Research

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Climate-resilient and biofortified tuber crop varieties

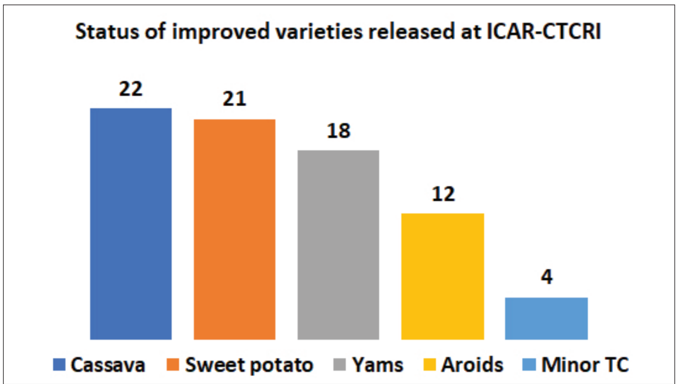
Climate vagaries have hitherto challenged tuber crop production and productivity worldwide. Tropical tuber crops such as cassava, yams, sweet potato, aroids, and minor tuber crops play a crucial role in food and nutritional security in resource-poor regions. Although tuber crops possess inherent resilience to harsh climatic conditions, which designates them as 'climate-smart', harnessing the potential relies upon strategic breeding approaches to develop more resilient varieties. Tuber crops, also known as a poor man's crop, are rich in antioxidants (anthocyanin), micronutrients (iron and zinc), and vitamins (Via. A, and B9-folate). These crops have the potential to mitigate hidden hunger, also known as micronutrient malnutrition, a serious global issue affecting one-third of the world's population. Vitamin A deficiency (VAD) is widespread in low-income tropical regions, which has driven a series of efforts toward the biofortification of plant-derived foods with provitamin A carotenoids (mainly β-carotene), promoting 'golden' crops. This article depicts a bird's-eye view of the breeding strategies undertaken at ICAR-CTCRI to develop climate-resilient and biofortified tuber crop varieties to address food and nutritional security under changing climatic conditions.

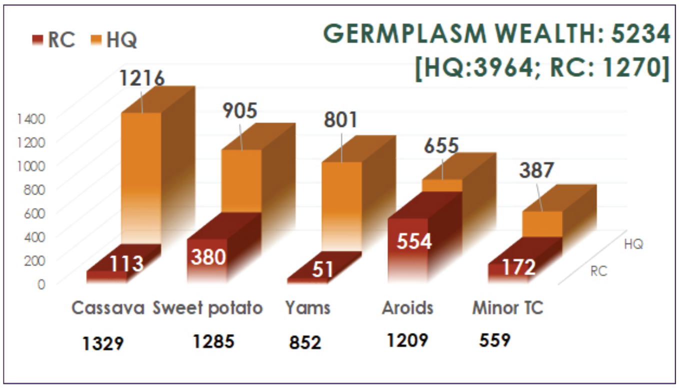
Keywords: Aroids, Cassava, Climate Resilient Varieties, Crispr-Cas, Germplasm, Improved Nutrition, Sweet Potato, Yams, ICAR-CTCRI

ICAR-Central Tuber Crops Research Institute (ICAR-CTCRI), Thiruvananthapuram, Kerala, India, has prioritized climate-resilience and biofortification traits and successfully developed several climate-resilient and biofortified varieties in tropical tuber crops with tolerance to biotic and abiotic stresses such as cassava mosaic disease (CMD), taro leaf blight (TLB), drought, salinity, and improved nutrition-rich varieties. National active germplasm sites (NAGs) at ICAR-CTCRI conserve a germplasm wealth of 5,234 at the headquarters (HQ) in Thiruvananthapuram, Kerala (3,964) and its regional centre (RC) in Bhubaneswar, Odisha (1,270), comprising 15 mandated tropical tuber crops. Of the total germplasms, 1,329 cassava (1,216 at HQ and 113 at RC), 1,285 sweet potato (905 at HQ and 380 at RC), 852 yams (801 at HQ and 51 at RC), 1,209 aroids (655 at HQ and 554 at RC), and 559 minor tuber crops (387 at HQ and 172 at RC) are being maintained at the NAGs-ICAR-CTCRI.

TRAIT-SPECIFIC BREEDING APPROACHES FOR TUBER CROP IMPROVEMENT

Improvement of tropical tuber crops such as cassava (*Manihot esculenta Crantz*), sweet potato (*Ipomoea batatas* L. (Lam)), yams (*Dioscorea* spp.), taro (*Colocasia esculenta* L. (Schott)) and aroids, and minor tuber crops are often hindered due to their long breeding cycles, erratic flowering, high heterozygosity, and vegetative propagation. Trait-specific breeding strategies provide





focused approaches to overcome the breeding barriers and develop improved varieties. Division of Crop Improvement, ICAR-CTCRI prioritized traits of interest in commercial tropical tuber crops, such as cassava mosaic virus, sweet potato weevil, taro leaf blight, and climate-resilience traits like drought, salinity, moisture stress tolerance, early maturity, and adaptability to marginal soil. Improvement of nutritional quality traits, including anthocyanin, β-carotene, minerals, and vitamins, is also emphasized.

Conventional selection of trait-specific genotypes from a wide genetic base and/or hybridization remains the foundation; however, advanced molecular tools have enhanced the breeding efficiency of tuber crop improvement. Marker-assisted selection (MAS) enables the precise genomic selection and introgression of resistant gene(s) to accelerate complex traits like stress tolerance and yield. Ploidy manipulation and mutation breeding induce novel variabilities in starch quality and tuber size. Advanced biotechnological tools such as genetic transformation and CRISPR-Cas-based genome editing facilitate targeted genetic improvement, voiding natural barriers. Participatory breeding involving farmers and consumers is another approach to ensure consumer preference for cooking quality, taste, and storability. During the last six decades of tuber crop research, the Division of Crop Improvement, ICAR-CTCRI, has developed 77 improved varieties, which include 22 cassava, 21 sweet potato, 18 yams, 12 aroids, and 4 minor tuber crop varieties.

Tuber crop varieties released at ICAR-CTCRI

Crops (9)	Varieties (77)
Cassava (22)	H-97, H-165, H-226, *Sree Sahya, Sree Visakham, Sree Prakash, Sree Harsha, Sree Jaya, Sree Vijaya, Sree Rekha, Sree Prabha, Sree Padmanabha, Sree Athulya, Sree Apoorva, Sree Pavithra, Sree Swarna, Sree Reksha, Sree Sakthi, Sree Suvarna, Sree Kaveri, Sree Manna, Sree Annam*
Sweet Potato (21)	H-41, H-42, *Varsha, Sree Nandini, Sree Vardhini, Sree Rethna, Sree Bhadra, Gouri, Sankar, Sree Arun, Sree Varun, Sree Kanaka, Kalinga, Goutam, Kishan, Sourin, Bhu Sona, Bhu Kanti, Bhu Krishna, Bhu Ja, Bhu Swami*
Greater Yam (10)	*Sree Keerthi, Sree Roopa, Sree Shilpa, Sree Karthika, Orissa Elite, Sree Neelima, Sree Swathy, Bhu Swar, Sree Nidhi, Sree Hima*
White Yam (6)	*Sree Subhra, Sree Priya, Sree Haritha, Sree Dhanya* (dwarf), *Sree Swetha* (dwarf), *Sree Dhrona*
Lesser Yam (2)	*Sree Latha, Sree Kala*
Taro (10)	*Sree Rashmi, Sree Pallavi, Muktakeshi, Sree Kiran, Pani Saru-1, Pani Saru-2, Bhu Kripa, Bhu Sree, Sree Hira, Sree Telia*
Elephant Foot Yam (2)	*Sree Padma, Sree Athira*
Arrowroot (3)	*Sree Nakshathra, Sree Karti, Sree Aadya*
Chinese Potato (1)	*Sree Dhara*

Breeding for climate-resilience tuber crop varieties

ICAR-CTCRI focuses on climate-resilient breeding, such as drought, heat, high temperature, salinity, and waterlogging tolerance, pest and disease resistance, early bulking/maturity, nutrient use efficiency, and stable yield performance, deploying traditional selection, clonal evaluation and hybridization along with MAS, mutation breeding, and ploidy manipulation.

Climate-resilient varieties in the spotlight

There are 26 climate-resilient varieties developed at ICAR-CTCRI, including 7 cassava, 10 sweet potato, yams, and 5 taro varieties to mitigate climate change. The following tables depict the crop-wise and variety-wise timelines, and the characteristics of climate-resilient varieties in tropical tuber crops developed at ICAR-CTCRI.

Climate-resilient cassava varieties


H-97

Sree Sahya

Sree Harsha


Sree Pavithra


Sree Reksha

Characteristics of climate-resilient cassava varieties developed at ICAR-CTCRI

Varieties	Year of release	Yield potential (t/ha)	Duration (Months)	Tolerant/ resistant to	Special features	States recommended
H-97	1971	25-35	10	Drought	High starch (27-31%), low cyanogen (180-200 ppm), good cooking quality, moderately resistant to *Cercospora* leaf spot, spider mite and scale insect	Kerala, Tamil Nadu, Karnataka and Andhra Pradesh
Sree Sahya	1977	35-40	10-11	Drought	High starch (29-31%), low cyanogen (75-85 ppm), good cooking quality, moderately resistant to *Cercospora* leaf spot	Kerala, Tamil Nadu, Karnataka, Maharashtra, Andhra Pradesh and NE Region
Sree Harsha	1996	35-40	10	Drought	High starch (38-41%), low cyanogen (40-55 ppm), good cooking quality, resistant to *Cercospora* leaf spot, spider mite and scale insect	Kerala and Tamil Nadu

Varieties	Year of release	Yield potential (t/ha)	Duration (Months)	Tolerant/ resistant to	Special features	States recommended
Sree Pavithra	2015	35-40	9-10	K-efficient	High starch (24.4%), excellent cooking quality	Kerala
Sree Reksha	2017	45-50	8-9	Drought, CMD, PPD	Medium starch (27-32%), low cyanogen (35.01 ppm), good cooking quality, low sugar (1.10%)	Kerala, Tamil Nadu
Sree Kaveri	2023	50	10	Drought, CMD, N and K-efficient	Medium starch (27-28%), industrial purpose	Kerala, Tamil Nadu, Andhra Pradesh
Sree Annam	2025	30-40	9-10	Nutrient use efficient, Drought	Good cooking quality, dark yellow flesh, sweet taste, moderately CMD-resistant	Kerala

Characteristics of climate-resilient sweet potato varieties developed at ICAR-CTCRI

Varieties	Year of release	Yield potential (t/ha)	Duration (Days)	Tolerant/ resistant to	Special features	States recommended
Varsha	1983	17-22	120	Drought	Fusiform tubers with reddish purple skin and light-yellow flesh	Maharashtra
Sree Nandhini	1987	20-25	100-105	Drought	Fusiform tubers with cream skin and yellow flesh, excellent cooking quality	Kerala
Gouri	1998	19	110-120	Moisture	High carotene content (7500-9100 IU/100g), excellent cooking quality	Odisha (Both *kharif* and *rabi* season)
Sourin	2005	16.2	105-110	Mid-season drought	Round to elliptic tubers with red skin, white rind and creamy white flesh.	Odisha (Both *kharif* and *rabi* season)
Kishan	2005	17	110-120	Weevil, mid-season drought	Elliptic tubers (18.2% starch) with reddish purple skin, white rind and creamy white flesh.	Odisha (Uplands and hills)
Bhu Sona	2017	20-24	105-110	Salinity	Orange flesh (β-carotene- 13.2-14.4 mg/ 100 g; dry matter 27-29%; Starch-18.8-19.7%; total sugar 2-2.24%), good cooking quality	Odisha
Bhu Kanti	2017	22-24	105-110	Salinity	Orange flesh (β-carotene- 6.2-7.8 mg/ 100 g; dry matter 24-26.6%; Starch-16-18.8%; total sugar 2-1.9-2.2%), good cooking quality	Odisha
Bhu Ja	2017	20-22	100-110	Salinity	β-carotene-rich sweet potato variety (5.5-6.4 mg/ 100), having a dry matter content of 23.2-24.8%, starch 16.6-17.20%, total sugar 2.4-3% has good cooking quality	Odisha
Bhu Krishna	2017	18-22	110-120	Salinity	Anthocyanin-rich sweet potato variety (85-90 mg/ 100), having a dry matter content of 24.25.5%, starch 19.5%, total sugar 1.9-2% has good cooking quality	Odisha
Bhu Swami	2017	20	105-110	Mid-season drought	Round tubers with white skin and white flesh, having a dry matter content of 27.4-29.7%, 21% starch, 3-3.7% total sugar, excellent cooking quality	Odisha

Climate-resilient sweet potato varieties

Varsha *Sree Nandini* *Gouri* *Sourin* *Kishan*

Bhu Sona *Bhu Kanti* *Bhu Ja* *Bhu Krishna* *Bhu Swami*

Characteristics of climate-resilient yam varieties developed at ICAR-CTCRI

Crops/ Varieties	Year of release	Yield potential (t/ha)	Duration (Months)	Tolerant/ resistant to	Special features	States recommended
Sree Keerthi (Greater yam)	1987	25-30	9-10	Drought, Anthracnose disease, Scale insect	Tubers are conical with rough texture, brown skin, yellowish cortex and white flesh colour	Kerala
Sree Swathy (Greater yam)	2014	30	9-10	Drought, Anthracnose disease	Good cooking and nutritional quality with medium starch (20.02%), high protein (16.94% DW) and ascorbic acid (6.9mg/100g DW) content	Kerala
Sree Subhra (White yam)	1987	35	9-10	Drought, Anthracnose disease	Good cooking with good flavour. It has medium starch (21.0- 22.0%) and protein (1.8-2.0%) content	Kerala
Sree Haritha (White yam)	2020	46	9-10	Drought	Trailing type with medium dry matter (37.6%), starch (26.0% FW) and crude protein (3.22% FW)	Kerala

Climate-resilient yam varieties


Sree Keerthi


Sree Swathy

Greater yam


Sree Subhra


Sree Haritha

White yam

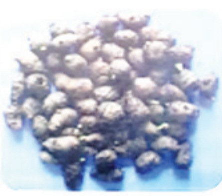
Characteristics of climate-resilient taro varieties developed at ICAR-CTCRI

Crops/ Varieties	Year of release	Yield potential (t/ha)	Duration (Months)	Tolerant/ resistant to	Special features	States recommended
Sree Rashmi	1987	18	7	Dasheen mosaic virus	Edible leaves, acrid-free corms and cormels	Kerala
Panisaru 1	2005	15.7	6-7	Leaf blight, Submerged	Good cooking quality, long shelf life	Odisha
Odisha	2005	13	6-7	Leaf blight, Submerged	Good cooking quality	
Bhu Kripa	2017	15-20	6-7	Drought and Salinity	Dry matter content ranged from 23.5-24.6%, starch 12.3-14.2% and total sugar 1.3- 1.7%	Odisha
Bhu Sree	2017	15-20	6-7	Drought and Salinity	Dry matter content ranged from 23-24.8%, starch 15.6-17.3% and total sugar 1.2- 1.5%	Odisha

Climate-resilient taro varieties


Sree Rashmi


Panisaru 1


Panisaru 2

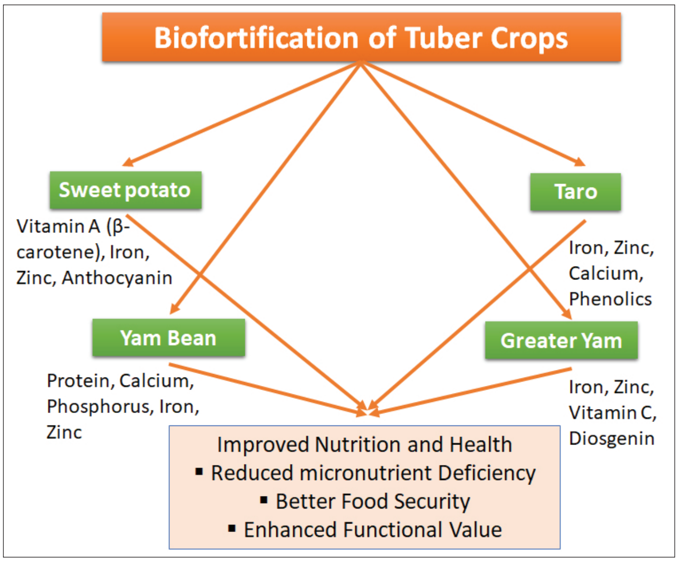

Bhu Kripa


Bhu Sree

Breeding for biofortified tuber crop varieties

Tuber crops form a vital component of global food and nutrition systems, particularly in tropical and subtropical regions. Despite their caloric richness, dietary fibre, minerals, and bioactive compounds, many tuber crops are deficient in essential micronutrients such as iron, zinc, vitamins, and antioxidants. Biofortification is an alternative to increase their nutritional status, specifically the levels of antioxidants, minerals, and vitamins. International organizations such as HarvestPlus, the International Potato Centre (CIP), and the International Centre for Tropical Agriculture (CIAT) played a pivotal role in developing and promoting biofortified varieties of sweet potato and cassava. Aligned with the objective, ICAR-CTCRI, Thiruvananthapuram and its regional station at Bhubaneswar, Odisha, have been involved in the biofortification of tropical tuber crops and successfully released many biofortified varieties in sweet potato, cassava and greater yam in the recent past.

Biofortification through conventional plant breeding is the most widely acknowledged, economically sustainable, and fastest strategy, referring to quality breeding aimed at enhancing the provitamin A, iron, and zinc contents in major food crops. Genetic or metabolic engineering, or the rDNA technology, would enhance micronutrient content in crop plants by inserting genes from another species.



Cassava

The BioCassava Plus (a CGIAR program) initiative, 2009, revolutionized cassava breeding, enhancing zinc, iron, vitamin A, vitamin E, and protein content, reducing cyanogen levels, delaying post-harvest deterioration, and developing virus-resistant cassava varieties to mitigate hidden hunger in Kenya and Nigeria. ICAR–CTCRI, Thiruvananthapuram, serves as the primary centre for cassava biofortification in India and has developed three improved, biofortified cassava varieties, namely, *Sree Visakham*, *Sree Vijaya*, and *Sree Swarna*.

Sweet potato

ICAR-CTCRI and different AICRP centres in India have released carotene-rich varieties of sweet potato, combining high yield, stress tolerance, and improved nutritional value. HarvestPlus and CIP have successfully introduced orange-fleshed sweet potato (OFSP) in Sub-Saharan Africa, significantly improving vitamin A intake and earning international recognition. Besides OFSP, *Bhu Krishna* (90-95 mg/100g) has been released as the anthocyanin (a powerful antioxidant with anti-cancerous properties)-rich variety. A promising hybrid *Sree Arunima* with high anthocyanin of 133-157 mg/100g submitted for variety release awaits SVRC Odisha notification. The collaborative ICAR-CTCRI and CIP research is now focused on the combination of β-carotene and anthocyanin-rich varieties.

Yams

Advances in genomic resources for yams have accelerated biofortification programs by facilitating marker-assisted selection for key nutritional traits. In India, several biofortified greater yam varieties such as *Hemalata*-1, *Sree Karthika*, *Sree Neelima*, and DA-340 are offering improved nutritional value alongside good yield potential. Greater yam variety, *Sree Neelima*, is a recently released as anthocyanin-rich (15 mg/100/HPLC) variety with an average yield of 33 t/ha and good cooking quality.

Aroids and other minor tuber crops

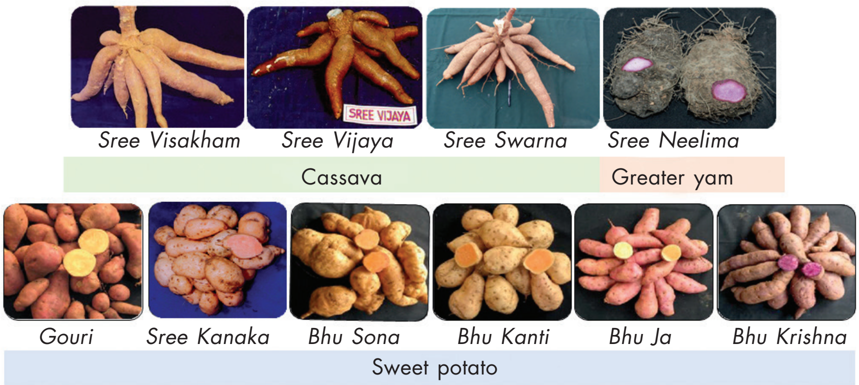
ICAR–CTCRI is emphasizing research on developing improved taro varieties for iron, zinc, calcium, and antioxidant properties. Biofortification programs for taro are less advanced than in sweet potato or cassava, but efforts are expanding with the availability of genomic tools. Similarly, we are exploring the potential of yam bean (*Pachyrhizus erosus* L., Fabaceae family) for enhanced iron and zinc biofortification, isoflavones and dietary fibre contents.

Characteristics of biofortified varieties developed at ICAR-CTCRI

Crops/ Varieties	Year of release	Yield potential (t/ha)	Duration (Months/ days)	Tolerant/ resistant to	Special features (Biofortified)	States recommended
				Cassava		
Sree Visakham	1977	35-38	10 months	*Cercospora* leaf spot	Starch: 25-27%; Carotene: 466 IU/100g; Cyanogen: 35-40 ppm, good cooking quality	Kerala
Sree Vijaya	1998	25-28	6-7 months	*Cercospora* leaf spot	Cyanogen: 40-60 ppm	Kerala
Sree Swarna	2015	35-40	7 months	Cassava mosaic disease	Yellow flesh colour, good culinary quality	Kerala

Crops/ Varieties	Year of release	Yield potential (t/ha)	Duration (Months/ days)	Tolerant/ resistant to	Special features (Biofortified)	States recommended
			Sweet potato			
Gouri	1998	19	110-120 days	Midseason moisture stress, susceptible to sweet potato weevil	A hybrid with fair, non-mealy cooking quality and β-carotene content (8.8-10.0 mg/100g FW)	Odisha
Sree Kanaka	2004	10-15	75-85 days	-	β-carotene content: 8.8-10.0 mg/100g FW, good cooking quality with a soft texture	Kerala
Bhu Sona	2017	20-24	105-110 days	-	Clonal selection from an exotic source, orange fleshed (β-carotene: 13.2-14.4mg/100g); dry matter: 27-29%, total starch: 18.8-19.7%, total sugar: 2-2.4%, good cooking quality	Odisha
Bhu Kanti	2017	22-24	105-110 days	-	Clonal selection from exotic CIP lines, orange fleshed (β-carotene: 6.2-7.8mg/100g), dry matter: 24-26.6%, total starch: 16-18.8%, total sugar: 1.9-2.2%, good cooking quality,	Odisha
Bhu Ja	2017	20-22	100-110 days	-	Clonal selection from exotic CIP lines, orange fleshed (β-carotene: 5.5-6.4mg/100g), dry matter: 23.2-24.8%, total starch: 16.6-17.2%, total sugar: 2.4-3%, good cooking quality	Odisha
Bhu Krishna	2017	18-22	110-120 days	-	Clonal selection from an exotic source, purple fleshed (anthocyanin 85- 90mg/100g), dry matter: 24-25.5%, total starch: 19.5%, total sugar: 1.9-2.2%, anthocyanin 85-90mg/100g, fair cooking quality	Odisha
			Yams			
Sree Neelima	2014	35	9-10 months	-	Light purple flesh (anthocyanin: (15 mg/100/ HPLC), dry matter: 32-33%, total starch: 20-22.5%, good culinary quality	Kerala

Naturally biofortified varieties of tuber crops



CONCLUSION

Climate-resilient, biofortified tuber crop varieties are impact-proven for broader climate adaptation and malnutrition mitigation, ensuring consumers' complete resilience and nutrition dividend. Over the years, ICAR-CTCRI has developed a sizeable climate-resilient and biofortified tuber crop varieties, and our future focus is to pyramid drought+heat+biotic factors with pro vit. A/Fe/ Zn-rich varieties using genomic selection and CRISPR-based genome editing to precisely target specific breeding. We have initiated a novel approach for modified waxy starch by editing GBSS and SBE genes using CRISPR-Cas technologies. Approaches have also been undertaken to develop vitamin (A, D, and E) and minerals (Zn and Fe) rich cassava varieties using a nutrigenomics approach. We have also initiated CRISPR-Cas-based genome editing in cassava for early bulking and drought stress tolerance. Mutation breeding and ploidy manipulation are underway to harness the genetic potential of the tuber crop wild relatives and broaden the genetic variability for augmenting future breeding strategies in tropical tuber crops.

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