Recent Trends in Cassava Breeding in India

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Introduction

Cassava along with maize, sugarcane and rice, constitute the most important sources of energy in the diet of tropical countries in the world. Cassava is rapidly emerging as a crop of considerable importance in India. Latin America has been reported as the place of origin, where the indigenous population for at least 4,000 years has grown it. After the discovery of America, Europeans soon recognized the advantages of the crop and took the crop to Africa as a potentially useful food crop, later to Asia also to be grown as a food security crop as for the extraction of starch (Howler, 2004). Cassava was either introduced into Sri Lanka and India by the Portuguese during the 17th century, or it was directly introduced from South America to India in 1840 (Abraham 1956). Kerala and Tamilnadu account for about 80% of the total acreage of the crop in India. India possesses the highest national tuberous root yield in the world (27.6 t ha-1). It is cultivated in an area of 0.2 million ha producing 5.5 million t of tuberous roots. Cassava has the capacity to produce large amount of food calories per unit area, ability to adopt to erratic climatic conditions, resistance to locusts and several pests and diseases. Easy culture, low labor requirement, and cost of production are among some of its unique features that further encourage the spread of its culture to several regions of the country. Besides being important in human diet in Kerala, cassava provides cheap nutritious feed for livestock as well. Its tuberous roots have innumerable industrial uses also, particularly for starch extraction (Magoon 1967).

Globally, cassava is grown in an area of 18.5 million ha producing 202.6 million t with a productivity of 10.95 t ha-1 (FAO 2005). All the major cassava growing countries in the Asian continent have the productivity of more than the world average productivity. Indonesia, Thailand and India are the major countries growing cassava in Asia. In the 19th century cassava became an important crop in southern India. It is a crop of food security in Kerala. By virtue of its diversifi ed uses, it has become an important commercial crop in the agricultural economy of the states like Tamil Nadu and Andra Pradesh. The diverse use of cassava is the reason for the sustainability of the crop in contrast to increased income and standard of living of the people (Sreenivas and Anantharaman 2005). Though cassava is under cultivation in India for more than one and a half century, systematic research in this crop was lagging until about 1940 when certain research projects were started in the Department of Botany, University of Travancore (Koshy 1947). In 1951, research was considerably expanded under a scheme jointly funded by the Indian Council of Agricultural Research and the Government of Travancore-Cochin (Abraham 1956). During the third 5-year plan, the Tuber Crops Research Institute was established (in 1963) by the Government of India for intensifi cation of research on the improvement of root and tuber crops. The approaches to cassava breeding at Central Tuber Crops Research Institute (CTCRI) in Trivandrum involved the use of familiar tools of introduction, assay, selection, intervarietal, and interspecifi c hybridization, production of chromosomal races, genome approach, mutation breeding, tissue culture, and a diverse improvement program keeping in view the requirement of farmer, consumer and industry is actively underway on this root crop at the Institute.

Cultivar improvement

Genetic variability is the essence for any plant-breeding program. An assembly of diverse genetic stocks of any crop is the raw material from which a new cultivar can be molded to suit the requirement of farmers. Considerable amount of variability exists in the crop in India and much more is available in other cassava growing regions particularly in tropical South America. A genebank including wild relatives from within and outside the country was built up. Starting from a meager collection of 56 cultivars by Koshy (1947), the Central Tuber Crops Research Institute had launched a program on the collection of genetic stocks on cassava soon after its inception in 1963. Currently, the Institute maintains a cassava germplasm collection of nearly 1650 genetic stock of indigenous and exotic origin, which is the largest assemblage in Asia. The important sources of exotic genetic stocks are Colombia, Madagascar, Nigeria, Thailand, Ghana, Uganda, Malaysia, Indonesia, Sri Lanka, Senegal and Gabon. In addition to such genetic resources, eight species of Manihot were also collected. The germplasm accessions have been evaluated based on the morphological and biochemical characters. Many of the cassava types under cultivation in Kerala and other states of India are either chance seedling or bud mutations selected for desirable characteristics and maintained by vegetative propagation. Cultivars best suited for the requirements imposed by the local environments are generally adopted and popularized in the various cassava growing locations. The majority of types have the native name which generally indicates one of the striking features of the plant, like for instance, 'Anakomban' meaning the tuberous roots are white and long similar to an elephant's tusk. The maturity period of the different indigenous cultivars varies from 6 to 12 months. Cultivars with lesser toxicity are generally preferred in many areas. Signifi cant diversity still exists for this crop in India, which can be used as sources of parents for intervarietal hybridization or released, after selection, for general cultivation. The evaluation of the early introduction from exotic sources resulted in the identifi cation of two promising cultivars M4 and M6 from Malaya (Abraham 1956). An indigenous selection S-856, high yielding cultivars with early harvest ability (7-8 months) was released for general cultivation in 1987 under the name Sree Prakash (Nair et al. 1988).

Intervarietal hybridization

An extensive intervarietal hybridization program having varied objectives is also underway. Several cultivars are distinctively better combiners than some others. Testing of indigenous and exotic cassava cultivars for their combining ability has been a regular activity of the cassava breeding program. A large number of intervarietal hybrids have thus been obtained and they are continuously being included in yield trials, followed by critical selection based on yield and several other criteria. Intervarietal hybridization in cassava, if carried out on a large scale, offers great combination of characters. Being highly heterozygous, such crosses can be expected to give a wide segregation and allow considerable scope for selection even in the fi rst generation. An extensive intervarietal hybridization program launched by CTCRI culminated in the evolution of promising hybrids H 97, H 165, H 226, H 1687, H 2304 (Magoon et al. 1970, Jos et al. 1980). Of these, H 97, H 226 and H 165 were released for general cultivation in 1971 and H 1687 and H 2304 in 1977 under the name Sree Vishakam and Sree Sahya, respectively. One of the hybrids H 3641 developed at CTCRI has been identifi ed as high yielding and was released in Tamil Nadu as cultivars Mulluvadi as CO3 (Nayar and Joseph 1994). The tuberous yield of the cultivar was 30 to 35 t ha-1 under the recommended package of practices while the local check recorded an average of 20 t ha-1. The Kerala Agricultural University has released a short duration cultivars called 'Nidhi' which can be harvested in 5.5 to 6 months and which has been recommended for paddy fallows. The Tamil Nadu Agricultural University has released CO1 and CO2 as high yielding cultivars, which recorded tuberous root yield 30-35 t ha-1. CO1 is a selection from local collection, while CO2 is a clonal selection from the seedling progeny of a local clone.

Combining ability in cassava

The common breeding approach in cassava is through hybridization among appropriate parents. Seedlings with desirable attributes are selected and subsequently propagated clonally. However, selection of parents based on their direct performance may not always be dependable due to the type of gene action involved for the trait and diverse genetic structure of the parent. Hence, it is necessary to estimate the combining ability of parents before they are used in hybridization program (Rajendran 1989). The line x tester analysis gives useful information regarding the choice of parents and elucidates the nature and magnitude of various types of gene action involved in the expression of quantitative traits. Recurrent selection and other procedures currently used in cassava also emphasize the importance of general combining ability and additive gene action (Byrne, 1984).. CTCRI has developed successive generations of inbred lines of cassava. Both additive and non-additive gene action were involved in the expression of all the characters (Eswari Amma et al. 1999). A straight forward hybridization program followed by phenotypic selection, as suggested by Kawano (1985), may be effective in creating desirable recombinants for traits with predominant additive gene action.

Heterosis breeding

Koshy (1947) and Abraham (1957) suggested that evolving homozygous lines in cassava for the purpose of exploiting hybrid vigor offers the most promising line of work in the improvement of cassava. Considering the highly heterozygous nature of cultivated cassava types, perpetuated through years of asexual propagation, selfi ng undoubtedly offers very good scope for exposing locked up variability for selection (Magoon 1967). After selfi ng, inbred lines up to fourth generation were produced. Inbreeding depression was evident in morphological characters, fi eld survival and above all yield of tuberous roots and components. The seed germination, in general, was less drastic due to inbreeding. Selected S1 and S2 progenies were top crossed with Sree Vishakam-a high yielding released cultivar. The top cross hybrids were signifi cantly superior to the inbred parents and some were superior to or equal to Sree Vishakam in yield. A few hybrids exceeded the released cultivars in cooking qualities, dry matter (DM), starch content and harvest index, reveals that top-crossing is effective in bringing about population improved in inbred lines. Seven elite top-cross selection (TCH1, TCH2, TCH3, TCH4, TCH5, TCH6 and TCH7) showed high tuberous root yield (37-44 t ha-1), high harvest index (61.6-74.9 %), high starch content (26.7- 34.3 %), low levels of HCN (53-89 ppm on fresh weight basis), and excellent cooking qualities. These selections were evaluated in multi-location trials and two promising top-cross hybrids TCH1 and TCH2 were released under the name Sree Rekha and Sree Prabha, respectively.

Breeding for early maturity

A majority of cultivated cassava cultivars take about ten months for maturity and thus occupy land for a longer period. Greater attention will have to be paid in developing early maturing cultivars, so that they can be effectively utilized in crop rotation program now in vogue in the country. At CTCRI, these early maturing clones viz. CI 649, CI 731 and CI 732 were identifi ed from the locally adapted germplasm. The clones had recorded a mean tuberous root yield of 25 t ha-1 at six months stage. Based on the evaluation trials and multilocation trials, two promising lines CI 649 and CI 731 were identifi ed and released for general cultivation under the names of Sree Jaya and Sree Vijaya.

Use of triploidy in cassava improvement

Another approach for cassava improvement, besides hybridization and analytical methods of breeding, which warrants investigation, is the production of colchiploids as well as triploids. Garner (1941) and Abraham et al. (1964) described colchicine induced tetraploids of cassava. Triploids (2n = 3x = 54) were also obtained later by other authors after crossing induced tetraploids with some of the cassava cultivars. They are found to be superior to colchiploids in yield and sometimes out-yielded ‘diploids’ (2n = 2x =36). Polyploidy breeding has unique advantages in cassava, because the economically useful product is a vegetative part. Commercial cultivation is through clonal propagation, while the crop is amenable to hybridization. As stated earlier, all cassava cultivars posses 36 chromosomes. Therefore with a view to test the yield potential and adaptability of colchiploids, tetraploidy has been successfully induced through colchicine treatment in a few agronomically superior cassava cultivars. The colchiploids possess 72 chromosomes. These induced tetraploids are also being crossed with some of the selected diploid cultivars to produce triploids (Magoon et al. 1969, Jos et al. 1970). The adoption of the diploid clone as female parent was found to be more successful than the reciprocal. The high recovery of triploid plants in a particular cross combination, suggests that meiosis in the tetraploid plants results, as expected, in a large number of diploid pollen. The leaf thickness was found to be a reliable parameter for the preliminary screening of the population of triploids. Most of the triploids were equal or better than the better parent for tuberous root yield, and root dry matter content and they had invariably compact plant types. The compact plant types and high harvest index prevalent in a number of triploids indicates the possibility of increasing planting density, thereby facilitating higher yields. The dry matter and starch content of triploids from specifi c cross combinations were higher than that of the diploids. An array of such clones have been identifi ed of which two best selections (76/9 and 2/14) had particularly higher yield and dry matter content. These clones are ideal for the starch industry: 2/14 recorded an average yield of 35 to 40 t ha-1 in multilocation trials. This selection was later released by the State Variety Release Committee for use in Industrial areas under the name of Sree Harsha.

Interspecific hybridization

Interspecific hybridization and genome analysis carried out on different crops have opened up new avenues of improvement of crop plants and have successfully contributed to the development of radically new and better types. However, as compared to other crops, cassava breeders have not yet scratched the surface of utilizing the genetic variability occurring within the species in nature. Added to the genes in the cultivated types are the vast arrays of genes in the related ‘species’ which possess reservoirs of unexplored genetic characters, incorporation of which into cultivars would appear to be of precise importance in any modern cassava breeding program. The transfer of characters from one taxa to another is not only of great practical importance, but is of considerable genetic interest as well. All species of the large genus Manihot are confi ned as wild plants to the American tropics; no native species are found in the old world (Rogers 1965). Very few species have been used in the breeding programs probably due to the non-availability of extensive specifi c collections at various Indian research centers. However some useful work relating to interspecifi c crossing for breeding improved cassava cultivars have been reported. There is an urgent need for international cooperation for collection, maintenance and proper evaluation of this vast diversity for effective screening and full exploitation of sources of this genetic diversity in improvement work of this crop. Cassava is not found in wild state but known to share a common gene pool with other species, which make the harnessing of the other desirable wild genes rather more important. However the preservation of wild species is rather diffi cult even though different methods of propagation are suggested (Nassar 1978). The survival of wild species under the climatic conditions of the Indian sub-continent is also poor. Although eight species are currently maintained at CTCRI, some of them have the desirable genes hitherto not identifi ed at inter-specifi c level of cassava. Transfer of disease resistance into cultivated cassava was attempted by hybridizing ceara rubber (Manihot glaziovii) on selected clones of cassava. Repeated backcrossing of the resulting inter-specifi c hybrid was carried out but appropriate root quality was not achieved (Abraham, 1972). Earlier attempts to introgress the cassava mosaic disease (CMD) resistant genes from Manihot glaziavii into cassava (Magoon et al. 1966, Vijaya Bai et al. 1972) did not result in high levels of resistance into the backcross offspring. Intensive work is in progress to utilize the desirable wild species genes. The interspecifi c hybrids of M. caerulescens and the backcross (BC) generation of the interspecifi c hybrid showed resistance to CMD. CMD resistant cultivars with the edible normal tuberous roots and high yield were obtained in the BC4 generation of the inter-specifi c hybrid of M. caerulescens with cassava.

Manihot caerulescens: A new source of resistance to CMD

CMD is the most important problem of the crop in India leading to 16 to 80% yield loss. Wild Manihot species has been used as source of many useful traits in cassava. At CTCRI, 37 accessions of wild Manihot species, comprising of M. glaziovii, M. pseudoglazovii, M. caerulescens, M. tristis, M. peruviana and M. fl abellifolia, were screened for resistance to CMD through wedge grafting. All accessions of M. caerulescens exhibited high level of resistance and were used as donor parents for transferring resistance to elite Indian cultivars. Resistant interspecifi c crosses were graft inoculated reciprocally with highly susceptible cultivars to confi rm resistance. This research suggests the need for characterization and utilization of this novel source of CMD resistance with other tools, including DNA markers.

Production of carotene rich cassava

Cassava is an important food crop grown in humid tropics and one of the most important sources of starch used in several industries. Besides, being important in human diet, it provides cheap nutritive feed for livestock. Even though the crop provides high energy, it is considered as a poor food in view of lack of nutrients other than carbohydrates. In most of the clones, the fl esh, the edible portion of the tuberous root is white and devoid of any carotene, the precursor of vitamin A. Malverhas (1964) reported yellow fl esh cassava cultivars from the Amazon that contain about 800 IU β-carotene. Cassava leaves are also rich in carotene: up to 16,000 IU (Van Veen 1975). A total of 21 clones, available in CTCRI, have yellow fl esh of different intensities, and with β-carotene content ranging from 65 to 670 IU/100g on fresh weight. An attempt was made to elevate the carotene levels through gene pool development from the existing gene resources. The carotene content could be enhanced to 1500 IU/100g in the fi rst cycle and later to 2200 IU/100g in the second cycle through gene pool development (Jos et al. 1990). In the third cycle, yellow fl esh clones had a carotene range of 1016 to 2983 IU/100g while the orange fl esh clones with carotene ranging from 1024 to 3217 IU/100g were noticed. Such levels hitherto never achieved in cassava (Nair and Santha Pillai 1999). This wide variation indicated that there is room for cultivar screening, selection, and gene manipulation to improve the carotenoid content of cassava tuberous roots, and thereby enhance its nutritive value (McDowell and Oduro 1983). By simple recurrent selection, the carotene content was enhanced to 1500 IU in the fi rst cycle, to 2200 IU in the second, to 3217 IU in the third and to 3983 IU/100g in the fourth cycle.

Cassava true seed program

Cassava has enormous potential in India for poverty alleviation and food security due to its ability to grow well in marginal and wastelands under poor management and its capability to yield well even under such unfavorable conditions. The slow multiplication rate under clonal multiplication, bulk of seed materials and the dreaded CMD are the major impediments that prevent the rapid spread of the crop in far-fl ung poverty stricken areas of the country (Rajendran et al. 2005). The propagation of cassava through true (sexual) seeds rather than by clones is a promising option due to its manifold advantages such as enhancing the multiplication rates, keeping the dreaded CMD under check, longer seed viability, ease of storage and transport. The high genetic heterogeneity and consequent variation in the seedling is the major stumbling block in sexual propagation. The rate of sexual propagation could be more than 20-fold over the traditional clonal propagation. Removal of taproot of seedling while transplanting enhanced tuberous root development. Seed treatment with 1% KNO_3 or 300ppm GA promoted uniform seed germination and seedling vigor and reduced transplanting period. Tuberous root yields of fi rst clone were signifi cantly superior to that of the seedlings. The dry matter content and starch output of the seedling and the fi rst clone were comparable to that of commercial cultivars. Similarly cyanide (HCN) and the cooking quality of the seedling and fi rst clone were at acceptable levels. Further research indicates that a cassava true seed program has potential in industrial areas due to its high multiplication rate, ease in covering extensive areas at lower cost and low transmission of cassava mosaic disease.

Evaluation of CIAT seedlings

Cassava seeds received from the Centro of Agricultura Tropical (CIAT) were initially screened at the regional center, Bhubaneswar (Orissa). During the period from 1989-1996, fi ve sets of cassava botanical seeds comprising 119 accessions were introduced from CIAT directly to CTCRI. The seedlings were evaluated preliminarily for yield characters and their host plant resistance to CMD, which was not noticed at the Regional Center in Bhubaneswar. However, when these promising selections were transferred to the germplasm bank at CTCRI, clear CMD symptoms were noticed in all the clones. Tissue culture materials were multiplied and evaluated in CTCRI. Out of these, one cultivar, MNga-1 showed resistance to CMD. The evaluation trials conducted at the institute recorded an average tuberous root yield of 25 28 t ha-1. The plant type is semi-spreading and tuberous root skin is white, long and cylindrical. Multi-location trials were conducted in the industrial areas of Tamil Nadu and showed resistance to CMD. It recorded an average tuberous root yield of 25 t ha-1 with 22 to 25% of starch. This cultivar is being proposed for release in the industrial belt of Tamil Nadu for general cultivation.

Area, production and yield

Globally cassava is grown in an area of 18.5 million ha producing 202.58 million t with a productivity of 10.95 t ha-1 (Table. 1).

Table 1. Area, production and productivity of cassava in major cassava growing countries of Asia

Country	Area (million ha)	Global area (%)	Production (Million t)	Global (production %)	Productivity (t ha^{-1})
World	18.50	100.00	202.58	100.00	10.95
Total Asia	3.52	19.00	58.92	29.09	16.76
Indonesia	1.27	6.85	19.26	9.51	15.20
Thailand	1.05	5.67	20.40	10.07	19.43
Vietnam	0.38	2.07	5.69	2.81	14.83
Sri Lanka	0.26	0.14	0.23	0.11	8.64
China	0.25	1.35	4.20	2.07	16.80
India	0.24	1.30	6.70	3.31	27.92
Philippines	0.21	1.11	1.64	0.81	7.99
Malaysia	0.04	0.22	0.43	0.21	10.49

Source: FAO (2005)

The crop is grown n 102 countries around the world. The African continent ranks fi rst with 66.2% of cassava growing area, and producing 52.4% of world cassava production and it is staple in many of the African countries. Even though the area is more in Africa, its production is low due to low productivity (8.8 t ha-1), which is lower than the world average productivity (Sreenivas and Anantharaman 2005). Though rice and wheat form a major part of the staple food of Asians, it is heartening to note that Asian continent is the second largest in terms of area and production of cassava with a productivity of 16.8 t ha-1. South America has 13.4% growing areas worldwide, and producing 16.9% of the world cassava. Nigeria has the largest area under cassava (22.25%) among all the cassava growing countries in the world with an annual output of 38.2 million t. Democratic Republic of Congo ranks second for area and accounts for 10% of the world production, followed by Brazil in terms of area, which ranks second for worldwide production. All the major cassava growing countries in the Asian continent have the productivity more than the world average productivity (Table.1). Indonesia, Thailand and India are the major cassava growing countries in Asia. India acquires signifi cant position in the global cassava scenario due to its highest productivity in the world (27.9 t ha-1). It is cultivated in 0.24 million ha producing 6.7 million t. It is a crop of food security in Kerala. By virtue of its diverse uses, it has become an important commercial crop in the agricultural economy of the states like Tamil Nadu and Andra Pradesh. A diverse use of cassava is the major reason for the sustainability of the crop in the country in the context of increased income and standard of living of the people. An analysis of cassava planted area and production in India shows an enormous increase up to 1974-1975 (0.39 million ha) after which it started declining fast until 1985-1996 (0.27 million ha) followed by a slower decrease thereafter (Table 2). Kerala where the crop was fi rst introduced, accounts for 50% of the area under cassava (0.13 million ha), Tamil Nadu for 32% (0.08 million ha), and Andhra Pradesh for 9% The production area in Kerala during the last four years (1999-2003) is showing a slight decreasing trend (Tables 3, 4 and 5). The major factor accounting for the decline is the shift in cropping pattern in Kerala, where plantation crops are starting to dominate the agricultural economy. Even though the production area of cassava is showing a decreasing trend, the production of cassava is almost same in every year or showing-increasing trend in 1999-2001. The productivity of cassava was more or less same up to 1986 (16-18 t ha-1) and after which it started an increasing trend and during 2000-2002 achieved 27 to 28 t ha-1.

Table 2. Area, production and yield of cassava in India (1973-1974 to 2003-2004)

Year	Area (`000 ha)	Production (`000 t)	Yield (kg ha^{-1})
1973-74	368.2	6420.9	17439
1974-75	387.6	6325.9	16321
1975-76	392.0	6638.3	16934
1976-77	385.8	6375.0	16524
1977-78	658.3	5688.3	15876
1978-79	361.5	6050.1	16736
1979-80	351.9	5845.3	16611
1980-81	346.2	5868.0	16950
1981-82	323.0	5292.0	16384
1982-83	302.0	5341.0	17685
1983-84	319.0	5886.0	18451
1984-85	305.3	5662.1	18546
1985-86	275.7	4884.3	17716
1986-87	265.3	4814.4	18147
1987-88	268.4	5416.5	20181
1988-89	249.0	4833.0	19410
1989-90	242.0	4962.0	20504
1990-91	243.0	5111.0	21033
1991-92	250.9	5832.5	23246
1992-93	234.9	5412.8	23043
1993-94	245.8	6028.9	24528
1994-95	242.8	5929.3	24420
1995-96	228.2	5443.2	23853
1996-97	256.1	5662.8	22112
1997-98	264.3	6681.9	25282
1998-99	243.4	5830.4	23954
1999-2000	223.5	6014.1	26909
2000-01	251.8	7123.8	28292
2001-02	247.6	6834.0	27601
2002-03	207.0	5426.2	26214
2003-04		5500.0	

Source: Agriculture, Center for monitoring Indian Economy.

Table 3. Major states by cassava area (000 ha) in India. (1995-96 to 2002-2003)

	1995 -1996	1996 -1997	1997 19-98	1998-1999	1999 -2000	2000 -2001	2001 -2002	2002 -2003
India	228.2	256.1	264.3	243.4	223.5	251.8	247.6	207.0
Kerala	118.7	120.4	132.9	129.9	109.3	114.6	109.3	
Tamilnadu	77.6	82.2	103.7	80.9	85.3	104.8	102.0	68.0
Andhra Pradesh	20.5	22.0	17.7	22.0	18.1	21.5	17.7	13.1
Meghalaya	3.9	3.9	4.0	4.0	4.0	4.1	4.0	
Assam	2.6	2.4	2.5	2.7	2.8	2.9	2.9	
Karnataka	0.9	0.9	0.9	1.0	1.0	1.0	0.9	
Nagaland	0.7	0.8	0.8	0.8	0.8	1.3	1.3	
Sikkim	1.6	1.6	0.5	0.5	0.5	0.5	0.5	
Mizoram	0.5	0.4	0.5	0.5	0.2	0.4	0.3	
Rajasthan	0.2	0.2	0.2	0.1	0.1	0.1		

Source: Agriculture, Center for monitoring Indian Economy.

Table 4. Major states by cassava production (000 t) in India (1995-1996 to 2003-2004)

	1995 -1996	1996 -1997	1997 -1998	1998 -1999	1999 -2000	2000 -2001	2001 -2002	2002 -2003	2003 -2004
India	5443.2	5662.8	6681.9	5830.4	6014.1	7123.8	6834.0	5426.2	5500.0
Kerala	2406.0	2588.3	2841.8	2810.9	2563.5	2586.9	2471.8		
Tamilnadu	2763.8	2819.9	3889.3	2804.7	3266.4	4295.5	3834.6	2146.5	
Andhra Pradesh	207.2	174.5	192.3	132.0	111.3	166.1	353.9	79.5	
Meghalaya	21.5	21.5	21.1	21.3	21.5	21.9	20.6		
Assam	12.1	11.5	11.7	13.4	13.4	13.5	13.7		
Karnataka	7.3	7.1	7.4	8.5	8.1	8.0	7.2		
Nagaland	1.4	1.3	15.8	15.8	15.8	16.0	16.0		
Sikkim	1.0	1.3	1.2	1.2	1.2	1.2	1.2		
Mizoram	6.6	6.7	7.0	2.5	0.2	2.0	1.5		
Rajasthan	0.3	0.3	0.3	0.4	0.4	0.2			

Source: Agriculture, Center for monitoring Indian Economy.

Table 5: Major states by cassava yield (kg ha^{-1}) in India (1995-1996 to 2002-2003)

	1995 -1996	1996 -1997	1997 -1998	1998 -1999	1999 -2000	2000 -2001	2001 -2002	2002 -2003
India	23853	22112	25282	23954	26909	28292	27260	26214
Kerala	20270	21500	21383	21639	23454	22572	22615	
Tamilnadu	35605	34291	37512	34654	38283	40988	37594	31589
Andhra Pradesh	10127	7920	10874	6000	6158	7724	20000	6049
Meghalaya	5513	5513	5275	5325	5375	5342	5150	
Assam	4654	4792	4680	4963	4786	4655	4724	
Karnataka	8111	7889	8222	8120	7951	7784	8021	
Nagaland	2000	1625	19750	19750	19750	12308	12308	
Sikkim	625	812	2400	2400	2400	2400	2400	
Mizoram	13200	16750	14000	5000	1000	5000	5000	
Rajasthan	1500	1500	1500	4000	4000	2000		

Source: Agriculture, Center for monitoring Indian Economy.

Cassava production statistics for 2001-2002 reveals that Tamil Nadu, the predominant state where cassava is grown as an industrial crop, the area, production and productivity increased (Tables 3, 4 and 5). The growing cassava area in Tamil Nadu increased from 0.08 million ha in 1995 to 0.1 million ha in 2001, with the production increasing from 2.8 million t to 3.8 million t in 2001. The productivity also showed a steady increase from 1995 (35.6 t ha-1) to 2001 (37.5 t ha-1). The productivity in 2000 was 40.1 t ha-1. The increased productivity was due to the popularization of the high yielding intervarietal cassava hybrids of CTCRI. The intervarietal hybrids H-165 and H-226 occupy more than 2/3 of the cassava area in Tamil Nadu. Similarly in Andhra Pradesh, another predominant cassava growing area for industrial products, the same two intervarietal cassava hybrids are gaining popularity and are grown in an area of about 17,700 ha in 2001-2002, with a total production 0.35 million t due to its productivity of about 20 t ha-1. Presently, there is a preference in the cultivation of short duration cassava (Sree Jaya) so that the plant can be harvested in six months, thereby utilizing the monsoon season more effectively in Andhra Pradesh. Cassava yields in Tamil Nadu can reach up to 40.9 t ha-1, which is the highest recorded worldwide. Even though the overall national trend in area and production is declining, India's current cassava yields of 28.2 t ha-1 (2000) or 27.6 t ha-1 (2001) are the world's highest and more than double of the world average (10.95 t ha-1). The foregoing trend in cassava cultivation and its utilization as an industrial crop for starch and value added products, amply explains the quantum leap that India had registered in record productivity of the crop in recent years.

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