

## Review

## Castor genetic resources: A primary gene pool for exploitation

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## ABSTRACT

Castor (*Ricinus communis* L.,  $2n = 2x = 20$ ) is grown across the world in tropical, sub-tropical and warm temperate regions. Castor oil has more than 700 industrial uses and its global demand is rising constantly at 3–5% per annum. Vast castor germplasm collections are being conserved in more than 50 genebanks across the world. But consolidated reports on their status and value are not available to tap their potential. Utilization of vast global germplasm could only be enhanced when the information on germplasm is shared and seed are exchanged. Therefore, the review provides information on current status of global castor collections and an overall view of potential of these collections besides highlighting the challenges and opportunities facing germplasm. This report serves as a unique starting point for the global castor community to build strong multinational collaborations to facilitate knowledge and resource integration and coordinated research planning.

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## 1. Introduction

Castor (*Ricinus communis* L.) is an important industrial oilseed crop. Its seed oil has multifarious applications in production of wide industrial products ranging from medicines to lower molecu-

lar weight aviation fuels, fuel additives, biopolymers and biodiesel (Caupin, 1997; Comar et al., 2004; Ogunniyi, 2006). Castor oil is the only vegetable oil that contains up to 85% of the unique hydroxy fatty acid, ricinoleic acid, which confers distinctive industrial properties to the oil. Castor grows as an indeterminate annual or perennial depending on climate and soil types in tropical, sub-tropical and warm temperate regions in the world. Castor is cultivated on commercial scale in an area of 1,525,000 ha in 30 countries with 1,581,000 MT seed production. India, China, Brazil,

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USSR, Thailand, Ethiopia and Philippines are the major castor growing countries in the world (Damodaram and Hegde, 2010). The imports and exports of castor oil from prominent countries in 2009 were estimated to be 268,500 tonnes and 289,500 tonnes, respectively ([www.oilworld.biz](http://www.oilworld.biz)). Demand for castor oil in the world is rising constantly at 3–5% per annum. Castor oil derivatives estimated potential to be more than US\$ 400 billions by 2012 (<http://www.castoroil.in/>). The major castor oil consuming countries are the European Union countries, USA and Japan. China and India are also emerging fast as major consumers. Most of the global castor is credited with 48% oil content out of which 42% could be extracted. Castor is an ideal candidate for bio-oil production with 500 to 1000 L ac<sup>-1</sup> (Auld et al., 2009). It is not a food crop and can be grown productively on underutilized marginal uplands. Castor will generate a positive energy balance producing 4–8 Calories in liquid fuel per Calorie invested in production and processing (Bilbro, 2007). Several high yielding varieties and hybrids were evolved in the last four decades. However, to meet the tremendous global demand for castor oil, cultivars with further enhanced yield and oil percentage, disease and insect resistance and drought tolerance are needed.

Germplasm is the basic gene pool to search for useful genes and genotypes needed for achieving desirable genetic improvement. Castor germplasm collections are extensive and conserved globally in more than 50 institutes/organizations. But consolidated reports on their status and value are not available to tap their potential. Utilization of vast global germplasm could only be enhanced when the information on germplasm is shared and seed are exchanged. In this report, an attempt was made to appraise the current status of global castor germplasm collections. The extent of diversity in castor gene pool, sources of resistance to various biotic and abiotic stresses, *ex situ* conservation and utilization of germplasm for castor improvement were highlighted in this report.

## 2. Origin and history of castor

Castor is a cross-pollinated diploid ( $2n = 2x = 20$ ) species belonging to the family Euphorbiaceae and genus *Ricinus*. Linnaeus identified the genus *Ricinus* in 1753. *R. communis* is monophyletic (Webster, 1994). The earlier taxonomists (Popova, 1930; Hilderbrandt, 1935; Moshkin, 1986) divided the genus *Ricinus* into several species and subspecies. There were around 91 species, subspecies and varieties in this genus. It is now believed that all these species and subspecies are synonymous to *R. communis*. It is untenable to consider them as separate species as they are all intercrossable and produce fertile intermediates, and there is lack of discretion of species based on morphological characteristics, geographical demarcation and chromosome number. The variability exists among earlier described species does not exceed the overall characteristics of *R. communis*. There are varied opinions about the site of origin of castor. Castor is believed to have four centres of origin, namely (i) Ethiopian–East African region, (ii) Northwest and Southwest Asia and Arabian Peninsula, (iii) Sub continents of India, and (iv) China. Ethiopian–East African region is considered to be the most probable site of origin because of presence of high diversity in Ethiopia (Moshkin, 1986; Carter and Smith, 1987). These centres are also considered to be the first places of castor introduction into cultivation.

Castor spread and history were dealt at length by Moshkin (1986). Castor seed were found in Egyptian tombs dating back to 4000 BC. The ancient people collected wild castor mainly for its medicinal use. The Ebers Papyrus, an ancient Egyptian medical treatise believed to date from 1552 BC, translated by George Ebers in 1872, described castor oil as a purgative. Herodotus in 500 BC reported that Egyptians used castor oil for purging

purpose. Arabs introduced productive type large seeded castor to Africa and Southeast Asia in the Middle Age. Europeans introduced castor as a plantation crop in islands of Caribbean Sea and American continent. Early-growing castor from Iran was introduced in Central Asia in 1921. Seed from wild castor plants were known to be gathered in Madagascar for cultivation. Castor was introduced in Brazil during the Portuguese colonization; it has since naturalized from Amazonas to Rio Grande do Sul (Costa et al., 2006). Iraq, Iran, Syria, Turkey and Armenia are considered to be areas of origin of castor in the West Asian region. In prehistoric times small seeded, indeterminate forms with dehiscent capsules were collected from arid climatic areas in territories of ancient Mesopotamia and Persia. Arabs did semi-nomadic cultivation of productive type wild forms with large seed, indehiscent capsules and dry or heat resistance (Moshkin, 1986). Wild castor was known to be cultivated during ancient periods in Gangetic Plains and South Arabia. There is no temporal gap between uncultivated and cultivated castor. Wild castor cultivated during ancient times was gradually transitioned into cultivated form initially through conscious selection for desirable types possessing traits like non-shattering, early maturity, bold seed, high oil content and tolerance to frost and drought. Breeding efforts further increased seed yield, oil content and resistance to diseases in castor.

### 2.1. Autopolyploid origin of castor

All natural types of castor are diploid ( $2n = 2x = 20$ ) (Hagerup, 1932). Based on secondary bivalent association, castor was reported to be a secondary balanced polyploid with a basic chromosome number ( $x$ ) 5 (Richharia, 1937; Kurita, 1946; Jacob, 1957). Ten pachytene bivalents were clearly distinguished morphologically in diploid castor (Jacob, 1956; Paris et al., 1978). Recently, castor karyogram of 10 pairs of mitotic chromosomes stained with fluorochromes CMA/DAPI was illustrated (Vasconcelos et al., 2010). Origin of castor with 20 chromosomes from a progenitor with 10 chromosomes was established through meiotic analysis of a spontaneously occurred haploid plant (Narain and Singh, 1968). Haploid meiotic study had clearly showed preponderance of nuclei with 10 rod-shaped univalents and occasional occurrence of five bivalents at both diakinesis and metaphase I, and five groups each with S-S chromosome pairing. The pairing capacity within the group was ascribed to residual homologies in some segments of the 10 chromosomes. This meiotic phenomenon of haploid confirmed that castor ( $2n = 2x = 20$ ) had arisen through the doubling of a diploid progenitor with  $2n = 10$ , which is now nonexistent. It was also attributed that the regular bivalents formation in castor was due to the high differentiation and diversification taken place in chromosome segments in the course of its evolution. And the traces of genetic homologies still left in some segments of the chromosomes in a single complement, elucidated the past history and contemporary status of the species (Narain and Singh, 1968).

## 3. World collections

Although castor collections date to many centuries ago, recorded history of castor collection and distribution can be traced to early taxonomists and botanists from former USSR between 1773 and 1976. All-Russia Research Institute of Oil Crops (VNI-IMK), N.I. Vavilov Institute of Plant Industry (VIR) and Botanical Institute of the Academy of Science of the USSR (BIN) are the oldest institutes which began collecting castor genetic resources in 19th century. Several global specimen collections maintained at these institutes were used to classify castor based on morphological and eco-geographical diversity. VNIIMK and VIR introduced several samples of world collection during 1952 and 1976 to study

**Table 1**  
Major castor germplasm collections in the world as of 2011.

Genebank	Number of accessions reported
National Bureau of Plant Genetic Resources (NBPGR), India	4307
Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences (ICGR-CAAS), China	2111
United States Department of Agriculture-Agricultural Research Service, USA	1390
Centro Nacional de Pesquisa de Algodão (CNPQ), Brazil	1000
Vavilov Institute of Plant Industry (VIR), Russia	696
Institute of Biodiversity Conservation (IBC), Ethiopia	510
Others (52 institutes)	8699

intraspecific variability of castor as well to review all previous classifications. At BIN and VIR more than 400 samples of castor were introduced from all continents and regions of castor cultivation. The collections of VIR were significantly added to by the expeditions of N.I. Vavilov and other associates of VIR (Moshkin, 1986).

There are no consolidated reports describing the exact status of castor germplasm collections conserved in the world. The FAO's Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture ([www.fao.org/docrep/013/j500e](http://www.fao.org/docrep/013/j500e)) states that 17,995 castor germplasm accessions are being held with various institutes in the world (Table 1). However, these collections may include several duplicates; therefore, determining the number of unique accessions worldwide is a difficult task. As per the Bioversity International Directory, 6588 castor germplasm collections are being conserved in different genebanks in the world (Auld et al., 2009).

There are very few reports on collections from Centres of Origin of castor. *Ex situ* collection of castor from Ethiopia is low in number despite prevalence of wide-spread natural diversity in wild and solitary condition in semi-desert, desert and high land areas, farmers' backyards, around town dwellings and many other areas (Seeger, 1983). China, which is believed to be an independent centre of origin of castor, holds the second highest collection in the world and about 32% of its collection is from the Inner Mongolian region in the northeastern China (Cao et al., 1997). Currently, around 1689 castor accessions are reported to be available with the Institute of Crop Science and 1652 accessions with the Institute of Oil Crops Research (Auld et al., 2009) apart from 630 accessions housed at Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences (ICGR-CAAS) (FAO, 2009).

India is also an independent Centre of Origin of castor where tremendous natural diversity is widespread. Semi-wild and wild perennial forms are found growing in diverse habitats like forests, settled sand dunes, sea coast, river beds, open-cast coal mines, hill tops, mountain-valleys, roadsides, field bunds, railway tracks, garbage dumps, wastelands, backyards and many other areas across the country. India currently holds 4373 castor accessions, of which 3416 accessions are being maintained by Directorate of Oilseeds Research (DOR), Hyderabad and 957 are being conserved by National Bureau of Plant Genetic Resources (NBPGR), New Delhi (Anjani and Hegde, 2007). The collection at DOR comprises 3051 indigenous and 365 exotic accessions introduced from 39 countries. Indian collection was augmented mainly through conduction of systematic germplasm explorations in various provinces namely, Bihar (Anjani et al., 1993), Assam, Meghalaya, Manipur, Mizoram and Nagaland (Anjani et al., 1994), Eastern Uttar Pradesh and Bundelakhanda zone of Uttar Pradesh and Madhya Pradesh (Duhoon et al., 1996), Haryana, Punjab, Himachal Pradesh and Jammu and



**Fig. 1.** Castor growing near sea shore (0' above mean sea level) in Middle Andaman Island, India.

Kashmir (Anjani et al., 1999), West Bengal, Maharashtra, Gujarat, Tamil Nadu, Kerala (Ashoka Vardhana Reddy et al., 2002) and Andhra Pradesh (Sunil et al., 2007), and Andaman and Nicobar Islands (Anjani, 2001) covering arid south-west coastal, humid tropical east coastal, north-eastern, Himalayan, north-west plains, sub-tropical central Indian and south-east regions. Castor is found growing at wide altitudes ranging from the sea level in Andaman and Nicobar Islands (Fig. 1) to more than 2000' above mean sea level in Kashmir Valley. Castor plants in Kashmir Valley shatter seeds before dying in peak winter in December month and the seeds germinate when temperature rises above 15 °C.

The wild and semi-wild forms found in Bihar, Uttar Pradesh and Madhya Pradesh were mostly of tall (>14 ft.) and woody perennial type with big leaves (50–70 cm diameter). The rural folks in these states use the woody types for firewood, house roofing and building huts. The big leaf types are grown as shade plants to protect tomato (*Lycopersicon esculentum*) and chilli (*Capsicum annuum*) crops from frost. Castor landraces are being maintained by rural poor in Bihar, Uttar Pradesh and Tamil Nadu States to get assured income during deficit monsoon years. Landrace are mostly very tall, woody and late flowering types. Landraces from Bihar mostly bear a single raceme on the main stem. The racemes are very long (80–100 cm), compact and productive. Racemes are mostly triangular in shape; capsules and seeds are mostly of bold type (Anjani and Hegde, 2007). In Tamil Nadu, tall and woody landraces are grown on field bunds of sugarcane (*Saccharum officinarum*), cotton (*Gossypium* spp.) and groundnut (*Arachis hypogaea*) crops, and the short bushy landraces are grown as a mixed crop with tapioca (*Manihot esculenta*) (Anjani and Hegde, 2007). The local name for castor in northeast India is 'Eri'. Eri-silk (*Samia ricini* Donovan) industry is an economically sustainable subsidiary occupation in rural areas in northeastern India. Leaves from the naturally growing wild and semi-wild castor plants are used to feed eri-silk worms. Eri-pupa is a favoured delicious dish in northeastern India and valued at par with meat and chicken (Saratchandra, 2010). Selling of pupae in local markets adds additional income to the rural economy.

#### 4. Diversity in castor germplasm

Uncultivated wild and semi-wild castor plants are widespread not only in its Centres of Origin, but also outside. They represent the tremendous variability existing in the species. Castor had been adapted to diverse ecological niches. Therefore, ecological heterogeneity, stresses, natural selection and its interaction with other evolutionary forces including mutation, migration and genetic drift

might have contributed greatly to genetic diversity according to circumstances in the natural niches. Studies on genetic diversity are necessary to elucidate and categorize the naturally existing variability. Genetic diversity in castor was assessed mostly by using agro-morphological traits and to some extent by molecular techniques. The vast worldwide castor collections reported were poorly studied and barely tapped for castor genetic improvement.

#### 4.1. Diversity for morphological traits

There are a very few documented evidences describing morphological diversity in castor. Earlier taxonomists and botanists studied morphological diversity with the purpose of classifying the genus *Ricinus*. Moshkin (1986) reported existence of diverse morphological variants in many parts of the world for plant height, branching, stem colour, leaf size, waxy coating, length, shape and compactness of raceme, pedicle length, size and shape of capsule and seed. Woodend (1993) described white, black and dark brown seed with varying mottling intensity, dark green and dark red colour stem, prostrate to columnar growth habit, weak-framed, robust and tree-like plant types among Zimbabwe collections.

Indian germplasm collection holds great morphological diversity. Most of the morphological variants observed in other Centres of Origin and tropical and sub-tropical countries are present in India. Twenty-four morphological descriptors were developed to characterize each germplasm accession. The most frequent morphological traits in native Indian collection are medium tall, red and green coloured woody stem, low to high number of nodes on main stem, divergent branching, waxy coating on stem, medium and semi-cup shaped leaves, medium long, loose, conical shaped racemes, medium sized, non-dehiscent, green, spiny capsules, and medium sized, oval shaped, brown coloured seeds with conspicuous mottling on seed coat and caruncle (Anjani, 2000).

Some distinct and rare morphotypes were identified in Indian collection. Purple colour morphotype (Fig. 2) collected from Assam and Manipur States in India is a distinct localized morphotype in which the entire plant including stem, leaves, peduncle, pedicle and capsules are dark purple in colour (Anjani, 2005a). Maternal inheritance of this phenotype was observed in a cross between purple and green colour morphotypes (Anjani et al., 2007). Papaya leaf type (Fig. 3), in which leaves are deeply dissected with serrated margins like those of papaya (*Carica papaya*) plant, is another rare distinct morphotype present among exotic collections in Indian repository. In addition, distinct variants for capsule colour (Fig. 4) and seed colour, shape and size (Fig. 5) were found in Indian collection (Anjani and Hegde, 2007; Suryanarayana and Anjani, 2009). Great variation for stem colour, internode nature, leaf size and shape,



Fig. 2. Purple colour morphotype in castor germplasm.



Fig. 3. Castor germplasm accession having papaya leaf type leaves.

raceme compactness (Fig. 6) and capsule shattering nature (Fig. 7) was also reported in Indian collection (Anjani, 1995; Anjani and Ashoka Vardhana Reddy, 2002). Geographical demarcation of morphological diversity was not observed in Indian collection, except the purple colour morphotype, all other types were found to be growing across the country.



Fig. 4. Variation in capsule colour in castor germplasm.



Fig. 5. Variation in seed colour, size and shape in castor germplasm.

#### 4.2. Variation in sex tendency

Castor inflorescence is monoecious monoecious raceme bearing female flowers near the apex and male flowers proximally. Great variation exists in proportion of male to female flowers on a raceme. The proportion of female flowers in the racemes of a given plant is a measure of female tendency and that of male flowers is a measure of male tendency. There are several sex variants (Joshi, 1926; Shifriss, 1956, 1957; Kulkarni and Ankineedu, 1966; Gopani et al., 1969) such as plants having racemes with only pistillate flowers, with only male flowers and with various proportions of pistillate and staminate flowers interspersed along the entire length of raceme (Fig. 8). Occasionally, castor inflorescence terminates with a hermaphrodite flower which invariably drops off before capsule setting. Jacob (1963) reported frequent occurrence of terminal hermaphrodite flowers in the variety, Adamdam.

Roxburgh (1874) first discovered a female wild castor plant. A study of sex variation by Shifriss (1960) revealed existence of recessive and dominant female mutants. Dominant female mutants are spontaneous and genetically unstable. Such female plants produce female racemes at first, but later revert to production of monoecious racemes having both male and female flowers. Spontaneous occurrence of unstable pistillate mutants ranging in frequency from 1:375 to 1:16400 in different castor populations was reported (Shifriss, 1957). Femaleness transmits higher to progeny through female inflorescences of sex reversal castor plants, than through reverted monoclinal monoecious inflorescences of the same plant (Jacob and Atsmon, 1965). Brigham (1967) reported a single recessive gene control of female sterility in castor. A colchicine derived trisomic plant from the variety Adamdam produced only male flowers (Jacob, 1963). Genetic mechanism governing interspersed sexuality was not well understood as the differentiation of interspersed staminate flowers is quantitative in nature and is greatly influenced by nongenetic variations. George and Shifriss (1967) reported that the combined action of two independent genes,  $id_1$ , and  $id_2$  in some genetic backgrounds resulted in a high level of expressivity of interspersed staminate flowers under a wide range of environmental conditions. The level of expressivity of interspersed staminate flowers appeared to be dependant upon dosage of these genes. In addition to these genes, there also exist some other genes for interspersed staminate flowers whose expression is particularly sensitive to environmental fluctuation. Zimmerman and Smith (1966) postulated polygenic inheritance of environmentally sensitive interspersed staminate flowers.

Nebraska 145-4 was one of the earliest reported stable pistillate lines in castor. The expression of pistillate character in this line is controlled by one major recessive gene and appeared to be influenced by modifying factors and environmental conditions (Claassen and Hoffman, 1950). At VNIIMK, female plants were discovered in a collection Crimea K-57. A non-reverted female mutant 'Queen 162' was discovered in a large population. An early-reverted female mutant 'Adom Mistaef' was discovered in an open-pollinated Israeli variety selected from a wild castor (Shifriss,



Fig. 6. Variation in compactness of capsules on raceme in castor germplasm: (a) very loose; (b) loose; (c) compact.

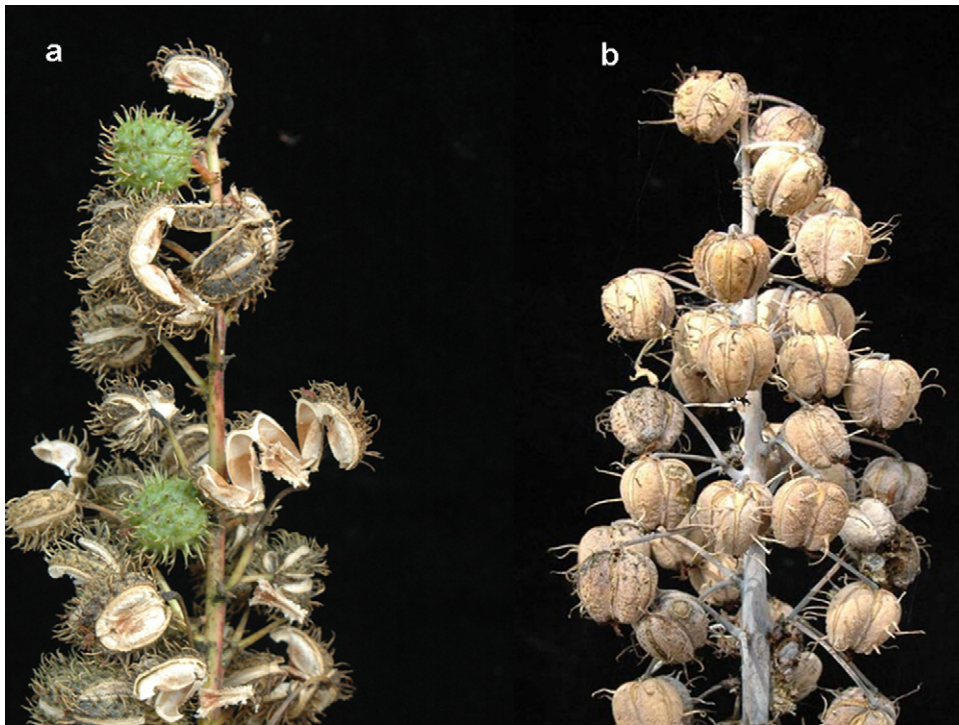


Fig. 7. Dehiscent (a) and non-dehiscent (b) capsules in castor germplasm.

1960). A stable pistillate line TSP-10R was released in USA in 1962.

#### 4.3. Diversity for agronomic and economic traits

There is very little published information on potentiality of world *ex situ* castor collections for agronomic and economic traits.

Woodend (1993) observed considerable diversity for days to flowering (64–105), days to maturity (130–200), number of nodes on main stem (10–23), plant height (1.9–3.8 m), number of racemes per plant (10–48), number of capsules on primary raceme (48–142) and seed yield per plant (0.54–1.82 kg) in 83 wild collections of Zimbabwe. Some of these wild types exhibited high yielding ability under low rainfall conditions. A survey of 1033 castor germplasm

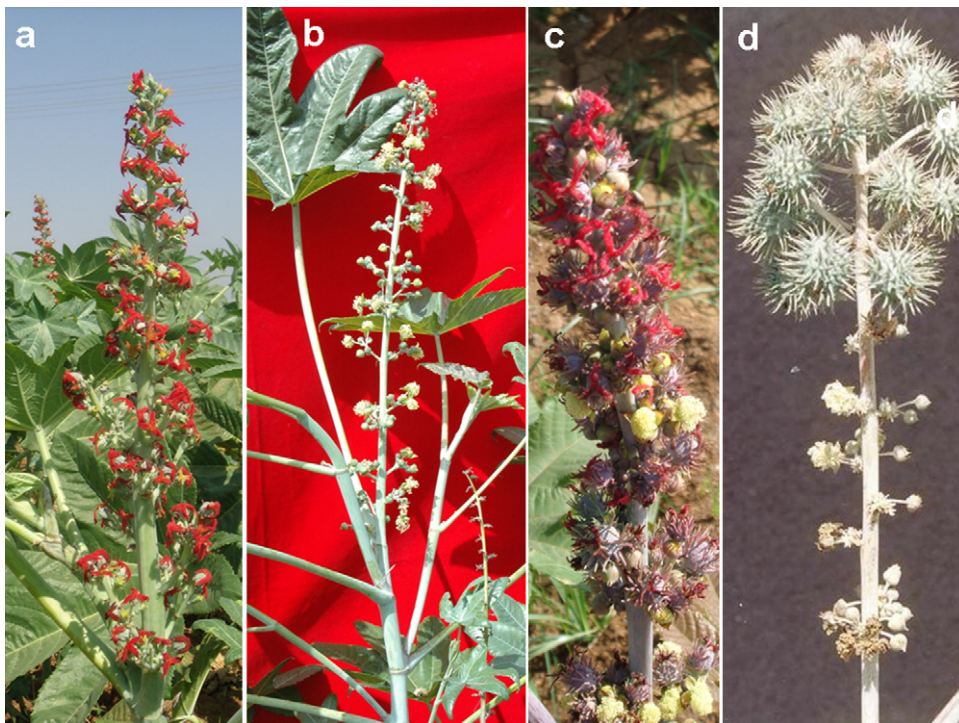


Fig. 8. Sex variants in castor germplasm: (a) raceme with only pistillate flowers; (b) raceme with only male flowers; (c) raceme with interspersed staminate flowers along the axis; (d) Raceme with male and female flowers in near equal proportion.

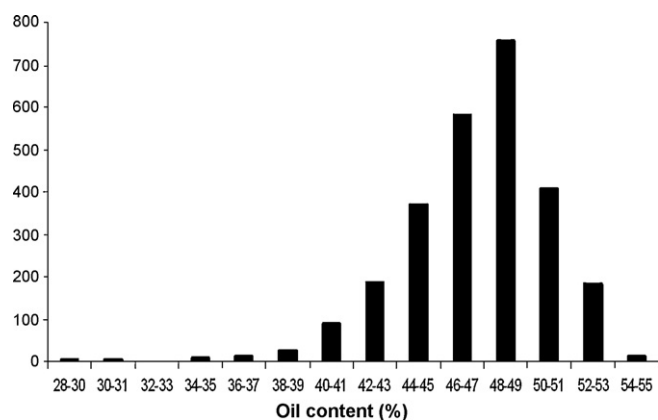


Fig. 9. Diversity for oil content in Indian castor collection.

accessions in the USDA revealed great diversity for 100-seed weight ranging from 10.1 to 73.3 g with an average of 28.3 g (Wang et al., 2010). Bhardwaj et al. (1996) also reported considerable variability for 100-seed weight (18.7–43.8 g) among 72 global collections received from USDA.

Indian collections were evaluated for various agronomic, economic and quality traits at different locations and years under All India Coordinated Research Project on Castor. Great diversity for these traits was observed in Indian collections. About 878 accessions were identified among Indian collections for desirable traits like dwarf plant type (<100 cm), very low number of nodes on main stem (4–7), extra-early flowering (26–29 days), early (<120 days) and medium (120–140 days) maturity, long primary raceme (80–100 cm), high number of productive racemes per plant (50–60), very heavy seed (70–80 g/100 seed), high oil content (54–55%), low (50%) and high ricinoleic acid (90%) contents and high seed yield at multiple harvests (Anjani and Hegde, 2007). Extra-early accessions that mature in less than 90 days were selected from heterogeneous populations of exotic collections introduced from the former USSR, USA and Hungary (Anjani, 2010a). These are of great value to breed extra-early castor cultivars as well to identify genes responsible for extra-earliness. An extra-early castor gene pool was also developed in India through random matting among extra-early accessions for six cycles (Anjani and Ashoka Vardhana Reddy, 2003).

#### 4.4. Diversity for oil content and quality

Castor oil is identified as a potential feed-stock for biofuel production because of its proven technical and ecological benefits and guaranteed sale (Conceicao et al., 2007). Oil content ranging from 42 to 58% was reported by Popova (1926) in a series of old castor collections. Da Silva Ramos et al. (1984) observed wide variability for seed oil content ranging from 39.6 to 59.5% among 36 castor collections from Brazil. Bhardwaj et al. (1996) reported 22–44% oil content in 72 USDA castor accessions collected from 15 countries. Rojas-Barros et al. (2004) reported 44.8–56.5% oil content among 191 USDA castor germplasm collections. Oil content ranging from 36.6 to 53.8% was observed in six Nigerian collections (Okoh et al., 2003). Indian germplasm collection at DOR exhibited 28–55% oil content (Fig. 9). Verma et al. (2007) reported 46–56% oil content in 30 Indian castor genotypes using Soxhlet extraction method.

Approximately 85% of total lipids found within a castor seed is ricinoleic acid which distinguishes castor oil from other seed oils. Accessions with 50–90% ricinoleic acid content are available in Indian castor gene pool. The accessions collected from Andaman and Nicobar Islands, India are distinctive from mainland castor with respect to fatty acid composition. The mean ricinoleic acid content

in this collection is 69% with maximum of 81% and minimum of 50% whereas it is between 82 and 90% in the mainland castor accessions. Bhardwaj et al. (1996) observed 58.5–92.3% ricinoleic acid in 72 USDA castor accessions. Rojas-Barros et al. (2004) reported 9.9–88.6% ricinoleic and 1.7–83.2% oleic content in various seeds of an Indian accession PI 179729.

Castor meal is unsuitable to feed animals because of presence of two toxic endosperm proteins viz., ricin and *Ricinus communis* agglutinin (RCA). A major application of ricin, currently being explored, is in the construction of immunotoxins. Cost of usage of ricin in clinical trials is very high because of low ricin productivity and difficulty in purification. Castor genotypes with high ricin concentration would be advantageous to produce high quantity of ricin for pharmaceutical industry. Ricin has the potential to be used as a poisonous biological warfare and bioterrorism agent, which has limited domestic castor production in the USA. Development of non-toxic castor cultivars with extremely reduced levels of ricin would eliminate the dangers and improve the economics of castor oil production. Ricin content ranging from 2.9 to 10.8 mg/g of meal was estimated among 51 USDA castor accessions (Bhardwaj et al., 1996). Pinkerton (1997) reported remarkable diversity for ricin + RCA<sub>120</sub> concentration ranging from 1.9 to 16 mg/g among 263 accessions received from USDA. Very low concentrations of ricin + RCA<sub>120</sub> were estimated in two former USSR introductions viz., PI 257654 (1.5 mg/g) and PI 250623 (1.8 mg/g) and in an Iranian introduction PI 222829 (1.9 mg/g). The 5 USDA collections (PI 182987, PI 257657, PI 258368, PI 267802, PI 486318), which were introduced from India, Soviet Union, Brazil and Peru, respectively, contained 2.4–3.9 mg/g of these two toxins (Pinkerton, 1997; Pinkerton et al., 1999; Auld et al., 2001). TTU-LRC, an open-pollinated germplasm population of castor having very low concentration of ricin + RCA<sub>120</sub> (1.86 mg/g) was developed at Texas Tech University, Texas. Seed of TTU-LRC can be obtained directly from the Plant Genetic Resources Conservation Unit in Griffin, GA as PI 631156 (Auld et al., 2003).

#### 4.5. Molecular diversity

Castor has the lowest DNA C-value known among the Euphorbiaceae species (2C = 0.46 pg) (<http://data.keew.org/cvalues>) and has moderate size genome with ~350 Mbp (Armuganathan and Earle, 1991). Cultivar, Hale, was used to sequence castor genome (Chan et al., 2010). Genetic polymorphism in ricin gene family, oil metabolism genes and disease resistant genes was analysed using the draft genome. Twenty-eight putative genes for ricin family, 71 genes involved in biosynthesis of fatty acids and triacylglycerols, mainly ricinoleic acid and 121 predicted proteins involved in disease resistance were identified. A preliminary sequencing of preproricin genes in 63 plants of USDA worldwide castor collection showed presence of a large number of nucleotide polymorphisms (Connell and Skowronski, 2006). Molecular markers such as RAPD, AFLP, ISSR and SNP were successfully used to characterize genetic variability among castor germplasm collections. The molecular diversity investigations conducted by Bajay (2010), Gajera et al. (2010) and Zheng et al. (2010) using SSR, RAPD, ISSR and SRAP markers showed existence of large genetic variation in castor germplasm collections. Allan et al. (2008) reported low genetic diversity using AFLP and SSR markers among 41 accessions from USDA. These accessions representing five continents and 35 countries were not geographically structured. It was suggested that the low genetic diversity might be due to one or more factors like sampling strategy that could not capture the full extent of genetic variation in the species, artificial variation due to long-term storage and seed regeneration and intense selection followed by domestication of a limited number of castor genotypes, which are widely propagated for agro-economic and horticultural traits. Foster et al.



**Fig. 10.** Wilt (*Fusarium oxysporum* f.sp. *ricini*) resistant (R) and susceptible (S) castor germplasm accessions planted in a plot heavily infested with wilt.

(2010) also reported low genome-wide SNP variation in 152 USDA global accessions possessing phenotypic variation including dwarf, large leaf, dark green to crimson leaf colour, small to large seed, brown, tan and reddish-brown coloured seed, early to late maturity and racemes of various sizes. Geographic structure was not observed in these collections despite coverage of substantially more genome by the SNP data than AFLPs and SSRs. It was argued that the multiple sources of introductions to individual countries were the most plausible reason for the non-geographic structuring of worldwide germplasm. However, the sampling strategies implemented and the less genome coverage by molecular primers seem to be the most probable factors for low diversity estimations. These studies are fragmentary and unsystematic, cannot be readily combined to provide a comprehensive view of genetic diversity present in *Ricinus*. Comprehensive and systematic investigations involving large collections, representing genome-phenome diversity under diverse ecological niches are needed to have a credible picture of diversity.

## 5. Sources of resistance to biotic and abiotic stresses

### 5.1. Sources of resistance to diseases and reniform nematode

Castor is susceptible to a large number of diseases (Brigham, 1961; Raof and Nageshwar Rao, 1999). High susceptibility to high resistance reaction against the major diseases such as wilt (*Fusarium oxysporum* f.sp. *ricini*), root rot (*Macrophomina phaseolina* (Tassi) Gold) and grey mold (*Botrytis ricini* Godfrey) was observed in castor collections. Evaluation of large collections at the VNIIMK proved inherited characteristic of resistance to wilt in castor. The first reported wilt resistant genotypes viz., Kitaiskii, Sangvineus, Gibridnyi, VNIIMK 18, VNIIMK 165 and Sizaya 7 were from VNIIMK and VIR (Podukuichenko, 1977, 1991; Moshkin, 1986). In India, several sources of stable resistance to *Fusarium* wilt (Fig. 10) were identified based on multi-year, multi-location screening in wilt sick plots under high disease pressure (Anjani et al., 2004, 2010a; Anjani and Raof, 2005). Anjani (2010b) showed wide genetic diversity based on agro-economic traits among wilt resistant accessions.

The castor varieties Dawn, Hale and Lynn developed by USDA and Texas Agricultural Experimental Station showed field resistance to *Verticillium* wilt, *Alternaria* leaf spot and tolerance to bacterial leaf spot (*Xanthomonas axonopodis* pv. *ricinicola*) (Brigham, 1970a,b,c). Grezes-Besset et al. (1996) characterized field resistance to root rot caused by *Macrophomina phaseolina* (Tassi)



**Fig. 11.** Root rot (*Macrophomina phaseolina*) resistant (R) and susceptible (S) castor germplasm accessions planted in a plot heavily infested with root rot.

Gold in castor collected from Medagaskar. In India, nine accessions collected from Andaman and Nicobar Islands and Tamil Nadu State exhibited high resistance to root rot (Fig. 11) in root rot (*Macrophomina phaseolina* (Tassi) Gold) sick plot (Anjani et al., 2004; Anjani, 2005d, 2006).

There are a very few studies on castor resistance to grey mold caused by *Botrytis ricini* (Godfrey). Thomas and Orellana (1963) suggested that resistance to grey mold in castor might be due to inactivation of pectic, cellulolytic, and other hydrolytic enzymes by oxidation products of phenolic compounds. Batista et al. (1998) identified four resistant accessions by counting the total number of racemes and number of disease infected racemes under natural infestation. Two Brazilian genotypes (CNPAM-93-168, CNPAM-89-34) exhibited moderate resistance under artificial inoculation condition (Costa et al., 2004). Milani et al. (2005) identified six grey mold resistant Brazilian castor genotypes (MPAI T63/6, Cinnamon Juriti, Sipeal 28, 2004 Sipeal, CNPA SM1, Ox Blood) based on screening under natural infestation. In India, Anjani and Raof (2010) identified five grey mold resistant indigenous accessions (RG 2787, RG 2836, RG 2980, RG 3126, RG 3139) based on screening under artificial epiphytotic conditions in glasshouse and field in three to six contiguous years. Accessions possessing multiple resistance to *Fusarium* wilt and root rot (Anjani, 2006), wilt, root rot, reniform nematode (*Rotylenchulus reniformis*) and grey mold (Anjani and Raof, 2009), wilt and leafminer (Anjani, 2005a), and wilt, nematode and leafhopper are also present among Indian collections. Rust (*Melampsora ricini*), *Alternaria* leaf spot (*Alternaria ricini*) and bacterial leaf spot (*Xanthomonas axonopodis* pv. *ricinicola*) are minor diseases of castor. Stable sources of resistance to these diseases are not reported so far (Chauhan and Swarup, 1984; Kishun et al., 1980).

Reniform nematode (*Rotylenchulus reniformis*) reduces plant growth and predisposes *Fusarium* wilt infection in castor (Patel et al., 2000). Based on multiyear confirmation testing under artificial inoculation condition in pots, 16 Indian castor collections (RG 43, RG109, RG 297, RG 1350, RG 1354, RG2271, RG 2582, RG 2694, RG 2723, RG 2725, RG 2728, RG 2730, RG 2767, RG 2787, RG 2800, RG 2837) were identified as sources of resistance to reniform nematode. Of these, three accessions (RG 109, RG 297, RG 2800) were found to be resistant to both nematode and wilt.

### 5.2. Sources of resistance to insect pests

Castor is a host to more than 100 species of insects and is used as an insect trap plant in several crops. Sources of



resistance to some of the insect pests are available in castor gene pool. Jayaraj (1966, 1967) identified RC1098 Baker, RC1094, RC 1092 Italy and RC1096 Cimmerron Coonoor as resistant sources and C3 Pakistan as a tolerant source against leafhopper (*Empoasca flavescens*). No-bloom and single-bloom types are reported to be less resistant to leafhopper than double and triple-bloom types in castor (Jayaraj, 1968; Srinivas Rao et al., 2000; Vijaya Lakshmi et al., 2005). Seventeen Indian collections were identified as stable sources of resistance against leafhopper (Lakshminarayana, 2003; Lakshminarayana and Anjani, 2009). The Indian accession RG 43 is multiple resistant to leafhopper, wilt and nematode. Whitefly, *Trialeurodes ricini* (Homoptera: Aleyrodidae) is another serious sucking pest in castor. An exotic accession EC 103745 was reported to be resistant to whitefly (Ramanathan, 2004). Forty three Indian accessions were identified as possible sources of resistance to whitefly (Lakshminarayana, 2003; Anjani and Jain, 2004).

Tobacco caterpillar (*Spodoptera litura* Fabr.) and semilooper (*Achoea janta* L.) are the most destructive defoliators in castor. Indian castor collections exhibited varying reaction against *Spodoptera* and semilooper when screened over years under natural infestation in hot-spot areas in multilocation trials of All India Coordinated Research Project (AICRP) on Castor. Thanki et al. (2001) observed moderate resistance to *Spodoptera* in an Indian castor cultivar CO-1. Five accessions (RG 5, RG 33, RG 221, RG 224, RG 449) were reported to be tolerant to semilooper based on screening under natural infestation in hot-spot areas. However, their true tolerance needs to be confirmed further. Capsule borer, *Conogathes (Dichocrocis) punctiferalis* Guen. (Pyralidae: Lepidoptera), is another serious pest of castor (*R. communis* L.). Yield loss to the tune of 53% in castor sole crop and 35–53% when castor was intercropped with green gram (*Vigna radiata*), sesame (*Sesamum indicum*), moth bean (*Vigna aconitifolia*) and cowpea (*Vigna unguiculata*) was reported (Patel and Patel, 2009). Chemical control of the pest is not effective as the larvae after hatching bore into capsules and pupate there. Breeding for capsule borer resistance is an effective means to manage the pest. Indian collections were screened against capsule borer under caged conditions. Five accessions (RG 1934, RG 2546, RG 2770, RG 2543, RG 2786) were identified as confirmed sources of resistance to capsule borer (Lakshminarayana, 2003; Lakshminarayana and Anjani, 2010).S

Leafminer, *Liriomyza trifolii* (Burgess), Diptera Agromyzidae, causes severe damage to castor foliage right from cotyledonary stage to 150 days after planting. Insecticides are not effective to control leafminer. Four Indian accessions (RG 1930, RG 2008, RG 1766, RG 1771) exhibited high resistance to leafmine. The former two are dark purple colour morphotypes and the later two are papaya leaf type morphotypes. High concentration of total phenols was observed in resistant genotypes (Prasad and Anjani, 2000; Anjani et al., 2010b). Anjani et al. (2007) reported maternal inheritance of leafminer resistance when the leafminer resistant purple colour accession RG 1930 was used as a female parent.

### 5.3. Sources of resistance to abiotic stresses

Castor is susceptible to frost particularly in the early growth stages as germination is effected when temperature drops below 15°C. The evaluation of castor germplasm in northeast USA at high latitudes identified accessions yielding 60–75% higher than the standard cultivar Hale under low soil temperature encountered in spring. Some geographically diverse castor accessions tested at Lubbock, TX, USA under dry condition showed drought tolerance. Tolerance to salinity was also observed in some of these accessions when tested at Pecos, TX, USA where salt concentration in irrigation water is approximately 3500 ppm. Some of these tolerant accessions yielded 30–60% higher than the standard cultivars Hale and Brigham under either salt or drought stress (Meeks et al., 2010).

In India, systematic screening of castor germplasm against moisture stress and temperature stress has been taken up using standard techniques such as temperature induction response (TIR) technique in the laboratory and moisture stress imposition during winter or summer season in the field. Root structures with controlled irrigation were used to study variation in root traits to determine water use efficiency of castor germplasm accessions. Eight accessions (RG 122, RG 226, RG 232, RG 235, RG 242, RG 247, RG 1096) were identified as thermal-tolerant sources (Lakshmi Prayaga and Lakshamma, 2006), which exhibited more than 80% recovery after induction temperature (35°C for 2 h followed by 40°C for 2 h and 45°C for 1 h) and less than 20% death even at the lethal temperature (48°C for 2 h). The accessions RG 17, RG 52 and RG 72 were identified for early maturity coupled drought tolerance (Lakshamma et al., 2004). Lakshamma and Lakshmi Prayaga (2006) identified 12 accessions (RG 89, RG 122, RG 214, RG 232, RG 297, RG 298, RG 332, RG 707, RG 1117, RG 1449, RG 1526) as sources of tolerance to drought. The accessions RG 17, RG 122 and RG 214 were developed from heterogeneous populations of introductions viz., EC168752 from Hungary, EC103743 from an unknown country of origin and EC198496 (AMM 930) from UK, respectively (Anjani, 2010a). Variability for root and shoot traits and drought tolerance was reported in castor germplasm. Six accessions (RG 1450, RG 1611, RG 2122, RG 2149, RG 2714, RG 2797, RG 2826), which are semi-wild and wild collections from India, exhibited longer root, higher root volume and dry weight and lower <sup>13</sup>C value. The accessions RG 2149 and RG 2714 also recorded high leaf area index, total dry matter and SAP chlorophyll meter reading (Lakshamma and Lakshmi Prayaga, 2010; Lakshamma et al., 2010).

## 6. Core collection

In India, Sarada and Anjani (2011) have developed a castor core collection comprising 165 accessions, which optimally represent the diversity present in the original collection of 3000 accessions representing 40 countries. It was developed with the idea of improving evaluation efficiency at multilocations by reducing the cost, to improve utilization of germplasm in castor breeding programmes, to promote the use of molecular markers for diversity assessment as well to identify the gaps and duplicates in the original collection. This core collection is dynamic rather than static, where new accessions can be introduced and old accessions can be replaced in future as per the research needs. Combination of agronomic and molecular data of core collection would provide vast opportunity to castor researchers to mine for important loci. Core collection is the logical first step in mining for desirable alleles, but search can be continued, if needed, in the original collection. The concept of developing a common global castor core collection is ideal to capture most of the genetic variability present in *Ricinus*. But major drawback to this approach is the current inadequate or lack of characterization of genetic variation existing in various world castor collections and non-availability of characterization information and material.

## 7. Conservation, documentation and distribution of germplasm

*Ex situ* conservation is the chief mode for conservation of castor genetic resources. Seed moisture content and storage temperature are the two key factors affecting the longevity of castor seed in *ex situ* conservation. Singh et al. (2003) observed decline in castor seed germination up to 3.2% moisture level both under ambient and 4°C storage temperatures. Castor genetic resources are being conserved in various genebanks in the world either at –10 to –20°C for long-term storage and/or at 4°C for medium-term storage (Table 2).

**Table 2**  
List of genebanks/institutes conserving castor germplasm.

1.	AGES Linz - Austrian Agency for Health and Food Safety/Seed Collection, Austria
2.	Agricultural Research Station Teleorman, Teleorman County, Romania
3.	Biodiversity Conservation and Research Institute, Ethiopia
4.	Comunidad de Madrid. Universidad Politécnica de Madrid. Escuela Técnica Superior de Ingenieros Agrónomos. Banco de Germoplasma, Spain
5.	Directorate of Oilseeds Research, India
6.	EMBRAPA/CENERGEN, Brasilia, Brazil
7.	Empresa Baiana de Desenvolvimento Agrícola SA, Brazil
8.	Faculty of Agriculture, University of Zagreb, Croatia
9.	Genebank, Leibniz Institute of Plant Genetics and Crop Plant Research, Germany
10.	Genetic Resources Institute, Azerbaijan
11.	Gobierno de Aragón. Centro de Investigación y Tecnología Agroalimentaria. Recursos Forestales, Spain
12.	Institute for Agrobotany, Hungary
13.	Institute for Plant Genetic Resources 'K.Malkov', Bulgaria
14.	Institute of Botany, Azerbaijan
15.	Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences, China
16.	Institute of Crop Science (CAAS), China
17.	Institute of Field and Vegetable Crops, Maksima Gorkog, Serbia
18.	Institute of Oil Crops Research, China
19.	Institute of Oil Crops, Ukraine
20.	Instituto Agronomico de Campinas, Brazil
21.	Maize Research Institute, Zemun Polje, Serbia
22.	Medicinal and Aromatic Plants Research Station Fundulea, Romania
23.	Millennium Seed Bank Project, Seed Conservation Department, Royal Botanic Gardens, Kew, UK
24.	N.I. Vavilov All-Russian Scientific Research, Institute of Plant Industry, Russia
25.	National Bureau of Plant Genetic Resources, India
26.	National Gene bank of Kenya, Crop Plant Genetic Resources Centre, KARI, Kenya
27.	Plant Breeding and Acclimatization Institute, Poland
28.	RARI-Katumani Research Centre Katumani, Kenya
29.	Research Station of Medicinal Crops, Ukraine
30.	USDA-ARS-PGRU, Griffins, Georgia, USA

In India, the base collection of castor germplasm is maintained in National Genebank, National Bureau of Plant Genetic Resources, New Delhi for long-term storage to serve as reserve and back up for the working collection, and the active collection is conserved at the Directorate of Oilseeds Research (DOR), Hyderabad at ambient temperature (25–42 °C). Seed from the active collection are constantly withdrawn and distributed but those in long-term storage are rarely distributed unless seed are unavailable in working collection. The base collection maintains the genetic variation that is initially present in each accession.

Active collection at DOR is maintained through self-pollination. Maintenance of genetic purity and heterozygosity while minimizing inbreeding depression in samples is the major constraint facing maintenance of germplasm collections. Active collections at DOR are regenerated once in 3 or 4 years as reduction in germination percentage was observed after 3 years of storage under ambient temperature. Controlled pollination is followed in multiplication of germplasm as castor reproduces both by self- and cross-pollination. Maintenance of original identity of populations or landraces is particularly challenging during regeneration for risk of losing initial genetic diversity due to low sample size. The major difficulty in multiplication of late maturing castor accessions is their management in the field for a long duration extending beyond a year.

Lack of availability of descriptive information of world *ex situ* castor collections is a serious limitation for their utilization. In most cases, the information is mostly limited to accession number, seed source and collector's number and some times country of origin or collecting site. Unconditional access to databases is allowed in very few genebanks. Castor database of USDA-ARS can be accessed through Germplasm Resources Information Network (GRIN) server (<http://www.ars-grin.gov>). The

Genebank Information System of IPK, Gatersleben (<http://gbis.ipk-gatersleben.de/gbis.i/>) and European Plant Genetic Resources Catalogue (EURISCO, [www.bioversityinternational.org](http://www.bioversityinternational.org)) provide access to information on their *ex situ* castor genetic resources. In India, castor genetic resources database is freely available only to Indian government organizations. The information is disseminated through conduction of germplasm field day every year.

## 8. Registration of germplasm

Plant genetic resources are considered as 'heritage of mankind' till the Convention on Biological Diversity (CBD) came into force in 1993. CBD considers genetic resources as 'national sovereignty'. Consequently many issues in protection and benefit sharing of genetic resources have occurred. The value of germplasm collections is now well recognized with the implementation of International Treat on Plant genetic Resources for Food and Agriculture. Very few castor germplasm accessions have been registered for specific traits to ensure long-term security as well to encourage germplasm utilization. CMR-1 castor germplasm (Stafford, 1973), T55001 castor composite germplasm (Brigham, 1973) and TTU-LRC castor germplasm open pollinated germplasm with reduced levels of ricin and RCA<sub>120</sub> (Auld et al., 2003) from USA were registered with Crop Science Society of America. CMR-1 is being maintained by the National Centre for Genetic Resources Preservation, USDA, ARS, Fort Collins, Colorado since 1983. The accession T55001 is an inactive germplasm, but its record is being maintained in the GRIN database for historical reasons. TTU-LRC accession developed at Texas, United States is currently maintained at Southern Regional PI Station, USDA, ARS, Griffins, USA. Seed of this accession are available for distribution with the developer. In India, 12 germplasm accessions possessing resistance to *Fusarium* wilt, *Macrophomina* root rot, *Botrytis* grey rot, reniform nematode, leafhopper, leafminer and moisture stress, early maturity and multiple resistance to diseases and insect pests (Table 3) were registered with Plant Germplasm Registration Committee (PGRC), ICAR, India.

## 9. Utilization of genetic resources

Germplasm accessions collected from various parts of the world were well utilized in development of castor varieties in the former USSR and USA. At VNIIMK, the first improved castor materials were obtained from crosses between large seeded Southwest Asian collections and small seeded Persian collections. By way of selection from local Persian collections, varieties namely, Tashkentskaya 351, Kavkazskaya improved, Donskaya 172/1 and Kruglik 5 were developed in the former USSR. Chinese and Persian collections were included in development of the cultivars Early hybrid and Kubanskaya at VIR and Shade in Bashkirskii SKh1–Prekoks, Bash SKh1 and Sha2 at VNIIMK. Germplasm collections of different origins were used as base material in development of the varieties Stepnaya 6 and Chervonnaya at VNIIMK and IAC-38 in Brazil. The variety, Chervonnaya, was the first *Fusarium* wilt resistant castor variety in which wilt resistance was introgressed from small seed Sanguineus castor. The wilt resistant variety VNIIMK 165 Improved was derived from crosses between Persian, Chinese and Java castor collections. An early maturing variety Shade was derived from a cross between Persian and Chinese collections at VIR. The high oil varieties Sanguineus 401 and Sanguineus Synthetic were developed through inbreeding of germplasm accessions and selection for high oil progenies. Two early maturing varieties from China (Kuha bi Bao, Fu gun'er) and one (Iregi) from Hungary were derived from germplasm. In the former USSR, germplasm collections were utilized in development of varieties namely, Kinel'skaya 4, Kinel'skaya 4127, Saratovskaya 66, Kievskaya and Skorospelka. The varieties

**Table 3**  
Indian castor germplasm registered for specific trait (s) with Plant Germplasm Registration Committee, Indian Council of Agricultural Research.

Accession	National identity number	Specific trait
RG 1930	IC 296922	Resistance to serpentine leafminer ( <i>Liriomyza trifolii</i> (Burgess), Diptera Agromyzidae)
RG 392	IC 373897	Resistance to wilt ( <i>Fusarium oxysporum</i> f.sp. <i>ricini</i> ) and moderate resistance to root rot ( <i>Macrophomina phaseolina</i> (Tassi) Gold)
RG 47	IC 373867	Resistance to wilt ( <i>Fusarium oxysporum</i> f.sp. <i>ricini</i> ) and root rot ( <i>Macrophomina phaseolina</i> (Tassi) Gold)
RG 297	IC 296578	Resistance to wilt ( <i>Fusarium oxysporum</i> f.sp. <i>ricini</i> )
RG 1608	IC 373978	Resistance to wilt ( <i>Fusarium oxysporum</i> f.sp. <i>ricini</i> )
RG 2722	IC 306138	Resistance to root rot ( <i>Macrophomina phaseolina</i> (Tassi) Gold)
RG 2819	IC 346591	Resistance to root rot ( <i>Macrophomina phaseolina</i> (Tassi) Gold) and wilt ( <i>Fusarium oxysporum</i> f.sp. <i>ricini</i> )
RG 1771	IC 522120	Resistance to serpentine leafminer ( <i>Liriomyza trifolii</i> (Burgess), Diptera Agromyzidae)
RG 72	IC 274758	Early maturity and moisture stress tolerance
RG 2787	IC 374319	Resistance to wilt ( <i>Fusarium oxysporum</i> f.sp. <i>ricini</i> ), root rot ( <i>Macrophomina phaseolina</i> (Tassi) Gold), <i>Botrytis</i> grey rot ( <i>Botrytis ricini</i> Godfrey) and reniform nematode ( <i>Rotylenchulus reniformis</i> )
RG 43	IC 0584671	Resistance to wilt ( <i>Fusarium oxysporum</i> f.sp. <i>ricini</i> ), reniform nematode ( <i>Rotylenchulus reniformis</i> ) and leafhopper ( <i>Empoasca flavescens</i> )
RG 18	IC 0585930	Extra-early maturity (84 days) coupled with high per day productivity and high seed yield at 120 days after planting

kk-7,332,401, 430, 433, 459, 471 and 472 were introduced from VIR castor collections. The Australian variety, Ceripi Wild, was an introduction from germplasm. Germplasm accessions were incorporated in development of Indian castor varieties namely, Aruna, Bhagya, Sowbhagya, 48-1, SA-1, SA-2, TMV-5, TMV-6, CO-1 and DCS-9.

Genetic diversity in cultivated castor was created by crossing with geographically diverse collections. Elite germplasm sources were incorporated into breeding of the castor cultivars Dawn, Hale, Baker 296, Cimmarron, Campinas and Lynn in USA. These were in turn extensively used in castor improvement programmes. The germplasm accession PI 179729 was used to isolate the natural mutant OLE-1 having high oleic (78%) and low ricinolic (14%) acids (Rojas-Barros et al., 2004). A low ricin and RCA accession PI257654 was used as base material in development of recently released low ricin and RAC germplasm population TTU-LRC (Auld et al., 2003).

The pistillate mutant Nebraska 145-4 identified in natural population was a female parent of commercial hybrids in USA. The pistillate line CNES 1 was derived from a VIR collection k-1182, which carries a recessive gene for pistillateness and environment sensitive gene for interspersed staminate flowers (ISF). Intensive castor breeding programmes in India capitalized on genetic resources to develop pistillate lines, varieties and hybrids. NES-type Indian pistillate lines were developed using germplasm accessions

Mauthner's dwarf, EC153432 and EC169761 (Ramanathan, 2004). NES-type pistillate system is homozygous for the pistillate gene (*f*) and contains environmentally sensitive genes (*s*) for interspersed staminate flowers (Zimmerman and Smith, 1966). This system was found to be advantageous to the breeders since introgression of a single recessive gene for femaleness is easy to accomplish and the environmentally sensitive genes confer advantages for its maintenance (Ankineedu and Rao, 1973).

In India, the first stable indigenous pistillate line VP-1 was evolved from an exotic pistillate line TSP-10R received from Texas, USA in 1965 (Ramachandram and Prasad, 1995). TSP-10R is the female parent of the first Indian castor hybrid GCH-3. Several pistillate lines namely, JP-58, JSP-10R, JP-65, JP-83, SKP-1, SKP-2, SKP-3, SKP-4, SKP-42 and SKP-106 (Patel et al., 1986, 2008; Dangaria et al., 1987; Fatteh et al., 1988; Solanki and Joshi, 2000) and four hybrids (GAUCH-1, GCH-2, GCH-4, RHC-1) were developed using VP-1. The *Fusarium* wilt resistant mutant pistillate M-574 was obtained through mutagenic treatment to VP-1. M-574 is the female parent of hybrid DCH-519. The wilt resistant variety 48-1 was derived from a cross between germplasm accessions High Oil (HO) and Mauthner's Dwarf (MD). The wilt resistant pistillate line, Geeta and a wilt resistant commercial hybrid GCH-4 were developed using 48-1. Geeta is the pistillate parent of wilt resistant hybrid GCH-5. Genetic base of pistillate trait in castor was diversified by deriving pistillate lines from Indian germplasm accessions (Ankineedu and Rao, 1973; Anjani, 2005b). In AICRP on Castor, several germplasm accessions have been incorporated in breeding cycles to derive inbred lines possessing high seed and oil yield, early and medium maturity and resistance to major disease and insect-pests.

Most of the requests for castor germplasm were for breeding and prebreeding purposes to use as progenitors in breeding cycles. The second most frequently cited reason for requesting castor germplasm was to carry out genetic studies and dissertation work. The most frequently sought trait in Indian germplasm collection was resistance to biotic stresses especially against wilt, root rot, *Botrytis*, nematode, whitefly, leafhopper, capsule borer and leafminer. High seed yield and yield traits, high oil content and early and extra-early maturity were the next frequently sought traits. The most preferred germplasm for molecular genetic studies were geographically and morphologically diverse types. Distinct morphotypes were found to be the preferential material to incorporate distinctness in breeding lines. Late maturity types with large leaf mass were the most sought ones for *eri*-silk worm culture.

## 10. Conclusions and future perspectives

Of late, global demand for castor oil has increased several folds due to its growing industrial applications. Increasing castor production from shrinking natural resources and increasing climate change is a real challenge to researchers. Discovery of new genes and gene combinations is crucial for newer requirements to challenge climate change effects. A diverse global gene pool is required for this purpose. Wild and semi-wild forms show a range of variability that *Ricinus* is capable of and its ecological and geographical range of distribution. Collection and conservation of these forms would provide diverse gene pool to researchers and prevent permanent loss of crop diversity due to human encroachment in their natural habitats. In the past, vast *ex situ* collections could be acquired either by collecting in native habitats or through exchange. Unfortunately, germplasm exchange among different countries has become a sensitive issue under the present international treaties. It necessitates thorough evaluation of the past exchanged exotic collections. Strategic international collaborations are needed to promote exchange and collection of new germplasm from diverse ecological niches. Simultaneously, intellectual prop-

erty protection laws must be used to protect individual national germplasm collections.

Given the great benefits derived from *ex situ* collections, genebanks have an extremely important role to play in unraveling the potentiality of vast *ex situ* collections and deserve greater support from funding agencies than at present. Characterization and evaluation are perhaps the greatest challenge facing the genebanks. Systematic evaluation under different environments is needed to unravel the true potential of accessions and provide globally useful datasets. At global level, uniform data collection standards, phenotypic descriptors, agronomic datasets and molecular marker sets are to be developed. These universal datasets would detect redundancy within and among vast collections, and also contribute to develop global core collection and environment-specific subsets. The core and subsets would provide great opportunity to exploit genetic diversity. Promotion of an international database and its dissemination would improve genetic resources utilization.

So far, only a fraction of *ex situ* collections could be tapped to bring in desirable genetic improvement in castor. Concerted exploration of genetic resources to discover genes and gene combinations for newer requirements would correspondingly increase value and utilization of germplasm. Physiological measures of various plant parameters can be used for more accurate determination of sources of useful traits in genetic resources. Targeted utilization of germplasm and synthesis of target-based populations and heterotic pools can bring in further rapid improvement in important characteristics. With the availability of draft genome sequence of castor, one can also think of development of introgression libraries and their molecular-genetic characterization to localize genomic regions carrying favourable alleles affecting *per se* performance of desirable traits. This would make germplasm more dynamic. Inter-institutional and international collaborations and public-private partnerships are to be capitalized for research capabilities, funding and infrastructure facilities to unravel the hidden potential of castor gene pool.

Overall, this report provides crucial information on castor germplasm resources available around the globe. It serves as a unique starting point for the global castor community to build strong multinational collaborations to facilitate knowledge and resource integration and coordinated research planning for substantial castor genetic improvement.

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