Advances in Agricultural Technology & Plant Sciences
ISSN: 2640-6586
Academic Strive
Researcher's perception is our reality

Review Article
Volume 7 Issue 2

Breeding for Nutrient Enriched Coloured Flesh Sweet Potato (*Ipomoea Batatas* L.) with Endurance to Abiotic and Biotic Stresses-- Revisiting the Past for Present and Emerging Future

Mukherjee A[1]*, Sahoo MR[1], Jyothi AN[1], Sreekumar J[1], Gowda H[1], Hegde V[2] and Dasgupta M[3]

[1]ICAR-CTCRI (Central Tuber Crops Research Institute), India

[2]ICAR-IIHR, India

[3]SOA University, India

***Corresponding author:** Archana Mukherjee, Former Director, ICAR-CTCRI, Thiruvananthapuram, Kerala, Plot No.152, Dharma Vihar, Khandagiri, Bhubaneswar-751030, Odisha, India, Emails: archanapsm57@gmail.com; archanapsm2@rediffmail.com

Received Date: September 02, 2024; **Published Date:** September 23, 2024

Abstract

Natural coloured food used to supplement required balanced nutrition for good physical and mental health. Such coloured diets have slowly vanished owing to various reasons. Such deficiency causing in malnutrition irrespective of rich and poor and resulting in shooting up of the spike of various diseases. Bharat Ratna Professor M.S. Swaminathan, the World renowned agriculturist had taken various programme like Zero hunger drive: 'LANSA' & FSN with realistic approaches to combat hunger and malnutrition. He emphasized more and more on local resources with high nutritional values, considering easy availability, accessibility and affordability of such resources by all sections of the society.

Sweet potato (*Ipomoea batatas* L.) is traditional food and super food for its calorie and vitamins contents. It can be easily available among small, marginal farming communities. Sweet potato breeders of ICAR-CTCRI were working on improvement of sweet potato. The breeders have developed spectrum of coloured flesh sweet potato in orange containing beta carotene (10-16mg/100g) and purple containing anthocyanine (60-100mg/100g). Among various coloured flesh sweet potato, Bhu Sona and Bhu Krishna are gaining momentum in nutritional programme of the country. Besides, these varieties can perform well in hilly backward and coastal areas. Breeders also raised varied spectrum of coloured breeding lines having more nutrients and starch (>18%) with minimum weevil infestation (0-10%) for future programme. Enrichment of sweet potato native starch into resistant starch (RS4) is user friendly for diet related ailments. Such modifications of starch & development of spectrum of coloured flesh sweet potatoes satisfy disruptive innovation matrix.

Keywords: Sweet Potato; Coloured Flesh; Nutrient Enriched; Tolerant to Stresses; Wellness for all

Abbreviations

PCM: Protein Calorie Malnutrition; DG: Director General; AICRP-TC: All India Coordinated Research Project on Tuber Crops; RKVY: Rashtriya Krishi Vikas Yojana.

Introduction

In present era for various reasons especially in the name of modernization, food habits have been changed and the 'Fast Food' is becoming favorite. This habit is growing at a faster pace across the world causing imbalances of bodies food requirements which ultimately resulting in various diseases owing to "Malnutrition".

There are two types of malnutrition. The rich food bowls resulting in Diabetes, Hyper tension, Heart attacks, Cancers, Dementia and so on. Whereas "have-nots" food bowls resulting in high rate of 'Infant Mortality': Underweight: Anemia, Iodine deficiency, Colour blindness etc.

The traditional coloured food bowl later, named as rainbow diet can combat many such dreaded diseases including cancer [1]. In fact, he has well explained the diet combination with various natural resources. However, such resources may not be accessed by all owing to various factors.

Whenever, we discuss about malnutrition and its remedy, the vision of Bharat Ratna Professor Dr. M.S. Swaminathan, the world renowned agriculturist, becomes an exemplary before the whole World. To transform his vision into reality, his strategic plan on "Availability, Accessibility and Affordability" (A^3) was unparallel realistic approach. His dedicated contributions against "Zero Hunger and Malnutrition Drive" are such unique mode of actions.

Archana Mukherjee was fortunate to had frequent interactions and meetings with Prof. Swaminathan at Bhubaneswar and Chennai, India in connection with LANSA(Leveraging Agriculture for Nutrition in South Asia) and FSN (Farming System Nutrition) programme. During interactions with him, he emphasized to work more on indigenous and on locally available resources to enrich coloured items in food bowls of 'Have-nots' or disadvantageous groups. In his programme- Papaya, Drum stick, its leaves, Millets, Gooseberry, Pumpkin, various leafy and locally grown vegetables, seasonal fruits and tuber crops found to be the items which can satisfy (A^3). He encouraged to work on coloured flesh sweet potato.

Sweet potato (*Ipomoea batatas* L.) Lam, family *convolvulaceae*) is the second most important root tuber and one of the ten important food crops of the world. It is grown as a starchy food crop throughout the tropical, sub-tropical and frost-free temperate climatic zones in the world. It is one of several crops recommended by National Aeronautics and Space Administration for bio regenerative life support studies. The edible tubers mature within 110-120 days. This carbohydrate rich root crop is used as subsidiary food, the vine tips used as vegetables and vines along with leaves serves as fodder. Sweet potato is considered as a "poor man's rich food" or "Famine Crop". Rather 'life saving crop' across the world since 1914 to 2013 [2,3] and is being cultivated in almost all states in India where Odisha, Uttar Pradesh and West Bengal being the leading producers. Sweet potato productivity in India is having increasing trend from 2015 onwards (11.48 t/ha). Hence better varieties with marketable traits with advanced production system will fill the existing lacunae of its production and productivity in our country. It occupies twelfth, eighth and fifth rank globally in terms of sweet potato area, production and productivity respectively while fifth rank in Asia in terms of area, production and productivity. Sweet potato predominantly cultivated as a rain fed crop in eastern India. Sweet potatoes have been ranked number one in nutrition out of all vegetables by the Centre for Science in the Public Interest, USA. Besides providing adequate cheap energy (300-400 calorie/100g), the tubers also supply essential micronutrients and antioxidants (Tables 1& 2). Sweet potato in combination with legumes can be an ideal food to combat protein calorie malnutrition (PCM).

These inbuilt resilience, nutritional components, natural active compounds mooted to work more and more on to enhance adaptive resilience and "functional food" properties of sweet potato. Further suggestions of Professor Swaminathan, enlightened us especially the sweet potato breeders' viz. Dr. S.K. Naskar, Dr. B. Vimala and me. We developed and had released coloured flesh sweet potatoes and also their breeding lines having white and different variations of orange and purple colours. We worked not only for colours but also for their adaptability in hilly, backward and coastal zones for disadvantageous communities. In the span of twelve years we released light orange to dark orange flesh and also purple flesh sweet potato varieties. Among which 'Bhu Sona' contains highest beta carotene (14mg/100g) as well as dark purple flesh variety 'Bhu Krishna' contains anthocyanin (90-100mg/100g). Concurrently we worked further on raising breeding lines using twenty different parents of white, orange and purple flesh sweet potato varieties with other valued traits. Sri Manoj Ahuja, the then Principal Secretary (2016-17), Dept. of Agri. & Farmers' Empowerment, Odisha, India and Sri S. Prusty the then Director, State, Horticulture department (Odisha, India) supported us to release the Bhu series varieties. As all those had completed all trials, formalities including All India Coordinated Research Project trials on tuber crops (AICRP-TC). Then popularized those improved varieties starting from 'Nutrition sensetive certain areas of Nabarangapur, Odisha to other unreached areas of the country with guidance of Dr. Trilochan Mohapatra, Former Director General (DG), ICAR & Secretary DARE, India; now Chairperson PPV & FRA, New Delhi, India.

In Nabarangapur district of Odisha, India we intervened along with ICAR-CIWA (NRCWA). Our intervention was found to be the first scientific intervention for better nutrition as published in various local media including Indian Express on 15.08.2016. Sri. Manoj Ahuja, encouraged us to carry forward Rashtriya Krishi Vikas Yojana (RKVY) project for betterment of small, marginal farmers in eight tribal dominated districts of Odisha.

Nutrient (Per 100 g)	Potato (Raw)	Sweet potato (Raw)	Cassava (Raw)
Calcium, Ca (mg)	9	10	30
Magnesium, Mg (mg)	21	22	25
Potassium, K (mg)	407	455	227
Phosphorus, P (mg)	62	61	47
Sodium, Na (mg)m	16	18	55
Iron. Fe (mg)	0.52	0.61	0.27
Zinc, Zn (mg)	0.29	0.3	0.34

(Source: Adapted from USDA National Nutrient Database for Standard Reference Legacy Release. 2018)
Table 1: Mineral composition of selected tuber crops.

Function	Related components	References
Anti-oxidation	Polyphenol,	Cevallos-Casals and Cisneros- Zevallos [4] Hayas and Kato [5]; Islam, et al. [6]; Oki, et al. [7]; Yoshimoto, et al. [8]; Yeh, et al. [9]; Mukherjee and Naskar [10]
	Anthocyanin	
	Sporamin	
	Betacarotene	
Antimutagenicity	Polyphenol,	Yoshimoto, et al. [11]; Yoshimoto, et al. [12]; Yoshimoto [13]
	anthocyanin	
Anti-carcinogenesis	Polyphenol,	Hou [14]; Hou, et al. [15]; Kurata, et al.[16]; Hagiwara, et al. [17]; Van Jaarsveld, et al. [18]
Vitamin-A suppl.	anthocyanin	
Anti-diabetes	Anthocyanin,	Matsui [19]; Matsui, et al. [20]; Terahara, et al. [21]; Yoshimoto, et al. [22]; Hwang, et al. [23]
Reducing Obesity	polyphenol	
Anti bacterial activity	Anthocyanin	Rath, et al. [24]
	Betacarotene	
Anti-proliferative agent against breast, cervical and colon cancer	Anthocyanin	Vishnu, et al. [25]

Table 2: Physiological functions and their related components of sweet potato.

The developed spectrum of coloured flesh sweet potatoes explore the avenues for diverse products. This paper deals in depth the development, release, interventions and popularization of varied coloured flesh sweet potato with other attributes for better nutrition and future directions for wellness.

Development and Release of Coloured Flesh Varieties of Sweet Potato- Cheap Source of Coloured Food Bowl

With the facts of sweet potato work, further research aimed not only for enhancing yield component but also for its quality traits like naturally available active components, antioxidants and other valued traits as have been well explained earlier [26-31].

Sweet potato productivity in India is having increasing trend from 2015 onwards (11.48 t/ha) and in 2022 (11.07t/ha). This trend can be increased further if we can address the National and International gaps of sweet potato breeding.

Focus in Enhancing Adaptability

More recently 'reverse designing' of crops with 'integrated grid model' based on phenotypes, bio-molecular markers with system biological approach are found to be the best option for "model product". Such study will harness the harvest of 'precise crop product'. In the context of climate change, low input high energy sweet potato tubers have immense potential towards food security. Further to address the agri-horticultural issues, today's breeding innovations conceptualized to satisfy 'consumer needs' and to 'cope with adverse climate'. Breeding strategies has to be designed for its 'product' with '**qualitative**' and '**quantitative' precision.** Precision and expression of desired characters (genes) can be harnessed holistically with integration of both traditional and advanced omics-biotechnological methods (Mukherjee, 2016). Natural resilience of sweet potato mooted to explore the potentials in enhancing its adaptability with other high value attributes. To mitigate hunger and nutrition 'climate proofing of tuber crops have been enhanced further [32-35].

Sweet Potato Breeding in India

In sweet potato, breeding objectives are multiple due to its heterozygous nature and wide cultivation adaptability. It can be grouped for yield, quality and resistance to abiotic and biotic stresses especially weevil (*Cylas formicarius*) which causes 60–100% yield losses across the world.

A better variety means all desirable traits like colour, culinary quality, process ability and adaptation to climate as well as varied cropping systems. Orange and purple flesh sweet potato is attractive for quality breeding for new market avenues [36]. However, market/consumer needs could be resolved by breeding such varieties with high dry matter and starch. Work was also done on drought, salinity and submergence tolerance in India and across.

Endurance to Drought and Flood

Regarding drought tolerance, the sweet potato genotypes including land races were subjected to moisture stress by withdrawing irrigation as well as by PEG induced stress. The lines responded are briefed as follows:

After initial screening, selected 27 genotypes subjected to field screening at Regional Centre of ICAR-CTCRI at Bhubaneswar, India. High yield under drought stress condition was recorded in the genotype 84 x 14 (8.55 t ha^{-1}), followed by S-783 (7.75 t ha^{-1}) and 84 x 1 (7.6 t ha^{-1}). Under control (irrigated) condition, high yield was obtained in the genotype 84x1 (15.78 t ha^{-1}), followed by Howrah (15.34 t ha^{-1}) and 84 x 14 (14.25 t ha^{-1}). High drought resistance index was recorded in Dhenkanal local-2 (1.87), followed by SB21/57 (1.8) and S-783 (1.58) and high mean productivity was recorded in 84 x 1 (11.69 t ha^{-1}), followed by Howrah (11.53 t ha^{-1}) and 84 x 14 (11.40 t ha^{-1}). High drought resistance index coupled with high yield under drought stress condition was recorded in Dhenkanal local-2 (1.87 and 7.45 t), followed by S-783 (1.58 and 7.75 t) and SB21/57 (1.81 and 7.03 t).

During *in vitro* screening, at 10 g l^{-1} of PEG treatment, the genotype Dhenkanal local-2 resulted in maximum shoot length, root length, shoot weight and root weight, followed by 84x1 for number of leaves, shoot weight and shoot length. Whereas, at 15 g l^{-1} of PEG treatment, the genotype 683 produced high root length, shoot weight and root weight, followed by SB21/57 for root length, shoot weight and number of leaves and Dhenkanal local-2 for number of leaves, shoot length and root length. The results showed that the genotypes 84x14, Dhenkanal local-2, Howrah and SB21/57 were drought tolerant. These genotypes can be used further to augment future breeding to pool gene sources for other quality traits along with reasonable yield. These drought tolerant genotypes have also shown less than 10% weevil infestation. Total starch in all those drought tolerant lines recorded more than 18%.

Flood Tolerance

Paclobutazol, Cacl2 medicated flooding tolerance in sweet potato have been explained by Lin, et al. [37,38]. Breeding activity in India had been taken up to address the gaps to endure climate changes, to meet consumer demands and also to enhance growers' income as suitable intercrop in coastal areas with the marketable traits [32,35,39,40].

Progressive Breeding and Evaluation for Coloured Flesh and other Traits

Since inception to till date at ICAR-CTCRI, India progressive breeding and evaluation resulted in evolving 21 sweet potato varieties as well as more than 37 varieties across the country (including 21). However the varieties evolved during 2014 to 2019 are tolerant to biotic (weevil) and abiotic salt stress (6-8dSm^{-1}) packed with high yield (>18tha^{-1}), total starch (20-25%), beta carotene (6-16mg/100g) and anthocyanin (90mg/100g) (Figure 1 (A-E)). Based on the results of Institutional trials, the entries which showed no disease and minimum weevil infestation (< 20%) with high yield, high beta carotene and tolerance to salinity (6-8.0 dSm^{-1}) as well as other quality attributes are only proposed for All India Coordinated Research Project (AICRP) on Tuber Crops (TC) recommended trials for evaluation across the country. Performance of the coloured fleshed sweet potato in different parts of Odisha, India are presented in Tables 3 & 4 and Figures 1A-E.

After recommendation by AICRP-TC committee such high valued sweet potato were released, notified and registered [10,27,28].

The, five sweet potato varieties released during 2017 from ICAR-CTCRI that include three with orange flesh. (Bhu Sona, Bhu Kanti and Bhu Ja) and one with purple flesh (Bhu Krishna) (Figures 1.A-D) as well as Bhu Swami (ST-10), the white fleshed variety (Figure 1E) tolerant to mid –season drought and is suitable for food and processing industry with extractable starch of 22-23%.

Bhu Sona (ST-14) is a β-carotene (14-16 mg/100 g) rich variety (Figure 1A) with dry matter content of 27-29%, starch 22%, total sugar 2-2.4% and an average yield of 19.9 t/ha. Bhu Krishna (ST-13) is anthocyanin rich variety (Figure 1B) with anthocyanin content of 90 mg/100 g, Beta carotene rich Bhu Sona, Bhu Ja, Bhu Kanti and anthocyanin rich Bhu Krishna. These four varieties are tolerant to salinity (6.0-8.0 dSm^{-1}). Bhu Krishna is also resistant to weevil.

Year	Varieties	Tuber yield ($t\ ha^{-1}$) in different areas*				
		Puri	Jagatsinghpur	Kendrapara	Balasore	Mean
2015-16	Bhu Sona (ST 14)	20.5	18.85	20.14	19.69	19.8
	Bhu Kanti (440127)	21.4	21	21.84	21.56	21.45
	Bhu Ja (CIPSWA - 2)	19.3	19.82	20.46	19.53	19.76
	Bhu Krishna** (ST - 13)	18.8	17.85	20.18	18.16	18.75
	Kamala Sundari	17.6	17	17.83	17.65	17.53
	Gouri	17.4	16.66	16.96	17.43	17.12
	CD at 5%	1.92	1.845	2.013	2.134	
2016-17	Bhu Sona (ST 14)	19.8	19.55	19.78	20.22	19.84
	Bhu Kanti (440127)	22.1	21.52	22	21	21.66
	Bhu Ja (CIPSWA - 2)	19	20.14	20.69	19.93	19.94
	Bhu Krishna** (ST - 13)	19.2	18.26	19.82	17.92	18.79
	Kamala Sundari	18.1	17.53	18.14	18	17.95
	Gouri	16.9	17.23	17.52	16.87	17.13
	CD at 5%	1.94	2.024	1.956	2.031	
2017-18	Bhu Sona (ST 14)	20	19.66	20.83	20.64	20.28
	Bhu Kanti (440127)	21.8	20.96	21.62	21.89	21.57
	Bhu Ja (CIPSWA - 2)	19.6	20.36	19.73	20.18	19.97
	Bhu Krishna** (ST - 13)	19.3	18	20.34	18.52	19.03
	Kamala Sundari	17.9	17.77	18	18.46	18.03
	Gouri	17.3	17	17.66	17.22	17.3
	CD at 5%	2.05	2.471	1.982	2.312	

Table 3: Performance of orange flesh (Bhu Sona, Bhu Kanti, Bhu Ja, Kamala Sundari & Gouri) and purple flesh Bhu Krishna at different coastal areas (6-8 dsm^{-1}) of Odisha, India during 2015-2018.

Varieties	Tuber yield (t ha^{-1})
Bhu Sona (ST 14)	19.97
Bhu Kanti (440127)	21.56
Bhu Ja (CIPSWA - 2)	19.89
Bhu Krishna** (ST - 13)	18.86
Kamala Sundari	17.83
Gouri	17.18

Table 4. Pooled of yield during 2015-2018

*Performance of all orange flesh entries Bhu Sona, Bhu Kanti, Bhu Ja observed to be in the range of 19.89 to 21.56 t ha^{-1} and found to be better than Kamala Sundari (17.83 t ha^{-1}) and check Gouri (17.18 t ha^{-1}).

Besides Odisha, orange flesh varieties viz. Bhu Sona, BhuKanti, Bhu Ja and Purple flesh variety Bhu Krishna performed well in other states of India like Jharkhand, Chhattisgarh, Maharashtra, West Bengal, Karnataka.

**Bhu Krishna is the only purple flesh variety, it contains anthocyanin 90mg/100g. Rest all the entries are orange flesh and rich in β-carotene. Of all the orange flesh varieties, Bhu Sona contains highest amount (12-14 mg/100g) followed by Kamala Sundari (7.5-8.0 mg/100g), Bhu Kanti (6.5-7.0mg/100g), Bhu Ja (5.5-6.5mg/100g) and Gouri (4.5-5.5mg/100g).

Among these coloured flesh, Bhu Krishna and Bhu Sona contains total starch more than 20%. Hence palatability is better for these two varieties as compared to the others.

Besides coastal areas, all these orange flesh varieties as well as purple flesh Bhu Krishna recorded yield in the range of 18 to 19 t ha^{-1} in tribal dominated areas of Odisha, India *viz.*, Koraput, Kandhamal, Nabarangpur, under the trials of various schemes.

Biotechnological, QTL, Anti Cancer and Weevil Resistance in Coloured Flesh Sweet Potato

Biotechnological work in sweet potato has gained momentum in many national and international laboratories [10,39,41-44]. 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 [45].

QTL study was conducted for b-carotene, starch, and dry-matter contents, the important marketable traits in sweet potato. However, this was first attempt to locate QTL associated with these traits in sweet potato [46], need further analyses to confirm and validate these regions to harvest desirable marketable traits.

Antiproliferative activity of sweet potato anthocyanins against breast, cervical and colon cancer has also been elucidated in India [25].

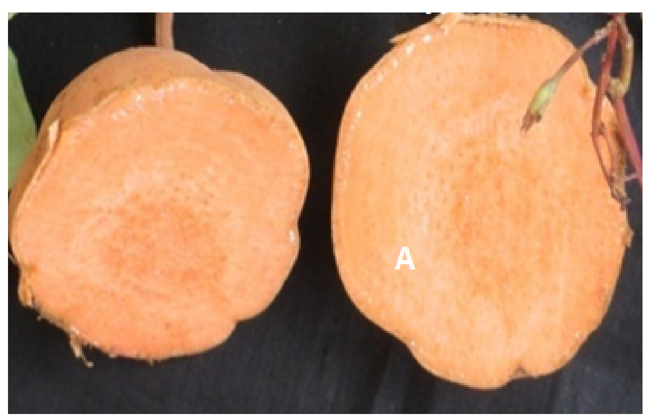
Transcriptome analyses for tuber flesh colour and weevil resistance in sweet potato was carried out and have identified differentially expressed genes [47].

Resistant Starch in sweet potato

Anti-diabetes [22], have been well illustrated. India is emerging a diabetic capital of the world, the tuber crops with medium to low glycemic index offer natural solutions for preventing or curing diabetes. The Glycemic index and glycemic load of sweet potato reveals lower glycemic load (Potato boiled in salt water- Glycemic index -76, Glycemic load-26, Sweet potato boiled - Glycemic index- 44, Glycemic load-11); [48].

Additionally orange flesh (100g flesh with 3-4mg beta carotene) can provide recommended dose of vitamin-A.

Further enrichment of native sweet potato starch into resistant starch (RS4) opens the gate way for user-friendly starch to combat diet related diseases [49,50]. Type 4 resistant starches are man-made starches that are developed through chemical modification and most commonly purchased in the form of a supplement, such as a prebiotic. Sweet potato RS4 type is developed at ICAR-CTCRI, India, have medium glyceamic index (58-63) in comparison to the corresponding high glyceaminc (>90) native starch. The functional properties are similar to dietary fibre and can act as prebiotic. It can be used as low-calorie functional food ingredients.



Bhu Sona
Rich in β- carotene (14mg/100g) Natural pigment prevents Vit. A deficiency, Extractable starch – 20%; Yield - 19.9 t ha^{-1}.

Bhu Krishna
Rich in anthocyanin content - 90mg/100g, Natural pigment with anti-cancer prop., Ext. Starch – 22.5%; Yield - 18.9 t ha^{-1}.

Bhu Kanti
Yield- 21.3 t/ha Beta carotene- 6-7mg/100g

Bhu Ja
Yield- 19.8 t/ha Beta carotene- 5-6mg/100g

Bhu Swami
Yield- 21.5 t/ha Extractable starch 21-23%

Figure 1 (A-E): Beta Carotene, Anthocyanin and Starch rich Sweet potato varieties released.

Developed Breeding Lines With High Valued Traits For Future Programme

To address the farmers- consumers demands, breeding efforts continued and developed 51 breeding lines targeting early maturity, high starch, high beta carotene, high anthocyanin and with weevil tolerance (< 10% infestation). All those breeding lines recorded 18-24 t/ha tuber yield, total starch (18-23%). Among those 11 are orange flesh lines with beta carotene (5-16mg/100g). The 10 purple flesh contain anthocyanin (64-110 mg/100g). Rest 8 is with pinkish white or cream flesh (Tables 5-7) (Figure 2 (A-C) & Figures 3 & 4). These spectrum of coloured flesh breeding lines from Bhu Sona and Bhu Krishna and other best parents need to be tested in different locations through ICAR-All India Coordinated Research Project on Tuber Crops prior to release.

Such studies are needed to test stable attributes as well as for location specific suitability. As these breeding lines were raised with culmination of better attributes having β-Carotene (8-14mg/100g), in combination with anthocyanin (60-80mg/100g), along with Iron (0.5-0.8mg/100g), Zinc (0.48-0.72 mg/100g), Vitamin-E (5-6mg/100g), Vitamin-C (23-25mg/100g) and good amount of starch (>18%). The nutrient composition of clonal generation of high yielding breeding lines is presented in table 8 (a-c). As some of the white flesh observed to be cream or pinkish, betacarotene and anthocyanin were also analyzed but were recorded to be less than 2mg/100g. Ca recorded in the range of 20-28mg/100g, Vitamin C (22.6 to 25.4 mg/100g), Zn and Fe in the range of 0.26 to 0.38 mg/100g.Vitamin E recorded more in orange flesh (5.6 to7.2mg/100g) followed by purple and white fleshed (4.6 to 5.8mg/100g) breeding lines.

The cross section of the nutrient contents of breeding lines reveals the superiority of orange and purple flesh over the white flesh varieties. The contents like carotenes, anthocyanin, Zn and Fe are comparable with other nutrient rich vegetables and fruits.

Sweet potato being propagated vegetatively, facilitate the scope to fix the valuable trait easily through breeding and with evaluation of the trait in corresponding clonal generation of the breeding lines unlike seed propagated other fruits and vegetables.

Moreover, enrichment of sweet potato starch into resistant starch with functional nutrients is no doubt going to be a boon to diet related ailments.

Hence the improved orange, purple and white flesh sweet potato can very well supplement the required balanced nutrients of mass in urban and rural areas across the world.

Root and tubers as such are the crops of small, marginal and the farmers live in the adverse agro-climatic zones. Rather those farmers are the custodian of root and tuber crops. Wherever there are adversities, it is difficult to grow other crops except root and tubers.

The breeding of sweet potato considering the mass consumers' requirements for affordable nutrients and endurance of the crop against stresses are no doubt open up ample market opportunities not only for food and nutrition but also in allied sectors as robust functional food ingredients.

However, multi location trials in different agro climatic zones are must to validate the stable attributes as have been done for Bhu Sona, Bhu Krishna and other varieties released for State or as Central from ICAR-CTCRI, India.

In Institutional trials during 2015 to 2019 all those breeding lines found to be early maturing 75-90days. This attribute is a good opportunity to escape weevil, which attack the tubers in dry spell especially in case of long duration crop of 110-120days. In case of 'Bhu Sona', 'Bhu Krishna' and other Bhu series sweet potato, we tested for their tolerance to salinity and performance in hilly, backward areas. In view of major section of socially disabled people and farming communities live in coastal as well as hilly backward fragile zones.

Performance of Bhu Sona, Bhu Krishna have been found better as evident from different location trials results (Table 3). They were also tested in different States of the Country through All India Coordinated Trials on tuber crops (AICRP-TC). Similarly the new generations coloured spectra of breeding lines raised from Bhu Sona, Bhu Krishna, Kamala Sundari along with other best parents need planned trials for their superior stable attributes. In general, post harvest shelf life of sweet potato tuber is 2-3 weeks but raised breeding lines as well as Bhu Sona, Bhu Krishna can be stored for 4-12 weeks owing to higher total starch (more than 20%) and dry matter contents. Such coloured flesh sweet potato with all essential attributes will enrich the food bowl. It will strengthen the nutrition of all human beings the rich and poor.

Sl. No.	Breeding lines	Yield(t/ha)
1	S1-9	18.24
2	KS-22	21.37
3	ST-10-19	22.45
4	KS-19	20.29
5	KS-34	18.9
6	KS-12	20.95
7	ST-10-14	19.1
8	KS-22	20.62
9	KS-27	21.33
10	ST-14-39	18.5

CD= 1.72

Table 5: Performance of clonal lines generated from purple flesh F1, on farm.

Sl. No.	Breeding lines	Yield(t/ha)
1	SV-22	21.57
2	ST-10-19	20.55
3	SV-3-8	20.17
4	CO3-50-23	20.93
5	ST-10-12	20.11
6	CO3-50-33	19.46
7	ST-14-16	21.15
8	CO3-50-43	20.86
9	SV-3-17	19.6
10	ST-14-34	21.84
11	108-14	20.33

CD=1.51

Table 6: Performance of clonal lines generated from Orange flesh F1, on farm.

Sl. No.	Breeding lines	Yield(t/ha)
1	IGSP-10-6	22.89
2	IGSP-10-24	22.54
3	CO3-4-8	25.3
4	S1-11	23.3
5	IGSP-10-17	23.49
6	IGSP-10-22	22.87
7	CO3-4-9	24.75
8	IGSP-14-6	22.28

CD=2.05

Table 7: Performance of clonal lines generated from white flesh F1, on farm.

Breeding Sweet Potato for Valued Traits for Future Programme

Figure 2 (A-C): Clonal lines of F_1 s having 75-85 days maturity: Purple flesh (A), Orange flesh (B & C) Sweet potato.

Yield-(18-24t/ha), Starch(18-23%), Beta Carotene(5-16mg/100g), Anthocyanin(64-110mg /100g), Reduced crop growth cycle (75-85 days), Weevil resistance (infestation4-10%).

Figure 3: Spectrum of Orange flesh**.**

Figure 4: Spectrum of purple flesh.

Spectrum of orange and purple coloured flesh sweet potato breeding lines
(Generated by Dr. Archana Mukherjee, Dr. S.K. Naskar and Dr. B. Vimala, sweet potato breeders, ICAR-CTCRI)

Table 8: Nutrient composition of high yielding purple (a), orange (b) and white flesh (c) clonal lines of F1

Sl. No.	Breeding Lines*	Total Yield (t/ha)	Total Starch (%)	Total Carotene	Ca	Fe	Zn
				(mg/100g)			
1	KS-22	21.37	20.4	6.4	25	0.5	0.5
2	KS-12	20.95	20.8	5.8	25	0.7	0.6
3	ST10-19	22.45	23.4	2.2	20	1.2	0.7
4	KS-27	21.33	21.8	4.4	24	0.8	0.7

*All these four lines recorded anthocyanine (65-85mg/100g)

Table 8(a): Purple flesh.

Sl. No.	Breeding Lines	Total Yield (t/ha)	Total Starch (%)	Total Carotene	Ca	Fe	Zn
				(mg/100g)			
1	ST14-34	21.84	23.6	13.8	38	0.7	0.6
2	SV-22	21.57	22.8	9.4	35	0.6	0.5
3	ST14-16	21.15	23.5	14.2	37	0.7	0.7
4	CO350-23	20.93	22.4	8.4	34	0.5	0.5

Table 8(b): Orange flesh.

Sl. No.	Breeding Lines	Total Yield (t/ha)	Total Starch (%)
1	ST-11	23.3	23.5
2	CO3 4-8	25.3	22.8
3	IGSP-10-17	23.49	22.6
4	CO3 4-9	24.75	23.4

Table 8(c): White flesh.

Discussion

The breeding objectives need to satisfy consumer needs. In case of sweet potato, the colour flesh is attractive but consumer would like to prefer colour with high dry matter and starch [36]. In the present study, the developed Bhu series sweet potatoes are having good amount of antioxidants for purple flesh Bhu Krishna- anthocyanin (90-100mg/100g), starch (23-25%). Similarly orange flesh Bhu Sona with high beta carotene (12-14mg/100g) and starch (22-23%). Other sweet potato viz. Bhu Kanti, Bhu Ja also contains resonable beta carotene (6-7mg/100g) and starch (18-20%). Further, the selected breeding lines raised from twenty best parents are not only rich in nutrients can mature within 75-85days (Figures 2-4, Table 8).

Medium to late maturing types (sweet potato-100 to 130 days) often limits its use as inter crop. Such duration invites pests, diseases and becoming unsuitable as intercrops. The basic needs of farmers' or consumers are changing and they wish to have short duration crops as intercrops to fit in different cropping systems with high yield and good culinary qualities along with shorter duration (75-90days), present varieties can fit different cropping systems and can add income to farmers.

A regular intake of 100g of orange fleshed containing at least 3-4mg, beta carotene in 100g sweet potato tubers per day can provide the recommended daily amount of vitamin A for adults and children. The consumption of orange fleshed sweet potato improves vitamin A status. Additionally, the purple fleshed sweet potato, being rich in anthocyanin (90-100 mg/100g), can provide good amounts of bio-available antioxidant to overcome oxidative stress. The orange and purple flesh sweet potato tubers rich in starch, sugars, minerals and vitamins are gaining importance as the cheapest source of antioxidants as bio-fortified crop to combat malnutrition especially in small and marginal farming community [32]. Considering the importance of sweet potato, the TIME magazine selected sweet potato as one of the 25 best inventions of 2016 for its ability to combat Vitamin A deficiency in a natural way as well as it withstand drought and tolerant to viral diseases.

India is becoming diabetes hub; other non-communicable diseases are also shooting up. Hence the association between plant food intake and reduced NCDs episodes has been the main focus of a number of scientific investigations in the recent past. Furthermore, identification of specific plant constituents which convey health benefits is of much interest. In this context, nutritionally enriched sweet potato tubers along with resistant starch are gaining importance as healthy-food sources.

Such scientific development mooted the then leader of ICAR family- Director General Dr.T. Mohapatra. He guided us to carry forward nutritional programme with system based cluster approach to improve nutrition status in nutrition vulnerable areas. Improved sweet potato varieties spread in nutrition sensitive different areas of Odisha, India through RKVY with support of Shri Ahuja. Similarly RKVY project enabled us to spread improved tuber crops in backward areas of Kerala with support from Advocate V.S Sunil Kumar and Dr. S.K. Malhotra, Agriculture Commissioner, New Delhi, India.

Those varieties had also been given to Jharkhand, Chhattisgarh and North Eastern hill regions, India for improvement of food bowls with coloured flesh sweet potato. Our research and development especially in case of coloured and high starch sweet potato are getting accepted not only by the custodian farmers of root and tuber crops but also by the farmers of nontraditional areas, entrepreneurs and other processing firms.

India today needs to intensity innovations for self sufficiency, wellness and prosperity. In this context, development of coloured flesh sweet potato can be placed under 'Disruptive' section based on 'Innovation Management Matrix' [51,52].

Conclusion

The development of coloured flesh sweet potato with good amount of beta carotene (14mg/100g) in orange flesh, anthocyanin (90-100mg/100g) in purple flesh their wide adaptability even in fragile zones has no doubt opened up ample scope in field of "Healthy food" at ICAR- CTCRI, India. Sweet potato is nevertheless, a 'super food' and more interestingly a 'savior crops' of the World. As had proved its credibility during Tsunami: Super Cyclone, Typhoons, Famines and so on. To enrich such crop with more and more desirable attributes like high nutritional components, enhanced shelf life, tolerance to diseases and pests along with wide adaptability comes under "**disruptive innovation".** The disruptive innovations open new market opportunities along with maintenance of "Sustaining" and "basic needs". We the breeders had developed the varieties, tested their scientific merits as much as possible. Even we intervened the most disadvantageous communities to enrich their food bowls as published in Indian Express as well as local news on 15th August, 2016. To mitigate Hunger- Malnutrition. We need "Holistic-System-Based- Approach". Involving all the line departments to reach the "Vulnerable" Hot Spots of 'Hunger - Malnutrition' [53-56]. In this context, I recall the support of Sri Srikant Prusty (IFS, Director of Hort.) and Sri Manoj Ahuja the then Principal Secretary Dept. of Agri. & Farmers' Empowerment, Odisha (2016-17), India. They have guided us in streamlining action areas in eight tribal dominated districts of the Odisha State to carry out the RKVY programme in collaboration with all line departments of each district including the Krishi Vigyan Kendras (KVKs), Panchayat Samiti with support of realistic datas and facts from respective Collectors of different districts of the state.

Once we got the project sanctioned in 2017 March, I had to move to Thiruvananthapuram being got selected as Director of ICAR- CTCRI, India. Other PI (Dr. Korada) moved to ICAR-NRRI, India. Hence I had handed over the RKVY project for eight Tribal districts to the rest of the colleagues of CTCRI, Regional Center, Bhubaneswar, India.

With support of different funding agencies viz., ICAR, AP CESS Fund, ICAR-NATP- CGP, PPV&FRA, New Delhi and INEA (International Network for Edible Aroids), we could developed improved tuber crop varieties including sweet potato with high valued traits. All these funding systems are having better review mechanisms. Critical reviews are also essential for the projects mostly dealt with transfer of technologies to "reach the unreached": "disabled" and disadvantageous people or the rural, backward and economically backward communities. Moreover, the sponsored projects like RKVYs, CSR etc. invest more than Crores amount. Hence the needy people of the country must enjoy the fruits of technology in lieu of huge investment made on research and its application for progressive transformation etc. Sometimes the scientific fruits, reach only to rich-firms or companies with shares among those who are not even actual innovators. Hence transfer to those fruits to needy people sometimes become secondary. But for real transformation we have to address "First the Vulnerable" hot spots of 'Hunger-Malnourished' zones. As discussed earlier and suggested by Dr. Trilochan Mohapatra, Former DG, ICAR & Secretary, DARE, India. Such working approach can only bring sea change. This will also transform Bharat Ratna Professor M.S. Swaminathan's vision into reality of 'Eradication of Hunger and Malnutrition'. We, the breeders or likeminded people will get great satisfaction that our scientific fruits are reaching to the vulnerable people. Progressive transformational changes will then accelerate the wellness of the needy communities and the country as a whole.

Acknowledgments

The authors gratefully acknowledge the overall support of Indian Coucil of Agricultural Research (ICAR), Council of Scientific and Industrial Research (CSIR), University Grants Commission (UGC), Government of India.

The authors also gratefully acknowledge the support of various schemes of Governemnt of India and the support of EU- aided "International Network for Edible Aroids (*INEA*)" Project.

References

1. Woollams C (2015) The Rainbow diet and how it can help you beat Cancer. Griffin Press, Australia, pp: 328.

2. Lebot V (2009) Tropical Root and Tuber Crops: Cassava, Sweet Potato, Yams and Aroids. Crop Production Science in Horticulture 17. CABI Publishing, UK, pp: 515.

3. Climate Change, Agriculture and Food Security in South East Asia (CCAFS-SEA, 2014) Seminar Workshop. 14-15 August, International Rice Research Institute (IRRI) Philippines.

4. Casals CBA, Zevallos CL (2003) Stoichiometric and kinetic studies of phenolic antioxidants from Andean purple corn and red-fleshed sweet potato. J Agric Food Chem 51(11): 3313-3319.

5. Hayase F, Kato H (1984) Antioxidative components of sweet potatoes. J Nutr Sci Vitaminol 30(1): 37-46.

6. Islam MS, Yoshimoto M, Yamakawa O (2003) Distribution and physiological functions of caffeoylquinic acid derivatives in leaves of sweet potato genotypes. J Food Sci 68(1): 111-116.

7. Oki T, Masuda M, Furuta S, Nishiba Y, Terahara N, et al. (2002) Involvement of athocyanins and other phenolic compounds in radical-scavenging activity of purple-fleshed sweet potato cultivars. J Food Sci 67(5): 1752-1756.

8. Yoshimoto M, Kurata AR, Fujii M, Hou DX, Ikeda K, et al. (2004) Phenolic composition and radical scavenging activity of sweet potato-derived *shochu* distillery by-products treated with koji. Biosci Biotechnol Biochem 68(12): 2477-2483.

9. Yeh KW, Chen JC, Lin MI, Chen YM, Lin CY (1997) Functional activity of sporamin from sweet potato (*Ipomoea batatas* L.): a tuber storage protein with trypsin inhibitory activity. Plant Mol Biol 33(3): 565-570.

10. Mukherjee A, Naskar SK (2012) Performance of orange and purple fleshed sweet potato genotypes in coastal locations of Odisha. J Root Crops 38(1): 26-31.

11. Yoshimoto M, Okuno S, Kumagai T, Yoshinaga M, Yamakawa O (1999a) Distribution of antimutagenic components in colored sweet potato. Jpn Agric Res Quarterly 33: 143-148.

12. Yoshimoto M, Okuno S, Yoshinaga M, Yamakawa O, Yamaguchi M, et al. (1999b) Antimutagenicity of sweet potato (*Ipomoea batatas*) roots. Biosci Biotechnol Biochem 63(3): 537-541.

13. Yoshimoto M (2001) New trends of processing and use of sweet potato in Japan. Farming Japan 35: 22-28.

14. Hou DX (2003) Potential mechanisms of cancer prevention by anthocyanins. Current Mol Med 3(2): 149-159.

15. Hou DX, Ose T, Lin S, Harazor K, Imamura I, et al. (2003) Anthocyanins induce apoptosis in human promyelocytic leukemia cells: Structure-activity relationship and mechanisms involved. Int J Oncol 23(3): 705-712.

16. Kurata R, Adachi M, Yamakawa O, Yoshimoto M (2007) Growth suppression of human cancer cells by polyphenolics from sweet potato (*Ipomoea batatas* L.) leaves. J Agric Food Chem 55(1): 185-190.

17. Hagiwara A, Yoshino H, Ichihara T, Kawabe M, Tamano S, et al. (2002) Prevention by natural food anthocyanins, purple sweet potato color and red cabbage color, of 2-amino-1-methyl-6- phenylimidazo [4,5-b] pyridine (PhIP)-associated colorectal carcinogenesis in rats initiated with 1,2-dimethylhydrazine. J Toxicol Sci 27(1): 57-68.

18. Van Jaarsveld PJ, Faber M, Tanumihardjo SA, Nestel P, Lombard CJ, et al. (2005) β-Carotene–rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test. Am J Clin Nutr 81(5): 1080-1087.

19. Matsui T (2002) Prophylaxis of hypertension by food components and their antihypertensive mechanism. Bioscience and Industry 60: 25-30.

20. Matsui T, Ebuchi S, Fukui N, Matsugano K, Terahara N, et al. (2004) Caffeoylsophorose, a new natural α-glucose inhibitor, from red vinegar by fermented purple-fleshed sweet potato. Biosci Biotechnol Biochem 68(11): 2239-2246.

21. Terahara N, Matsui T, Fukui K, Matsugano K, Sugita K, et al. (2003) Caffeoylsophorose in red vinegar produced through fermentation with purple sweet potato. J Agric Food Chem 51: 2539-2543.

22. Yoshimoto M, Kurata R, Okuno S, Ishiguro K, Yamakawa O, et al. (2006) Nutritional value and physiological functions of sweet potato leaves. Acta Hort 703: 107-

116.

23. Hwang YP, Choi JH, Hwang YP, Choi JH, Han EH, et al. (2011) Purple sweet potato anthocyanins attenuate hepatic lipid accumulation through activating adenosine monophosphate–activated protein kinase in human HepG2 cells and obese mice. Nutr Res 31(12): 896-906.

24. Rath D, George J, Mukherjee A, Naskar SK, Mohandas C (2016) Antibacterial activity of leaf and tuber extract of orange, purple flesh antioxidants rich sweet potato (*Ipomoea batatas* L.). Merit Res J Agri Sci Soil Sci 4(4): 067-071.

25. Vishnu VR, Renjith RS, Mukherjee A, Anil SR, Sreekumar J, et al. (2019) Comparative study on the chemical structure and in vitro anti-proliferative activity of anthocyanins in purple root tubers and leaves of sweet potato (*Ipomoea batatas*). J Agric Food Chem 67(9): 2467-2475.

26. Mukherjee A (2010) Sweet potato varietal importance and its potential contribution to enhancing rural livelihoods in Orissa. In: Attaluri S, Janardhan KV, et al. (Eds.), Proc. of a workshop and training on sustainable sweet potato production and utilization in Orissa, India. International Potato Centre (CIP), SWCA, India, pp: 19-29.

27. Mukherjee A, Anil SR, Radhika KN, Sheela MN, Devi A, et al. (2018) A Catalogue on Bio-fortified Sweet Potato Varieties for India. ICAR-Central Tuber Crops Research Institute, Sreekariyam, India, pp: 16.

28. Mukherjee A, Sheela MN, Asha KI, Devi AA, Anil SR, et al. (2019a) Tuber crops varieties released by ICAR – Central Tuber Crops Research Institute, Technical Bulletin.77, ICAR – Central Tuber Crops Research Institute, Sreekariyam, India, pp: 48.

29. Mukherjee A, Immanuel S, Sreekumar J, Sivakumar PS (2019) Tropical Tubers: Journey from 'Life Saving Food' To 'Future Smart Crops' Lead Paper. In: 8th (Edn.), Horticultural Congress at Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh during pp: 17-21.

30. Mukherjee A, Immanuel S, Sreekumar J, Jaganathan D (2019) Produce Tuber Reduce Hunger: Video on Technologies of ICAR-CTCRI. ICAR-Central Tuber Crops Research Institute, Sreekariyam, India.

31. Mukherjee A, Sreekumar J, Immanuel S, Sivakumar PS (2019) Innovations in Production and Value Chain Management of Tuber Crops. International Conference on Innovative Horticulture and Value Chain Management held during 28-31 May 2019, GBPUA&T, Pantnagar, Uttarakhand, India.

32. Mukherjee A, Naskar SK, Edison S (2009) Salt tolerant biofortified orange and purple flesh sweet potato: coastal food and nutrition security, CTCRI, Trivandrum, Tech. Bull 51: 36.

33. Mukherjee A, Naskar SK, Poddar A, Dasgupta M, Sahoo MR, et al. (2009) Submergence and salinity tolerance in sweet potato (Ipomoea batatas L.) : progress and prospects. Plant Sci. Res 31(1&2): 1-9.

34. Mukherjee A, Naskar SK, Rao KR, Ray RC (2012) Sweet Potato: Gains through Biotechnology. Fruit, Vegetable and Cereal Science and Biotechnology. Global Science Books 6(1): 30-42.

35. Mukherjee A (2013) Climatic resilience and salinity cum submergence stresses tolerance of sweet potato (Ipomoea batatas L.) genotypes. Climate Changes and Environment. In: Sundaresan J, et al. (Eds.), scientific publisher, New Delhi, pp: 89-99.

36. Konczak I (2006) Anthocyanin rich polyphenolic complex with enhanced physiological activity from a sweet potato cell line. Innovative Technologies for Commercialization, pp: 207-208.

37. Lin KHR, Tsou CC, Hwang SY, Chen LFO, Lo HF (2006) Paclobutazol pretreatment enhanced flooding tolerance of sweet potato. J Plant Physiol 163(7): 750-760.

38. Lin KH, Chiou YK, Hwang SY, Chen LFO, Lo HF (2008) Calcium chloride enhances the antioxidative system of sweet potato (Ipomoea batatas) under flooding stress. Annals of Applies Biology 152(2): 157-168.

39. Mukherjee A (2002) Effect of NaCl on In Vitro Propagation of Sweet Potato (Ipomoea batatas L.). Applied Biochemistry and Biotechnology 102: 431-441.

40. Dasgupta M, Sahoo MR, Kole PC, Mukherjee A (2008) Evaluation of orange fleshed sweet potato (Ipomoea batatas L.) genotypes for salt tolerance through shoot apex culture under in vitro NaCl mediated salinity stress conditions. Plant Cell Tissue organ culture 94: 161-170.

41. Mukherjee A, Unnikrishnan M, Nair NG (1991) Growth and morphogenesis of immature embryos of sweet potato (Ipomoea batatas L.) in vitro. Plant Cell, Tissue and Organ Culture 26: 97-99.

42. Mukherjee A, Debata BK, Naskar SK (1998) Somatic embryogenesis and chromosomal stability of regenerants in sweet potato and taro. J. Sci. and Ind. Res. 57: 709-715.

43. Mukherjee A, Debata BK, Mukherjee PS, Malik SK (2001) Morpho-histo-biochemical characteristics of embryogenic and non embryogenic callus cultures of

sweet potato (Ipomoea batatas L). Cytobios 106(412): 113-124.

44. Mukherjee A, Dasgupta M, Debata BK, Naskar SK (2003) Enhancement of somatic embryogenesis in sweet potato: effect of growth regulators sodium chloride, proline and maltose. Indian J Plant physiol, pp: 326-331.

45. Mukherjee A (2016) Distant hybridization and tropical tuber crops: Designing for adaptive food-nutrition and livelihood, presented as lead paper. National seminar on 'Distant hybridization in Horticultural crops during 22nd- 23rd Jan, ICAR-IIHR, Bangalore, New Delhi, India.

46. Cervantes Flores JC, Sosinski B, Pecota KV, Mwanga ROM, Catignani GL, et al. (2011) Identification of quantitative trait loci for dry-matter, starch, and b-carotene content in sweetpotato. Mol Breeding 28: 201-216.

47. ICAR-CTCRI (2019) Annual Report 2018-19, ICAR-Central Tuber Crops Research Institute, Thiruvanathapuram, Kerala, India, pp: 189.

48. Atkinson FS, Powell KF, Jennie C, Brand Miller JC (2008) Diabetes Care. 31(12): 2281-2283.

49. Remya R, Jyothi AN, Sreekumar J (2018a) Morphological, structural and digestibility properties of RS4 enriched octenyl succinylated sweet potato, banana and lentil starches. Food Hydrocolloids 82: 219-229.

50. Remya R, Jyothi AN, Sreekumar J (2018b) Effect of chemical modification with citric acid on the physicochemical properties and resistant starch formation in different starches. Carbohydrate Polymers 202: 29-38.

51. Kalbach J (2012) Clarifying Innovation: Four Zones of Innovation.

52. Satell G (2012) Before You Innovate, Ask the Right Questions. Harvard Business Review.

53. Mukherjee (2015) Global vision of 'zero hunger challenge' with homage to 'APJ Kalam' and tribute to Prof. M. S. Swaminathan. J Environ & Sociobiol 12(2): 249-252.

54. Mukherjee A (2019) 'Ascent to Entrepreneurship Development and Commercialization with Roots and Tuber Crops' Lead Paper presented at the National Agri-Business Entrepreneurship Conclave (NABEC-2019): Building Agri-Business Start-Up Ecosystem organized at Umiam, Meghalaya, India, pp: 9-11.

55. Times.com (2016) The 25 Best Inventions of 2016.

56. USDA (2018) National Nutrient Data Base for standard Reference Legacy Release.