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Sunnhemp breeding: Challenges and prospects

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ABSTRACT

Sunnhemp (*Crotalaria juncea* L.) is an important fibre crop of tropical and sub-tropical parts of the world and has multiple uses. With the commercialization of agriculture, major food crops and cash crops gained momentum and fibre crops, particularly sunnhemp lagged behind on account of increased availability of cheap synthetic fibres. In the present context, the cultivation of sunnhemp is limited to marginal lands and with minimum inputs. Subsequently, the production and productivity of the crop has declined. Productivity of sunnhemp can be increased by genetic improvement of the crop. However, very little reports are available detailing genetics of different economic traits. Hence, an attempt is being made to collect all the scattered relevant genetic information in order to make the information useful in expediting the genetic improvement of the crop.

Key words: *Crotalaria*, Genetic improvement, Pollination biology, Self-incompatibility, Sunnhemp

Sunnhemp (*Crotalaria juncea* L.) is an important fibre crop grown commercially for the soft, slightly lignified fibre found in the stems. The fibre has high cellulose, low lignin and negligible ash content (Tripathi *et al*. 2013) making it suitable for manufacture of high quality tissue paper, cigarette paper and currency paper (Chawla *et al*. 1967). In India, traditionally it is used for making ropes, twines, net, handmade paper, tat-patties and canvas (Tripathi *et al*. 2012), for green manuring and for medicinal purposes (Chopra *et al*. 1956, Oruganti *et al*. 2014). It is also used as fodder and for culinary purposes *albeit* to a limited extent. Sunnhemp has gained importance as a substitute of nitrate fertilizers in the form of green manure capable of fixing 60-80 kg N/ha. It increases the sustainability of agricultural system, improves the physical and biological properties of soil and reduces pollution. It has high photosynthetic rate enabling it to trap atmospheric carbon dioxide thereby reducing green house gas (GHG) effect. Apart, it is also valued for its weed-suppressing- (Rupper 1987), anthelminthic- (Rotar and Joy 1983) and soil erosion resistive-properties. On account of its ability to produce exceedingly high biomass (Kumar and Dwivedi 2014) coupled with little amount of lignin, it is considered a potential biofuel crop. The sticks of sunnhemp are used for staking beetle vines in many part of India especially in Bundelkhand, Eastern Uttar Pradesh and West Bengal (Chaudhary *et al*. 2015 and 2016).

Sunnhemp (*C. juncea*) is a native of India and is predominantly cultivated in different parts of the world. India, Brazil, Bangladesh, Pakistan, China, Korea are the major producers of sunnhemp. In India, the genus is represented by 81 species, out of which 21 are endemic. The archaeological evidences indicate its mention during the period of Indus civilization (Good 2007) and in literatures of 16th century by Bhavamisra under the name 'shanapushpika' (Chunekar and Pandey 1998) and in 'Ain-E-Akbari'.

Sunnhemp, despite being suitable for a range of uses ranging from rural household to specialized industries, has almost remained a neglected crop. Post green-revolution period, most of the area under sunnhemp was replaced by more remunerative and staple crops. Subsequently, the area under sunnhemp reduced considerably. Alongside, the cultivation of crop shifted to summer season instead of *kharif*. No special attention was given towards development of varieties suitable for summer season. Receiving little research attention, the crop, once a lifeline of rural economy, had gone into a stage of oblivion and neglect. In recent years, the production and productivity has remained abysmally low. The reasons underlying are lack of knowledge about germplasm including related and wild species, lack of genetic information regarding breeding behavior, gene action governing different yield traits etc. In this context, an attempt is being made to gather information related to karyology, breeding behavior, genetic studies and genetic improvement made so far, in sunnhemp and related species.

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Botanical description

Sunnhemp is a member of crotalaria genus which comprises about 600 species. With the exception of *C. juncea*, no species is cultivated for fibre. Other species are either used for green manuring or for fodders. Sunnhemp is a short day, erect herbaceous shrub. The plants consist of strong tap root system with nodules on root surface. Plants generally reach up to a height of 2.5-3.0m. Leaves are simple, stipulated, entire and elliptical to oblong in shape. Sunnhemp bears terminal raceme inflorescence with indeterminate growth habit. Flowers are typical standard type with a broad ovate standard petal with a strong midrib at the back of the petal. Petals act as a point of attraction for different types of insect on account of its orientation. Wings are medium in size and keel petals are pointed and are slightly twisted.

The flower is complete, zygomorphic and pentamerous. The flower comprises of five fused sepals (gamosepalous), five free petals (polypetalous), 10 free stamens present in two whorls and gynoecium represented by single pistil. Androecium exhibits anther dimorphism. The 1st whorl of androecium consists of five elongated adnate stamens on smaller filaments. The 2nd whorl lies in inner position of flower and is represented by five globose, basifixed anthers on slender and longer filaments. Anther dimorphism has also been reported in *C. retusa* (Tidke and Patil 2000) and in *C. digitata* (Muthu and Ganesan 2012). The period of maturation of 1st whorl of anther almost matches with the stigma receptivity. Second whorl of anther is late in pollen dispersal and suuplies pollen to stigma upon elongation once the 1st whorl of anthers withers. Fruit is an inflated pod containing 10-15 seeds inside. Seeds are small and kidney shaped and mostly black in colour. Exceptions are found in variety K-12 yellow with yellow seeds.

No reports are available detailing pollen and pistil morphology in *C. juncea* although reports are available on related species. Pollen morphology was studied in Taiwanian species of crotolaria (Lin and Huang 1999) and pollen was reported to be tri-colporate, prolate to sub-prolate and circular to semi-angular in shape with stratification on exine. The exine stratification of various crotalaria species was more or less similar. Malti and Shivanna (1985) studied pistil structure in *C. retusa* and found stigma to be wet type. They reported the presence of a papillate region in the upper part of the ovary, which was involved in pollen tube screening. Effect of leachates from different parts of pistil, viz. stigma and style, upper non-ovulate part and lower ovulate part of the ovary was studied on pollen tube growth. Presence of leachates stimulated limited numbers of pollen tube length under *in-vitro* condition. This indicated evidence for the operation of a selection pressure during pollen-pistil interaction. This could result in rejection of self-pollen.

Karyological studies

Karyological studies among crotalaria indicate that the genus is dibasic with two basic chromosome numbers, i.e x=8 and x=7 (Subramaniam and Pandey 2013). Earlier studies indicated monosomic chromosome number of 8 for almost 87% of the species studied (Raghaven and Venkatasubban 1943, Atchison 1950). The species with basic chromosome number of 7 are assumed to have evolved from those with basic chromosome number of 8 following aneuploid reduction (Senn 1938) or due to loss of a meta-centric chromosome (Atchison 1950). Those species with variant chromosome numbers also show variation in either distribution or morphology. Most of the species are diploid with some polypoid species (Table 1). Deviation in chromosome number is supposed to be a result of viable gametes produced as a consequence of meiotic irregularities (Ferreira *et al*. 2009). In several species of crotalaria, a high proportion of meiotic irregularities was reported resulting in production of cytomixis. These numbers were found in many different species of crotalaria representing broad morphological variation and a wide distribution in the tropics and subtropics (Palomino and Ricardo 1991).

Table 1 Ploidy level of different species belonging to genus *crotalaria*

Species	Chromosome no.	References
C. spectabilis	2n=2x=16	Atchison (1950)
C. longirostrata	2n=4x=32	Palomino and Vazquez (1991)
C.pumila	2n=2x=32	Atchison 1950, Tapia-Pastrana (2012)
C.incana	2n=2x=14	Chennaveeraiah and Patil (1973), Gupta and Gupta (1978)
C. linifolia	2n=2x=16	Patil (1983)
C. sagittalis	2n=4x=32	Tapia-Pastrana (2012)
C. nitens	2n=4x=32	Chennaveeraiah and Patil (1973)
C. ferruginea	2n=6x=48	Bhaumik (1975) Mangotra and Koul (1979)

Pollination biology and self-incompatibility

Different views were expressed regarding pollination behaviour of *C. juncea*. Some reports indicate it to be obligatory outcrossing species (Howard *et al*. 1919, Patel and Kamath 1950, Mitra 1970, Mohan 1971). In contrast, it has been also listed as a self-pollinated crop (Hayes *et al*. 1955). Chaudhari (2000) mentions sunnhemp as a primarily self-pollinated crop which is benefited by insect visits. Although the structural and temporal features of flowers are indicative of possibility of selfing (Bhandari *et al*. 2014), selfing of flowers doesn't result in pod formation. The failure of pod formation under selfing is suggestive of role of self-incompatibility.

A large number of insect species is reported to visit sunnhemp crop. However, only the species strong enough to carry out tripping bring about pollination. Several species of honeybees like *Apis florae* and *A. cerana* (Howard *et* *al*. 1919) and *A. indica* (Mohan 1971) are reported to be ineffective tripper. Bumble bees have sufficient body weight which causes stigma to protrude out upon boarding of the insect on petals resulting in contact of stigma with insect body and bringing out pollination. Several species of bumble bees are efficient pollinators effecting pollination in crotalaria like *Xylocopa fenistroides* Fabr. in *C. juncea*, *X. frontalis* and *X. grisescens* in *C. retusa* (Jacobi 2005). *Xylocopa* species have preference towards zyomorphic, yellow flowers (Raju and Rao 2006) which are present in sunnhemp. Bees visit fully open flowers and prefer to collect pollen in afternoon (Maiti 1997). It was reported that *Xylocopa* species favour medium to large flowers which are strong enough to sustain rough foot work by insects. Yellow coloured flower in most of the species of crotalaria attracts xylocopa bees. The insects are attracted by plants as they serve as source of food in form of pollen or nectar or both. Some species of crotalaria are found to have nectar and attract large carpenter bees like *C. laburnifolia* (Raju and Rao 2006). Other species like *Apis mellifera* and ants are also involved in pollination of related species in *C. micans* (Villalobos and Ramirez 2010).

Mohan (1971) established self-incompatibility in sunnhemp and suggested that it contributed to out-crossing. He ascribed some deviation in out-crossing from 100% to break-down of self-incompatibility due to age of the flowers. Miranda (1981) reported that self-incompatibility in sunnhemp was governed gametophytically. Self-incompatibility is due to presence of membrane on stigmatic surface, characteristic of tribe crotalarieae. Absence of such membrane restores self-compatibility in *C. retusa* (Jacobi *et al*. 2005). Other mechanism operating towards self-incompatibility may be due to screening of pollen by pistil (Malti and Shivanna 1985). In contrast, selfing in many species of crotalaria is reported as a rule as in *C. sericeae* (Tidke and Patil 2000) or in the absence of insect visits and involves delayed selfing as in case of *C. micans* (Etcheverry *et al*. 2003). Attempts of bud pollination in sunnhemp to avoid self-incompatibility have largely remained unsuccessful. Other techniques of temporary suppression of self-incompatibilty may be evaluated for their effectiveness in getting selfed seeds. A self-compatible line "Bidhan Shan" was identified in seed production trials and self-pollinated seeds were collected from the plants (Das *et al*. 2000).

Crop improvement programmes

Genetic Resources and their evaluation : The National Bureau of Plant Genetic Resources (NBPGR), New Delhi, facilitates collection, regeneration, characterization and conservation of crotalaria germplasm in India. The most of the research for genetic improvement of sunnhemp particularly for fibre purpose, is undertaken at Central Research Institute for Jute & Allied Fibres (CRIJAF), Barrackpore, Kolkata, West Bengal and Sunnhemp Research Station, Pratapgarh, Uttar Pradesh, a constituent of CRIJAF.

Existence of genetic variability is of utmost importance for genetic improvement of any crop. In the genus crotalaria, the lack of genetic variability in phenotypic traits particularly at intra-specific level has hindered the crop improvement so far. Most of the species of the genus are unifoliate, carry zygomorphic flowers with green sepals and yellow showy petals. Exceptions are found for floral symmetry (actinomorphic flowers in *C. graminicola*), sepal colour (blue in *C. incana*) (Okeke *et al*. 2009) and petal colours (blue in *C. verrucosa)*. *C. retusa* is caharacteristic in having longest and widest pods.

Studies have been made towards understanding the genetic variability for different traits like for green manuring traits (Virdi *et al*. 2004) and for fibre yield traits (Mukherjee *et al*. 2009) and sufficient variability were recorded for the traits. Evaluation of germplasm collected from different sources revealed variability among the lines for different fibre yield traits. Kumar *et al*. (2008) evaluated sunnhemp germplasm lines collected from different parts of India and reported significant differences for most of the characters and indicated existence of genotypic variability.

Genetic diversity assessed using different techniques revealed a limited genetic diversity at intra-specific and moderate genetic diversity at inter-specific level. Genetic diversity studies using seed protein profile in different species of genus *Crotalaria* through SDS-PAGE (Raj *et al*. 2011) revealed distinctly different protein patterns. Jayanthi and Mandal (2001) using random amplified polymorphic DNA (RAPD) analysis in two populations of *C. longipes* reported limited polymorphism (0 to 33 %). No population differentiation was observed and individuals of both populations clustered with each other. Wang *et al*. (2006) assessed genetic diversity of the crotalaria germplasm collection using expressed sequence tag-simple sequence repeat (EST-SSR) markers derived from medicago and soybean. Phylogenetic analysis partitioned accessions into four main groups generally along species lines. A comprehensive study covering a few more economically important species of *Crotalaria* seems to be necessary to construct a more satisfactory classification and interpretation of evolutionary relationships. The intra-specific variations between the two accessions of any species can be resolved only by DNA based techniques. Sequence analysis of chloroplast genes could obtain a much more resolved phylogeny for genus *Crotalaria.*

Genetic Studies : Few studies are available regarding genetics of different traits in the crop. The lack of classical genetic studies might be attributed to the absence of morphologically distinct characters. The only distinctness observed is for seed colour with two froms, i.e. black and yellow. The hypocotyl pigmentation is another trait where two varieites can be distinguished. The inheritance pattern of anthocyanin pigmentation in flowers and hypocotyl of *C. juncea* was reported to be controlled by a single gene with anthocyanin pigmentation as dominant and no pigmentation as recessive form (Miranda *et al.* 1989). Similarly, seed coat colour was also reported to be a monogenic trait. Pleiotropy was noted for pigmentation on the seeds, petal bases and hypocotyls.

Study on green manuring aspect of sunnhemp revealed significant positive relationship among plant height, green and dry biomass and root nodule characters (Virdi *et al*. 2004). Tripathi *et al*. (2005) reported that the basal diameter of the plant had a high and positive correlation with the fibre yield. Plant height and total green weight at harvest were also significantly correlated with the fibre yield. Predominance of specific combining ability (sca) was reported in all the component traits like plant height, basal diameter *etc*. with the exception of fibre percentage (Kumar *et al.* 2012). The general combining ability (gca) was significant only in case of plant height.

Breeding Methodologies : Systematic sunnhemp breeding research in India started in early twentieth century with development of new strains of sunnhemp, viz. Jabalpur, K-12 Black etc. The earliest sunnhemp variety released officially was K-12 earlier known as "Cownpore-12" evolved in 1926 (Sabnis 1931) as a result of experiments conducted at Kanpur. The variety 'K-12 yellow' was developed from this variety (K-12) in the year 1971 with characteristic yellow seed coat colour. Subsequently, the breeding programme of Sunnhemp gained momentum by the support of Indian Council of Agricultural Research (ICAR, New Delhi, India). This resulted in identification new varieties like M-18, M-35 etc with novel traits like earliness and higher yield. Different methodologies employed for genetic improvement are mentioned in following paragraphs.

Conventional : Very little attention has been paid towards breeding efficient suunhemp variety. Most of the varieties released so far, are predominantly selection from the germplasm. Some features of crop like complex breeding behaviour including presence of self-incompatibility and extensive cross-pollination almost to the exclusion of selfing, lack of genetic variability and incongruence of distant crosses have hindered development of superior varieties. Another reason underlying is its predominant use for green manure where the crop is either ploughed at vegetative stage or at the onset of flowering. However, efficient varieties are required when the crops is to be grown for commercial value like yield or quality. Most of the varieties released so far, in sunnhemp are the result of mass selection. The variety development is focused towards higher yield (K-12 Black, K-12 Yellow), early maturity (M-18, ST-112), resistance to shoot borer (M-19 and M-35) and resistance towards wilt (ST-95, D-IX) and drought (M-18). The variety T-6 was reported to be day-neutral. Till recently, the varieties K-12 Black and K-12 yellow were the most popular. However, with time the variety K-12 yellow turned susceptible to viral infection. Present decade has evidenced release of superior varieties namely Shailesh, Swastika, Ankur and Prankur. Some of the improved varieties of sunnhemp are listed in Table 2.

Mutation : Mutation is regarded as a process known to increase genetic diversity (Yilmaz and Boydak, 2006). Induced mutagenesis was attempted in sunnhemp with a view to increase variability and isolate novel lines with improved characteristics. Khan (1981) reported variations among 10 doses of four crotalaria species for their effect on different quantitative traits. Translocation lines were induced in *C. juncea* as a resut of irradiation with gamma rays floowed by treatement with EMS or MMS (Verma and Raina 1991). Islam *et al*. (1994) also reported morphological abnormalities of *C. juncea* due to treatment with gamma rays and temperature for 12 to 36 h. Post-irradiation ageing effect on seed germinability and different morphological characters of *Crotalaria saltiana* were reported (Shah *et al*. 2008). Treated seeds showed diversity among themselves regarding morphological characters. Variation in plant height was observed. Irradiation of gamma rays resulted in mitotic disturbances and impaired seed germination (Kumar and Dwivedi 2014). Irradiated seeds may be used as a source of creating genetic variability. Mutations can be explored for their utility in developing efficient genotypes for increased fibre yield and enhanced green manuring ability.

Table 2 Improved varieties of Sunnhemp

Varieties	Year of release	Yield (q/ha)	Released from	Area recommended
K-12 Yellow	1971	9	Sunnhemp Research Station, (CRIJAF), Uttar Pradesh, India	All the sunnhemp growing areas of India.
Shailesh (SH-4)	2005	10-11		
Swastik (SUIN-053)	2009	11-12		
Ankur (SUIN-037)	2013	11-12		
Prankur (JRJ-610)	2015	11-12		

Polyploidy : Polyploidy was attempted in different species of crotalaria to enhance forage value of the crop. However, the results have not been encouraging in *C. juncea* (Dyansagar 1983, Arya and Rama Rao 1989) and in *C. sericea* (Gupta and Sinha 1978, Raghuvanshi and Joshi 1965). Induction of polyploidy was attempted in *C. linofolia* (Patil 1992) with the view to increase its forage value. Autotetraploid plants were produced by seedling treatment with colchicine. Leaves of tetraploid plants were thick, dark green and large in size with coarse texture. The large size of leaves in tetraploids enhances the forage value. However, contrary results have been reported in this regard in other species of crotalaria (Gupta and Gupta 1975, Gupta and Sinha 1978). Other effects of tetraploidy include increased stomata size, delayed flowering, prolonged flowering duration, reduction in frequency of flowers per inflorescence, remarked increase in pollen size, pollen sterility, low fruit set, appearance of rudimentary pods, smaller pods and wrinkled seeds. These may be due to chromosomal and genetic imbalance. Seeds obtained from polyploidy plants were slightly bigger than that of diploid seeds. The pollen sterility was attributed to high frequency of laggards, micronuclei during anaphase and telophase. The increased size of leaves make it economically more important. Most of the induced polyploids reported were sterile and revert to diploidy within few generations

(Mangotra and Koul 1991). It may be expected that selection among polyploid segregating generation may yield improved genotype.

Heterosis breeding : Heterosis has been exploited efficiently in many self- and cross-pollinated crops with great strides resulting in increased yield. Male sterility is the basic requirements for utilization of heterosis mechanism. Identification of male sterile lines in germplasm lines and their maintenance may necessarily break the yield barrier in sunnhemp. Male sterile plants have been reported in different species of the genus. Kempanna and Sastry (1958 noticed a single plant in *C. striata* with poorly developed, empty, small anthers that failed to dehisce in contrast to the big, yellow and plumpy anthers with abundant yellow pollen. They confirmed shrivelled microspores devoid of any content. The plant when bagged did not set any fruit. The progeny from outcrossing of such male-sterile line also produced male-sterile plants revealing dominance of male-sterile factor. Subsequently, male-sterility was also observed in *C. mucronata* Desv. (Edwardson 1967), *C. juncea* L. (Mitra 1976) and *C. pallida* Ait. (Gupta 1975). Arora and Gupta (1984) ascribed male sterility in *C. pallida* to some biochemical rather than morphological changes in tapetum and due to failure of cytokinesis after meiosis in microspore mother cells.

The production of inbreds in sunnhemp is constrained by near absence of seed setting under selfing. Chemical induction of male sterility was attempted in *C. juncea* using Maleic Hydrazide and Mendok (Kaul and Singh 1967). However, most of the chemicals able to induce male sterility possessed undesirable effects including harmful effect on female gametes, reduced pod set and other harmful effects. An extensive survey of many new chemicals possessing properties of ideal male gametocides is highly warranted.

Non-conventional/modern/biotechnological : The *in-vitro* technologies of tissue culture and transgenesis offer the scope for genetic enhancement of the crops and supplement conventional tools of crop improvement. The studies on micropropagation in *C. juncea* are lacking. However, reports are available on related species like *C. retusa,* where multiple shooting was induced from leaf cuttings on MS medium supplemented with growth regulators (Devendra and Srinivas 2011). The rooted shoots were successfully transplanted with 90% success. Micropropagation has also been acheived in *C. laburnifolia* (Rajender *et al*. 2012), *C. verrucosa* (Hussain *et al.,* 2008) and in *C. lutescens* (Naomita and Rai 2000). Micropropagation can be utilized in inducing desirable plants by somaclonal variation and in mass propagation of desired plants. Inbreds lines can be achieved in the froms of doubled haploids under *in-vitro* condition. Genetic purity can be maintained by sib-mating (with the aid of insects) of clones under controlled conditions like glass house/poly house.

Genetic engineering has emerged as an efficient tool in breeding efficient varieties or to induce variation in existing plant types. Transgenesis can be utilized in getting desired plants by introducing foreign genes across the kingdom and broadening the genetic base of the crop. A lot of genetic improvement can be expected in sunnhemp by use of transgenic technology which is difficult by conventional means on account of floral constraints. A transformation system free of *in-vitro* plant regeneration following *Agrobacterium* infection was established for sunnhemp (Rao *et al.* 2012). Transgenics were developed harboring the gene of the two major foot and mouth disease virus (FMDV) serotypes. Other *in-vitro* techniques like somaclonal variation and somatic hybridization may aid in induction of variability across species or genera and may yield efficient genotypes.

Future prospects

The limited genetic variability and genetic information has remained a bottleneck in the genetic improvement of the crop. However, the crop can gain momentum

Creation of genetic variation: The genetic variability can be increased by making a good collection of germplasm from diverse regions of the country and abroad. Peninsular India and North-Eastern considered to be hot-spot of biodiversity may be explored extensively for germplasm collection. Mutation can be employed to generate variability with particular emphasis on micro-mutation as they are considered the base for evolution. Mutant generations must be screened for different economic traits and for novel traits like self-compatibility.

Germplasm maintenance: It is mandatory to develop an efficient mechanism of ensuring germplasm purity or seed purity in seed multiplication trials keeping an account of its out-crossing behaviour. A method of selfing was standardized in CRIJAF, that consisted of controlled pollnation (sib-mating) in cages with the help of natural pollinators (*X. fenistroides, X. latipus species*.) kept in captivity. However, the possibility of its application has to be evaluated in case of large number of germplasm. Generation of clones using micropropgartion followed by sib-mating under controlled conditions offer the way for maintenance of genetic purity. This is subject to standardization of efficient micro-propagation protocol.

Genetic enhancement: Inter-specific crosses may be attempted to enhance the genetic value of the crop keeping in view of the limited variability in existing germplasm collection, particularly at intra-specific level. However, before making such attempts karyological study of species particularly with respect to ploidy level must be taken into account in order to get more number of fertile hybrids. Further, the techniques of ovule- and embryo-culture must be standardized in order to culture incongruent or semi-congruent crosses. The Somatic hybridization technique may be useful in achieving distant hybrids.

Exploitation of heterosis: Isolation of self-compatible lines and male sterile lines are needed for breakthrough in sunnhemp productivity enhancement. Self-compatible lines will be instrumental in ensuring the application of employing recurrent selection, an effective method of population improvement. Further, self-compatible lines will pave the way for isolation of inbred lines, which is essential for exploitation of heterosis. Male-sterility can be induced using new chemicals. Induction of male sterility can break the yield barrier in sunnhemp.

Ideotype breeding : Specific plant ideotype needs to be evolved for different usage like fibre, biofuel and green manuring species. Tallness, increased basal diameter, absence of branches etc. are required for high fibre yield. Higher biomass, high cellulose content and reduced lignin are desirable from bio-fuel point of view. The varieties intended for green manuring pupose must have extensive roots with effective nodules, more leaves, more branches etc. Selective elimination of pyrrolizidine alkaloids will add to its acceptance as forage crop.

Sunnhemp is a crop much valued for its economic and ecological importance. It finds multiple uses in rural household and in industries. However, the crop has received little research attention. Consequently, the genetic improvement in the crop has been limited. Unable to face stiff competition from staple crops, the crop has been shifted to marginal lands and to summer season. Conventional tools of plant breeding are of limited use in its improvement on account of complex breeding behavior. Hence, there is an urgent need to complement conventional tools with modern tools of crop improvement. The immediate solution in this regard may be development of composites. The long term aim is to develop new genetic lines (male sterile and self-compatible) that may result in high yielding varieties/hybrids with tolerant to abiotic stresses and biotic stresses. Since most of the sunnhemp area in India is now limited to marginal lands, there is a need of efficient genotypes having the potential to give high yield under low-input cultivation.

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