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Cashew improvement in India: retrospect and prospects

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ABSTRACT

Cashew, being an economically important crop, has been witnessing steady internal demand in addition to its export potential in the recent years. It is imperative to invest in crop improvement efforts for improving productivity and production. ICAR-Directorate of Cashew Research in Puttur, Karnataka is the nodal agency for cashew research in the country and it has the largest germplasm collection of cashew in its field gene bank. Sizable portion of the germplasm collection had been utilized in hybridization programme and molecular studies in various AICRP centers spread across the country. As many as 54 improved varieties have been released countrywide. The breeding efforts in cashew so far have concentrated on cashew nut but none of the evolve varieties are in jumbo nut category (>10 g nut weight). Also efforts are initiated towards development of varieties for cashew apple (fruit) and Cashew Nut Shell Liquid (CNSL) which have high industrial application. Recently, attempts are being made to change the genetic architecture of the plant from tall to dwarf, to cater to the needs of high density planting systems. However, source of resistance for major pests of cashew i.e. Tea Mosquito Bug (TMB) and Cashew Stem and Root Borer (CARB) are not available and this has hindered the development of resistant varieties. With these in background, a stock of information has been generated on genetic resource management, diversity analysis of cashew germplasm, finger printing, various breeding methods deployed and future thrust areas in crop improvement of cashew are discussed to address the ever increasing demand for cashew kernel, cashew apple and CNSL.

Keywords: *Anacardium occidentale*, breeding, diversity analysis, finger printing, germplasm, hybridization

INTRODUCTION

Cashew (*Anacardium occidentale* L.) belongs to the family *Anacardiaceae* and is a native of Brazil. It was introduced to India by Portugese during 16th century. Moreover, India is the first country to realize its importance of cashew and started growing it as commercial plantation crop but even today, cashew plantations are mostly on degraded lands in wild state in the states of Maharashtra, Goa, Karnataka and Kerala along the west coast, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal on the east coast. In recent years, some well managed cashew orchards are seen as in these states. To a limited extent, cashew is also grown in Chattisgarh, Gujarath, Assam, Arunachal Pradesh, Meghalaya, Tripura, Manipura, Nagaland and Andaman and Nicobar Islands (Singh, 1998). At present cashew is grown in an area of 10.27 lakh hectares with production of 7.25 lakh metric tons and productivity of 706 kg/ha i.e. during 2014-15. In addition to its export potential, the internal demand for cashew is ever increasing and hence it is imperative to increase production and productivity. Besides production management, the other feasible approach of achieving this is to intensify crop improvement efforts and development of high yielding varieties needs regular attention as the risk of production is increasing under the scenario of climate change which has association with biotic and abiotic factors. Thus, an effort has been made to review the work done in cashew improvement in India and future strategies have also been suggested after retrospection in order to address future challenges.

CASHEW IMPROVEMENT: HISTORICAL TIMELINE

Cashew research was initiated during 1950's by the Indian Council of Agricultural Research (ICAR) through *ad-hoc* scheme. The research activities got impetus as early as in 1971 with the establishment of All India Coordinated Spices and Cashew nut Improvement Project (AICS & CIP) at Central Plantation Crops Research Institute (CPCRI), Vittal

Campus (Karnataka). The National Research Centre for Cashew (NRCC) at Puttur, Karnataka was established in 1986 (Now the ICAR-Directorate of Cashew Research) and a coordinated approach for cashew research and germplasm collection was streamlined (Table 1).

Table 1: Chronology of cashew research in India

1950	ICAR *Ad-hoc* scheme on Improvement of cashew was taken up.
1971	All India Coordinated Spices and Cashew nut Improvement Project (AICS & CIP) was started.AICRP centers at different stations: 1970-Vengurla (Maharashtra) 1971- Bapatla (Andhra Pradesh), Vridhachalam (Tamil Nadu), 1972- Madakkathara (Kerala), 1975- Bhubaneswar (Odisha) and 1980-Chintamani (Karnataka),1982- Jhargram (West Bengal); 1993- Jagdalpur (Chattisgarh), Pilicode (Kerala); 2009- Paria (Gujarat), Kanabargi (Karnataka), Tura (Meghalaya) and Old Goa (Goa); 2010-Darisai in Jharkhand.
1986	Establishment of National Research Centre (NRCC), Puttur (Karnataka)During the Seventh Plan period, the project (AICS & CIP) was bifurcated into: –
	All India Coordinated Cashew Improvement Project and– All India Coordinated Spices Improvement Project. Headquarters of the independent cashew project shifted from CPCRI, Kasaragod to National Research Centre for Cashew, Puttur (Karnataka)
2009	NRCC was upgraded to ICAR-Directorate of Cashew Research, Puttur (Karnataka) along with All India Coordinated Research Project on Cashew (AICRP-Cashew) with 14 centres located in Paria (Gujarat); Vengurla (Maharashtra); Goa; Hogaligera and Kanabargi (Karnataka); Madakkathara and Pilicode (Kerala); Jhargram (West Bengal); Bhubaneswar (Odisha); Bapatla (Andhra Pradesh); Vridhachalam (Tamil Nadu); Jagdalpur (Chattisgarh); Darisai (Jharkhand) and Tura (Meghalaya).

GENETIC RESOURCE MANAGEMENT

Genetic resource management is the key component for crop improvement programme. In cashew also, initially impetus was given for germplasm collection and surveys were conducted by joint teams consisting of scientists of ICAR-DCR (the then NRCC) and the centres of All India Coordinated Research Project on Cashew (AICRP on Cashew) of the respective States (Bhaskara Rao and Swamy, 2000). The germplasm survey and collection were carried out in cashew growing States namely, Karnataka, Kerala, Maharashtra, Goa, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal. The non-traditional areas such as Garo Hills (Meghalaya), Bastar (Chhattisgarh), Gujarath, Dadra & Nagar Haveli and Andaman & Nicobar Islands were also surveyed for germplasm collection. So far, 539 accessions have been collected and conserved in the National Cashew Field Gene Bank (NCFGB) at the Directorate. Similarly, Regional Cashew Gene Banks (RCGBs) were also established at AICRP Centres which are maintaining a total of 1104 accessions (Table 2).

Table 2: Status of cashew germplasm holding in India

State	At NCFGB	At AICRP centers	Total
Andaman & Nicobar Islands	10	—	10
Andhra Pradesh	103	48	151
Arunachal Pradesh	2	—	2
Assam	3	—	3
Chattisgarh	1	61	62
Goa	45	—	45
Karnataka	128	128	256
Kerala	72	181	253
Maharashtra	45	297	342
Manipur	1	—	1
Meghalaya	11	—	11
Mizoram	1	—	1
Orissa	21	97	118
Tamil Nadu	46	200	246
Tripura	3	—	3
West Bengal	14	92	106
Exotic	22	—	22
Total	528	1104	1632

NCFGB: National Cashew Field Gene Bank; AICRP: All India Coordinated Research Project on Cashew

The germplasm accessions conserved in the NCFGB at NRCC, Puttur include the diverse types such as high yield, bold nut, semi-tall, compact, Cashew Nut Shell Liquid (CNSL) free, purple pigmented, high shelling percentage, cluster bearing, big apple and early maturity types. Further biochemical profiling of cashew varieties has been accomplished and accession with high mineral composition, neutraceuticals, proteins, starch, lipids, sugars, tannins, phenols, ascorbic acid and Cashew Nut Shell Liquid (CNSL) have been identified. The collection also has seedling accessions of 23 exotic collections of which nine were collected from Brazil, Nairobi, Mtwara, Lindi, Nacala, Mozambique, Ex Tanganyka, Singapore and Australia and 14 from Republic of Panama.

Of the 29 cashew varieties and 13 hybrids released in the country, the varieties are *per se* selections made from the germplasm material. These 28 varieties were identified at different centres. About 155 germplasm accessions have been effectively utilized for crossing programme at the ICAR-Directorate of Cashew Reserach (DCR), Puttur and several of these were also supplied to other cashew research centres for hybridization programme and other studies. For instance, a total of 75 cashew accessions have been supplied to AICRP on Cashew Centers/ICAR Research Complex for Goa for evaluation and hybridization programme. A total of 107 accessions (65 during 2001 and 42 during 2002 fruiting season) in NCFGB have been utilized as parents under the adhoc research scheme "Network Programme on Hybridization in Cashew" which was in operation during 2000-2003. Leaf samples of 34 varieties and 153 gemrplasm accessions have been supplied to Division of Horticulture, UAS, Bangalore for DNA Finger Printing of varieties and germplasm under the DST funded project. Leaf samples of 142 accessions have also been supplied to NRC DNA Finger Printing, New Delhi.

Presently, the hybridization programme is going on at DCR, Puttur and AICRP on Cashew centres at Bapatla, Bhubaneswar, Vridhachalam, Madakkatahra and Vengurle. The review of performance of varieties and hybrids indicated that in the States where both selections and hybrids were released for cultivation, the performance of hybrids is better than the selections. Hybrid vigour can easily be exploited in cashew because of the amenability of this crop for vegetative propagation. Recently, a program for development of varieties for cashew apple has also been initiated at the Directorate and this is expected to provide impetus for cashew apple utilisation.

Diversity Analysis

Moderate genetic diversity has been observed in germplasm collections in studies with RAPD markers. Further it was found that among RAPD, ISSR and AFLP markers, AFLP was found to have superior marker efficiency in differentiating germplasm accessions. A total of 172 accessions comprising collections from 9 states of India and exotic sources were fingerprinted using both RAPD and ISSR markers (Thimmappaiah *et al*., 2009). Based on Shannon's information index and percentage of polymorphic loci, it is evident that high genetic variation was observed in the collections of Karnataka, Kerala and Andhra Pradesh. There was more diversity (96% variation) existed within the groups than between the collections (4% variation) from different states. Among the accessions NRC-432 and NRC-119 were highly divergent and NRC-235 and NRC-216 were highly similar. The cluster analysis performed to create dendrogram distinguished 17 clusters in all. Although there was no correspondence between the centre of collections and clusters, there were some exceptions as species from Brazil like *A. othonianum* and *A. pumilum* were found to cluster together in the same sub-group and some sub-clusters were in agreement with morphological clusters . From 17 clusters, 63 accessions were identified to form a 'core collection'.

Similarly genetic diversity and species relationship in 10 diverse types of cashew including three species (*Anacardium pumilum* St. Hillarie, *A. microcarpum* Ducke, *A. othonianum,* three inter-specific hybrids i.e. V-5 (*A. occidentale*) x *A. pumilum*, *A. pumilum* X V-5 (*A. occidentale*) and *A. orthonianum* X V-5 (*A. occidentale*) and four genotypes of *A.occidentale* was assessed using RAPD, Isozymes and SSR markers. In the cluster analysis three broad groupings were distinguished: In first group *Anacardium pumilum* was found clustering with two of its inter-specific hybrids, in the second group *Anacardium othonianum* clustered with one of its inter-specific hybrid and a dwarf accession Kodippady and while in the third group contained most accessions of *Anacardium occidentale* clustering with *Anacardium microcarpum* thus indicating close affinity between *A.occidentale* and of wild species *A. microcarpum*.

Fingerprinting of Cashew Varieties

Fingerprinting of 40 varieties released in the country was carried out in ICAR-DCR laboratory using RAPD, ISSR and SSR markers. Polymorphic markers generated with a combination of 10 primers each of RAPD and ISSR markers and 15 primer pairs of SSR of cashew used in the analysis. Marker analysis was carried individually and by combining all the three markers. Based on the combined markers, Jaccard's coefficient of genetic similarity between the different pairs of varieties varied from 0.54 to 0.81 with an average similarity of 0.68 indicated low diversity existing among the varieties studied. Highest similarity was observed between Goa 11/6 and VRI-3 and lowest similarity was observed between Kanaka and V-2. UPGMA dendrogram grouped 40 varieties in to 8 to 10 clusters at 75% similarity. Among the varieties, Kanaka, Jhargram and V-6 were highly divergent. Varieties clustered together irrespective of their geographic origin indicating no relation between the clusters and the origin of varieties.

Apart from DNA markers, Isozyme markers which are co-dominant were used for characterization of varieties. In our laboratory, Isozyme extraction from young cashew leaves was standardized using Arulsekhar and Parfitt buffer. Extraction and staining protocols for 14 enzymes have been standardized so far. Fingerprinting of 30 varieties of cashew was carried out with Isozyme polymorphism of 10 enzymes. By assaying 10 enzymes, 33 Isozyme bands (loci) were observed (1-4 bands per enzyme) with an average of 3.3 bands per enzyme; of which 23 bands were polymorphic (69.7%) and 10 were monomorphic. Among the different enzymes, Isozymes of Shikimate dehydrogenase were found to be highly informative. Cluster diagram made with Isozyme markers indicated that Ullal-1 and V1 as most divergent. Groupings based on Isozyme and RAPD were not identical nor with any marker type.

CROP IMPROVEMENT

Improving the nut yield is the major objective of breeding in view of lower productivity in cashew. The variability existing in the germplasm suggests that the objectives of breeding are attainable once positive results are already obtained for nut yield and apple quality which are important in Brazil (Barros *et al*., 2000). Since cashew apple, which yields nearly 10 times that of nut, has tremendous potential to be exploited as value added product, breeding objectives should also consider apple parameters for improvement. Pests and diseases as well as abiotic stresses also affect the yield and must be given priority while formulating breeding programmes. As cashew shell has Cashew Nut Shell Liquid (CNSL), which is a valued product, crop improvement programme can also include attributes related to CNSL yield also. In the Directorate of Cashew Research, it was observed that when tall accessions are crossed with dwarf accessions, majority of the resulting progenies have tall stature indicating that tall is dominant over dwarf character. In Madakkathara centre, when three parents with prolific bearing and three bold nut type parents were used for hybridisation, It was evident that wherever Brazil-18, an exotic bold nut accession was used in hybridisation, the percentage of high yielding progenies was more compared to other accessions within the country.

BREEDING OBJECTIVES

1. **High yield potential:** Cashew is a trade oriented crop; emphasis should be given to develop variety with bold nuts coupled with high yield which gives kernels of superior grade. This is a great challenge for the cashew breeders even though some achievements are visible. A breeder must aim at developing a variety giving a minimum of 10 kg yield / tree after attaining stabilized bearing i.e., 10 years after planting at normal spacing.
2. **Dwarf and compact canopy types:** Required for high density planting system. These types minimize cost of cultivation and give more return per unit area.
3. **Short flowering duration:** Short flowering types will reduce the crop loss due to pest and disease infestation, reduce the expenditure for managing the pests and diseases and also reduces the cost of harvesting of nuts.
4. **High sex ratio (hermaphrodite: staminate):** Care should be given to select trees with higher extent of mixed phase of flowering with higher percentage of hermaphrodite flowers as parents than trees having distinct male or hermaphrodite phases. This would result in increased proportion of trees having more percentage of bisexual flowers culminating into higher fruit set in the selected progenies.
5. **Resistance/ Tolerance to Tea Mosquito Bug (TMB):** Developing varieties having field tolerance to this pest and mid season flowering types to escape from attack of this pest should be given importance.
6. **Resistance/ Tolerance to Cashew Stem and Root Borer (CSRB)**: This is the serious pest as it kills the tree slowly after infestation. Hence development of varieties resistant to this pest is more important. However, at present, there are no genotypes in germplasm which are tolerant or fairly resistant to CSRB.
7. **Disease resistance:** Anthracnose and black mold are the major global fungal diseases which cause huge losses in nut yield and nut and apple quality. Hence efforts should be made to develop varieties resistant these diseases.
8. **High shelling percentage:** For higher recovery of kernels, a variety should have shelling percentage of more than 28% which is the major concern of the processing industries.
9. **Nutrition quality:** Need to develop varieties with high nutritive value like rich in kernel protein and minerals and less in sugars.
10. **Breeding for cashew apple:** Varieties possessing big size of cashew apple with higher juice recovery and high TSS need to be developed for cashew apple processing industries.
11. **Breeding for varied CNSL content:** Cashew Nut Shell Liquid, a byproduct of cashew, is a raw material for various industries like paints and varnishes, resins, industrial and decorative laminates, brake linings and rubber resins. The genotypes having more of CNSL contents are also required to be identified. However, lower CNSL content is not desirable as those plants with less CNSL are more prone for insect attack and rat and porcupine damage to the nuts.

BREEDING METHODS

Cashew is a highly cross pollinated crop and hence is highly heterozygous. It has the twin advantages of propagation through seeds and vegetative means. The commonly pursued breeding methods in cashew are plant introduction, hybridization and clonal selection and population improvement. The best identified hybrids can be multiplied by vegetative method called wedge grafting or soft wood grafting technique and thus hybrid vigour can be easily fixed and exploited in cashew. According to Barros *et al*.

(2002) cashew breeding programs typically comprise the following stages: plant introduction, progeny testing, individual selection and hybrid breeding. Much emphasis was given in the past to exploit heterosis in the improvement of cashew since hybrids were found to perform better than selections. Hence the breeding strategies have been focused on generation and selection of superior hybrids, combined with the vegetative propagation of elite clones. But the genetic base of the crop for some desirable traits still needs to be expanded by targeted introgression of new desirable alleles (Cavalcanti *et al*., 2000, Cavalcanti *et al*., 2003). Recently molecular Marker Assisted Selection (MAS) is also being employed in cashew breeding programmes to reduce the breeding time. The breeding methods applicable in cashew are detailed below.

Plant Introduction

Plant introduction is the easiest way of collecting genetic resources from the country of origin or from the countries or regions where variability already exists. Cashew belongs to Brazil but it has now been introduced to other parts of the world and adapted to environments prevailing in those regions. By this way other countries are exploiting the benefits offered by this crop. Besides, related species and genotypes can also be introduced to enrich diversity, particularly from Brazil, provided it permits to do so under WTO regime.

Individual Phenotype Selection

The cashew genotype is selected for particular trait of interest based on the phenotype. Here the selection depends on the influence of environmental factors on characters under consideration. In order to reduce the time lag, there is a scope to select the phenotype in the desired environment only. Also there is no control on the male parent and selected plants are pollinated with a random mixture of pollen which ensures cross pollination with related genotypes. The disadvantage of this methodology is the possibility of loss of genotypes with potentialities not expressed in the environment in which the selection is made because of adverse environmental conditions as well as inadequate evaluation. Parent control occurs only on the female side. This kind of lack of control on environmental effect and male parent effect can be minimized when clonal selection is done through progeny test or hybridization followed by individual selection.

Hybridization

Hybridization can expand the gene pool in relation to genes with different adaptive values, as long as the hybrids are able to produce segregating progeny in future generations (Stebbins, 1974). Evidence of hybrid vigour with an increase of up to 153 per cent in the nut yield as compared to plants derived from outcrossed pollinations were reported by Damodaran (1975). The prevalence of heterosis in hybrids of cashew with respect to nut yield, nut weight and kernel weight were reported by Manoj and George (1993) and Cavalcanti *et al*. (2000). Hybridization work carried out at several cashew research centres in India (Puttur, Vengurla, Bapatla, Madakkathara and Bhubaneswar) showed that hybrid vigour existed for yield and hybrids were found to perform better than selections in cashew.

Hybrid Vigour

It was observed from the hybridisation work carried out at Anakkayam (Kerala) that whenever an exotic parent was involved, the progeny showed better performance than crosses between local types. These results are in agreement with the established concept that hybrid vigour is best manifested in crosses involving parents with greater genetic diversity. Hybridization work carried out at other centres (Vengurla, Bapatla and Vridhachalam) also confirms expression of hybrid vigour in cashew. Comparison of the performance of hybrids with open pollinated and selfed progenies also showed the superiority of the hybrids over others (Nambiar *et al.,* 1990). Manoj and George (1993) reported heterosis for nut yield per tree in 10 year old F_1 hybrids and the standard heterosis (standard variety-Madakkathara-1) ranged from 11.0 – 33.4%. They have also reported standard heterosis for mean nut weight (11.4 – 54.8%) and weight of kernel (29.8 – 84.7%).

RESEARCH ACCOMPLISHMENTS

So far, 54 varieties have been released from different research centers and ICAR-DCR (formerly NRCC). Among them 34 are selections and 20 are hybrids. Twenty four varieties are having kernels with export grade (W 180 - W 240). A National Group meeting was convened in 1988 to finalise production strategy of different plantation crops. This group suggested cultivation of several varieties of cashew in different states based on the varietal performance in different regions and their availability. Subsequently several cashew varieties have been released for general cultivation by different AICRP centers in different states. Some varieties developed in one state/region were found to perform well in other states/regions as well. The list of recommended varieties for each state is given in the Table 3.

Table 3: Recommended varieties of cashew for different states

State	Recommended varieties
Karnataka	NRCC Sel-2, Bhaskara, Ullal-1, Ullal-3, Ullal-4, UN-50, Vengurla-1 (Uttara Kannada), Vengurla-4 (Uttara Kannada), Vengurla-7 (Uttara Kannada)
Karnataka (Plains region)	Chintamani-1, Chintamani-2 and Dhana (H 1608)
Kerala	BLA-39-4 (Madakkathara-1), NDR-2-1 (Madakkathara-2), K-22-1, Kanaka (H 1598), Dhana (H 1608), Priyanka (H 1591), Amrutha (H 1597), VRI-3
Maharashtra	Vengurle-1, Vengurle-4, Vengurle-6, Vengurle-7, Vengurle- 8 Vengurle-9
Goa	Goa-1, Goa-2, Vengurla-1, Vengurla-4, Vengurla-6, Vengurla-7
West Bengal	Jhargram-1, Bidan Jhargram-2, BPP-8
Orissa	Bhubaneswar-1, BPP-8, Dhana
Tamil Nadu	VRI-3, VRI (Cw) 5
Andhra Pradesh	BPP-4, BPP-6, BPP-8
Chattisgarh	Indira Kaju-1

H-126 : FIRST JUMBO NUT HYBRID

As a result of massive hybridization programme to evolve bold nut hybrids to fetch premium in export market several hybrids were generated under an ICAR ad-hoc scheme "Network programme on Hybridization in Cashew. As a result, hybrid H-126 (cross combinations of NRCC Selection-2 × Bhedasi) has been identified as promising and found to be consistently performing good for both annual (8 kg nut /tree) and cumulative yield(46.10kg nut/ tree) over eight harvest under un replicated trial, recording an average yield of nearly 6 kg/tree including juvenile plant yield(up to sixth harvest). Up on replicated trial also, the hybrid, H-126 was found promising with a special character of jumbo nut (nut weight of 11.5-12g), with a shelling percentage of 29.1 and kernel weight of 3.3 g which fits in to kernel grade bigger than W150. So far no released hybrid has recorded kernel grade above W 180. Because of the jumbo nuts, apart from saving labour on picking, this hybrid can ensure about 15% higher price for the farmers due to higher nut size (Adiga *et al,* 2015).

Apart from saving labour on shelling and peeling during processing in the industry, due to high shelling percentage coupled with higher nut weight, this hybrid produces kernels with higher grade (kernel grade higher than W 180), which fetches premium price in the market for the processors. The added advantage is the uniformity in nut size, wherein, more than 95% nuts fall in to jumbo nut category. The kernels of these hybrids fetch nearly double the price that of W320 grade kernels. This hybrid recorded 91.50% higher nut weight and 79.50 % higher kernel weight compared to popular variety Bhaskara. As compared to bold nut variety NRCC Selection-2, H-126 recorded 46% higher nut weight and 36% higher kernel weight. The hybrid also recorded higher values for nut parameters like nut thickness and nut width. The hybrid recorded significantly higher annual yield in the fifth harvest compared to local checks(Bhaskara and NRCC Selection-2).The yield potential in the fifth harvest (juvenile harvest) was found as 1.65t/ ha, which is highly promising in view of the jumbo nut size and higher kernel grade. The hybrid also recorded an apple weight of 102g with a juice content of 72% with a TSS of 13 degree brix. The bigger size of apple coupled with high juice content and TSS can make this hybrid suitable for apple utilization also. This hybrid is expected to fetch premium in export market because of jumbo nut size.

Fruiting bunch of H-126 Kernels of H-126

BREEDING FOR SPECIAL CHARACTERS

The special characters looked at for cashew breeding are as follows.

a) For bold/ jumbo nuts

Bolder cashew kernels fetch premium price in the international markets. Hence, emphasis is being given to develop new improved cashew varieties with bold nut size and high yield potential. More than 70 bold nut types having a mean nut weight of 12-21 g have been collected by Regional Fruit Research Station, Vengurla (Maharashtra). Some of these bold nut types have been used in the hybridisation with existing high yielding varieties like Vengurla-2 and Vengurla-5. Some of the hybrids, viz., H-610, H-613 had given high yield and bold nut size (10 g) (Gunjate and Deshpande, 1994). Large scale hybridization was carried out under an ICAR ad-hoc scheme "Network programme on Hybridization in Cashew Among the hybrid seedlings under evaluation at DCR, Puttur, hybrids namely H-43, H-66, H-68 (cross combinations of NRCC Selection-2 × Bhutnath-II), H-125 and H-126 (cross combinations of NRCC Selection-2 × Bhedasi) have been identified as promising and found to be consistently performing good for both annual and cumulative yield. Upon testing under replicated trial, the hybrids, namely H-125 and H-126 were found promising with a special character of jumbo nut (nut weight of 11-12g) with kernel grade better than W150.

b) For dwarf tree stature and prone to pruning

Currently, the concept of high density planting using dwarf genotypes with compact canopy is gaining more acceptances in cashew cultivation. In Brazil, dwarf root stock seedlings have been used for several years. More recently, research workers were able to succeed by using seedlings from *A. microcarpum* Ducke and *A. Pumilum*, the slow growing species. These two types of root stocks, more markedly the latter, exert a dwarfing effect and induce earlier bearing upon the grafted trees. No symptoms of root stock–scion incompatibility have been observed so far (Ascenso, 1986). The spreading nature of the tree is not desired for commercial orchards as it does not allow high density plantings (Chacko *et al.* 1990). Therefore, trees with more erect growth are currently being selected in Australia. Efforts are also on at Directorate of Cashew Research to develop dwarf and compact hybrids with high yield and better nut characters. These hybrids developed by hybridizing recommended popular varieties with dwarf types from germplasm block as donors showed the signs of precocity and reduced growth habit.

For high density planting system, not only dwarf varieties are ideal but varieties responsive to pruning should be preferred. Varieties like VRI-3, NRCC Selection-2, K-22-1 and Ullal-1 are preferred due to their productive response to pruning (Saroj and Nayak, 2016).

c) For drought tolerance

Cashew is predominantly grown in rainfed conditions on marginal soils and hence often experiences drought stress. Plants adaptation to such situations by increasing efficiency of water use for biomass production is an important physiological trait. Any attempt to improve water use efficiency (WUE) primarily depends on the existence of sufficient genetic variability and availability of a convenient technique for its rapid determination. Genetic variability in WUE was determined by both Gravimetry and Gas Exchange approaches in 10 cashew clones. Carbon Isotope Discrimination (CID) ($D^{13}C$) could be a potential too in quantifying the variability in WUE. Plants discriminate against the heavy isotope of carbon ($D^{13}C$) during photosynthesis. This carbon isotope discrimination (CID) ($D^{13}C$) has been well established as a measure of WUE in several crop plants. A strong association between ($D^{13}C$) and WUE in cashew suggests that CID techniques can be employed as a powerful approach to assess the genetic variability in cashew also. Breeding for WUE will succeed only when selection for high WUE accompanies higher growth rates (Udaya Kumar *et al.,* 2000). Not much work has been done on this aspect of cashew so far. However, cashew varieties namely, VRI-2, VRI-3, BPP-1, BPP-2, BPP-8 and Dhana were reported to be drought tolerant. Therefore, screening of high yielding types in drought prone areas for yield may be taken up.

d) Breeding for pest resistance/ tolerance

Tea mosquito, stem and root borer and thrips are the major pests of cashew for which resistant/ tolerant types need to be developed. Laboratory screening of 27 accessions at DCR to tea mosquito tolerance has indicated that two accessions/ types, namely G 11/6(released and popularly known as "Bhaskara) and VTH 153/1, are relatively tolerant than the susceptible check and some of the test accessions (Nagaraja *et al.,* 1990). Uthaiah *et al*. (1994) reported low infestation of tea mosquito on type 9/72 at Ullal, Karnataka as compared to the susceptible types 2/48 and 145. The hybrids were also generated from cross combinations involving popular and recommended varieties with wild species like *A. microcarpum* and *A. orthonianum* to look for tolerance to pests of cashew. These inter specific hybrids are under field evaluation at DCR, Puttur.

e) For quality kernels

At present no emphasis is placed on the quality of cashew kernel. But with increasing competition from African countries in the international market, it is essential to breed varieties with superior quality. Data collected so far from defatted kernel flour indicated that there is considerable variability for protein ranging from 32-44 per cent, lysine 35-75 mg/mg protein, vitamin-C 144-274 mg/ 100g and kernel sugar 10-19 per cent. It is desirable to identify the varieties with the protein level of over 35 per cent, lysine level of over 50 mg/mg protein and sugar content of not more than 14 per cent (Bhagavan, 1986).

f) Mutation breeding

Occurrence of natural mutants and bud sports in woody trees like cashew is very rare. Induction of mutation with chemical or irradiation has not been practised regularly. However, this tool appears to be very potent from the work initiated at Regional Fruit Research Station, Vengurle, in 1985. The irradiation of cashew bud sticks with one, two and three Kr gamma rays at the Bhaba Atomic Research Centre, Bombay and soft wood grafting led to mortality of all the bud sticks subjected to 3 Kr dose. Whereas those subjected to 1 and 2 Kr dose led to 100 per cent sprouting and variation in phenotypic characters. The variations included changes in leaf shape, leaf thickness and leaf venation. When these plants were examined subsequently, many were observed to revert to original characters in subsequent growth. At Cashew Research Station, Madakkathara (Kerala), dwarfism was observed in seedlings produced from the nuts irradiated at 40 Kr to 60

Kr using Cobalt 60. The LD 50 value for cashew nut is between 40-50 Kr. The dwarf seedlings have been planted in the field and are being observed. Beyond 60 Kr, the seed nuts did not germinate (Abdul Salam *et al.,* 1992).

g) Distant hybridization

National Cashew Field Gene Bank at the ICAR-Directorate of Cashew Research, Puttur conserves 539 germplasm accessions including three wild species *Anacardium microcarpum, A. othonianum and A. pumilum*. An attempt of interspecific hybridization with four varieties (Ullal-1,Ullal-3, Vengurla -4 and Bhaskara) of cultivated cashew (*Anacardium occidentale* L.) was made during 2010 involving two wild species viz, *Anacardium microcarpum* and *Anacardium othonianum* with the objective of introgressing characters related to biotic and abiotic stress tolerance. The average seed set of all the successful cross combinations put together was 53%.The average seed set was 51 % when *A. microcarpum* was used either as male or female parent, while, it was 55 % when *A. othonianum* was used as male parent. However, highest success of 71% seed set was observed in the cross Ullal-3 x *A. microcarpum* and the lowest success of 25 % seed set was observed in the cross Vengurla-4 x *A. microcarpum*. The varied success could be attributed to extent of cross compatibility between different combinations involving wild species of cashew.

The frequency distribution of girth, height, spread (in both directions) showed approximately symmetrical distribution. The number of flowering laterals in East, West, North and South directions showed highly positively skewed distribution indicating the absence of individuals having higher number of flowering laterals. However, non flowering laterals in East, West and South directions showed approximately symmetric distribution and in North direction it showed moderately positively skewed distribution. The yield of interspecific progenies (N=189) ranged from 0 - 0.83 kg/tree in the fourth year after planting with a mean yield of 0.34 kg/tree. The frequency distribution pattern of yield per tree revealed that it was approximately symmetrically distributed (Skewness = 0.23). It can be observed that yield in interspecific progenies in very low due to introgression of wild alleles. Making one or two further backcrosses may help in improving the yield levels along with tolerance to biotic and abiotic stress in these progenies (Adiga *et al*, 2015)

FUTURE STRATEGIES

Hitherto, crop improvement in cashew was aimed at higher yield with high shelling. Recently, efforts are under progress to breed bold nut types, dwarf types to suit high density orchard as well as to introgress desirable genes from wild species of *Anacardium* to the recommended varieties by hybridizing with them. In order to reorient the crop improvement programme to cater the present and future needs of cashew industry, the following strategies seem to be appropriate.

Since there is a moderate amount of diversity available in Indian cashew germplasm due to limited introduction episodes, it is essential to introduce and enhance genetic variability from countries of Central and South America. The introduction of dwarf accessions from Brazil needs and subsequent development of dwarf hybrids needs special mention since dwarf types are very much required for high density planting systems to improve productivity. Further, rootstock breeding to address issues related to tree vigour (dwarfing) and adaptability to biotic and abiotic stresses needs attention.

Breeding for cashew apple with regard to better size, shelf life, juice content, TSS, vitamin C, antioxidants etc to address issues related to secondary agriculture need to be given importance. Introduction of *A. gigantium* from Surinam which with biggest apple (200 g) will be advantageous, especially in states like Goa where the cashew apple utilization contributes substantially to the economy of the state. Generation of core collections, further utilization of germplasm accessions in hybridization programs, exploitation of unique types such CNSL free and rich types are some of the areas that need attention in the ensuing days. Molecular marker assisted selection/ molecular breeding to speed up the process of evolving desired varieties and development of genotypes with high productivity (minimum 2 tonnes/ha) even under rainfed conditions with low soil fertility are among priority areas.

One of the main problems in cashew is that all the existing germplasm and released vareiteies/hybrids are susceptible to CSRB which kills the trees. There is a need to screen the allied species (for their suitability as root stocks) which have relatively hard wood and also posses smooth bark. It is suggested that introduction of species like *A. rhinocarpus* and *A. spruceanum* from Brazil which are reported to possess hard wood will be useful for testing their suitability as root stocks. However, more comprehensive exploration is required for target specific traits such as resistance to Tea Mosquito Bug (TMB) and Cashew Stem and Root Borer (CSRB), high yield, dwarf and compact, bold nut with cluster bearing, tolerance to drought, frost, salt and other problematic soils etc. In addition, breeding for resistance/ tolerance to diseases like anthracnose, powdery mildew, panicle drying, gummosis etc. needs to be imitated.

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