

Enhancing Adaptability, Nutritional Quality in Tropical Tuber Crops: Source for Adaptive Food and Nutrition

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Abstract

The tropical roots and tuber crops (R and T) consist of cassava, sweet potato, yams, elephant foot yam, taro, tannia and a couple of minor tuber crops. Tropical tuber crops are the third most important food crops after cereals and pulses. These crops play a crucial role in providing food and nutritional security to the rural masses in Africa, Latin America and parts of Asia. Cassava and sweet potato rank among the top 10 food crops produced in developing countries and contribute to about 6% of world's dietary calories. In India, tropical tubers are grown mostly in states like Odisha, West Bengal, Andhra Pradesh, Kerala, Tamil Nadu, Bihar and North East covering 4.5% of the total area under vegetables with 5.7% of the total vegetable production. Low income farmers and most undernourished households in India depend on R and T crops. They value these crops for their high calorie and stable yields under conditions in which other crops may fail. Genetic diversity of major tropical tuber crops provides options for its diverse usage in "multicuisine", "nutrition", "feed", health care" and renewable resources of processing firms. Water productivity is also higher, for example, to produce 1 kg of tubers, sweet potatoes require water (383 l), taro (606 l), yam (343 l), as compared to rice (1673 l), maize (1222 l), wheat (1827 l), etc. Tuber crops are one of most efficient producers of dry matter and edible energy. These crops have potential to reverse soil degradation. Cassava is already recognized as drought tolerant followed by yam. Tubers of taro, elephant foot yam and yams can be stored under zero energy conditions for 6 - 7 months unlike temperate potatoes in cold storage. The natural climatic resilience as well as inherent nutrition attributes, has been explored further. Such studies made these crops more robust to changing climate and as the source of nutrient enriched food bowls. Sweet potato variety Bhu

Krishna is the first purple flesh variety in India containing (90 mg/100 g anthocyanin) coupled with starch 22% - 25%. Similarly, the orange flesh Bhu Sona containing beta carotene (14 mg/100 g) coupled with high starch 22% - 24% is the first variety having both high beta carotene and high starch. These varieties are tolerant to salinity and Bhu Krishna is resistant to weevil. Likewise, developed improved taro varieties resistant to biotic blight stress, tolerant to salinity and are enriched with micro nutrients. These improved varieties are used to breed the superior types further. All these climate resilient, nutritionally enriched varieties will have a greater impact on supplementing rainbow food for all. These can address the issues like “food insecurity”, “malnutrition”, diet related issue of mass consumers across the world. The analysis of innovations on enhancing adaptability, nutritional quality with a management matrix would help in strengthening future programme.

Keywords

Tuber Crops, Enhancing, Adaptability, Nutritional Quality, Adaptive Food-Nutrition

1. Introduction

The tropical tuber crops viz. Cassava (*Manihot esculenta*), Sweet potato (*Ipomoea batatas*), Taro (*Colocasia esculenta* (L.) Schott) and yam especially Greater yam (*Dioscorea alata*) and Elephant foot yam (*Amorphophallus paeoniifolius*) are the food crops since ancient time across the world. Being high yielder with considerable period of storability, they are commercially grown in many parts of the world including India. Of the various food crops, cassava and sweet potato rank among the top 10 food crops produced in developing countries. Thus these groups of crops are becoming the crop of present and future in the context of climate change vs. food, nutrition and sustainable livelihood. Genetic enhancement for adaptability, nutritional quality or any other attribute depends on diversity. Diversity comes from gene sources attributing to genetic improvement. Wide hybridization and domestication played a pivotal role in genetic improvement and development of agri-horticultural crops including tropical tuber crops. In fact, scientific advancement of crop breeding had actually progressed with Mendelism, as did vegetable crops in 1860. Such a logistic approach was the key guidance in breeding of other food crops. Wide crosses which were earlier Intergeneric, Interspecific even Intervarietal often had incompatibility. Such incompatible combinations can be made by Chromosome manipulation, through polyploidization and mutations. Thereafter “transgene” combinations became a reality with the discovery of recombinant DNA technology. Such techniques advanced further with genomics, functional genomics, omics aided with the CRISPR-CAS 9 [1].

Conventional or nonconventional breeding, gene source is the key component for improvement. It is causing more concern about conserving all the races of any

plant species and tuber crops. Genetic diversity of major tropical tuber crops viz. cassava, sweet potato, taro, elephant foot yam and yams are the reservoir of “food”, “feed”, “nutrition” and “health care”. Therefore conservation of biodiversity of these crops is most important in the context of food nutrition security and sustainable livelihood.

A number of studies covering developed and developing countries have shown greater concerns about the loss of genetic diversity of such climate resilient valued tuber crop genotypes. In general, tuber crops are grown in vulnerable agro-climatic conditions and provide food for more than 500 million people across the globe. Such high value clonally propagated crops are going to play a pivotal role in coming years when cereal and pulses are attaining yield stability and depend on climate for flowering and seeding. Hence research and developmental work on root and tuber crops is now gaining popularity as source of food nutrition and livelihood even under climatic adversities [2] [3].

India, having more than 8000 km of coastline and many islands, is highly vulnerable to climate change. Rural India including coastal belt is home to 833.10 million people in 6,40,867 villages. Food-insecure vast coastal wet lands in India and other countries are prone to frequent cyclones and floods (IPCC). Shrinking of available arable land and land fragmentation is reducing the per capita land availability. Population, poverty and pollution are the haunting issues compounding to wide spread poverty, malnutrition & high infant mortality rate.

Importance of tuber crops is quite evident from 1914 to 2013 as life support crops in different parts of the world during vagaries of nature [4] [5].

The potential of tuber crops to provide adaptive food and nutrition by withstanding adverse climate with natural resilience, its nutritional attributes and minimal water requirements are briefed prior to discussion on enhancing adaptability and nutritional quality.

2. Tuber Crops and Climate Change

Climate change and climate variability have become a reality today, with significant threats to ecosystem, food security, water resources and economic stability of the burgeoning populations. With the changing environment, the Green House Gases (GHG) such as atmospheric carbon dioxide (CO₂) present concentration 360 ppm will be doubled to 700 ppm by the end of 21st century. Other gases will also increase to alarming levels [Methane(CH₄) from 700 to 1720 ppm; Nitrous Oxide (N₂O) from 275 to 310 ppm; Intergovernmental Panel on Climate Change]. Besides, the mean global surface temperature is also predicted to increase by 3°C to 5°C from present levels. In the rice producing zones of South and East Asia air temperature is predicted to increase up to 7°C. The resultant heat stress is likely to cause significant crop yield losses. The yield loss of cereals like wheat, rice maize is estimated to be in the vicinity of 50%, 17%, and 6% respectively by 2050. For every 1°C increase in temperature adversely affects yield of wheat, soybean, mustard, groundnut, potato are expected to decline by 3% - 7%. Yield of rice may

decline by 6% for every 1 °C increase in temperature [6]. In this context, the tuber crops can play a crucial role in providing food and nutritional security due to their minimal effects on rise of temperature. Crops like sweet potato, taro can tolerate salt stress (4 - 8 dSm⁻¹) and served as life support species in rehabilitating affected farm families during post super cyclone (1999) in Odisha, Tsunami (2004) in coastal Andhra and Tamil Nadu States, India [3] [7].

To feed the world population which is expected to be 9.7 billion in 2050 with less per capita available water and land resources, the humankind would depend largely on “Precise technology”. Sustainable food security can be achieved only through higher productivity per unit of land, water, energy and time. In this regard, tropical tuber crops can play a greater role.

Tropical tuber crops grow well in marginal soil with fewer inputs, where other crops usually fail to grow. Most of these crops have resilience and potential for better return under harsh conditions & reversing soil degradation. Tuber crops are suitable for sustainable production intensification (SPI). This has been campaigned as “save and grow” [8], the first policy paper with regard to cassava towards its sustainable production intensification (SPI). Being naturally resilient these groups of crops can be made more adaptive. As underground food producers, tuber crops can withstand the adverse soil and climatic conditions as well as other biotic and abiotic stresses through their inbuilt survival mechanisms. Tuber crops were widely spread during colonial period and occupied a significant place in the food system in African and Latin American countries. Later, the wide niche of tropical tubers was squeezed out with advancement of civilization along with diversified culture including food habits. These food crops with natural resilience, high calorie and nutrition smart attributes deserve further innovations [4]. They can be a better choice for food, and nutrition under changing climate.

Tuber crops research in India was initially focused on improving yields. Recently, a paradigm shift has taken place for climate resilient crops with valued traits [3]. Therefore the developmental work on energy rich root and tuber crops viz. cassava, sweet potato, taro, yam and elephant foot yam in India is redesigned to enhance the nutritional quality along with better adaptability so as to fit to changing climate.

It is essential to know the strengths and opportunities of tuber crops and the threats of climate change to make these crops more adaptive and nutritive.

2.1. Natural Attributes of Tuber Crops and Food-Nutrition

Production system in India has a great challenge to feed 17.5 percent of the global population with only 2.4 percent of land and 4 percent of water resources [9]. Sustainable agriculture is at stake in India under declining per capita availability of surface and ground water resources. In this context, the tuber crops can play a crucial role in providing food and nutritional security. The tropical tuber crops viz. cassava, sweet potato, taro and yams highly responsive to organics are the staple food of people living in Islands and fragile environment. In India unlike

cassava, sweet potato grows in most of the States. Its area, percent share, production and yield are presented in **Table 1**. In production of sweet potato, Odisha ranks no.1 followed by Uttar Pradesh (APEDA (2021) <http://www.apeda.gov.in> & <http://www.indiastatagri.com>). Productivity can be enhanced further with improved varieties under précised production system.

These crops are gaining importance for their high yield potential (20 - 50 t·ha⁻¹), dietary energy (361 - 386 calories/100g), and nutritional attributes in wide & adverse conditions. The minerals and fibre contents in most of these crops are 1.5 to 5 times higher than rice and wheat. Production of one ton yield of sweet potato tuber requires less water (387 l) compared to rice (1673 l) and wheat (1827 l).

The inbuilt adaptability, water use efficiency and inherent nutritional attributes in tropical tubers are the boons in the context of sustainable food security and climate change. It is essential to have preparedness and disruptive technologies to provide solutions for maintaining food and nutritional security in adverse situations.

Table 1. State-wise area, production and productivity of sweet potato in India (2021-2022).

States/UTs	Area (ha)	% share	Production (tons)	% share	Yield (tons/ha)
Andaman & Nicobar Islands	50	0.05	600	0.05	12.00
Andhra Pradesh	470	0.44	14,080	1.19	29.96
Assam	5050	4.73	27,670	2.34	5.48
Bihar	2390	2.24	44,920	3.79	18.79
Chhattisgarh	4800	4.49	54,710	4.62	11.40
Goa	80	0.07	230	0.02	2.88
Jammu & Kashmir	1370	1.28	41,110	3.47	30.01
Jharkhand	80	0.07	1920	0.16	24.00
Karnataka	4480	4.19	51,140	4.32	11.42
Kerala	180	0.17	2580	0.22	14.33
Madhya Pradesh	6690	6.26	104,730	8.84	15.65
Maharashtra	1750	1.64	10,560	0.89	6.03
Meghalaya	4940	4.62	16,650	1.41	3.37
Mizoram	100	0.09	1000	0.08	10.00
Nagaland	960	0.90	10,400	0.88	10.83
Odisha	34,030	31.84	330,570	27.91	9.71
Rajasthan	710	0.66	15,260	1.29	21.49
Tamil Nadu	510	0.48	8740	0.74	17.14
Telangana	190	0.18	3450	0.29	18.16
Uttar Pradesh	18,840	17.63	254,250	21.47	13.50
West Bengal	19,210	17.98	189,670	16.02	9.87
India	106,870	100.00	1,184,230	100.00	11.08

Source: APEDA (2021) <http://www.apeda.gov.in> & <http://www.indiastatagri.com>.

To make tuber crops more resilient, extensive studies were taken up integrating conventional and non-conventional methods to tap the vast potential of genetic diversity in isolating the stress tolerant genotypes. Basic innovations on “stress adaptability” with associated morpho-physiological, biochemical and bio molecular changes enabled to identify the valued traits in developing the marketable varieties. In recent years, innovations in evolving food, nutrition, industry and climate smart tuber crops technologies are reemphasizing their potential to meet “Climate Smart Future Demands” [10]-[12].

2.2. Natural Endurance, Nutritional Composition

The tuber crops can withstand adverse soil and climatic conditions and provide staple food adequately during disasters. To adapt climatic changes, a global approach has already been made with vegetatively propagated crop like taro through EU-aided International Network for Edible Aroids (*INEA*) programme. The inherent smart abilities of different tuber crops (**Table 2**) indicate their adaptability to diverse environmental conditions [4].

The high yield potential (90 - 120 t/ha) of tropical tubers under wide range of precipitation, temperature as well as tolerance to shade, submergence, drought with nutritional attributes (**Table 2** and **Table 3**) are the base to explore their “smart attributes” to cope with changing climate.

Table 2. Inbuilt climatic resilience of tropical tuber crops.

Characteristics	Cassava	Sweet potato	Yams	Aroids
Yield potential (t/ha)	90	120	110	110
Optimal rainfall (mm)	1000 - 1500	750 - 1000	1200 - 1500	2500 - 3500
Optimal temperature (°C)	25 - 30	20 - 25	30	20 - 35
Drought resistance	Yes	Yes	Yes	No
Tolerance to water logging	No	No	No	Yes
Tolerance to shade	No	No	No	Yes
Fertility and organic matter requirements	Low	Low	High	High
Seasonality of crop cycle	No	Yes	Yes	No
In-ground storage life	Long	Moderate	Moderate	Long
Postharvest storage life	Very short	Short	Long	Moderate
Leaves used for human consumption	Yes	Yes	No	Yes
Leaves used for animal feed	Yes	Yes	No	Yes

Source: Adapted from [4].

Table 3. Nutritional composition of tropical tuber crops.

Particulars	Cassava	Sweet Potato	Yams	Aroids
Dry matter (% fresh weight, FW)	30 - 40	20 - 35	20 - 40	20 - 30
Starch (% FW)	27 - 37	18 - 28	20 - 25	15 - 25
Starch grain (in microns)	5 - 50	2 - 40	1 - 70	1 - 6

Continued

Amylose (% starch)	15 - 30	8 - 32	10 - 30	3 - 45
Gelatinization temperature (°C)	49 - 73	58 - 65	69 - 88	68 - 75
Total sugars (% FW)	0.5 - 2.5	1.5 - 5.0	0.5 - 2.0	2.0 - 3.0
Proteins (% FW)	0.5 - 2.0	1.0 - 3.0	2.0 - 4.0	1.5 - 3.0
Fibers (% FW)	1.0	1.0	0.6	0.5 - 3.0
Vitamin A (µg/100 g/FW)	17	900	117	0 - 42
Vitamin C (mg/100 g/FW)	50	35	25	10
Minerals (% FW)	0.5 - 1.5	1.0	0.5 - 1.0	0.5 - 1.5
Energy (kJ/100 g/FW)	600	500	440	400

Source: Adapted from [4].

2.3. Climate Change, Water Footprint and Sustainable Production

Climate resilient agriculture (CRA), involving efficient water-agro input management practices, adaptation, mitigation strategies with effective use of genetic resource suiting judiciously to respective agro-ecosystem is vital for sustainable production system.

Concept of “water footprint” and results on its modular studies would help to evolve efficient water management practices. The concept of “water footprint” introduced by Hoekstra and subsequently elaborated [13] provides a framework to analyze the link between human consumption and the appropriation of the globe’s freshwater. The water footprint of a product (alternatively known as “virtual water content”) expressed in water volume per unit of product usually expressed as ‘m³·ton⁻¹, is the sum of the water footprints of the process involved to produce the product.

Water footprint studies [13] assessed the green, blue and grey water footprint of crop production by using a grid-based dynamic water balance model, that was based on the local climate and soil conditions as well as nitrogen fertilizer application rates. Calculations were based on crop water requirements, actual crop water use and yields at grid level. The model’s concept was based on the CROPWAT approach. The actual crop evapo transpiration depends on climate parameters (which determine potential evapotranspiration), crop characteristics and soil water availability [14].

The water footprint of primary crops would help to understand the better productivity of tuber crops which minimize water. Such knowledge would lead to develop a better production system for all crops including tuber crops.

2.4. The Water Footprint of Primary Crops Including Tuber Crops

The average water footprint per ton of primary crop differs significantly among crops and across production regions. Crops with a high yield or large fraction of crop biomass generally have a smaller water footprint per ton than crops with a low yield or small fraction of harvested crop biomass. When considered per ton

of product, commodities with relatively large water footprints are: coffee, tea, cocoa, tobacco, spices, nuts, rubber and fibres (**Table 4**). For food crops, the global average water footprint per ton of crop increases from sugar crops (roughly 200 $\text{m}^3\cdot\text{ton}^{-1}$), vegetables (300 $\text{m}^3\cdot\text{ton}^{-1}$), roots and tubers (400 $\text{m}^3\cdot\text{ton}^{-1}$), fruits (1000 $\text{m}^3\cdot\text{ton}^{-1}$), cereals (1600 $\text{m}^3\cdot\text{ton}^{-1}$), oil crops (2400 $\text{m}^3\cdot\text{ton}^{-1}$), pulses (4000 $\text{m}^3\cdot\text{ton}^{-1}$), spices (7000 $\text{m}^3\cdot\text{ton}^{-1}$) to nuts (9000 $\text{m}^3\cdot\text{ton}^{-1}$) [8].

Globally, 86.5% of the water consumed in crop production is green water. This offers a good opportunity to increase food production from rain-fed agriculture by raising water productivity without requiring additional blue water resources [15]-[17]. As shown most countries, in theory have a green water based self-sufficiency potential and are in a position to produce the great opportunity to improve water productivity through improving yield levels as much as four folds within the available water balance in rain-fed agriculture [17]. However, the marginal benefit of additional blue water in semi-arid and arid regions could be quite large in terms of raising productivity.

Water footprint per ton of product was recorded as high as 1827 m^3 in wheat, 1673 m^3 in rice as compared to 383 m^3 in sweet potato followed by 343 m^3 in yam [13] (**Table 5**).

In depth studies [13] indicate the potential of further augmentation in suitable crop water management practices.

Table 4. Global average water footprint of 14 primary crop categories, Period: 1996-2005.

Primary crop category	Water footprint ($\text{m}^3\cdot\text{ton}^{-1}$)				Water footprint ($\text{kg}\cdot\text{m}^{-3}$)	Caloric value ($\text{kcal}\cdot\text{kg}^{-1}$)	Water footprint (l kcal^{-1})
	Green	Blue	Grey	Total			
Sugar crops	130	52	15	197	5.076	290	0.68
Fodder crops	207	27	20	253	3.953	-	-
Vegetables	194	43	85	322	3.106	240	1.34
Roots and tubers	327	16	43	387	2.584	830	0.47
Fruits	727	147	93	967	1.034	460	2.10
Cereals	1232	228	184	1644	0.608	3200	0.51
Oil crops	2023	220	121	2364	0.423	2900	0.81
Tobacco	2021	205	700	2925	0.342	-	-
Fibres, vegetable origin	3375	163	300	3837	0.261	-	-
Pulses	3180	141	734	4055	0.247	3400	1.19
Spices	5872	744	432	7048	0.142	3000	2.35
Nuts	7016	1367	680	9063	0.110	2500	3.63
Rubber, gums, waxes	12,964	361	422	13,748	0.073	-	-
Stimulants	13,731	252	460	14,443	0.069	880	16.40

Source: [8].

Table 5. Water footprints (m³/t), water productivity (kg product/m³) in selected food crops.

Crop	Water footprint (m ³ of water/ton of product)	Water productivity (kg·m ⁻³)
Wheat	1827	0.547
Rice	1673	0.598
Maize	1222	0.818
Sweet potato	383	2.611
Cassava	564	1.773
Taro	606	1.658
Yam	343	2.915

Source: Adapted from [13].

2.5. Water Availability and Agriculture in India

The availability of water for agriculture in India is projected to decline 84% in 2010 to 74% by 2050 [18]. Therefore to produce 350 M t food grain from shrinking water resources would put existing water sources under immense pressure. Water being the critical input for productivity enhancement, there is a need for its optimum and judicious use (through need based supplementary irrigation) for realizing higher input use efficiency through various technological options available.

It has been estimated that about 1% annual increase in water productivity (quantity per unit consumptive water use) would meet additional water demand for grain production and its further increase to 1.3% would satisfy all crops water demand. Water productivity of crops thus can be enhanced with scientific crop-water management practices, especially with sensor based on site real time mechanisms.

2.6. Techniques for Saving Water and Farm Inputs

Various water saving techniques like mulching, amendment of soil with coir pith have been studied to reduce water requirement up to 50% in different tuber crops including elephant foot yam. Mukherjee *et al.* reported [19] [20] significantly higher yield in tropical tuber crops when soil was amended with coir pith owing to its slow release leaching water and other macro and micro elements.

Water and farm inputs saving mechanisms developed using drip fertigation, micro-irrigation, Site Specific Nutrient Management (SSNM) as well as use of different mulch can reduce inputs use by 30-50%. Yield can be enhanced by 20% - 30%. Dry leaf mulches with drip fertigation can save resources and can enhance yield by 30% - 40%.

The water productivity of the tuber crops was higher than most commonly cultivated cereals, pulses and other food/commodity crops [13]. Water productivity can also be expressed in “terms of money/m³” of water.

If water productivity is expressed in terms of marketable values of respective

crop instead of its yield/m³ then productivity curve will be entirely different for the crops. Such valuations can be understood from the water footprint of primary crops (Table 5). Water productivity of a crop is not merely dependent on water alone but also on other inputs starting from crop type, soil based nutrients, climatic conditions. Hence water productivity needs to be addressed holistically under integrated “crop specific agro-ecosystem”. Moreover in current climatic turbulence, adaptation and mitigation strategies are equally important.

2.7. Adaptation-Mitigation to Climatic Changes

There was a strong positive influence of elevated CO₂ up to 700 ppm on the rate of photosynthesis and yield in cassava. Further physiological experiments conducted in tuber crops under elevated CO₂ (eCO₂) were quite encouraging. Maximum increment in net photosynthesis was recorded at CO₂ between 400 - 600 ppm relative to 400 ppm. Of the different varieties of tuber crops exposed to eCO₂, some of the cassava varieties viz. H-226 and Sree Reksha responded well. Similarly sweet potato varieties like Gouri, Sankar, Sree Arun; elephant foot yam varieties like Sree Padma and Gajendra; taro varieties like Sree Pallavi, Muktakeshi & Telia and yam varieties like Sree Priya (white yam) and Sree Shilpa (greater yam) had good response to elevated CO₂ (1000 ppm) compared to ambient CO₂ (400 ppm) [21]. Among the tropical tubers, cassava was observed to have minimal effects on rise of temperature and CO₂ concentration.

2.8. Stress Endurance

The basic research on crop speciation, its growth and development under induced and *in situ* stresses led to evolve improved tuber crop varieties [3] [11] [12] [22]. Similarly water management practices like irrigation under water deficit stress and pressurized irrigation in tuber crops have enhanced water productivity. Further, the studies on adaptation-mitigation to climate change conducted at ICAR-CTCRI clearly indicate the potential of root and tubers as “climate resilient characters”.

Studies in India and abroad revealed the potentiality of these root and tubers to adapt more & more under unfavorable agro-climatic conditions. Hence research and development efforts have taken a paradigm shift in India and abroad to enhance resilience and water productivity of these crops. To make these crops more resilient, extensive studies were taken up in isolating the stress tolerant genotypes. Basic innovations on “stress adaptability” with associated morpho-physiological, biochemical and bio molecular changes enabled to identify the valued traits in developing the marketable varieties.

To mitigate hunger and nutrition “climate proofing of tuber crops” can be enhanced further [23] [24]. Thus, an outline of natural resilience of these groups of crops has been discussed to shed more light on exploring the potential in enhancing their adaptability and nutritional quality.

Work on enhancing adaptability, nutritional quality to cope adverse climate by

increasing inbuilt sustenance mechanisms in tropical tuber crops are briefed as follows.

3. Innovations in Enhancing Adaptability to Stresses and Enriching Nutritional Quality of Tuber Crops

Genetic diversity of these crops, and their wide distribution and potential to adapt in harsh environmental condition has led to further innovations. However, gene flow through conventional breeding is hindered owing to flowering behaviors, cytogenetical anomalies like polyploidy coupled with self incompatibility, heterozygosity etc. in tropical tuber crops. Hence, extensive studies have been taken up for genetic enhancement integrating conventional and non conventional methods to tap the vast potential of diverse resources in developing resilient varieties.

The results on evolving improved varieties of tropical tuber crops with climate, nutrition and health benefit smart attributes are briefed crop wise as follows.

3.1. Sweet Potato

Sweet potato [(*Ipomoea batatas* (L.), family *Convolvulaceae*.] most suitable to grow and check soil erosion in degrading and fragile lands as ecofriendly crops.

Of the various *Ipomoea* species, sweet potato botanically known *Ipomoea batatas* is the only edible species. It is hexaploid with basic chromosomes of $x=15$. [25]-[27]. It has many wild relatives. Embryo rescue techniques have been developed in sweet potato and its wild relatives [28] [29] to recover desirable wild hybrids. Polyploidization is usually followed by a genome-wide loss of some of the redundant genomic material [30]. Sweet potato is usually grown well in well drained sandy loam soil. Innovations have enhanced its adaptability to grow under drought, salt and submergence stresses.

3.1.1. Drought Tolerance

Tuber initiations influenced by various factors were studied under moisture deficit stress by various researchers. Cultivars differ in their tolerance to water deficit stress (WDS) conditions. High stomata resistance in tolerant cultivars may be advantageous for conserving leaf water content at the cost of reduction in photosynthesis under WDS. This helps tolerant cultivars to have lower desiccation rate in the leaf tissue than the susceptible ones [31].

Drought tolerant sweet potato cultivars accumulate greater amount of proline in the leaf and fibrous root tissues than the plants under water deficit free conditions. In both tolerant and susceptible cultivars, leaves accumulate greater amount of proline than the non-storage, fibrous roots. However, some susceptible cultivars which do not yield but survive under WDS also accumulate good amount of proline in their leaf tissues. Recent studies at ICAR-CTCRI resulted in identifying genotypes with drought stress tolerance. Further, the survival of some of the varieties of sweet potato over dry period reflects their tolerance to drought stress and can be adapted for cultivation in high lands, where such conditions prevail [32] [33]. Studies on DUS (Distinctness, Uniformity and Stability) traits indicate

tolerance to drought in some cultivars [34].

3.1.2. Submergence Tolerance

Paclobutrazol (PBZ) mediated flooding tolerance was substantiated in sweet potato.

Plants receiving paclobutrazol (PBZ) under environmental stress have significantly higher antioxidative system levels compared to plants under non stressed conditions [35]. Changes in antioxidants and antioxidative enzymes in the flooding stressed sweet potato leaf as affected by PBZ treatment at 24 h prior to flooding were studied [36]. Their results showed that under flooding stress conditions, the level of antioxidative system is linked to PBZ treatment. Pre-treating with PBZ may increase levels of various components of antioxidative systems after exposure to different durations of flooding and drainage, thus inducing flooding tolerance. The PBZ exhibited an important function of enhancing the restoration of leaf oxidative damage under flooding stress after the pre-application of 0.5 mg per plant. These findings will have greater significance for farming in frequently flooded areas. Similarly, pretreating with CaCl_2 could enhance tolerance to flooding stress by enhancing reduced glutathione (GSH). Pretreatment with 60 and 120 kg ha^{-1} CaCl_2 enhanced the flooding tolerance in studied genotypes and mitigated the effects of flooding stress. CaCl_2 mediated tolerance would help further genetic and physiological studies in sweet potato to adapt in submergence stresses [32] [33] [37]. Three cultivars tolerant to submergence have already been identified in sweet potato under induced flooding stress [3].

3.1.3. Salinity Tolerance

In India, information on salinity tolerance is virtually confined to the work carried out at ICAR-Central Tuber Crops Research Institute [38]-[42]. *In vitro* propagation studies revealed enhanced rate of propagation of sweet potato with supplementation of NaCl in culture medium [39]-[41]. Though rate of propagation in all possible routes was higher in NaCl supplemented medium, level of NaCl tolerance was quite high in case of embryogenic regeneration pathway. Regenerated plants recorded high rate (90% - 100%) of survival in the field. The embryos produced with NaCl supplementation were quite hardy and could tolerate low temperature (8°C) stress during storage without the protective covering of costly sodium alginate. The hydroponic cultures and NaCl mediated *in vitro* protocols developed [40] [43] in sweet potato and other tuber crops facilitated faster screening of large collection. Isoenzymes and RAPD marker studies carried out in sweet potato [43] hastened their characterization. The varied growth response, morpho-physio-biochemical changes studied under *in vitro* NaCl mediated stress and under *in situ* saline conditions [41] speeded up to isolate the salt tolerant sweet potato genotypes. An extensive study under *in vitro* and *in vivo* screening and evaluation of 171 sweet potato genotypes and their successive evaluation under *in situ* salt stress ($6.0 - 8.0 \text{ dSm}^{-1}$) in coastal Odisha and West Bengal resulted in identification of 11 salt tolerant genotypes packed with high yield ($>18 \text{ t}\cdot\text{ha}^{-1}$), starch

(16% - 24%), beta carotene (5 - 14 mg/100 g) and anthocyanin (90 mg/100 g).

3.1.4. Health Benefit Attributes

Apart from naturally occurring nutrients, the innovative breeding programme has resulted in developing orange and purple flesh sweet potato varieties rich in anti-oxidants. The specific physiological functions as source of anti-oxidant [44] anti-mutagenic [45] anti-carcinogenic [46] anti-diabetes [47] have been well illustrated. Further, antiproliferative activity of sweet potato anthocyanins against breast, cervical and colon cancer has also been elucidated in India [48].

3.1.5. Breeding Progress in India through Integrated Approaches

Breeding activities had been taken up to endure adverse climate and resistance to weevil (*Cylas formicarius*) which causes 60% - 100% yield losses across the world.

Progressive breeding and evaluation since inception onwards at ICAR-CTCRI resulted in evolving 21 sweet potato varieties (Figure 1). The varieties evolved from 2014 to 2019 are tolerant to biotic (weevil) and abiotic salt stress (6 - 8 dSm⁻¹) packed with high yield (>18 t·ha⁻¹), starch (18% - 24%), beta carotene (6 - 14 mg/100g) and anthocyanin (90 mg/100g). Such high valued sweet potatoes were released, notified and registered [2] [3].

The five varieties released recently from ICAR-CTCRI that include three with orange flesh (Bhu Sona, Bhu Ja and Bhu Kanti) and one with purple flesh (Bhu Krishna). Bhu Swami (ST-10), the white fleshed variety tolerant to mid-season drought and is suitable for food and processing industry with extractable starch of 22% - 23%. Those four orange fleshed varieties and purple flesh Bhu Krishna are tolerant to salinity (6.0 - 8.0 dSm⁻¹). Bhu Krishna is also resistant to weevil.

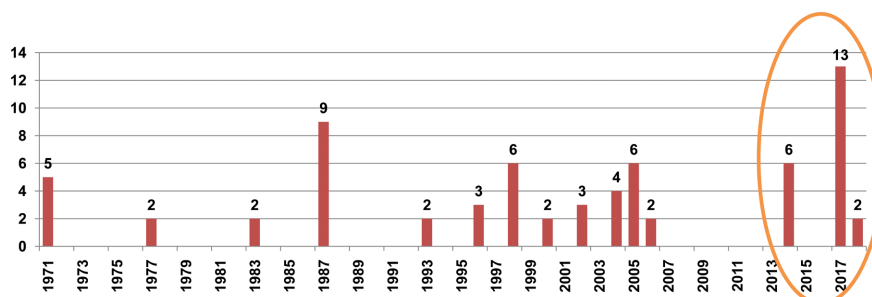


Figure 1. Development and release of improved tropical tuber crops varieties.

3.1.6. Biotechnological Approach for Biotic Stress Tolerance

Biotechnological work in sweet potato has gained momentum in many national and international laboratories [33] [40]. Genetic engineering coupled with tissue culture technology is redesigning the crops to make it more productive. Development of transgenic sweet potato for resistance to weevil, feathery mottle virus and fungal diseases have been reported in international and national laboratories. Genetic engineering for higher protein content is also found to be quite successful in sweet potato. Transcriptome analyses for tuber flesh colour and weevil resistance in sweet potato was carried out and have identified differentially expressed genes.

3.2. Cassava

Cassava or tapioca (*Manihot esculenta* Crantz) belongs to the family *Euphorbiaceae* is a native of Brazil (South America), widely cultivated in the tropics. It is also the raw material for starch & sago industry and a component of animal, fish and poultry feeds in many developing nations including India. It is also a saviour crop as source of high energy under vulnerable climate. Regarding speciation, hybridity and polyploidy confer variability to a certain population. Then apomixis fixes and perpetuates genotypes to adapt in certain environment [49]. This drought tolerant crop responds well physiologically under desiccation. However, its susceptibility to Cassava Mosaic disease (CMD) and short shelf life of harvested tubers are the major bottle necks for cassava farming.

In India, cassava is cultivated predominantly in Kerala and Tamil Nadu. It is also grown in Andhra Pradesh, Assam, Karnataka, Madhya Pradesh, Pondicherry, Nagaland, Tripura, Mizoram and the Andaman & Nicobar group of islands.

Cassava Mosaic disease (CMD) the virus in Africa in the 1920s led to a major famine. CMD is spread by the whitefly and also through infected planting material. Yield loss in susceptible cultivars varies from 20% - 95% [50].

In the interspecific breeding programme, hybrids of *M. caerulescens* exhibited high level of resistance and were used as donor parents for transferring resistance to elite Indian cultivars [51]. To date, two CMD resistance genes CMD1 and CMD2 have been placed on the genetic map [52].

Cassava roots have an endogenous disorder known as postharvest physiological deterioration (PPD) which is reported to cause an economic loss of up to 30% within 2 days of harvest. Therefore it necessitates that the tubers must be consumed or processed immediately after harvest which in practical terms is difficult for marginal farmers and traders. Hence breeding for resistance is the solution.

3.2.1. Progress in India

Breeding activities in cassava emphasized for resistance to CMD, PPD in India and across. Development of improved cassava with disease resistance and longer shelf life would help to recover the revenue loss and enhance the commercial utility for food, feed, nutrition and processed products.

Cassava breeding in India resulted in developing and release of cassava varieties like Sree Visakhm, Sree Jaya, Sree Vijaya, Sree Prabha, Sree Rekha, Sree Padmanabha, Sree Prakash, Sree Sahya. Among these, Sree Padmanabha (MNga-1) is the product of wide cross of East and West African cassava gene sources. The varieties developed and released during the last 56 years (Figure 1) found to be high yielding with other agronomic attributes. However the varieties developed after 2000 onwards have marketable traits and enhanced adaptability to tolerate biotic mosaic, abiotic drought and post physiological deterioration (PPD).

Recently ICAR-CTCRI developed high starch yielding triploids—Sree Athulya and Sree Apporva. Three cassava mosaic disease (CMD) resistant varieties (Sree Rekha, Sree Sakthi and Sree Suvarna) were also released. Highly drought tolerant

lines have also been identified. One yellow fleshed carotene rich variety (Sree Swarna) has also been released. Studies on physiological parameters to assess water use efficiency with carbon isotope discrimination (CID) and drought tolerance revealed better performance of the variety Sree Reksha. Tolerance to environmental stresses by released cassava varieties have been well illustrated [34].

3.2.2. Biotechnological and Bio-Modeling Approach

Tissue culture techniques especially micropropagation and somatic embryogenesis have developed in cassava [38]. Disease free propagules can be produced in cassava through syn-seeds. Transgenic resistances for common mosaic virus (ACMV) with dysfunctional ACMV genes were identified. Four different research groups have developed transgenic cassava plants. The CIAT, Cali, Colombia, was the first laboratory to claim it [1]. Transgenic research on CMD resistance is underway in India. Transformation strategies have been standardized for developing waxy cassava for commercial purpose.

Biomodelling is the *in silico* fastest strategy to harness wet lab experiments and gaining momentum in artificial intelligence era to speed up the molecular breeding products.

Three hundred potential target genes were identified for the predicted miRNAs, of which two cassava miRNAs having target in Cassava Mosaic Viruses (CMVs) were validated. Carotenoids biosynthesis pathway analysis in cassava was carried out *in silico* to identify the genes and identified 39 carotenoid genes in cassava. The regulatory sequence analysis showed 18 significant transcription factors regulating carotenoid genes in cassava. Analysis of abiotic stress specific regulation of heat shock proteins (HSP) and SnRK family genes in cassava led to the identification of 67 small heat shock proteins (MeHSP20) and 41 SNF-related family genes in cassava. Promoter analysis revealed the presence of tissue-specific, biotic, abiotic, light-responsive, cis-regulatory elements. Expression analysis revealed the constitutive and stress-specific induction of MeHSP20 and MeSnRK family genes in cassava. These *in silico* information would speed up molecular breeding to have precised quality product in enriching climate resilient marketable traits.

3.3. Taro

Taro [*Colocasia esculenta* (L.) Schott] belonging to the family *Araceae* (Aroideae). It ranks fourteenth among staple/vegetable crops worldwide. It is most popular food cum vegetable crop.

Taro is an environment friendly unique crop. It is able to grow in harsh ecological conditions. It is highly productive (15 - 22 t/h), short duration and shade loving crop. Shade tolerance fits taro as a profitable inter-crop. Taro is the first staple crop of the world, domesticated earlier to rice. This ancient crop is also associated with ethnic culture. It fits well as an alternative crop in the rice-based cropping systems as land that has been prepared for flooded rice is equally suitable for flooded taro.

3.3.1. Speciation

Two gene pools appeared with domestication occurring in Southeast Asia and with separation of the land masses of Sunda and Sahul overlapping in Indonesia. Based on these gene pools, two botanical varieties of taro have been designated *C. esculenta* var. *esculenta*, commonly known as dasheen and *C. esculenta* var. *antiquorum*, commonly known as eddoe with different cytotypes. In general, cytotypes (triploids, diploids) varied at high altitude and latitude environments suggesting that such conditions promote the occurrence of unreduced gametes. Biochemical, molecular marker studies have shown the following gene pools [53].

- Two distinct gene pools, one in Southeast Asia and the other from Southwest Pacific.
- The allelic diversity of the wild taros is similar to that of cultivated forms.

Studies conducted with DNA markers revealed that for most of these roots and tuber crop species, genetic distances correspond to geographic distances and there are different gene pools. Markers also revealed that new variants spontaneously appearing in farmers' plots are hybrids.

RFLP analysis of chloroplast DNA was also used to study phylogenetic affinities between taro species in genus *Alocasia* [54] [55]. These studies indicated the presence of *Alocasia* chloroplast DNA in *Colocasia* samples, suggesting possible hybridization between the two genera. Isozyme variation in taro cultivars and wild type from Asia and Oceania showed greater variations in Asian cultivars [53].

3.3.2. Tolerance to Leaf Blight, Drought and Salinity

To make taro more adaptive to climate changes, an extensive study was taken up at ICAR-CTCRI to tap the vast potential of genetic diversity in isolating biotic (blight) and abiotic (drought, salinity) stress tolerant taro.

Screening of 174 taro genotypes integrating *in vitro-in vivo* methods, evaluation under integrated stresses and its further validation under *in situ* stresses resulted in identifying stress tolerant taro. The cumulative effect of morphological, physiological, and biochemical gestures on tuberization were also studied under osmotic stress. Tolerant genotypes have the ability to maintain tuber yield under osmotic stress conditions and exhibit minimum yield reductions under scarce water conditions. Significant and strong correlation of photosynthetic parameters towards yield maintenance under osmotic stress showed its crucial role on source-sink relationship in taro. Balanced physiological and biochemical attributes with a strong enzymatic anti oxidative system resulted in the low yield reduction in the tolerant as compared to the susceptible variety [22].

Genetic variation is the most important source of adaptive potential. Lack of allelic diversity within same geographical location suggested the need for a dynamic breeding approach among the taro growing countries including India [Dr. Vincent Lebot (Vanuatu; CIRAD-France)]. A global initiative thus was taken up by Dr. Vincent Lebot for *INEA* (International Network for Edible Aroids-Taro project) to increase genetic and phenotypic diversity in taro to adapt to climatic changes. The global experiment, involving 14 countries from America, Africa,

Asia and the Pacific was conducted to test this approach. Under *INEA*, every country received a set of 50 indexed genotypes *in vitro* assembling significant genetic diversity. After on station agronomic evaluation trials, the best genotypes were distributed to farmers for participatory on-farm evaluation. Introduced genotypes were successfully crossed (controlled crossing) with local cultivars and new hybrids were produced. Seeds were exchanged internationally to enhance allelic diversity in different countries for the first time in Aroids research. This has widened the genetic base in taro farming which will help in overcoming the disasters that will otherwise ensue.

Studies under *INEA* revealed very high nutrient contents of Ca (1327 - 3775 mg/kg), Fe (38 - 74 mg/kg), Zn (50 - 131 mg/kg) in Indian taro. Such high nutritionally valued crops can address the issues of “hidden hunger” apart from its calorie value. DNA analysis revealed two distinct gene pools with wide genetic diversity. Hence wide hybridization between indigenous and geographically distant exotic taro can strengthen the adaptive food-nutrition and livelihood programme. Considering the opportunities of taro farming across the globe, the *INEA* programme which was launched in 2011 concluded successfully with the following outcomes:

- Synthesis of new “hybrid products” adaptive to climatic and consumer needs
- Molecular tools with integrated grid of morpho-phylogenetic studies of “desirable natural product” open up newer avenues to analyse its origin and profiling of marketable traits.
- National, International Network programme to accelerate the process in developing high value products

3.3.3. Developed and Released Stress Tolerant Varieties in India

In taro, shy erratic flowering and asynchrony is the major blockade in breeding. However, perennial plantation and pollination with cryopreserved pollen was found to be successful in recovering desirable hybrids in taro [56]. Progressive breeding and evaluation resulted in developing biotic (blight) and abiotic (salt, drought, submergence) stress tolerant taro with good yield (12 - 15 t/ha) [24]. The varieties released viz. Muktakeshi, Bhu Kripa, Bhu Sree are resistant to taro leaf blight and can tolerate drought, salt stresses. Similarly the varieties viz.

Pani Saru1, Pani Saru2 can give good return in water logged conditions. On site participatory breeding under *INEA* resulted in developing early maturing, blight resistant taro hybrids which are also rich in minerals [57].

Higher antioxidant and pronounced isozymes activities were studied in tolerant genotypes under stress [7] [58]-[60]. An in depth study was also conducted on phenotypic variability in taro. Cluster analysis of tolerant and sensitive lines revealed that tolerant lines share the same node [7] [24].

Like taro, studies on elephant foot yam, yams and other minor tuber crops have evolved to endure stresses and have been released. The dendrogram shows the release of improved tuber crops varieties from ICAR-CTCRI (Figure 1) from 1971 to 2019.

ICAR-CTCRI has released 67 varieties of tropical tuber crops (19 cassava, 21 sweet potato, 16 yams, 2 elephant foot yam, 8 taro & 1 Chinese potato) since inception to 2019 of which 21 varieties released during 2014-2019 period are resilient to stresses.

The nutritionally enriched as well as stress resistant sweet potato and taro varieties and the hybrids raised from best parents are presented as follows.

3.4. The First Purple Flesh Bhu Krishna and Orange Flesh Bhu Sona with High Starch & High Antioxidants Sweet Potato Varieties Released in India in 2017 are Boon to Enrich Food Bowls

During 2017, ICAR-CTCRI released three orange, one purple and one white flesh sweet potato varieties. Purple flesh Bhu Krishna is the nation's first anthocyanine rich (90 - 91 mg/100g) sweet potato. Orange flesh Bhu Sona is the nation's first high beta carotene rich (12 - 14 mg/100g) with high starch (22% - 24%) palatable varieties. The nutritional composition of Bhu Sona, Bhu Krishna along with control Kamala Sundari is presented below (**Table 6**).

Besides these two said varieties, the other orange flesh varieties released viz. Bhu Kanti, Bhu Jha contain beta carotene (6 - 7 mg) and starch (18% - 20%). All these four varieties are tolerant to salinity (6 - 8 dSm⁻¹). The white flesh Bhu Swami has the highest amount of extractable starch (22% - 23%) and is tolerant to mid season drought. All these orange, purple, and white flesh varieties are palatable and have Vitamin C (23 - 26 mg/100g) and Vitamin E (5 - 7 mg/100g). In this context, coloured flesh varieties are more nutritious than white flesh. These varieties could have been released during 2014 as all those Bhu Series tuber crops varieties had completed the required trials, test as well as All India Coordinated Research Project Trials on Tuber crops (AICRP-TC). Those were recommended to release by a panel of experts during biennial meeting of AICRP-TC in 2013. However, the release got delayed in Odisha owing to a lack of processing by Hort. Dept. Odisha, India. During 2016-17, Sri S. Prusty joined as Director of Directorate of Horticulture, Odisha and facilitated the release of pending varieties promptly in 2017.

During development of these varieties we got inspired by Bharat Ratna Prof. M.S Swaminathan the pioneer of "Zero Hunger Challenge" and "Malnutrition drive" [61]. He encouraged us to enrich the local food and vegetables. Root and tubers as such the regular dishes of low income group as well as food of small - marginal farming communities. Enrichment of these crops with nutrients no

Table 6. Nutrient composition of purple flesh Bhu Krishna, Orange flesh Bhu Sona and Kamala Sundari.

Sl. No.	Varieties	Total Yield (t/ha)	Total Starch (%)	Total Carotene	Total Anthocyanin	Ca	Zn	Fe
				(mg/100g)				
1	Bhu Krishna (purple flesh)	17.85 - 20.18	22 - 25	-	90 - 90.8	28.5	0.8	0.9
2	Bhu Sona (orange flesh)	18.85 - 20.52	22 - 24	14.8	-	37.2	0.7	0.7
3	Kamala Sundari (orange flesh)	17 - 17.83	18 - 19	8-9.2	-	24.5	0.4	0.5

doubt help to have affordable nutrition for all. Dr. T. Mohapatra the then Director General, ICAR and Secretary DARE, India guided us to work in system based approach with sister Institutions and other line departments to intervene the nutrition vulnerable areas “cluster wise” to improve nutrition status effectively. We also got encouraged by Shri. M Ahuja the then Principal Secretary (2016-17), Department of Agriculture and Farmers empowerment, Odisha; Watershed Mission development. He supported us with Rashtriya Krishi Vikas Yojana (RKVY) programme for development of eight tribal dominated districts of Odisha, India.

Similarly, RKVY project on Popularization of climate resilient and nutritionally rich varieties of tuber crops for doubling farmers’ income and better nutrition in tribal dominated 3 districts of Kerala was also launched with support from the then Kerala Agriculture Minister Advocate V.S Sunil Kumar and Dr. S.K. Malhotra, Agriculture Commissioner, New Delhi, India during 2017-18. We also had spread improved varieties in other backward areas of Jharkhand, Chhattisgarh, North East hill regions, Kerala, Tamil Nadu, including Andaman and Nicobar Islands in India.

Being breeders, it always haunts us for further improvement of the crops. The sweet potato variety-Bhu Krishna is resistant to weevil owing to 90 - 100 days maturity as well as high dry matter and starch contents.

We, the breeders (Dr. Archana Mukherjee, Dr. S.K Naskar, Dr. B. Vimala) continued planned breeding among the best varieties to shorten the crop duration but with high nutrient composition. Progressive breeding and successive evaluation of clonal generations resulted in developing ten purple flesh, eleven orange flesh and eight white flesh which gave reasonable yield in first year during on farm trial.

However, repeated trials had shown better yield by four lines each of purple, orange and white clonal generation of F1. Those again tested for nutrient composition (**Table 7**, **Figure 2** and **Figure 3**).

Table 7. Nutrient composition of clonal generations of selected breeding lines in sweet potato (raised from 20 best parents including Bhu Sona, Bhu Krishna).

Sl. No.	Breeding lines	Yield (t/ha)	Total Starch (%)	Total Carotene	Anthocyanine (mg/100g)	Ca	Zn	Fe
1	<u>Purple flesh</u> KS-22							
2	KS-12	20.95	20.4	2.2	65	20.4	0.52	0.52
3	ST 10-19	to	to	to	To	to	to	to
4	KS-27	22.45	23.4	6.4	85	25.3	0.72	1.23
1	<u>Orange flesh</u> ST 14-34							
2	SV-22	20.93	22.4	8.4	0.8	34.2	0.48	0.52
3	ST 14-16	to	to	to	to	To	to	to
4	CO3-50-23	21.84	23.6	13.8	1.8	37.6	0.66	0.72
1	<u>White flesh</u> ST-11							
2	CO3-4-8	22.8	22.6		0.8	20	0.25	0.26
3	IGSP 10-17	to	to	1.4 to 1.8	to	to	to	to
4	CO3-4-9	23.5	23.5		1.5	28	0.36	0.38

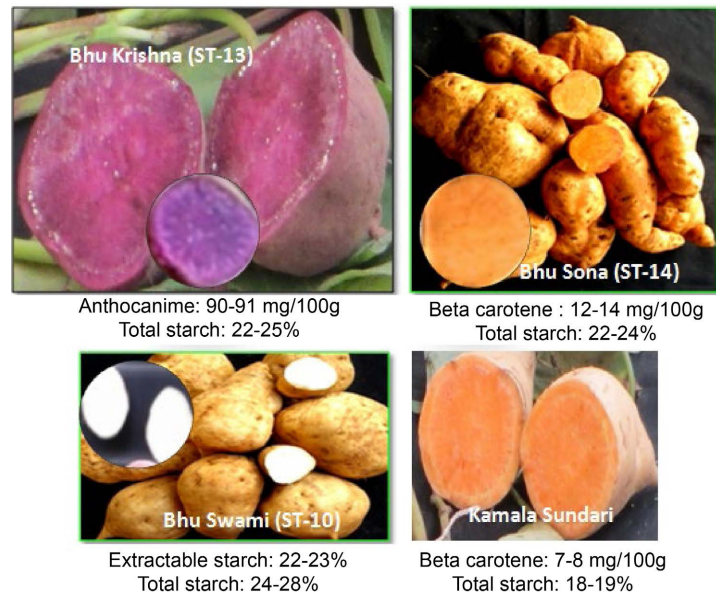
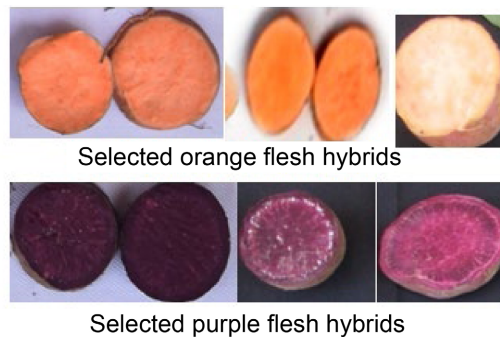


Figure 2. Improved varieties of sweet potato (Bhu Krishna, Bhu Sona, Bhu Swami and Kamala Sundari).



Orange flesh contain beta carotene 5-12mg/100g, Purple flesh contain anthocyanin 60-95mg / 100g; Matures by 75 - 85 days.
Developed by Dr. Archana Mukherjee, Dr. S.K. Naskar & Dr. B.Vimala

Besides sweet potato tubers, leaves are also nutritionally enriched

- Sweet potato leaves & vine tops are nutritionally rich
- Sweet potato leaves are one of the richest sources of anthocyanin (15 types)
- Contain higher level of 'Lutein' (0.38-0.58 mg/g fwb) more than Spinach, broccoli, lettuce etc. the major pigment of human retina

Figure 3. The spectrum of colored flesh hybrids raised from Bhu Sona, Bhu Krishna and other improved varieties.

All these hybrid lines found to mature within 75 - 85 days. This may allow escaping from weevil attack before ensuing of dry spell. However, these results need to be validated in different agro climatic zones through All India Coordinated Trials to fix the stable attributes as have been done for all “Bhu Series” and other tuber crops varieties released from ICAR- CTCRI, India. The anti cancer properties of anthocyanin rich Bhu Krishna (purple flesh) is well illustrated in case of breast, cervical and colon by [48]. Further, modification of native starch into resistant starch (RS4) in sweet potato have enhanced functional food value to sweet

potato. These high anthocyanin, beta carotene rich sweet potatoes coupled with high starch, no doubt tally the “disruptive” section of innovation matrix if discussed based on it [62] [63].

3.5. Blight Resistant Nutrient Rich Taro

The taro varieties viz. Bhu kripa, Bhu Sree are also good sources of nutrients. These were used as parental stock for breeding with exotic taro lines received through EU aided *INEA* programme from SPC-Fiji. The exotic lines received were thoroughly evaluated. Those, found to be resistant to taro blight, good yielders and palatable were used to breed with Muktakeshi, Bhu Kripa and Bhu Sree. The evaluation of hybrid lines revealed blight resistance, better yield, better palatability and short duration (150 - 160 days). Blight is the major problem of taro growers across the world and acidity of taro is another issue for consumers. However, the varieties released viz. Bhu Kripa, Bhu Sree, Muktakeshi and the selected exotic lines were found to be free from all those undesirable traits. Even the hybrids developed from selected indigenous and exotic lines are found to be non acid and rich in nutrients (Table 8 and Figure 4). All these raised improved varieties of sweet potato and taro as well as their breeding lines will have far reaching results in food and nutrition across the world.



Figure 4. Improved varieties of taro (Muktakeshi, Bhu Sree, Bhu Kripa) and Hybrids raised from these improved eddoe and exotic dasheen types of taro resistant to leaf blight and enriched with nutrients.

Table 8. The Salient characteristics of Indigenous, exotic and hybrid taros.

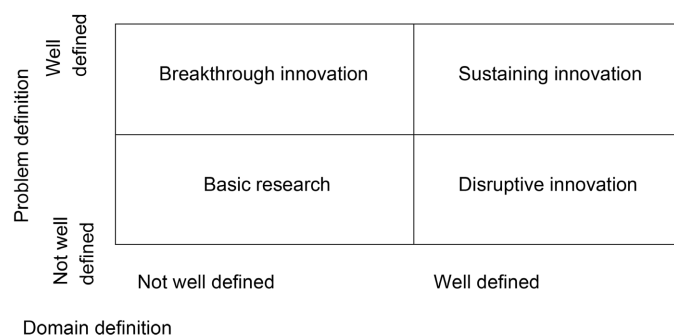
Varieties	Total Yield (t/ha)	Plant Type	Resistance to Blight (R)	Tuber type	Ca	Zn	Fe
					(mg/100g)		
Muktakeshi	14 - 16	80 - 100 cm (Medium)	R	Eddoe	31.3 - 34.2	0.75 - 0.81	0.58 - 0.63
Bhu Kripa	15 - 18	40 - 50 cm (Dwarf)	R	Eddoe	30.5 - 32.7	0.77 - 0.81	0.64 - 0.68
Bhu Sree	15 - 16	40 - 50 cm (Dwarf)	R	Eddoe	24.2 - 26.5	0.87 - 0.92	0.72 - 0.75
Exotics	20 - 22	120 - 150 cm (Tall)	R	Dashen	22.5 - 25.3	0.71 - 0.74	0.48 - 0.56
Hybrids	18 - 20	80 - 120 cm (Medium)	R	Inter mediate	26.4 - 28.2	0.82 - 0.85	0.64 - 0.71

Besides Edible energy, parents and hybrid tubers are rich in micro nutrients

- Taro tubers are good source of Zn & Fe
- 100 g of taro fresh leaves can supplement 4825 IU or 161% of RDA of Vitamin-A
- 100 g tubers provide 11% daily requirement of dietary fibre

3.6. An Outline of Innovative Tuber Crops Technologies with Regard to Management Matrix

To cater to food and nutritional security, innovative tuber crops technologies have been developed at ICAR-CTCRI. With regard to market needs, innovations can be classified into four categories [62] using Innovation Management Matrix (Figure 5). This matrix identifies four types of innovations including basic research based on the problem they resolve with applicability.

**Figure 5.** Innovation management matrix.

The transition of tropical tuber crops from staple food to industrial raw materials is increasingly benefitting farmers in both traditional and non-traditional areas across the country.

Recent innovations on tuber crops at ICAR-CTCRI satisfy the demands of market and climate change. Improved technologies with diverse applications have ample avenues in national and new international markets.

3.6.1. Basic Innovations

These are pillars or base to offer viable solutions for the basic problems. They can

propel towards other innovations depending on the magnitude of the problems, their address & impact in the market.

3.6.2. Breakthrough Innovation

Breakthrough innovation refers to immense technological advances that propel an existing product or service ahead of competitors [63]. The breakthrough technologies are results of research conducted in R & D organizations with clearly defined problems, but the outputs are significant enough for use in diverse application domains. Breakthrough innovation can be explained well with high starch yielding improved cassava and sweet potato varieties.

3.6.3. Disruptive and Sustaining Innovations

A disruptive innovation is an innovation which provides high through put consumer value of the existing product. Thereby creating a new market. In the process of providing high-quality consumer benefits, this innovation eventually disrupts the existing market and makes.

With this back ground of management matrix, the innovations in enhancing adaptability are mostly in the domain of basic or break through. Often, these innovations are observed to be sustaining or even disruptive depending on market potential. The disruptive and sustaining innovations can be explained with the following products.

Coloured flesh sweet potato containing high anthocyanin, Beta Carotene and high starch are required for diverse markets as functional food sources. Apart from those, encapsulated anthocyanin pigment provide natural colour and ingredients of “Functional food”. Further anti-proliferative attribute of purple flesh sweet potato, yam anthocyanins against different types of cancers have been elucidated in India [48]. It will have immense impact as “Health Benefit” product in new market. Hence the development of purple and orange flesh nutritionally enriched sweet potato varieties have newer market avenues as “Source of functional food capsules, herbal therapeutics” apart from nutrient rich food bowls. These diversified markets indicate those varieties under “Disruptive types”.

Sustaining

The sustaining innovations are technological advances which systematically improve the performance of current technologies along with dimensions of existing market. In contrast to disruptive innovation, sustaining innovation does not create new markets. Rather it evolves only existing ones with better value. This can be explained with the developed disease resistant tuber crops which are replacing the existing varieties with more return.

Basic to break through cannot be defined well with the background of management matrix as have already been explained earlier [62] [63]. The “basic innovations” often can be “breakthrough” depending on the commercial value of the commodity. For example basic innovation in cassava can be “break through” for the crops like greater yam, elephant foot yam as these crops have higher market values [64].

Though tuber crops require less water, irrigation for tuber crops need to be disruptive as water is the most scarce resource. Robust sensor based technology for onsite real time surface irrigation mechanism will be breakthrough. Similarly, the real time sensor based on site drip irrigation, and fertigation will disrupt in enhancing the production. Likewise in every sector innovation needs to be either break through or disruptive. Such innovations are the need of the hour.

4. Discussion

The commercial part of tropical root and tubers are underground and are least affected by changing climate. Moreover, their source plant parts can tolerate drought, water logging, high temperatures, and high CO₂ concentrations. The changes are now frequent owing to adverse climate.

Hence the strength and opportunities of these ancient food sources have been reemphasized and re-explored. The root and tubers as source for adaptive food and nutrition have been explained in the context of changing climate. Instead of “Adaptive” the word “Re-recognized” would have been better. The tuber crops researchers across the world have shown the value of these crops as “Lifesaving crops” whenever there is a disaster anywhere across the globe. Enhancing adaptability actually depends on various factors. In the whole vegetable world, tropical root and tubers are bestowed with natural endurance and are also enriched with nutrients. Such cross sectional studies have enabled researchers to understand the potential of these crops as source for adaptive food-nutrition. In this communication, the natural resilience, inherent edible energy, and nutrients have been explained in prologue in the context of changing climatic scenario including precious water footprints.

Based on the overall back ground to withstand adverse climates and the scope to enhance nutritional quality has led to further developments. Such studies resulted in developing robust crop varieties enriched with calorie and essential micronutrients [65]. We, the breeders have continued planned breeding to get superior types of climate robust, nutritionally enriched Bhu Krishna, Bhu Sona and other improved tuber crops. Breeding lines raised from best improved parents are found to be on par with the parents but having additional attributes of short duration to fit different cropping systems. Such a short cycle will also allow escaping pest and diseases. This will also satisfy consumer demands. Hence the popularity of the ancient food crops is again gaining momentum. Recent development of “functional food properties” along with endurance to stresses indicates “Disruptive” developments. Such developments open up new avenues for root and tubers as source for adaptive food and nutrition especially under a changing climate.

5. Conclusion

In depth analysis of natural endurance, nutritional attributes of root and tubers and further enhancement of climatic resilience as well as functional food attributes are boon to food and allied sectors. Analysis of innovations on enhancing

adaptability and nutritional quality revealed most of the innovations are sustaining, followed by break through and “disruptive types”. The overall studies dealt here would help to plan in “strengthening innovations” with “break through and disruptive types” for developing need based marketable trait specific robust technologies, for wellness of all. In this context, sweet potato varieties viz. Bhu Sona, Bhu Krishna; Cassava varieties viz. Sree Athulya, Sree Apporva; Yam variety, Sree Nelima, Taro varieties viz. Muktakeshi, Bhu Kripa, Bhu Sree and the hybrids raised from improved varieties can satisfy the demands of mass consumers including diverse markets. Steps towards adaptive nutritional advancements depending on climatic situations are needed.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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