*					
A. todayensis	subsp. *tuberosus*		subsp. *tuberosus*		
A. rhodopetalus					
A. brevicapsulatus					
A. sharpei					
A. biankensis	subsp. *biakensis*		subsp. *biakensis*		
A. manihot	*A. manihot*	*A. manihot*	*A. manihot*	*A. manihot*	*A. manihot*
var. *genuinus*	subsp. *manihot*	subsp. *manihot*			
var. *timorensis*	subsp. *tetraphyllus*	subsp. *tetraphyllus*			
var. *tetraphyllus*	var. *tetraphyllus*	var. *tetraphyllus*	*A. tetraphyllus*		*A. tetraphyllus*
var. *luzoensis*			var. *tetraphyllus*		var. *tetraphyllus*
var. *mindanaensis*			var. *pungens*		var. *pungens*
var. *pungens*	var. *pungens*	var. *pungens*			
A. ficulneoides					
A. esculentus	*A. esculentus*	*A. esculentus*	*A. esculentus*	*A. esculentus*	*A. esculentus*
		A. tuberculatus	*A. tuberculatus*		*A. tuberculatus*
		var. *tuberculatus*			
		var. *deltoidefolius*			
			A. caillei		*A. caillei*
A. sublobatus					
					A. palianus
					A.enbeepeegearense

Flower color, fruit size, seed shape and size and occurrence of trichomes on seeds are of diagnostic value and play a vital role in species identification of *Abelmoschus*. Sporadic attempts have been made for morphological characterization of *Abelmoschus* and its wild germplasm with more than 40 morphological descriptors (Thomas *et al.*, 1991; Bisht *et al.*, 1995a, 1995b; Duzyaman & Vural, 2003). Among the characters, pigmentation and pubescence of stem, leaf, fruit and seed exhibit significant variability in the germplasm. A primary study has been undertaken for earliness of flowering, plant height, dimension, weight of fruit and susceptibility to pests (Siemonsmo, 1982a; Bisht *et al.*, 1995b).Studies revealed that flowering behavior can be useful in differentiating different varieties of *A. esculentus* (Ariyo & Odulaja, 1991; Sneath & Sokal, 1973).

Heywood (1971) and Cole (1975) drew attention to the importance and impact of scanning electron microscopy (SEM) in solving systematic problems and subsequently provides very significant evidence for species differentiation within the genus (Barthlott, 1990). Sivarajan and Pradeep (1996) and Salah and Naggar (2001) reported that seed coat sculpture plays a significant role in species differentiation in the family Malvaceae. Until now, no study has been undertaken on the utility of seed macro and micromorphology to define species boundaries and its subsequent application for species identifications.

Recently, it has been suggested that multidisciplinary studies using different data sources have significantly improved the delimitation of species within complex taxonomic groups (Edlley *et al.*, 2012). With a view to define the species distinctiveness in *Abelmoschus*, plant taxonomist should expand the realm of studies to include anatomical, micromorphological (seeds and pollen), biochemical, cytological and eco-geographical aspects. Moreover, in order to solve ambiguity in *Abelmoschus* taxonomy, study should be further extended with advanced molecular markers such as RAPD, SSR and locus specific (*nr*DNA, *cp*DNA and *mt*DNA) sequence data with all wild, semiwild, putative progenitor and cultivated forms of *Abelmoschus*.

Origin, domestication and cultivation

One of the essential questions regarding cultivated plants, is their geographic origin and region of domestication. Concerning the geographical origin of cultivated okra (*A. esculentus*) two controversial hypotheses have been suggested, viz., Ethiopian domestication (de Candolle, 1883; Vavilov, 1926) and Asian origin (Masters, 1874; Joshi *et al.*, 1974), but supportive evidences for former are still unexploited. Moreover, cultivated and wild species of *Abelmoschus* clearly show an overlapping distribution in Southeast Asia which has been considered as the center of diversity (Borssum Waalkes, 1966). Among the putative wild progenitor of *A. esculentus*, existence of diversity of *A. ficulneus* with *A. tuberculatus* provide further support to the theory of an Asiatic origin of *A. esculentus* (Vredebregt, 1991). Additionally, linguistic evidence as mentioned in Sanskrit language, *tindisha* and *gandhamulla* meaning okra in Indian literature has supported the view of Asiatic origin for okra (Bisht & Bhat, 2006).

The identity of the ancestral species of okra is a matter of uncertainty. Very little efforts have been made to solve the issue of origin of cultivated okra (Joshi & Hardas, 1956; Joshi *et al.*, 1974; Bhat, 1996). In view of cytological evidences regarding origin of cultivated okra, the hypothesis that *A. esculentus* ($2n$=130) is an amphidiploid of *A. tuberculatus* ($2n$=58) and an unknown species ($2n$=72), probably the most likely source of complementary genome has much credence. Joshi and Hardas (1956) and Joshi *et al.* (1974) observed chromosome homology during meiotic event of hybrids between *A. esculentus* and *A. tuberculatus*. They found that out of 65 chromosomes of *A. esculentus* (n=65), 29 had complete homology with 29 of *A. tuberculatus* (n=29) and remaining 36 showed considerable but incomplete pairing with 36 of *A. ficulneus* (n=36). They suggested that one of the parents of *A. esculentus* (n=65) should have been *A. tuberculatus* (n=29) and either of the two Indian species, namely *A. ficulneus* and *A. moschatus* possibly play a role of complementary genome, yet to be established.

The process of domestication includes gathering of seeds and fruits of all kinds of wild plants without altering their nature, harvesting and replanting year after year. During this practice several morphological and structural changes such as increase in size of seeds and fruits might have significantly contributed to the evolution of wild and cultivated species (deWet & Harlan, 1975). Unfortunately, there is no authentic report on domestication of cultivated species in this

genus. With respect to the cultivated species, *A. esculentus* and wild species, extreme morphological diversity has been reported in Asia (Thomas *et al*., 1990; 1991; Bisht *et al*., 1993) and Africa (Chheda & Fatokun, 1991; Jarvis *et al*., 2008). Therefore, to understand the extent and origin of morphological diversities in *A. esculentus*, systematic studies should be undertaken on the complex group of cultivated forms, wild, semiwild forms and putative progenitors.

In the history of okra cultivation, people mostly preferred either home gardens or mixed cropping with other crops like Sorghum or Cotton (Rashid *et al*., 2002). It prefers sandy to clay soils and also light, well drained as well as loose, friable soils for effective seed germination (Lamont, 1999; Akande *et al*., 2003; Abd El-Kader *et al*., 2010). Fortunately, Indian agro-climatic conditions are favorable for okra cultivation and therefore farmers are able to take one crop in hilly region, two to three crops in the east, west and north plains and regularly throughout the year in south India. Reproduction is based on true seed (Thakur & Arora, 1993) while in some wild species stem cuttings with nodal buds found to be suitable for multiplication (Joseph *et al*., 2013).

Seeds and seed dormancy

Wild species are grown easily in nature. Apparently, due to prevalence of hard seed coat and consequent seed dormancy in some *Abelmoschus* species, germinations get distracted. In such cases, dormancy breaking treatments are essential for successful seed germination, for example, scarification with acetone or acid treatment, overnight presoaking and hot water treatment are useful in desirable seed germination (Johnston, 1949; Anderson *et al*., 1953; Edmond & Drapala, 1960; Singh & Singh, 1969). Scarification with sand paper is effective in enhancing speed and rate of germination in all *Abelmoschus* species (JJK, personal communication).

Geographical distribution

The species of *Abelmoschus* are naturally distributed throughout the tropical and subtropical countries (Vredebregt, 1991). Majority of the species occur in South Asia and Southwest Pacific (Bisht & Bhat, 2006). Apart from the morphological diversity, species of *Abelmoschus* also differ in their geographical distribution and habitat requirements (Paul, 1993; Sivarajan & Pradeep, 1996; Bisht & Bhat, 2006). Occurrence of some of the wild forms has also been reported in North Australia, South America and Africa (IBPGR, 1991). In India, species of *Abelmoschus* are widely distributed in different phytogeographical regions from Himalayan region (Velayudhan & Upadhay, 1994; Negi & Pant, 1998), to Southern peninsular parts of India (Sivarajan *et al*., 1994; Sivarajan & Pradeep, 1996; Velayudhan *et al*., 1996).

Among the species, *A. esculentus* is economically very important and highly nutritious crop which is widely cultivated throughout world. Another cultivated species *A. caillei* has an occurrence limited to West and Central Africa. *A. moschatus* is grown for aromatic seeds as well as an ornamental plant, although found escaped in the wild habitats. The rest of species namely, *A. manihot*, *A. tetraphyllus*, *A. tuberculatus*, *A. ficulneus*, *A. crinitus*, *A. enbeepeegearense*, *A. palianus* and *A. angulosus* are truly wild species.

In case of tender, juicy, immature fruit bearing cultivated species, *A. esculentus* popularly known as 'bhendi' has a wide distribution in India. Among the states of India, Karnataka and West Bengal are the highest okra producing states followed by Uttar Pradesh, Assam, Bihar, Orissa and Maharashtra (FAOSTAT, 2010). Apart from India, it is also grown in Nigeria, Sudan, Pakistan, Ghana, Egypt, Benin, Saudi Arabia, Mexico and Cameroon (FAOSTAT, 2010). Interestingly, okra is known by different names in different parts of world such as bamia in Middle East, gumbo in Southern USA, lady's finger in England, *quiabo* in Portuguese and Angola, *quimbombo* in Cuba, *gumbo* in France, *mbinda* in Sweden, and lastly in Japan as *okura* (Chauhan, 1972; Lamont, 1999; Ndunguru & Rajabu, 2004). Second edible okra species, *A. caillei* has a limited distribution to West and central Africa with huge socio-economic potential (Kumar *et al*., 2010; Osawaru & Dania-Ogbe, 2010).

Cytological studies

Despite of enormous morphological diversity, there has been no strong consensus among the cytologists to the actual number of chromosome counts that constitute the species of *Abelmoschus*. On the basis of cytogenetical observations Siemonsmo (1982a) suggested that taxonomical classification at species level is much more complex than elaborated by Borssum Waalkes (1966). With the massive morphological variation, the genus

constitutes a polyploid complex ranging from 2*n*=38 to 2*n*=200. **Table 2**

Highly variable chromosome counts were reported for *A. esculentus* from 2*n*=66 (Ford, 1938), 2*n*=130 (Joshi & Hardas, 1953) whereas Datta and Naug (1968) recorded eight chromosome types (A to H) and suggested that genus appears as a regular series of polyploids with *x*=12. Among the species, lowest 2*n*=56 was reported for *A. angulosus* (Ford, 1938). Authentic chromosome number, 2*n* = 66, 2*n* = 72 and 2*n*=130 have been reported for *A. angulosus* var. *grandiflorus*, *A. moschatus* subsp. *moschatus*, *A. moschatus* subsp. *tuberosus* and *A. esculentus*, respectively (Merita *et al*., 2013).

Hamon and Sloten (1995) provided synthetic view of cytogenetic relationships among the species of *Abelmoschus* dividing the genus into four ploidy level, each with mitotic integrity: Ploidy level 1: 2*n*=38 (*A. moschatus* subsp. *tuberosus*, *A. angulosus*, *A. crinitus*); ploidy level 2: 2*n*=58-72(*A. moschatus*, *A. manihot*, *A. tuberculatus*, *A. ficulneus*); ploidy level 3: 2*n*=120–140 (*A. betulifolius*, *A. tetraphyllus*, *A. esculentus*) and ploidy level 4: 2*n*=185–200 included only one species, *A. caillei* which is thought to be of amphidiploid origin from *A. esculentus* (*n*=62–65) and *A. manihot* (*n*=30–34) (Siemonsmo, 1982b).

Molecular studies

Unfortunately, molecular studies in genus *Abelmoschus* are lacking as compared to other crops. Iso-enzymatic markers recommended by Second and Trouslot (1980) for rice was used for interspecific discrimination between *A. esculentus* and *A. caillei* (Hamon & Yapo, 1986). Martinello *et al.* (2001) investigated the genetic diversity among the species of *Abelmoschu*s using random amplified polymorphic DNA (RAPD) marker. Twenty two accessions of *A. esculentus* were assayed for diversity in esterases and total storage proteins by Torkpo *et al.* (2006). Sequence-related amplified polymorphism (SRAP) and phenotypic markers were used to determine diversity and relationships among 23 okra (*A. esculentus*) genotypes by Gulsen *et al.* (2007). A significant genetic diversity in okra was demonstrated using cross species simple sequence repeats (SSR) primers by Sawadogo *et al.* (2009). Recently, molecular characterization was done by Nwangburuka *et al.* (2011) using RAPD from Nigeria. Most recently, okra transcriptome sequences were mined for SSR to assess the genetic diversity of 65 okra accessions comprising two wild species by Schafleitner *et al.* (2013), which revealed highest polymorphism rate for tri- and hexa-nucleotide repeat SSRs in okra germplasm.

Genetic diversity in *A. esculentus* and four related species viz., *A. ficulneus*, *A. manihot* subsp. *tetraphyllus, A. moschatus*and *A. tuberculatus*were studied using isozyme electrophoresis and RAPD techniques (Bhat, 1996). Genetic diversity within *A. ficulneus* and *A. moschatus* as revealed by both isozyme and RAPD analysis was moderate while that of the other taxa was low. On the genetic relationship study based on RAPD, Sunday *et al.* (2008) has demonstrated that Asian genotypes (*A. esculentus*) were more diverse than West African genotypes (*A. caillei*).

In the recent years, several studies have included DNA sequence data to resolve phylogenetic relationships among the taxa belonging to the family Malvaceae and the evolution of their morphological characteristics has been reinterpreted accordingly (Alverson *et al*., 1998; 1999; Soltis *et al*., 1998; Pfeil *et al*., 2002; Cronn *et al*., 2002; Andreasen & Baldwin, 2003; Tate & Simpson, 2003; Pfeil *et al*., 2004; Won, 2009). Unfortunately, no single species of *Abelmoschus* has been addressed for species origin and phylogenetic relationships till now.

Interspecific hybridization

Breeding system

The breeding system among the cultivated and wild species of *Abelmoschus* is still not well known as compared to other vegetables crops. Typical hermaphrodite features keep the okra species as self-fertile (Wyatt, 1983). Cruden (1977) suggested that pollen production (P) and ovule production (O) seems to be correlated with breeding system. On the basis of Cruden's index (log P/O), Hamon and Koechlin (1991) have suggested that breeding system of *Abelmoschus* is near facultative autogamy. However, Purewal and Randhawa (1947) suggested strong autogamy in species of*Abelmoschus*, which was further supported by Srivastava and Sachan (1973) and Chandra and Bhatnagar (1975). In contrast, Chauhan *et al.* (1968), Chaudhary and Choomsai (1970), Shalaby (1972), Mitidieri and Vencovsky (1974) and Martin (1983) studies reflects contradictory results which show wide range of variation in allogamy level.

Table 2. Chromosome numbers in the genus *Abelmoschus* Medik.

Species	Chromosome Numbers (2n)	Authors	Ploidy level
A. esculentus	± 66	Ford (1938)	
	72	Teshima (1933), Ugale *et al.* (1976); Kamalova (1977)	
	108	Datta & Naug (1968)	2
	118	Krenke In: Tischler (1931)	2
	120	Krenke In: Tischler (1931); Purewal & Randhawa (1947); Datta & Naug (1968)	2
	122	Krenke In: Tischler (1931)	2
	124	Kuwada (1957, 1966)	2
	126–134	Chizaki (1934)	2
	130	Skovsted (1935); Joshi & Hardas (1953); Gadwal In: Joshi & Hardas (1976); Gadwal *et al.* (1968); Joshi *et al.* (1974); Singh & Bhatnagar (1975)	2
	131–143	Siemonsma (1982a, 1982b)	2
	132	Medwedewa (1936); Roy & Jha (1958)	2
	± 132	Ford (1938)	2
	144	Datta & Naug (1968)	2
A. manihot			
subsp. *manihot*	60	Teshima (1933); Chizaki (1934)	1
	66	Skovsted (1935); Kamalova (1977)	1
	68	Kuwada (1957, 1974)	1
subsp. *tetraphyllus*	130	Ugale *et al.* (1976)	2
var. *tetraphyllus*	138	Gadwal In: Joshi & Hardas (1976)	2
subsp. *tetraphyllus* var. *pungens*	138	Gadwal In: Joshi & Hardas (1976)	2
A. moschatus	72	Skovsted (1935); Gadwal *et al.* (1968); Joshi *et al.* (1974)	1
A. ficulneus	72	Kuwada (1966, 1974); Gadwal *et al.* (1968);	1
	78	Skovsted (1935); Joshi *et al.* (1974)	1
A. angulosus	56	Ford (1938)	1
A. tuberculatus	58	Joshi & Hardas (1953); Kuwada (1966, 1974); Gadwal *et al.* (1968); Joshi *et al.* (1974)	1
A. caillei (Ghana)	194	Singh & Bhatnagar (1975)	3
A. manihot var. *caillei* (Guinean)	185–199	Siemonsma (1982a, 1982b)	3

Ploidy level 1: 2n=56-72; Ploidy level 2n=108-144; Ploidy level 2n=185-199.
Source: Charrier, A., Genetic resources of the genus *Abelmoschus* Med. (Okra), IBPGR, Rome, 1984.

Crossability and pollen-pistil interactions

In *Abelmoschus*, though artificial crossing method is easy and simple to use but rate of success is still an important constrain in interspecific hybridization. Studies revealed that, it is more difficult to cross cultivated species with wild species of *Abelmoschus* and to this context several attempts have been made for interspecific hybridization between ploidy level 1, 2 and 3 species by various authors

(Joshi & Hardas, 1956; Kuwada, 1957, 1961; Hamon & Yapo, 1985).

The natural amphidiploids of *A. esculentus* and *A. manihot* have been reported by Siemonsmo (1982). However, artificial amphidiploids were also developed using wild species (Jambhale & Nerkar, 1981). Among the species, *A. moschatus* (Hamon & Yapo, 1985) and *A. manihot* subsp. *tetraphyllus* var. *pungens* (Patil *et al.*, 2013) found to be highly incompatible with *A. esculentus* whereas, *A. tetraphyllus*, *A. tuberculatus* and *A. caillei* produced viable hybrids with more or less extent of fertility (Singh & Bhatnagar, 1975; Joshi & Hardas, 1976; Siemonsmo, 1982a; Hamon & Yapo, 1986; Hamon, 1988).

Now it is well recognized that successful hybridization between cultivated and wild species of the same genus will be successful only if there is perfect co-ordination (compatibility) between gene complexes of pollen and the ovule parents (Kuboyama *et al.*, 1994). Regarding failure of fruit and seed set in interspecific hybridization of *Abelmoschus*, various reasons such as chromosomal differences, genomic differences, pre- and post-fertilization barriers may be attributable. By means of fluorescence microscopy, influence of pollen-pistil interaction on seed set were decisively studied by aniline blue method in various crops like sorghum (Hodnett *et al.*, 2005), cotton, sesame (Ganesh Ram *et al.*, 2006; 2007), *Vigna* (Krishnasamy, 2008) and *Cucumis* (Yuichi *et al.*, 2012).

However, in okra very few attempts have been made to detect the reasons for failure of seed set by means of pollen-pistil interactions (Abdullah *et al.*, 2000, Tyagi, 2002). For a better understanding of the incompatibility system existing in *Abelmoschus* further genetic analysis is needed, since the S-allele status and the genetic distance among the *Abelmoschus* species/cultivars is not yet known. Authors found that, pre-fertilization barriers have been significantly affecting the fruit and seed set in interspecific hybridization of *Abelmoschus* (Patil *et al*. 2013). For deployment of useful genes from wild germplasm to cultivar, study should be extended with respect to overcoming the hybridization barriers.

Economic importance

Nutritional profile of cultivated okra

To meet demand for nutritionally balanced foods for the increasing population, an alternative food diet must be implemented in a regular diet food. Over the years, several vegetables have been critically studied for their nutritional contents. Among them, okra has been found to be a potential alternative nutritional source which has a relatively good source of proteins, carbohydrates, dietary fibre, fat, mineral, ash and vitamin C (Al-Wandawi, 1983; Lamont, 1999; Owolarafe & Shotonde, 2004; Deters *et al.*, 2005; Gopalan *et al.*, 2007; Dilruba *et al.*, 2009), and plays a vital role in human diet (Lengsfeld *et al.*, 2004, 2007; Kahlon *et al.*, 2007; Moyin-Jesu, 2007; Wittschier *et al.*, 2007; Saifullah & Rabbani, 2009). The polyphenolic compounds also have been identified recently (Shui & Peng, 2004; Huang *et al.*, 2007; Arapitsas, 2008).

Okra is popular for its young, tender, juicy pods which can be consumed in different forms like boiled, fried or cooked (Ndunguru & Rajabu, 2004; Akintoye *et al.*, 2011). High protein source due to high lysine level in seeds make this crop as an alternative to soybean and therefore could be used as a supplement to cereal based diets (Al-Wandawi, 1983; Karakoltsidis & Constantinides, 1975). Also, okra seeds can be dried and used to prepare curds, slimy soups and sauces whereas ground and roasted seeds can be used as a substitute for coffee (Moekchantuk & Kumar, 2004). Recently, Liu *et al.* (2005) and Kumar *et al.* (2009) suggested that an alcohol extract of leaves can eliminate oxygen free radicals, alleviate renal tubular-interstitial diseases, reduce proteinuria, and also improve renal function.

Wild species: potential source of genes for agronomic traits

The prolonged controversies surrounding the release of GM crops make it difficult to develop new resistant varieties by advanced genetic engineering approaches. Therefore, deployment of useful alien genes from wild germplasm of *Abelmoschus* to existing varieties is the only way out possible by traditional breeding approaches. Hence, okra breeders have the primary objective of germplasm characterization, particularly identification of high yielding genotypes with resistance to yellow vein mosaic virus (YVMV), fruit borer, jassids and higher vitamin C in wild crop relatives (WCR) for the improvement of cultivated okra. Among the wild species, *A. angulosus* was identified as an YVMV and powdery mildew disease resistance

source (Samarajeewa & Rathnayaka, 2004). Other wild species like *A. manihot*, *A. manihot* subsp. *tetraphyllus* var. *pungens* and *A. crinitus* carry complete resistance to YVMV (Bisht & Bhat, 2006). A number of wild relatives of *Abelmoschus* have been identified as potential source of resistance for jassids and white flies, *Fusarium* wilt, *Alternaria* blight, powdery mildew and YVMV as well as abiotic stresses (Sandhu *et al*., 1974; Arumugam *et al*., 1975; Dhankar *et al*., 2005).

Other uses

Akinyele and Temikotan (2007) pointed out that okra mucilage is suitable for glace paper production and also has a confectionery use. In medical application, okra has been found as a good component for plasma replacement or blood volume expander (Savello *et al*., 1980, Markose & Peter, 1990; Lengsfeld *et al*., 2004; Adetuyi *et al*., 2008; Kumar *et al*., 2010). Among the wild species of *Abelmoschus*, *A. manihot* types (*Aibika*) has been reported as medicine for the control of fertility, childbirth and also act as a stimulator in milk production for lactating mothers (Powell, 1976; Perry, 1980; Bourdy & Walter, 1992; Salomon-Nekiriai, 1995). Root derivative of *A. manihot*, mucin a deflocculating agent is used in the manufacturing of hand-made paper (Ishikawa *et al*., 1980; Sang Gon Kim *et al*., 1993). *Abelmoschus moschatus* subsp. *moschatus*, is grown primarily for its scented seed oil, ambrette, which is used in perfume industry (Borssum Waalkes, 1966). Along with the vegetable use of West African Okra (*A. caillei*), it is also used for medicine, myth/religion, soil fertility indicator and fuel purpose by tribal peoples of Nigeria (Osawaru & Dania-Ogbe, 2010).

A novel type-1 ribosome-inactivating protein (RIPs), abelesculin, from the mature seeds has been recently identified which could be useful in pharmacological activities and clinical applications as immunotoxins, abortifacients and antiviral agent (Kondo & Yoshikawa, 2007). Most recently, Anwar *et al.* (2010) have reported that okra seed oil can be effectively utilized in biodiesel production.

Conclusion

Indian continent has been considered a center of diversity for *Abelmoschus*. A number of wild and semi-wild species of *Abelmoschus* are available in dense forests, open waste lands as well as homestead and backyard gardens without any commercial use and with least care. The confusion concerning *Abelmoschus* taxonomy is compounded by the lack of consistent criteria within current taxonomic treatments for species identification and differentiation, existence of many synonyms for a single species and unsolved problem of phylogeny. In addition to this, there is a need to address the conservation issues of *Abelmoschus* genetic resources to protect the existing genetic diversity that is of great relevance in okra breeding.

Though India is enjoying the status of one of the largest okra production countries in the world, several aspects still needs to be addressed. Some of the important aspects are described as follows:

1. Need for taxonomic revision in the context of defining species boundaries critically for genus *Abelmoschus* especially for those occurring in Indian agro-climatic region. Also a new standardized descriptor should be proposed.
2. Need to study the phylogenetic relationships not only for cultivated species (*A. esculentus* and *A. caillei*) but also for wild species with reference to the origin of cultivars.
3. Apart from the morphological characters, advanced molecular markers should be surveyed to estimate the genetic diversity and locus specific sequence data to be employed for species differentiation in *Abelmoschus*.
4. Crossability barriers existing in interspecific hybridization among *A. esculentus* and wild relatives needs to be fully studied.
5. In order to reduce the germplasm loss *ex-situ* and *in-situ* conservation of rare and endangered species should be urgently undertaken. For example, cryopreservation of seeds and pollen and *in vitro* storage of tissue.
6. Need to screen and identify the wild germplasm for polyphenolic compounds and other nutrient contents as well as for the presence of abelesculin protein.

Acknowledgements

This work was carried out with the funding from National Agriculture Innovation Project (NAIP) of Indian Council of Agriculture Research, Government of India. The facilitation of work by Director, NBPGR, New Delhi is acknowledged.

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Received: 19.10.2013
Revised and Accepted: 25.06.2015