**Castor Hybrids in India: A Success story**

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**Abstract**

*Castor, a cross pollinated crop with sexual polymorphism which is highly sensitive to environmental conditions was successfully utilized to develop a two line breeding system. The present paper historically reviewed the development of hybrids and refinements in seed production technology to facilitate genetically high quality seed. Status of sex expression, developing pistillate lines and the historical achievements in heterosis breeding in India, seed production related issues and future outlook for castor hybrids have been broadly presented highlighting the role of hybrids placing India as a current global leader in production and productivity.*

Castor (*Ricinus communis* L.), a member of *Euphorbiaceae* or spurge family (2n=20) earns a specific place in oilseeds scenario as successful commercial, non-edible and industrial annual oilseed crop. Castor though of polyphyletic origin, both India and Africa were considered as the origin of castor. Due to its widespread survival and perennial nature, all possible transitions from an uncultivated plant to a weedy plant and from semi cultivated to a field crop exist and there is no gap between uncultivated and cultivated castor. Castor is a monotypic genus and the species *communis* is subdivided to six sub-species based on eco-geographical grouping. There is no difference in the chromosome number among the sub-species and they all can cross easily with each other.

Castor, a natural perennial and tall crop of more than six feet height was initially grown for domestic use and local markets. Natural and artificial selections for medium plant height (5 feet), medium to long duration (210-240 days) and non-shattering types led to its commercial use (Weiss, 1971, Kulkarni and Ramanamurthy, 1977, Moshkin, 1986). In India, it is cultivated both as a rain-fed crop in marginal lands under harsh conditions with minimum inputs *viz*., Andhra Pradesh, Karnataka, Tamilnadu, Orissa and as irrigated crop under intensive management conditions like Gujarat, Rajasthan, Haryana etc. Among the states, Gujarat accounts for 32 % of India’s castor production with about 44 % of the castor area and has the highest productivity of 1699 kg/ha in 2011-12 (1964 kg/ha). Castor is the only crop with stable compound annual growth rate in productivity (3.71%) with the exception of cotton growth rate in the recent past due to introduction of Bt cotton and also soybean.

 The success story of castor is a record historical event of the Indian agricultural science of this century. The area under castor enhanced from a mere 40,000 ha in 1920’s to over one million ha of with the highest national average productivity of 1.354 t/ha. The national productivity is 0.3 t/ha above the global average productivity and thus emerged as principal castor producer in the world. The other major castor producing countries areChina, Brazil and Thailand. Castor oil has a wide market, as there are no synthetic alternatives to the unique castor oil. India earned a foreign exchange worth of 2036 crores of rupess by the export of 2.79 lakh metric tonnes castor oil and products to several countries in 2011-12.

In India, hybrid development was initiated with the introduction of an S type pistillate line, TSP 10 R (Texas stable pistillate 10) and CNES 1 from USA in 1960s. The first castor hybrid in the world, GCH 3 was developed by crossing TSP 10 R with the native varietal selection, JI 15. Hybrids cultivation over time resulted in spectacular rise in production and productivity from 2.1 to 10.03 lakh tones and 220 to 1334 kg/ha during the last six decades (Hegde, 2010). The success is mainly attributed to the commercial exploitation of heterosis especially under high input intensive and management conditions of Gujarat which accounts for 73% castor production from 50% of area with highest productivity (1964 kg/ha) (Hegde, 2010). Despite the lack of inter specific diversity, castor breeders in India were successful in exploiting the existing intra specific diversity for diversification of parental lines. A wide variation in morphological diversity owing to its cross pollinated nature and independent assortment of several traits aided the breeders to overcome the limited genetic diversity in the monotypic genus.

**Sex expression**

Castor, though a sexually polymorphic species, occurs in nature as mostly monoecious. The basic sex forms are monoecious, pistillate, pistillate with interspersed staminate flowers (ISF) and sex revertants (Moshkin, 1986; Shiffriss, 1960, Lavanya and Gopinath, 2010). Sex expression in castor is highly influenced by environmental conditions (Shifriss, 1960, Ramachandram and Rangarao,1978). Winter, low temperatures (<30°C), young plants, high nutrition promote female flowers and shift the balance towards femaleness on a spike. Summer or rainy season, high temperatures (>32°C), old plants, late order spikes, low nutrition promote male flowers on a spike and incline towards maleness (Lavanya, 2002). The role of exogenous and endogenous growth harmones like gibberellic acid, silver nitrate and ethylene in shifting the female and male tendency has been well documented (Lavanya and Solanki, 2010).

**Pistillate lines**

Sexual polymorphism in castor was best utilized for development of a two line breeding system unlike the three line system or CMS based hybrids in other field crops like pearl millet, maize, sorghum, rice, and pigeonpea. The initial efforts on selection of highly female spikes from germplasm and breeding material led to the identification of three types of pistillate mechanism- N, S and NES types.

 The N type is governed by recessive sex switching gene and maintained by sib mating. In commercial hybrid seed production plots, normal monoecious plants have to be rouged out before anthesis leading to low genetic purity and high cost of rouging. The N type of pistillate source has been greatly improved leading to a female line, CNES-1 which requires little or no rouging (Classen and Hoffman, 1950).

 S type pistillate line was obtained by selection within sex reversals at the Weizmann Institute, Israel and governed by dominant and epistatic effects. Sex reversals are plant variants which begin as female and revert to normal monoecism at any time after the first raceme and 10 or more racemes when grown as perennials. These perennial plants were considered as females, if grown only as annuals. Sex reversion is ontogenetically irreversible and is variegated where a part of the plant may still be pistillate while the other half is reverted to monoecious (Shiffriss, 1960, Ramachandram and Rangarao, 1978).

 NES pistillate type is a combination of both N and S type as it carries the homozygous recessive gene for pistillateness and environment sensitive genes for ISF. Production of ISF is not confined to any particular raceme order and temperature dependent (Ankineedu and Ganga Prasada Rao, 1973). NES type can be easily developed by transfer of a single recessive gene as compared to the polygenic complex of both dominant and epistatic S type. Pistillate lines like 240, NES 6, NES 17, NES 19, JP 65 are of NES type (Lavanya et al.,2006).

**Heterosis breeding**

 Exploitation of heterosis in castor was initiated since 1960s even before the identification of pistillate lines. Heterosis over the standard checks was reported to vary from <20 to >100 percent over the years (Lavanya *et al*.,2006). However, heterosis observed in castor is not as substantially as high as in other cross-pollinated crops due to its inherent ability to self-pollinate, especially in the primary spike. Initial reports suggested heterosis for germination rate, formation of leaves and plant height in early seedling stages, leaf number and leaf area index. Attempts to exploit hybrid vigour through monoecious lines were not successful due to laborious process of emasculation. Although heterosis for total seed yield occurred, there was no significant increase in the percentage of female flowers on racemes (Lavanya *et al*., 2006).

Heterosis was high for seed yield followed by number of capsules on the main raceme and 100 seed weight. Heterosis and heterobeltiosis for seed yield per plant was due to heterosis for capsules on main raceme, length of pistillate region of main raceme, effective branches per plant and seed yield of main raceme while heterosis for seed yield was associated with number of effective spikes per plant (Lavanya *et al*., 2006).

A contradictory opinion was that the magnitude of heterosis was mainly due to the highly female expression inherited from the dominant female nature of the S type pistillate line (Moshkin, 1986; Atsmon, 1989) which contribute to the raise in seed yield. Genetic basis of heterosis of seed yield is due to the factors other than heterosis *per se* like the improved parental lines for spike density, highly female spikes, earliness, short stature, etc (Atsmon, 1989).

Heterosis was mainly manifested in parental lines of contrasting morphological characters like dwarf plant type with condensed nodes, cup shaped leaves in pistillate lines *vs* normal tall plant type, elongated nodes, flat leaves in male lines (Lavanya *et al*., 2006). *Per* se performance and average heterosis in dwarf x tall crosses were higher to the parents involving moderately tall x tall and tall x dwarf crosses. Heterosis for seed yield was correlated with heterosis for main spike length and capsules / primary spike when one of the parents was tall.

The first generation hybrid between Kruglik 5 and Sanguineus gave 1400 -1900 kg/ha higher seed yield than both the parents in erstwhile USSR (Moshkin, 1986). Heterosis has increased up to 18-23% when parents were of diverse origin and upon emasculation of pistillate lines. Heterosis breeding gained its momentum due to the identification of pistillate lines and suitable male lines.

VP-1 is the first stable pistillate line developed in Gujarat from the segregation of a double cross between F2 of JHB 48 (JP 5 x 26006) x JHB 67 (TSP 10R x 719/1) with distinct morphological characters like green stem, triple bloom, cup shaped leaves, condensed nodes, long primary spike with spiny capsules (Lavanya *et al*.,2006). Development of stable pistillate lines from S-type is based on selection from late order of revertants. Selfed plants of the second and third orders of reversion yielded more number of pistillate plants than sibbed pistillate and selfed first order revertants. Selfed plants of the 10th order of reversion yielded nearly all pistillate plants in their progenies. Several pistillate lines *viz.,* SKP 4, LRES 17, DPC 9, DPC 13, DPC 14, SKP 120, MCP 1-1, JP 58 etc., were developed using VP-1 source of pistillate expression (Lavanya *et al*.,2006).

 The hybrid GCH 3 was an instant success due to its high yielding ability (88% yield increase over S-20), drought resistance, medium maturity (140-210 days) and high oil content (46.6%). Though the hybrid was released for irrigated castor growing areas, it became popular even in rainfed castor growing areas. Due to its early maturity Gujarat farmers of *Mehsana* district were able to take up castor as a kharif crop followed by a second crop of either wheat or summer pearl millet wherever irrigation facilities were available. However, the major demerit is its shattering habit. This problem was overcome in another early maturing hybrid GAUCH-1(VP-1 x VI-9) with drought escape mechanism and 16% yield increase over GCH 3. This hybrid had undergone extensive testing under All India Coordinated Research Project on Dryland Agriculture and was found to posses efficient root system than the varieties under receding moisture conditions (Reddy *et al*., 1999). Due to its attractive morphological characters *viz*., green stem, non-shattering, long, compact spike and good yield, this hybrid also became popular among farmers. Another hybrid GCH 2(VP-1 x JI 35) was released in 1985 for irrigated areas of Gujarat with tolerance to root rot, 13% yield increase over GAUCH 1. The hybrid has spikes with interspersed male flowers increasing the number of capsules in higher order spikes (Lavanya *et al*.,2006).

 The research efforts initiated during the latter part of 70’s resulted in the development of first wilt resistant hybrid GCH 4 (VP-1 x 48-1) released in 1986 for commercial cultivation in entire castor growing areas of the country (Lavanya *et al*., 2006). It is superior in yield over GAUCH 1 (13%) and GCH 2 (9%). It is well adapted to both rainfed and irrigated castor growing regions of the country. This hybrid, when grown as a horticultural crop under intensive cultivation with high inputs near riverbanks of Khisurpuri regions of Ahmedabad district, gave a seed yield of more than 9 tonnes/ha which is still a world record (Lavanya *et al*., 2006).

Susceptibility of VP-1 to *Fusarium* wilt led to efforts on diversification of pistillate source through conventional and mutation breeding approach. Three early duration, high yielding hybrids *viz*., DCH 32, DCH 177, DCH 519, suitable for rainfed and irrigated conditions were developed from DOR, Hyderabad. DCH 177 (DPC 9 x DCS 9) and DCH 519 (M 574 x DCS 78) involved wilt resistant parents and resistant to *Fusarium* wilt. Among the 14 hybrids released so far in the public sector system, GCH-4 is high yielding (1200-2200 kg/ha), suitable for rainfed and irrigated conditions, tolerant to wilt and still the most popular hybrid even after 24 years of release. It is now being replaced by the latest high yielding hybrid GCH-7 (3000 kg/ha) which is resistant to both *Fusarium* wilt and reniform nematode complex (Table 1).

**Table 1. Salient features of castor hybrids recommended for different regions**

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| **Hybrid** | **Year of release** | **Mean seed yield (kg/ha)** | **Areas recommended** | **Salient features** |
| GCH 3 | 1976 | 1540 (I) | Gujarat | Heavy branching, dark brown seed with black spot |
| GAUCH-1 | 1976 | 1520 (I) | Irrigated areas of Gujarat, rainfed areas of southern India | Early maturing hybrid with drought escape mechanism |
| GCH 2 | 1986 | 1750 (I) | Irrigated areas of Gujarat | Tolerant to root rot |
| GCH 4 | 1988 | 1200 (R)2200 (I) | Both rainfed and irrigate areas, all over country | Resistant to leafhoppers, tolerant to *Fusarium* wilt |
| GCH 5 | 1997 | 1800(R)2800 (I) | Rainfed and irrigated areas of Gujarat | Red, double bloom, medium duration (120-180 days), semi spiny, wilt tolerant. |
| DCH 32 | 1998 | 1030 (R)2460 (I) | Rainfed areas of Andhra Pradesh, Karnataka, Tamil Nadu, Maharashtra and Orissa | Red, triple bloom, spiny, early duration (90-150 days), resistant to jassids |
| GCH 6 | 1999 | 1300 (R)2300 (I) | Rainfed and irrigated late*kharif* regions of Gujarat, Rajasthan and Maharashtra | Red, single bloom, spiny, medium duration (120-180 days), Tolerant to *Macrophomina* root rot |
| TMVCH 1 | 1999 | 1180 (R) | Rainfed areas of Tamil Nadu | Red, triple bloom, spiny, resistant to jassids |
| DCH 177 | 2000 | 1550 (R)2130 (I) | Rainfed areas of Andhra Pradesh, Karnataka, Tamil Nadu, Maharashtra and Orissa | Red single bloom, spiny, early duration (90-150 days), Resistant to *Fusarium* wilt, both parents are resistant to wilt |
| RHC 1 | 2000 | 900-1200 (R)3000-3200 (I) | Rainfed and irrigated areas of Rajasthan | Mahogany, triple bloom, spiny, medium duration (100-180 days), resistant to jassids |
| PCH 1 | 2001 | 1500 (R)2000 (I) | Rainfed areas of Andhra Pradesh | Tolerant to wilt, resistant to jassids. |
| DCH 519 | 2006 | 1740(R)2130 (I) | Both rainfed and irrigatedareas | Green, triple bloom, spiny, resistant to *Fusarium* wilt, leaf hoppers and both parents are resistant to wilt. |
| GCH 7 | 2006 | 3000 (I) | Irrigated areas of Gujarat | Resistant to nematode-wilt complex |

*R=Rainfed; I=Irrigated*

Among the latest hybrids released, YRCH 1 hybrid is suitable for cultivation in rain-fed areas of Tamil Nadu while PCH-111 and PCH-222 are suitable for rainfed castor growing areas of Andhra Pradesh. Castor, being a commercial crop in Gujarat, 43 private seed companies registered 88 hybrids for commercial sale since the last five years (agri.gujarat.gov.in). Among the public and private sector hybrids, GCH-4 occupies a major share of the private castor seed market (up to 50-60%). This is mainly due to the popularity of GCH-4 hybrid among farmers, easy access to the parental lines of GCH-4 and standard seed production technology developed. Many of the private companies though still depend on VP-1 for generation of experimental hybrids. More than 95% of the castor growing area in Gujarat is occupied by castor hybrids and the rise in productivity is spectacular from 350 to 1970 kg/ha (Damodaram and Hegde, 2010).

**Seed production technology**

Success of any seed production technology depends on the availability of pure, stable parental lines, heterotic hybrid combination and standard seed production technology. The cross-pollinated nature of the crop and complexity of sex and its high sensitivity to genotype-environment interactions (climate, nutrition, management, etc.) further make seed production in castor complicated. Stages of seed production like foundation, certified hybrid seed production in castor are highly season bound to exploit the environmental sensitive nature of the parental lines.

 Foundation seed production of both female and male lines is done in summer season while the certified hybrid seed production is sown as an early *rabi* crop from September second fortnight to October second fortnight. Initial delays in popularization of castor hybrids were mainly associated with inherent problems like low genetic purity in commercial hybrids. This was attributed with the instability of parental lines, improper rouging and insufficient isolation distance leading to poor seed quality and rejection of seed lots by certifying agencies prior to 2002-03 (Lavanya *et al.,*2006).

 The breakthrough in successful cultivation of castor hybrids was mainly possible due to the interventions in seed production technology leading to availability of high quality hybrid seed to the farmers. Major success in hybrid breeding technology is the significant modifications in the seed production technology by increasing isolation distance from 150 to 300m, and imposing refined method of seed production technology of the pistillate lines in place of conventional method of seed production (Lavanya and Solanki, 2010, Zaveri, 2009).

 The conventional or traditional method of maintenance of pistillate plants relies upon maintaining 20 to 25% monoecious or revertant plants as a pollen source resulting in high proportion of monoecists, 40-65% early revertants in certified hybrid seed under extreme conditions (Ramachandram and Ranga Rao, 1988; Prabakaran *et al*., 2009). This leads to high cost of rouging and low genetic purity in the female line. Sowing season for conventional method is recommended as *kharif* or post rainy season. The estimated loss by adopting conventional method of seed production owing to rejection of seed lots based on the low genetic purity was nearly 100 crores of rupees to the seed producing farmers in Gujarat alone during the last two decades.

 The method has been modified or refined by allowing the environmentally sensitive interspersed staminate flowers (ISF) as the pollen source in summer season with an isolation distance of 1000m (Ramachandram and Rangarao, 1978; Prabakaran et al., 2009). There is a spectacular improvement in seed production programmes due to the implementation of refined method of maintenance of pistillate line and doubling of isolation distance (150 m to 300 m) for certified hybrid seed production The mean percent rejection of seed lot in GCH-4, during 1992-2002 was 43% (971.6q) of the total seed lot which reduced to 29.5% (3130.7q) in 2003-08 after the implementation of 300 m isolation distance in 2002-03. (Zaveri, 2009). A study conducted by Navbharat Seeds, Gujarat using 17 lots of GCH-4 for grow out test indicated that rejection of seed lots in modified method has significantly reduced to 5.9% compared to 23.5% in conventional method (Lavanya and Solanki, 2010),(Table 2).

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| **Table 2. Genetic purity of GCH-4 using VP-1 produced by conventional and refined metho**enetic purity (%)\* |  Conventional method |  Refined method |
| No. of lots | Accepted+/rejected- (%)  | No. of lots | Accepted+/rejected -(%)  |
| 95+ | 3 | 17.6 | 2 | 11.8 |
| 90-95+ | 7 | 41.2 | 13 | 76.5 |
| 85-90+ | 3 | 17.6 | 1 | 5.9 |
| <85\*\*- | 4 | 23.5 | 1 | 5.9 |
| Total | 17 | 76.5 | 17 | 94.1 |

\*- > 85% accepted; <85% rejected; + accepted (>85%), - rejected (<85%)

Source: GOT results of 17 lots of GCH-4 of Navbharat Seeds,Gujarat, Ahmedabad,

 **Future out look**

Development of cryptic hybrids as in maize was proposed in a recent paper on castor (Liv *et al*., 2012). Clean Genome Technology for developing castor hybrids with a claim of very high productivity need to be seen for its field performance. Indian castor researchers both in private and public need to be alert for these advanced technologies and competition that is likely to arise from China and Brazil. Short and medium duration *kharif* hybrids with *Botrytis* resistance are likely to enhance the area under rain-fed castor not only in Andhra Pradesh but also in non-traditional areas such as Madhya Pradesh and Maharashtra. Short duration hybrids targeting primary spike alone may also have potential in Orissa and other North Eastern States fitting in to the cropping system after *kharif*. There is a tremendous scope of exploiting available genetic diversity to develop new parental lines with stable sex expression to achieve higher levels of heterosis.

Challenge of lepidopteron pests particularly semilooper, spodoptera and the capsule borer haunts the future of castor expansion. The Directorate of Oilseeds Research has initiated research on developing markers for biotic and abiotic challenges with a hope to develop Marker Assisted Hybrids in the near future. Castor being non-edible crop, exploitation of novel approaches including transgenic approach for developing new generation hybrids is worth-while exploring. Diversifying sources of wilt resistance and drought tolerance in parental lines shall be a priority.

Castor seed oil (45-55%) has a unique fatty acid, ricinoleic acid (80-90%) which is indispensable in the manufacture of more than 250 industrial products (Suresh, 2009). However, industrial recovery of ricinoleic acid hovers around 85-87% in hybrids. There is a need to focus research on developing parental lines of castor hybrids with higher recovery of ricinolic acid adding industrial value. Developing CMS based hybrids and low ricin hybrids need a fresh look based on demand and available resources. Genetic purity of parental lines, maintenance breeding, testing new parental lines for seed production systems with current challenges of changing temperature and moisture regimes are the key factors for hybrids success.

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VP-1, the first stable pistillate line



DCH-177, early duration (110 days to maturity), wilt resistant hybrid



DCH-519, medium duration (120-130 days to maturity), wilt resistant hybrid released for both rainfed and irrigated castor growing regions

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