Sweet potato biofortification priority index – a strategic tool for scaling up of biofortified varieties

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Scaling up of biofortified varieties is the key component of food-based approaches in addressing micronutrient deficiency. Orange-fleshed sweet potato varieties rich in β-carotene can address the vitamin A deficiency prevalent in rural and tribal areas. We developed a 'sweet potato biofortification priority index' (SPBPI), a strategic planning tool for identifying priority states for implementing biofortification field interventions. A scaling-up intervention 'Rainbow Diet Campaign' is being implemented in the 'high-priority' states, Meghalaya, Mizoram and Arunachal Pradesh identified by SPBPI.

Keywords: Biofortification priority index, micronutrients, scaling-up intervention, sweet potato, vitamin A deficiency.

The pain of hidden hunger

VITAMINS and minerals, together known as micronutrients, are essential for growth and development in children and to maintain physical and mental functionality in adults. When these nutrients are deficient in food intake or absorption, the resulting condition is 'hidden hunger[1]. Globally two billion people are estimated to be facing micronutrient deficiency[2]. Malnutrition is recognized as one of the principal causes limiting the global economy[3]. The cost of hidden hunger is estimated to be US$ 3.5 trillion per year globally[4], and for India, it is estimated between 0.8% and 2.5% of GDP, equivalent to US $15–$46 billion[5].

Vitamin A deficiency

Vitamin A is a fat-soluble vitamin essential for clear vision and eye health, maintaining the integrity of epithelial tissues and functioning of the immune system[6]. It is found in green, yellow/orange-coloured vegetables such as carrot, sweet potatoes and green leafy vegetables. Prolonged dietary deprivation, fat malabsorption and liver disorders lead to vitamin A deficiency (VAD). It affects immunity and causes xerophthalmia, night blindness[7] and diarrhoea[8]. Young children and lactating women are prone to VAD. It is recognized as a 'public health problem' in India and categorized as one of the nationwide deficiencies which requires widespread interventions[9]. The Comprehensive National Nutrition Survey (CNNS)[10] estimated the prevalence of VAD in India as 18% among pre-school children, 22% among school-age children and 16% among adolescents[10]. Severe VAD (prevalence ≥20%) is found among pre-school children in Manipur, Mizoram, Tripura, Bihar, Jharkhand, Chhattisgarh, Telangana, Andhra Pradesh, Kerala, Punjab, Haryana, Uttar Pradesh, Uttarakhand and Gujarat.

Interventions for addressing vitamin A deficiency

VAD is common in poverty-ridden tropical countries where fresh fruits and vegetables are not readily available, and people rely heavily on starchy staples to meet their nutritional needs[11]. Various national-level interventions are being implemented to address VAD in India. These mainly include vitamin A supplementation, food fortification, nutrigardens and biofortification. The supplementation interventions are short-term strategies to combat VAD, where infants and children are administered a high dose of vitamin A to prevent night blindness and control hypovitaminosis. In 1970, The Government of India (GoI) initiated a National Prophylaxis Programme against VAD to prevent night blindness, and later broadened its scope to cover all forms of nutritional blindness and empowered the states to implement it[12]. Under this Programme, infants and children were administered high doses of vitamin A. Despite its success, this universal prophylactic mega-dose vitamin A supplementation approach

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was criticized for its unjustified claims of reduced mortality, indiscriminate dosing, adverse effects and high cost[13]. Food fortification is a medium-term strategy for VAD, where common foods are fortified with vitamin A. Examples include fortified edible oils in India, sugar in Guatemala and Honduras, monosodium glutamate in the Philippines and Indonesia, and soybean oil in Brazil[12]. The National Nutrition Strategy aims to reduce malnutrition by 2030 in India and suggests bi-annual vitamin A supplements to address VAD[14]. A communication strategy which encourages individual/community to change their behaviour, such as camping, role play, street plays, drama and many more.

Biofortification – a silver bullet

According to the World Health Organization (WHO), 'Biofortification is the process of improving the nutritional quality of food crops through agronomic practices, conventional plant breeding, or modern biotechnology'[15]. Biofortification is a food-based strategy to enhance nutrient levels in crops during plant growth, rather than through manual methods during the processing of crops. Therefore, biofortification is a feasible and cost-effective approach of delivering micronutrients to populations with limited access to diverse diets and other micronutrient interventions such as supplementation and conventional fortification[16]. Further, the small and marginal, resource-poor, subsistence farmers, who consume the bulk of their harvested produce in their households, can easily integrate biofortified foods in their regular diet to address nutrient deficiencies[17]. Therefore, biofortification is considered as an effective alternative to supplementation to address the burden of micronutrient deficiency in developing countries[18]. In the past two decades, the global breeding programmes on biofortification have focused on three major micronutrients, viz. vitamin A, iron (Fe) and zinc (Zn), and developed varieties such as provitamin A-rich, orange-fleshed sweet potato (OFSP), yellow-fleshed cassava and orange maize, iron-rich pearl millet and beans, and zinc-rich rice and wheat[19]. Some of the biofortified crop varieties developed in India are CR Dhan 310 (protein-rich rice variety), 3 DRR Dhan 45 (zinc-rich rice variety), WB 02 (zinc and iron-rich wheat variety), Pusa Vivek QPM9 Improved (provitamin-A, lysine and tryptophan-rich maize hybrid), HHB 299 (iron and zinc-rich pearl millet hybrid), Pusa Beta Kesari 1 (β-carotene-rich cauliflower variety), Bhu Sona (β-carotene-rich sweet potato variety) and Bhu Krishna (anthocyanin-rich sweet potato variety)[20].

Why biofortified orange-fleshed sweet potato is a promising solution?

Sweet potato is a popular snack food in urban India, and serves as a secondary food staple for the tribals and people living in geographically disadvantaged areas. In India, sweet potato is cultivated in 116,000 ha with a production of 1,186,000 MT (ref. 21). OFSP is a biofortified sweet potato variety that are rich in vitamin A, easy to cultivate and cost-effective and serves as an ideal food and nutritional security crop. Consuming one sweet potato tuber of 100 g weight of a medium intensity OFSP variety can meet the daily vitamin A needs of a young child[22]. With higher bioavailability of 80% of β-carotene in the boiled form, OFSP provides a sustainable alternative to supplementation in order to combat VAD in a natural way[23]. Most OFSP varieties released in India are climate-smart, producing a profitable yield in saline soils and under varied climatic conditions[24]. It can be cultivated in marginal lands in areas ranging from the tropics to temperate zones and requires less chemical inputs[25].

OFSP varieties were promoted as a food-based approach for preventing or reducing VAD naturally and in a cost-effective manner among the population who consume sweet potato as the primary or secondary staple[26]. A HarvestPlus intervention implemented in Uganda and Mozambique has proved that regular consumption of OFSP contributed to 78% of total vitamin A intake among children aged 6–35 months in Mozambique, and 53% in Uganda[27]. In terms of vitamin A derived from OFSP, this approach was found to be highly cost-effective. In Uganda, the field interventions implemented to promote OFSP cost only US$ 15–20 per disability-adjusted life years (DALYs) saved[28].

Considering the need for developing biofortified sweet potato varieties for combating VAD, the ICAR – Central Tuber Crops Research Institute (ICAR-CTCRI), Thiruvananthapuram, along with its All India Coordinated Research Project on Tuber Crops (AICRP-TC) Centres has developed five OFSP varieties (Table 1).

These varieties are currently promoted through field-intervention programmes of ICAR-CTCRI such as 'Rainbow Diet Campaign for the north eastern hill region' in Tripura and Arunachal Pradesh, and other frontline extension programmes.

Table 1. Vitamin A biofortified sweet potato varieties released in India

Sweet potato variety	β-Carotene content (mg/100 g)
Bhu Sona (ST-14)	11.5–12.5
Sree Kanaka	8.8–10
Bhu Kanti (CIP-440127)	6.5
Bhu Ja (CIPSWA-2)	5.5–6.4
Gouri	4.5–5.5
Sree Retina	3.2–3.5
Kamala Sundari	8.2
CO-5 (CIP-440038)	6
Indira Narangi	5.72
Indira Madhur	4.5

Source: Mukherjee *et al.*[34].

Need for targeted intervention for scaling up of biofortified orange sweet potato

Biofortification involves investing scarce and valuable resources by various international, national, public and private organizations. In India, global players like Consultative Group on International Agricultural Research (CGIAR) and Harvest Plus are implementing a scaling up of biofortified crop varieties like iron-rich pearl millet and zinc-fortified wheat[29]. The International Potato Centre (CIP) is also promoting OFSP varieties in Odisha on a limited scale[30]. Whereas ICAR-CTCRT has released a biofortified sweet potato variety (Table 1), it needs to be scaled up to reach the targeted groups to address VAD. Considering the high cost, diversity of the target population in terms of culture and economic status, the scaling up efforts need to be planned systematically to address vitamin A needs. The HarvestPlus programme had developed a biofortification priority index (BPI) – an intervention prioritization tool to guide strategic decisions for investment, policy and practice about introducing and scaling up of biofortified staples[31]. Though BPI helps identify the priority countries for implementing field interventions of biofortified crops, this index needs to be customized to identify 'micro-intervention points'. These are the states or regions where a specific crop is consumed as a staple food and has a substantial proportion of the population suffering from a specific micronutrient deficiency. Therefore, we have modified BPI to develop a sweet potato biofortification priority index (SPBPI) in order to identify priority Indian states for implementing biofortified sweet potato field interventions. This article describes the development of SPBPI and using it to identify priority states for implementing field interventions for VAD alleviation.

Methodology

BPI is a composite crop and micronutrient-specific index that identifies priority regions for biofortification interventions[31]. Since our work focuses on adapting BPI to identify the priority states for promoting biofortified sweet potato varieties, the basic assumptions of BPI were modified. (i) The state must produce sweet potato and retain it (all the produce must be consumed). (ii) The state's population must consume a significant portion of sweet potato from their own production and it must not be sourced from either imports or neighbouring states. (iii) The state's population suffers from significant prevalence of VAD, which can be addressed through the biofortified sweet potato varieties.

SPBPI is composed of three sub-indices emanating out of three assumptions. The first assumption contributes to the production sub-index, whereas the other two assumptions lead to consumption and VAD sub-indices.

Data and calculations

Data for the present study were obtained from various authentic primary and secondary sources. Primary sources for the data were official websites and reports published by government institutions only. Data on all the variables were updated to the most recent years available in the government websites and reports. The data for production sub-index variables were obtained from Indiastatagri, and a three-year average was adopted to account for the variation in the agricultural sector. Data for the consumption sub-index were obtained from the National Sample Survey Office report (66th round). Since data on state-wise export share and import share were not available with the government sources, an expert survey was conducted. Experts with a minimum of 10 years of experience in sweet potato research and extension were requested to provide estimates of export/import quantities of sweet potato in various states. Data on VAD sub-index variables were obtained from CNNS and ICMR reports. Among the 28 states and 8 Union Territories of India, only 15 states were included in the analysis for which complete data on all the variables were available.

Furthermore, due to missing data for most variables, the North-East states such as Tripura, Nagaland and the southern state of Telangana were omitted from analysis. It is important to note that sweet potato is not cultivated in every part of the country; so all the states cannot be included in the analysis. Table 2 provides the details of variable and data sources.

Table 3 presents the calculations adopted in developing SPBPI. The calculations yield SPBPI value between 0 and 1. For ease of use, SPBPI is multiplied by 100 to obtain a final SPBPI score between 0 and 100. Further, all non-zero SPBPI values are categorized into quartiles to identify the priority states – fourth quartile being 'top priority' followed by 'high priority' (third quartile) 'medium priority' (second quartile), 'low priority' (first quartile) and 'no priority' for the states with SPBPI score of zero.

Results and discussion

Modifications of BPI

The original BPI value was computed using country-level data. In this study, while computing SPBPI for Indian states, we found that data for selected variables were not available. Therefore, some modifications were introduced. The state-level data for export and import share of sweet potato were elicited from an expert survey. This indicated that the export of sweet potato to other states and importing sweet potato for consumption by various states were negligible or zero. Therefore, both export share and import share were assumed to be zero in this study. We

Table 2. Variables and data sources

Sub-index	Variable	Variable explanation	Main data source and year
Sweet potato production sub-index (SPPSI)	Share of area harvested (%)	Total area harvested of sweet potato (ha)/ net sown area of a state (ha)	Indiastatagri.com 2016, 2017, 2018 average
	Per-capita area harvested (ha)	Total area harvested of sweet potato (ha)/ total population in the state	Indiastatagri.com 2016, 2017, 2018 average censusindia.gov.in 2011
	Export share	If production is greater than 0 – Export share = Exports/(Production + imports); otherwise export share is 0%	Expert survey
Sweet potato consumption sub-index (SPCSI)	Per-capita food consumption	Per-capita sweet potato supply (kg/year)	NSS 66th round 2009–2010
	Import share	If production is greater than 0 – Import share = Imports/(Production + imports – exports); otherwise import share is 100%	Expert survey
Vitamin A deficiency sub-index (VADSI)	Serum retinol concentration <20 μg/dl	Proportion of preschool-age children with retinol <20 μg/dl	CNN Report 2016–18
	Disability-adjusted life years (DALYs)	DALYs per 100,000 inhabitants in a state due to diarrhoeal disease	ICMR, PHFI, and IHME[35]

Source: Authors' compilation and Herrington *et al.*[31].

Table 3. Variables of sweet potato biofortification priority index (SPBPI) and their estimation procedures

Procedure	Formula
Rescaling of variables	$\text{Rescaled value } (r) = \frac{\text{Actual value} - \text{Minimum value}}{\text{Maximum value} - \text{Minimum value}}.$ (1)
SPPSI	$\text{SPPSI} = \left[\left(\frac{1}{2} * \text{Per capita area harvested}\right)^r + \left(\frac{1}{2} * \text{share of area allocated to sweet potato}\right)\right] * (1 - \text{export share}^r).$ (2)
SPCSI	$\text{SPCSI} = [(\text{Consumption per capita per year})^r] * (1 - \text{import dependency ratio})^r.$ (3)
VADSI	$\text{VADSI} = \left[\left(\frac{1}{2} * \text{Proportion of preschool} - \text{age children with retinol} < 20\ \mu\text{g/d}l\right)^r + \left(\frac{1}{2} * \text{DALYs per } 100,000 \text{ inhabitants due to diarrhoeal disease}\right)\right].$ (4)
SPBPI	$\text{SPBPI} = \sqrt[3]{\text{SPPSI} * \text{SPCSI} * \text{VADSI}}.$ (5)

Source: Adopted from Herrington *et al.*[31].

adopted diarrhoeal disease as a proxy for DALY due to VAD, since state-level DALY data were unavailable.

Prioritization of states

Table 4 shows absolute rankings of the Indian states in terms of production and consumption intensity of sweet potato and prevalence of VAD. The sweet potato production sub-index (SPPSI) measures the intensity of production, or supply, of sweet potato within a given state. Among the 15 states selected, the top 5 sweet potato production potential states are Meghalaya, Odisha, Kerala, West Bengal and Assam. Interestingly, SPPSI was 100% for Meghalaya, whereas for the other states, it was below 10%, except for Tamil Nadu for which it was zero.

The sweet potato consumption sub-index (SPCSI) measures the intensity of consumption within each state through per capita consumption of sweet potato. The top five sweet potato consumption potential states are Arunachal Pradesh, Tamil Nadu, Mizoram, Meghalaya and Assam. Arunachal Pradesh had 100% SPCSI, whereas all other states had SPCSI values below 10%. For Kerala, SPCSI was computed as zero due to zero consumption sub-index.

The vitamin A deficiency sub-index (VADSI) measures the prevalence of VAD in the given state. Among the 15 states, 8 had VADSI value of more than 55%. The top five states with high VADSI are Odisha, Karnataka, Bihar, Chhattisgarh and Assam. Correlation between individual parts of the index was low or even negative, indicating that states are not uniformly ranked across individual indicators.

Table 5 shows the rank order of states according to their SPBPI values. Higher the SPBPI value, higher is the priority for vitamin A-biofortified sweet potato

Table 4. SPPSI, SPCSI and VADSI scores and ranks for 15 states of India

State	SPPSI%	Rank	SPCSI%	Rank	VADSI%	Rank
Meghalaya	100.00*	1	19.00	4	19.74	12
Odisha	57.52	2	4.99	6	71.64*	1
Mizoram	7.89	6	35.12	3	59.47	7
Assam	10.23	5	10.75	5	60.81	5
Arunachal Pradesh	0.63	12	100.00*	1	29.41	10
Chhattisgarh	6.91	7	2.69	9	61.59	4
West Bengal	18.56	4	3.26	7	10.93#	15
Uttar Pradesh	5.15	8	1.73	12	55.92	8
Madhya Pradesh	2.40	9	2.11	11	59.81	6
Andhra Pradesh	0.50	13	2.69	8	39.91	9
Bihar	0.36	14	2.30	10	64.76	3
Karnataka	1.58	10	0.19	14	65.55	2
Maharashtra	0.68	11	1.54	13	16.06	14
Kerala	46.63	3	0.00#	15	17.69	13
Tamil Nadu	0.00#	15	35.89	2	21.33	11

Source: Authors' calculation.

Table 5. Classification of states according to their SPBPI values

State	SPBPI%	Rank	Priority levels
Meghalaya	33.47	I	Top priority
Odisha	27.40	II	
Mizoram	25.45	III	
Assam	18.84	IV	
Arunachal Pradesh	12.27	V	High priority
Chhattisgarh	10.46	VI	
West Bengal	8.71	VII	
Uttar Pradesh	7.92	VIII	Medium priority
Madhya Pradesh	6.72	IX	
Andhra Pradesh	3.76	X	
Bihar	3.75	XI	
Karnataka	2.71	XII	Low priority
Maharashtra	2.56	XIII	
Kerala	0.00	–	No priority
Tamil Nadu	0.00	–	

Source: Author's calculation.

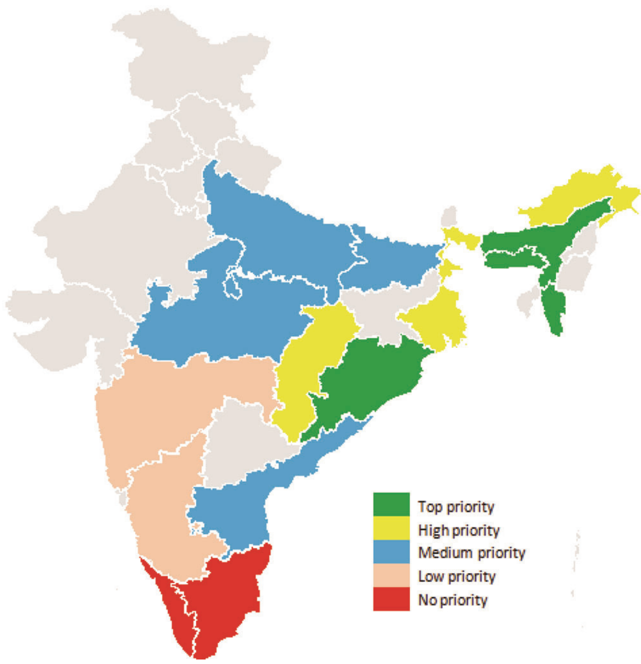

Figure 1. Sweet potato biofortification priority index map. (Source Authors' calculation based visualization.)

intervention. It is evident from Table 5 and Figure 1 that the top priority states for vitamin A-biofortified sweet potato field intervention were Meghalaya (rank 1), Odisha (rank 2), Mizoram (rank 3) and Assam (rank 4). In these top priority states, biofortified sweet potato interventions can effectively address the prevailing VAD. The high priority states are Arunachal Pradesh (rank 5), Chhattisgarh (rank 6) and West Bengal (rank 7). Though SPPSI for Arunachala Pradesh is low, due to the high per capita consumption of sweet potato and prevalence of VAD, it is classified as a high priority state. Therefore, field-based biofortified sweet potato interventions in Arunachal Pradesh should increase sweet potato production intensity for effective results. The VADSI value for Chhattisgarh was 61.59%. For effective biofortified sweet potato interventions, the focus must be on increasing production and promoting sweet potato consumption. Uttar Pradesh, Madhya Pradesh, Andhra Pradesh and Bihar fall under the medium priority category, with ranks of 8, 9 10 and 11 respectively. Medium priority states have relatively low-production and consumption of sweet potato with a severe level of VAD prevalence. Thus, biofortified sweet potato interventions will be less effective in addressing VAD.

The low priority states are Karnataka and Maharashtra, ranked 12 and 13 respectively. Karnataka has 66.55% of VAD prevalence; for biofortified sweet potato intervention, the production and consumption aspects need to be improved. Kerala and Tamil Nadu are not priority states, the main reason being zero consumption sub-index for Kerala and zero production sub-index for Tamil Nadu.

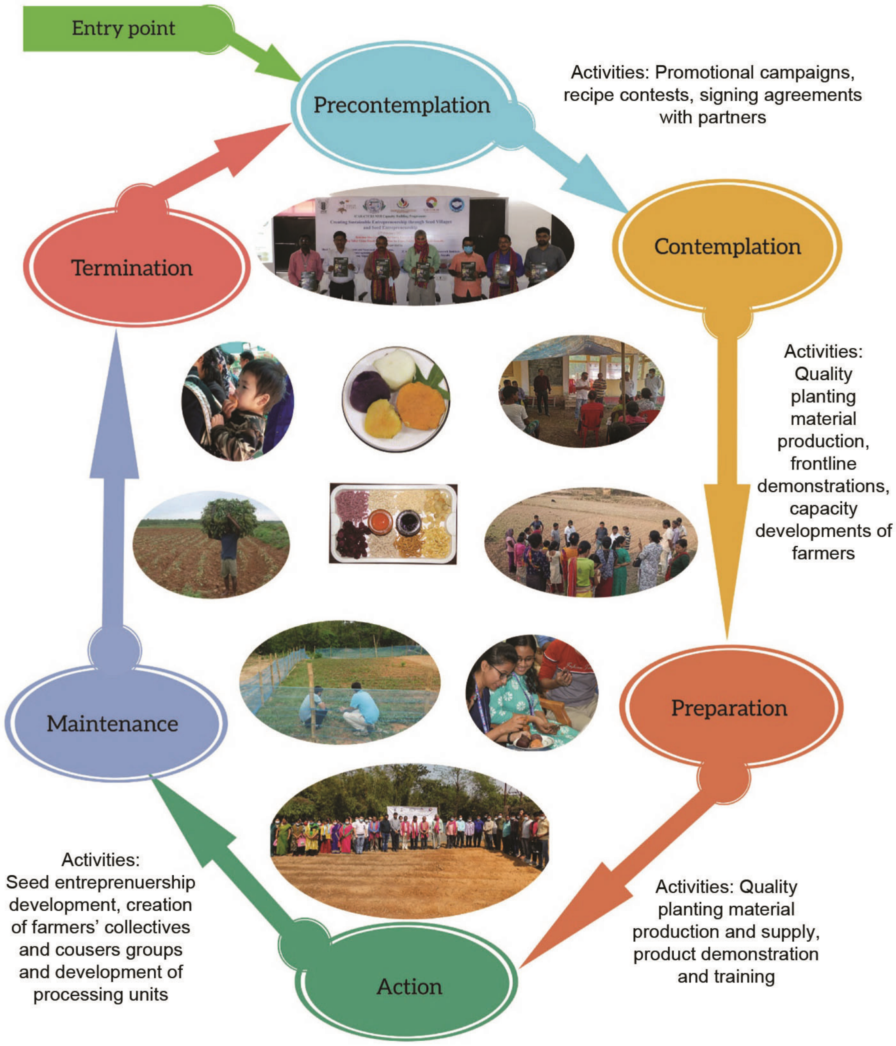

Figure 2. Rainbow Diet Campaign Strategy. (Source: Authors' compilation-based visualization.)

As expected, the results of our analysis showed that the top and high priority states for biofortified sweet potato intervention are in the eastern part of India (Figure 1).

In summary, our analysis using SPBPI reveals that over 90% of the states identified for biofortified sweet potato field interventions fall under the eastern and North East Hill Region (Figure 1), whereas the southern states are in either 'low' or 'no priority' class (Figure 1). Since several studies have identified sweet potato as a secondary staple food[26] in the tribal areas of the Eastern and North East Hill Region as well[32], it can be concluded that SPBPI yields reasonably accurate results.

Field Intervention for promoting vitamin A-rich sweet potato varieties

Following the SPBPI results, ICAR-CTCRI has designed a biofortified tuber crops variety scaling up programme, viz. 'Rainbow Diet Campaign' to address VAD for the North Eastern Hill states. Initiated in February 2020, this Programme is being implemented in Meghalaya, Mizoram, Tripura and Arunachal Pradesh. This campaign follows the 'Rainbow Diet approach', which promotes a 'food basket approach' (Figure 2) – a specific combination of tuber crops food designed for alleviating VAD and promoting overall health (Figure 2). This food basket is composed of OFSP (beta-carotene rich), purple-fleshed sweet potato (anthocyanin-rich) and purple yam (anthocyanin rich), along with edible taro/sweet potato leaves (green–chlorophyll) and white-fleshed sweet potato. While a boiled or vegetable form of sweet potato consumption is promoted among adults, the processed products target children.

The Rainbow Diet Campaign is a field-intervention programme which follows a 'behaviour change' strategy based on the 'transtheoretical model or stages of change model'[33,34] (Figure 2). The programme is targeted towards behaviour change of the work actor of the tuber crops value chain – farmers, traders, entrepreneurs, general consumers, school children and their parents.

Table 6. Components of rainbow diet campaign

Components	Objectives	Partners	Programmes conducted
Public awareness rallies	To promote consumer awareness about health benefits of consuming orange-fleshed sweet potato (OFSP) and other biofortified tuber crops	Meghalaya North-Eastern Hill University, Tura, West Garo Hills district	A public rally with 70 college students
		Arunachal Pradesh Krishi Vigyan Kendra, Khupa, Anjaw district	A public rally with 120 school students
Promoting biofortified sweet potato through nutrigardens	To create awareness about consuming biofortified sweet potato among school children	Arunachal Pradesh Krishi Vigyan Kendra, Khupa, Anjaw district	Two nutrigardens established in Anjaw district
Awareness programme-cum-product demonstrations	To create awareness about value-added products prepared from biofortified sweet potato (pasta, chips) among school and college students and other consumers	Meghalaya North-Eastern Hill University, Tura, West Garo Hills district	A college awareness programme involving 200 students
		Arunachal Pradesh Krishi Vigyan Kendra, Khupa, Anjaw district	Two school awareness programmes involving over 300 students
		Tripura College of Fisheries, Central Agricultural University (Imphal), Lembucherra	A college awareness programme involving 300 college students
		Mizoram ICAR Research Complex for NEH Region – Mizoram Centre, Kolasib	An awareness and product demonstration programme with 200 farmers and consumers
Creation of seed villages for large-scale multiplication of planting materials of biofortified varieties	To supply adequate quantity of planting materials of biofortified varieties to farmers	Tripura College of Fisheries, Central Agricultural University (Imphal), Lembucherra	Two seed villages were created and 70 seed producers trained in quality planting material production of biofortified sweet potato
		Arunachal Pradesh Krishi Vigyan Kendra, Khupa, Anjaw district	Three seed villages were created and 55 seed producers trained in quality planting material production of biofortified sweet potato
Frontline demonstrations (FLDs)	To maximize adoption of biofortified sweet potato varieties by farmers	Meghalaya, Mizoram, Tripura and Arunachal Pradesh	Sixty FLDs of biofortified sweet potato varieties in North Eastern Hill Region states
Entrepreneurship development through value addition	To catalyse entrepreneurship on value-added products from biofortified varieties	Meghalaya, Mizoram, Tripura, Manipur and Arunachal Pradesh	Multipurpose chipping machines for producing fried chips/animal feed supplied for developing a village-level custom hiring centre

Source: Authors' compilation from Rainbow Diet Campaign programme.

Table 6 gives the field intervention programmes implemented under the Rainbow Diet Campaign. The strength of this study is modifying BPI to develop SPBPI to scale up vitamin A biofortified sweet potato varieties. The study has limitations. The present analysis did not include several potential states such as Tripura, Nagaland and Telangana due to non-availability of data for various BPI variables.

Conclusion

In this study, we have prioritized states in India for implementing biofortified sweet potato intervention utilizing BPI developed by HarvestPlus with due modifications. Based on the findings, we suggest various stakeholders involved in addressing VAD through biofortified sweet potato to invest in the top and medium priority states for the desired outcome. In these states, the scaling up of biofortified sweet potato is implemented through field extension programmes by agencies like ICAR-CTCRI, AICRPTC Centres, State Agriculture or Horticulture Departments, Krishi Vigyan Kendra, MTTC and VTC, and NGOs. Under the Rainbow Diet Campaign programme of ICAR-CTCRI, various scaling-up activities for biofortified sweet potato varieties are currently being implemented in four states in the North East Hill Region. Considering the need for promoting these varieties among those deprived, a coordinated approach involving stakeholders from central/state governments and the private sector is necessary.

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