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Cashew research in India

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ABSTRACT

Cashew, after its introduction from Brazil during the16th Century, has established very well in India. A total of 40 high-yielding varieties have been released so far by the Directorate of Cashew Research, Puttur, and various Agricultural Universities, for cultivation. Of these, 13 are hybrids and 27 are selections. Research achievements in the area of crop improvement, management, protection and post-harvest technology over the last six decades are reviewed and documented here. As India has been importing raw nuts to the tune of 6.5 lakh tons annually to cater the demand of established processing factories, research priorities have been identified to meet the challenges of enhancing production and productivity of cashew in the country.

Key words : Cashew, research achievements, research priorities

INTRODUCTION

Cashew is native to Brazil. It was introduced into India by Portuguese travellers in the 16th Century for afforestation and soil conservation. India was the first country in the world to exploit international trade in cashew kernels in the early part of 20th Century. Cashew is presently grown in an area of 8,93,000 ha. with annual production of 6,95,000 tons of raw cashewnuts. Most of the area under cashew is the in East-Coast and West-Coast regions of the country. In India cashew is grown mainly in Maharashtra, Goa, Karnataka and Kerala along the West Coast and Tamil Nadu, Andhra Pradesh, Orissa and West Bengal along the East Coast. It is also grown to a limited extent in non-traditional areas such as the Bastar region of Chattisgarh and Kolar (Plains) region of Karnataka, in Gujarat, Jharkhand and NEH region. Although Andhra Pradesh has the largest area under cashew, Maharashtra ranks first in production and productivity (Table 1).

India requires about 12-13 lakh tons of raw cashewnuts to feed the large number of cashew processing units (1800 medium to large, and 1850 on-farm processing units) engaging over 5 lakh workers, especially women. As India produces just 6.95 lakh tons of raw cashewnuts annually, the balance of 6.0 lakh tons of raw cashewnuts is imported annually by India from the African and South East Asian countries. India exports 1.1 lakh tons of cashew kernel to over 65 countries in the world. About Rs.2,906 crore is earned as foreign exchange through export of cashew kernel, and an additional Rs. 24 crore by export of the Cashew Nut Shell Liquid (CNSL) (Table 2).

Table 1. Area, production and productivity of cashew in India in 2008-09

State	Area (ha)	Production (tons)	Productivity (kg/ha)
Kerala	70,000	75,000	900
Karnataka	1,07,000	60,000	720
Goa	55,000	30,000	700
Maharashtra	1,70,000	2,25,000	1,500
Tamil Nadu	1,31,000	68,000	710
Andhra Pradesh	1,82,000	1,12,000	920
Orissa	1,37,000	95,000	865
West Bengal	11,000	11,000	1,000
Gujarat	6,000	4,000	700
NE States	16,000	12,000	750
Others	8,000	3,000	460
Total	8,93,000	6,95,000	Average 900

There is an ever-increasing demand for cashew kernel both in international and domestic markets. Countries such as Vietnam and Brazil compete with India in the international market. Since African countries have started processing raw cashewnuts themselves, availability of raw cashewnuts for import by India may gradually decline or altogether stop. A few African countries have already taken steps to ban export of raw cashewnuts. Hence, there is an urgent need to increase domestic raw cashewnut production and become self-sufficient.

Table 2. Trade analysis in cashew produced during – 2007-08, 2008-09 and 2009-10

Particulars	2007-08	2008-09	2009-10
Import of raw cashewnut (quantity)	6.06 lakh tons	6.06 lakh tons	7.53 lakh tons
Import of raw cashewnut (value)	Rs.1746.80 Crore	Rs.2631.78 Crore	Rs.3,037.35 Crore
Export of cashew kernel (quantity)	1.14 lakh tons	1.08 lakh tons	1.08 lakh tons
Export of cashew kernel (value)	Rs.2288.89 Crore	Rs. 2950.24 Crore	Rs.2905.82 Crore
Export of CNSL* (quantity)	7813 tons	6976 tons	9748 tons
Export of CNSL* (value)	Rs.11.97 Crore	16.79 Crores	24.11 Crore
Foreign exchange earning (Kernel + CNSL*)	Rs.2300.86 Crore	Rs.2967.03 Crore	Rs.2929.93 Crore

*CNSL: Cashew Nut Shell Liquid

Table 3. Potential area available for expansion of cashew

State	Area(ha)
Bihar	25,000
Goa	10,000
Jharkhand	25,000
Chhattisgarh	50,000
Kerala	25,000
West Bengal	25,000
Gujarat	25,000
Tamil Nadu	25,000
NEH Region	50,000
Andhra Pradesh	1,00,000
Karnataka	1,00,000
Orissa	1,00,000
Maharashtra	1,50,000
Total	7,10,000

Traditionally, cashew has been an important crop in the Coastal Region (Western and Eastern) of the country but has been recently spreading to non-traditional areas as well. There is great scope for expanding area under cashew in the plains of Karnataka, Chattisgarh and non-traditional areas of Gujarat, Jharkhand, North Eastern Hilly Region and Andaman and Nicobar Islands (Table 3).

Cashew research in India started way back in 1950s through launch of *ad-hoc* schemes sanctioned by Indian Council of Agricultural Research (ICAR). Cashew research got further impetus through formation of Central Plantation Crops Research Institute and, later, establishment of an independent National Research Centre for Cashew (NRCC), Puttur, in Karnataka in 1986. Location-specific research programmes in the eight cashew growing states are conducted through All India Coordinated Research Project on Cashew (AICRP on Cashew) whose Headquarters are also located at the Directorate of Cashew Research (DCR) (formerly National Research Centre for Cashew), Puttur. There were eight centres and one sub-centre under AICRP on Cashew, located all over the country till the end of 10th Five Year Plan. In the year 2009 during 11th Plan, one centre each in Gujarat and Jharkand and 3 co-operating centres (Arabhavi in Karnataka, Goa and Tura – Barapani in Meghalaya) were included under AICRP on Cashew.

With combined efforts of the Directorate of Cashew Research, Centres of the AICRP-Cashew and SAUs, over 40 high yielding cashew varieties have been developed and released in the country (Table 4).

CROP PRODUCTION AND IMPROVEMENT

As cashew is a cross-pollinated crop, propagation by vegetative means was attempted. Among the various methods tested, softwood grafting was found to be the best for vegetative propagation (Swamy *et al*, 1993). It has also been shown that softwood grafting is feasible for commercial multiplication. Based on these results, India has been producing over 15 million grafts annually under both government and private sectors.

Germplasm collection and characterization

Attempts have been made to collect, conserve, evaluate and catalogue all cashew germplasm available in the country. Regional Cashew Germplasm Centres have been established, both at DCR and various AICRP Cashew Centres spread out over the country. Germplasm-holding at DCR, Cashew, and AICRP Cashew Centres is presented

Table 4. Cashew varieties released in India

Centre	Number	Variety
East Coast		
Bapatla	7	BPP-1 to BPP-6 and BPP-8
Vridhachalam	4	VRI-1, VRI-2, VRI-3 and VRI (Cw) 5
Bhubaneswar	1	Bhubaneswar-1
Jhargram	1	Jhargram-1
West Coast		
Vengurla	7	Vengurla-1 to Vengurla-7
Goa	2	Goa-1 and Goa-2
Madakkathara	8	Anakkayam-1, Madak-1 (BLA-39-4), Madak-2 (NDR-2-1), K-22-1, Kanaka, Dhana, Priyanka and Amrutha
Ullal	5	Ullal-1, Ullal-2, Ullal-3, Ullal-4, UN-50
DCR Puttur	3	NRCC Selection-1, NRCC Selection-2 and Bhaskara
Maidan Area		
Chintamani	2	Chintamani-1 and Chintamani-2
Total	40	

Table 5. Cashew germplasm-holding

Centre	Number
DCR, Puttur	527
AICRP- Cashew Centres :	
Bapatla	132
Bhubaneswar	98
Jhargram	119
Vridhachalam	208
Madakkathara	130
Pilicode	43
Vengurla	302
Chintamani	128
Jagdalpur	65
Total	1225

in Table 5. Cashew germplasm collection in National Cashew Field Gene Bank (NCFGB) at DCR, Puttur has 527 accessions (Fig. 1). A total of 433 cashew accessions have been assigned National Collection numbers. A total of 285 accessions have been characterized as per IPGRI descriptors. Three germplasm catalogues for 255 accessions have been brought out (Swamy *et al,* 1997; 1998 and 2000). Further, over 1200 cashew accessions are conserved in Regional Cashew Field Gene Bank in various centres under AICRP on Cashew (Fig. 2).

Fig 1. Bunch-bearing accession at DCR, Puttur

Fig 2. Variability in cashewnut and apple

Hybridization

Hybridization techniques for breeding varieties in cashew have been standardized by various workers and 13 hybrids have been developed and released for commercial cultivation in the country. Bhat *et al* (1998) showed that the paper-roll method of hybridization was better than other methods.

Of the 40 improved clones released so far, 13 are hybrids and 27 are selections. Screening of cashew varieties for drought, high-density planting (Salam, 1997), and for nutrient-deficient soils, has been reported (Latha, 2000; Latha and Salam, 2001). Anakkayam-1, K-22-1, Madakkathara-1 Madakkathara-2, Kanaka, Dhana, Priyanka, Sulabha, Dharasree, Amrutha, Akshaya, Anagha, Vengurla-1 to Vengurla-7, BPP-01 to BPP-8, Vridhachalam-1, 2, 3 and 5, Ullal-1 to Ullal-4, UN-50, NRCC Selection-1 and 2, Bhaskara, Jhargram-1, Bhubaneswar-1, Goa-1 and 2, Chintamani-1 and 2 are some of the improved varieties of cashew in India (Abdul Salam and Peter, 2010).

Pruning and training

Pruning provides a definite form and shape to the tree. Pruning of dead wood and criss-cross branches can increase yield by 30-40% (Khan *et al*, 1987). Training indirectly assists in ease of other operations such as weeding, manuring and hoeing (Satpathy, 1988). Results of pruning on 28-year old trees revealed that trees with three branches pruned recorded the highest number of panicles/sq.m (39), highest number of flowers/panicle (588.70) and fruit-set to an extent of 14.42%, while unpruned trees recorded only 7.75% increase in yield (Panda, 1990). Under Jhargram conditions, pruning of leader-shoots during July enhanced the number of productive laterals, increased the number of bisexual flowers per panicle, fruits per panicle and yield per tree (Chattopadhyay and Ghose, 1994). Leader-shoot pruning doubled the yield in cashew (Mohan and Room Singh, 1988). Pruning treatment increased the number of laterals/leader but did not affect duration of flowering and harvest (Mohan and Rao, 1995). Leader-shoot pruning at least once every 2-3 years helps boost nut yield (Nayak, 1996).

Top-working

The technique of rejuvenation of existing, unthrifty cashew plantations by top-working boosts cashew production 3-4 fold in a short span (Fig. 3). This technology can also be adopted for mass production of scions since, production can be expected to be almost five times that by conventional methods (Khan *et al*, 1988). Top-working trials in red and laterite zone of West Bengal showed that beheading of trees (Fig. 4) at 1.0 m height was ideal

Fig 3. Flush emergence after top-working

Fig 4. Rejuvenation upon beheading

from the paint of view of sprouting, growth of sprouted shoots and graft success. The month of October was most suitable for beheading and February for grafting, irrespective of age of the tree (Ghose, 1991). whereas, under Ullal conditions of Karnataka, December to February was found to be suitable for beheading and, February to April for grafting (Khan *et al*, 1985). Uneconomical cashew trees top-worked with high-yielding Ullal-1 variety resulted in a four-fold increase in nut yield per tree within five years (Kumar, 1990). Wherever populations of cashew stem and root borer (CSRB) are maximum, top-working technology may not be suitable, unless regular follow-up action is taken to manage the incidence of CSRB (Swamy, 1995).

Biotechnology in cashew

Work on cashew tissue culture has been in progress on developing multiplication protocols from cashew explants. However, regeneration protocols from mature explants are yet to be developed, although, reports are available on multiplication and field establishment of cashew regenerated from young nodal cuttings (Philip, 1984; D'Silva and D'Souza, 1992; Lievens *et al*, 1989; Keshavachandran and Khader, 1990; Leva and Falcone, 1990; Nair and Mohanakumar, 1993; Das *et al*, 1996; Thimmappaiah and Shirly, 1999). Somatic embryogenesis was induced from nucellar tissue cultured from 2-3 week old immature nuts. So far nucellar tissues from 14 varieties have been tested for embryogenesis. Embryogenesis and germination of somatic embryos was achieved in two varieties (Thimmappiah, 1997; Shirly and Thimmappaiah, 2005).

Attempts have been made to fingerprint cashew using RAPD markers. Twenty Tanzanian accessions (Mneney *et al,* 2001), 90 germplasm accessions at DCR, Puttur (Dhanaraj *et al*, 2002) and 19 germplasm accessions (Archak *et al*, 2002) have been fingerprinted. Based on this analysis, a moderate range of genetic variability among the accessions analysed in India. About 239 accessions at DCR have been fingerprinted by Thimmappaiah *et al* (2009a). Low-level diversity has been observed in 40 elite varieties using RAPD, ISSR and SSR markers at DCR, Puttur. Moderate diversity has been reported in cashew population using protein isoenzyme electrophoretic analysis (Aliyu and Awopetu, 2007; Maranan and Mendiore, 2008; Thimmappaiah *et al* (2009a, b). Cashew microsatellites from non-enriched genomic library and sequences of 21 polymorphic SSR markers have been detected and used for multiplex analysis in cashew (Croxford *et al*, 2005). Gene cloning studies have been reported (Wang *et al*, 2002). Transformation in cashew using *Agrobacterium tumefasciens* strain EHA-105 has been reported by Kiran *et al* (2007). Neto *et al* (1995) showed utility of RAPD markers in distinguishing dwarf seedlings in cashew. Bulk Segregant Analysis (BSA) in germplasm bulks at DCR, Puttur, could identify four RAPD markers linked to economic characters like nut weight and plant stature.

Regeneration from explants of mature origin has met with difficulties due to a high rate of contamination and poor response (Thimmappaiah and Shirly, 2000; Thimmappaiah *et al,* 2002a, c). Micrografting technique was standardised in cashew (Mantell *et al,* 1997; Ramanayake and Kovoor, 1999, Thimmappiah *et al*, 2002b). Embryogenesis was induced in immature cotyledonary segments (Hegde *et al*, 1994; Nair and Mohanakumar, 1993; Sy *et al,* 1991; Thimmappiah, 1997) and nucellar tissue (Nair and Mohanakumar, 1993; Ananthakrishnan *et al*, 1999; Gogate and Nadgauda, 2000; Cardoza and D'Souza, 2002).

CROP MANAGEMENT

Nutrient studies

Cashew is often grown on marginal soils and on wastelands mostly unsuitable for other economic crops. Nitrogen and P were found to be the most important nutrients during pre-bearing stage. At the bearing stage, K, together with N, is important. Application of fertilizers, their dosage, time and schedule under different agroclimatic zones has been standardized (Veeraraghavan *et al,* 1985; Sawke *et al,* 1985; Harishu Kumar and Sreedharan, 1986; Ghosh and Bose, 1986; Kumar *et al,* 1997; Latha *et al,* 1994; Lenka *et al,* 1998; Grundon, 1999; Grundon, 2001**;** Shingre *et al,* 2001; Patrick *et al*, 2002; Vishnuvardhana and Thirumalaraju, 2002; Yadukumar *et al,* 2003; Prasanna Kumar *et al,* 2006; Salam *et al,* 2008**;** Yadukumar *et al*, 2008; Aikpokpodion *et al*, 2009; O'Farrell *et al* 2010)**.**

Rootstocks and grafts of cashew supplied with 150:20:100 ppm of N:P:K at the rate of 100 ml/plant/week had higher plant-height, stem-girth and number of leaves (Manjunatha, 2001). The ratio 2:1 of N:P is ideal for young cashew trees (Shi-Wenge *et al,* 2005). Application of mineral nutrients in combination with organic fertilizers significantly increased plant height, dry weight of aerial parts and number of leaves in cashew seedlings (Lima *et al,* 2001).

A 30-year old cashew tree removes 2.85 kg of N, 0.75 kg of P_2O_5 and 1.27 kg of K_2O (Mohapatra *et al,* 1973) from the soil. Leaf N content of 1.51% in the month of April is considered optimum for high nut yield (Ghose and Bose, 1986). Macronutrient removal by cashew nuts and the cashew apple was N > K > Mg > P > S > Ca and

K > N > Mg > P > S > Ca, respectively (Fragoso, 1999). Use-efficiency of N and K in cashew was 24.7% and 12.37%, respectively (Latha, 2000; Latha and Salam, 2001).

Foliar sprays of nutrients (urea 2 to 4%; DAP 1%; orthophosphoric acid; $ZnSO_4$ 4%; Cu 0.3 to 0.6%), at emergence of the flush, panicle initiation and fruit-set stages, ensure better fruit-set and enhanced nut yield (Ghose, 1988; Ankaiah and Rao, 1987; Sapkal, 2000). Yellow leaf spot occurrence in low soil pH (4.5 – 5.0) could be corrected by foliar sprays of Mo salts (Subbaiah *et al,* 1986). Foliar spray of growth regulators Planofix, Nutron, IAA, IBA, NAA, 2,4-D and Ethrel were effective in increasing total number of flowers, hermaphrodite flowers, sex ratio, fruit and yield per panicle and, also improved physico-chemical composition of apples and nuts (Ghosh, 1988; Singh *et al,* 1992 and Kumar *et al,* 1994).

Biofertilizers

Application of *Azospirillum*, *Azotobacter* and VAM increased germination percentage of nuts and plant growth, and reduced the incidence of fungal diseases in the nursery (Kumar *et al,* 1998; Ramesh *et al,* 1999). Inoculation of *Azotobacter* resulted in higher root growth (Oblisami *et al,* 1985) and yield (Singh, 1997) in cashew. Among VAM, *Acaulospora laevis* and *Gigaspora mosseae* were better symbionts for inoculating cashew with (Lakshmipathy, 2000). Anantha Krishnan *et al* (2004) reported that among VAM, *Glomus fasciculatum* was superior in terms of increased shoot-length, internode number, number of leaves, stem diameter, root length and root number, under nursery conditions. Sivaprasad *et al* (1992) also reported that *Gomus fasciculatum* to be more effective at enhancing growth and P uptake of cashew plants. VAM (25 g/bag) was helpful for better graft-uptake at the time of grafting (Sridhar *et al*, 1990).

Organic recycling

Cashew plantations have a vast potential for organic biomass for recycling. Availability of cashew leaf-litter from plantations of different age groups (10 to 40 years) ranged from 1.38 to 5.20 t ha^{-1} (Guruprasad *et al,* 2009). About 5.5 t ha^{-1} available cashew- biomass waste can be converted into 3.5 tonnes of compost or vermicompost and helps to meet nutrient requirement of cashew plants 50% (Yadukumar and Nandan, 2005; Yadukumar, 2007).

Abiotic stress

Cashew cannot grow and yield well in saline soils (Marlos *et al,* 2007). Electrical conductivity of irrigation water at 1.48 dSm^{-1} is threshold tolerance for precocious cashew during its initial growth (Carneiro *et al,* 2002). Higher soil-temperature and density resulted in reduction of plant growth and roots (Oliveira *et al,* 2003). Flowering in cashew requires mild winters and availability of soil-moisture plays a key role in kernel development (Rao *et al,* 2001). Relative humidity during pre-flowering is a key factor in explaining yield variation in cashew (Haldankar *et al,* 2003). Cashew can tolerate mild to moderate levels of moisture stress and growth of seedlings is unaffected (Latha, 2003; Souza *et al,* 2004). Strong and severe water stress resulted in 20 and 22% reduction in the number of scions produced respectively (Shingre *et al,* 2003).

Soil and water conservation techniques

Fig 5. Crescent bund for soil and water conservation

Under medium to steep slopes, 'terrace with crescent bund' (Fig. 5) and application of 20 kg poultry manure in cashew is beneficial for improving soil moisture content, yield and also reduced runoff and soil-loss (Yadukumar and Rejani, 2006; Rejani and Yadukumar, 2006; Yadukumar and Rejani, 2008; Asogwa *et al*, 2008). Reduction in peak runoff and increase in recession time and groundwater recharge due to soil and water conservation practices have been reported by several workers (Sastry and Druvanarayana, 1984; Singh *et al,* 1989; Deshmukh *et al,* 1992). Black polythene mulch was helpful in conserving soil moisture (Nawale *et al,* 1985)**.** Using coconut coir pith as soil mulch in cashew plantations resulted in 14.15% higher water retention and suppression of weeds upto 73.52% (Kumar *et al,* 1989). Badhe and Mayar (2004) reported that trapezoidal shaped staggered trenches (230 ha^{-1}) of 4.5 m length, 0.60 m top-width, 0.30 m bottom-width and 0.30 m depth were effective in reducing runoff and for conservation of soil and nutrients. Mane *et al* (2009) demonstrated that continuous contour trench (0.5 m x 0.6 m) was the best soil-conservation practice for cashew on hands with 7 to 8% slope.

High density planting

It has been reported that high-density planting

system in cashew is economical (Salam, 1997 and Ghosh *et al,* 2000). Maintaining tree-density of 625 ha^{-1} (4 m x 4 m) for the first 11 years, and diagonal thinning thereafter to reduce the population to 50%, resulted in maximum yield (Yadukumar *et al*, 2001). High-density planting system in cashew doubled nut-yield during the first 10 years of planting (Yadukumar *et al*, 2002). Salam (1999) reported that the varieties '44/3', 'Anakkayam-1' and 'H-1608' were suitable for high-density planting.

Intercropping

Intercrops like cowpea, French bean, cluster bean, rice bean, red bean, mung bean, soybean and groundnut could be grown along with cashew to get additional profit

Fig 6. Cashew intercropped with pineapple and gooseberry (top), Elephant foot yam (left) and brinjal (bottom)

(Gupta, 1999). Maize and groundnut can be grown successfully as intercrops in newly-planted and two year-old cashew orchards (Abeysinghe *et al,* 2003). Intercropping cashew with pineapple, turmeric or elephant foot yam under normal-density planting system during the first five years increased net benefit from cashew gardens (Yadukumar *et al,* 2003; Fig. 6). Weed-suppression was best in plots carrying cashew / cassava and cashew / plantation / cassava mixtures with 50-60% reduction in frequency of weeding per annum (Adeyemi, 1998).

Irrigation

It was reported that fertigation saved 50% fertilizer requirement and doubled cashew yield (Richards, 1993; Yadukumar and Mandal, 1994; Mishra *et al*, 2008). Irrigation at 200 litres of water tree^{-1} once in every 15 days after flowering during summer months increased cashew yield. Irrigating cashew with 60-80 litres of water tree^{-1} every four days through drip after flowering until fruit-set and development, in combination with application of 750:187.5: 187.5 g NPK tree^{-1} led to significantly higher yields (Yadukumar and Rejani, 2008; Yadukumar *et al*, 2009). Several researchers have reported superiority of fertigation in terms of higher scion production and nut yield (Nawale *et al,* 1985; Yadukumar and Mandal, 1994; Kumar *et al,* 1998; Blaikie *et al,* 2001, Ingle *et al,* 2005). Response to irrigation varied among cashew genotypes (Oliveira *et al,* 2006). Dwarf clones did not respond well to irrigation (Oliveira *et al,* 2003).

CROP PROTECTION

Cashew is attacked by around 180 species of insect and non-insect pests in India resulting in substantial yield loss (Sundararaju, 1993b). The most important pests that limit production are the cashew stem and borer (CSRB) and the tea mosquito bug (TMB). In addition, leaf and blossom webber, shoot tip caterpillar, and, apple and nut borer cause damage.

Cashew stem and root borers

CSRB (*Plocaederus ferrugineus* L.) (Coleoptera: Cerambycidae) is the primary species, infesting cashew in all parts of India, and, two other species, viz., *P. obesus* G. and *Batocera rufomaculata* DeG. were also reported in association with *P. ferrugineus* (Abraham, 1958; Uthaiah *et al*, 1989 and Rai,1984). Symptoms of damage include extrusion of frass, occurrence of gummosis, premature yellowing and shedding of leaves, drying of twigs and, finally, death of the tree.

It is essential to adopt two important approaches, viz., a) phytosanitation, to achieve reduction of pest population in a given location, and b) saving the infested trees in the initial stages of infestation itself. To minimize CSRB infestation in the plantations, dead trees and trees beyond recovery (those with over 50% damaged bark-circumference and / or showing yellowing of the canopy) should be uprooted and removed from the plantation immediately before and after the monsoon, since these serve as natural inoculum for multiplication and spread of the pest (Raviprasad *et al*, 2009 and Sundararaju and Bakthavatsalam, 1990).

All the trees in the plantation should be examined for CSRB at the tree base at monthly intervals, especially, during harvest (January-May). If external infestation is observed, CSRB grubs should be removed mechanically by carefully chipping the bark. The injured portion and base of the tree, and any exposed root should be swabbed with / drenched in Chlorpyriphos 0.2% solution (Raviprasad *et al*, 2009 and Sundararaju and Bakthavatsalam, 1994).

In Brazil, progression of gummosis in cashew trunks could be mitigated by application of Benomyl either alone, or, in combination with copper oxychloride (Cardoso and Freire, 1998).

Entomopathogens like *Metarhizium anisopliae* and *Beauveria bassiana* are known to cause mycosis in grubs of CSRB (Bhat and Raviprasad, 1996). Spores of *M. anisopliae* survive for three months under field conditions. Mixing the spawn with organic matter like FYM, neem cake and cashew apple, can enhance spore load under field condition.

Newly-planted grafts should be trained to bear branches at a height of 0.75m to 1.00m from ground level for facilitating inspection and pest management techniques effectively.

Tea Mosquito Bug (TMB)

Under the West Coast conditions, three species of tea mosquito bug *Helopeltis* (*H. antonii* S., *H. theivora* W. and *H. bradyi* W.) infest cashew, whereas, in other regions, only one species (*H. antonii*) attack cashew. However, in all the regions, *H. antonii* is the dominant species infesting cashew, causing severe damage. Both nymphs and adults suck sap from tender shoots and leaves, floral branches and from developing nuts and apples by making a number of feeding lesions. During outbreaks of the pest, the entire flush dries up and trees present a scorched appearance. This pest has a potential to cause 100% loss in yield. However, on an average, yield loss of about 30% is caused as a result of damage by this pest (Fig. 7).

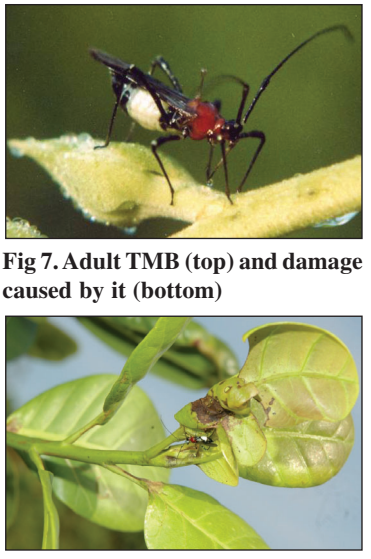

Fig 7. Adult TMB (top) and damage caused by it (bottom)

All the recommended cashew varieties are susceptible to this pest. However, mid season/late season flowering cashew varieties are able to escape from the severity of the pest to some extent. Cashew accession, Goa 11/6, showed consistent performance with yield of 2 t ha^{-1} under unsprayed situations, under moderate level of pest-incidence. Recently this accession has been released as variety 'Bhaskara' from the Directorate of Cashew Research, Puttur (Sundararaju *et al*, 2006).

Erythmelus helopeltidis Gahan (Hymenoptera: Mymaridae) *Telenomus* sp. (Laricis group) (Scelionidae) *Chaetostricha* sp. (Trichogrammatidae) and *Gonatocerus* sp. nr. *bialbifuniculatus* Subba Rao are the egg parasitoids reported on this pest from West Coast regions, while, *Ufens* sp is an egg parasitoid reported from the East Coast (Vridhachalam). The build-up of TMB is naturally regulated through these egg-parasitoids (Devashayam, 1989; and Sundararaju, 1993a and Sundararaju, 1996). However, their activities are naturally promoted under favourable weather conditions (increased minimum temperature and relative humidity) during vulnerable period (November-February).

Crematogaster wroughtonii Forel (Formicidae) has been recorded as a predator on nymphs of TMB. Several species of spider, *Hyllus* sp., *Oxyopes sehireta*, *Phidippus patch* and *Matidia* sp., five species of reduviid bugs (*Sycanus collaris* (Fab), *Sphedanolestes signatus* Dist. and *Endochus inornatus* Stal., *Irantha armipes* Stal. and *Occamus typicus* Dist., have also been recorded as predators of the tea mosquito bug. *Aspergillus flavus* and *A. tamarii* were confirmed to be pathogenic to *H. antoni* (Ambika and Abraham, 1979; Devashayam and Nair; 1986 and Sundararaju, 1984).

Even though all groups of insecticides and several plant products (botanicals) were evaluated against this pest, none exhibited any ovicidal action (Raviprasad *et al*, 2005). However, λ-Cyhalothrin (0.003%) and Carbaryl (0.1%) showed longest residual action against nymphs and adults (Sundararaju *et al*, 1993). In the endemic areas, it is appropriate to spray three times with any of these insecticides during the most vulnerable periods of crop coinciding with flushing, flowering and fruiting of the crop, based on pest-incidence. Spraying recommended insecticides is remunerative if the trees bear economical yield (>2.0 kg $tree^{-1}$). Although cashew is an insect-pollinated crop, spraying these insecticides during the flowering season did not influence fruit-set (Pillai *et al,* 1984; Rai, 1984 and Sundararaju *et al*, 1993)

Leaf and Blossom Webber, Shoot Tip caterpillar and Cashew apple and nut borer

The other insect pests causing considerable damage to cashew are leaf and blossom webbers, shoot tip caterpillars and apple and nut borers, which damage shoots and blossoms, shoot tips, and, apple and immature nuts, respectively.

Leaf and blossom webber

Cashew shoots bearing fresh flushes and flowers are attacked by two species of leaf and shoot webbing

caterpillars, *Lamida* (= *Macalla*) *moncusalis* Wlk. (Lepidoptera: Pyralidae) and *Orthaga exvinaceae* Hamps. (Lepidoptera: Noctuidae). Of these, *moncusalis* is a major pest in East Coast tracts. Symptoms of infestation are presence of webs on terminal portions, with clumped appearance, and drying of webbed shoot/ inflorescences. Galleries of silken webs reinforced with plant scraps, and castings, indicate presence of caterpillars.

Shoot tip caterpillar

The tiny, yellowish to greenish-brown larvae of the moth *Hypotima (=Chelaria) haligramma* M. (Lepidoptera: Gelechidae) damage shoot tips and inflorescences. Tender shoot tips are bored occasionally upto 25-35 mm, leading to drying-up of shoot tips. This pest is regularly reported from the East Coast tracts (Mohapatra *et al*, 1998).

Apple and nut borers

Usually, these borers tunnel near the joint of the apple and the nut, and cause shrivelling and premature fall of fruits. Damaged fruits can be easily located as the infested fruits have frass at the damaged portion. Several lepidopteran species have been recorded as apple and nut borers of cashew. Variable degree of damage by the most common species, *Thylocoptila paurosema* M. (Pyralidae), has been reported from different cashew-growing tracts. *Panerotoma* sp. (Braconidae) and *Trathala* sp. (Ichneumonidae), have been recorded as hymenopteran larval parasitoids of *T. paurosema*.

Even though incidence of shoot tip caterpillars and apple and nut borers was observed in all the recommended varieties of cashew, fruit-set was only partially affected in varieties that showed early mixed-phase of flowering, with male and hermaphrodite flowers; whereas, in varieties with an early male-phase, damage was severe, resulting in poor fruit-set.

Three rounds of insecticidal sprays recommended against tea mosquito bug also manage all these minor foliage pests, if infestation levels are low to medium (Pillai *et al*, 1984). However, indiscriminate spraying must be avoided as the above mentioned pests are parasitised by a number of larval parasitoids. Repeated spraying can also induce outbreak of secondary pests like mealy bug (*Ferrisia virgata*) and aphids (*Toxoptera odinae*).

POST-HARVEST TECHNOLOGY

Cashew requires to be processed to get an edible kernel. Various methods such as Drum roasting, Steam boiling and Oil bath roasting have been employed for commercial processing. In recent times, Drum roasting and Steam roasting methods have been employed for processing. Commercial processing by Steam roasting involves drying of raw nuts, steam roasting them for 18-20 min, shelling the raw nuts, peeling, grading and packing the kernels under vacuum (Ohler, 1979). Equilibrium moisture content of cashew kernels has been shown to decrease with increasing temperature, at constant water activity (Balasubramanian and Narayanan, 2006). Physical properties of raw cashew nuts as a function of moisture content has been studied (Balasubramanian, 2001). Equilibrium moisture content of raw cashewnuts at different levels of relative humidity has been determined. Increase in the moisture content with relative humidity exhibits desorption isotherm up to 74.12%, but at 81.33% it follows adsorption isotherm. Mould-growth and nut-deterioration took place after 28 days at 81.33% from commencement of the experiment. The data were fitted in the Henderson's equation and, by solving simultaneous equations, values of the constants were found to be 7.09×10^{-4} and 0.865 for c and n, respectively (Balsubramanian, 1998).

Cavalcanti-junior *et al* (2004) reported that cashew nuts, after harvest, retained high water content. The water content should be reduced to values close to that of the hygroscopic balance. In this study, samples of dried and humid nuts were stored in airy and humid conditions for determining the hygroscopic curve. It was verified that more than 70% of the cashew nut humidity can be explained by relative humidity of the air and that the degree of humidity at the equilibrium points assumes two different values during the year: 11.4% in the dry season, and 13.6% in the rainy season, with an annual average of 12.5%.

The device developed by Tropical Product Institute (TPI) has a capacity of 11.5 kg kernels day^{-1} using cutting and sawing mechanism and the turnout was 76% whole kernels. The Cardoso system uses knives to cut the shell into two halves and separates them by a push using a pin. The capacity with this is 240 nuts $minute^{-1}$. The Italian type SIMA process is based on a shelling machine for each size of graded nuts, with capacity of about 70 kg nuts hr^{-1}. The nuts are cut with semicircular knives that have the same curves as the nut on the longitudinal section. The outturn of whole kernel was 53%. In oltremare system, the shells are cut longitudinally and separated by a pair of gripers, freeing the kernel, with an outturn of 80% whole kernel (Hall, 1965).

Hand-operated shelling units used in Thailand has a lever to lower the upper blade to cut the raw nut placed at

the bottom and, also, to pry open the cut shells. The kernels are then extracted manually using a pin. However, it was found that use of hand for cutting was strenuous and was changed over to the pedal system, as reported by Mathew (1995).

Centrifugal cracking is done in the SICOL system (also called Tonelli or Albators), the JUR system and the Barbieri system. The nuts are placed in a certain position on a rotating disc and thrown with a speed of 250 km hr^{-1} against vertical placed knives. The capacity is 870-1200 kg nuts hr^{-1}. The outturn of whole kernels is 67%. Design considerations on the manually operated sheller used the new principle of press-twist action of the sheller's blade, resulting in two versions, viz., manually operated sheller and semi-automatic sheller.

Cashew kernel packaging has evolved from the days of wooden cases to flexi- packaging (Fernandez *et al*, 2003). A comparative analysis was made of packaging of cashew kernels in tin containers and flexi-bags, in terms of cost-effectiveness and eco-friendliness. The additional investment involved in changing over from tin packaging to flexi packaging works out to an amount ranging from Rs.4.57 lakh to 11.66 lakh, depending upon capacity of the machine installed. This investment can be recovered within a span of 56 to 96 days, based on the type of machine installed. Flexi-packaging is cost-effective to both processor-exported and the importer, and is eco-friendly.

Lima *et al* (2004) investigated the effect of packaging and salting on cashew nut kernel stability during storage. Cashew kernels with and without salt treatment were packed in flexible plastic bags laminated with aluminium foil, polypropylene (PP) vessels and low density polythylene bags (LDPE) and stored at room temperature (28°C). Peroxide and acid values were evaluated on the lipid fraction, while, water activity, sensory acceptance and microbiological quality were evaluated for the kernels. Peroxide showed high values at 150 days. Microorganism count was lower than 105 for all treatments. *Salmonella* sp., 45°C coliforms and *Staphylococcus aureus* were not detected. Sensory changes were observed under PP vessel packaging at 100 days and under LDPE packaging at 200 days. Kernels packed in plastic/ aluminium foil laminate did not show sensory changes up to 250 days of storage, indicating higher stability. Salting did not affect kernel quality during storage.

Cashew apple, the pseudo-fruit, is quite nutritious and rich in Vitamin C. For every ton of raw-nut produced, 10 tons of apples are produced, which are not commercially exploited. Various products such as juice, jam, jelly, pickle, etc. can be prepared from cashew apple. The technology for these has been developed by CFTRI (Mysore), UAS (Bangalore), KAU (Madakkathara) and various other Agricultural Universities. Various aspects such as development, nutritive value, value addition and host plant insect interaction in cashew has been reviewed recently (Nagaraja, 2007, 2010).

FUTURE STRATEGIES

In order to face challenges within the country from other crops like rubber and mango, and to face challenges from countries like Vietnam, Brazil etc., research strategies need to be reoriented. Areas needing emphasis in future research programmes are:

Crop improvement

- Collection, conservation, evaluation and cataloguing of both exotic and indigenous cashew germplasm, especially dwarf and compact plant types
- Development of compact and dwarf varieties suitable for high-density planting
- Evolving varieties with high-yield, resistance to biotic and abiotic stresses, better flowering behaviour/ characters (synchronized and staggered), and, better kernel quality for domestic consumption and export
- Standardization of protocol for regeneration of cashew from mature (tree) explants
- Molecular characterization of germplasm through DNA and isozyme markers
- Identification of molecular markers linked to economic characters in cashew and construction of genpme maps

Crop management

- Integrated Plant Nutrient Management (IPNM) including nutrient budgeting, orchard management, weed management, irrigation management, micronutrient deficiency management and, soil and water conservation techniques, for achieving high yield
- Canopy management and rejuvenation of old cashew plantations/orchards; Canopy architecture and management to suit requirement for different plant-densities and system of planting
- Detailed studies on high-density planting system to increase productivity of cashew
- Integrated cashew-based farming systems research,

including cashew-based cropping system (mixed and intercropping)

- Organic farming research, including biodynamic farming in cashew for producing quality nuts, especially for the international market
- Physiology of flowering and off-season flowering, including studies on hormones
- Studies on role of pollinators in cashew for enhancing yield

Crop protection

- Studies on kairomones and pheromones for effective and economic control of Tea Mosquito Bug and Cashew Stem and Root Borer
- Development of eco-friendly IPM strategies, including entomo-pathogenic nematodes for control of major insect pests
- Studies on pest complex at post-harvest and pre-processing stages
- Investigation on panicle-drying in the absence of tea mosquito bug
- Isolation of pheromones for control of tea mosquito bug
- Intensification of survey, both in traditional and non-traditional cashew growing tracts, for identification of accessions with tolerance to pest attack
- Conservation of natural enemies of these pests by avoiding indiscriminate use of insecticides
- Development of eco-friendly pest-management practices using new molecules

Post-harvest technology

- Development of value-added products from low grade kernels
- Developing technologies for alternate use of byproducts of the cashew processing industry, such as cashew kernel rejects, Cashew Nut Shell Liquid (CNSL), cashew shell cake and cashew kernel testa
- Exploring the possibility of cashew apple utilization for production of industrial alcohol / bio-fuel / syrup on commercial scale
- Extraction of nutraceuticals such as natural colours, flavours, pectin and nutritionally beneficial compounds and minerals and crude fibre from cashew apple powder / pomace
- Assessment of bio-availability of minerals in cashew
- Refinement of on-farm processing machinery
- Development of low cost mini cashew processing units, moisture meter for rawnuts
- Development of dryers for drying the nuts during the rainy season

Transfer of technology

- Development of farmer-friendly technologies through farmers' participatory technology development programmes
- Extension efforts to bridge the gap between actual yield and potential yield
- Developing training methodologies for transfer of technology cashew

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