Sustainable Utilization of Genetic Resources of Neglected and Underutilized Tuber Crops for Climate Resilience and Nutritional Security

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(Photo credit: P. Murugesan)

1st row: Chinese potato, West Indian arrowroot and East Indian arrowroot

2nd row: Queensland arrowroot and Yam bean

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Contents

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From The Director

Globally about 30000 edible plant species have been identified out of which, about 7000 crop species are being cultivated for human food. Among these, only 150 crop species are commercially cultivated. A total of 103 crops provide up to 90% of the calories for human being. It is to be noted that only four crops (rice, wheat, maize, and potato) provide 60% of the human food energy. From these data it is very clear that thousands of edible crops remain unutilized even though they possess great potential for providing food and nutrition in a sustainable manner and have real strength to feed the growing population by fulfilling global food requirements. Concerted efforts for collection, conservation, evaluation and cataloguing of genetic resources of minor tuber crops are needed. Use of improved breeding techniques will help in increasing the yield coupled with tolerance to biotic and abiotic stresses. Development of improved varieties and cultivation practices, innovative value addition technologies, better access of producers to markets, validation and promotion of nutritional benefits, effective maintenance of genetic and cultural diversity on-farm, sustained capacity building of stakeholders, and policy support at the national and international levels are essentially required for sustainable conservation and utilization of these crops. ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram organized ICAR-Winter School on 'Sustainable exploitation of genetic resources of neglected and underutilized tuber crops' during 29th November to 19th December

2022. I am happy to note that the important lectures delivered in the winter school by the experts are compiled and edited in the form of a book and I appreciate the commendable editorial job done by Dr. P. Murugesan and his team in bringing out this book.

11 July 2023
Sreekariyam

Dr. G. Byju
Director

Preface

Many potential crop species used for food purpose are not effectively utilized due to several socio-economic reasons. Some of them are completely neglected and will soon become extinct due to non-utilization and low level of domestication and cultivation. The major problem here is that these crops are not included in the mainstream diet, and mostly the consumption is limited within tribal local communities. Moreover, there is nil to very low level of information available about the value additions and post-harvest utilization of these crops. However, ample information is available about the merits of these crops particularly on climate resilience, nutritional contents, medicinal properties and multipurpose utilities. Most of these crops are highly nutritious and yields many economically valuable products even under marginal growing conditions with low to medium input.

The book on "Sustainable utilization of neglected and under utilized tuber crops for climate resilience and nutritional security" brings out the information on usage of neglected and under utilized crops. The chapters include following topics; Importance, prospects and overview of minor tuber crops, Underutilised tuber crops diversity in eastern and north eastern India: An explorer's perspective, Research status, advances and prospects of breeding of neglected and underutilized tuber crops, Prospects of utilization of yam bean germplasm - Tuber yield and nutrients, Guidelines and procedures for exchange of plant genetic resources, *In silico* analysis of genes governing climate resilience and nutrient contents of tuber crops, Studies on the impact of climate change on minor tuber crops, Crop diversification with minor tuber crops for food and nutritional security, Climate change modelling studies of tuber crops, Organic production of minor tuber crops, Protocol for screening nutrient use efficient genotypes in tuber crops, Nematodes threats and their management in minor tuber crops, Phytosanitary measures for exchange of germplasm, Advances in quality planting material production in minor tuber crops, *In vivo* and *in vitro* methods of quality planting material production in yams and aroids, Seed rules and regulations applicable to vegetatively propagated crops, Indigenous technical knowledge and farmers innovations on conservation of tropical tuber crops and Linkage and association mapping approaches for improvement of tuber crops.

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Chapter 1

Importance, prospects and overview of minor tuber crops

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Many types of underutilized - minor tuber crops are grown and utilized all over the world on a limited scale. But they are considered as important food crops in many developing countries as they play multiple roles in meeting food and nutritional security, adaptation to climate change, plant genetic resources conservation at local and regional levels. They also generate income for resource-poor farmers and consumers. In this article, research on biodiversity, improvement, and prospects in minor tuber crops (MTC), *viz*., chinese potato (or) country potato, yam bean, Queensland arrowroot, East Indian arrowroot west Indian arrow root and other minor tuber crops.are discussed with a major focus on genetic resources and future prospects.

Chinese potato (*Plectranthus rotundifolius*)

The genus *Plectranthus* has four cultivated crops *viz*., *Plectranthus edulis* (Ethiopian potato) *P. esculentus* (Livingstone potato), *P. parviflorus* (Sudan potato) and *P. rotundifolius* (Madagascar potato) (Allemann et al., 2004). The main cultivated type of coleus (*Plectranthus rotundifolius*) is also known as Chinese Potato, belongs to the family Labiatae of order Lamiales with a chromosome number of 2n= 64 (Murugesan et al., 2020). The wide diversity of wild and cultivated germplasm of Chinese potato is available throughout the African continent (Enyiukwu et al., 2014). Chinese potato has been reported to have extremely low genetic variability owing to barriers in sexual reproduction such as sporadic flowering and pollen sterility and hence very little breeding work has been done on this crop. Induced mutations to generate variability were well exploited in Coleus (Abraham and Radhakrishna, 2005). A variety "Sree Dhara" (CP-58) has the yield potential, dry matter, and starch content of 25.0-28.0 t ha^{-1}, 28.5 %, and 19.5%, respectively. The tubers of country potato are eaten as a vegetable and show potential for emerging commercial crop (Venter et al., 2000). Interventions to support improved cultivation practices, better yield and marketability through development of high yielding varieties are suggested. Apart from these, it is also essential to strengthen the conservation of genetic diversity, morphological, genetic and molecular characterization; and crop improvement programmes in this crop. Widening genetic base with diversity available in Africa will give good prospect for breeding for large tuber size, increased yield with non-tuber branching characters (Figure 1 and 2). Tuber skin colour can be red, white or black (Dittoh et al. 1998). According to Tindall (1983), *Solenostemon rotundifolius* has three varieties with respect to skin colour: var. nigra A. Chev. (Which is black in colour), var. rubra A. Chev. (Which is reddish-grey or reddish yellow in colour) and var. alba A. Chev (which is white in colour). Even though tubers of Frafra potato are of different colour, the tuber flesh in all three varieties is white (Opoku-Agyeman et al. 2004). However, dark-brown, reddish-yellow and light-grey flesh colour has also been documented (Burkill 1985). According to Prematilake, (2004), the average diameter of the tuber of coleus is 2.5 cm in the report from Srilanka. Hence large size tuber with wider diameter is desirable for easy peeling and handling for culinary purposes. The tubers

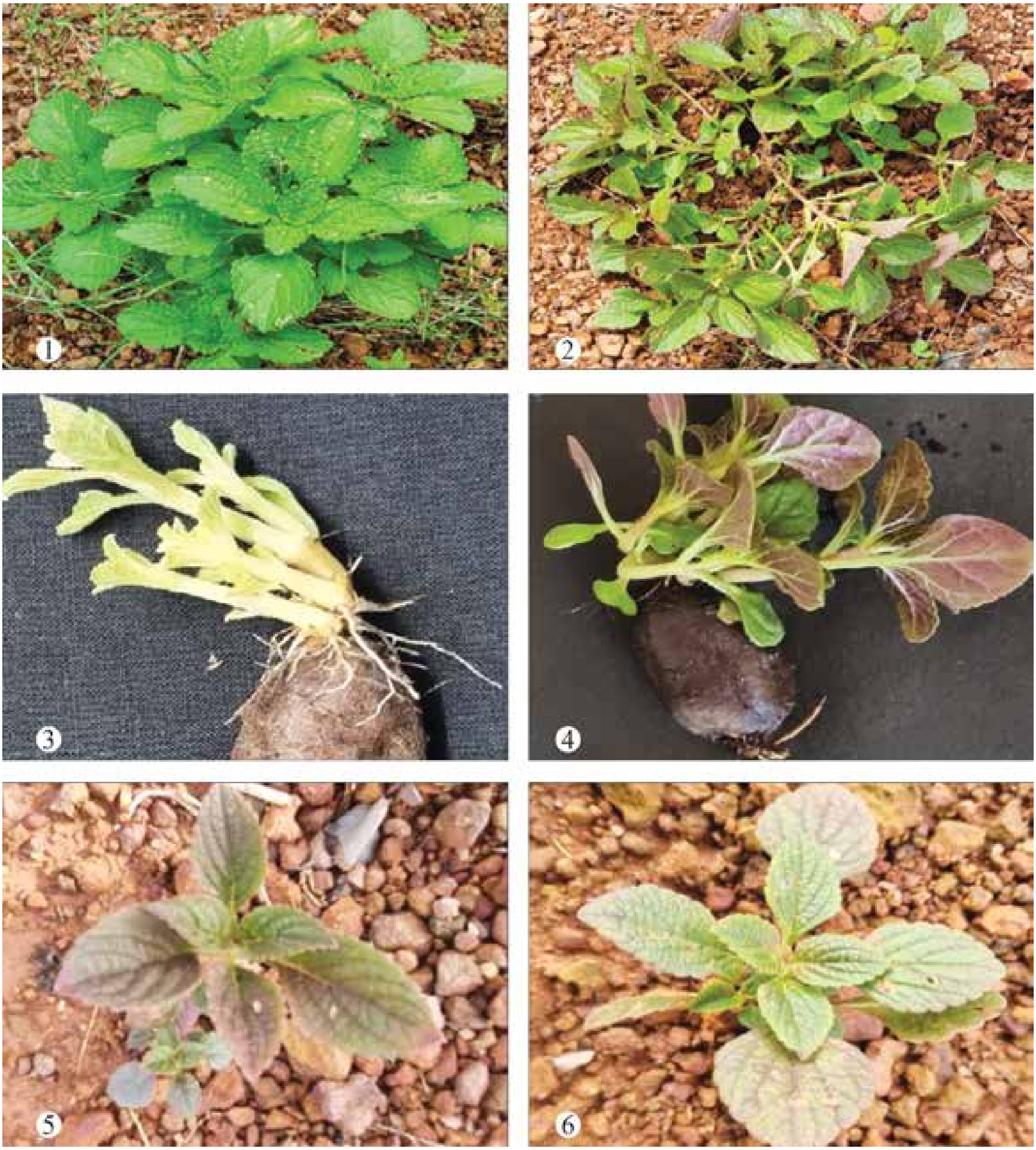

Fig.1. Chinese potato – Morphological variations in leaves – variety and land races 1. Chinese Potato - *Sree Dhara*, 2. Land race - purple pigmented, 3. Land race – light green pigmented, 4. Land race – deep purple pigmented 5 & 6. Land race-intermediate and deep pigmented.

were classified manually as marketable (having tuber circumference > 7 cm) and marketable (tuber circumference 0-7 cm) tubers, based on visual scrutiny.

Multilocation trials in four locations of Kerala (Trivandrum, Chokkad, Kozha and Anchal) conducted with 10 pre-selected accessions resulted in identification and selection of a high yielding clone CP58. This was released as state variety with a yield potential of 25-28 t/ha^{-1}. The estimated dry matter and starch contents were 28.5%

Fig.2. Chinese potato – Morphological variations in tubers – variety and land races 1. Chinese Potato - *Sree Dhara*, 2. Land race – white flesh, 3. Land race – light orange skin, 4. Land race – cylindrical tuber, 5. Land race – thin cylindrical tuber, 6. Land race – light brown skin

and 19.5%, respectively. Sree Dhara is a high yielding (25 t ha^{-1}) variety of Chinese potato with duration of five months and released from Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India (Vimala, 1994).

Another variety called 'Suphala' was developed from College of Horticulture, Vellanikara (Kerala Agricultural University) through *in vitro* mutagenesis followed by somaclonal selection. It was sourced from tissue culture mutant derived from a local cultivar. This was recommended in 23rd Kerala State Sub-Committee meeting during 2006. It has yield potential of 33.2t/ha with duration of 120-140 days and adoptable to year-round cultivation. It has dark green leaves and short internodes. Tubers are large in size and emerge mostly from basal nodes. Suphala has a productivity of 15.93 t ha^{-1}. (Gopalakrishnan and Devadas, 2014). During the normal planting season, var. Sree Dhara produced higher yields and profit than the var. Suphala. But the var. Suphala which is recommended for year-round cultivation was found to be early maturing than the var. Sree Dhara. (Jayapal *et al*., 2013)

Another variety, Nidhi (CP-79) was developed by breeding clonal selection sourced and improved from NBPGR collection, IC 85708 and released from RARS, Pattambi, KAU and released for cultivation for the state of Kerala in 20th State Seed Sub Committee. The spacing of 30×15 cm, organic manure of 10t/ha and NPK of 30:60:50kg/ha are recommended package of practice for its cultivation in central zone of Kerala state. The variety has five months duration, with characteristic aroma and produced large and oblong shaped tubers of good cooking quality. Flowering of all the germplasm accessions in Kerala were observed during October-November. It starts from 60 days of planting and continued for 2 months (Suma, *et al* 2014).

Co-1 is a variety released from Tamil Nadu Agricultural University during 1991 as state variety for Tamil Nadu. It is a clonal selection from local type introduced from Tenkasi. The starch yield recorded in this variety is 21.5%. The specialties of this variety are tasty tubers and have less soil odour. The Indian varieties released from ICAR-Central Tuber Crops Research Institute, Kerala Agricultural University and Tamil Nadu Agricultural University are given in table 1.

Table 1. Chinese potato varieties released in India

Name	Particulars	Traits	Year of release
Sree Dhara (CP58)	From high yielding clone CP58. State variety released from ICAR-CTCRI	Dry matter and starch contents of 28.5% and 19.5%. Five months duration and high yielding (25 t ha^{-1})	1994
Suphala	*In vitro* mutagenesis followed by somaclonal selection by KAU	High yield potential of 33.2 t ha^{-1}. Duration is 120-140 days and suitable for year-round cultivation	2006
Nidhi (CP-79)	Clonal selection from NBPGR collection IC 85708 developed from RARS, Pattambi, KAU	Five months duration, with characteristic aroma and produce large and oblong tubers of good cooking quality.	2004
CO-1	Clonal selection from local type introduced from Tenkasi. (TNAU)	High starch content (21.5 %). The specialties of this variety are tasty tubers and e less soil odour.	1991

Chinese potato is belonging to the family Lamiaceae (Labiatae) with a chromosome number of 2n= 64. This country potato is an annual herb with tender stem, branches emit aroma due to the presence of volatile oils in the glands or sacs of leaves. It grows upto a height of 15-30 cm. The plant is characterized by a square stem in cross section. Certain genotypes have purple pigmentation in the lamina and stem and majority of the cultivars has green colours of stem and leaves. The inflorescence of the plant is seen in the terminal and their length grows upto 15 cm. Flowers are bisexual, zygomorphous bears the pedicel up to 1–2 mm long (Enyiukwu *et al*. 2014) (Fig 3 and 4). Tubers are produced at the bottom of the stem with a cluster numbering 3 to 7 and sometimes tubers are seen in nodes touching soil. (Tindall 1983; Opoku-Agyemang *et al*. 2007). Tuber maturity is reported to occur 150–200 days after planting and harvesting maturity can be assessed through senescence, withering of leaves and other aerial parts of the plants. The flowers are blue pinkish white or pale violet in a distal inflorescence (Fig 5 & 6). The tuber yield varied among the accessions from 58.50 g to 216.25 g on a per plant basis. Tarpaga (2001) and Nanema *et al*. (2009)

observed mean single plant yield of 369.31 g and 62.07 g, respectively. Yield average of 5-15 MT/ha has been reported from the crop in Ghana and Nigeria, the potential yield of the crop could be up to 18–20 MT/ha.

Fig 3 and 4. The Chinese potato inflorescence and colour difference in stalks

Fig. 5 and 6. Chinese potato harvest maturity

The yield of this tuber crop is very low and owing to the poor seed set no appreciable variability is present in the population for genetic improvement. Other problems reported are rapid tuber deterioration in storage, lack of healthy planting materials, pests and diseases and declining soil fertility. High post harvest losses (20 to 40%) and lack of appropriate post harvest preservation methods were identified as key constraints. The tubers show natural dormancy from 3 months after harvest, becoming fibrous and begin to sprout. So far little research has been conducted to improve upon tuber size which is essential to increase production and utilization. Commercially, tuber size, shape and appearance are important physical quality features that determine both market value and consumer preference in Chinese potato. The most unfavourable feature of Chinese potato is the small and non-uniform size and often odd shape of the tuber due to which cleaning and de-skinning for culinary preparations becomes time consuming. The extent of adoption of improved technologies of Chinese potato by the farmers is comparatively low due to various constraints including technological, management, marketing and socio-economic factors. According to Manikandan *et al*., (2016), the tubers of Indian country potato are harvested about four to five months after planting on attaining flowering and aerial parts become dried. Chinese potato is a season bound crop, and the recommended time of planting is July in Kerala. There is great scope for off season production of Chinese potato using photo-insensitive varieties. Interventions to support improved cultivation practices, better yield and marketability through development to high yielding varieties, improving agronomic practices, enhancing value addition technologies, better access to markets are suggested (Safwan and Mohammed, 2016). Apart from these, it is also essential to strengthen the conservation of genetic diversity; morphological, genetic and molecular characterization; and crop improvement programmes in this crop.

Chinese potato is succeptable to root knot nematode which is a serious problem in Chinese potato cultivation. Severe infection of nematode leads to low tuber quality and marketability (Okorocha *et al*., 2006). Affected plants exhibit stunted growth, wilting and tubers show swellings (Fig 7 and 8). Infestation of root tubers by root knot nematodes in the field in addition to abrasions sustained during harvesting, strongly predispose tubers to rapid decay during transit and storage. Sree Bhadra, a high-yielding variety of sweet potato released by ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, is identified as a resistant trap crop for the root-knot nematode. Planting this variety in root-knot nematode-infested field helped in clearing the field free of nematodes and giving good tuber yield. Subsequently growing of susceptible crop like Chinese potato escaped nematode damage (Mohandas 2001). Crop rotation is also one effective cultural method. Farmers rotate Chinese potato after rice in Tirunelveli district of Tamil Nadu. Application of carbofuran 3 % granules at the rate of 20 kg per hectare under wet conditions near the root zone was also found effective.

Fig 7 and 8. Chinese potato plant and tubers affected by root knot nematode

Chinese potato is an under utilised tuber crop which has great potential to become major crop due to its food value, dietary and medicinal properties (Sethuraman *et al*., 2020). Kwarteng *et al*., (2017) reviewed the latest research of country potato and emphasized the need for breeding large tuber size. IC468968 being maintained by NBPGR is a promising accession which can be further utilized in the crop improvement programme (Suma *et al*., 2014). The variability in Chinese potato can only be enriched by widening the germplasm collections. Tuber size, shape and appearance are important characters which need be taken care to satisfy consumers and market needs. This underexploited tuber can be popularized among farmers by integrating in the sole cropping as well as to different farming systems such as rotation and intercropping.

Yam bean (*Pachyrhizus erosus*)

Yam bean is a leguminous root crop of good nutritional value (Fig. 9 and 10). The mature tuber yields starch which is similar to arrowroot starch. The origin of yam bean species *P. erosus* is Mexico and Central America, and it is cultivated in Mexico, Guatemala, ElSalvador. It has been introduced to different pantropical regions, with notable success in Southeast Asia. The yam bean is mainly a self-pollinating crop propagated by seed. The seeds are poisonous due to the presence of the toxic substance "rotenone". Yam bean (*Pachyrhizus* spp.) comprises three closely related cultivated species: *P. ahipa, P. tuberous* and *P. erosus.* Cassandria et al., (2021) studied the genetic diversity and reported that yam bean has diverse morphologies within the species and the genus. The species viz., *P. erosus,* and *P. tuberosus* are climbing plants, late maturing (170-270 days), and with comparatively high fresh root yields (44-110 t ha^{-1}). Yam bean is diploid (2x= 2n = 22), self-fertilizing and can be easily hybridized. Rajendra Mishrikand 1 (RM-1) was released by Central Agricultural University, Pusa, Bihar way back in 1980s. Murugesan et al., (2021) reported intra-varietal variation for breeder seed quality in RM-1 and suggested quality regulations to maintain high genetic purity. Further concerted research efforts are required for this crop on germplasm utilization and improvement. The short duration,

Fig. 9. Yam bean (*Pachyrhizus erosus*) – view of seed and plant

Fig. 10. Yam bean (*Pachyrhizus erosus*) – view of inflorescence and tuber

earliness, high dry matter and improved nutrition are desirable traits suggested for this crop improvement. Trait-specific introduction and evaluation of potential yam bean germplasm is a prerequisite for achieving good prospects in India. Breeding of new interspecific hybrids can be strengthened for high dry matter and soluble sugar contents and tuber yield.

Queensland arrowroot (*Canna indica*)

Edible Canna (*Canna indica*) is a perennial herb (Fig. 11 a & b), growing to a height of 1.0 -2.5 with highly branched rhizomes. Its origin is Central and South America and is distributed in Europe, North America, and many tropical regions of the world. Canna has chromosome make up of diploid (2n = 18), triploid (2n = 3x =27) and tetraploid (2n = 4x = 36). Although both ornamental and edible types of canna store starch in the rootstocks, the edible types have more fleshy rhizomes. Within edible canna, there are green and dark purple types available. Dark purple recorded a maximum yield of 32.8 t ha^{-1} and green had 24.7 t ha^{-1} with starch content and dry matter content of 27.03% and 35.7 % in 8-10 months of crop growth. The net photosynthetic rate of edible cannais moderately high among C_3 species. Its rhizome contains 20% of starch and is utilized as a stock food and commercial source of starch. Based on molecular characters edible canna (*Canna indica* L.) in Indonesia was divided into two as green and 'red' cultivar which green cultivar divided into two sub-cultivars, 'green' and 'green purplish'. The red cultivar was also divided into two sub-cultivars, 'red' and 'red purplish'. Four canna varieties *viz*., Thai-green, Japanese- green, Thai-purple, and Chinese-purple were reported in Thailand. All four varieties produced 30.4–38.4 t ha^{-1} of rhizomes with a starch content of about 13% (wet basis). Starch yields of canna 4.1–4.9 t ha^{-1} Despite genetic diversification, there were no variations for starch properties. *Canna indica* has been reported to be cultivated as a tuber crop in India mainly in the north-eastern himalayan regions. Two different forms were found in that region reddish-brown leaves, brownish-purple stems, and orange-red flowers are the most common and preferred ones due to their bigger tubers and their better cooking quality and the other is with green-leaves and orange-yellow or orange flowers. Due to vigorous growth; this crop experiences the problem of lodging. Reduction of plant

Fig. 11a. Queensland arrowroot (*Canna indica*) – Whole plant, rhyzome and green capsule without seed

Fig. 11b. Queensland arrowroot (*Canna indica*) – Whole plant, rhyzome and red capsule with seed

height is a practical strategy for protecting plants from lodging. Edible canna provides starch with large granule size and other desirable properties and has good potential for food industry. It is reported that only two major groups *viz*, green and red cultivars are available with very narrow genetic base. Moreover, this crop is cultivated on a limited scale in temperate to tropical areas without intensive selection and breeding.

East Indian Arrowroot (*Curcuma angustifolia*)

Tikhur (*Curcuma angustifolia*; family Zingiberaceae) is a rhizomatous herb also known as white turmeric or East Indian Arrowroot (Fig. 12). Tikhur is cultivated as a tuber crop in many parts of the country under moist deciduous mixed and *sal* forest of Madhya Pradesh, Chhattisgarh, and Jharkhand. Tikhur is also found in the central province, Bihar, Maharashtra, and the Southern part of India. Partial shade is more suitable for the growth and yield of tikhur rhizomes as compared to open fields. We need to screen superior genotypes assessing their genetic diversity and variation for its improvement. Chhattisgarh Tikhur-1 (IGSJT-10-2) is the first variety of tikhur in India with a potential rhizome yield of 33.43 t/ha and 16.57% of starch in 150-160 days. A total of five pre-selected Tikhur germplasm accessions and one *C. zedoaria* of Idukki collections were characterized for rhizome morphology and other important biochemical parameters. The GCMS analysis of this study indicated that starch powder

Fig. 12. East Indian Arrowroot (*Curcuma angustifolia*) –
Two types of rhyzome (smooth and scaly), plant views with, without flower and rhizome starch

of Tikhur-1 variety and Idukki zedoaria possessed antimicrobial phytochemicals (Saju et al., 2021). Farmers of India, grow locally available genotypes of tikhur for rhizome production and processing through the traditional method of starch extraction. One problem with starch extract is light bitter taste and other breeding objectives with respect to Tikhur are breeding for high rhizome yield coupled with high starch content. The breeding techniques *viz*., somaclonal variations, mutation breeding, inductions of polyploidy and genetic engineering are suggested for this crop for improvement.

Other minor tuber crops

The crops under minor tuber crops category are Arisaema, Typhonium, Tacca and Winged bean (Fig. 13 and 14) etc. The genus *Arisaema* (Areaceae), popularly known as cobra lilies and jack in pulpit is mainly found in temperate to tropical areas of all continents except South America, Europe and Australia and contain about more than 250 species. *Arisaema* genus is being used by the different folks of human populations for medicinal as well as food purposes. Arisaema plants are used for the treatment of different types of diseases. Rodent tuber (*Typhonium flagelliforme* Lodd.) is an herbal plant from the Araceae family. Rodent tuber has low genetic diversity. It usually reproduces vegetatively through tuber separation. The pollination of rodent tuber rarely happens. Vegetative propagation of rodent tuber reduces the formation

Fig. 13. Other minor tuber crops – Arisaema and Typhonium

Fig. 14a. Other minor tuber crops – a Tacca (flower, pod and tuber)

of new genotypes. *Tacca leontopetaloides* is a species of flowering plant in the yam family Dioscoreaceae. It is native to Island Southeast Asia but has been introduced as canoe plants throughout the Indo-Pacific tropics by Austronesian peoples during prehistoric times. They have become naturalized to tropical Africa, South Asia, northern Australia, and Oceania. The winged bean (*Psophocarpus tetragonolobus* (L.) DC.) is an underutilized tropical leguminous species, classified in the family of Fabaceae and subfamily of Papilionoideaeis. Winged bean is an important tropical vegetable legume with high nutritional value that are grown in humid, tropical countries such as Indonesia, Malaysia, Bangladesh, and Thailand.

14b. Winged bean (leaf, seed, tuber and pod)

Conclusion

In view of the narrow genetic base and low variability, the introduction and exchange of germplasm are suggested especially from Africa to achieve high productivity in Coleus

(*Plectranthus rotundifolius*). Similarly, introduction and interspecific hybridization with wild as well as exotic introductions are recommended for Yam bean (*Pachyrhizus erosus*)**.** The other important minor tubers *viz*., Queensland arrowroot (*Canna indica*) West Indian arrowroot (*Maranta Arundinacca*) and East Indian arrowroot (*Curcuma angustifolia*) deserve immediate attention of R&D in India as they are cultivated on a limited scale without intensive selection, breeding and promotion.

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Chapter 2

Underutilised tuber crops diversity in eastern and northeastern India: An explorer's perspective

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The eastern and north-eastern regions of India comprise 12 states, *viz*., Odisha, Jharkhand, Bihar, West Bengal, Sikkim, Assam, Arunachal Pradesh, Manipur, Meghalaya, Nagaland, Mizoram and Tripura. These regions are known for their rich biodiversity owing to varied topography, and high rainfall resulting in a multitude of forest types. Floristically, the north-eastern region forms a part of Himalaya and Indo-Burma biodiversity hotspots and houses at least half the angiospermic taxa reported in India, of which 30 per cent are endemic in nature. This region is also the home of approximately 225 tribes, out of about 460 in the country, indicating rich ethnic diversity. Collective learning experience through the process of trial and error has helped the natives to make the best use of available bioresources for catering for their day-to-day needs.

Underground tubers from wild plants constitute an important source of starchy foods for tribal inhabitants and those dwelling in forest fringe areas. Arora and Pandey (1996) reported 145 wild edible species (including 33 semi-domesticates) of tuber value across different phytogeographic regions of the country. This includes 39 from Gangetic Plains, 24 from Eastern Himalayas and 71 from northeast India. However, from Simlipal Biosphere Reserve within a single district of Odisha, Misra et al., (2013) inventoried a total of 55 wild edible tuber-bearing species indicating that the Indian checklist prepared some 25 years is far from complete. These wild tuberous plants are useful as an article of food, medicines, liquor additives, spices and other cultural items by the local people, and are under different stages of domestication, i.e., gathered from the wild, protected in the wild, growing in the village/kitchen backyards, cultivated in the field, and so on. Besides native species, some exotic species are introduced long back and often found under cultivation to a lesser extent. Irrespective of the origin, all these species add dietary diversity and are helpful in achieving nutritional and livelihood security as a source of supplementary food materials during food scarcity or lean periods between harvesting seasons. Only a handful of potential edible tubers, primarily based on the author's observation from 17 exploration trips conducted in the target regions, are highlighted here.

Queensland arrowroot

Predominantly grown for ornamental flowers throughout the country, Queensland arrowroot (*Canna indica*, syn. *C. edulis*), originated in northwestern South America. This erect growing monocotyledonous herbaceous perennial plant is often cultivated in Sikkim and Darjeeling areas for tuber value where it is locally known as *Phul-Tarul*. At least two forms were observed under cultivation, often in the same field one with reddish brown leaves, brownish purple stems and orange-red coloured flowers (most common and preferred owing to its bigger tuber size and cooking quality), and another green-leaved form with yellowish orange flowers (Pradheep et al., 2014). Small young tubers are cooked and used like boiled potatoes; these had a rather mucilaginous consistency with a mild sweet taste. Its starch is easy to digest, therefore used as food for children and invalids. *Sherpas* and *Bhutias* of Sikkim frequently use the tubers as supplementary food to the staple cereals during the lean season. Considering the minimal care needed in its cultivation, and low incidence of pests and diseases, it could become a good alternative to other tuber crops in mid to high altitudes.

Soh-Phlong

A locally domesticated leguminous trailing herb of tuber value, *Flemingia procumbens* (syn. *Moghania vestita*), known as 'soh-phlong', is cultivated as a cash crop under shifting cultivation in the Khasi and Jaintia Hills (1000-1600 m) of Meghalaya for the past 50-100 years. Pandey et al., (2019) documented the changes in plant characteristics that occurred during domestication which include changes in plant morphology (prostrate dense spreading canopy; shallow easy-to- peel, smooth roots vs loose canopy; deep, uneven roots), economic parts (tubers in clumps of 3-6,sweet nutty flavoured vs single less-fleshy fibrous extremely bitter tubers). Propagated by tubers,this crop is raised in slopy terrain, and takes nearly seven months to mature; maturity is indicated when two-thirds of the aerial parts start drying. Tubers are manually harvested and stored in a pit covered with earth.

Its peeled ready-to-eat raw tubers are regularly available in the local markets from October to May and are taken along with the paste made from the seeds of *Perilla frutescens*, red chilli powder and salt. Apart from it, a health drink "Sohph-drink" is prepared from powdered tuber mixed with sugar and rock salt, which is added to lukewarm water. Tubers are packed with a unique combination of minerals like high iron (3.50 mg 100 g^{-1}) and zinc (0.58 mg 100 g^{-1}) and proximate components viz. protein (3.25%) and starch (21.8%), may be superior to other starchy root tubers. Mature root tubers have peanut flavour. It is reported that regular consumption of raw tubers and tuber peel helps in getting rid of intestinal worms, dysentery and stomach aches (Pandey et al., 2019).

Ground apple

The ground apple or yacon (*Smallanthus sonchifolius*), belonging to the family Asteraceae, is a native of the northern and central Andes from Colombia to northern Argentina. The plants are vigorous, herbaceous perennials that attain a height of up to 2 m; leaves are large, opposite, winged petiole with serrate lamina; flowers yellow-orange, about 2.5 cm in diameter. Hardly known in India for some eight years ago, it was first known in cultivation from Sikkim. Now it is commonly found in kitchen gardens and jhum fields, and as an intercrop in citrus orchards in Manipur – Mizoram border areas like Ngopa, Mimbung, Sinzawl, Teikang, Khawkawn, Northeast Khawdungsei, etc. It is cultivated for its crispy, crunchy-fleshed, sweet-tasting, spherical to oblong tuberous roots. Plants are hardy, pest and disease-free, able to grow well under hot or cold conditions, and cultivation is picking up in faster way. The fleshy roots contain non-digestible oligosaccharides and fructose and therefore low glycemic index, hence shall be consumed even by patients ailing with diabetes. The average tuber yield per plant is 3 kg, along with 10-12 numbers of subterranean vegetative buds, which can be used as propagating material. The total soluble solids content of the tuber just after harvest was found tobe 15° Brix. Local people informed that a week of storage of roots develops further sweetness. The biochemical study revealed that tuber manifested low levels of anti-nutritional factors such as phenols, flavonoids, tannins, alkaloids and saponins, which makes it useful for raw consumption (Negi et al., 2022).

Tuber cowpea

Vigna vexillata is a pan-tropical herbaceous legume that grows wild in the Western Ghats, Central Peninsular hills, the Himalayas, and northeast India up to 2500 m. It is locally called *Banoria Urahi* (Assamese), and *Latchai* (Bengali). This plant is protected in the wild and is often found in kitchen gardens in Assam. Its fusiform roots are eaten raw or boiled in tribal pockets and are considered superior to sweet potato in flavour and nutrition. Tripathi et al., (2021) observed a good variability for tuber characteristics. Protein content ranged from 7.64-9.93%. It was found to have a seven-fold and nine-fold higher amount of protein content than sweet potato and cassava respectively.

Other important minor tubers

Non-native species: Yam bean (*Pachyrhizus erosus*) is a leguminous tuber crop native to Central and South America and has found a favourable niche in northern Bihar, West Bengal and Western Assam (BTAD areas). Propagated by seeds, this high-yielding starchy root crop has a comparatively high sugar content (5-6%) and is a moderately good source of ascorbic acid. Rajendra Mishrikand is a variety tolerant to major pests and diseases developed through seedling selection. Tubers of chow-chow (*Sechium edule*) were found sold in markets of Darjeeling (West Bengal) and Gangtok (Sikkim) for vegetable use after boiling (like that of tapioca). Its edible starch is used similarly to arrowroot. Winged bean (*Psophocarpus tetragonolobus*), a homestead plant of the NE Hill region, is cultivated for tender pods as vegetables; its tubers contain higher crude protein than many other tuber crops. Jerusalem artichoke (*Helianthus tuberosus*) is cultivated sporadically in northern Sikkim. Its tubers consist of inulin than starch, and is boiled, pickled, made into chips or ground into flour, and is reported to be equal to potato in food value.

Native species: East Indian Arrowroot (*Curcuma angustifolia*) occurring in low hill tracts of Bihar, West Bengal and Assam (up to 500 m) yields starchy rhizomes substitute for true arrowroot (*Maranta arundinacea*) powder. Often, related wild species like *Curcuma aromatica* and *C. zedoaria* are used for the extraction of starch having medicinal applications and are found under cultivation, as well. *Eriosema chinense*, a leguminous erect growing herb with simple leaves, locally known as *kondan*, is sporadically found in hilly grasslands of eastern and NE India. The root tubers are eaten raw, besides, traditionally used for the treatment of diarrhoea in Meghalaya. Indian kudzu (*Pueraria tuberosa*) locally known as *sural* or *bilaikhund*, is again a leguminous species, but with three big leaflets, observed commonly in these regions. Its large tuberous roots taste like liquorice and are eaten raw or boiled. Incidentally, while on exploration, the author observed *Bombax ceiba* sold in Dakshin Dinajpur district of West Bengal for its mucilaginous deskinned roots, useful as a laxative.

Crop wild relatives as minor tubers**:** Native tuber crops like greater yam, potato yam, taro and elephant foot yam had a lot of related wild species distributed in India, some of which are often semi-domesticated for tuber value in eastern and northeastern India. Most important among this group is the species of *Dioscorea* which includes *D. hamiltonii* (occurs in semi- evergreen forests, protected as well as cultivated; large deeply buried tubers are delicious to eat), *D. bulbifera* (dull brownish tubers with yellowish flesh eaten; var. *sativa* has smooth bulbils), *D. pentaphylla* (brownish-skinned tubers eaten after boiling), *D. hispida* (locally known as *karukandu*, globose tubers borne close to the soil surface; yields edible floor after processing), *D. glabra* (tubers deep-seated, earth-skinned, white-fleshed), *D. pubera* (tubers eaten after boiling; potato-like bulbils taken as food during scarcity), *D. oppositifolia* (reddish-skinned deep-seated tubers with soft white flesh eaten) and *D. belophylla* (tubers preferred raw by children). According to Misra et al., (2013), stored tubers of *Dioscorea bulibifera* and *D. pentaphylla* are consumed in Simlipal Biosphere Reserve from June to September, when crops are in their early growth stage. A taro relative, *Colocasia gigantea* is often cultivated as a tuber crop in remote areas of Manipur bordering Myanmar. However, it is astonishing to know that in the genus *Amorphophallus*, none of the wild species than *A. paeoniifolius* (with the possible exception of *A. bulbifer* in Simlipal Biosphere Reserve) is reported to have an edible value. Table 1 provides information about some more minor but potential tuber crops occurring in this part of the country.

Some considerations

Non-traditional species contribute to agricultural diversity by supplementing/substituting well- known crops and helping to diversify the food basket, increasing farm income, and contributing to food and nutritional security in the region. Most of these edible tuber-bearing species are known for more than one useful part and/or more than one common use. Usually, they store well, suit marginal lands, and not have exact climate requirements, and are climate-resilient. Cultivation initiatives taken in some of these wild species have drastically reduced the threat of their extinction in wild habitats. There are some exotic tuber crops that appeared to have been introduced within the century or so, most probably by Christian missionaries, which are patronized by farming communities in these regions. It is a welcome situation is that exotic crops such as yam bean and Queensland arrowroot are figured as the mandate crops of ICAR-CTCRI (ICAR-CTCRI, 2021).

- There is a dire need for updated documentation of all the wild tuber resources available in the country along with places of availability/areas with rich germplasm collection potential, ethnobotanical information (which is fast-eroding) and high-quality photos, esp. of the economic part (for field/market identification). This would help in especially the effective prioritization of species for research in a phased manner. Misra et al., (2013) prioritized the wild tubers of Simlipal Biosphere Reserve based on availability, cultural preferences, easy extraction or processing, market value and safe consumption without toxic effects.

- Introduction of more germplasm in already-existing exotic tuber crops and studies on adaptability and agronomic performance in suitable locations. Besides, testing tuber crops new to the country such as arracacha (*Arracacia xanthorrhiza*), maca (*Lepidium meyenii*), mauka (*Mirabilis expansa*), oca (*Oxalis tuberosa*), mashua (*Tropaeolum tuberosum*), ulluco (*Ullucus tuberosus*), swamp taro (*Cyrtosperma merkusii*), and ahipa (*Pachyrhizus ahipa*) in suitable isoclimatic regimes driven by similarities in latitude, altitude, soil, and topographic factors (with the original cultivation areas) would further widen the dietary diversity. There are different prediction models available for possible area expansion/ adaptability studies.

- Agro-techniques standardization including their inclusion in different cropping systems, value-addition (including different product development) and exploring market potential. Research on processing for removal of anti-nutritional factors, if any. Tribals use slicing, soaking in running water and prolonged boiling to eliminate the bitter taste.

- Strong linkage with various stakeholders, apart from those in the National Agricultural Research System, like state agricultural departments, NGOs, passionate farmers, etc. Blanket permission needs to be granted from the forest authorities to the bonafide researchers for entry into protected areas for the collection of germplasm and associated ethnobotanical information from the tribal groups.

Table 1: Some underutilized minor tuber crops in eastern and northeastern India (mainly from Arora and Pandey 1996; Misra et al., 2013)

S. No.	**Scientific name (*vernacular name*)**	**Locality/region where use reported/ observed**	**Remarks**
1.	*Abelmoschus crinitus*	Palamau Hills, Jharkhand	Tuberous fusiform roots are eaten raw

S. No.	Scientific name (*vernacular name*)	Locality/region where use reported/ observed	Remarks
2.	*Amorphophallus bulbifer*	Odisha (Simlipal BR)	Tubers boiled and taken during lean periods
3.	*Arisaema tortuosum*	Odisha (Simlipal BR)	Tubers boiled and taken during lean periods
4.	*Asparagus officinalis*	All over	Very commonly used; powder used as sherbet, pudding and liquor additive
5.	*Commelina benghalensis* (*kanchata*, *kanchara*)	Jharkhand	Mucilaginous and starchy rhizomes eatenafter cooking
6.	*Curculigo trichocarpa*	Odisha (Simlipal BR)	Burnt tuber is eaten as snacks
7.	*Curcuma zedoaria*	Eastern Himalaya, Assam	Large fleshy rhizomes starchy; also cultivated as a substitute for *C. angustifolia*. Known for its yellow musk-smelling odour with a slight smell of camphor
8.	*Decalepis hamiltonii*	Odisha (Simlipal BR)	Fleshy root tubers are tasty; considered delicious snacks by children when thirstyor hungry
9.	*Elaeocharis dulcis*	Manipur (LoktakLake)	Sold in Imphal and Nambol markets; dark brown, round to onion-shaped starchy tubers eaten
10.	*Lasia spinosa*	E India and NE India	Rhizomes eaten as a vegetable, commonly and regularly coming to market
11.	*Momordica dioica*	E India	Tuberous roots are eaten as a vegetable
12.	*Nervilia aragoana, N.discolor*	Odisha (Simlipal BR)	The burnt tubers are eaten as snacks
13.	*Peucedanum dhana*	Humid parts of E India	Swollen roots taste like carrots and are eaten raw

S. No.	Scientific name (*vernacular name*)	Locality/region where use reported/ observed	Remarks
14.	*Potamogeton filiformis*, *P. gramineus*, and *P.pectinatus*	Marshy ponds	Starchy rootstock eaten
15.	*Pueraria thomsonii*	Lushai Hills of Mizoram	Tubers edible
16.	*Remusatia vivipara*	Odisha (Simlipal BR)	Tubers boiled and taken during lean periods
17.	*Sauromatum venosum*	Indo-Gangetic plains	Acrid tubers are eaten after boiling
18.	*Scirpus grossus* (*Kachar*)	Marshy ponds	Tubers are sliced and eaten. Sweet, starchy and nutritious
19.	*Scirpus tuberosus*	Marshy ponds	In marshy areas; rhizomes are made into flour for use as bread
20.	*Solena amplexicaulis*	Odisha (Simlipal BR)	Tubers are eaten raw just after collection and peeling the outer skin owing to its good taste
21.	*Tacca leontopetaloides* (*Dive*)	E India	Tubers are eaten after boiling

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Chapter 3

Research status, advances and prospects of breeding of neglected and underutilized tuber crops

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The availability of food supply worldwide is dependent on few crop species or 'major crops'. Till today, only 30 plant species are used to meet 95 % of the world's food requirements. There is a great need to expand the exploitation of the plant genetic diversity that would broaden the crop diversity for food supply in order to feed the ever growing human population and avoid dependence on few food crops, especially under the climatic change. The neglected crops could become an excellent source for useful gene source, *e.g.,* Human nutrition enrichment, abiotic and biotic stresses, source of bioactive molecule on pharmaceutical industries *etc* (Jain and Gupta, 2013).

Roots and tubers are important diet components too and many tuber crop species are bestowed with immense medicinal value. A variety of foods can be prepared using tubers and type and usage vary with the country and region. Processing affects the bioactivities of constituent compounds. Tubers may serve as functional foods and nutraceutical ingredients to attenuate non-communicable chronic diseases and maintain the wellness of the human beings. In addition to the main role as an energy contributor, they have antioxidative, hypoglycemic, hypocholesterolemic, antimicrobial, and immune modulatory activities. Traditionally tribal population has been using tuber crops for curing several ailments. Tapping the precious knowledge available with the tribal farmers will help in exploiting the use of tuber crops as pharmaceutical raw materials.

The underutilized tuber crops which are edible and grown in a limited area, and also used to a limited extent only. These crops are given very low priority in the agricultural scenario. However, some of them have high potential and they are yet to be properly exploited. Exploration, conservation and breeding can be combined to secure the genetic wealth of such crops. The breeding approaches may differ, depending on whether the crop is seed propagated or clonally propagated, annual or perennial, out breeding or self-pollinated. However, breeding in underutilized crops is meager and the available research status and prospects are described hereunder.

Table 1. List of Underutilized tuber crops

S. No.	Common Name	Botanical Name	Family
I	ARROWROOT		
	i.West Indian arrowroot	*Maranta arundinacea* L.	Marantaceae
	ii. East Indian arrowroot	*Curcuma angustifolia* Roxb	Zingiberaceae
II	YAMS		
	i. Greater yam	*Dioescorea alata*	Dioescoreaceae
	ii. Lesser yam	*Dioescorea esculenta*	Dioescoreaceae
	iii. Aerial yam	*Dioescorea bulbifera*	Dioescoreaceae
III	Chinese potato / Coleus	*Coleus parviflorus* Benth	Labiatae
IV	Yam bean	*Pachyrrhizus erosus* L.	Leguminosae
V	Clove bean	*Ipomoea muricata*	Convulvulaceae
VI	Athalaikai	*Momordica cymbalaria*	Cucurbitaceae

I. Arrowroot

Arrowroot (*Maranta arundinaceae* L.) is an alternative crop source of carbohydrate with enormous potential. Flour products from arrowroot have special features, which are easy to digest because the content of the glycemic index (GI) is low so it is very good for health. The starch powder is white, odorless and is used as a thickening agent in the food industry, starches contain amylopectin (80%) and amylose (20%). it is widely used as a stabilizing agent in food, condiments, soup, candy, pudding and ice cream. Arrowroot also contain more protein compared to other tubers like sweet potatoes, potatoes and cassava. The other advantage of arrowroot tubers is that they are gluten-free as in other roots and tubers. Gluten-free starch is used for patients with celiac disease (Deswina and Priadi, 2020).

i). West Indian arrowroot

The true arrowroot of commercial importance is the West Indian arrowroot (*Maranta arundinacea* Linn.) of family Marantaceae (2n=48). It is indigenous to tropical America and constitutes one of the main sources of food starch production in the tropics. It is widely distributed throughout the tropical countries like India, Sri Lanka, Indonesia, Philippines and Australia. *Maranta indica*, *Maranta nobilis* and *Maranta ramosisima* are the other species of *Maranta*, which produce starch. It is a major component of farming community and their diet in Kerala state. The starch obtained from its rhizomes is used both for food and nutraceutical purposes.

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The improvement of Maranta as a cultivated species was originally started in West Indies and the chief improvement was effected mainly at Lava. The improved varieties exhibit smooth leaves. There are several varieties distinguished as red and white of which the red are most esteemed. The two main white cultivars recognized in St. Vincent are Creole and Banana. Difficulty in seed setting is the major setback in crop improvement of this crop. It is propagated vegetatively, so it has a narrow genetic diversity. Various efforts have been made to improve the genetic diversity of arrowroot plants, in order to obtain superior types with high productivity. However, utilization of this variability both for conservation and improvement of the species is essential since the crop is being marginalized due to changes in cropping patterns, utilization of agricultural land for other purposes and change in food habits of the local people from locally available crop diversity to commercial carbohydrate sources.

Shintu et al., (2016) assessed the genetic variability of West Indian arrowroot in relation to morphological growth and yield characters. Sixty accessions of *Maranta arundinacea* collected from different locations in the Northern districts of Kerala. Yield per plant showed the highest range of performance followed by starch content and leaf area. Studies revealed that genetic advance was found to be the maximum for starch content followed by number of primary fingers and number of tillers and indicate the occurrence of broad genetic base and shows the feasibility to select the superior genotypes.

ii. East Indian arrowroot (*Curcuma angustifolia*)

It is grows wild in the Western Ghats. It belongs to family Zingiberaceae. It is grown wild in the Western Ghats and is particularly seen in the Malabar Coast. It also occurs in the hilly tracts of Central India, Bengal, Maharashtra, Tamil Nadu and in a few of the lower Himalayan ranges. It is commonly white, sometimes pale yellow in colour and less crackling between the fingers. It does not form jelly quickly and is of inferior value.

II. Yams (*Dioscorea* spp.)

Yam plants are members of the genus Dioscorea and produce tubers, bulbils or rhizomes that are of economic importance. They are monocots belonging to the family Dioscoreaceae with in the order Dioscoreales. Within the genus Dioscorea, the most economically important species are *Dioscorea alata, Dioscorea esculenta, Dioscorea rotundata.* The other species are *Dioscorea cayenensis, Dioscorea dumetorum, Dioscorea japonica, Dioscorea hispida, Dioscorea bulbifera, Dioscorea trifida and Dioscorea opposita.*

Taxonomically the genus Dioscorea is sub divided into sections within which the species fall. The section Enantiophyllum contains most of the economically important yam species (rotundata, alata, cayenensis, opposita and japonica) and is characterized by the fact that the vines twine to the right in clockwise direction when viewed from ground upwards. Species in sections Lasiophyton (*D. dumetorium and D. hispida*) and Opsophyton (*D. bulbifera*), Combilium (*D. esculenta*) and Macrogynodium (*D. trifida*) twine to the left.

Dioscorea plant is a twiner with a slender stem. The stem possesses four or more rows of wings, so that it is more or less stellate in cross section. The wings are also present on the petioles. At the junction of the petioles and the opposite stem, the wings widen to form auricles. The stem is usually green and twines to the right. There are no spines on the stem. Many cultivars have varying degrees of purple colouration in the leaves. Tuber shape is extremely variable flesh is white or purplish and loose (watery) in texture (Tubers of *D. alata* are nearly single, but may be very large. Many cultivars of *Dioscorea alata* possess a thin layer of tough sclerenchymatous fiber just below the tuber skin. Axillary tubers and bulbils are produced in leaf axils. *Dioscorea alata* is commonly called greater yam or larger yam or water yam. This is the most widely distributed species of yam. It is the most important edible yam of Asia. This species originated in South East Asia, probably in Burma. From there, it first spread to India, Malaysia, Indonesia and the eastern portion of South East Asia. CTCRI is maintaining 215 accessions of greater yam. “Sree Keerthi”, “Sree Roopa” are the first two varieties of greater yam released by CTCRI, which yields 25-30 t ha^{-1} within 9-10 months crop period.

Yams are dioecious, vegetatively propagated species and hence clonal selection has been the only mode of improvement. In *D. alata*, flowering is not regular and synchronous flowering of male and female flowers is rare. Besides a large number of female varieties are sterile due to higher levels of polyploidy. Overcoming these barriers, inter varietal hybridization was carried out and true seeds were produced. The production of true seeds has been a significant achievement in the breeding of *D. alata*. The resultant sexual progeny showed wide variation in almost all the characters through segregation and genetic recombination. The first inter varietal hybrid Sree Shilpa was released during 1998. It is a male clone with green stem and leaves. The petiole of this hybrid is purple at the base and tip. Tubers are swollen, oval shaped and medium sized with smooth surface and black skin. The mean tuber yield is 28 t ha^{-1}. Propagation of yam by tissue culture is recent. Using this technique, large number of plantlets has been produced by International Institute of Tropical Agriculture (IITA) by culturing 50 g yam tuber blocks. Yam propagation by tissue culture offers the ultimate in clonal multiplication. This method offers promise when rapid multiplication of a single desirable plant is required. Aerial yam *(Dioscorea bulbifera*) is one of the economically most important species of yam. It is an unpopular species among the edible yam species. It is cultivated in the Southeast Asia, West Africa, and South and Central America. It is distinguished from all other species by having particular bulbils on the base of leaves petioles. It produces aerial bulbis that look like potatoes hence it is also called as aerial/air potatoes. The aerial yam grows aggressively on diverse soil types often reaching up to 20 metre or more in length. This species of yam is consumed by a small number of communities and is generally underutilized both at subsistence and commercial levels. Collection, evaluation and characterization of the accessions is thus important for crop improvement and to reduce genetic erosion of this crop .

The high carbohydrate content of aerial yam tubers indicates that these cultivars are an excellent source of energy. Okwu and Ndu, 2006 revealed that the white cultivar produced flour with high tannin (0.72 mg $100g^{-1}$), phytate (0.12mg $100g^{-1}$) and flavonoid (1.63mg $100g^{-1}$) content while the yellow cultivar had the lowest values for flavonoid, oxalate and alkaloid contents (1.54mg $100g^{-1}$; 0.24mg $100g^{-1}$; 0.92mg $100g^{-1}$). The alkaloid and oxalate contents of the samples reduced by blanching and oven-drying methods during flour production. Both the cultivars produced low level of antinutrients that are within acceptable limit for human consumption . Tubers rich in diosgenin, which is a useful bioactive substance in the production of some steroidal hormones and synthetic birth control pills. The small quantities of tannin available in the tubers act as a repellants against rot in yams. However, the tannins, phytate, alkaloids and oxalate content were found to be lower when compared with other yams.

III. Chinese potato (*Coleus* spp.)

Coleus, commonly known as Chinese potato, is a minor tuber crop of the tropical regions of India, Indonesia, Malaysia, Sri Lanka and Africa. It is considered as a native of India, where its cultivation is mostly confined to the Southern states. In Kerala, it is commonly known as koorka or cheevakizhangu. *Coleus parviflorus* Benth is synonymous with *Coleus tuberosus* (Blume) Benth. It belongs to the family Labiatae and polyploid with (2n= (6x)=72). The plant is a small herbaceous annual, 15-30 cm high, with a succulent stem and somewhat thick leaves having an aromatic smell. Flowers are small and pale violet in colour and are produced on racemose cymes with pairs of very caducous floral leaves. Very low variability exists in this species, mainly due to pollen sterility and problems of seed set. Attempts have been made to study the seed setting of this crop. Major essential oil components found in *C. parviflorus* are beta thujone and alpha farnesene.

Vasudevan et al., (1992) irradiated the cultivar CP-11 with 1-4 KR gamma rays and evaluated the plants, raised from nodal cuttings, for morphological, yield and quality traits compared to untreated plants, the mutants showed reduced canopy spread and biomass yield with fewer tubers per plant; whereas higher values were observed for harvest index, yield per plant and uniformity of tuber size. Only a few distinct varieties have been identified so far. The two varieties *viz.,* Sree Dhara and Nidhi has been released from the Central Tuber Crops Research Institute, Sreekaryam and Kerala Agricultural University respectively. *In vitro* shoot regeneration of *C. parviflorus* was reported by Samson *et al.,* (1990); Niino et al., (2000) succeeded in the cryopreservation of coleus. Nodal segments from *in vitro* grown shoots were cultured on MS medium containing 0.1M sucrose for 3 weeks under 16-h photoperiod at 25°C. This pre-growth induced a large number of uniform young lateral buds. Nodal segments of 0.5 to 1.0 mm length, with two lateral buds were dissected from the shoots and pre-cultured with 0.3 M sucrose for 2 days at 25°C. They were then treated with loading solution containing 2 M glycerol and 0.4 M sucrose for 20 min at 25°C and dehydrated with the PVS2 vitrification solution for 18 min at 25°C prior to either rapid immersion in liquid nitrogen. Surviving lateral buds resumed growth within three days and developed shoots without intermediary callus formation. About 85 % growth recovery resulted, after cryopreservation.

IV. Athalaikai (*Momordica cymbalaria* Hook f.)

The *Momordica cymbalaria* Hook f. is a least concerned minor and underexploited tuber forming cucurbitacous species, habitats in Western and Eastern Ghats of India. The fruits and tubers were used in the traditional medicine as well as vegetable by the tribal farmers (Chinthan et al., 2021). The tubers and leaves of this crop are used for therapeutic uses which contains flavonoids, steroids, triterpenes, saponins. It also helps to sustain and enhance human health and food security as the world's population grows. Due to anthropogenic assisted habitat destruction, overexploitation without protection and a lack of scientific understanding, or mere documentation regarding development, propagation and breeding, *M. cymbalaria* are on the verge of extinction. The phenogram studies conducted among the *Momordica* species also indicated that *M. cymbalaria* differs from the other species in a large number of conspicuous characters (Bharathi et al., 2011). As a result, substantial genetic resources of *M. cymbalaria* remain untapped and necessitating the focus of researchers on important aspects such as characterization of local genotypes for pre-breeding activities, and there is a need to divulge the genotypes useful for horticultural, nutritional, and medicinal traits for local and global trade. The preliminary collection, evaluation and conservation strategies have been undertaken. Thirteen ecotypes of *Momordica cymbalaraia* were evaluated to estimate the variability parameters and inferred that tubers collected from same location are also different from one another due to the presence of monoecious flowers which promotes cross pollination (Rekha and Jagadeesha, 2018). However, the crop is not commercially grown and seeds of this crop are not available in the market due to poor germination efficiency (Pramod Kumar et al., 2010). Tubers of this crop also remain dormant in winter and they germinate during the onset of monsoon (Fernandes et al., 2007). Hence, alternate multiplication strategies must be standardized. Few micropropagation and biotechnological approaches have been initiated in *M. cymbalaria*. Nikam et al., (2009) had reported successful plant regeneration of *M. cymbalaria* using different explants *viz.,* leaf, node and shoot tip. Concomitant to this finding, Chaitanya et al., (2020) reported that combination of BAP (1.5 mg l^{-1}) and IBA (1.5 mg l^{-1}) showed best results for shoot regeneration through indirect organogenesis using leaf, node and shoot tip. Hence, applications of emerging genomics and biotechnological tools regarding preservation, genetic diversity analysis may provide an avenue to enhance the genetic gain and mainstreaming the cultivation of this crop.

V. Yam bean (*Pachyrrhizus erosus*)

Yam bean (*Pachyrizhus erosus* (L) is one of the underutilized leguminous tuber crops gaining importance in recent years due to its cultivation improves the soil fertility. It is also known as potato bean, belongs to the family Leguminaceae and sub family Fabaceae, native of Mexico and Central America , is a starchy root crop with comparatively high sugar content and a moderately good source of ascorbic acid. Though, a native of Mexico, the crop is well distributed in the tropics. In India, tender tubers are consumed. The mature seeds have high content of alkaloids and insecticidal properties. In India, it is mostly grown in North Bihar extending parts of West Bengal, Assam, Orissa and eastern Uttar Pradesh. As it is a crop of small farmers, information on area and production of this crop has not been documented. Tubers contain more than 82% water, 1.5% protein, 10% starch and 5-6% sugar. The young tubers are edible and rich in ascorbic acid, while matured tubers yield high quality starch and the seeds can be used as insecticides. The crop is well adaptable to a wide range of climatic and edaphic ranges, well balanced and nutritious composition of protein/ starch contents, acceptable taste, good post-harvest/ storage characters, biological N fixation *etc.* Owing to these features, the crop may be effectively exploited to meet a wide range of needs in developing countries. Yam bean research in India has not received much attention from the national research system. Hence farmers in the country still rely on traditional land races.

Breeding in yam bean is limited to selection and with the breeding objectives *viz.,* earliness, high dry matter, improved nutrition, drought tolerance and pest and disease resistance. Attempts have already been made to develop hybrids using Mexican and local types and some of the lines were promising (Mukhopadhyay et al., 2008). Genetic variability is limited in yam bean. For inducing specific genetic changes, an exploratory gamma irradiation was carried out in seed samples of a superior collection (Sreekumari et al., 1983; Nair and Abraham, 1988,1989). Yam bean seeds treated with gamma radiation (5 - 25 kR) or ethyl methane sulphonate (EMS, 0.5 – 1.25%) induced greater variability with regard to shoot length, number of branches, number of leaves and tuber yield. Treatment with gamma radiation greater than 7.5 kR significantly reduced vegetative vigour and yield. Yam bean seeds treated with gamma radiation (5 kR) stimulated vegetative vigour, induced greater shoot length, number of branches, number of leaves and tuber yield than control plants. The occurrence of multiple shoot (twins, triples and quadruplets seedlings) which accounted for nearly 2% of germinated seeds has also been reported in yam bean (Sreekumari and Abraham, 1980). In India two types of cultivars (Mexican and local) are grown. Mexican types are larger in size and attain a diameter of 10-15 cm and weigh up to 1.5 – 2.0 kg. The Mexican types are less sweet compared to local ones and develop cracks on tubers. The local types have smaller tubers (200 – 300 g), moderate to high sweetness, less fiber, conical shape, white flesh and are soft with creamy skin. They do not develop cracks on tubers. Rajendra Mishrikand 1 (RM-1), an improved selection, released by the AICRP on Tuber crops at Rajendra Agriculture University and it is popular in Bihar and West Bengal. Its average tuber yield is 40 – 55 t ha^{-1} in 110 – 140 days. The individual tuber weighs 0.6 – 0.7 kg, sweet, comparatively free from cracking with smooth surface, napiform with cream coloured tuber skin. Flesh is white. Other promising Mexican line L-19 produces better yield in Bihar, West Bengal and Orissa. Package of practices have been standardized. Yam bean will be an important crop to meet the nutritional and fuel requirements in the near future. Hence more scientific knowledge has to be generated about the production and chemical constituents to exploit the potential of the crop. The crop comes up well even under semi-arid conditions and gives good tuber yield indicating that there is scope for extending its cultivation to non-traditional areas to improve the rural economy. All the wildest possible range of endangered land races of yam bean should be conserved both *in situ* and *ex situ*. Early maturing, high yielding varieties with improved nutritional qualities, resistance to biotic and abiotic stress is to be developed. Low cost crop management practices need to be standardized for high yield and quality of yam bean. There is need to study fatty acid composition of seed and processing technique for eliminating rotenone from seeds. In India, the young tubers are consumed and other uses of the various plant parts especially that of pods are yet to be exploited as there is wide scope for it. Emphasis should be given to exploit yam bean pods on a commercial basis for production of rotenone based crop protective agents.

VI. Clove bean (*Ipomoea muricata*)

Clove bean (*Ipomoea muricata* (*L.*) Jack is one of the most important underexploited leguminous vegetable cultivated mainly for its fruits and thickened pedicel. It is popularly known as "Nidhya Vazhuthana" and widely cultivated in Kerala throughout the year (Divya et al., 2019). The seeds, stems and leaves are used for treating chronic and gangrenous wounds, cuts and blisters due to burns and it well known reputed drug. Patil et al., (2012) standardized the protocol for quantification of Lysergol from *I. muricata* using column chromatography. Mal sawmkimi et al., (2008) evaluated 25 accessions of clove bean for variability and inferred that straight selection has limited scope due to the action of non-additive gene effects including dominance and epistasis.

Future thrust

In future, smart foods play a key role in transforming agriculture and food systems into diversified, nutrition-sensitive and climate resilient by exploring the neglected and underutilized species which offer enormous opportunities for fighting poverty, hunger, and malnutrition. Hence, the future endeavors should promote the neglected and underutilized species in terms of production, post-harvest and processing, marketing, and consumption.

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Chapter 4

Prospects of utilization of yam bean germplasm-tuber yield and nutrients

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The underutilized legume crop known as yam bean, or *Pachyrhizus erosus* (L.) Urban, has numerous health benefits for people due to its nutrients and therapeutic characteristics. A sizeable root with a high starch and sugar content is produced by the cultivated yam bean. However, it is difficult to genetically improve this crop due to the low availability of accurate documentation of the germplasm and genetic information. By 2100, the anticipated global population would be 10.9 billion, making the issue of food security more and more difficult. Many crop plant species are neglected despite their many advantages for food, fiber, fodder, oil, nutrition, and medicinal properties. On the other hand, these crops contribute significantly to the agrobiodiversity, the nourishment, and the economic advancement of poor people throughout their lifetimes. These crops are still underutilized, and a lack of research and development

funding has led to a decline in agricultural biodiversity while simultaneously making the world's food supply more vulnerable.

Introduction

Yam bean [*Pachyrhizus erosus* (L.) Urban] is an underexploited vegetable crop recently gaining attention due to its high nutritional benefits. The name *Pachyrhizus* comes from the Greek word *Pachys* = thick (ended) and *Rhiza* = (root). Crop belongs to the Family Fabaceae, Sub family Faboidae, Tribus Phaseoleae and Subtribe Diocleinae which is close relationship to the Subtribe Glycininae and Phaseolinae. (Sorenson 1996; Tay et al., 2021). It is known as Shankalu (Bengali), Kasaur, Sankalu, Misrikand (Hindi), Tani Uttan Kai (Tamil) and Kandha (Telugu) in India (Lim, 2016). Yam bean is a diploid and the genome size is estimated to range from 572 to 597 Mbp (Pati et al., 2019). *Pachyrhizus erosus* came from the semi-arid tropics of Central America, *P. tuberosus* came from the tropical lowlands on both sides of the Andean mountain range, and *P. ahipa* came from Andean England (Sorenson et al., 1996). The majority of the world's yam bean production takes place in Central America, China, India, Southeast Asia, Bangladesh, the Caribbean, French Guyana, Brazil, and Central and West Africa (Lauti´e et al., 2013; Sørensen, 1996). It is grown in Andhra Pradesh, West Bengal, Assam, Bihar, and Odisha in India (Pati et al., 2021).

Yam bean has several health benefits due to its nutritional and medicinal properties. The fresh tuber contains carbohydrate (14.9%), crude fiber (1.4%), protein (1.2%) and lipid (0.1%) (Noman et al., 2007). The colour of the tuber is white or creamy white with a crisp texture like water chestnut, while the colour of the tuber skin is yellowish brown or brownish. There are several different tuber morphologies, including spherical, fusiform, and irregular. The mature seed pods, which are typically 7 to 15 cm long and nearly smooth, contain 8 to 10 square or flattened yellow, brown, or reddish seeds. Rotenone, a potentially poisonous isoflavonoid, prevents yam bean seeds from being used as food (Lautie *et al.,* 2013). Yam beans are only reproduced by seeds, but they are raised for their starchy root. The dynamics of the crop's genetic diversity must be understood in order to set conservation strategies, but this requires molecular tools that provide data on crucial variables like heterozygosity and allelic frequencies that are necessary for computing the majority of population genetic statistics. Conventional breeding techniques are unable to address the complicated genetic behaviour of desirable features since they are affected by the yam bean's growth phases and have several issues with the environment. However, the development of molecular markers provides us with a good substitute for morphological markers, and they are a crucial tool in a variety of applications since they enable quick and precise identification. In agriculture, varietal identification is necessary for breeding, registration, the manufacturing of seeds, commerce, and inspection. For registration with the appropriate agency, the granting of plant breeder rights under the Distinctness, Uniformity, and Stability (DUS) requirements, as well as farmer rights under the Protection of Plant Varieties & Famer's Rights Authority of India, characterizing genetic stocks is necessary (PPV&FRA).

Importance and Uses

Eaten fleshy tubers have a conical or turnip shape and are starchy. When eaten raw, jicama' high sugar content gives them a sweet flavour. The raw tubers can be turned into chips or used in salads. Young tubers have refreshingly crisp, juicy flesh. The fibrous, over-matured tubers are no longer appropriate for human consumption. According to reports, mature dried roots are utilized as a cooling aid for persons with high fevers. In some of the Asian countries, the fibrous, stiff stem is used to make fishnets. A high concentration of alkaloids and insecticidal qualities can be found in mature seeds. The tubers are used in Mexico in a variety of ways, (i) as a fruit, where fresh tubers are cut into sticks and sprinkled with lime juice and chilies (these are frequently sold by street vendors); (ii) as a vegetable, where fresh tuber slices are used in various salad dishes; (iii) cooked tubers are used to prepare a soup, either alone or in combination with other vegetables; (iv) tuber slices may be stir-fried.

Botanical Description

The yam bean is a member of the subfamily *Fabaceae* of the family *Leguminaceae*. This leguminous herb has a rough-haired vine that can climb or trail. The huge, trifoliate, alternating leaves with toothed leaflets. The leaflets range in size from 5 to 15 cm in width and 6.5 to 13 cm in length. They are green in color. Up until the upper margin, the margin is either entire or coarsely dentate. An inflorescence ranges in length from 8 to 45 cm and has four to eleven blooms. The racemes of violet flowers are carried on fasciated pedicels. The seed pods are typically smooth and 7–15 cm long. They contain 8–10 yellow, brown, or red squares that have been somewhat flattened. The tubers come in a variety of simple or complicated shapes. Typically, they have a conical or turnip shape. The plant's aerial segments are seasonal, but its underground components are perennial.

Agronomy

The yam bean grown well to humid, hot, and temperate zones. Its primary climatic need is for there to be no frost during vegetative growth. Its cultivation is not favoured by excessive rains or waterlogging circumstances. However, rain that falls consistently over the course of the growth period is beneficial for healthy tuber development. Early in the vegetative growth cycle, cool temperatures are ideal for healthy tuber development. Yam bean requires 14-15h of photoperiod for good vegetative growth, shorter days are required for better tuberization. Hot days and cooler nights are suited for good tuberization. Fertile, well drained Sandy loam soil is considered ideal for the cultivation of yam bean. The cultivation of yam beans is thought to be best suited to sandy loam soil that is fertile and well drained. This crop does well on soil that is loamy and clay loam. For the cultivation of yam beans, waterlogging is not at all desirable. The ideal pH range for soil is 6.0 to 7.0. Depending on the crop, seeds are sown anywhere between June and September. The optimal period to sow seeds is between June and July, with a spacing of 30 by 30 cm. The seed should be sown for tubers in August through September with a 30x30cm spacing. Depending on planting time and spacing, the typical seed rate is 20-60Kg ha^{-1}.

In North-Eastern India, yam beans are customarily planted in June or July when the rainy season begins, and they are typically harvested in December or January. In Odisha, West Bengal, and Bihar, the peak harvesting season falls between the last of January and the beginning of February, during the Saraswati Puja festival. Almost at the same time that a plant develops, a flower and a tuber are formed. The yield, biomass production, sugar content, and protein content all increase when flowers are removed. Deflowering by hand takes a lot of time and money. Chemical deflowering using a single application of 2, 4-D (50 ppm) during the bud initiation stage is both labor- and cost-intensive. After sowing, the yam bean is harvested 110–120 days later. Local varieties generate 18–20 t ha^{-1} on average, while RM-1 varieties produce 30-35 t/ha on average.

Germplasm Characterization

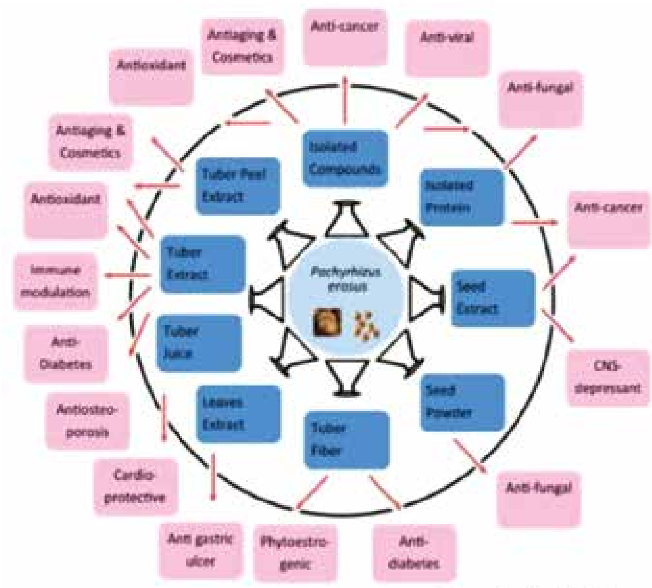
Pati et al., (2020) observed the inheritance pattern of flower colour in underutilized tuberous legume crop yam bean. It was studied by utilizing a white flower colour line (YBWF1) and two purple flower colour lines (RM-1 and L No-3). The F1 and F2 population along with parental lines were evaluated to study the inheritance pattern of the flower colour. All the F1 hybrids showed purple colour in both the crosses and in the F2 segregating generation, the observed distribution of the flower colour fitted the expected Mendalian ratio of 3 (Purple flower colour):1(white flower colour). The segregation of flower colour suggested monogenic dominant control of purple flower colour in yam bean using white flower colour genotype YBWF-1. This is the first report of flower colour inheritance pattern in yam bean. Phenological study in yam bean will be helpful for better crop management, crop improvement and characterization of germplasm. This scale will also be useful for the yield enhancement of this crop as an emerging underutilized tuber crop. Biologische Bundesanstalt, Bundessortenamnt and Chemische Industrie (BBCH) scale was developed for the identification of different phenological growth stages of yam bean like, germination, leaf, formation of side shoots, stem elongation, tuber formation, inflorescence emergence, flowering, development of pods, ripening of pods, and senescence (Pati et al., 2020). Thirty genotypes of yam beans were examined using the proton-induced X-ray emission technology to determine the availability of nutrients. Using the software programme known as GUPIX-2000, specific minor and trace element concentration as P, S, K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, Rb and Sr were detected and measured in yam bean genotypes. For element analysis, PIXE measurements were performed using 3 Me V proton beams with 20 nA beam current on target. (Pati et al., 2021).

Molecular and Biochemical Characterization

For the Pachyrhizus species, no genetic markers are currently accessible. Yam bean is a socially and culturally significant but economically marginalized crop. Yam beans are considered "orphans" by crop science, and little effort has been made to assess the genetic diversity of these small but promising crops at the moment. It is likely that efforts to document these mainly unexplored genetic resources have been hampered by a lack of molecular tools. Deletre et al., (2013) reported 17 simple sequence repeat (SSR) markers with perfect di and tri- nucleotide repeats developed from 454 pyro sequencing of SSR-enriched genomic libraries in yam bean. Loci were characterized in *P. ahipa* and wild and cultivated populations of four closely related species. All loci successfully cross-amplified and showed high levels of polymorphism, with number of alleles ranging from 3 to 12 and expected heterozygosity ranging from 0.095 to 0.831 across the genus. Santayan et al., (2014) evaluated the genetic diversity and interspecific connections of 58 accessions of three cultivated Pachyrhizus species using amplified fragment length polymorphism (AFLP) molecular markers. Eight different AFLP primer sets found 136 (68.7%) polymorphic bands.

Tay Fernandez et al., (2021) assembled a draft genome of *P. erosus* of 460 Mbp in size containing 37,886 gene models. Compare three cultivars each of *P. erosus* and the closely related *P. tuberosus* and identified 10,187,899 candidate single nucleotide polymorphisms (SNPs). The assembly revealed that *P. erosus* is more genetically distinct than *P. tuberosus* and adds support to the *Glycine* family being the closest major crop relative to the *Pachyrhizus* species. Future research can use the assembled data as a starting point, and the results can be used to characterize the genetic makeup of yam bean.

Different biochemical properties discovered by researchers, primarily from seeds and tubers of yam bean. It has been stated in the literature that *P. erosus* has pharmacological properties, which have been further investigated in studies conducted mostly in the last two decades. These pharmacological properties have been recognized since ancient times. *P. erosus* is a likely candidate for further development due to its biological actions against many diseases and other pharmacological features (Jaiswal et al., 2022,



Source: Jaiswal et al., 2022

Fig. 1). Noman *et al.,* (2007) analyzed tuber of *Pachyrhizus erosus* to determine its proximate chemical composition, vitamin, mineral, amino acid contents, and enzymatic activity. The tuber had a high level of moisture, appreciable amounts of carbohydrate, crude fiber protein and negligibly low amount of lipid. A significant amount of ascorbic acid, thiamine, riboflavin, pyridoxine, niacin and folic acid were also detected in the tuber comparison with the other commonly consumed local tubers revealed that *P. erosus* tuber could be included in dietary formulae for human or monogastric animals, especially in those areas where carbohydrate is in short supply.

Breeding in Yam bean

The yam bean is thought to be an underutilized legume food source that is desirable for breeding as well as agronomy: In addition to having a wide eco-geographical distribution and high self- fertilization rates, this root crop has the following advantages: (i) as a root crop, it can produce high yields and high yield stability; (ii) as a legume, it offers more protein than traditional root crops and has the ability to increase soil fertility (N-fixation and P-efficiency); (iii) it has a wide eco-geographical distribution (Sorensen, 1996). Initial hybridization experiments were conducted to examine the interspecific compatibility of the three cultivated species, *P. erosus*, *P. ahipa* and

P. tuberosus (Sorensen 1993). ICAR- Central Tuber Crops Research Institute (ICAR-CTCRI), and its Regional Centre, Bhubaneswar and ICAR-All India Co-ordinated Research Project on Tuber Crops (AICRPTC) are conducting yam bean research in India. Hybridization and selection of best hybrids in yam bean programme is going on at ICAR-CTCRI, Regional Centre for selection of early maturity, high dry matter content, enhanced nutrition and pest and disease resistance (ICAR-CTCRI Annual Report 2020).

Conclusion

The yam bean has the potential to significantly enhance food assistance, particularly in areas with limited resources. ICAR-CTCRI and its All India Co-ordinated Research Project on Tuber Crops (AICRPTC) conducting research on the yam bean. Additional analysis of the range of yam bean variants under various circumstances is required. It's crucial to gather more details about their capacity for cultivation, agronomic potential, and genetic diversity in order to choose the right breeding programmes for yam beans. As a significant future crop for food and nutritional security for India and other parts of the world, yam bean production requires attention among the research community. The yam bean is referred to as a minor crop, underutilized crop, or crop that has been ignored yet has enormous potential for generating income and providing health and nutritional security.

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Chapter 5

Guidelines and procedures for exchange of plant genetic resources

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Germplasm exchange refers to the mutual give and take of germplasm from all available sources. Germplasm is the building block for the creation of new cultivars. It is defined as a seed, a plant, or a plant part that is useful in crop breeding, research, or conservation due to its genetic attributes. Germplasm exchange provides enormous opportunity for improved economic growth, potential stability, human health, and environmental sustainability. Germplasm exchange activities in India began in the early twentieth century, but systematic efforts started in the 1960s with the establishment of the Division of Plant Introduction at IARI, New Delhi, and its subsequent expansion to a full-fledged institute, the National Bureau of Plant Genetic Resources in 1976 which played an important role in providing germplasm, exotic as well as indigenous collections, for crop improvement programmes throughout the country. The Division of Germplasm Exchange at ICAR-NBPGR under the single window system of exchange undertakes the activities of import, export and national supply in a systematic manner as per the national and international regulations/conventions/agreements.

I. Procedures for Germplasm Exchange

a. Introduction/Import of PGR

Plant introduction is defined as the introduction of a genotype or a group of genotypes of plants into new environments where they have not previously been grown. The term is frequently used for introduction of material from other countries, but the movement of crop varieties from one environment to another within the country is also referred to as introduction. New crop introductions include important crops such as maize, potato, tomato, tobacco, soybean, sunflower, kiwi fruit, tree tomato, hazel nut, guayle, jojoba, and geranium. When an introduced variety is well suited to a new environment and is released for commercial cultivation with no changes to the original genotype, it is referred to as a primary introduction; however, when the introduced variety is subjected to selection to isolate a superior variety or is hybridized with localvarieties to transfer one or few characters from this variety to the local ones, it is referred to as a secondary introduction. Introduction of semi-dwarf wheat varieties Sonora 64, Lerma Rojo from CIMMYT, Mexico; and rice varieties Taichung Native 1, IR 8, 1R 28, 1R 36 from IRRI, Philippines are some examples of primary introduction and wheat varieties Kalyan Sona, Sonalika, selected from material introduced from CIMMYT, Mexico are examples of secondary introduction. Though introduction is important, we must have a proper pest risk analysis (PRA) system in place to avoid the risk of introducing associated pests and diseases with the plants. Several pests and diseases have been reported to have been introduced with the imported material, including late blight of potato, flag smut of wheat, bunchy top of banana, woolly aphid, and fluted scale of citrus. Many countries have established plant introduction services for systematic introduction. These services have some features in common which facilitate their efficientoperation such as: they usually form part of the department of agriculture or a major research organization to draw upon extensive resources; has direct responsibility for plant quarantine and work in close collaboration with the quarantine authority; have good testing facilities in all the major climatic zones; maintain records of introduced plants and provides a contact point for the international collaboration through FAO and other agencies.

Historical background of introduction in India

Centralized Plant Introduction agency was initiated in 1946 at Indian Agricultural Research Institute (IARI) in the Division of Botany, New Delhi which was expanded as Plant Introduction and Exploration organization in 1956 under second five-year plan and further upgraded into an independent Division of Plant Introduction, of IARI, New Delhi in 1961. In 1976, it was upgraded to an independent institute as National Bureau of Plant Introduction (NBPI) and in 1977, renamed as National Bureau of Plant Genetic Resources (NBPGR). The ICAR-NBPGR, as a single window system, is responsible for introduction/ import and maintenance of germplasm of agri-horticultural crops. Central Research Institute for various crops e.g. tea, coffee, sugarcane, potato, tobacco, cassava, coconut, rubber etc. introduce, test and maintain plant material of interest, but their activities are coordinated by ICAR- NBPGR which has the ultimate responsibility for introduction activities. PGR may also be introduced by individual scientist, universities and other research organization, but all the introductions in India must be routed through the NBPGR, New Delhi.

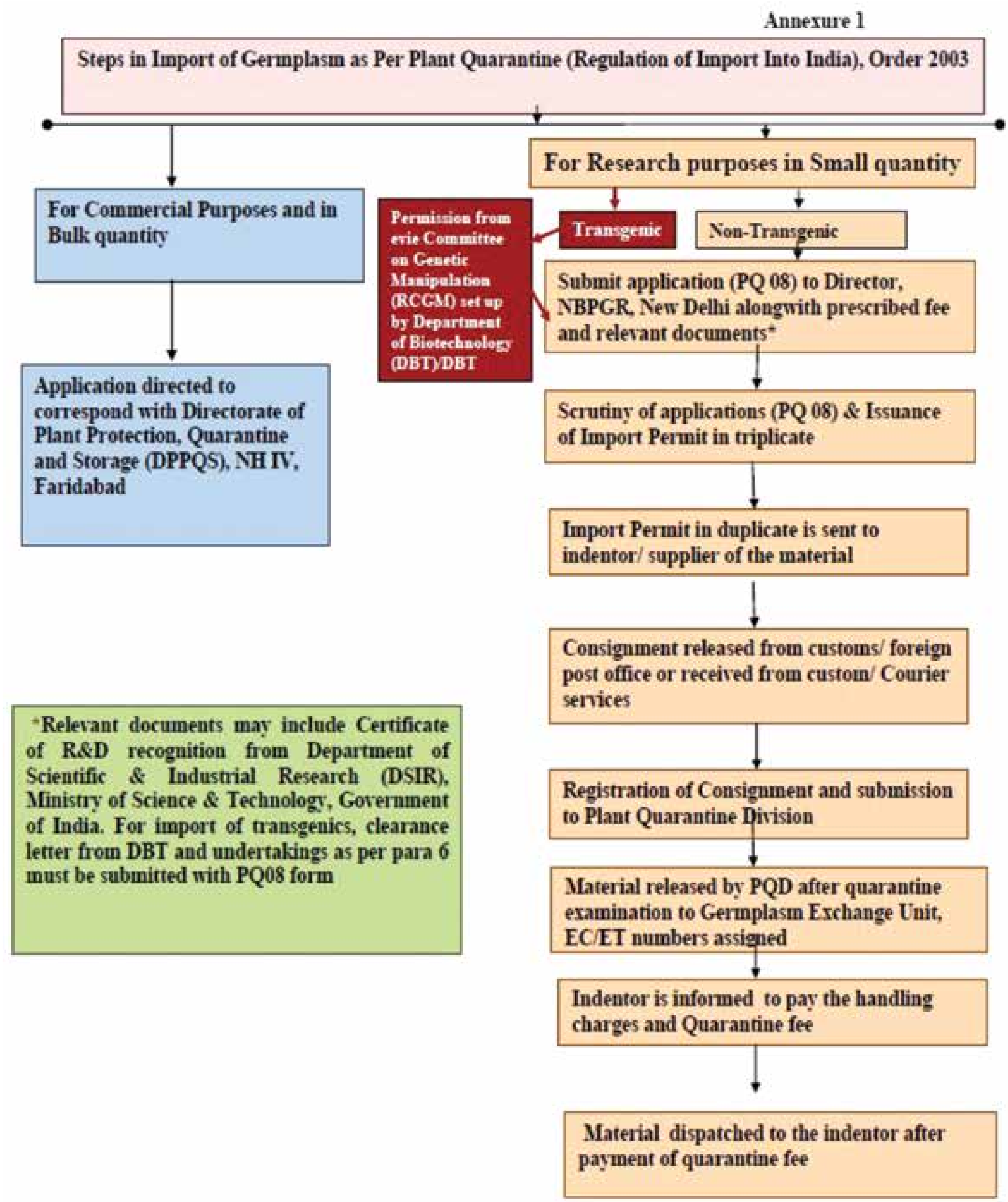
Importing PGR for research use

The Plant Quarantine Order, 2003, governs the import of any seed/planting material for research purposes in small quantities in India (www.plantquarantineindia.org). According to this order, we must meet two mandatory requirements before importing any seed or planting material from other countries. 1) Import permit (IP) issued by ICAR-NBPGR prior to the import of any material and 2) Phytosanitary certificate (PC) from the country of origin. These two documents must accompany every consignment imported from abroad.

Issuance of import permit:

As per clause 6 (2) of PQ Order 2003, Director, ICAR-NBPGR has been authorized to issue import permit for import of germplasm, transgenic or genetically modified organisms for research purposes and receive imported materials from custom authorities for its quarantine inspection and clearance and further distribution to the researchers in the country. Along with the application form PQ08, processing fee for the issuance of IP should be sent (Annexure 1). The fee is non refundable. It should be ensured that the consignment be always be addressed to the Director, NBPGR, New Delhi. Quarantine examination charges and handling fee per consignment may be accessed from ICAR-NBPGR website www.nbpgr.ernet.in. The IP is issued in form PQ 09 in triplicate and is valid for six months from the date of issue and valid for successive shipment provided the exporter and importer, bill of entry, country of origin and phytosanitary certificate are the same for the entire consignment. Validity may be extended up to one year on request, if adequate reasons in writing are justified. Import permit is non- transferable. After obtaining import permit the applicant should send it to the concerned source that has agreed to supply the required germplasm with the request that the import permit in duplicate must be enclosed along with the seed/ planting material. Private seed companies are required to submit a certificate ensuring their research and development activity is recognized byDepartment of Scientific and Industrial Research (DSIR). However, under the provisions of Clause 3(3) (4), commercial import of consignments of seeds of coarse cereals, pulses, oil seeds and fodder seeds and seeds/stock material of fruit plant species for propagation shall only be permitted based on the recommendations of EXIM Committee of Department of Agriculture, Cooperation and Farmers Welfare, except the trial material of the same as specified in Schedule- XII of Plant Quarantine Order. Every application for permit shall be made to Plant Protection Advisor or to issuing Authority as listed in schedule X of PQ Order, 2003 in from PQ 01 for the import of plants and plant products for consumption and processing and in from PQ 02 for imports of seeds and plants for propagation covered under schedule V and VI.

Phytosanitary Certificate: Phytosanitary certificate is a document regarding the health status of consignment issued by Government Official from country of origin in the prescribed format of Food and Agriculture Organization (FAO). Every consignment should be accompanied by PC (original copy) issued by authorized officer at country of origin/ supplier country with additional declarations for freedom from specific pests


Annexure 1
Steps in Import of Germplasm as Per Plant Quarantine (Regulation of Import Into India), Order 2003
For Commercial Purposes and in Bulk quantity
Application directed to correspond with Directorate of Plant Protection, Quarantine and Storage (DPPQS), NH IV, Faridabad
Permission from evie Committee on Genetic Manipulation (RCGM) set up by Department of Biotechnology (DBT)/DBT
For Research purposes in Small quantity
Transgenic
Non-Transgenic
Submit application (PQ 08) to Director, NBPGR, New Delhi alongwith prescribed fee and relevant documents*
Scrutiny of applications (PQ 08) & Issuance of Import Permit in triplicate
Import Permit in duplicate is sent to indentor/ supplier of the material
Consignment released from customs/ foreign post office or received from custom/ Courier services
Registration of Consignment and submission to Plant Quarantine Division
Material released by PQD after quarantine examination to Germplasm Exchange Unit, EC/ET numbers assigned
Indentor is informed to pay the handling charges and Quarantine fee
Material dispatched to the indentor after payment of quarantine fee
*Relevant documents may include Certificate of R&D recognition from Department of Scientific & Industrial Research (DSIR), Ministry of Science & Technology, Government of India. For import of transgenics, clearance letter from DBT and undertakings as per para 6 must be submitted with PQ08 form

and diseases as specified or that the pests specified do not occur in the country or state of origin as supported by documentary evidence thereof. PC is also issued by the ICAR-NBPGR for all the germplasm material meant for export to foreign countries.

Import of Transgenics

Gazette of India extra ordinary Part II Section -3 sub section (1) published by authority No. 621, New Delhi has defined the rules for the manufacture, use, import, export and storage of hazardous microorganism/genetically engineered organisms or cells made under sections 6, 8 and 25 of the Environment (Protection) Act, EPA 1986 (29 of 1986). These rules are applicable for importing any transgenic seed/planting material into the country. EPA plays a major role in minimizing the risk from pollutants and contaminants affecting flora and fauna, human and animal health and preserving the environment. In accordance with this Act, all transgenic plants are regulated items. The provisions of PQ Order, 2003 are applicable to import of transgenic seeds as well. Department of Biotechnology (DBT), under Ministry of Science and Technology and the Ministry of Environment, Forests and Climate Change (MoEFCC) has a set of prescribed procedures for providing permission for import of transgenics. Proposals for import of transgenics are submitted to Review Committee on Genetic Manipulation (RCGM) through the Institutional Biosafety Committee (IBSC). RCGM is an authorized agency of the Government of India, functioning under DBT, which assesses the applications submitted for importing transgenic material for research purposes and issues Seed Transfer Clearance Letter. RCGM examines the desirability of import of transgenic line, from the biosafety point of view. It includes representatives from DBT, Indian Council of Medical Sciences (ICMR), Indian Council of Agricultural Research (ICAR), Council of Scientific and Industrial Research (CSIR) and other experts in their individual capacity. After getting the technical clearance for Seed Transfer Clearance Letter issued by DBT, application for issuance of IP is submitted to the Director, ICAR-NBPGR in the prescribed PQ08 form.

Quantity of seed permitted for import

Importing a small amount of seed/planting material for research purposes is permitted. The optimum and safest quantity of seed or planting material is considered to be just enough for plant establishment (Annexure 2). The seed quantity for transgenic plants is specified in the DBT clearance letter. Five to ten percent of the seed/planting material is saved in the National Gene bank as a voucher specimen for future reference.

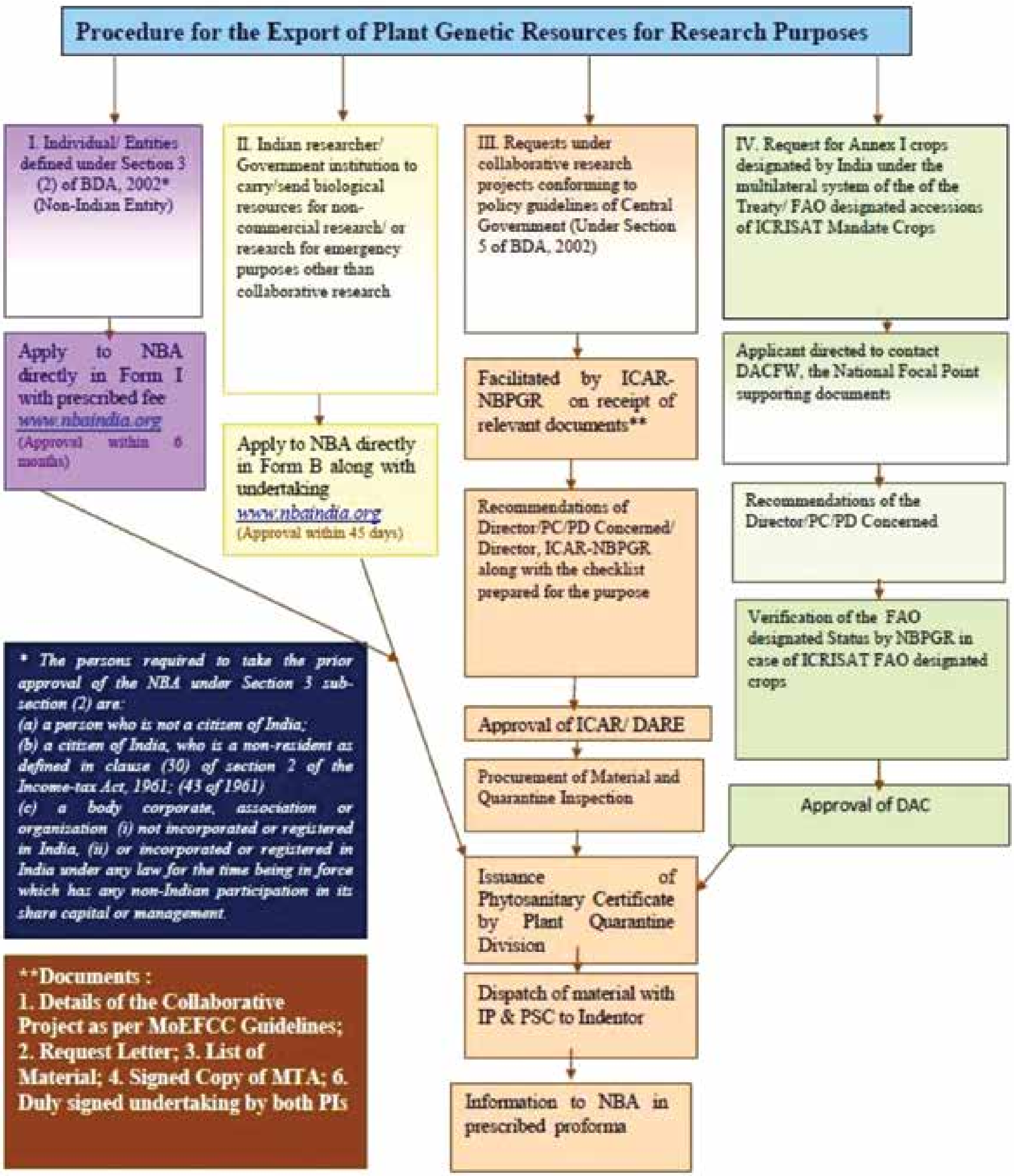
Annexure 2 shows the seed quantity permitted for import and export.

b. Export of PGR:

Under the provisions of the Convention on Biological Diversity (CBD), Government of India enacted legislation called Biological Diversity Act (BDA), 2002, and also notified the Biological Diversity Rules, 2004 which suggests that no person from outside India or a body corporate, association, organization incorporated or registered in India having non-Indian participation in its share capital or management, can access any biological resources or knowledge associated, for research, commercial utilization, bio-prospecting or bio-utilization, without prior approval of National Biodiversity Authority (NBA). However, as per Section 5 of BDA, 2002, exchange of germplasm for collaborative research projects which confirm to the policy guidelines issued by the Central Government or approved by the Central Government are exempted from Section 3 and 4 of BDA, 2002. The request for access to germplasm occurring in India, only for research purposes is categorized under the four categories:

1. Export of germplasm under collaborative research projects, under Section 5 of the BDA, 2002
2. Export of Annex 1 crops under International Treaty on Plant Genetic Resources (ITPGRFA) and FAO designated accessions of CG Centers located in India
3. Indian researcher/ Government institution to carry/send germplasm for non-commercial research/ or research for emergency purposes other than collaborative research
4. Export of germplasm not covered in any of the above category that is access by non- Indian entity for any biological resource occurring in India which is not Annex I crop under ITPGRFA neither covered under any collaborative research project

Annexure 2


Procedure for the Export of Plant Genetic Resources for Research Purposes
I. Individual/ Entities defined under Section 3 (2) of BDA, 2002* (Non-Indian Entity)
II. Indian researcher/ Government institution to carry/send biological resources for non-commercial research/ or research for emergency purposes other than collaborative research
III. Requests under collaborative research projects conforming to policy guidelines of Central Government (Under Section 5 of BDA, 2002)
IV. Request for Annex I crops designated by India under the multilateral system of the of the Treaty/ FAO designated accessions of ICRISAT Mandate Crops
Apply to NBA directly in Form I with prescribed fee www.nbaindia.org (Approval within 6 months)
Apply to NBA directly in Form B along with undertaking www.nbaindia.org (Approval within 45 days)
Facilitated by ICAR-NBPGR on receipt of relevant documents**
Applicant directed to contact DACFW, the National Focal Point supporting documents
Recommendations of Director/PC/PD Concerned/ Director, ICAR-NBPGR along with the checklist prepared for the purpose
Recommendations of the Director/PC/PD Concerned
Verification of the FAO designated Status by NBPGR in case of ICRISAT FAO designated crops
Approval of ICAR/ DARE
Procurement of Material and Quarantine Inspection
Approval of DAC
Issuance of Phytosanitary Certificate by Plant Quarantine Division
Dispatch of material with IP & PSC to Indentor
Information to NBA in prescribed proforma
* The persons required to take the prior approval of the NBA under Section 3 sub-section (2) are:
(a) a person who is not a citizen of India;
(b) a citizen of India, who is a non-resident as defined in clause (30) of section 2 of the Income-tax Act, 1961; (43 of 1961)
(c) a body corporate, association or organization (i) not incorporated or registered in India, (ii) or incorporated or registered in India under any law for the time being in force which has any non-Indian participation in its share capital or management.
**Documents :
1. Details of the Collaborative Project as per MoEFCC Guidelines; 2. Request Letter; 3. List of Material; 4. Signed Copy of MTA; 6. Duly signed undertaking by both PIs

For export of PGR under collaborative research projects which are compliant to MOEFCC Guidelines as per provisions of Section 5 of the BDA, 2002, ICAR-NBPGR facilitates the procedure for approval of export from the Competent Authority. For requests of Annex 1 crops under ITPGRFA and FAO designated accessions of CG Centers located in India (ICRISAT), ICAR-NBPGR facilitates the process for approval of the Competent Authority i.e. Department of Agricultural Research and Education (DARE) export of germplasm under Collaborative Research Project and Department of Agricultural Cooperation and Farmers Welfare (DAC&FW) for export under ITPGRFA. For all other cases, the applicant is required to contact NBA for seeking approval (Category 3 or 4). Once NBA grants approval for export the PC shall be issued by Division of Plant Quarantine after quarantine inspection. Procedure for export of PGR is depicted in the flow chart (Annexure 4).

c. Domestic supply of PGR

Requests for samples of plant germplasm available with/maintained by NBPGR/ NAGS should be sent to the Director, NBPGR, Pusa Campus, New Delhi 110012, in the prescribed GEX 01 form along with a signed MTA by the indenter of germplasm. The GEX 01 and MTA can also be downloaded from NBPGR website (www. nbpgr.ernet.in). Acknowledgement of receipt of germplasm from NBPGR should be provided by the indenter immediately after receipt of material. Indenter should retain the unique identity no. assigned by NBPGR (IC/EC/ET) while using the germplasm. Feedback information (in the prescribed format) on the performance or utilization of material should be sent to the Director, NBPGR, New Delhi.

II. International regulations/ conventions/agreements

Convention on Biological Diversity (CBD)

Aa paradigm policy shift was witnessed in the international policy environment from "heritage of mankind" to "sovereign rights of a nation". The major events which led to this shift was the Convention of Biological Diversity (CBD) which came into force in 1993, adopted during the Rio Earth Summit of the United Nations. It was the first legally binding institutional mechanism, providing for conservation and sustainable use of all biological diversity and intends to establish the process of the equitable sharing of benefits arising out of the use of biodiversity. The CBD reaffirmed national sovereignty over genetic resources and stressed that the authority to determine access to genetic resources rests with the national governments and is subject to national legislations. It provides for a bilateral approach to access/exchange between countries on prior informed consent (PIC) and mutually agreed terms (MAT).

Nagoya Protocol

India has ratified the Nagoya Protocol (NP) which is an international agreement which aims at sharing the benefits arising from the utilization of genetic resources in a fair and equitable way, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding. NP entered into force on 12 October 2014. Nagoya Protocol provides a strong base for legal certainty and transparency for both providers and users of genetic resources. It recognizes the importance of promoting equity and fairness innegotiation between providers and users.

International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)

FAO in 1983 adopted an International Undertaking on Plant Genetic Resources (IUPGR) with the objective to ensure that PGR are of economic and / or social interest particularly for agriculture, will be explored, preserved, evaluated and made available for plant breeding and research purposes. FAO Commission on Genetic Resources for Food & Agriculture (CGRFA) monitored the implementation of IUPGR. The IUPGR was non-legally binding and many developed nations with major private sector breeding companies were not signatories to this. It was, therefore revised under the guidance of CGRFA. The revised text of IUPGR was submittedto the 31st session of FAO Conference that adopted it as the International Treaty on Plant Genetic Resources for Food and Agriculture in November 2001. Legally binding ITPGRFA was thus negotiated as a direct response to CBD in 2001, came into force in 2004 to facilitate access to PGRFA in harmony with CBD, through an efficient mutually agreed system of access and benefit sharing. Access here is only for research, breeding and training and not for chemical, pharmaceutical or nonfood/feed industrial use.

No Intellectual Property rights can be claimed on PGRFA in the form received from the multilateral system that limits the facilitated access to PGRFA/genetic parts or components. The multilateral system applies to a list of 64 plant genera, including 35 crop and 29 forage plants, agreed on the basis of interdependence and food security and are referred to as Annex 1 crops. The conditions for access and benefit sharing are set out in a 'Standard Material Transfer Agreement' (SMTA), adopted by the Governing Body of the Treaty.

References

https://www.plantquarantineindia.org

https://www.nbpgr.ernet.in

https://www.cbd.int

https://www.genres.de/en/

Chapter 6

In silico analysis of genes governing climate resilience and nutrient contents of tuber crops

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Introduction

Root and tuber crops constitute as a staple food for nearly 20% of the global population. They are hardy crops and characterized by starch rich roots/tubers. However, due to the shifts in climate change patterns during the recent years including a rise in temperature and changes in the pattern and quantum of rainfall received. Climate change also poses threats to land by inducing submergence, drought, and salinity, and to air by increase in carbon di oxide concentration. Extreme weather events such as hot waves, cold waves, fire, earthquakes, tsunami, and floods are frequently occurring in recent years. Tuber crops are rich in nutrients but sometimes anti-nutrient contents present in them also pose health hazards. Hence it is important to develop high starch, low amylase and low cyanide cassava, high pigment (β carotene, anthocyanin) sweet potato and less oxalate yams, taro. The current article attempts to highlight the significance of climate change and nutritional, ant nutrient and pharmaceutical compounds in tuber crops and the role of specific genes governing the tolerance to abiotic stress induced by climate change events, and chemical composition. Whole genome sequence is available (Table 1) for cassava, sweet potato, white yam, and taro. Bioinformatics/ *in silico* tools are employed to analyze the genomes and gene sequences using computer to understand the homology, exon-intron structure, identify single nucleotide polymorphism (SNP) markers, simple sequence repeat (SSR) markers.

Climate change

Climate change impacts on yields of roots, tuber crops compared to rice and potato has been reported by Velmurugan et al., (2021). Projections of suitability of tuber crops in the future show that by 2030, most districts of Kerala and two districts of Tamil Nadu might experience 0.9°C increase in mean temperature. East Godavari and West Godavari of Andhra Pradesh, and Ganjam and Nayagargh of Odisha are expected to record 1°C increase. The yam-growing areas are anticipated to show increase in temperature from 0.9 to 1.3°C and shift in rain fall from 9 to 128 mm respectively (Remesh et al., 2019). Cassava plants survive with vegetative growth and biomass even at high (33-40ºC) temperatures with sufficient soil water conditions. But when the temperature go above 30ºC, the biochemical processes of synthesis of sucrose and its transport

Table 1. Whole genome sequences of tuber crops (review: Chapman et al., 2022)

Crop	Chromosome number	Genome size	Reference
Cassava	2n = 2x = 36	746 Mb	Wang et al., 2014
Sweet potato	2n = 6x = 90	4.4 Gb	Yang et al., 2017
Taro	2n=2x=28 2n=3x=42	2,405 Mb	Yin et al., 2021
White guinea yam (*Dioscorea rotundata*)	2n = 2x = 40	579 Mb	Tamiru et al., 2017

to tuber towards starch formation is reduced. The number of tubers of sweet potato reduced when the soil moisture go below 20% especially during the initiation period of tuber (Malhotra, 2017). Sweet potato is sensitive to the low temperature and frost and display yellowish-brown discoloration water-soaked appearance in tissues leading to softening of roots and decay (Caplan 1988). Water logging / hypoxia due to flash flooding caused by heavy rains is a serious threat to tuber crops. It leads to reduction in chlorophyll content of leaves leading to yellowing, senescence and enhanced activity of enzymes such as catalase, superoxide dismutase, and peroxidase. Transcription factors such ethylene responsive factors (ERFs), MYBs, WRKYs, and NACs regulate the tolerance to submergence (Cao et al., 2022). ERFs involve in abiotic stress tolerance in plants (Debbarma et al., 2019). Role of spermidine synthase genes in tolerance to drought and salinity is elucidated in sweet potato (Kasukabe et al., 2006).

Taro crop was found as a future crop for Trivandrum of Kerala and is also suitable for Kalyani of West Bengal (Pushpalatha et al., 2021). Taro and other edible aroids suffer serious yield loss due to drought. Taro blight incidence occurs high when

Table 2. Genes for climate smart traits of tuber crops

Stress	Crop	Genes	Reference
Drought	Cassava	*MeALDH*, *MeZFP*, *MeMSD* and *MeRD28*	Turyagyenda et al., 2013
Submergence	Cassava	(ERFs), MYBs, WRKYs, and NACs	Cao et al., 2022
Drought/ Salinity	Cassava	Dof	Zou et al., 2019
Drought/ Salinity	Cassava	Aquaporins	Zou and Yang 2019
Drought Salinity	Sweet potato	spermidine synthase	Kasukabe et al., 2006
Heat stress	Yams	ERFs	Debbarma et al., 2019
Chilling /flood	*Dioscorea alata*	Ascorbate peroxidase	Chen et al., 2019
Leaf blight resistance	Taro	QTL mapping of genes	Bellinger et al., 2020

there is increase in humidity and night temperature. Temperature beyond 32° C is not favourable for taro cultivation (Taylor et al., 2019). Hence climate-smart taro cultivars with tolerance to drought, high temperature, and tolerance to leaf blight disease need to be developed. Some of the selected genes governing climate smart traits in tuber crops are listed in Table 2.

Nutrients, anti- nutrients and compounds

Vitamin A deficiency is a major health concern hence bio fortified tuber crop cultivars with increased beta carotene content are significant. *Lycopene epsilon-cyclase* gene in the carotenoid biosynthesis pathway governed the enrichment of pro vitamin A in banana (Kaur et al., 2020). Related to improvement of carotenoid contens cassava, single nucleotide polymorphism of phyteone synthase(PSY2) in QTL analysis of cassava yellow root phenotype indicated relation with yellow colour and carotenoid contents. Starch forms the major component in tuber crops. AGPase (ADP-glucose pyrophosphorylase) is the major enzyme for starch synthesis in plants. Amylose (20-30%) and amylopectin (70-80%) are two types of polysaccharides that can be found in starch granules. Waxy starch is a premium product with low or zero amylose content with high viscosity and desirable for processing industry due to favourable gelling properties. Hence, the mutant tuber crop germplasm with waxy starch have high market value. *GBSSI* (*Granule Bound Starch Synthase I*) gene governs the GBSS enzyme which is important in waxy starch formation.

A nsSNP (non-synonymous Single Nucleotide Polymorphism) causing Ala > Asp mutation in the *PSY2* gene product produces yellow roots of cassava (Welsch et al., 2010). Linamarin is the major cyanogen in cassava stored in the vacuole. Acetone cyanohydrin is broken down to acetone and cyanide by either pH (>5) or higher temperature (above 35^{o} C) orby hydroxynitrile lyase (*HNL*) enzyme (Narayanan et al., 2011). Authors found lines over expressing the gene HNL are shown to contain low levels of cyanide and high protein content. Taro germplasm with low oxalate (Kizhakedathil, et al., 2022) are important to avoid formation kidney stones in taro consuming persons. Some of the selected genes governing nutrients or anti nutrient contents in tuber crops are listed in Table. 3.

Table 3. Genes for nutrients, anti-nutrients of tuber crops

Crop	Gene / phenotype	Reference
Cassava	*Sucrose synthase*	Huang et al., 2021
Cassava	Waxy starch	Do Carmo et al., 2020
Taro	Starch	Liu et al., 2015
Taro	Starch	Dong et al., 2021
Cassava	*PSY2* gene yellow roots	Welsch et al., 2010
Sweet potato	Anthocyanin pigmentation	Yan et al., 2022
Taro	Anthocyanin pigmentation	He et al., 2021
Taro	Low oxalate	Kizhakedathil, et al., 2022
Cassava	cyanogenic glycoside *CYP79D/D2*	Siritunga and Sayre 2003
Yam	*Dioscorin*	Hou et al., 1999, 2000, 2001

Tools and softwares for *in silico* analysis

Phytozome is a useful resource for analyzing the whole genome of cassava. Bioedit software helps to analyze the sequences and MEGA is a useful software for inferring the evolution using the DNA sequences. Some of the selected tools and software URL links arelisted in Table.4. Single Nucleotide Polymorphisms (SNPs) and Insertions/ Deletions (Indels) are the major source of point mutations. SNPs are nucleotide substitutions and of two types transitions (where a purine is replaced by a purine or a pyrimidine is replaced by a pyridimine A-G, C-T, G-A, T-C), Transversion (where a purine is replaced by a pyridimidine or vice versa, G-T, T-G, A-C, C-A, A-T, T-A, C-G, G-C). SNP and indel markers are used in cultivar identification and marker-trait association studies.

Simple Sequence repeats (SSRs) or microsatellites are repeats of DNA sequences of atleast 20 bases long and could be a monomer occurring a minimum 20 times at a stretch (eg. AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA) or a dimer occurring minimum 10 times (eg. ATATATATATATATATATATATATATATATAT) or a trimer

Table.4. URLs of tools and softwares

Theme	URL
Cassava genome database	https://phytozome-next.jgi.doe.gov/info/Mesculenta_v8_1
Sweet potato genome browser	http://public-genomes-ngs.molgen.mpg.de/SweetPotato/
Bioedit software	https://bioedit.software.informer.com/7.2/
MEGA software	www.megasoftware.net
SNP software	www.genecodes.com
SSR software	https://webblast.ipk-gatersleben.de/misa/
BLAST	https://blast.ncbi.nlm.nih.gov/Blast.cgi
Literature search	https://scholar.google.co.in/

occurring a minimum of 7 times (eg. ATCATCATCATCATCATCATCATCATCATC) or tetramer occurring a minimum of 5 times (eg. ATCGATCGATCGATCGATCGATCG) etc., Microsatellite regions can be located using softwares and developed as molecular markers.

Conclusion

The whole genome requence and other omics. Information available in tuber crops provide scope for analysis using computational tools. The current chapter lists tools and resources available. for such bioinformatics research. The genes and single nucleotide polymorphism and simple sequence repeat regions in the genes of tuber crops governing climate resilient traits and nutrient composition are highlighted.

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Chapter 7

Studies on the impact of climate change on minor tuber Crops

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Minor tropical tuber crops popular in India include *Pachyrhizus erosus*, arrow root (*Maranta arundinacea*), tannia (*Xanthosoma sagittifolium*), curcuma sp., winged bean (*Psophocarpus tetragonolobus*) are cultivated in different parts of the country in smaller area. Global climate change involves a rise in atmospheric carbon dioxide (CO_2) up to 700 ppm, rise in mean air temperature up to 6-7°C, frequent soil drought and a rise in salinity and UV-B radiation. Compared to other fruit/vegetable crops tuber crops are tolerant to water deficit stress conditions. This is because, unlike that of other crops, in tuber crops, both source and sink develops simultaneously. Mild water deficit stress (WDS) is favourable for tuber growth. But under prolonged WDS conditions (WDS >30 days), both vegetative growth as well as tuber bulking ceases, plant sheds about 80% of leaves and the plant becomes dormant.

The growth and productivity (tuber yield) response of tropical tuber crops such as cassava, sweet potato and taro to drought/water deficit stress (WDS) has been studied by many researchers. However, the response of minor tuber crops to drought and other such abiotic stress is not known. Among tropical root and tuber crops, cassava, greater yam (*Dioscorea*) are tolerant to drought / WDS conditions. Sweet potato is tolerant to saline conditions (identified varieties: CIP 440127 and Samrat). Elephant foot yam (*Amorphophallus*) and tannia (*Xanthosoma*) are tolerant to shade conditions and therefore adapted to coconut gardens. Taro (*Colocasia*) is adapted to water logged conditions. The critical period of crop sensitivity to water deficit stress (WDS) is the tuber initiation period. In cassava and sweet potato, it is 4^{th} week after planting. In cassava and sweet potato, WDS during tuber initiation period induces lignification of tuber forming roots. Prolonged drought during tuber bulking period significantly decreases tuber yield of all tropical tuber crops.

Although cassava is considered to be tolerant to drought conditions, under field conditions, significant reduction in photosynthetic rate, total dry matter production and tuber yield (28–42%) under WDS conditions has been reported and a wide variability was found in tuber yield among 62 genotypes under drought conditions. Cassava varieties tolerant to drought conditions are H-226, H-165, H-1687. Although cassava sustains vegetative growth and biomass at high temperatures (>33-40^{o}C) under adequate soil moisture, sucrose synthesis and export from the leaves and starch synthesis in tubers will be affected. The enzymes involved in starch biosynthesis are highly sensitive to higher atmospheric temperatures (>33^{o}C). In cassava, starch content of tubers is greater 5% or more at cooler climate in high altitude (1000 amsl) than warmer conditions in plain. The effects of high CO_2 on cassava tuber yield and starch enhancement will be strongly temperature dependent. Higher temperatures and drought also can divert photosynthates to lignification and tubers become woody. Thus, high temperatures (>33^{o}C) and drought can significantly reduce the tuber yield and starch content of cassava/sweet potato tubers. In cassava, photosynthetic rate was maximum at 25 to 35^{o}C. Variations in photosynthetic response of cassava to different temperatures have been reported. In cassava, photosynthesis increased @ 0.2 to 0.7 mg CO_2 dm^{-2} h^{-1} per 1^{o}C rise in temperature and between temperatures 15-35^{o}C whereas @ 0.5 to 1.4 mg CO_2 dm^{-2} h^{-1} per 1^{o}C rise in temperature between temperatures 25 – 45^{o}C.

Tuber yield increase due to 1°C rise in temperature was 1.13 t ha^{-1} at 12 MAP and 3.47 t ha^{-1} at 18 MAP at 24°C compared to yield at 2°C. The increase in tuber yield at 28°C was not significant.

Research work on the response of cassava to elevated CO_2 is much limited. Cassava being a C_3 plant has a unique, partial Krant'z anatomical feature in leaf. It has 15-25% phosphoenol pyruvate corboxylase (PEP case) activity of typical C_4 plants like maize and sorghum. The PEP case activity of cassava is greater than typical C_3 plants and equivalent to that of C_3 – C_4 intermediates. The PEP case activity of cassava increased by 13% whereas the RUBPcase activity decreased by 42% under water deficit stress and heat stress conditions. These features offer cassava a greater advantage to respond to elevated CO_2 concentrations. Under controlled conditions, cassava photosynthetic rate increased up to 500 ppm CO_2 and there after the increase in PN rate was negligible. In cassava, a combination of high CO_2 (700 ppm) and high temperature (33/26°C) increased the tuber yield than control plants that grew at 350 ppm CO_2. The photosynthetic response of 15 varieties and land races of cassava, 9 varieties and land races in Taro and three varieties of *Amorphophallus* has been investigated at ICAR-CTCRI. In sweet potato, photosynthetic rate increased with increase in temperature up to 34°C and increase in CO_2 up to 560 ppm. At temperatures greater than 34°C, increase in CO_2 did not increase photosynthetic rate.

Sweet potato photosynthetic rate increases due to 1°C rise from 20 to 34°C was maximum (1.36 CO_2 µmol m-2s^{-1}) at 560 ppm as compared to ambient CO_2 (360 ppm). Increase in photosynthetic rate due to increase in CO_2 between 250 to 560 ppm was 0.057 µmol CO_2 m-2s^{-1} per 1 ppm rise in CO_2. Studies under field conditions revealed a 3.45 t ha^{-1} decrease in sweet potato yield due to 1°C rise in temperature from 23.5 to 25.9°C. SPOTSCOM model developed at ICAR-CTCRI revealed that sweet potato yield increased due to 1°C rise in mean temperature between 19.24 to 20.24°C was 1.26 t ha^{-1}. The yield decreased by 0.12 t/ha due to 1°C rise in mean temperature between 28.24 to 29.24°C. Under controlled conditions sweet potato yield increased by 3.76 t/ha due to increase in CO_2 from 363 to 514 / 666 ppm. (Note: In both cassava & sweet potato most of the studies were conducted under controlled conditions). The results were inconsistent due to variations in varieties and growth conditions). Studies conducted at CTCRI revealed photosynthetic rates of 10 sweet potato varieties significantly increased at CO_2 concentrations between 400 and 1000 ppm CO_2. Few varieties such as Sree Arun, Gouri, Sankar, S-1466 had 61-74% increase in photosynthetic rates at 1000 ppm CO_2 as compared to 400 ppm CO_2.

Tropical root and tuber crops have high CO_2 sequestering/capturing potential as they produce high biomass per ha. Among all tropical tuber crops, sweet potato has the maximum CO_2 sequestration/ capture potential (40 t CO2 ha^{-1}) whereas arrow root has 35 t CO_2 ha^{-1} and cassava and greater yam have 30 t CO_2 ha^{-1}. Thus, tropical root & tuber crops can significantly contribute for global CO_2 mitigation. Cassava can significantly enhance soil organic carbon. Cassava on an average annually produced 3.57 t dry biomass ha^{-1}. It contributed for reduction of 60.38 ppm CO_2 per year and an increase in soil carbon from 0.82% to 1.08% over a period of 25 years.

The rate of growth and development of a crop is a function of the energy receipt and thermal regime in any given crop growth season. The duration of a particular stage of growth was directly related to temperature and this duration for particular species could be predicted using the sum of daily air temperature. Temperature based indices like growing degree days (GDD), Photothermal units (HTU) and Photothermal index (PTI), Heat use efficiency (HUE) can successfully be used for describing phonological behaviour and other growth parameters like leaf area development, biomass production, Harvest Index (HI), yield etc.

Growing Degree Days (GDD) are used to estimate the growth and development of plants during the growing season. The basic concept is that development will only occur if the temperature exceeds some minimum development threshold, or base temperature (TBASE). The base temperatures are determined experimentally and are different for each organism. To calculate GDDs, you must first find the mean temperature for the day. The mean temperature is found by adding together the high and low temperature for the day and dividing by two. If the mean temperature is at or below TBASE, then the Growing degree day value is zero. If the mean temperature is above TBASE, then the Growing degree day amount equals the mean temperature minus TBASE. For example, if the mean temperature was 75° F, then the GDD amount equals 10 for a TBASE of 65° F. You can think of Growing degree day as similar to

Cooling degree days, only the base temperature can be something besides 65° F. In equation form:

GDD=T*mean* - T*base*, if T *mean* is >T *base*

GDD=0, if T *mean* is < T *base*

Where:

T *mean* = average of daily maximum and minimum temperature

T *base* = Threshold temperature above which the crop grows. This is 13°C for cassava, 15.56°C for sweet potato and 17°C for taro.

Adaptation/mitigation measures/strategies for climate change

1. Altering the planting dates to combat the likely increase in temperature and water deficit stress period during the crop growing season.
2. Modifying fertilizer application and enhance nutrient availability.
3. Providing micro irrigation during critical period of crop growth and conservation of soil moisture.
4. Growing crops in raised beds to overcome the water stagnation due to flood.
5. Intensifying multiple cropping systems and enhancing CO_2 sequestration.
6. Increase soil carbon through replacement of chemical fertilizers by organic manures, vermicompost and crop residues and maintenance of soil quality and health.
7. Use of organic formulations and increasing crop productivity.
8. Exploring availability of traditional, indigenous technologies / knowledge, crop varieties and evaluating them for possible exploitation for changing climatic conditions.
9. Promoting organic farming or eco-friendly farming.

Mitigation strategies

1. Developing new varieties (through hybridization / polyploidy / gene engineering) and evaluating them for changing climatic conditions.
2. Development of transgenic varieties with tolerant genes to heat / drought stress.
3. Several genes have been attributed for inducing heat / drought tolerance. These genes / transcription factors (TFs) may be over-expressed / introduced into high yielding varieties for developing drought / heat tolerance.

Future Strategies

Bridging of yield gap between potential yield and average yield

There is a wide gap between the potential yield and average yield of released varieties of cassava and sweet potato. In the case of cassava, the potential tuber yield of released varieties varies between 40.0 and 62.0 t ha^{-1} whereas the average tuber yield varies between 25.0 and 48.0 t ha^{-1}. So, there is an yield gap of 15.0 t ha^{-1}. Similarly in the case of sweet potato, the potential tuber yield of released varieties varies between 25.0 and 37.0 t ha^{-1} whereas the average tuber yield varies between 16.0 and 28.0 t ha^{-1}. So, there is a yield gap of 9.0 t ha^{-1}. This gap needs to be bridged through adopting

1. Improved agronomic practices (manipulating date of planting, mulching technique)
2. Water and nutrient management (through micro-irrigation and fertigation)
3. Introducing genes tolerant to abiotic stress conditions to improved, high yielding varieties.

1. Evaluation of high yielding varieties for heat / drought tolerance under elevated CO_2 conditions

Presently several minor tuber crops accessions, and land races are available. These varieties need to be evaluated under high CO_2 and high temperature (>35°C) and identify high yielding varieties with high sink potential and high starch metabolic activities to cope with the high temperature (35-40°C) under high CO_2 environment.

2. Studies on photosynthetic responses and productivity of minor tuber crops to elevated CO_2

Photosynthetic response of cassava, sweet potato, taro, elephant foot yam, yams and *Pachyrhizus* to CO_2 has been studied between 400-1000 ppm. Other minor tuber crops are yet to be studied.

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Chapter 8

Crop diversification with minor tuber crops for food and nutritional security

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Poverty and paddy cultivation has become nearly synonymous worldwide where crop diversification can be a savior from the situation. It is proved beyond doubt statistically that agriculture growth reduces poverty but it will be negligible if growth is driven by large farms. But real growth in food production, nutrition security and poverty alleviation can occur only when advanced production technologies are made success with the marginal farmers who have less than a hectare. Diversification with different crops bringing in stability, meeting the diversified needs of the farm family, offer of an insurance against crop/ market risk and overall sustainability of soil have proven advantages over the monocropped situations. Further the crop diversification, the farmer and labour engaged all the year round in different activities, less risk to market price of the product, the by-products of this farm can utilize properly as cattle, poultry, birds, etc.

Minor tuber crops

Tropical tuber crops are the most important food crop after cereals and grain legumes. They are used for food, medicine, animal feed and raw material for starch-based industries. Among tropical tuber crops, minor tuber crops play significant role in food and nutrition security of poor and downtrodden. The tubers of some of the minor tuber crops are consumed after boiling and baking. Some of the minor tuber crops are cultivated for starch purpose. In India, the minor tuber crops grown in region specific areas are arrowroot (*Maranta arundinacea* L.; *Curcuma ungustifolius* L.; *Canna edulis* Ker-Gawler*),* yam bean (*Pachyrrhizus erosus* (L) Urban*)*, tuber cowpea or Zombi pea (*Vigna vexillata*), Chinese potato (*Plectranthus rotundifolius* (Poir.) Spreng), tannia (*Xanthosoma sagittifolium* (L.) Schott.), giant taro (*Alocasia macrorrhizos* (L.) G.Don), winged bean (*Psophocarpus tetragonolobus* (L.) DC.), swamp taro (*Colocasia esculenta* var. *stoloniferum* (L.) Schott.), giant swamp taro (*Cyrtosperma chamissionis* (Schott.) Merr.), typhonium (*Typhonium trilobatum* (L.) Schott.), costus (*Costus speciosus* (Koenig) Sm. (J. Konig) C. Specht.), Jerusalem artichoke (*Helianthus tuberosus* L.), tacca (*Tacca pinnatifida* Frost and Frost. f.) etc.

Minor tuber crops are rich in minerals and vitamins. They have quality starches and easily digestible. Minor tuber crops are having varied growth habit, drought and flood resistance and crop duration. Though minor tuber crops are perennial in nature but domesticated as seasonal/ annual. This provides an opportunity for staggered harvesting as per household and market needs. Minor tuber crops are also having great flexibility in planting and can fit into any cropping/ farming system. This is possible because the propagating material is asexual stem or vine or tuber cuttings. As the economic part is swollen roots or modified stem, photoperiod has no significant effect on yield forming factors. Thus, minor tuber crops are both thermo and photo insensitive. However, extreme high and low temperature affects the growth and yield. Minor tuber crops grow well in marginal soil with fewer inputs where other crops usually fail to grow. They are tolerant to drought and some of them grow fast and provide a wide soil cover to prevent erosion. It also produces high amount of dry matter per unit area per unit time compared to cereals. They are most efficient in converting solar energy, arrowroot produces higher dry matter under partial shaded conditions compared to other species (Nedunchezhiyan and Laxminarayana, 2006). Thus, minor tuber crops are suitable candidature to include in crop diversification programme. These crops have great flexibility in mixed cropping systems to generate additional employment and income. Minor tuber crops are capable to utilize available resources more efficiently especially in partial sunlight and residual moisture. In the present chapter, cultural practices of most important minor tuber crops *viz*. yam bean, arrow root, East Indian arrowroot, Queen land arrowroot, gaint taro, typhonium, tacca and tuber cowpea are discussed.

1. Yam bean

Yam bean (*Pachyrrhizus erosus* (L) Urban) popularly known as potato bean. In India it is called 'Mishrikkand' in Bihar, 'Kesaru' in Eastern Uttar Pradesh and 'Sank alu' in Orissa, West Bengal and Assam. The starchy conical or turnip shaped fleshy tubers are eaten by consumers. High sugar content in tubers imparts sweet taste when eaten raw. The fresh tubers are used as salad and can also be made into chips. The young tubers have crisp juicy and refreshing flesh. The over matured tubers become fibrous, hence unsuitable for consumption. In China mature dried roots are reported to be used as a cooling agent for people suffering from high fever. In many countries young immature pods are used as a vegetable. The stem is tough and fibrous and is used for making fish nets in Fiji. The mature seeds have high content of alkaloids and insecticidal properties. In many developed countries the tubers are processed, canned and many sweet preparations are made.

Climate and soil

Yam bean is adapted well in subtropical to humid, hot temperate zones (Nedunchezhiyan and Sahoo, 2019). Its main climatic requirement is frost free conditions during vegetative growth. It can be grown upto 1000 m above mean sea level. Sandy loam soil of good depth is favourable for its cultivation. The soil pH of 6.0-7.0 is ideal.

Variety

Rajendra Mishrikand-1 (RM-1) was released for commercial cultivation. It produces an average yield of 30-35 t ha^{-1}. It matures in 120-135 days.

Land preparation

Deep ploughing of land is done 2-3 times with mould board plough followed by thorough planking to bring the soil to good tilt. This helps conserve moisture in the fields.

Time of sowing

Sowing is done June-September depending upon location/region.

Spacing

Spacing of 60 x 30 cm is recommended. However, in case of late sowing the spacing can be reduced to 45 x 15 cm.

Seed rate

Yam bean is propagated through sexually developed seed. A seed rate of 10-20 kg ha^{-1} is recommended.

Nutritional requirement

Application of farmyard manure @ 10 t ha^{-1} along with NPK @ 80:60:80 kg ha^{-1} is recommended.

Intercultural operation

After planting, care is taken to keep the field weed-free up to first 2 months of crop growth.

Water management

The crop is predominantly grown as a rainfed crop. Optimum moisture supply throughout the growth period gives better yield.

Plant protection

Mealy bug infestation in yam bean was noticed in Odisha. It completely defoliates the leaves and deforms the pods (Nedunchezhiyan et al., 2019). Spraying of imidacloprid 3 ml per 10 litre of water is recommended for effective control.

Intercropping

Generally, it is cultivated as sole crop. Maize is intercropped in yam bean to provide staking support apart from additional yield. Yam bean also intercropped in sweet potato fields to reduce sweet potato weevil incidence.

Harvesting and yield

The crop is harvested 110-130 days after sowing depending upon the location. The variety RM-1 produces an average yield of 30-35 t ha^{-1}.

2. Arrowroot

Starch is a major energy source in human diet. The use of starch products as a food ingredient is usually not based on their nutritional value but on their functional value. In India, three types of arrowroots are cultivated for starch purposes. They are (1) West Indian arrowroot (*Maranta arundinacea* L.), (2) East Indian arrowroot (*Curcuma* spp.) and (3) Queensland arrowroot (*Canna edulis* L.). The starch is extracted by traditional methods from the above three arrowroot crops by the farmers as an off-seasonal activity and marketed locally.

A. West Indian Arrowroot

West Indian arrowroot (*Maranta arundinacea* L.) is grown for its edible rhizomes and starch extraction.

Importance and uses

The high quality starch content of arrowroot is used as food for infants. Arrowroot starch is also used in pharmaceutical industries such as barium meals and in manufacture of tablets.

Nutritive value

The dry matter content varied between 29.5-31.6%. The chemically estimated starch content ranged from 19.1 to 23.0%, whereas extractable starch varied between 16.1 and 19.9%.

Origin and history

The crop is native of tropical America and has long been cultivated in West Indies particularly St. Vincent.

Area and distribution

In Odisha, it is cultivated in Khurdha and Nayagarh districts commercially, and homestead garden in Puri, Cuttack, Ganjam, Kendrapada, Bhadrak, Balasore and Jagatsinghpur districts (Nedunchezhiyan et al., 2022). It is cultivated around 75 ha in Odisha. The exact figures on area under cultivation in other srutes of India is not available.

Climate and soil

The crop grows best at temperature of 20-30^{o}C with a minimum annual rainfall of 95- 150 cm favours its growth. A slightly acidic fertile, deep, sandy loam to loam soil with better drainage facility is most-suited for its cultivation.

Varieties

Generally yellow coloured local cultivars are grown. However, cultivars having blue rhizomes give higher yield of starch than yellow coloured cultivars.

Seed and planting material

Small pieces of rhizomes (known as bits), 4-7 cm long, having 2-4 nodes each is planted in well manured pits. Suckers are also used as planting material. About 1.5 tons of planting material is enough for a hectare of land.

Sowing and planting

The land should be prepared by deep ploughing and bringing soil to fine tilth. Rhizome pieces of 15-20 g were planted on raised bed at a spacing of 60 cm x 30 cm under.

Nutritional requirement

Application of farmyard manure @ 10 t ha^{-1} along with NPK @ 50:25:75 kg ha^{-1} is recommended.

Intercultural operation

After planting, care is taken to keep the field weed-free up to first 3-4 months of crop growth.

Water management

The crop is predominantly grown as a rainfed crop. Optimum moisture supply throughout the growth period gives better yield.

Plant protection

It was observed that *Maranta* species is a handy crop and there is no report of pest and diseases.

Harvesting and yield

The crop attains maturity in 10-11 months after planting. Maturity is indicated by yellowing, wilting and drying up of leaves. At this stage, the plants are dug out and the rhizomes separated from the leafy stem. Under favourable conditions rhizome yield of 25-30 t ha^{-1} can be obtained. Intercropping arrowroot in coconut, arecanut and rubber also augments the net income from these plantations. The amount of starch obtained is 16-18% of the fresh weight of the rhizome. Average production of starch per hectare is 3-3.5 t.

Post harvest and processing

Small rhizomes are used for generating planting material whereas bigger sized rhizomes are mainly used for starch production through further processing. For preparing starch, the rhizomes are washed, cleaned and made into a paste in a grinding stone. The starch gives highly viscous paste with water. The paste is stirred up with water and starch is allowed to settle. The supernatant liquid is decanted residue again stirred up with water strained through muslin and starch allowed to settle. The process is repeated several times until the bitter taste is removed and a white product is obtained. The flour is finely dried in the sun.

Traditional food preparation

The arrowroot tubers are eaten after boiling or roasting. The arrowroot powder is made by grounding dried roots into very fine flour. Unlike corn starch, it doesn't impart a chalky taste when undercooked. Arrowroot thickens at a lower temperature than does flour or corn starch. It is recommended to mix Arrowroot with a cool liquid before adding to a hot fluid. The lack of gluten in arrowroot flour makes it ideal as a replacement for wheat flour in baking. So it is employed widely in the preparation of pastries, biscuits, cakes, puddings, and jellies. Arrowroot makes clear, shimmering fruit gels and prevents ice crystals from forming in homemade ice cream. In India, it is added to vegetable, fish and meat dishes not only as spice for taste but also as food thickener. The leaves of the plant are used with meat and fish. In Kerala state of India, Arrowroot *Halwa* is a popular food, which is recommended for people with digestive disorders. The *halwa* is prepared using arrowroot flour along with Jaggery, nuts, raisings cooked in ghee. In Odisha state of India, the crude starch extracted from East Indian Arrowroot is used for preparation of a baby food, 'Palua', which is mixed with milk for feeding babies. Arrowroot is respected as food for infants, invalids and convalescents due to its easy digestibility. Arrowroot flour is used as binder in soups and sauces.

B. East Indian Arrowroot

East Indian arrowroot (*Curcuma* spp.) is a perennial herb and grown for its starchy rhizomes. In India, it is locally known as 'Shoti'. *Curcuma angustifolia* Roxb. and *Curcuma zedoaria* Rosc. are cultivated for starch production.

Importance and uses

The tubers are rich in starch. The 'Shoti' starch is highly valued as an article of diet, especially for infants and convalescents.

Nutritive values

The dry matter content varied between 24.5-25.2%. The extractable starch is varied between 14 and 15%.

Area and distribution

In Odisha, it is cultivated in Keonjhar and Mayurbanjh districts commercially, and homestead garden in Kandhamal and Koraput districts (Nedunchezhiyan et al., 2022). It is cultivated around 50 ha in Odisha.

Climate and soil

It is widely cultivated in many parts of Ceylon and China. It grows well up to 3000 ft altitudes and requires 100-125 cm rain year^{-1}. It can be grown as a crop after summer fallows varieties

Local land races are in cultivation in traditional cultivated areas in central, East, and NE states.

Seed and planting material

The plant is propagated by rhizomes. The seed materials are large mother rhizomes cut into small pieces bearing buds.

Sowing and planting

The land should be prepared by deep ploughing and bringing soil to fine tilth during February-March. Ridge and furrow should be made at 45-60 cm spacing. Planting is done just before the onset of the monsoon during early-June. Rhizome pieces of 15-20 g were planted on raised bed at a spacing of 30 cm.

Nutritional requirement

Application of farmyard manure @ 10 t ha^{-1} along with NPK @ 50:25:75 kg ha^{-1} is recommended.

Intercultural operation

After planting, care is taken to keep the field weed-free up to first 3-4 months of crop growth.

Water management

The crop is predominantly grown as a rainfed crop. Optimum moisture supply throughout the growth period gives better yield.

Plant protection

No pest and diseases incidence we are noticed in this crop.

Harvesting and yield

The plant withers and dries upwards in December-January. The rhizomes are large, fleshy branched and the inner part of which is pale yellowish brown. The yield of tubers varies from 20- 22 t ha^{-1}.

Post harvest and processing

For preparing 'Shoti' starch, the rhizomes are washed, cleaned and made into a paste in a grinding stone. The starch gives highly viscous paste with water. The paste is stirred up with water and starch is allowed to settle. The supernatant liquid is decanted residue again stirred up with water strained through muslin and starch allowed to settle. The process is repeated several times until the bitter taste is removed and a white product is obtained. The flour is finely dried in the sun. Steam distillation of the rhizome yields 1-2 per cent light yellow colour essential oil.

C. Queensland Arrowroot

Queensland arrowroot (*Canna edulis* L.) is a perennial herb and grown for the branched fleshy rhizomes. The plant is hardy and in view of the low incidence of pests and diseases and wind resistance of the crop in the typhoon prone regions, it is considered easy to grow.

Importance and uses

The tuber and top of the plant are used as livestock feed. The starch extracted from the Queensland arrowroot is easy to digest and hence used as a food for children and invalids. The young rhizomes are eaten as vegetable. The cooked tubers are delicious whereas the young shoots and petioles are used as fodder (Nedunchezhiyan et al., 2022).

Nutritive value

The dry matter ranged from 34.5 to 36.4%, whereas starch ranged between 26.2 to 27.9%.

Origin and history

It is native of tropical America. The genus *Canna* contains about 65 species and widely distributed in the tropics and subtropics particularly in the western hemisphere. It is commercially cultivated in Australia for its starch.

Area and distribution

In India, it is cultivated in Odisha and Kerala. In Odisha, around 125 ha cultivated in Koraput and Rayagada districts (Nedunchezhiyan et al., 2022).

Climate and soil

It grows in most of the soils except gravelly and heavy wet clay soils.

Varieties

Local land races are in cultivation in traditional cultivated areas.

Seed and planting material

The plant is propagated by rhizomes. The seed materials are large mature rhizomes cut into small pieces bearing buds.

Sowing and planting

The land should be prepared by deep ploughing and bringing soil to fine tilth during February-March. Ridge and furrow should be made at 60 cm spacing. Planting is done just before the onset of the monsoon during early-June. Rhizome pieces of 15-20 g were planted on raised bed at a spacing of 30-60 cm at 5 cm depth.

Nutritional requirement

Application of farmyard manure @ 10 t ha^{-1} along with NPK @ 50:25:75 kg ha^{-1} is recommended.

Intercultural operation

After planting, care is taken to keep the field weed-free up to first 3-4 months of crop growth.

Water management

The crop is predominantly grown as a rainfed crop. Optimum moisture supply throughout the growth period gives better yield.

Plant protection

It was observed that *Canna* species is not infested with pest and diseases.

Intercropping

Maize is intercropped in *Canna* to increase farm productivity and income. In Odisha, *Canna* is planted at 60 x 60 cm spacing. *Canna* being a long duration crop gives return after 7-8 months. Wide spacing allows short duration intercrops. Maize being short duration crop is sown in intra-rows at a spacing of 60 cm i.e. 1:1 ratio. Thus, full population of *Canna* (27,777 plants ha^{-1}) and 27,777 plants ha^{-1} of maize is accommodated. Maize is harvested 3 months after sowing at physiological maturity to facilitate *Canna* to grow without any competition for nutrient and shade at the later stage.

Harvesting and yield

The plant withers and dries upwards in December-January. The rhizomes are large, fleshy branched purple in colour. The yield of tubers varies from 20-25 t ha^{-1}.

Post-harvest and processing

Canna starch is obtained from the tubers by a process of rasping, washing, and straining.

The final product is a shiny cream coloured powder.

3. Giant taro

Giant taro (*Alocasia indica* (Roxb) Schott.) is also called elephant ear because it produces large undivided leaves some what similar to those of *Xanthosoma* and *Colocasia* which has led gardeners to confusion between the genera. However, there are lot of differences and apart from size and shape of the plant and leaves. There is a difference in flowering and flowers.

Importance and uses

Modified stem (corm) is the edible economic part in giant taro. It has lot of acridity. Hence it is not popular. Addition of small amount of betel nut chips (*Areca catechu*) or small amount of slake lime will remove the acridity during boiling. Leaves also consumed as vegetable. Petiole and corms have a lot of medicinal value. It is considered as famine food in Pacific Islands. Being rich in minerals especially iron, it is widely used as an important diet during the postnatal period.

Climate and soil

Alocasia grows well in tropical conditions with well distributed rainfall of over 1500 mm and does best in rich moist but well drained high organic matter content soil. Partial shade is ideal for its growth but it can tolerate full shade. Although tropical in origin this herbaceous perennial is a little hardy for colder than many of its relatives. It can also tolerate shallow flooding but it cannot tolerate salt.

Seed and planting material

Propagation is by severing the rhizomes between upright stems or separating shoots off from the parent plant. Stem cuttings also root readily in spring and summer. The reddish seeds that develop along the spadix should be planted as soon as they ripen.

Spacing

A spacing of 90 cm row to row and 90 cm plant to plant is recommended for commercial cultivation of alocasia.

Fertlizer

A fertilizer dose of N;P_2O_5:K_2O 150:75:100 kg/ha is required for a commercial crop. Half dose of nitrogen and potassium and full dose of phosphorus can be applied as basal and the remaining half dose of nitrogen and potassium can be applied two months after planting.

Weeding

Two to three weeding at monthly interval is required for reduction of weed impact on crop yield.

Harvest

The cylindrical corm is stem like with part of it under ground. Annual crop yield is 25-30 t ha^{-1}. However, in perennial crops, the corm is 1-2 m high and 0.3 m in diameter. The corm increases in length and breadth during the growth period and a 15-25 kg corm can be harvested with 2-3 years crop cycle per plant. The corm though edible is not popular because of its acridity.

Giant swamp taro

Giant swamp taro (*Cyrtosperma chamissionis* syn. *Cyrtosperma merkusii* Schott) is small species of aquatic aroids, found growing wild in fresh water swamps, rivers and lakes as weeds. During the early twentieth century it was a very popular crop in South East Asia and staple food for some people in Malay Island and Philippines but today there is hardly any cultivation of this plant except self-sown in swampy areas. It is generally called Palauan in Philippines. It is rich in carbohydrates but poor in other nutrients. Decoction of the spadix of this plant is used as indigenous medicine.

Origin and history

Cyrtosperma is a small genus with 12 species. All species with exception of *Cyrtosperma merkusii* are confined to New Guinea and associated islands, Philippines, Borneo, Sumatra, Java and Oceania. *Cyrtosperma merkusii* or swamp taro is terrestrial usually grown in a toll pit gardens and in freshwater swamp or marsh area and is the largest of taros. Originated in South-East Asia, perhaps in Indonesia it spread throughout Malayan Archipelago and Pacific territories.

Corms

The corms develop by thickening at base of stem and almost cylindrical in shape and externally resemble a banana sucker (Nedunchezhiyan and Misra, 2013).

4. Typhonium

Typhonium trilobatum (L.) Schott. is belongs to araceae family. The crop is grown in tropical and sub tropical regions is a rich source of carbohydrates and minerals (Nedunchezhiyan and Misra, 2013). It is used as a vegetable and for preparation of chips and pickles. The plant is hypnotic. Fresh corms are very acrid and a powerful stimulant; employed as a poultice in tumours. The corms are reported to relax the bowels and provide relief in haemorrhoids and piles. They are eaten with bananas to cure the stomach complaints. The Garo of Madhupur applies root paste locally on ulcer of cattle. Tubers and roots contain a volatile acrid principle, β- sitosterol, two unidentified sterols and an unidentified crystalline compound.

It is a popular tuber crop in Tamil Nadu, India. With a high demand and price in the market, *Typhonium* is a preferred crop in irrigated dry lands as well as command areas.

Climate and soil

Typhonium grows well in tropical conditions with well distributed rainfall of over 1500 mm and does best in rich moist but well drained high organic matter content soil.

Spacing

A spacing of 90 cm row to row and 30 cm plant to plant is recommended for commercial cultivation of *Typhonium*.

Fertlizer

A fertilizer dose of NPK 100:75:100 kg ha^{-1} is required. Half dose of nitrogen and potassium and full dose of phosphorus can be applied as basal and the remaining half dose of nitrogen and potassium can be applied two months after planting.

Weeding

Two to three weeding at monthly interval is required for reduction of weed impact on crop yield.

Irrigation

Drip irrigation at 75 or 100% CPE with fertigation of N and K was found to increase the tuber yield 55-62%.

Harvest

The crop recorded tuber yield of 750-1200 g $plant^{-1}$ and 25-35 t ha^{-1}.

5. Tacca

Tacca pinnatifida Forst and Forst. f. is originated in South East Asia and is widely distributed on the moist tropics of Asia, Australia and Pacific islands. The genus *Tacca* includes about 30 species of perennial herbs with tuberous or creeping rhizome. The plant is a perennial herb grows to a height of 60-90 cm. The tubers are globose 15-20 cm in diameter and harvested after the lops have died down. The tubers are used for the treatment of piles. The Rubefacient, a bitter extract is prepared by washing the grated tubers in running water and that is given in diarrhea and dysentery (Nedunchezhiyan and Misra, 2013).

The fresh acrid bitter tuber yields a nutritive starch having excellent culinary properties. It is known as 'Tahiti' or 'Fiji' or 'East Indian arrowroot starch'. The starch is used to prepare porridges, cakes and other sweet meals. It is also mixed with wheat flour for making bread. The starch is recommended as a food for invalids and also used as laundary starch. Tuber yield ranged from 150-250 g plant^{-1} and the shape of the tubers resembles potato. The tubers possess 22.4% dry matter and 10.2% starch.

6. Jerusalem artichoke

Jerusalem artichoke (*Helianthus tuberosus* L.) is one of the tuber yielding crops in the genus *Helianthus* which comprises about 75 species. The tubers resemble potatoes but with larger eyes (Nedunchezhiyan and Sahoo, 2019).

Importance and uses

Jerusalem artichoke tubers are eaten as raw or boiled. In food value, they are considered equal to potatoes. They are also pickled made into chips or ground into flour. Jerusalem artichoke has aroused much interest since the commercial source of levulose used as sweetening agent for diabetics. Fresh tubers are sliced and juice is acidified and heated to hydrolase inulin and inulides. Neutralization with lime yields calcium levulate which is separated by precipitation and filtration. Carbonation of calcium levulose yields a syrup containing levulose from which sugar is crystallized (yields 6% on fresh weight of tuber). Fructose syrups suitable for use as sweeting agents may be prepared. The tuber may also be utilized for the preparation of industrial alcohol by fermentation and beer like beverages. Tubers are used as feed for stock. A rich palatable feed for good digestability comparable to sugar beet in feeding value is obtained by ensilage. Green tips and stems of young plants are used as feed for cattle, they may be ensilaged. The stalks may be treated by soda chlorine process to give a pulp which is suitable for the manufacture of certain type of papers.

Area and distribution

This hardy crop is cultivated for its edible tubers in Europe, parts of Asia and throughout the temperate regions of many parts of the world. In India, it is reported to have been introduced in Assam, Bengal, UP, Bombay, Vadodara and Hyderabad.

Climate and soil

In India the plant is grown to a limited extent in gardens and in the hill stations at an elevation of 300-800 m but it can be grown under wide range of soil and climatic conditions. It can be cultivated successfully even in lands unsuitable for many other vegetable crops. It is well adapted to rich sandy or light loam and alluvial soil, the digging of tubers is easier.

Seed and planting material

The plant is propagated by tubers or setts.

Sowing and planting

The soil should be well prepared by ploughing. Whole tuber or tuber pieces with 2-3 eye buds planted about 8 cm deep and 30-45 cm apart in rows the spacing between rows being 60-90 cm. the planting is done during March-May in the plains and February-April in the hills.

Nutritional requirement

The crop should be adequately manured either farmyard manure or compost. The crop is also responds to application of chemical fertilizers.

Intercultural operation

Keeping weed free for first three months is essential for growth and development of the crop. Earthing up is necessary as in the case of potato crops when seedlings reach about 30 cm height. Flowers are to be removed as soon as they appear.

Water management

Irrigation may be necessary once a week during dry weather.

Harvesting and yield

The crop takes 4-6 months from planting to mature. The tubers are ready for harvest when the leaves are withering and the stem commences to die down. It is advisable to leave the tubers in the soil until required as they preserve their delicacy and flavor better when left undisturbed. The yield of tubers varies from 12.0-24.5 t ha^{-1}.

7. Tuber cowpea

Tuber cowpea (*Vigna vexillata* (L.) A. Rich) is a pan-tropical herbaceous legume having a chromosome number 2n-2x=22. It is widely distributed throughout southern and eastern Africa, the Indian subcontinent, south-east Asia, Indonesia, Papua New Guinea and Australia. Two domesticated forms of *Vigna vexillata* have been reported; seed type and tuber (storage root) type. Considered to have domesticated the seed type in Sudan (Africa), the tuber type is thought to have originated in the Indonesian region that extends to India (Dachapak et al., 2018). The cultivation of *Vigna vexillata* as a root crop has been reported in East and North-eastern India, where it is locally known as 'halunda' (Sasikumar and Sardana, 1988), and in the foothills of the Himalaya region. Cultivated forms of *Vigna vexillata* from several localities in Bali and West Timor in Indonesia, where it is known to be more adapted to drought compared with other traditional, non-legume, root crops. In Bali, the local people know the crop as Jempirangan, while in West Timor, it is recognized as Kamberiti. In the islands of Sumba and Flores, where the plant is called Oehala and Fanuatuful, the tubers are collected from plants in the wild. Wild forms of *V. vexillata* have also been used as a 'bush tucker' plant by aborigines in Australia. It is a potential and under-exploited legume bearing both edible green pods and root tubers in the same plant known by several names *viz*. tuber cowpea, zombi pea, wild cowpea, etc. (Tripathi et al., 2021). The main roots develop tubers after 2-3 months of growth. These resemble those of sweet potato and average 12-13 cm long. The plant can be propagated by seed and vegetatively by stem cuttings.

Vigna vexillata is considered as a donor for cowpea improvement because of resistance to bruchids, flower thrips, pod borer, powdery mildew and cowpea mottle virus. The storage roots had a light brown skin, a creamy coloured flesh inside had a taste like potatoes with a small groundnut aroma. The protein content of edible tubers of *Vigna vexillata* is about 15%, which is about three times higher than that of potatoes and yams and six times more than that of cassava.

Climate and soil

It grows well in sub-tropical and temperate conditions in sandy loam soil.

Spacing

Plant spacing of 45 x 15-30 cm is recommended (Priyadarsini, 2022).

Fertlizer

FYM 5 t ha^{-1} along with NPK 20-40-20 kg ha^{-1} is recommended. Half dose of nitrogen and potassium and full dose of phosphorus can be applied as basal and the remaining half dose of nitrogen and potassium can be applied one months after sowing.

Weeding

Two weeding at monthly interval is required for reduction of weed impact on crop yield.

Harvest

The crop recorded tuber yield of 11-15 t ha^{-1} and green pod yield of 5-6 q ha^{-1}.

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Chapter 9

Climate change modelling studies of tuber crops

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Climate change

The industrial revolution which started with the invention of steam engine in 1780 by James Watt marked the beginning of a more active human interference in the web of life. This has been causing increase in the concentrations of atmospheric gases through increased emissions from energy, industry, agriculture, forestry, land use and land use change. The concentrations of CO_2, CH_4 and N_2O, the three most important greenhouse gases (GHG), in 1850-1900 were 280 ppm, 790 ppb and 270 ppb which in 2019, as per assessment report 6 (AR6), increased to 410 ppm, 1866 ppb and 332 ppb. Since 1750, there were 47, 156 and 23% increase of these gases in 2019. In 2019, concentrations of other important GHGs namely PFCs, SF_6, NF_3, HFCs and CFCs & HCFCs were 109, 10, 2, 237 and 1032 ppt. Table 1 shows the

Table 1. Annual, cumulative and per capita emissions of GHGs

Emission	Unit	World	China	US	India
CO_2 (land use change not included)					
Annual Emission, 2020	Billion tons	34.81	10.67 (31%)	4.71 (14%)	2.44 (7%)
Cumulative Emission (1850-2019)	Billion tons	2390	235.56 (13.89%)	416.72 (24.56%)	54.42 (3.21%)
Per capita Emission, 2020	Tons	4.47	7.41	14.24	1.77
CH_4					
Annual Emission, 2016	Billion tons	8.55	1.26	0.629	0.663
Per capita Emission, 2016	Ton	1.15	0.89	1.95	0.5
N_2O					
Annual Emission, 2016	Billion tons	3.05	0.556	0.252	0.247
Per capita Emission, 2016	Ton	0.41	0.39	0.78	0.19
Total GHG					
Annual Emission, 2016	Billion ton	49.36	11.58	5.83	3.24
Per capita Emission, 2016	Ton	4.92	6.72	14.83	1.74

annual, cumulative and per capita GHG emissions. According to AR6, starting 2020, the world is left with a total C budget of 400 billion tons for all times to come if we have to limit the temperature rise to the ambitious 1.5^{o}C goal of 2015 Conference of the Parties (CoP-21) or the Paris Agreement. For this, we have to bring down the current annual emission of 34.81 billion tons of CO_2 to 18.22 billion tons in 2030. In 'business-as-usual' scenario, it will be 40.66 billion tons and even if all countries meet their nationally determined contributions (NDCs), it will be 37.71 billion tons.

The AR6 says that the radiative forcing in 2010-2019 increased to 1.96-3.48 W m^{-2} with a best estimate of 2.72 W m^{-2} relative to 1750. The rate of heating of the climate system increased from 0.50 (0.32-0.69) W m^{-2} for the period 1971-2005, to 0.79 (0.52-1.06) W m^{-2} for the period 2006- 2018. Over 1971-2006 period, the cumulative energy increase was 282 (177-387) ZJ, while it was 152 (100-205) ZJ over 2006-2018 (1ZJ = 10^{21}J). Ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for 5, 3 and 1%, respectively. Compared to 1850-1900, global surface temperature averaged over 2010-2019 increased to 0.8-1.3^{0}C with a best estimate of 1.07^{o}C and is projected to increase to 1.0-1.8^{o}C (1.4^{o}C), 2.1-3.5^{o}C (2.7^{o}C) and 3.3-5.7^{o}C (4.4^{o}C) under shared socioeconomic pathways, SSP1-1.9 (low emission), SSP2-4.5 (intermediate emission) and SSP5-8.5 (high emission) scenarios. Hot extremes including heatwaves have become more frequent and more intense since 1950s, while cold extremes including cold waves have become less frequent and less severe. Marine heat waves have approximately doubled in frequency since 1980s. Globally averaged precipitation increased since 1950 with a faster rate of increase since 1980s. The frequency and intensity of heavy precipitation events have increased since 1950s. The average annual global land precipitation is projected to increase by 0–5% under the very low GHG emissions scenario (SSP1-1.9), 1.5-8% for the intermediate GHG emissions scenario (SSP2-4.5) and 1–13% under the very high GHG emissions scenario (SSP5-8.5) by 2081–2100 relative to 1995-2014. It is very likely that rainfall variability related to the El Nino–Southern Oscillation (ENSO) is projected to be amplified by the second half of the 21st century in the SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios. Human-induced climate change has contributed to increases in agricultural and ecological droughts. Occurrence of major tropical cyclones has increased over the last four decades. Human influence also contributed to increase in near-surface ocean salinity. Human influence is the main driver of the global retreat of glaciers since 1990s and the decrease in Arctic sea ice between 1979-1988 and 2010-2019. Human influence is the main driver for the warming of the upper ocean since 1970s as well as in increasing global mean sea level since 1901. Global mean sea level increased by 0.20 (0.15-0.25) m between 1901 and 2018. The average rate of sea level rise was 1.3 (0.6-2.1) mm $year^{-1}$ between 1901-1971, increasing to 1.9 (0.8-2.9) mm $year^{-1}$ between 1971 and 2006, and further increasing to 3.7 (3.2-4.2) mm $year^{-1}$ between 2006 and 2018. Relative to 1995-2014, the likely global mean sea level rise by 2100 is 0.28-0.55

m under the very low GHG emissions scenario (SSP1-1.9), 0.32-0.62 m under the low GHG emissions scenario (SSP1-2.6), 0.44-0.76 m under the intermediate GHG emissions scenario (SSP2-4.5), and 0.63-1.01 m under the very high GHG emissions scenario (SSP5-8.5). Changes in land biosphere since 1970, pole ward shifting of climate zones in both hemispheres and average lengthening of growing period up to 2 days per decade since 1950s in the northern hemisphere extratropics are the other important effects of global warming.

Possible climate futures show that global warming of 1.5°C relative to 1850-1900 would be exceeded during the 21st century under the intermediate, high and very high scenarios (SSP2-4.5, SSP3-7.0 and SSP5-8.5, respectively). Under the 5 illustrative scenarios, in the near term (2021- 2040), the 1.5°C global warming level is very likely to be exceeded under the very high GHG emissions scenario (SSP5-8.5), likely to be exceeded under the intermediate and high GHG emissions scenarios (SSP2-4.5 and SSP3-7.0), more likely than not to be exceeded under the low GHG emissions scenario (SSP1-2.6) and more likely than not to be reached under the very low GHG emissions scenario (SSP1-1.9). Furthermore, for the very low GHG emissions scenario (SSP1-1.9), it is more likely than not that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.

Fossil fuel combustion and cement manufacture contributes 75% of CO_2 emission into atmosphere. Other major CO_2 sources are deforestation, microbial decay of plant litter, crop residue barning, changing agricultural practices and land use changes. Ruminant livestock and water logged rice cultivation are the major sources of CH_4. Ruminant animals such as cattle, goat and sheep and some non-ruminant animals such as pigs and horse produce methane through enteric fermentation. Fermentative digestion of stored manures also release CH_4. Organic matter decomposition under anaerobic conditions – methanogenesis- produce CH_4 and it escape through air bubbles and by transport through rice plants. Decomposition of manure under anaerobic conditions is another source of CH_4. Incomplete combustion of biomass during burning, decomposition of organic wastes in landfills and 'fugitive emissions' during oil and gas extraction from fossil fuel are other important CH_4 sources. Application of N chemical fertilizers to soils is the major N_2O source and is more under wet conditions where available N is more than plant requirements. Aerobic or mixed aerobic/anaerobic conditions, addition of N through biological fixation, crop residues, sewage sludge or other organic N sources also contribute to atmospheric N_2O emissions.

Energy sector is first major source contributing 73.20% GHG emission which include industry (24.20%), transport (16.2%), buildings (17.5%), unallocated fuel combustion (7.80%) and fugitive emission from fuel production (5.80%). Industry sector includes iron and steel (7.20%), chemical and petrochemical (3.60%), feed and tobacco (1.00%), non-ferrous metals (0.70%), paper and pulp (0.60%), machinery (0.50%) and other industry (10.60%). Transport sector includes road transport (11.90%), aviation (1.90%), shipping (1.70%), rail (0.40%) and pipeline (0.30%). In buildings sector, residential buildings contribute 10.90% and commercial buildings 6.6%. Second major source is direct industrial processes contributing 5.20% which include cement manufacture (3.00%) and petrochemicals (2.20%). Waste is the third source causing 3.20% GHG emissions which include landfills (1.90%) and waste water (1.30%). Fourth and the source of our interest is agriculture, forestry and land use which contribute 18.40% of total GHG emissions. Livestock and manure (5.80%), agricultural soils (4.10%), crop residue burning (3.50%), deforestation (2.20%), cropland (1.40%), rice cultivation (1.30%) and grassland (0.10%) are the contributors in this sector.

Climate change and food security

In terms of population, it is estimated that between 720 and 811 million people in the world faced hunger in 2020. Considering the middle of the projected range (768 million), 118 million more people were facing hunger in 2020 than in 2019, with estimates ranging from 70 to 161 million. About one in five people (21 percent of the population) was facing hunger in Africa in 2020 – more than double the proportion of any other region. This is followed by Latin America and the Caribbean (9.1 percent) and Asia (9.0 percent). Of the total number of undernourished people in 2020 (768 million), more than half (418 million) live in Asia and more than one-third (282 million) in Africa, while Latin America and the Caribbean accounts for about 8 percent (60 million). Moderate or severe food insecurity (based on the Food Insecurity Experience

Scale) at the global level has been slowly on the rise, from 22.6 percent in 2014 to 26.6 percent in 2019. Then in 2020, the year the COVID-19 pandemic spread across the globe, it rose nearly as much as in the previous five years combined, to 30.4 percent. Thus, nearly one in three people in the world did not have access to adequate food in 2020 – an increase of 320 million people in just one year, from 2.05 to 2.37 billion. Nearly 40 percent of those people – 11.9 percent of the global population, or almost 928 million – faced food insecurity at severe levels. Close to 148 million more people were severely food insecure in 2020 than in 2019.

Food security is achieved "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life". Climate change influences food production in many ways. Increase in ambient CO_2 concentration leads to increased photosynthesis in C_3 plants such as wheat and rice and decreased evaporative losses. Despite this, yields of major cereal crops, especially wheat, are likely to be reduced due to decrease in grain filling duration, increased respiration, and / or reduction in rainfall / irrigation. Extreme weather events such as floods, droughts, cyclones and heat will adversely affect agricultural productivity. India and its neighboring countries experienced a severe and longest heatwave from mid-May to mid-June in 2019. Chiru in Rajasthan state, India documented a record of high temperature up to 50.8°C, which was very close to the highest recorded value of 51.0°C in 2016. Yield of rice declined by 10% for each 1°C increase in the growing season minimum temperature above 32°C. When all other climatic variables were kept constant, temperature increases of 1, 2 and 3 reduced yield of rice by 5.4, 7.4 and 25.1%, respectively. Doubling of CO_2 concentration will decrease global rice yields up to 40%, primarily due to heat-induced floret sterility. A 0.5°C increase in winter temperature will reduce wheat yield by 0.45 t ha^{-1} by decreasing the crop duration by 7 days. Climate change is projected to reduce wheat yield in India by 6-23% and 15-25% in 2050 and 2080. Crop yields under optimal growth conditions will increase by 10-20% and 0-10% for C_3 (wheat, rice and soybean) and C_4 (maize and sorghum) plants at 550 ppm CO_2. Increasing CO_2 declines protein levels in legumes and grain quality of cereals. Quality of fruits, vegetables, tea, coffee, aromatic and medicinal plants also may be affected. Crop yields in rainfed areas will decrease due to changes in rainfall pattern during monsoon and increased crop water demand. Incidence of cold waves and frost events may decrease in future and will lead to decreased yield loss of mustard and vegetables in northern India. Pests, diseases and weeds are likely to move, following climate change, affecting areas previously immune, and thus less prepared, biologically and institutionally, to manage and control them, with potentially higher negative impacts.

Climate change and climate variability are impacting forests and their capacity to deliver the wide range of goods and environmental services on which an estimated 1.6 billion people fully or partly depend for their livelihoods and resilience. Climate change is contributing to decreased productivity and dieback of trees from drought and temperature stress, increased wind and water erosion, increased storm damage, increased frequency of forest fires, pest and disease outbreaks, landslides and avalanches, changes in ranges of forest plants and animals, inundation and flood damage, salt water intrusion and sea-level rise, and damage from coastal storms. This can jeopardize the contribution of forests to the resilience of agricultural systems, such as water and temperature regulation at landscape level and the provision of habitats for important species like pollinators. Incidence of weeds, insects and diseases will be altered and there will be rapid pathogen transmission and increased host susceptibility. Agricultural biodiversity is also threatened under changing climate. Extended wet conditions affect harvest of crops and disruption of crop storage facilities. Demand for irrigation water will increase causing lowering of groundwater table at some places. The melting of glaciers in the Himalayas will increase water availability in the Ganges, Brahmaputra and their tributaries in the short-run, but in the long run, the availability of water will decrease considerably. A significant increase in run off is projected in wet season which may lead to increase in frequency and duration of floods. Groundwater quality along the coastal tract will be affected due to intrusion of sea water. Loss of soil organic matter will happen due to accelerated erosion which will also affect organic matter quality. Higher C:N ratio of crop residues may reduce rate of decomposition and nutrient supply. Increase in soil temperature will increase N mineralization, but its availability may decrease due to increased gaseous losses through volatilization and denitrification. Climate change will affect fodder production and nutritional security of livestock. Increased temperature will enhance lignification of plant tissues and reduce digestibility. Increased water scarcity will also decrease production of feed and fodder. Increase in vector population in cooler and wetter areas lead to large outbreak of diseases. There will be increase in water, shelter and energy requirements of livestock for meeting the projected milk demands. Climate change also aggravates heat stress in dairy animals, adversely affecting their reproductive performance. Increased occurrence of coral reef bleaching has been observed, threatening habitats of one out of four marine species. Various fish species are already migrating poleward, resulting in the rapid 'tropicalization' of mid - and high - latitude systems. A large - scale redistribution of global marine fish catch potential is forecast, with a decrease of up to 40 percent in the tropics, and an increase of 30 to 70 percent in high- latitude regions.

The normal rainfall of our country based on 50 years (1961-2010) long period average is 1187 mm of which 73.4 percent (880 mm) is received during south-west monsoon (June-September), 13.3 percent during north-east monsoon (post-monsoon), 10.4 percent during pre-monsoon (March-May) and 2.9 percent during winter rains (January-February). Fifty six percent of the net cultivated area in India is rainfed contributing 44 percent of annual food production. Hence our country's food security is closely linked with rainfall. Timely onset and spatial distribution of south west monsoon (June-September) rainfall is crucial for farming and kharif crops account for 90 percent of paddy, 70 percent of coarse cereals and 70 percent of oilseeds production in India. Coastal areas of India, especially Tamil Nadu receive a major portion of rain from north east monsoon (October-December). Our country is facing recurrent droughts in the recent past and during the period 1801-2019, there were 45 drought years of which 1972, 1979, 1987, 2002, 2009, 2015 and 2018 were the severe drought years and all these occurred during the past 50 years.

The above impacts of climate change on agricultural production translate into economic and social consequences, affecting food security. At the farm/household level, climate change impacts may reduce income level and stability, through effects on productivity, production costs or prices. Such variations can drive sales of productive capital, such as cattle, which reduces long-term household productive capacity. Reductions and risks to agricultural income have also been shown to have effects on household capacity and willingness to spend on health and education. At national level, exposure to climate risks can trigger shocks on agricultural production and food availability, with risks of market disruptions, effects on supply and storage systems, as well as increases in agricultural commodity prices (food and feed), impacting accessibility and stability of food supplies for the entire population, particularly in countries with significant shares of the population spending a large part of their income on food. At global level, it affects supply flows and food price spikes, with increased market volatility and impact bilateral contracts and/or import/export behaviour, with disruption of trade patterns. Food price volatility is likely to be exacerbated by climate change. Trade is expected to play a major role in adjusting to climate-change- driven shifts in agricultural and food production patterns. As shown above, climate change affects food production, and thus food availability. Climate change will impact the livelihoods and income of small- scale food producers and also, through food price increases and volatility, the livelihoods of poor net food buyers, restricting access to food. Impacts of climate change on nutrition have been much less studied. Studies point to potential changes in the nutritional quality of some foods (e.g. reduced concentration in proteins and in some vitamins and minerals), due to elevated CO_2, particularly for flour from major cereals and cassava. Climate change can have a variety of impacts on the quality of drinking water, which is key to the good absorption of nutrients. Climate change has been found to have an impact on food safety, particularly on incidence and prevalence of food-borne diseases. Increased climate variability, increased frequency and intensity of extreme events as well as slow ongoing changes will affect the stability of food supply, access and utilization.

Ensuring food security under changing climate

Increasing the resilience of livelihoods is an urgent area of intervention. Firstly, adequate and well-designed social protection would tackle some of the main vulnerabilities of households to climate risks. Income provided to the poor and hungry through social protection can enable them to access sufficient food to meet their basic nourishment needs, without compromising the future productivity of their livelihoods. Secondly, building resilience of agricultural systems by implementing measures that are very system- and local-specific is important. Adaptation measures for crops include use of adapted varieties with different environmental optima and/or broader environmental tolerances. Germplasm with greater oxidative stress tolerance may be exploited as oxidative stress tolerance is one example where plant's defense mechanism targets multiple biotic stresses. Increasing the radiation use efficiency is another area that needs research attention.

Erosion control (contour ploughing, terracing), conservation tillage, addition of organic amendments (compost, manures, crop residues), use of Pusa Bio Decomposer to turn crop residue into organic manure in 15-20 days, use of cover crops, legume intercropping, crop rotation, integrated cropping/farming systems and scientific organic farming are important. Subsoiling to enhance soil moisture and nutrient availability; conservation furrows to conserve percolated rain water in plant root zone; trench-cum-bunding allowing percolation of rainwater and retention of moisture at the root zone for longer period; broad bed furrows to improve drainage and conserve soil moisture; ridges and furrows that retain soil moisture and maintains proper drainage; zero tillage that utilizes residual soil moisture, add organic matter and reduces cost of cultivation; plastic mulching to control weeds, conserve soil moisture, reduce erosion, improve soil structure and enhance soil organic matter content; crop intensification with conserved soil moisture – eg. sunhemp seed production in rice fallows; compartmental bunding; use of Pusa Hydrogel for absorption and retention of soil moisture and slow release for longer period and pani pipe technology to reduce number of irrigations and recharging of ground water are important *in situ* soil moisture conservation techniques. Water saving techniques include SRI method of paddy cultivation utilizing less water, less seed, less chemical fertilizers and pesticides; direct seeding of paddy with drum seeder to conserve seed, moisture and labour; broadcasting of paddy which is labour saving with low cost of cultivation and drip irrigation with high water use efficiency. Technologies to improve nutrient use efficiency such as site specific nutrient management (SSNM), leaf colour chart (LCC), use of urease inhibitor (NBPT, hydroquinone), nitrification inhibitor (neem coated urea, dicyandiamide, DMPP, nitrapyrin, SBT), double inhibitors (NBPT+DCD, super U) and controlled release N fertilizers (polymer coated urea, ESN, RCU, PoCU, N fusion) need wider adoption. Principles of increasing water infiltration with improvements in soil aggregation, decreasing run-off with use of contours, ridges, vegetative hedges etc. and reducing soil evaporation using crop residue mulch can be adopted. Adaptive changes in crop management – especially planting dates, cultivar choice and sometimes increased irrigation–increase yields by 7-15% on average. Conservation agriculture and resource conservation technologies (RCTs) have proved to be highly useful to enhance resource or input-use efficiency and provide immediate, identifiable and demonstrable economic benefits such as reductions in production costs, savings in water, fuel and labour requirements and timely establishment of crops resulting in improved yields. We also need to consider the extent to which grain may require drying and how products are stored after harvest. Weather forecasting and early warning systems will be very useful in minimizing risks of climatic adversaries. Information and communication technologies (ICT) could greatly help the researchers and administrators in developing contingency plans. Thirdly, appropriate policies and institutions are needed to enable, support and complement the above economic and technical options.

Tuber crops in ensuring food security under changing climate

Potato, sweet potato and cassava, plus a range of yams and aroid species, are staples for poor farming households in many less favourable agro-ecologies and remote communities. These crops contribute directly to food security through their production in small holder farming systems, they are also directly consumed in a variety of traditional fresh and processed forms. Both of these elements are essential to food security. In addition, tuber crops play an increasing role in food security as a source of income. Significant role of tuber crops in ensuring food security is evident from the fact that global production of four major tuber crops in 2020 was 826.03 million tons which includes potato (359.07 mt), cassava (302.66 mt), sweet potato (89.48 mt) and yams (74.82 mt), while production of four major cereals was 2837.04 million tons including maize (1162.35 mt), wheat (760.92 mt), rice (756.74 mt) and barley (157.03 mt). In India, agriculture and allied activities contribute 17.8% of the GDP at constant prices in 2019-20 while this sector still accounts for 54.6% of the total workforce in the country. Current share of tropical tuber crops to agricultural GDP in India is 0.7% out of 0.32% cultivable area. On the contrary, the two principal food crops, rice and wheat, contribute 18.25% and 8.22% of agricultural GDP, respectively from 31.19% and 20.56% cultivable area, respectively. It shows that the contribution of tropical tuber crops in agricultural GDP from unit area of land is 2.63 times higher than rice and 3.85 times higher than wheat.

In ensuring food security under changing climate, cassava could and should play an important role for various reasons. First, it is a major food security crop for millions of people in our country, but it is also increasingly supporting a growing industry for starch production. Second, the crop is well-known for its drought tolerance and performance under marginal soil conditions. Its stomatal sensitivity to changes in atmospheric humidity (VPD_{air}) and soil water, deeper rooting capacity of more than 2 m and the ability to reduce leaf canopy so that crop water consumption is reduced are the main reasons for drought tolerance. Third, particularities in photosynthesis – it is a C_4-C_3 intermediate - displaying a large net photosynthetic rate due to elevated activity of the C_4 enzyme PEPC - 15-25% of C_4 species - (under high humidity, wet soil, high leaf temperature and high solar radiation, it exceeds 40 □mol CO_2 m^{-2} s^{-1} (for rice, it is 20)); radiation use efficiency (RUE) is 1.5-2.30 g DM MJ^{-1} iPAR, a large potential productivity (simultaneous development allows more time for filling the economic part, high leaf photosynthetic potential, long leaf life of more than 60 days, sustainable leaf canopy that optimizes photon interception during a significant portion of the growth cycle, high HI of above 0.5 and leaf size reduction that maintains high leaf nutrient concentration) and a large water use efficiency (2.9 g dry biomass kg^{-1} water transpired or 0.4-4.8 g dry biomass kg^{-1} water evapotranspiration) render it a crop of choice to mitigate the adverse effects of climate change, which will hit strongly in major cassava growing areas of southern India in terms of excessive heat and drought spells.

Studies have been conducted to understand the impacts or responses of tuber crops to climate change. All studies have found cassava to be the least affected crop when compared with other major staples such as maize, sorghum and millets. Cassava is found to moderately benefit from climate change by 2030 with an average increase of 1.1% in production from 2000. Another study found a decrease in production of 8% for cassava by mid-century, compared with much more severe impacts for maize

(−22%), sorghum (−17%) and millets (−17%). Enhanced CO_2 levels is found to reduce growth in cassava as well as increased cyanide concentrations in leaves, but another study showed contrasting results based on Free Air CO_2 Enrichment (FACE) experiments where root biomass was found to increase under elevated CO_2. A group of scientists from CIAT, Colombia found that cassava is actually positively impacted in many areas of Africa, with −3.7% to +17.5% changes in climate suitability across the continent. Conversely, other major food staples are projected to experience negative impacts, with the greatest impacts for beans (−16% ± 8.8), potato (−14.7 ± 8.2), banana (−2.5% ± 4.9), and sorghum (−2.66% ± 6.45). The study concluded that cassava is potentially highly resilient to future climatic changes and could provide Africa with options for adaptation whilst other major food staples face challenges. A few studies show the climate resilience of yams and 7-14% gain in yield under changing climate was reported in one study in West Africa. In the case of yam, after surviving a dry period, new yam plants emerge with considerable vine length expansion (sometimes exceeding two meters) without forming new leaves. These vines, which initially obtain moisture and nutrients from the parent tuber, are also covered with a waxy bloom that reduces moisture loss as the plant continues to develop.

Studies at ICAR-CTCRI calibrated World Food Studies (WOFOST) model to understand the impact of future climate on yield of tuber crops and rice using 30 years historic weather data from NASA POWER and 2030, 2050 and 2070 future climates predicted using LARS Weather Generator. Field data generated from 6 centers of All India Coordinated Research Project on Tuber Crops (AICRPTC) in Tamil Nadu, Andhra Pradesh, Odisha, UP, West Bengal and Assam were used for model calibration and validation. There is a likelihood of increasing the minimum temperature of major cassava growing areas up to 1.1°C and the maximum temperature up to 2.2°C in the year 2070. Rainfall shows erratic trends with increase up to 448 mm in Salem, Tamil Nadu and a fall in rainfall up to 72 mm in Thiruvananthapuram, Kerala. Cassava yield in Salem, Tamil Nadu will be reduced by 7, 11 and 13% during 2030, 2050 and 2070 for representative concentration pathway (RCP) 4.5. The corresponding decrease in yield for RCP 8.5 will be 7, 12 and 17. Similar yield reductions are predicted to happen in Andhra Pradesh too. But in Thiruvananthapuram, Kerala, cassava yield will increase by 12, 9 and 7% during 2030, 2050 and 2070 for RCP 4.5. The corresponding yield increase for RCP 8.5 will be 8, 5 and 0.2%. Rice yields in UP, Andhra Pradesh and Tamil Nadu show severe yield reductions compared to cassava and can go up to 40% less yield under RCP 8.5 in 2070. In the case of potato, its yield can go down up to 51% in 2070 under RCP 8.5. While rice and potato yields can be lowered by 40% and 51%, cassava yield will reduce only up to a maximum of 17%. Maximum yield reductions for sweet potato, greater yam, elephant foot yam and taro are in the order 38, 14, 12 and 28%. Detailed results are given in Table 2. Tropical tuber crops have more climate resilience and hence a greater role to play in ensuring future food and nutrition security under changing climate**.**

Table 2. Impact of climate change on yield of tuber crops and rice (WOFOST model)

Crop	Location	RCP	Yield variation (%)		
			2030	2050	2070
Cassava	Kerala	4.5	12	9	7
		8.5	8	5	0.2
	Tamil Nadu	4.5	-7	-11	-13
		8.5	-7	-12	-17
	Andhra Pradesh	4.5	-6	-9	-10
		8.5	-2	-6	-12
Sweet Potato	Odisha	4.5	6	3	-2
		8.5	5	-3	-11
	West Bengal	4.5	14	6	3
		8.5	13	6	-1
	Uttar Pradesh	4.5	-18	-27	-32
		8.5	-18	-30	-38
Greater Yam	Kerala	4.5	8	5	3
		8.5	6	3	-1
	Andhra Pradesh	4.5	-2	-7	-8
		8.5	-5	-10	-16
	Assam	4.5	-3	-8	-11
		8.5	1	-7	-14

Crop	Location	RCP	Yield variation (%)		
			2030	2050	2070
Elephant Foot Yam	Kerala	4.5	6	2	0
		8.5	4	0	6
	Odisha	4.5	-2	-6	-10
		8.5	1	-6	-11
	West Bengal	4.5	1	-5	-6
		8.5	0	-7	-12
Taro	Kerala	4.5	19	16	14
		8.5	18	13	8
	Uttar Pradesh	4.5	-6	-13	-16
		8.5	-14	-22	-28
	West Bengal	4.5	10	3	3
		8.5	8	1	-4
Rice	Kerala	4.5	14	8	3
		8.5	10	2	-10
	Tamil Nadu	4.5	-12	-19	-24
		8.5	-7	-18	-28
	Andhra Pradesh	4.5	3	-9	-10
		8.5	-13	-25	-36
	Uttar Pradesh	4.5	-12	-19	-23
		8.5	-15	-27	-40
	Assam	4.5	-2	-9	-13
		8.5	12	0	-15
	Odisha	4.5	9	-1	-11
		8.5	15	-2	-17
	West Bengal	4.5	5	-9	-11
		8.5	3	-13	-27
Potato	Odisha	4.5	-3	-9	-15
		8.5	-3	-13	-24
	Uttar Pradesh	4.5	-15	-23	-30
		8.5	-18	-29	-46
	Assam	4.5	5	-3	-9
		8.5	6	-6	-18
	West Bengal	4.5	-20	-28	-31
		8.5	-23	-33	-51

Source: Raji et al., 2021

Table 3. Impact of climate change on change in land suitability of tropical tuber crops (ECOCROP model)

Crop	Scenario	Year	Tmin (°C)	Tmax (°C)	Tmean (°C)	Total precipitation (mm)	Overall suitability change %)
Cassava	SRES-A1B	2030	-	-	0.9 to 1.2	6.80 to 112.40	-2.2 to 15.1
Cassava	RCP 4.5	2030	1.32 to 1.80	0.93 to 1.14	1.18 to 1.55	13.57 to 92.40	-1 to 8
	RCP 4.5	2050	1.60 to 1.85	1.45 to 1.69	1.62 to 1.78	-1.91 to 73.9	-1.27 to 11.67
Cassava	RCP 8.5	2030	1.38 to 1.52	1.13 to 1.36	1.29 to 1.49	25.27 to 103.70	-1.34 to 12.02
	RCP 8.5	2050	1.79 to 2.55	2.03 to 2.42	2.03 to 2.28	5.31 to 56.60	-3.76 to 6.59
Yams	S R E S - A1B	2030	-	-	0.9 to 1.30	9 to 128	-14 to 23.5
Elephant footyam	S R E S - A1B	2030	-	-	0.9 to 1.20	19 to 68 mm	0.8 to 9.6

Source: Sabitha et al., 2016; Byju et al., 2018; Remya Remesh et al., 2019; Shiny et al., 2019; Raji et al., 2021

Studies were also conducted to find out the change in land suitability due to the impact of future climate (2030, 2050 and 2070) on tropical tuber crops in India. The ECOCROP model of FAO was calibrated and validated to understand the change in land suitability of cassava, yams and elephant foot yam (Table 3).

Subsequently, maximum entropy (MAXENT) model was calibrated and validated to understand the change in geographical or land suitability of cassava in 2030, 2050 and 2070. The model showed excellent performance based on the AUC (area under the ROC (receiver operating characteristic) curve) values (> 0.8) obtained during training and testing. Changes in geographical suitability at different time scales under two RCPs are shown in Table 4. The calibrated model can be used to find out the suitable areas in 2030, 2050 and 2070 for cassava and sweet potato and accordingly crop

Table 4. Impact of climate change on change in land suitability of tuber crops and rice (MAXENT model)

Crop	Scenario	Year	Suitability change %)
Cassava	RCP 4.5	2030	42
	RCP 4.5	2050	32
	RCP 4.5	2070	33
	RCP 8.5	2030	41
	RCP 8.5	2050	43
	RCP 8.5	2070	32
Sweet potato	RCP 4.5	2030	32
	RCP 4.5	2050	27
	RCP 4.5	2070	23
	RCP 8.5	2030	25
	RCP 8.5	2050	31
	RCP 8.5	2070	21
Rice	RCP 4.5	2030	17
	RCP 4.5	2050	15
	RCP 4.5	2070	13
	RCP 8.5	2030	15
	RCP 8.5	2050	17
	RCP 8.5	2070	11
Potato	RCP 4.5	2030	10
	RCP 4.5	2050	10
	RCP 4.5	2070	10
	RCP 8.5	2030	11
	RCP 8.5	2050	9
	RCP 8.5	2070	9

Source : Raji et al., 2021

planning can be decided and suitable crop management practices can be developed to ensure food security.

Information about the impact of climate change on crop water requirements and irrigation requirements is needed to maximize crop production in the context of water scarcity and food security. This assists farmers in wisely utilizing the available water source among other crops as well. A study was conducted to analyse the impact of climate change on crop water requirement and irrigation requirements of cassava, sweet potato, taro, greater yam and elephant foot yam followed by the development of optimal irrigation schedules. CROPWAT, a crop model developed by the FAO is used in this study for calculating actual crop water requirement, and for estimating optimal irrigation water requirement. Weather inputs for CROPWAT included the monthly mean values of maximum and minimum temperatures, relative humidity, wind velocity, sunshine duration, and monthly total rainfall. Long Ashton Research Station (LARS-WG) is used to derive future climate scenarios for the study locations. Other inputs needed for this model are the crop and soil data. For each crop, the crop period is selected based on the cropping season in each study location. The actual crop water requirement is the crop evaporation (ET_c) and it is calculated by multiplying the already estimated reference evapo transpiration (ET_0) by crop coefficient, K_c. The crop coefficient for sweet potato is taken as 1.15 (mid growth stage), and for other tuber crops, the value is taken as 1.1 as prescribed in the FAO. The critical depletion fraction in the case of root and tuber crops is taken as 0.65 - 0.75, as they can tolerate the 65 to 75% depletion of available moisture. The yield response fraction for these crops is considered as 0.60, a value less than 1 indicates its tolerance to water stress. The scheduling is based on the depletion of available moisture (the difference between field capacity and permanent wilting point). The crop is irrigated when 75% of the available moisture is completely depleted, and refills the soil moisture to the field capacity. However, this value can change from one crop to another depending on the maximum allowable depletion for each crop to avoid any stresses due to water scarcity.

The changes in magnitudes of minimum and maximum temperatures and rainfall in all the study locations are mainly responsible for the probable changes in the crop water and irrigation requirements. The crop water requirement of cassava and sweet potato ranges from 950.8 to 1303 mm and 336.2 to 788.8 mm respectively. The water requirement of taro in the three locations ranges from 569.1 to 814.8 mm. The water requirements of greater yam and elephant foot yam range from 550 to 1346.7 mm, and 943 to 1138.7 mm, respectively.

The irrigation requirement of cassava in the study locations changes from the present value by -97.9 to 291.9 mm for future scenarios (Table 5). The irrigation requirement of sweet potato compared to the present values changes from -0.9 to 18.4 mm, which is less affected by the changing climate as sweet potato is a short duration crop. The irrigation requirement of taro shows an increase and it changes from 100.8 to

Table 5. The changes in magnitudes of gross irrigation requirements in the study locations

Crop	Location	Change in IR_g (mm)	
		2030	2050
Cassava	Thiruvananthapuram, Kerala	291.1	282.4
	Salem, Tamil Nadu	-97.9	-2.9
	West Godavari, Andhra Pradesh	-2.6	125.4
Sweet potato	Bhubaneswar, Odisha	3.1	-0.9
	Kalyani, West Bengal	7.5	18.4
	Faizabad, Uttar Pradesh	-0.3	8.1
Taro	Thiruvananthapuram, Kerala	263.5	263.8
	Kalyani, West Bengal	102.3	100.8
	Faizabad, Uttar Pradesh	104.4	107.1
Greater yam	Thiruvananthapuram, Kerala	392.1	381.9
	West Godavari, Andhra Pradesh	8.4	5.3
	Jorhat, Assam	124.2	123.7
Elephant foot yam	Thiruvananthapuram, Kerala	311.2	296.3
	Bhubaneswar, Odisha	-33.6	-44.6
	Kalyani, West Bengal	141.3	139.4

263.8 mm compared to the current irrigation requirements. The gross irrigations for greater yam and elephant foot yams change from the present value by 5.3 to 392.1 mm and -44.6 to 311.2 mm, respectively. The derived crop water production functions (CWPF) together with the optimal irrigation schedules is a useful tool for water managers and farmers to develop appropriate irrigation plans in advance to mitigate the water scarcity as the result of climate change.

Conclusions

Climate change brings a cascade of risks from physical impacts to ecosystems, agro-ecosystems, agricultural production, food chains, incomes and trade, with economic and social impacts on livelihoods and food and nutrition security. The people who are projected to suffer the earlier and the worst impacts from climate change are the most vulnerable populations, with livelihoods depending on agriculture sectors in areas vulnerable to climate change. Understanding the cascade of risks, as well as the vulnerabilities to these risks, is key to frame ways to adapt. Reducing vulnerabilities is key to reducing the net impacts on food security and nutrition and also to reducing long-term effects. Increasing resilience of food security in the face of climate change calls for multiple interventions, from social protection to agricultural practices and risk management. For the world's poor, adapting to climate change and ensuring food security go hand in hand. A paradigm shift towards agriculture and food systems that are more resilient, more productive, and more sustainable is required. In this context, tuber crops have a greater role to play in future considering their phenotypic plasticity and resilience to climate aberrations.

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Chapter 10

Organic production of minor tuber crops

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Call for organic farming

Currently, there is an upsurge in consumer apprehensions regarding the quality and safety of foods. Hence, more attention is paid to organic production as an alternative form of agriculture to obtain high-quality safe food in an environment friendly manner (Benbi et al., 2018). Organic production methods exclude the use of synthetic chemicals like fertilizers and pesticides and depend on ecological processes and biological cycles to maintain or improve soil fertility, minimize environmental pollution and produce sufficient quantity of good quality food (IFOAM, 1998). The organic farming practices are based on maximum use of on-farm generated resources, minimal use of off-farm inputs and resort mostly to animal manures and green manure as source of nutrients. The less use of off–farm inputs, higher input–output efficiency and environmental benefits make organic agriculture sustainable.

Lesser known plant resources will bridge the yield gap

It has become imperative to exploit the lesser-known plant resources in order to meet the growing food requirements of the burgeoning global population. The focus of scientific attention on a particular minor tuber crop depends on its yield potential, the availability of varieties or land races with good adaptation to fit into the existing cropping systems and scope for value addition. Out of a number of minor tuber crops, Chinese potato and arrowroot has been identified to be very potential.

Chinese potato *(Plectranthus rotundifolius)*, an underutilized plant species (UPS), is generally a women-grown crop in homesteads popular as an ethnic vegetable and preferred due to its excellent cooking quality, aromatic flavour and delicious taste. It is a food security-cum- nutritional security crop. It is also medicinally important and preferred as a health food due to the anti-oxidant potential of flavonoids present in it. It is often referred to as native potato or country potato or Hausa potato in Africa. It is native to tropical Africa, cultivated in parts of West Africa, South Africa, Madagascar, South Asia, South East Asia, India and Sri Lanka for its edible tubers. In addition, Hausa potato is also known as a substitute for sweet potato in most parts of Africa. It is widely cultivated in Northern Kerala, Tirunelveli district of Tamil Nadu and tribal settlements in India.

Arrowroot (*Maranta arundinacea* L.) is mostly cultivated by tribal and marginal farmers for the rhizomatous edible tubers, which contains good quality starch. Arrowroot starch has versatile uses in food, pharmaceutical, and cosmetic industries. Rhizomes are valued as a food stuff, particularly for infants and invalids. Arrowroot has been used as thickening agent in food products. It is also used for making various bakery products, special glue and paste, as a base for face powder, as an ice cream stabilizer and in carbon-less paper used for computer printouts. Arrowroot starch possesses demulcent properties and is used in the treatment of intestinal disorders. It is also employed in the preparation of barium meals and in the manufacture of tablets. The rhizomes are also a good substitute for maize in broiler rations. The fibrous debris after starch extraction is used as feed or manure (Suja et al., 2006; Suja et al., 2021a). Moreover, arrowroot is a profitable intercrop in coconut, arecanut and rubber plantations (Nayar and Suja, 2004). In spite of the wide applications of arrowroot starch, it is mostly left as an unexploited crop in the homesteads under shade of fruit crops like jack, mango and other tree crops, tribal pockets and marginal lands with little care and management.

Considering the use of Chinese potato as a vegetable and economic importance of arrowroot starch, scientific organic production techniques would help a great deal in the promotion of cultivation of these minor tuber crops in home gardens as well as for commercial exploitation.

General strategies for organic farming in tropical tuber crops

General practices to be followed in the organic farming of tropical tuber crops (Suja, 2008) are given below:

Building up of soil fertility: Before the establishment of an organic management system, the fertility status of the land must be improved by growing green manure crops like cowpea twice or thrice during a year and incorporation of the green leaf matter at the appropriate pre-flowering stage. This will help to re-establish the balance of the eco-system and offset the yield decline, if any, during the initial period of organic conversion, as tuber crops are highly nutrient depleting crops.

Quality planting materials: Varieties cultivated should be adapted to the soil and climatic conditions and as far as possible resistant to pests and diseases. Local market preference also should be taken into account. The planting materials should be produced by adopting organic management practices.

Nutrient management: Harnessing the easily available organic sources of plant nutrients conjointly and judiciously to meet the nutrient needs of highly nutrient exhausting crops like tropical tubers will definitely help to maintain/promote productivity in organic farming in the absence of chemical inputs. The potential organic sources of plant nutrients for tropical tuber crops are farmyard manure, poultry manure, composts like vermicompost, coir pith compost, mushroom spent compost, saw dust compost, press mud compost, green manures, crop residues, ash, oil cakes like neem cake etc.

Weed management: Since most of the tuber crops (except sweet potato) take about 75-90 days for sufficient canopy coverage, raising a short duration intercrop (like green manure/ vegetable/grain cowpea, vegetables, groundnut etc. in cassava, cowpea in yams and aroids) can also help to a great extent to reduce weed problem. Mulching the crop using any locally available plant materials (green leaves, dried leaves etc.) immediately after planting (in yams and aroids) will help to conserve moisture and regulate temperature, apart from weed control.

Pest and disease management: Few pests and diseases like cassava mosaic disease (CMD), cassava tuber rot, sweet potato weevil (SPW), taro leaf blight (TLB), collar rot in elephant foot yam are causing economic loss. Use of tolerant/ resistant varieties, use of healthy and disease free planting materials, strict field sanitation (against almost all), deep ploughing (eg. tuber rot), rogueing the field (eg. CMD), use of pheromone traps (eg. SPW), use of trap crops (eg. SPW, root knot nematodes), adapted crop rotations, use of neem cake (collar rot, tuber rot), use of bio- control agents like *Trichoderma, Pseudomonas* (collar rot, leaf blight) etc. are the efficient management practices.

Impact of organic management in Chinese potato and arrowroot

Biomass, yield, economics organic management promoted greater biomass partitioning to tubers, resulting in higher harvest index in Chinese potato and arrowroot in both years.

Table 1. Economic analysis of management practices in Chinese potato

Production systems	Average yield (t ha^{-1})	Gross income (Rs. ha^{-1})	Gross costs (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B:C ratio
Traditional	12.34	493600	119400	374200	4.13
Conventional	12.61	504400	118086	386314	4.27
Integrated	13.82	552800	146020	406780	3.79
Organic	13.94	557600	144600	413000	3.86
Organic (biofertilizers)	13.31	532400	169800	362600	3.14

Fig. 1 Crop growth and tuber yield under organic practice in Chinese potato

In Chinese potato, yield under organic management (13.94 t ha^{-1}) was 10.5% higher over conventional system (12.61 t ha^{-1}). Organic practice resulted in higher net income (Rs. 413,000 ha^{-1}) and added profit of Rs. 26,686 ha^{-1} over conventional practice due to 10.50% higher yield (Suja et al., 2021b).

In arrowroot, yield under organic management (12.81 t ha^{-1}) was 2% lower than conventional (13.05 t ha^{-1}) and integrated (12. 93 t ha^{-1}) practices. In arrowroot, conventional practice resulted in higher net returns and B:C ratio (Rs. 215, 017 ha^{-1}; 2.22 respectively) due to higher yield.

Table 2. Economic analysis of management practices in arrowroot

Production systems	Yield (t ha^{-1})	Gross income (Rs. ha^{-1})	Gross costs (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B:C ratio
Traditional	11.49	344700	178500	166200	1.93
Conventional	13.05	391500	176483	215017	2.22
Integrated	12.93	387900	205287	182613	1.89
Organic	10.45	313500	183700	129800	1.71
Organic (biofertilizers)	12.81	384300	210400	173900	1.83

Fig. 2 Crop growth and tuber yield under organic (biofertilizers) practice in arrowroot

Soil properties

The pH (by +1.14 unit over conventional), organic C (+15%), available N and available P (in Chinese potato) and exchangeable Ca (in arrowroot) increased significantly under organic management. There was no significant difference in the status of secondary and micro-nutrients, physical properties of soil, enzyme activities and soil microbial count. There was slight lowering of bulk density and particle density and improvement in water holding capacity and higher dehydrogenase enzyme activity under organic management in Chinese potato and arrowroot.

Tuber quality and nutrient uptake

In general, tuber quality was not significantly affected. In Chinese potato, K content was significantly higher and dry matter, starch, crude protein, P, Mg, Fe, Mn, Zn and Cu contents were enhanced under organic management.

Organic management resulted in significantly higher P and Zn uptake in the first year of study in Chinese potato. In general, higher uptake of most of the nutrients was evident under organic management in Chinese potato and arrowroot.

Organic package

In Chinese potato, organic package comprised FYM @ 10 t ha^{-1}, green manure @ 10-15 t ha^{-1}, neem cake @ 1 t ha^{-1} and ash @ 2 t ha^{-1} or biofertilizers (*Azospirillum*, P solubilizer and K solubilizer @ 3 kg ha^{-1} each).

In arrowroot, FYM @ 10 t ha^{-1}, green manure @ 10-15 t ha^{-1} and biofertilizers (*Azospirillum*, P solubilizer and K solubilizer @ 3 kg ha^{-1} each) formed the organic package.

Conclusions

In order to attain sustainable food-cum-livelihood-cum environmental security in India we may require an array of alternatives to chemical intensive agriculture. Instead of seriously debating on organic vs conventional agriculture it is better to examine critically the costs and benefits of the different alternative management options. It has been conclusively proved in tuber crops that organic management is an alternative viable option for sustainable and safe food production with less soil degradation and environmental pollution. Tuber crops, especially elephant foot yam and yams are prospective candidates for organic farming. Elephant foot yam is the most responsive followed by greater yam, white yam, lesser yam, Chinese potato, cassava, arrowroot and taro (Suja et al., 2010; Suja et al., 2012a; Suja et al., 2012b; Suja, 2013; Suja and Sreekumar, 2014; Suja et al., 2015; Suja et al., 2016a; Suja et al., 2016b; Suja, et al., 2017; Seena Radhakrishnan et al., 2021; Suja et al., 2021b). Generation of sufficient biomass, addition of crop residues, green manuring, use of liquid organic manures, farm waste recycling, fortification of manures through proper composting, adoption of crop rotations involving legumes, establishment of biogas plants and development of agro-forestry for alternate source of fuels are some of the strategies that will help to promote organic farming of tuber crops. These practices would help a great deal in supplementing/rationalizing the use of inorganic fertilizers, which cannot be totally eliminated in Indian Agriculture.

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Chapter 11

Protocol for screening nutrient use efficient genotypes in tuber crops

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Introduction

Among the many factors contributing to the productivity and quality of produce, at least 50% of crop yield is attributable to commercial fertilizers. However, the continuous and indiscriminate use of chemical fertilizers somehow caused physico-chemical and biological deterioration of soil which in turn gradually might have resulted in non-response to applied fertilizers. The concern on soil health urged in evolving the concept of need-based application of fertilizers based on soil nutrient status and crop requirement through soil testing and plant tissue analysis. However, the present scenario of fertilizer markets with respect to its price and availability at times of need are not that encouraging especially for a State like Kerala where the percentage of 'real farmers' are very meagre. Considering these factors, it was thought of reducing the use of commercial fertilizers through the use of genotypes which can explore the soil nutrients from deeper soil layers due to its unique root system or microbes which can harness the soil and atmospheric nutrients. In this regard, the concept of nutrient use efficient (NUE) cultivars and NUE microbes play a crucial role.

Though NUE cultivars is a new concept as an alternative to reducing or substituting chemical fertilizers, nutrient use efficiency of genotypes was defined as the ability to produce high yield in a soil which is limiting in that particular nutrient. In other words, NUE is the ability of a genotype or cultivar to acquire nutrients from growth medium and to incorporate or utilize them in the production of root or shoot biomass or utilizable plant material.

In the case of tuber crops especially for cassava, K is considered as the 'key nutrient' with respect to yield and quality. We have initiated research work in the line of identifying some K use efficient cassava cultivars since 2006 and it resulted in the release of the first K efficient genotype by name 'Sree Pavithra' (CI-1100, Aniyoor) in 2015 for Kerala State. The protocol followed is as below:

a. Evaluation of physiological efficiency of the selected elite genotypes

A total of 100 elite genotypes from the germplasm collection of ICAR-CTCRI was evaluated for their inherent NUE (physiological efficiency) by growing them in a row trial without application of any chemical fertilizers and manures. In addition to this, other required attributes like plant stature, tuber yield, mosaic tolerance, tuber yield, tuber quality also were considered and hence selected six genotypes.

b. Evaluation of the selected genotypes at different levels of the nutrient in question

These six genotypes were further evaluated for three years under a split plot design with the six genotypes as main plot treatment and four levels of K viz., 0,50,100 and 150 kg ha^{-1} as sub plot treatment. The mean tuber yield over three years at the research station with K @ 0,50,100 and 150 kg ha^{-1} was 30.953, 36.298, 39.863 and 35.787 t ha^{-1} respectively indicating no significant difference in tuber yield between 0 and 50 kg ha^{-1} and 50 and 100 kg ha^{-1} further revealing that, when NUE genotypes are cultivated, the application of K can be avoided or can be reduced to 50%. Among the six genotypes evaluated, CR 43-8, followed by 7 III E3-5 and Sree Pavithra recorded highest yields to the tune of 40.572, 38.388 and 35.828 t ha^{-1} respectively.

c. Determination of NUE & physiological parameters

Estimated all the NUE parameters like agronomic efficiency (AE), physiological efficiency (PE), agro physiological efficiency (APE), utilization efficiency (UE), K uptake ratio (KUpR), apparent recovery efficiency (ARE), harvest index (HI), K harvest index (KHI), K utilization for biomass (KUtB) and K utilization for tuber (KUtT) and physiological parameters like crop growth rate (CGR), relative growth rate (RGR), tuber bulking rate (TBR) and leaf area index (LAI). The NUE is justified in terms of root architecture and LAI and the maximum number thin/white roots coupled with highest LAI was seen in CI-1100 among the six selected genotypes (Susan John et al., 2020a, Susan John et al., 2020b, 2020d).

d. Confirmation through farmers participatory trials

These genotypes were tested for two seasons in farmers' fields of the three districts of Kerala viz., Thiruvananthapuram, Pathanamthitta and Kollam under the aegis of Krishi Vignan Kendras (KVK's) of these districts. Ultimately, based on farmers' preference as regards to yield and very good cooking quality, mosaic tolerance and plant stature, CI-1100 (locally known as Aniyoor) which is a local selection from a place called Aniyoor near Sreekariyam in Thiruvananthapuram district was released under the name 'Sree Pavithra'.

e. Testing the N efficiency potential of K eficient genotypes

The N efficiency potential of the six physiologically efficient K efficient cultivars were tested by conducting the trials at four levels of N and identified W-19 and CR43-8 as N efficient which can save N up to 50% . The mean tuber yield of the six selected genotypes at four levels of N viz., 0, 50, 100 and 150 kg ha^{-1} were 26.063, 28.023, 32.721 and 33.284 t ha^{-1} respectively which indicated no significant yield difference between 0 and 50 kg ha^{-1} and between 50 and 100 kg ha^{-1}. In other words, the tuber yield at 50 kg ha^{-1} N was on par with 100 kg ha^{-1} N. Among these genotypes, CR 43-8 followed by W-19 recorded the highest tuber yield of 34.680 and 33.116 t ha^{-1} respectively. Since the plant stature, tuber quality and tuber shape was not much farmer acceptable, it was not field validated under on farm trials and intended for registration as N efficient genotypes (Susan John et al., 200d).

f. Identification of NPK efficient genotypes

Simultaneously identified 16 NUE genotypes of cassava through the screening of another set of 300 elite genotypes by testing its physiological NPK efficiency and Sree Pavithra, 7 III E3-5, CI- 905 and CI-906 were tested for NPK use efficiency under four levels of NPK viz., 25, 50, 75 and 100% of PoP for three seasons continuously to see the extent of reduction of chemical fertilizers by using these NUE genotypes. Though all these four genotypes were not influenced by levels fertilizers, significant effect of genotypes were seen in the case of tuber yield. During all the three seasons, the tuber yield realized under all the four levels of NPK were on par indicating the level of application of NPK fertilizers can be reduced up to 25% (saving of 75% NPK fertilizers) when the NUE genotypes are used. The mean tuber yield over three years at 25, 50, 75, 100% NPK was 32.032, 33.024,34.292 and 36.174 t ha^{-1} (Susan John et al., 2020c).

They were tested in 24 farmers fields across the 23 agro ecological units of Kerala with 25% of the PoP recommendation and found very much farmer acceptable with respect to high yield, good tuber quality in terms of better cooking quality, low cyanogen and good starch content, low dose of NPK requirement, pink rind (7 III E3-5) and dark yellow colour of the flesh (CI 905). The same procedure can be adopted for screening NUE genotypes in minor tuber crops too.

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Chapter 12

Nematodes threats and their management in minor tuber crops

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Tuber crops are the third most important food after cereals and pulses in most parts of the nations worldwide. They are rich in carbohydrates, dietary fiber, micronutrients, etc. Apart from human consumption, they are often used as livestock feed and as raw materials in industrial products. The major tropical tubers are tapioca (*Manihot esculenta*), sweet potato (*Ipomoea batatus*), yams (*Dioscorea* spp.) and elephant foot yam (*Amorphophallus paeonifolious*). The minor tuber crops include Chinese potato (*Plectranthus rotundifolius*), yam bean (*Pachyrhizus erosus*), arrowroot (*Maranta arundinacea*), winged bean (*Psophocarpus tetragonolobus*), enset (*Ensete ventricosum*), *Tacca* spp., *Canna* spp. and *Costus* spp. Chinese potato, elephant foot yam and yams are the most vulnerable tuber crops to nematodes. Among the minor tuber crops, Chinese potato, yam bean, winged bean and enset are susceptible to nematodes. The above-ground symptoms of nematode attack is not very specific and often confused with nutrient deficiency symptoms. They cause both qualitative and quantitative yield losses. If the population of nematodes is very high, they may cause a cent percent yield loss. Even concomitant infections of multiple nematode species are recorded on the same tubers. A disease complex is also observed involving fungus/ bacteria and nematodes. The cumulative damage is sometimes higher than the individual ones. No single management strategy can contain the nematodes hence an integrated approach is followed for effective and sustainable management of nematodes.

Chinese potato, (*Plectranthus rotundifolius*)

Chinese potato, *Plectranthus rotundifolius* formerly known as *Solenostemon rotundifolius* belongs to the Family Lamiaceae. It is also known as the Hausa potato, Madagascar potato, Salaga-potato, Sudan potato, country potato and Zulu potato in different nations. In Hindi and Malayalam it is referred to as Kukra and Koorka, respectively, while in Kannada and Tamil as Sambrani and Sirukizhangu, respectively. The crop is cultivated in East Africa, tropical Africa, Togo, Guinea, India, Sri Lanka, Malaysia, and Indonesia (Harlan et al., 1976). Chinese potato is an important minor tuber crop cultivated in India. It is grown in most of the homestead gardens of Kerala as an aromatic tuber vegetable. It is intensely cultivated in more than 1000 ha in South Tamil Nadu, particularly in Tirunelveli and Tenkasi districts. They possess antioxidant activity due to the presence of essential oils, diterpenoids, phenolics and flavonoids. The decoctions of boiled leaves of Chinese potatoes are used to treat many disorders like dysentery, glaucoma, etc., (Schipper 2000). It is mainly cultivated for its edible tubers. Tubers of the crop provide essential dietary and energy requirements. The tubers are rich in protein, vitamins, and minerals. The yields are higher on well-drained light sandy loams, while heavy soils prone to water logging are unsuitable.

Nematodes

Chinese potato cultivation is severely dented by the infection of the root-knot nematode as it reduces the yield, quality and marketability of tubers (Patnaik and Das, 1986; Mohandas, 1994). In India, the root-knot nematode infestation is widely reported in Tamil Nadu, Kerala and Odisha. In Chinese potato, the root-knot nematode has the ability to multiply during storage (Mohandas and Ramakrishnan, 1998) and is known to cause 20% dry weight loss of the tubers. The injury sustained by the tubers during harvesting hastens the tuber decay during transit and storage (Okigbo 2004). Senthamarai et al., (2006b) reported a yield reduction of up to 86% in Chinese potatoes, while *M. arenaria* was recorded to cause severe losses (Bhandari et al., 2007). The nematode-affected plants wilt and wither as the nematode impairs water and nutrient uptake. Severe infestation by the nematode results in total crop failure (Asawalam and Adesanya 2001).

The *M. incognita* infected Chinese potato plant exhibit a multitude of symptoms, including stunted growth, yellow patches, and severe galling of roots. Infested tubers are malformed, irregular in shape, having wart-like projections. Due to heavy galling, tubers become unsuitable for consumption and marketing. The galls on Chinese potato roots are more pronounced and bigger. A nematode population of about 1,000 juveniles per plant can cause economic damage. They are often associated with other pathogens in the disease complex. Root-knot nematode, *M. incognita* was found to be associated with wilt pathogen, *F. Chlamydosporum* (Mallesh 2008); collar rot pathogen, *Rhizoctonia bataticola* and *Sclerotium rolfsii*, (Ramaprasad Shresti 2005) and root rot pathogen, *Macrophomina phaseolina*. The nematode has the ability to predispose the plant to infection by pathogens and can aggravate the disease. Due to the disease complex, up to 60% yield loss has been observed.

Management

Physical Methods: Hot water treatment of Chinese potato tubers at 53 °C for 10 min kills root- knot nematodes.

Cultural Methods: Use of clean planting material as infestation spreads through the planting material. Following crop rotation with non-host crops. Farmers rotate Chinese potato after rice in the Tirunelveli district of Tamil Nadu. Growing of trap crop, Sree Bhadra, (a variety of sweet potato) is recommended as a resistant trap crop for the root-knot nematode. The nematodes were able to penetrate the root but failed to initiate giant cells, and as a result, the nematodes, prevented to complete their lifecycle. Planting this variety in the root-knot nematode-infested fields helped the subsequent crop to escape nematode damage (Mohandas 2001).

Biological Methods: Soil application of *Trichoderma harzianum* and *Pseudomonas fluorescens* each at 2.5 kg/ha increased plant growth, yield and reduced *M. incognita* population (Senthamarai et al., 2008). Plant growth parameters (plant height, number of branches, fresh and dry weight of the plant) also increased, and less root-knot index wasobserved (Mallesh, 2008).

Chemical Methods: Newer nematicides, namely Fluopyram 34.48% SC and Fleunsulfone 2% GR can cause a significant reduction in nematode population.

Integrated nematode management:

- Selection of clean and healthy Chinese potato cuttings.
- Soil solarisation: Covering the irrigated soil with 150 gauge LDPE film during the hot summer months for 30 days kills the nematodes.
- Growing of sweet potato cultivar "Sree Bhadra" or marigold as a resistant trap crop followed by their biomass incorporation during earthing up can increase the yield and reduce the root-knot nematode population (Seenivasan and Deevrajan 2008).
- Application of farm yard manure @ 12.5 t/ha or neem cake at 400 kg/ha reduces the root- knot nematode index.
- Application of fungal bioagents, *Paecilomyces lilacinus*/ *Trichoderma viride*/ *Bacillus macerans* at 10 g/ kg of soil improved the plant growth and decreased nematode damage (Nisha and Sheela 2006).
- Application of newer nematicides, Fluopyram 34.5% SL and Fleunsulfone 2% GR.

Yam bean

Yam bean, *Pachyrhizus erosus* belonging to the family Fabaceae is a leguminous root crop. It is also known as Jicama, Mexican yam bean, or

Mexican turnip widely grown in India, Mexico, China, Singapore, Philippines, Hawaii, and Indonesia. In India, it is cultivated in parts of West Bengal, Tripura, Bihar, Orissa, and Assam. It has a white-fleshed tuber. The tuber is eaten raw or cooked. The starches extracted from the tubers are used in puddings. The mature pods, seeds, leaves and filage are poisonous. The plant shares a symbiotic relationship with root nodule forming bacteria and fixes atmospheric nitrogen as a result; it is also used as green manure. Yam bean contains rotenone and it has biopesticide property.

Nematodes

Yam bean is known to be affected by both root-knot nematode, *Meloidogyne* spp. and lesion nematode, *Pratylenchus* spp. (Noda et al., 1979). *M. arenaria* has been reported to cause cent percent damage to tubers in Ecuador (Duke, 1981). The cyst nematode, *Heterodera marioni* was also found infecting the crop (Duke, 1981). Nematode causes irregular warts on the surface of tubers. The affected tubers also taste bitter thereby causing qualitative damage and rendering them unfit for consumption.

Management

- Use of clean & healthy planting material and potting mixture.
- Following crop rotation with non-host crops.

Winged bean (*Psophocarpus tetragonolobus*)

The winged bean, *Psophocarpus* is a perennial crop grown for its edible pods and tuberous roots in India, Myanmar, tropical Africa, Asia, and Madagascar. In India, it is cultivated in Maharashtra, Karnataka, Bihar, Orissa, Tripura, West Bengal, Assam, Tamil Nadu, and Kerala. Like bananas, all parts of winged bean are edible (leaves, flowers, stems, pods, roots, etc.) They are a rich source of protein (20%) and oil (17%). When grown in a mixed cropping system, the crop is free from pests and diseases, but if grown as a monoculture, they become susceptible. Earlier, it was considered as a ‘poor man’s food’, but now owing to its economic importance it is recognised as a ‘proteinaceous crop for the tropics’. They fix atmospheric nitrogen with the help of the symbiotic bacteria.

Nematodes

Root-knot nematodes, *Meloidogyne incognita*, *M. javanica*, and *M. arenaria* have been reported to cause damage to the winged bean. They cause around 70% losses in tuberous roots.

M. incognita causes more extensive damage than the other two species. The root-knot nematodes cause stunting of plants, yellowing of leaves, patchy growth and severe galling of roots. They also reduce tuber production, pod and seed yield. Nematode damage has been reported in Papua New Guinea, Philippines, Ivory Coast, Indonesia, and Mauritius. In India, root-knot nematode infestation was observed in a farmer's fields of Allahabad in Uttar Pradesh. The problem is more infection is reported in sandy soils. According to a survey in 1978, an estimated 50% of the tubers of the Papua cultivar and 60–70% of the Ghana cultivar were affected by nematodes. If the infection is very severe, galled roots are also observed.

Management

- Use of clean & healthy planting material and potting mixture.
- Following crop rotation with non-host crops.

Flooding for 30–40 days is practiced as a control method in the Philippines.

Enset, (*Ensete ventricosum*)

Enset, also known as false banana is a staple food of Ethiopia. It is a cheap source of carbohydrates, calcium and iron (Kefale and Stephen 1991). It is a climate-resilient crop (drought tolerant). Apart from culinary use, starch is also widely used in the textile, paper, and adhesive industries (Edwards 1991).

Nematodes

Root lesion nematode, *Pratylenchus goodeyi* is often involved in the complex associations with bacterial wilt-affected plants. The nematode can predispose the plant to infection by wilt pathogens and increase the severity of the disease.

Management

- Use of clean & healthy planting material and potting mixture.
- Following crop rotation with non-host crops.

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Chapter 13

Phytosanitary measures for exchange of germplasm

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Quarantine is a strategy of control to prevent the spread of pests and diseases. It covers all regulatory actions taken to exclude animal or plant pests or pathogens from a site, area, country, or group of countries. For example, when plant genetic resources are imported from another country or region, there is a risk that they may contain or carry pests or pathogens that could be damaging to agriculture. For this reason, countries use quarantine practices to protect their agriculture and living natural resources from potential damage or destruction. Quarantine is usually a government responsibility, and the manner in which quarantine is executed differs among nations. National agencies responsible for plant quarantine may have other responsibilities, such as domestic pest control; research; pesticide registration, safety, and residue monitoring; or seed quality and labeling.

Reducing the risks from pests and pathogens

Quarantine practices in most countries have at least three common functions. The first is exclusion or regulatory actions to prevent or reduce the risk of entry of exotic pathogens, pests, or parasites along artificial pathways. Second is the containment, suppression, or eradication of pests or pathogens that have been recently introduced. Third is the assisting of exporters to meet the quarantine requirements of importing countries. The general concepts and objectives of plant and animal quarantine are similar; but differences in biology, agricultural production, marketing, exporting, and importing necessitate a variety of quarantine procedures. Plant quarantine programs are intended to protect agriculture from the threat of entry of exotic hazardous organisms. In some countries this objective may be extended to the protection of natural domestic flora and fauna. Both types of programs regulate the importation of living individuals (for example, plants or plant parts capable of propagation) and various commodities or unprocessed agricultural raw materials.

Plant quarantine regulations are:

- Require import permits issued by the quarantine service of the importing country (these may require the exporting country to certify that specified conditions have been met prior to shipment);
- Specify things that are prohibited from entry;
- Grant exceptions to the prohibitions for scientific purposes;
- Require inspection of imported materials upon arrival;
- Require appropriate treatment, if warranted, as a condition of entry; and
- Require, after arrival, quarantine or isolation in an approved facility.

Currently more than 240 crops or plant species are prohibited from entry to one or more countries

Quarantine as a pest control strategy

Quarantine is often combined with plant protection to include all regulatory activities carried out by local, regional, national, and international government agencies or organizations. Two components of quarantine that affect the exchange of plant genetic resources on a global scale are (1) exclusion of plant parts or taking of regulatory actions that will reduce the chances that pests and pathogens might enter a country along artificial pathways; and (2) phytosanitary certification or providing of assistance to a country's exporters to meet the quarantine requirements of importing countries. Both importers and exporters of plant germplasm are affected by these two functions. Importers are subject to the regulations of their own country, which might not only require that exporting countries meet certain phytosanitary standards but might also place some restrictions on the imported germplasm after entry. Although the quarantine service of the exporting country may assist in meeting the requirements, it is the importing country that sets quarantine standards.

Quarantine and genetic resources

Plant quarantine practices are frequently viewed as an impediment by those working in research, breeding, or genetic resources management. This has been particularly true for germplasm that is transferred in a vegetative form The timely transfer of some, but not all, species may be adversely affected by quarantine-imposed delays.

Legal basis of quarantine

The legal foundation that supports national quarantine regulations and actions is usually either legislation passed by national governments as acts, statutes, orders, decrees, or directives or enabling legislation that authorizes a minister or secretary of agriculture to issue regulations. State governments may enact legislation or promulgate rules and regulations to exclude or reduce the chances for entry of pests. State quarantine services often assist the national government in quarantine activities such as survey or export certification. The international exchange of plant genetic resources is not usually affected by state quarantines, except in so far as state officials must often be used to obtain phytosanitary certificates for export. The International Plant Protection

Convention of 1951 provides an international mechanism for harmonizing most international plant quarantine activities. By 1987, 89 countries were signatories to the convention, and many others followed. The quarantine services of most importing countries require that plant genetic resources be accompanied by a phytosanitary certificate issued according to the standards set by the Food and Agriculture Organization of the United Nations. The certificate must be addressed to the quarantine service of the importing country and signed by an authorized officer of the quarantine service of the exporting country. The certificate must include the plant's place of origin and botanical name. The certificate must also contain a statement certifying that the plants or plant products have been inspected and found to be free from quarantined pests. A phytosanitary certificate does not ensure that the plant material will be able to enter a country. Countries with developed quarantine services usually do not rely on these documents as a sole safeguard, even though they may be required for entry.

Quarantine is essential for protecting a nation's agricultural system. However, regulations and practices must continually balance the potential for release of harmful pests or pathogens with the needs of germplasm scientists, research efforts, and breeding programs. Protection of agriculture is not, however, solely the responsibility of quarantine services. Efforts are needed on the part of national and international germplasm programs to reduce the potential for harboring pathogens in the collections they manage. For quarantine, opportunities to improve present efforts exist in the areas of cooperation, information, and technology. Tissue culture has been successfully used to eliminate pathogens from a number of crop species and enable their safe transfer. New and emerging molecular technologies promise to provide the capacity for rapid detection of pathogens that may currently be severely restricted in their transfer because of potential quarantine difficulties. Movement of germplasm through quarantine could be made more efficient through increased cooperation between nations and international institutes, and between quarantine officials and the users of germplasm. Many regional quarantine programs already exist, and these should continue to be supported. In many cases, it may be both practical and efficient to establish regional centers for the quarantine testing of particular materials and, thus, share responsibilities, costs, and benefits. Quarantine services should be flexible in decisions regarding the fate of germplasm that is endangered or of particular value. Germplasm scientists with specific expertise in a crop can, with appropriate safeguards, receive and test germplasm that might otherwise be detained in quarantine or denied entry into a country. For such cooperation to succeed, germplasm scientists and quarantine officials must acknowledge a mutual goal of efficient and safe transfer of germplasm. Germplasm collections should, to the extent possible, be tested for at least the most potentially significant pests or pathogens they may contain. It has been suggested that, for vegetatively propagated germplasm collections, information about whether the plants have been tested for pathogens and the results of those tests should be part of the data available to quarantine officials (International Board for Plant Genetic Resources, 1988b). Such information should be available for seed collections that are likely sources of seed borne pathogens as well. It may not be technically feasible to eliminate easily some pathogens from some accessions. Although this might limit the distribution of those accessions, it should not be cause to remove them from collections. Wild species, for example, might possess potentially serious pathogens, but their potential contribution of new genes may justify their continued maintenance in a collection. The technique of reducing or eliminating pathogens by selection of disease-free plants during growouts should also be applied cautiously. Although this may yield a disease-free sample, in many cases the selection of a few plants as seed sources for a heterogeneous accession could result in significant loss of genetic diversity. Quarantine should not be used as a mechanism to further economic or political objectives. Sound quarantine policies and practices should be biologically based and in accordance with known or potential pest risk (an estimation of the chances that a hazardous pest or pathogen will gain entry along artificial pathways). They should be executed through the least drastic actions that will provide the safeguards and reduce the risk to an acceptable level in a timely fashion. Finally, considerations of the costs of accidental release of a harmful pest or disease versus the benefits to be gained from the imported material should be considered. Usually, the benefits to be derived from the importation of genetic resources justify taking the risk, provided that safeguards are in place, whereas the benefits derived from commercial importations may not necessarily support taking the same risk.

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Chapter 14

Advances in quality planting material production in minor tuber crops

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Importance of using quality planting material of tuber crops

Quality planting material is the propagation material of tuber crops which have (i) genetic purity - true– to–type variety; (ii) physical purity - free from debris, inert matter, diseased and insect damaged planting materials, (iii) seed health – free from diseases, insects, pests (planting material health) and (iv) posses good seed germination – high germination percentage and viability. These planting materials are produced through a systematic and supervised process and are considered as standardized form of planting materials that produce consistent yield.

Quality planting material production - Chinese potato

Chinese potato (*Plectranthus rotundifolius*) is one of the important tropical tuber crops grown in India, Sri Lanka, South East Asia and parts of Africa mainly for edible purpose. Chinese potato is known as *Koorka* and *Cheeva Kizhangu* (Malayalam) and *Chiru kizhangu* (Tamil). The tubers resemble potato in appearance, consumed as vegetable after cooking which has an aromatic flavour and delicious taste. It is a bushy herbaceous annual with succulent stems and aromatic leaves. It grows well under tropical and sub-tropical conditions.

The plant produces a cluster of dark brown aromatic tubers at the base and lower parts of the stem. The tubers contain dry matter (31-33%) and starch (18-21%) with a characteristic flavour due to essential oils (0.05 to 0.12%) which is preferred by the consumers. The moisture content of the tubers ranges between 73-75%. The tubers are also rich in minerals like calcium and iron and contain vitamins *viz*., thiamine, riboflavin, niacin and ascorbic acid.

Chinese potato (Coleus) is supposed to be a native of Central East Africa but has adapted well in South East Asia including India and Sri Lanka. In India, it is mainly cultivated in Kerala (Thrissur, Palakkad, Kasaragod and Kannur), Tamil Nadu (Tirunelveli, Tenkasi, Tuticorin, Virudhunagar and Kanyakumari) and in tribal settlements throughout the country.

Fig. 1 Chinese potato field

Fig. 2 Chinese potato tubers

Soil

A fertile well drained sandy loam to alluvial soil rich in organic matter is ideal for cultivation of Chinese potato. Heavy clay soils are not suitable and the crop cannot withstand water logging as excess soil moisture reduces tuber yield considerably. It is desirable to cultivate the crop on ridges and furrows to avoid water stagnation. The best soil pH requirement ranges between slightly acidic to neutral (6.6-7.0).

Climate

Coleus comes up well in hot humid climate. A comparatively lower temperature in night than day time which favours better tuber development. It grows well in subtropical and hot temperature areas where there is no incidence of frost. It requires a reasonably good rainfall for its growth and cannot withstand drought conditions. In case rains are not received, irrigation has to be provided for establishment of the crop. Tuber yield is reduced considerably under shade conditions.

Planting season

The planting is done from the month of July to November depending upon the irrigation facilities. The planting in september has resulted in the production of fairly big tubers. In most parts of the country, it is cultivated in rainy season as a monsoon crop.

High yielding variety

A promising selection (CP-58) was released as a variety 'Sree Dhara' by ICAR-CTCRI for cultivation in the states of Kerala. It has a yield potential of 25 t ha^{-1}. The dry matter is about 28.5 per cent and the starch content is 19.5 per cent.

Fig. 3 Sree Dhara: Improved variety of Chinese potato released by ICAR-CTCRI

Nursery

Nursery has to be raised approximately one and half months prior to planting. An area of 500 m^2 (12.5 cents) is required to produce stem cuttings for planting in one ha of land. Farm yard manure or compost has to be applied @ 1 kg m^{-2} and ridges/mounds are to be prepared at a close spacing of 45 or 60 cm. Healthy tubers that weigh about 15-20 g are planted on the ridges/mounds so as to accommodate 75-100 kg tubers in 500 m^2 area. Top dressing with urea @ 5 kg is done at three weeks after planting to get good stem growth. At about 45 days after planting clip off the terminal portion of the stem devoid of roots to a length of 10-15 cm for use as planting material. To enable rapid multiplication, single node cuttings are planted directly in the secondary nursery. Such single node cuttings produce auxiliary shoots within one week.

Land preparation and planting

The crop is raised both under upland and lowland situations where there is no water logging. Soil is deeply ploughed to a depth of 20-25 cm so that the soil gets pulverised and levelled. Prepare ridges of 15-30 cm height at a spacing of 45 cm. Plant the stem at a spacing of 30 cm on the ridges either in vertical or horizontal position. Horizontal planting of stem cutting of 15-20 cm length with 5 leaves are planted to a depth of 4-5 cm and exposing the terminal bud ensures quick establishment and promote tuber yield. In loose soils having good drainage, planting can also be done on flat beds with proper drainage.

Irrigation is given immediately after planting to ensure adequate soil moisture for establishment of suckers. If sufficient rain is not received, supplementary irrigations are to be given for proper growth and development.

Intercultural operations

A weeding and earthing up at 6 weeks after planting along with top dressing of fertilizers are to be done. It is important at this stage to cover a portion of the stem with soil to promote better tuberization and tuber development. One more earthing up has to be given one month after the first earthing up (Hrishi and Mohankumar 1976).

Nutrient management

Application of FYM @ 10 t ha^{-1} and NPK @ 30:60:50 kg ha^{-1} and incorporate into the soil at the time of land preparation (Raj Mohan and Sethumadhavan, 1980). Top dressing with 30 kg N and 50 kg K_2O at 45 days after planting is recommended to promote good vegetative growth and tuber formation (Geetha,1983). This is followed by intercultural operations and earthing up of the soil. In case, the soil is very loose and chance for eroding from the base of the plant, one more earthing up has to be given to promote tuber formation.

Crop Protection

Root knot nematode is a serious pest of Chinese potato and the infested plants exhibit swellings or galls in the roots resulting in suppressed roots, yellowing of leaves, stunted growth, wilting of plants, tuber rot and malformed/small tubers. The nematodes are tiny worms less than one mm long which enter the plant roots when the plant is most vulnerable. Hence, selection of the seed tubers free from nematodes is the foremost step in plant health management. Deep summer ploughing of the field immediately after harvest exposes the soil and kills the nematodes. Cultivation of sweet potato variety 'Sree Bhadra' as a preceding crop in the month of may-june enables trapping of root knot nematodes in the soil. Crop rotation with other crops, maintenance of field hygiene, use of optimum fertilizers including organic manures, application of neem cake enriched with *Trichoderma* sp, use of resistant variety like Sree Dhara and application of new nematicides *viz*., Fluopyrum 34% SC or Fluensulfone 2% GR are to be adopted for managing the nematode in Chinese potato. To manage leaf eating caterpillars and vine borers, dipping the stem cuttings in insecticides solution *viz*., Dimethoate or Rogar 30 EC @ 1.7 ml l^{-1} for 10 minutes prior to planting is helpful in killing the insects. If severe damage is noticed in the field, spraying of insecticides is recommended using Fenthion/Fenitrothion 50 EC @ 1 ml/litre.

Harvesting

Harvesting is done when the leaves and shoots of the plants dry up at 4-5 months after planting. The plant may be uprooted after loosening the base with pick axe/spade/hand hoe or any other sharp implements. The tuber may be separated from the plant and the crop residues may be recycled in the field. The tuber yield ranges from 20-25 t ha^{-1} .

Fig. 4 Harvesting of Chinese potato tubers

Fig. 5 Harvested tubers and different grades of Chinese potato

Quality standards for planting materials production of Chinese potato

- The planting material crop is separated from other crops meant for ware purpose by a distance of at least five meters to avoid crop admixture and spread of viral diseases.
- Isolation - Fields shall be maintain with minimum isolation distance 5 meter for foundation seed and certified seed for planting material production.
- Basic stock must be selected from healthy planting materials that are disease free, true-to- type and selected from a reliable source.

- The foundation or certified seed should be used and the stocks should be replaced every 3 to 4 years.
- Chinese potato is propagated asexually by means of stem cuttings and tubers
- Land used for planting material production of Chinese potato shall be free of volunteer plants.
- Avoid Chinese potato crop residues and drainage from other Chinese potato fields.
- The cutting obtained from the apical portion of the stem (10-15 cm) with at least 2-3 nodes is found to be optimum for tuber production
- Use disease free healthy planting materials for planting.
- Use of meristem cultured disease free plants.
- Strict field sanitation and rogue out infected or self-grown plants and burn
- Spray Profenophos 50 EC@ 2 ml/l (or) Dichlorvos 76 EC @ 2 ml/ l (or) Acephate 75 SP @ 2 g/lit, Chlorpyriphos 20 EC @ 2 ml/l (or) Imidacloprid 17.8 SL @ 0.5 ml/l (or) Thiamethoxam 25 WDG @ 0.5 g/l at 7 days interval for control of insect.
- Remove the stem and dig out the tubers without injuring them.
- Only the well-shaped, disease or pest free without any defects is selected as planting material. Apical vines are preferred.
- Stem may be stored under shade for one -two days before planting. Stored stem are superior to fresh vines. Store the planting material vines upright side under shaded conditions.
- Dust and debris from the grading and packing area must not come in contact with planting material stem must be stored in well-ventilated, shaded places before planting.

- All tubers and vines for planting material must be transported in net bags or well-aerated containers to avoid excess heat damage due to respiration and close packing

Seed Village Programme (SVP)

Seed is the most important and comparatively low cost input in agriculture. The quality of seed is to be maintained by various good agricultural practices and at all levels in the supply chain. The availability of quality seed at proper time determines the agriculture growth through accelerated productivity. Replacement of the farmer saved seeds with the certified and high-quality seeds may increase the yield potential to 15-25%.

Seeds are the main factor which decides the productivity of other inputs. Small and marginal farmers are often at a disadvantageous position in adopting the agricultural technology related to genetic enhancement of production potential of agricultural crops. This is because of centralized production and distribution of improved seeds by research organizations/seed companies. Though the organized sectors are producing large quantity of seeds, the supply chain is unable to meet the huge demand for seeds across the country. Thus, the farming community depends largely on external sources for seeds. Seed village programme provides an alternative to this problem and helps farmers to become self-reliant. This initiative needs both organized communities and scientific backstopping. The seed village concept not only ensures good quality seeds for enhancing productivity but also helps in distribution of seeds among the villagers. It also helps in generating income for the community members resulting in improved livelihood.

Seed Village Programme aims at improving the quality of farm saved seeds. It is also termed as 'compact area approach'. The quality seed is the key input in agriculture. The seed replacement rate is 100% for hybrid seeds and for non-hybrids it is every 3 to 4 years. Therefore, it is essential to upgrade the availability of quality seeds to raise the Seed Replacement Rate (SRR). Information on the gap between the demand and supply of quality seeds helps to decide upon the creation of seed villages in every block to cater to the needs of farmers.

A village, wherein trained group of farmers are involved in seed production of various crops and serve to the essentials of themselves, fellow farmers of the village and farmers of the neighboring village in appropriate time and at economical cost is called Seed Village. State Department of Agriculture, State Agricultural Universities, ICAR Institutes, Krishi Vigyan Kendras, State Seeds Corporation, National Seeds Corporation, and State Farms Corporation of India (SFCI), State Seeds Certification Agencies and Department of Seed Certification are the implementing agencies.

Objectives

Specific objectives of Seed Village Programme are:

- Increasing production of certified/quality seeds.
- Increasing Seed Replacement Rate in different important crops.
- Upgrading the quality of farm saved seeds through farmers' participatory seed production.
- Familiarizing new varieties to uplift varietal replacement.
- Securing availability of seed in contingent situation.

Seed villages for Chinese potato

Seed villages for Chinese potato were established for increasing the quality seed production of improved varieties.

Partners

Tuber crop growers, scientists/staff of ICAR-CTCRI, officials of state Department of Horticulture and KVK were the partners in seed village programme (SVP).

- Lead Institute: ICAR-CTCRI, Thiruvananthapuram
- Supporting Institutes: Department of Horticulture, State Governments/KVK's
- Chinese potato growers

Selection of seed growers of Chinese potato

A total of 60 farmers (with 50 cents plot each) those farmers showing interest in taking up scientific interventions were selected during 2018-2019 to 2021-2022 with the help of State Department of Horticulture, Government of Tamil Nadu/KVK by following the guidelines of SVP (Table 3). Improved variety of Chinese potato 'Sree Dhara' was supplied to the farmers for proving its technical feasibility and economic viability. Demonstrations under SVP were conducted by multidisciplinary team from ICAR-CTCRI comprising scientists and technical staff. Quality planting materials and critical inputs were supplied to the farmers for establishing demonstration plots under SVP. Monitoring and field inspection were carried out during the crop growth period.

Table1. Details of Seed Village Programmes of Chinese potato in Tenkasi and Tirunelveli districts of Tamil Nadu

S.No.	Year	No. of demonstrations	Places of SVP
1	2018-2019	05	Alvan Thulukapatti, Tenkasi, TN
2	2019-2020	15	Pallakkal Pothukudi, Tirunelveli, TN Keezhakuthapanjan, Tenkasi, TN
3	2020-2021	15	Pallakkal Pothukudi, Tirunelveli, TN Keezhakuthapanjan, Tenkasi, TN
4	2021-2022	25	Pallakkal Pothukudi & Mannarkovil, Tirunelveli, TN Keezhakuthapanjan & Rajankhapuram, Tenkasi, TN
	Total	**60**	

Fig. 6 View of demonstration plots on Chinese potato (Sree Dhara) under SVP

Decentralized Seed Multiplier (DSM) for quality planting material of tuber crops

The objective is to establish the tuber crop farmers' network for production of quality planting materials of tuber crops under the guidance of ICAR-CTCRI. The beneficiary farmers of on farm demonstrations and frontline demonstrations. of ICAR-CTCRI under various R&D projects who cultivate tuber crop varieties in less than 1 ha area approved as Decentralized Seed Multiplier (DSM) of quality planting material of tuber crops. A team of scientists monitor the planting material production on regular basis and provide agro-advisories as per the standard seed guidelines, the planting materials are of requisite quality standards as per ICAR-CTCRI guidelines.

1. Quality planting material production of arrowroot

Arrowroot (*Maranta arundinacae)* Arr owroot commonly known as West Indian arrowroot is an erect herbaceous plant belonging to the family Marantaceae. Arrowroot is primarily grown for its quality starch which is valued as food stuff particularly for infants and invalids.

The crop is native of tropical America. In India, it is grown in north eastern States, West Bengal, Assam and in South India mostly in Kerala as a rainfed crop.

Climate and Soil

The crop is grown best at temperatures of 20-30^{0}C. A minimum annual rainfall of 950-1500 mm is required for the better growth and development of the crop. The crop thrives best in deep, well drained, slightly acid loam soils under partial shade.

Planting season

Planting should be done during the last week of May or in early June with the onset of rainfall

Planting method

Plough the land to obtain a fine tilth. Prepare raised beds of 15-20 cm height and convenient length and breadth. Plan the rhizome bits 30 cm apart at a depth of 5.0-7.5 cm and cover with soil. Experiments conducted at ICAR-CTCRI revealed that planting at a spacing of 30 x15 cm produced significantly higher tuber yield (CTCRI 1997-98a). If clumps are used, plant two clumps at a distanceof 45 cm.

Planting material

Arrowroot does not set seeds and is normally propagated from small pieces of rhizomes which are 4-7 cm in length, with 2-4 nodes known as bits. Suckers are also occasionally used as planting after raising them in the nursery. These suckers give rise to new plants which are uprooted and cut off to retain 10 cm of the shoot intact with roots. The requirement of planting material is about 5.5 t ha^{-1}

Nutrient management

Application of 10 t ha^{-1} of FYM or compost is suitable for arrowroot cultivation. Applicationof 50 kg N, 25 kg P_2O_5 and 75 kg K_2O ha^{-1} is required to get higher yields.

Intercultural operations

It is essential to keep the field clean and free of weeds during the first 3-4 months. Earthingup should be done along with weeding. Mulching using green leaves or dried leaves significantly influence tuber yield to the tune of 39.79 t ha $^{-1}$ and 36.19 t ha $^{-1}$ respectively (CTCRI 1997-98 b).

Irrigation

The crop is grown purely as a rainfed crop. However, if dry spell occurs during the initial 3-4 months, supplementary irrigation at weekly intervals become necessary

Harvesting

The crop attains maturity in 10-11 months after planting. Maturity is indicated by yellowing, wilting and drying up of the leaves. At this stage, the plants are dug out and the rhizomes are separated. An average yield of 20-25 t ha^{-1} is obtained.

Quality standards for planting materials production of arrowroot

- Main seed crop is separated from other crops meant for ware purpose by a distance of at least five meters to avoid crop admixture and spread of viral diseases.
- Isolation - Seed crop fields shall maintain minimum isolation distance 5 meter for foundation seed and certified seed. .
- Selected from healthy planting materials that are disease free, true-to- type and selected from a reliable source.
- The foundation or certified seed should be used and the stocks should be replaced every 3 to 4 years.
- Arrowroot is propagated asexually by means of rhizomes and sucker
- Land used for planting material production of Arrowroot shall be free of volunteer plants.
- Avoid Arrowroot seed crop residues and drainage from other Arrowroot fields.
- The cutting obtained from of rhizomes which are 4-7 cm in length, with 2-4 nodes is found to be optimum for planting material production
- Use disease free healthy planting materials for planting.
- Use of meristem cultured disease free plants.

- Strict field sanitation must be followed and rogue out infected or self-grown plants.
- Spray Profenophos 50 EC@ 2 ml/l (or) Dichlorvos 76 EC @ 2 ml/ l (or) Acephate 75 SP @ 2 g/lit, Chlorpyriphos 20 EC @ 2 ml/l (or) Imidacloprid 17.8 SL @ 0.5 ml/l (or) Thiamethoxam 25 WDG @ 0.5 g/l at 7 days interval for control of insect.
- Remove the stem and dig out the tubers without injuring them.
- Only the well-shaped, disease or pest free without any defects is selected as planting material.
- Rhizomes and suckers may be stored under shade condition before planting. Stored rhizomes are superior to fresh vines. Store the planting material vines upright side under shaded conditions.
- Dust and debris from the grading and packing area must not come in contact with planting material. stem must be stored in well-ventilated, shaded places before planting.
- All tubers and vines for planting material must be transported in net bags or well-aerated containers to avoid excess heat damage due to respiration and close packing.

2. Quality planting material production of Yam Bean

Yam Bean (*Pachyrrhizus erosus L)* is a leguminous tuber crop. Unlike other commercial tuber crops, it is propagated by seed. It is popularly known as *Mishrikand* in Hindi. Yam bean is a starchy root crop with comparatively high sugar content and moderate content of ascorbic acid.

In India, tender tubers are consumed as a vegetable. Young tubers are crisp, succulent and sweet which are highly preferred for salad making, the mature seeds contain high content of alkaloids and insecticides properties. In many developed countries the tubers are processed, canned and many sweet preparations are made.

Yam bean plants

Yam bean tubers

Yam bean seeds

Climate and Soil

Yam bean can be easily grown in tropical as well as sub-tropical climatic conditions. Sandy loam soil is considered ideal for the cultivation of yam bean. The soil should be slightly acidic to saline in reaction with good drainage facilities. Tuber produced on light soil having desirable shape and brighter skin colour fetches good price in the market. Plants grown in heavy soil are usually producing tubers which are rough and irregular in shape

Planting season

Planting should be done during the month of June-July with the onset of rainfall in North –Eastern India and is usually harvested during December-January

Planting method

Deep ploughing of land followed by pulverizing the soil fecilitate conservation of moisture. Prepare mounds at a spacing of 75-100 cm with 15 cm height and planting the seed on ridges results in better yield. Yam bean seeds can be sown on mounds at the rate of 3-5 seeds per hill.

Plant spacing

Seed production of yam bean requires a spacing of 50x30 cm where as a closer spacing 30x15 cm between rows and plant sown in August produce more acceptable tuber size for table purpose. The crop can also be sown till the middle of september at even more closer spacing of 15 x15 cm. Higher seed rate to the tune of 50 kg and 80 kg ha^{-1} will be required at the spacing of 30 x15 cm and 15x15 cm, respectively.

Planting material

Yam bean is usually raised by seed. Seed rate is 20-60 kg ha^{-1}

Improved variety

The line No. 29 under the name of Rajendra Mishrikand-1 (RM-1) was released for commercial cultivation in Bihar, it produces an average yield of 30-35 t ha^{-1} of marketable tuber which is double the yield of indigenous cultivars. It has a maturity period of 120-135 days with shallow rooted fleshy and juicy tubers having swollen upper part being spherical and sharply tapering lower part.

Nutrient management

Application of 15-20 t ha^{-1} of FYM or compost is required for yam bean cultivation. Application of 80 kg N, 40 kg P_2O_5 and 80 kg K_2O ha^{-1}. Entire dose of P and K is applied as basal dose at the time of planting along with half dose of N. Remaining half dose of N is top dressed at 40-50 days after sowing along with interculturing and earthing up. Ramaswamy *et al.,* (1980) suggested a fertilizer dose of 80:60: 80 kg N, P_2O_5 and K_2O ha^{-1}

in Tamil Nadu. Similar results were obtained with the application of 80 kg ha^{-1} each of nitrogen and potash at AICRP centre, BCKV, Kalyani, (Sen and Mukhopadhyay, 1989). Higher K_2O application reduced cracking of tubers (Mishra *et al.,* 1993).

Intercultural operations

Normally yam bean starts flowering at 75 days after sowing and it is desirable to remove the flowers for getting better tuber yield. Weed infestation is more during June-August sown crop compared to September sown crop. It is essential to keep the field clean and free of weeds. It is advisable to do first inter culturing at 40 days after sowing and the second 30 days after the first weeding.

Irrigation

Normally there is no need to irrigate a June–July crop. In case, there is scarcity of rains, irrigation is essential, as yam bean requires lot of moisture. For the September sown crop, itis advisable to give supplementary irrigation so that the crop will not face moisture stress during tuberisation.

Harvesting

The yam bean crop attains maturity in 150 days after sowing. Usually it is harvested on the occasion of Saraswathi pooja festival because of market demand. If harvesting is delayed, cracking of tubers are more. Harvested tubers can be stored for 2-3 days without any deterioration. The average yield of local cultivars is 18-20 t ha^{-1} while that of improved varieties like Rajendra Mishrikand (RM-1) is 30-35 t ha^{-1}.

Quality standards for planting materials production of Yam Bean

- The planting material crop is separated from other crops meant for ware purpose by a distance of at least five meters to avoid crop admixture and spread of viral diseases.
- Isolation - Planting material production fields shall maintain minimum isolation distance 5 meter for foundation seed and certified seed.
- Selected from healthy planting materials that are disease free, true-to- type and selected from a reliable source.
- The foundation or certified seed should be used and the stocks should be replaced every 3 to 4 years.
- Yam Bean is propagated by seeds
- Land used for planting material production of Yam Bean shall be free of volunteer plants.
- Avoid yam bean crop residues and drainage from other yam bean fields.
- Yam bean seeds can be sown on mounds at the rate of 3-5 seeds per hill

- Use disease free seed materials for planting.
- Strict field sanitation need to be done and rogue out infected or self-grown plants.
- Spray Profenophos 50 EC@ 2 ml/l (or) Dichlorvos 76 EC @ 2 ml/ l (or) Acephate 75 SP @ 2 g/lit, Chlorpyriphos 20 EC @ 2ml/l (or) Imidacloprid 17.8 SL @ 0.5 ml/l (or) Thiamethoxam 25 WDG @ 0.5 g/l at 15 days interval for control of insect.
- Only the well-shaped seed, disease or pest free without any defects is selected as planting material.

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Chapter 15

In vivo and *in vitro* methods of quality planting material production in yams and aroids

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Why quality planting material?

- Quality seed/ planting material is the most important input in any farming practice as it affects the production, productivity and hence profitability of the crop. Tropical tuber crops, are no way different from this.

Features of tuber seed material

- Tuber crops are mostly propagated through vegetative means (via. tuber, root, stem, vine etc.). Hence vulnerable to build up of viruses or other pathogens and seed degeneration in repeated use multiplication

- Bulkiness, low multiplication rate and perishability of tubers impact storage, transportation etc.
- While in case of grain crops (propagated through true seeds), the rate of multiplication is high (1:100 or more) whereas the tuber crops have low rate (1: 5 to 10) of multiplication.
- Hence, the land area required for seed production is very high; *viz*.1 ha of the crop can generally produce planting materials for only 5-10 ha.
- Long crop cycle (about 9 months except for sweet potato) and dormancy periods in case of elephant foot yams and yams (2-3 months).
- Since, seed material and edible part are same in most of the cases, there is competition between ware tuber and seed tubers. As a result, often quality and quantity of next crop is affected.
- All these attributes to shortage of quality seed/planting material which in turn has become main bottleneck in expanding production of tuber crops.

Planting materials production

A.YAMS

Method of seed production is same as method of cultivation

Details of released varieties

Crop	Variety
Greater yam	Sree Keerthi, Sree Roopa, Sree Shilpa, Sree Karthika, Co-1, Konkan, Gorkand, Orissa Elite, Sree Swathy, Bhu Swar, Sree Neelima, Sree Nidhi
African yam/White Yam	Sree Priya, Sree Shubhra, Sree Dhanya, Sree Swetha, Sree Haritha
Lesser Yam	Sree Latha, Sree Kala, Konkan Kanchan

Selection of planting material

- Select tubers weighing between 200 g and 2000 g with 8-12 cm diameter

- Prepare tuber pieces of 250-300 g
- In a lot, the tuber not conforming to size should not be more than 5% (by number)
- Clean, healthy, conforming to variety characters alone need to be considered. Tubers not conforming to variety character should be less than 0.1%
- Cut, bruised, irregular shape, cracked or tubers damaged by insects, slugs, worms shall not exceed 1%, by weight
- There should not be any visible symptom of infestation by scale insects/nematodes or rotting
- Tolerance level for scale insects, mealy bug, nematodes, anthracnose are none.

Standards in field

- Isolation distance is -5 m from other varieties or same variety
- Off types 0.1% in field is allowed
- Tolerance level is none for tubers infested with scale insects, mealy bug, nematodes, anthracnose disease
- Number of field inspection required is four

Storage of yam tubers

- Store only healthy tubers
- Remove all soil before storing
- Do proper curing by drying and fungicide treatment
- Regular inspection and removal of any rotting tubers
- Protect from direct sun
- Keep the tubers upright under shaded condition with ventilation.
- The moisture content should be 60-70%
- Avoid rubbing between tubers. Use baskets, crates etc with cover on it to minimize bruising while handling

Minisett method

- In traditional method, tuber /tuber pieces of 250-300 g size is used as planting material with a spacing of 90x90 cm
- In minisett method, sett size of 30 g is used
- Here, the whole tuber is made into cylindrical pieces of 5 cm thickness
- Then , it is radially cut to have 30 g pieces ensuring that each piece have a portion of outer skin to enable sprouting
- This can be raised in nursery or in pot trays
- Pot trays are beneficial to get unifrom germination and it is easy handle of plants
- Treating the minsetts with biofertilizers during planting was found to improve percent germination and uniformity
- In case of pot trays the sprouted minisetts could be transplanted easily. But when nursery bed is used for germination, the plants are to be uprooted carefully without damage to roots
- Planting could be done in ridges
- Closer spacing of 60x45cm is sufficient for minisetts in which up to 37037 plants could be accommodated in one Ha which will increase total yield. Further selling as seed tuber fetches more returns compared to ware tuber selling
- Mean size of harvested tubers range from 300 g to one kg
- Multiplication ration is 1:24 against 1:6 in conventional method

Vine cutting method

- Use of vine cuttings ensures rapid multiplication of planting material while sparing edible tubers
- Rooted vine cuttings of 20 cm length and 2-3 nodes produced mini tubers of 50-600 g with a multiplication ratio of 1:30 (Acha *et al.,*2004; Kikuno *et al.,* 2007 and Agele *et al.,* 2010)

B. ELEPHANT FOOT YAM

Quality standards for planting material

- Tuber size with a portion of bud is 500 to 2000 g
- In seed lot, tubers not conforming to size should not exceed 5% (by number)
- Clean, healthy and conform to variety characteristics. Those not conforming to character of variety shall not exceed 0.1% for certified seed
- Cut, bruised, irregular, cracked tuber or tubers damaged by insects (other than scale insects) shall not exceed more than1%
- There should not be any visible symptom of tuber infested with scale insects/ nematodes for use as planting material

Field standards

- Isolation distance is 5 m
- Tolerance levels for pest or disease infestation
- Off types is 0.1%
- Symptom of dasheen mosaic is 5%
- None for collar rot, scale insects, mealy bug, nematodes
- Field inspection schedule: 4 inspections

Storage standards

- Keep the planting material upright ,under shade condition with proper ventilation
- Seed tuber moisture content should be 60-70%

Important varieties

- Sree Padma
- Sree Athira

- Gajendra
- Bidhan Kusum

Minisett method

- In conventional method 750 g size setts are used for planting where as in minisett method 100 g size sett is used
- As the buds are located as a ring around the central portion, care must be taken to ensure a portion of this in each sett. Otherwise it will not sprout
- The setts are dipped in cowdung slurry and shade dried for 1 day before planting
- It is recommended to plant the minsetts directly to filed and provide mulching. At the same time, planting some minisetts in nursery bed /bags will help in gap filling of unsprouted ones in field
- The land is thoroughly prepared and minsetts planted at a spacing of 60x45 cm compared to 90x90 cm in conventional method. As a result 37037 plants could be accommodated in one hacter
- Pits should be prepared with 1ft cube size and filled with 1 kg FYM and top soil
- Seed sprouts are planted at the centre of the pit with bud portion upwards
- Sprouting takes place in 2-3 weeks
- If irrigation available, minisett can be planted at any time
- In case of basal rot disease, drenching of 1% bavistin solution is recommented
- From 100g minsett, corms of 600 g^{-1}.5 kg could be obtained
- Rate of multiplication is 1:15 in minsett method against 1:4 in normal method
- Minisett method is reported to reduce the requirement of initial seed material and give more returns by sale of seed corms compared to ware corms

C. Taro and Tannia

Released varieties

Crop	Varieties
Taro	Satamukhi, Sree pallavi, Sree Rashmi, Sree Kiran, Co-1, Narendra Arvi-1, Narendra Arvi-2, Bidhan Chaitanya, Muktakeshi, Indira Arvi-1, Pani Saru-I, PaniSaru-II,Bhavapuri, Rajendra Arvi-1, Bhu Kripa, Bhu Sree, Godavari Chema
Tannia	Konkan Haritparni
Bunda	Narendra Bunda-1

- Traditionally 25-35 g size cormels or mother corms will be used as planting material with spacing of 60x45 cm
- In case of minsett, mother corms are cut into cylindrical pieces and then cut longitudinally to get minisetts of 10 g size
- The minisetts are planted in mounds prepared over pits at spacing of 45x30 cm in field.
- Multiplication ratio will be increased to 1:120 from 1:20

IN VITRO METHODS

As tuber crops are prone to virus diseases and always there is threat of spread through vegetative propagation, *in vitro* or micro propagation will help raising virus free planting material

Elephant foot yam

- Anil et al., (2012) achieved plant development through corm like structures (CLS) from petiole explants from plants raised *in vitro* from seeds.
- Kamala and Makeshkumar (2014) developed micro propagation through lateral buds excised from cormels and could transplant to soil in 7 months

Taro and Tannia

- Virus free plants could be generated through cormel tip and meristem cultured in MS media supplemented with NAA and BAP (1.0 µM) in Taro and Tannia (Unnikrishna *et al.,* 2006)

Yams

- *In vitro* culture of meristem tip or nodal explants of vine or tuber sprouts was effective in yams.
- In greater yam and white yam, MS medium supplemented with NAA (1 µM)+BAP (2 µM) was found effective while in lesser yam NAA (1 µM)+BAP (10 µM) was found effective (Unnikrishna *et al.,* 2006)

Problems to be addressed

Tuber crops seed material have certain inherent problems associated with it.

- Acute shortage of quality seed/planting material of improved varieties.
- The public sector does not have capacity or the reach.
- Large scale private companies are not interested or not available in the planting material sector of tuber crops.
- Seed degeneration and hence need for seed replacement at regular intervals say 4-5 years.
- Poor percolation of elite varieties mainly attributable to poor or under developed seed system.
- Complex nature of farmer demand for seed and the demand is often unpredictable.

Decentralized Seed Multiplier

- Decentralised Seed Multipliers (DSM) or local seed producers will be identified is recommended for large scale production of quality planting material. It can be farmers/farmer groups/incubatees/FPOs/SHGs etc under designated krishibhavan jurisdiction

- In addition, concerned state farm/district farm under DoA may multiply improved varieties to partly meet the demand
- Nucleus planting material/source material of elite varieties to be made available to selected seed producers (named as DSM)
- Training on (a).Quality standards and (b) Rapid multiplication techniques of tuber crops
- Technical guidance and supervision by ICAR-CTCRI/KAU for respective varieties in association with agriculture department.
- DSMs may be authenticated to supply quality declared planting material (QDPM) to various stake holders (Department of Agriculture, KVKs as well as fellow farmers).
- Directory of DSMs and availability of QDPM may be prepared and made available to all stake holders.

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Chapter 16

Seed rules and regulations applicable to vegetatively propagated crops with special reference to tuber crops

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Introduction

An estimated 300 million people living in poverty throughout the developing world depend on at least one type of root, tuber, and banana crop for their livelihoods. One pathway to increasing VPC yields and returns is through the use of quality planting materials by farmers (Almekinders et al., 2019). These planting materials are cuttings, stems, buddings, tubers, or other vegetative material used to asexually propagate a plant that is genetically identical to its parent. Systems that deliver seed of both good genetic and physical quality are an essential complement to other yield-enhancing inputs and crop management practices.

Seed Act (1966) and Seed Rules

To ensure the availability of quality seeds, GOI has enacted Seed Act in October 1966 and Seed Rules in September 1968. Seed Act implemented by the Indian Parliament in 1969 (25 sections). The Objective is to regulate the quality of certain notified kind/ varieties of seeds for sale and for matters connected therewith. Seed (Control) order 1983 promulgated under Essential Commodities Act, 1955 to ensure the production, marketing and distribution of the seeds.

As per seed act 1966 (Section 2), "seed" means any of the following classes of seeds used for sowing or planting (i) seeds of food crops including edible oil seeds and seeds

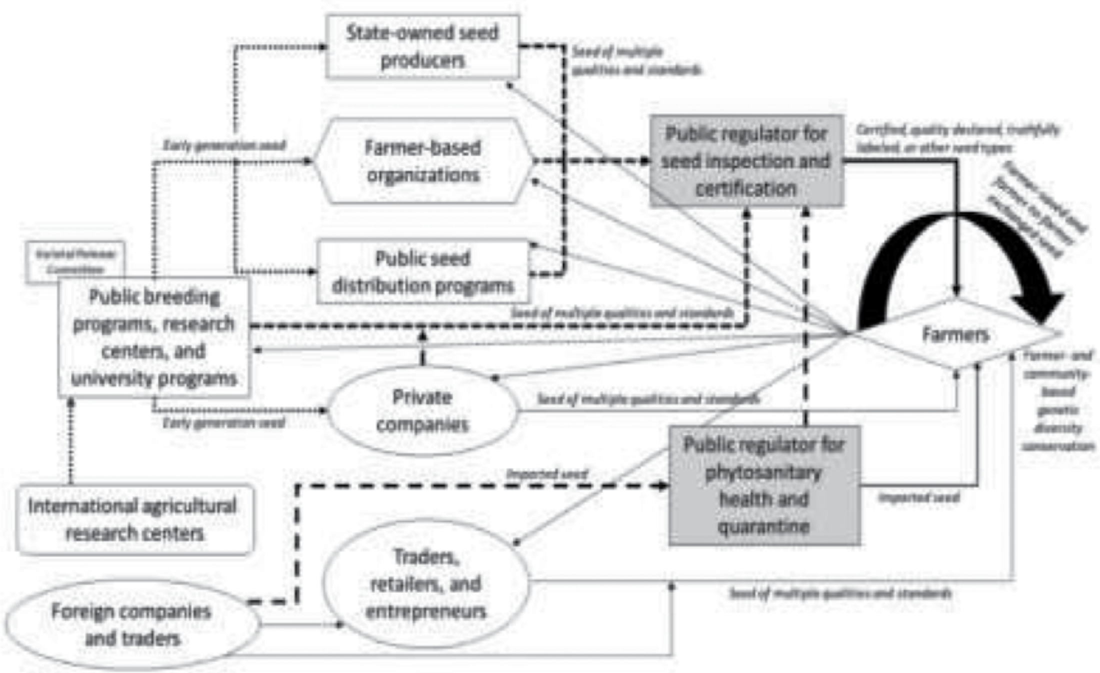

Figure 1: Generalizable schematic of seed systems for vegetatively propagated crops across the crop-country combinations

Note: Solid lines denote seed used in cultivation. The weight of each line denotes indicative volumes of seed moving through the indicated channel. Large dashed lines indicate regulatory channels, small dotted lines indicate channels for early-generation seed movement, and smaller dotted lines indicate farmer production and supply of seed-to-seed providers.

of fruits and vegetables; (ii) cotton seeds; (iii) seeds of cattle fodder; and includes seedlings, and tubers, bulbs, rhizomes, roots, cuttings, all types of grafts and other vegetatively propagated material, of food crops or cattle fodder. Key to the Seeds Act, 1966 and the Seeds Rules, 1968

Sl. no.	Subject	Related section(s) ofthe Seed Act	Related rules of Seeds Rules	Related forms of Seeds Rules
1	**Minimum limits and labeling (Seed Quality control)**			
	General	1,2,23,25	Part I-1, 2 Part XI-38	
	Central Seed Committee	3	Part II-3, 4	
	Seed Testing Laboratory	4, 16(2), 16(3), 16(4)	Part III-5 Part X-36	
	Notification of kinds and varieties	5		
	Labeling provisions	6, 7, 17	Part V-7, 8, 9, 10, 11, 12 Part VI-13	
	Seed Analyst	12, 16(1)	Part IX-20, 21, 33, 35	VII
	Seed Inspector	13, 14, 15	Part IX-22,23 Part X-24, 25, 26, 27, 28, 29, 30, 31, 32, 34, 37, 39	III, IV, V,VI, VIII
	Penalty	19, 20, 21 22		
	Exemption	24		
2	**Seed Certification**			
	Certification agency	8, 18	Part IV-6	
	Certification	9, 10	Part VI-14	I, II
			Part VII-15, 16, 17	
	Appeal	11	Part VIII-18, 19	

Form I : Form of application for seed production under the seed certification programme

Form II : Application for the Grant of a Certificate : Every certificate granted under sub-section 3 of section 9 shall be in Form II and shall be granted by the certification agency.

Form III : Form of Order: The order to be given in writing by the Seed Inspector under clause (c) of sub-section (1) of section 14 shall be in Form III.

Form IV : Form of Receipt for Records – When a Seed Inspector seizes any record, register, document or any other material object under clause (d) of sub-section (1) of section 14, he shall issue a receipt in Form IV to the person concerned

Form V : Samples how to be sent to the Seed Analyst. – The container of sample for analysis shall be sent to the Seed Analyst by registered post or by hand in a sealed packed enclosed together with a memorandum in Form V in an outer cover addressed to the Seed Analyst.

Form VII : The report of the result of the analysis under sub-section (1) or sub-section (2) of section 16 shall be delivered or sent in Form VII.

Form VIII : The memorandum to be prepared under subsection (4) of section 14 shall be in Form VIII for stock record of seed; record of the sale of seeds.

Field standards

Crops	No of inspection	Field standards (Isolation distance m)		Off types (%)	
		Foundation	Certified	Foundation	Certified
Garlic	2	5	5	0.10	0.20
Multiplier onion (potato onion)	2 (1st after transplanting, 2nd after lifting of bulb from mother bulb production plot)	5	5	0.10	0.20

Onion	Mother bulb production: 2 (1st after transplanting, 2nd after lifting of bulb from mother bulb production plot)	5	5	0.10	0.20
	Seed production: 4 1st before flowering, 2nd and 3rd during flowering in seed production plot, 4th at maturity	1000	500	0.10	0.20
Onion hybrids	Mother bulb production: 2 (1st after transplanting, 2nd after lifting of bulb from mother bulb production plot)	5	5	0.010	0.050
	Seed production: 4 1st before flowering, 2nd and 3rd during flowering in seed production plot, 4th at maturity	1200	600	0.010	0.050
Lesser Yam (hybrids)	3 (90, 150, 200 days after planting)	5	5	0.050	0.10
Ginger	4	3	3	0.5	1
Potato	4 (35-45 days and 60-75 days after planting, immediately after haulm cutting and 10 days after haulmcutting)	5	5	0.050	0.10

True potato seed (TPS)	4		50		0.10
Taro (Arvi)	3	5	5	0.1	0.5
Turmeric	4	3	3	0.5	1

Field counts

- **Field count:** Number of plants/earheads of seed crop to be observed during field inspection as one unit depending upon the cropping pattern and crop.
- **Example:** If one field requires 1000 plants/earheads and in one step one can observe 25 plant/earheads of seed crop. Then, to complete one field count one has to take 40 steps *i.e.*, 25 x 40 = 1000 plants/earheads. Observation of one count indicates seed plants, rogue and other observations taken in 40 steps movement in the field.
- Number of plants/heads/count for bulb and root crops = 100

$$\text{No. of steps required for one field count} = \frac{\text{No. of plants/earheads to be observed in one field count}}{\text{Number of steps required for one crop}}$$

The number of counts taken and the method of taking counts vary from crop-to-crop (Fig. 2, 3). Normally in all crops five counts are taken for an area upto 5 acres, and an additional count taken for each additional five acres as given below:

Area of the field crops (acres)	No. of counts to be taken
0–5	5
6–10	6
11–15	7
16–20	8
21–25	9

1. Tenth plant. Within these ten plants, count plants with receptive silks and plants which are off types. Now, cross over the pre-determined number of rows and continue similar counts.

2. Starting point. Randomly selected plant in a randomly selected row.
3. Sixty plants have been counted over six randomly selected rows. Continue to count 100 plants. This completes one count. Repeat the process five more times.

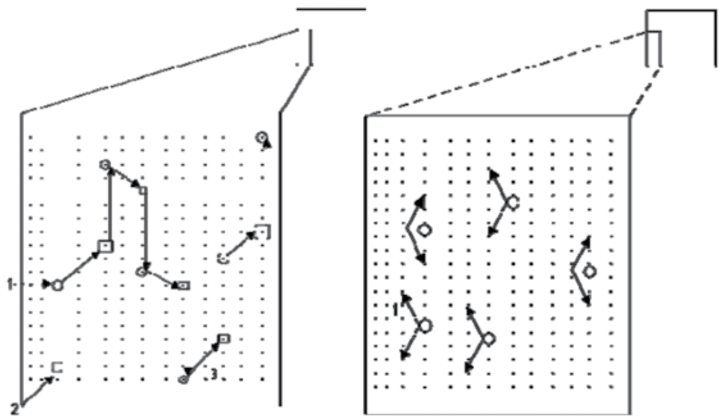

Fig. 2 & 3 Field counts

a) In any inspection, if the first set of counts shows that the seed crop does not conform to any one of the prescribed standards (factor), a second set of counts should be taken, to ascertain the conformity. However, second set of counts is not necessary when a particular factor shows twice the maximum prescribed during the first set of counts. Two sets of counts are called double counts.

Seed standards

Crops	
Garlic	Average diameter of each bulb shall not be less than 2.5 cm or 25gm in weight.
Multiplier onion (potato onion)	Average diameter of each bulb shall not be less than 2cm 2.
Lesser Yam (hybrids)	Seed size (weight of the tuber): 100-150 gm.

		Pure Seed (min.)	Inert matter (max.)	Other crop seeds (max.)	Weed seeds (max.)	Germination (min.)	Moisture (max.)	For vapour-proof container (max.)
Onion	Foundation	98.0%	2.0%	5/kg	5/kg	70%	8.0%	6.0%
	Certified	98.0%	2.0%	10/kg	10/kg	70%	8.0%	6.0%
Onion hybrids	Foundation	98.0%	2.0%	5/kg	5/kg	70%	8.0%	6.0%
	Certified	98.0%	2.0%	10/kg	10/kg	70%	8.0%	6.0%
True potato seed (TPS)	Certified	98.0%	2.0%	-	10/kg	80%	8.0%	6.0%
Taro (Arvi)	Specification for FS and CS shall be as under: Size of seed corms: 4-6 cm x 2.5 to 3.5 cm ,Corresponding weight 20-40 gm In a seed lot, corms not conforming to specific size of seed shall not exceed more than5.0% (by number) The corms not conforming to varietal characteristics shall not exceed 0.10% and 0.50%(by number) for FS and CS classes respectively							
Turmeric	Foundation	Uniformity (Minimum): 95.0-100.0% In a seed lot, rhizomes not conforming to specific characteristics of a variety shall not exceed 0.5% and 1.0% (by number – maximum) for FS and CS classes, respectively.						
	Certified	Uniformity (Minimum): 85.0%						
Ginger	Foundation	Uniformity (Minimum): 95.0%. In a seed lot, rhizomes not conforming to specific characteristics of a variety shall not exceed 0.5% and 1.0% (by number – maximum) for foundation and certified seed classes, respectively. Cut, bruised, or those damaged by insects shall not exceed more than 1.0% (by weight)						
	Certified	Uniformity (Minimum): 85.0-95.0%						

Potato

Specification in respect of size and weight of seed material for FS-I, FS-II and CS class shall be as under

Size	Mean length and two widths at the middle of tuber	Corresponding weight
(a) Hill seed (HS)Seed size Large size	30mm – 60 mmabove 60 mm	25 – 150 gm above 150 gm
(b) Plains seed (PS)Seed size Large size	30mm – 55 mmabove 55 mm	25 – 125 gm above 125 gm

- In a seed lot, tubers not conforming to specific size of seed shall not exceed more than 5.0% (by number)
- The seed material shall be reasonably clean healthy firm and shall conform to the characteristics of the variety the tubers not conforming to the varietal characteristics shall not exceed 0.050% and 0.10% (by number) for foundation and certified seed classes respectively.

Recommendations

Recommendation option	Description
Reform language in national policy on seedsystems and markets	Legalize informal VPC seed production and withdraw language that criminalizes informal VPC seed production and trade, where relevant; recognize informal seed production and trade as extant systems that require public and private support, not elimination or replacement.
Prioritize public investment in earlygeneration seed production	Concentrate public spending on the production and distribution of high-quality early – generation seed in research centers, state-owner enterprises, government development programs, or through public private partnership arrangements.
Introduce multiple or alternative seedquality categories	Introduce quality-declared seed or similar categories, along with related standards and protocols for rural entrepreneurs and farmer based organizations, to complement existing classes of early-generation seed.

Recommendation option	Description
Decentralize regulation to local levels	Pursue approaches that combine internal (producer-level) quality assurance systemswith decentralized external regulatory oversight to accommodate the unique biological aspects of VPC seed.
Increase use of accredited third-partyquality assurance services	Use accredited third-party inspection services, facilities and inspectors or internal (firm-level) quality assurance systems to increase the coverage of regulatory oversight, given the need for decentralized regulation and limits on public resources
Invest in the development and use of seedtraceability systems	Invest public and private-sector resources in the design, testing, and application of seed traceability systems that track material from source to field and possibly allow for monitoring of varietal adoption quality seed use and pest and disease management susceptibilities.
Harmonize national policy and regulation with regional and global standards	Update national policy and regulations to align with commitments made underregional and global agreements on policyand regular harmonization of seed trade, with specific reference to VPCs
Provide subsidies to incentivize production,marketing and use of quality seed	Design and implement targeted subsidy programs that support seed producers, distributors, and/ or farmers as a means of lowering costs and encouraging production and use of quality seed
Develop capacity or rural entrepreneurs andfarmer-based organizations	Develop capacity of entrepreneurs and farmer-based organization through technical training, business services and other support to produce, brand and distribute seed in localized markets using high quality early- generation seed; develop internal quality assurance practices and protocols.

Recommendation option	Description
Strengthen risk assessment and communication for VPCs	Develop more effective, farmer-facing tools to assess and communicate the technical, social and economic risks of biotic and abiotic threats to VPC production and the contribution of quality seed to mitigating these risks
Invest public resources in breeding for hostresistance	Invest public resources in breeding programs that focus on host resistanceespecially for intractable seed home pests and diseases

Conclusions

Efforts to build effective quality assurance systems for VPC seed are challenged by the fundamental nature of VPC seeds and seed markets in many developing countries. Binding constraints include not only biological characteristics such as perishability, bulkiness, low multiplication rates, and high rates of pest and disease accumulation, but also economic characteristics: market frictions such as highly localized, dispersed, and fragmented market structures and the non-appropriability of gains from innovation in these markets. To date, few developing countries have invested sufficient public resources in designing regulatory systems that are cognizant of these constraints and tailored to the characteristics of each crop and the context in which farmers cultivate these crops.

Solutions require longer-term strategies that rely not only on technological fixes such as advanced propagation systems and seed tracking apps, but also on a policy and regulatory environment that explicitly encourages the coexistence of multiple seed quality categories and the integration of multiple seed production and marketing systems. We recommend a set of public policy, investment, and regulatory reforms that

- Recognize extant seed systems and end the marginalization or criminalization of informal seed production and trade;
- Prioritize public investment in early-generation seed production, distribution, and traceability systems;

- Invest in capacity development for rural entrepreneurs and farmer-based organizations in VPC seed production and marketing;
- Introduce multiple or alternate seed quality categories such as quality-declared seed along with decentralization of quality assurance systems that combine internal systems with external oversight or the threat of such oversight; and
- Improve assessment and communication of risk associated with biotic and abiotic threats to VPCs that may be mitigated through the use of quality seed and improved genetics.

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Chapter 17

Indigenous technical knowledge and farmers innovations on conservation of tropical tuber crops

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Introduction

Tuber crops are considered as the third most important food crops after cereals and green legumes which form staple/supplementary food for about 800 million people around the world. India is one of the major producers of tuber crops *viz*., cassava, sweet potato, greater yam, lesser yam, white yam, taro, tannia and arrowroot with an area of about 4 lakhs ha. Through the systematic research conducted at ICAR-Central Tuber Crops Research Institute (ICAR-CTCRI) and State Agricultural Universities (SAUs) during the last few decades, a substantial number of viable technologies related to crop improvement, production, protection and processing have been evolved for enhancing productivity of tuber crops. The Central Tuber Crops Research Institute is the pioneering research organization conducting research on different aspects of the tropical tuber crops. The ICAR-CTCRI also coordinates research on tuber crops within the country and execute the research programmes under the All India Coordinated Research Project on Tuber Crops (AICRP TC). Various programmes are being implemented by R & D agencies as part of the efforts to disseminate the research results among the farmers. Front line extension programmes like On farm Trials (OFTs),Frontline demonstrations (FLDs) are also being organized by ICAR-CTCRI and SAUs. Majority of the tuber crops growers are small and marginal farmers and the factors like cost of input, labour and small land holdings limits the adoption of recommended technologies for higher productivity and income from tuber crops farming.

Agriculture plays an important role in Indian economy and continues to be one of the most vibrant sectors in ensuring food security of the country. Development of this important sector depends on several critical factors like inputs, resources, services, education, research, and innovations. Research and innovations plays an important role in achieving growth in agriculture sector. Indian public-sector research system, international agricultural research centers and private players constantly providing new technologies to the growth of agriculture sector. So these trends generate demand for innovations to increase the productivity of the major food crops and also overall development of the agriculture sector. In the meantime, farmers have taken a lead in inventing new methods/practices to overcome their problems and enhancing their productivity and the type of innovation ultimately makes the difference is what farmers decide to do. Normally, the term "innovation" at farmers level means adoption of new technologies coming from outside. But it is evident that farming is their traditional occupation, many new practices or modifications of existing practices become the part of the system. Even then little attention was given to the new technologies, management practices and institutions that farmers and farming communities have developed themselves- to "local innovation". This refers to the dynamics of indigenous knowledge- the knowledge that has developed over time within a social group incorporating both learning's from the experience of earlier generations and knowledge that has been gained in the meantime from whatever source and has been fully internalized within local ways of thinking and doing. Innovation is defined as an idea, practice, or object that is perceived as new by an individual or another unit of adoption.

Farmers' innovations are also a way of life for the farmers who are being challenged by the ever- changing, technical, environmental, policy and market situations in the country. For them, innovation is not academic work or an extra curricular activity. Rather, it is an inherent characteristic of those who are striving to make a living out of the difficult situation they are in. Almost every single farmer who is living in such challenging circumstances has to innovate in order to adapt and survive.

Indigenous Technical Knowledge (ITK) is as old as the human civilization. It is the knowledge of local people that helps them to solve most of their problems at their own places, by using their logic and innovative mind. Indigenous technical knowledge (ITK) refers to the unique local knowledge existing within and developed around the specific conditions of women and men indigenous to a particular geographic area. The indigenous knowledge is locally available, cost effective, socially compatible and economically sustainable with the held belief among farmers that it is more efficacious (Bhanotra and Gupta, 2016; Harun-or-Rashid et al., 2010). Thus the latest trend all over the world is unravelling the indigenous knowledge as an alternative to high external input agriculture.

Definitions of ITKs

- Indigenous knowledge refers to the unique traditional, local knowledge existing within and developed around the specific conditions of women and men indigenous to a particular geographic area. (Grenier, 1998).
- Indigenous Technical Knowledge (ITK) is the treasure of knowledge that the people in a given community have developed over time and have been passed on from generation to generation. It is not a one-time technology. It is generated based on practical knowledge and wisdom of indigenous people, tested for its effectiveness and hence transferred to the succeeding generations. It is therefore eco-friendly, sustainable and in turn human- friendly.

- According to ICAR (2002), indigenous knowledge is the participant's knowledge of their temporal and social space. Indigenous knowledge as such refers not only to knowledge of indigenous people, but to that of any other defined community.
- According to World Bank (1998), the special features of ITK are: it is local and rooted in a particular community; it is tacit knowledge and not easily codifiable; transmitted orally; experiential rather than theoretical knowledge; learned through repetition and constantly changing.
- The term indigenous knowledge is used synonymously with indigenous technical knowledge, traditional knowledge, local knowledge, folk knowledge, traditional wisdom, and wisdom of elders. Seeland (2000) observes that these synonyms refer to the local origin and promotion by a community. However, IK is dynamic and not static as the word 'traditional' commonly implies. As Berkes (1999) rightly puts it, traditional does not mean an inflexible adherence to the past; it simply means time tested and wise.
- Further, IK is the social capital of the poor, their main asset to invest in the struggle for survival, to produce food, to provide for shelter, or to achieve control of their own lives. In the words of Husain (2010), indigenous practices in agriculture are those practices developed and/or adopted by the farmers of a specific geographical area to solve their problems and/or fulfill their requirements in the cultivation of crops, with much reliance on local inputs and internal solutions. Indigenous knowledge in agriculture may be classified into different types such as information, practices and technologies, beliefs, tools, materials, experimentation, biological resources, human resources, education, and communication (IIRR, 1996). In the field of crop agriculture, ITKs are available in all the areas of crop production, crop protection, post- harvest management and natural resource management for agriculture.

Indigenous Knowledge System and Scientific System

The major differences between indigenous knowledge system and scientific system are given in Table 1.

Table 1. Differences between Indigenous Knowledge System and Scientific System

S. No.	Indigenous Knowledge System	Scientific System
1	All parts of the natural world are regarded as animate, all life forms as interdependent	Human life is generally regarded as superior, with a moral right to control other life forms
2	Knowledge is transmitted largely through oral media	Knowledge is transmitted largely through the written word
3	Knowledge is developed and acquired through observation and practical experience	Knowledge is generally learned in a situation, which is remote from its applied context
4	Knowledge is holistic, intuitive, qualitative and practical	Knowledge is essentially reductionist, quantitative, analytical and theoretical.
5	Knowledge is generated by resource users in a diachronic (long term) time scale	Knowledge is generated largely by specialist researchers on a synchronic (short term) time scale
6	The nature and status of particular knowledge is influenced by socio cultural factors such as spiritual beliefs, and is communally held	The nature and status of particular knowledge is influenced by peer review, and is held by individual specialists
7	Explanations behind perceived phenomena are often spiritually based on subjective	Explanation behind perceived phenomena are essentially rational and objective
8	Knowledge is used to make suitable decisions under variable conditions	Knowledge is used to put forward hypothesis and to verify underlying laws and constants

Features of ITKs

- Local in that it is rooted in a particular community and situated within broader cultural traditions; it is a set of experiences generated by people living is those communities.
- Tacit knowledge and, therefore, not easily modifiable.
- Transmitted orally, or through imitation and demonstration. Codifying it may lead to the loss of some of its properties.

- Experiential rather than theoretical knowledge. Experience and trial and error tested in the rigorous laboratory of survival of local communities constantly reinforce indigenous knowledge.
- Learned through repetition, which is a defining characteristic of tradition even when new knowledge is added. Repetition aids is the retention and reinforcement of indigenous knowledge.
- Constantly changing, being produced as well as reproduced, discovered as well as lost; though it is often perceived by external observers as being somewhat static.

Characteristics of ITKs

- ITK is not static but dynamic
- Exogenous knowledge and endogenous creativity brings change to ITK
- ITK is intuitive in its mode of thinking
- ITK is mainly qualitative in nature
- ITK study needs a holistic approach
- ITK, if properly tapped, can provide valuable insights into resources, processes, possibilities and problems in particular area
- ITK is recorded and transferred through oral tradition
- ITK is learned through observation and hands-on experience
- ITK forms an information base for variety
- ITK reflects local tradition

Importance of ITKs

- ITK may have scientific basis and its technologies could be transferred to other similar farming situations
- Documentation and screening of ITK is necessary before the valuable information is lost for ever

- ITK may be an alternative, a substitute or a complement to modern technology
- ITK may generate ideas for future research
- It is often easier to secure adoption of ITK than modern technology

Roles and scope of ITKs

- It can aid development efforts
- It can facilitate local people's participation
- It is a valuable source of developing appropriate technologies
- New biological and ecological insight
- Resource management
- Protected areas and conservation education
- Development planning
- Environment assessment

Types of indigenous technical knowledge

The types of indigenous knowledge could be classified as follows (IIRR, 1996)

- Information: Trees and plants that grow well together, indicator plants that show soil salinity or wilting point
- Practices and technologies: Seed treatment and storage methods, bone setting methods, disease treatments etc.
- Beliefs: Holly forests protected for religious reasons
- Tools: Equipment for planting and harvesting, cooking pots and implements
- Materials: House construction materials, materials for basketry, handicrafts etc.
- Experimentation: Healers' tests for new plant medicines
- Biological resources: Animal breeds, local crop and tree species
- Human resources: Specialists such as healers and black smiths

- Education: Traditional instruction methods, apprenticeships etc.
- Communication: Stories and messages carved on lontar palm leaves, folk media, traditional information exchange

There can have ITK on all aspects of crop cultivation such as varieties, climate and season, soil, seeds, preparatory cultivation, sowing/planting, water management, nutrient management, intercultural operations, weed management, plant protection, harvest, post- harvest and value addition etc.

Sources of indigenous knowledge

According to IIRR (1996), indigenous knowledge or the practices could be collected from the following sources:

- Community members, especially the elders: Indigenous experts(such as a farmer particularly skilled in a specific area); Indigenous professionals (such as healers and irrigation specialists); Innovators (people who experiment with and develop new techniques); Intermediaries (those who pass on messages such as "town criers" and messengers) and Recipient disseminators (all those who receive information, modify it and pass it on).
- Folk lore, songs, poetry and theatres
- Community records like writing, painting and carvings. Records can also consist of trees planted as boundaries, notched poles, bones and many other forms.
- People working with communities such as extensionists.
- Secondary sources include published and unpublished documents, databases, videos, photos, museums and exhibits.

Strategies for integration of ITKs into scientific research process

It is well understood by the scientists that reassessment of indigenous technical knowledge is an indispensable part of the introduction of new agricultural technology. It is recognized that the knowledge of farmers must be taken into account before any new technology is developed and disseminated. The four important steps in inclusion of the ITKs in technology generation, reassessment and adaptation process are, documentation, validation, refinement and integration.

Document the ITKs (Survey/RRA/PRA/Observations documentary evidences)

⇩

Validate the ITKs/Assess the ITKs for Scientific Logic (Survey/Lab analysis/On Farm Testing)

⇩

Refine the ITKs for increasing its applicability on wider scale
(Input to research/On Farm Research/Farmers Participatory Research/Lab studies)

⇩

Patent the valid and refined ITKs
(Guard &legalize the ITKs/ Ensure ownership to local community)

⇩

Promote the use of validated and refined ITKs
(Use media mix/Integrated Indigenous Networks, Publicize & reward)

Methods for documenting indigenous knowledge

The methods through which the indigenous knowledge or the practices could be collected are: Interviews with indigenous specialists, case studies, field observation, in depth interviews, participant observation, participative techniques, surveys, brain storming, games, group discussions, village level workshop, participatory videos and photos, key informants, case histories, observation of technology in operation, controlled trials, unstructured exchanges, agro-eco system analysis, participatory technology development, travelling to interior regions, the delphi method, manual discriminative analysis (ask farmers to discriminate practices and find rationality), decision tree analysis, linguistic and historic analysis of concepts, vocabulary and key words, ethnobotany, critical incident analysis (farmers' seed exchanges and new variety introduction), analysis of peasants' journals and newspapers, arranging competition, anthropological methods (investigation into the social, culture and other aspects of ruraltradition), local taxonomy, hear-say method and crop histories

Validation of ITKs

Validation of ITKs is to be done with set of criteria *viz*., cost-effectiveness, adaptability, observability, trialbility, complexity, relative advantage, sustainability, efficacy, availability, cultural appropriateness, effect on different groups in communities and environmental soundness. The steps involved in validation of ITKs are given below.

- Prepare a list of all the collected ITK practices
- Decide the continuum for rating the rationality of ITK with specific weightages ie. continuum weightage *viz*., very rational 5, rational 4, undecided 3, irrational 2 and very irrational 1
- Send the list of ITK practices to experts for their opinion and judgement on each practice
- Calculate the weighed mean score of individual practices
- Select practices above mean score as rational

The perceived effectiveness index for ITKs can be estimated using the procedure as given below. Indigenous Technical Knowledge (ITK) possessed by farmers can be assessed using PRA technique. ITK practices are then identified based on the expert validation using rationality score. Later, farmers in the villages can be requested to provide the opinion on the selected ITK practices which have been already validated by experts in order to understand the perceived effectiveness. Perceived effectiveness implies the degree to which the farmer perceive that a positive outcome is obtainable by using a particular ITK practice in solving the field problems. It is the perception of the respondent about the attributes of the indigenous technology like relative advantage, compatibility, trialability, sustainability and observability. It can be measured using the mean perceived effectiveness index (MPEI) methodology (Sundaramari, 2001). The index consisted of seven traits, with their relevancy weightage as given in Table 2.

Table 2. Weightage scores of various parameters of ITK practices

Sl. No.	Parameter	Relevancy weightage
1	Cost effectiveness	0.88
2	Adaptability	0.76
3	Observability	0.80
4	Trailability	0.72
5	Complexity	0.81
6	Relative Advantage	0.84
7	Sustainability	0.86

The farmers are asked to rate each identified ITK practice based on these traits on a three-point scale (Concurred, No idea and Not concurred).The perceived effectiveness index (PEI) score of a particular ITK practice was calculated using the formula:

$$\text{PEI score} = \frac{(W1R1 + W22.... \text{Wn Rn}}{R1 + R2 + R3 ....Rn}$$

Where, R1, R2, R3.......R7 were relevancy weights of the seven traits and

W1, W2, W3................W7 were scores obtained for the traits for ITK from a respondent.

$$\text{MPEI score} = \frac{\text{PEI score of a individual farmer for each ITK}}{\text{Total sample size}}$$

The above formula can be used to calculate the Mean Perceived Effectiveness Index (MPEI) score for a particular ITK practice. Based on MPEI score, all the indigenous technical knowledge practices can be categorized into three categories *viz*., less effective, moderately effective and highly effective.

Organizations working on ITKs

- TNAU Agritech Portal: TNAU has documented ITK information crop wise, operation wise, district wise, other related information related to ITK with related websites and ITC mailing address which can be accessed at http://agritech.tnau.ac.in/itk/itk_sub_topics.html.
- The honey bee network

- FARMESA: the farm level applied research methods for eastern and south africa (FARMESA) is a regional collaborative institute operating is five countries including Kenya, Tanzania, Uganda, Zambia and Zimbabwe with associate countries including Botswana, Malawi, Mozambique and South Africa.
- Nuffic-CIRAN: (Centre for International Research and Advisory Network (CIRAN) is a division of Netherlands organization for international cooperation in higher education (Nuffic).
- FAO- AGRIS Memory banking protocol : a guide for documenting indigenous knowledge associated with traditional crop varieties
- UNESCO-MOST: Management of Social Transformation Programme is a research programme designed to promote social science research

Limitations of ITKs

- Scattered in space and time
- All ITK's may not have scientific rationale (some, in fact, may be mere superstitions/ taboos)
- ITK cannot be manipulated independently of social, political, economic structures
- ITKs have poor generalizability

Innovations in Agriculture

- Innovation: Use of new knowledge or new use of existing knowledge and its application for social and/or economic use
- Innovation is the process by which individuals or organizations master and implement the design and production of goods and services that are new to them, irrespective of whether they are new to their competitors, their country, or the world. (World Bank, 2006)
- Agricultural innovation is the process whereby individuals or organizations bring new or existing products, processes or ways of organization into use for the first

time in a specific context in order to increase effectiveness, competitiveness, environmental sustainability or resilience to shocks and thereby contribute to food security and nutrition, economic development or sustainable natural resource management (FAO, 2018)

- Innovation systems is a network of all public and private sector organizations, enterprises and individuals involved in the process of knowledge creation, dissemination, adoption and use, together with the institutions and policies that affect their behavior and performance (World Bank, 2006)

Innovation systems in Agriculture

The differences between conventional agricultural system, agricultural innovation system and farmers innovation system (World Bank, 2006) are given in Table 3.

Table 3 Comparison of different innovation systems

Features	Conventional agricultural innovation system	Agricultural innovation system	Farmers innovation system
Focus	Innovation for farmers	Innovation with farmers	Innovation by farmers
Innovation type	Output	Process	Output & Process
Primary actors	Formal institutions and organizations	Formal institutions and organizations	Farmers
Role of formal sector	Innovate and facilitate technology transfer	Facilities research process and technology adoption	Provide resource and facilities
Role of farmers	Adopt new technologies	Participate innovation process	Innovate & adapt
Type of Innovation	Modern varieties and farm management practices	Modern varieties, farm management practices and alternative ways of organizing	Adaptation of modern varieties and practices, integration of knowledge system, on-farm experimentation

Major themes in literature	Investment in R & D, improving technology transfer	Investment in R & D and extension services, multiple stakeholder platforms, participatory research	Innovation as a social learning process, building social capital, roles of supporting actors

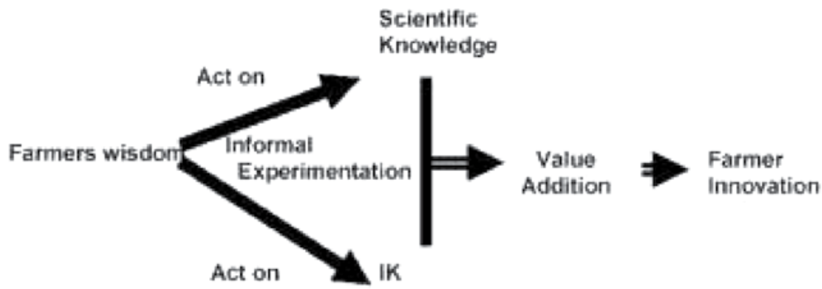
Farmers Innovations

According to Prolinnova (2006) and the World Bank (2004), local (farmer) innovation refers to the dynamics of indigenous knowledge i.e., knowledge that grows within a social group, incorporating learning from own experience over generations, but also external knowledge internalized within the local ways of thinking and doing. The outcome of this process are farmer innovations, for example, farming techniques or ways of organizing work that are new for that particular locality.

- All farmer led innovations are not of a technical nature but rather are socio-economic and institutional innovations.
- Inexpensive, easily accessible, locally appropriate and already tested in real farm practice
- Farmer innovation is also a way of life for poor farmers who are being challenged by the ever-changing environmental, policy and market situations in the country.
- Farmer innovation is all about new ways of doing agriculture and natural resource management.

Importance of farmers innovations

- Helping resource poor farmers
- Necessary for localized success
- Farmers as innovators
- Increases success of programs
- Social learning
- Effective communication



Conceptual framework on farmers innovations

Source: Promoting local innovation in ecologically oriented agriculture and natural resource management (PROLINNOVA, 2006)

Organizations/Programmes for promotion of Farmers Innovations

- Indian Council of Agricultural Research (ICAR), National Innovation Foundation (NIF) under Department of Science and Technology, Protection of Plant Varieties and Farmers Rights Authority (PPV&FRA), National Research and Development Corporation (NRDC), Agricultural Universities (AUs), Krishi Vigyan Kendras (KVKs), Agricultural Technology Management Agency (ATMA), Non-Governmental Organizations (NGOs), Farmers Organizations etc.
- NIF under DST, Govt. of India has documented more than 3.1lakhs of ideas, farm innovations and ITKs and recognized 992 grassroot innovators since march 2000
- ICAR is recognizing farmer innovations by giving Jagjivan Ram Innovative farmer award in agriculture and allied sciences
- Farmers Innovation Fund and Innovation Centre across the states throughout the country
- Initiatives by the Indian Council of Agricultural Research (ICAR) in documenting ITKs (seven volumes) under NAIP Project
- Paramparagat Krishi Vikas Yojana (PKVY) by Government of India for promotion of organic farming in India

Examples of Farmers Innovations

- New crop varieties by farmers (mainly by selection): Thirumali, a cardamom variety by a farmer (Mr. T.P. Joseph), for which he was awarded nationally (National Grass roots Innovation Award).
- New farm equipments and machineries: Mango plucking machine (by Mr. P.P. Gangadharan), natural fiber extraction machine (by Mr. P.V. Eldo), tree climber (by Mr. M.J. Joseph) etc.
- New farm techniques and practices: A farmer's successful experimentation of pepper (grafted with Collubrinum) cultivation in wet lands (by Mr. Mathai)
- Characterization of coconut based cropping systems covering socio-personal profile characteristics, farming details, extent of adoption of improved farming practices, water management techniques, integrated nutrient management, multiple cropping and integrated farming, integrated pest and disease management, value addition, innovative farming practices, economics of coconut farming, marketing practices, efforts made for disseminating technologies among other farmers and linkages with research, development and extension institutions were collected and documented from 12 states of India and a book titled 'Harvesting wisdom of coconut growers' was published (Thamban et al., 2016).

ITKs and Farmers Innovations in tropical tuber crops

- Sankaran et al., 2015 documented Indigenous Traditional Knowledge (ITK) on tuber crops practiced by Nicobar Tribes in Andaman and Nicobar Islands, India
- Scientific rationality, adoption and perceived effectiveness of traditional agricultural practices of cassava (*Manihot esculenta* Crantz.) was done in Kolli Hills, Namakkal district, Tamil Nadu (Venkatesan and Sundaramari, 2014).
- Sivakumar et al., 2019 documented indigenous knowledge of food systems of tribal communities in north eastern states of India.
- ITKs and farmers' innovations pertaining to varieties, agronomic practices, nutrient management, pest and disease management, mechanization, pre- and post-harvest

processing, value addition, storage of planting materials and tubers etc. were documented from tuber crops growers of Kerala and Tamil Nadu (CTCRI 2022) and the details are given below.

- **Varieties of cassava:** Ullichuvala, Nadan Chuvappu, Kandhari Padappan, Mankuzhulandan, Vella Thandan, Mixture Vella, Ambakadan, Mixture Chuvapu, Pathinettu, Kalikalan, Singapore Karupu, Aarumasa Chuvapu, Aarumasa Vella, Ummen, Diwan, Kottarakara Vella, Malabar, Pulladu Kappa, Etha Kappa
- **Varieties of Yams:** MattuKachal, NeendiKachal, Parisa Kodan, Neela Kachal, Inchi Kachal, Mukkizhangu, Sugantha Kachal, Thunan Kachal, Payasam Kachal, Mooduvanni, Soorai Kachal, Noor Kizhangu, Ari Kizhangu, Kaduvai Kayan, Karadi Karan
- Seed treatment: Method, duration, materials used (Cowdung, Ash, Biofertilizers, neem oil emulsion)
- Agronomic practices: Season, spacing, planting method, cultural practices, mulching, and drainage practices
- Cropping/farming system: Tuber crops based perennials and annuals, crop rotation, intercropping, mixed cropping
- Nutrient management: Rotation with pulses, green manuring, compost, ash, fermented oil cakes, cow dung slurry, panchagavya, dasagavya, jeevamrutham
- Botanicals: Ginger-chilli-garlic extract, ash, oil cakes, neem oil, nicotine, tobacco decoction, neem cake and rice husk/ border crop with chrysanthemum (nematodes), placement of cow dung balls (fungal diseases), warm ash (leaf eating insects), border cropping with red gram/leadwort (rat control)
- Castor based herbal extract for managing rodents/ wild boars
- Scaring device for managing wild animals
- Pre and post-harvest processing: Tools, machineries, equipments (cassava stem cutter, cassava harvester, Chinese potato harvesting device and sieving device)
- Value addition: Dehydrated products, Snack food products, jam, jelly etc.

- Storage of planting materials: Method, duration, place, treatment, smoking with neem and mango leaves

Challenges for documentation and validation of ITKs/Farmers Innovations

- Lack of accommodative attitude of outsiders
- Lack of adequate opportunity for farmers to decide on research priorities
- Lack of financial support
- Lack of peers' support
- Illiteracy
- Less support from researchers/extension agents
- Requires time, patience and commitment

Conclusion

ITKs/Farmers innovations play a significant role both in human and animal health related issues ranging from nutrition to healthy life system. Documentation of these practices and innovations is extremely important as it will help in creating a way towards sustainable development, protecting the intellectual property rights and will give deep insight into agriculture sector. Hence, indigenous practices and farmer innovations in tropical tuber crops need to be promoted by researchers, policy makers, extension professionals and development officers for achieving the safe food production and sustainability in the long run.

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Chapter 18

Linakge and association mapping approaches for improvement of tuber crops

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Introduction

Improving plant populations through hybridization and selection involves identifying beneficial alleles with discernible genetic effects. One effective method is selecting traits conditioned by additive allelic effects, which can lead to significant and valuable changes in breeding populations. To enhance the selection process, plant breeders can use genetic markers, which are heritable entities linked to economically important traits. Marker-assisted selection (MAS) provides a way to increase selection efficiency by enabling earlier selection and reducing the size of the plant population used during selection. However, the degree of linkage disequilibrium in the mapping population determines the association between markers and phenotypes.

Structure of population

In order to study the variation in plant populations and select desirable plants from the germplasm, it is important to understand the structure of the population. In nature, crop plants maintain all available genes in a population according to Hardy-Weinberg's law (1908), which means that gene and genotypic frequencies in a Mendelian population remain constant from generation to generation if there is no selection, mutation, migration, or random drift. When breeding plants to improve a desired trait, selected parents are crossed to produce a mapping population, which is used to construct a linkage map and identify the gene. For a locus with two alleles, A and a, the frequencies of three genotypes will remain constant at (p2) AA, (2pq) Aa, and (q2) aa, where p and q are the frequencies of alleles A and a, respectively. The validity of Hardy-Weinberg's law can be demonstrated through random union of gametes or random mating among genotypes. Gene frequency refers to the proportions of different alleles of a gene present in a Mendelian population. In contrast, genotypic frequency refers to the proportion of different genotypes for a gene in a population. When breeding plants to improve a desired trait, it is important to select desirable plants from the germplasm and study the variation in the population. This can be done by using the entire germplasm and selecting extreme plants to develop a mapping population. These populations are used to construct a linkage map and identify the gene. Usually, for constructing a linkage map, selected parents are crossed to produce a mapping population (Flint-Garcia et al., 2003).

Linkage disequilibrium (LD)

Linkage disequilibrium (LD) refers to the chance of co-inheritance of alleles at different loci. Alleles at neighbouring loci tend to be co-inherited, which might lead to associations between alleles in the population. LD arises when a new mutation occurs on a chromosome that carries a particular allele at a nearby locus, and it is gradually eroded by recombination over time. Recurrent mutations can also lessen the association between alleles at adjacent loci. The extent of LD in populations is expected to decrease with both time and recombinational distance between markers. However, the factors governing LD among any specific collection of loci are numerous, complex, and often poorly understood.

Nature of linkage disequilibrium

Linkage disequilibrium (LD) is a phenomenon that characterizes the non-random association of alleles at neighboring loci. This association is quantified using a statistic denoted as D, which measures the deviation between the observed frequency of a two-locus haplotype and the expected frequency if alleles were segregating independently. LD arises when a novel mutation occurs on a chromosome bearing a specific allele at an adjacent locus and is gradually diminished by recombination over time. Repeated mutations can also reduce the correlation between alleles at nearby loci. Increasing recombinational distance between markers is expected to decrease the extend of LD within populations over time. However, the determinants of LD for a specific set of loci are manifold, intricate, and often not fully comprehended. Hence, LD remains an active area of research in genetics and genomics.

The concept of LD is formally represented by one of the earliest proposed measures of disequilibrium, symbolized as *D*. *D*, similar to most other LD measures, quantifies disequilibrium as the disparity between the observed frequency of a two-locus haplotype (P (AB)) and the expected frequency if alleles segregated independently (P (A) × P (B)). Assuming independent assortment of alleles at two adjacent loci (denoted as A and B, with alleles A, a, B and b), the expected haplotype frequency is calculated as the product of the allele frequencies of each allele, i.e., *P (A) × P (B)*. The simplest measures of disequilibrium is expressed as D = P AB - P A × P B. *, where* P (A) is the frequency of allele A at the first locus and P (B) is the frequency of allele (B) at the second locus.

A practical way to conceptualize the emergence of LD is to consider how polymorphisms are generated through mutations. LD occurs when a new mutation arises on a chromosome carrying a specific allele at a neighboring locus and is subsequently reduced by recombination (Fig. 1). Recurrent mutations can also weaken the association between alleles at adjacent loci. However, for single nucleotide polymorphisms (SNPs), as opposed to microsatellites, recurrent mutations are typically rare, and mutation is not a significant contributor to LD erosion between SNPs (Ardlie et al., 2002). The role of recombination in shaping LD patterns is acknowledged by the term “linkage.” Theoretically, LD diminishes over time and distance according to the following

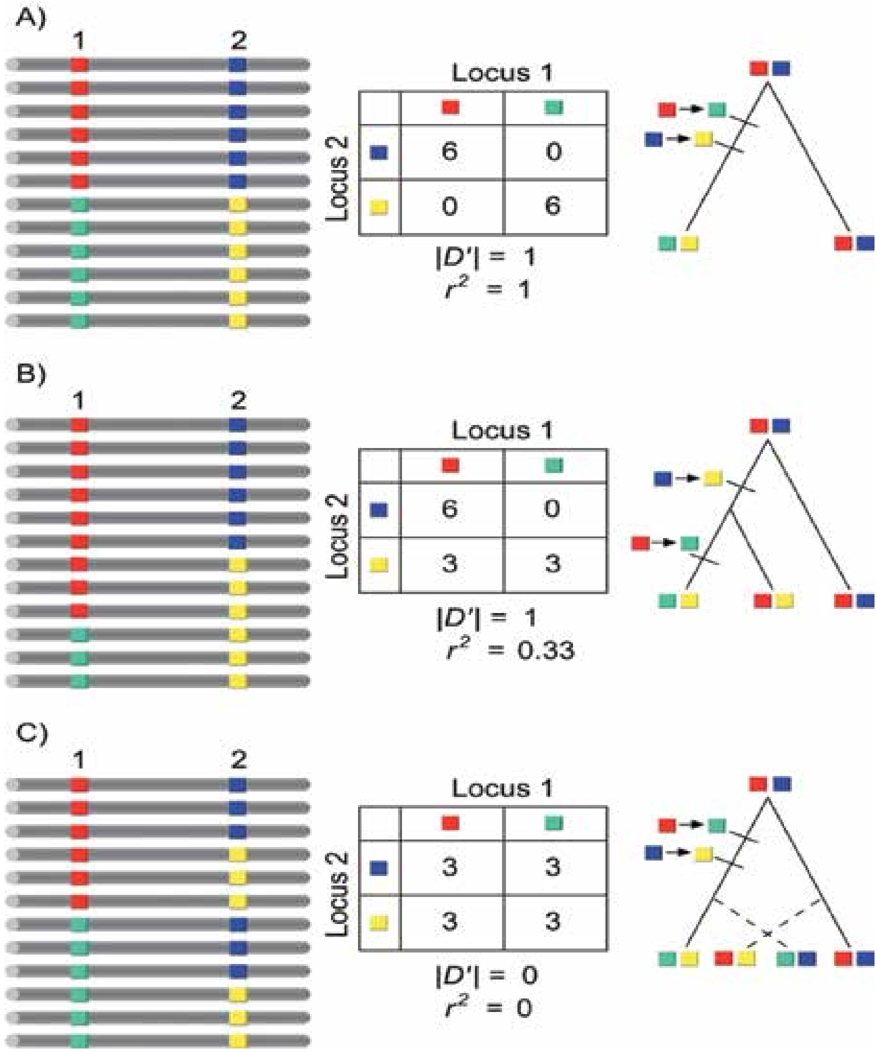

Fig. 1. The behavior of r^2 and D' statistics when there is linkage disequilibrium (LD) between linked polymorphisms caused by different mutational and recombinational histories. The figure included images that represented the allelic states of two loci in the left column, the 2 × 2 contingency table of haplotypes and the resulting r^2 and D' statistics in the middle column, and a possible tree responsible for the observed LD present in the right column. Absolute LD occurs when two loci share a similar mutational history without recombination, resulting in both r^2 and D' equaling 1. When mutations occur on different lineages without recombination between the loci, LD can result, and there is a large difference in measures of LD as calculated by r^2 and D'. Linkage equilibrium is produced when there is recombination between loci, regardless of mutational history, and in this situation, both r^2 and D' equal 0. (adapted from Jeffry et al., 2003).

formula, where D_o represents the initial extent of disequilibrium and Dt is the extent of disequilibrium t generations later: $D_t = (1 - r)^t D_o$. However, this deterministic equation inadequately represents LD behavior over short distances, where stochastic factors dominate. Consequently, while a general trend of decreasing disequilibrium with greater marker distance has been observed in empirical data, closely "linked" markers do not always exhibit LD. Conversely in certain cases, LD has been reported between relatively distant markers. This variability underscores that the determinants of LD for any specific set of loci are numerous, complex, and sometimes only partially understood. A variety of demographic, molecular and evolutionary forces exert significant influence on LD patterns.

Gene mapping using linkage disequilibrium can be achieved through two main approaches,

I. Linkage mapping

II. Association mapping

I. Linkage mapping

Linkage mapping involves the determination of gene linkage by assessing whether two genes are located on the same chromosome. Alleles that display random association are considered to be in linkage equilibrium. In linkage equilibrium, the likelihood of finding one allele at a specific locus is independent of finding another allele at a different locus. To facilitate gene mapping, segregating populations are developed, preferably through crosses involving inbred parents. Such crosses enhance the presence of linkage disequilibrium, which is essential for mapping purposes. In cases where an F_1 population results from crossing two inbred lines, complete linkage disequilibrium exists for loci harbouring contrasting alleles between the parental lines. Consequently, specific alleles become associated with each other. When recombination is introduced in the F_2 generation through backcrosses, recombinant inbred lines, or advanced intercross lines, linkage can be detected through the persistence of some linkage disequilibrium. The degree of linkage disequilibrium decreases as a population becomes more randomly mated over time, making the linkage detection progressively challenging, resulting in shorter segments of chromosomes remaining in disequilibrium.

The genetic maps are constructed by analysing the alleles of the segregating plant populations developed through crossing parents with contrasting traits. In this process, molecular markers play a crucial role in identifying regions on the plant chromosomes that contain important genetic regions associated with the heritable phenotypic traits. During the reproductive phase, recombination or cross-over occurs between the corresponding chromosomes from the two parents in the cross. The distance between two loci on the chromosome impacts the likelihood of a cross-over point being located between them. Closer loci are less likely to experience cross-over. By observing the inheritance of molecular markers, we can measure the closeness of the linkage between two loci and order them on the genetic map. This allows us to identify which region of a particular chromosome is important for the phenotype and use markers to test for the presence of important traits rather than testing for the traits themselves. It is important to note that when two genes are located on the same chromosome, they are considered to be linked. However, alleles that are in random association are said to be in linkage equilibrium. This means that finding one allele at one locus is independent of finding another allele at another locus. To facilitate mapping, segregating populations from inbred parents are developed. This increases the amount of linkage disequilibrium, making it easier to detect linkage. For example, an F_1 population from the cross of two inbred lines is in complete linkage disequilibrium for loci with contrasting alleles between the parents.

Mapping population:

The genome map of an organism serves as a comprehensive repository of genetic information and facilitates the development and testing of genetic hypotheses. However, constructing a complete linkage map remains a challenging endeavor due to the need for suitable mapping populations. Various options are available for generating suitable mapping populations (Maheswaran, 1997).

Diversity in mapping populations:

In nature, crop plants and trees can be categorized into self-pollinating or cross-pollinating based on their nature of reproduction. The population structure of self-pollinating and cross-pollinating crops differs based on the homozygous or heterozygous nature of the parents. Self-pollinating crops, due to their highly homozygous nature, facilitate the development of mapping populations with relative simplicity. In self pollinated crops heterozygous locus segregates and last it will reach the homozygosity within 5- 6 generations but in case of cross pollinated crops like vegetative propagated tuber crops and tree crops it will maintain the heterozygosity generation after generation.

Nature of self pollinated crops

The development of mapping population in self-pollinated is simple because of the highly homozygous nature of crops, the population is homogeneous (F_1), during selfing and there is no inbreeding depression and completes its life cycle within 3 - 5 months duration and maintains the linkage disequilibrium more stably. (e.g.) rice, wheat, pulses.

Different mapping populations

- F_2 population
- Backcross (BC) population
- Double Haploid (DH) population
- Recombined inbred lines (RILs)
- Near Isogenic Lines (NILs)

1. F_2 population

Phenotypically distinct homozygous parents for particular character under study will be crossed to develop F_1 progenies. By selfing or intermating F_1 hybrids, F_2 population can be made. Because F_2 population will horbouring all possible recombination of parental alleles (ie) AA, Aa, aa. Most of the molecular maps are based on segregating data from F_2 progenies (Avila *et al*., 2003, Tanhuanpaa, 2004).

2. Backcross (BC) population

The segregating progenies of F_1s backcrossed to recurrent parent were also used to construct linkage maps. The saturated RFLP map of rice, is of one such origin from the backcross progenies of *Oryza sativa*/O. longistaminata cross (Causse *et al*., 1994), rice blast (Wu *et al*., 2004), rice low-temperature germination (Fujino *et al*., 2004) and brassica (Hughes *et al*., 2003). In backcross, alleles segregate in 1:1 ratio.

3. Doubled haploid (DH) population

Doubled haploids derived from single pollen grains. Mostly used in crops, which are amenable for anther culture eg. rice. Generation of doubled haploids from anther or microspore culture is an established technique to attain homozygosity in a single step in most of the crop species. Moreover, among doubled haploids recombination events are fixed resulting in stable recombination values. DH were used for linkage map construction in Rice (Maheswaran *et al*., 1997), barley (Behn *et al*., 2004, Gouis *et al*., 2004). In DH population all the progenies are homozygous.

4. Recombined inbred lines (RILs)

Developing a population of recombinant inbred lines (RILs) is an alternative strategy in mapping projects. RILs are developed by continuous selfing of F_2 individuals until the homozygosity is achived by Single Seed Descent (SSD). Several permanent populations of RILs are developed to construct map (Wang *et al*., 1994, Koeyer *et al*., 2004). The advantage of using RILs as a mapping populations is that the resulting map shows higher resolutions of closely linked loci as compared to F_2 populations (Burr and Burr,1991). The major disadvantage is that constructing RILs is a time consuming process.

5. Near isogenic lines (NILs)

NILs are identical lines except for the gene of interest. It will be produced by continue backcrossing with the recurrent parent for BC_6 generation, by the time recurrent parent will get the resistant or gene of interest will be received from the non-recurrent parent. From this isogenic line identification of gene will be very easy. In rice, fertility restoration gene (*Rf1*) is located 22.4 kb region in the rice genome. This gene is mapped using cross between near isogenic line differing for the *Rf-1* locus (Akagi *et al*., 2004). General advantage of this NILs is whether transferred gene amenable for testing under many environment to assess G x E effect.

Nature of cross-pollinated crops

In case cross pollinated crops, predominantly highly heterozygous – cassava, sugarcane and the population heterogeneous (F_1). During selfing pollination inbreeding depression appear in the population and mostly perennial in nature – Apple. In perennial tree crops construction of genetic linkage map is difficult. Some of the difficulties faced in heterozygous trees are perennials in nature, longer generation time, land for trials, development of specific genetic stock, pedigree limitation for genome mapping , vegetative propagation, high chromosome number, self-incompatibility (Hackett *et al*., 2000).

Different breeding population used for heterozygous crops

- Two non-inbred parental cross – F_1 Segregating full sib progeny
- Pseudo test cross
- Selfed progenies from non-inbred plants
- Polyploid population
- Examples : potato, apple, cassava, eucalyptus ,alfalfa, tea, coffee

1. Two non-inbred parental cross

In cross pollinated crops, two non-inbred parents crossed eg. in cassava CMD resistance and susceptible parents, the resultant F_1 population will be heterogenous ie each and every individual in the population will be different from each other. This populations will be segregating for all the character including disease resistance. So this population itself used for linkage analysis (Akano *et al*., 2002, Okogbenin *et al*., 2002).

2. Pseudo-test cross population

In this approach, female parent is heterozygous for the character of interest and the male parent is homozygous for that character. So the F_1 will be segregating for that characters in 1:1 ratio in the population. This is the basic for this study, i.e. variety of interest is crossed with standard variety known (not segregating for the trait) eg: apple (Hemmat *et al*., 1994) and tea (Hackett *et al*., 2000).

3. Selfed progenies from non-inbred plant

In cross pollinated crops, many loci will be in heterozygous and will segregate during self pollination. Here the selfed pollinated population can used for the linkage map construction as in cassava and sugarcane (Grivet *et al*., 1996).

4. Polyploid population

Polyploidy is observed in various species, including cotton, potato, sugarcane, banana, and canola. Polyploidy can occur naturally or be induced chemically. During meiotic configuration, the occurrence of preferential pairing and the formation of multivalents lead to the segregation of allopolyploid and autopolyploid plants (Wu et al., 2001). Molecular markers play a crucial role in understanding this segregation pattern. Wu et al., 2001, developed a model for polyploid crops that proves useful in classifying polyploids, conducting linkage mapping, and studying population genetics. For e.g. In the case of sugarcane, *Saccharum spontaneum* was employed to construct a linkage map (Salah et al., 1993).

Advantage and disadvantage of linkage mapping

Linkage analysis is traditionally used to measure the genetic proximity of loci, map qualitative traits, and identify quantitative trait loci (QTLs). In plants, these cosegregation analysis are often conducted in highly structured populations with known pedigrees, such as F_2 populations. However, these populations have three significant limitations (Wu et al., 2001).

First, the limited number of recombination events results in low resolution for quantitative traits. Second, only two alleles at any given locus can be studied simultaneously, and thirdly, homozygous inbred lines used to generate the F_1 parents with known linkage phases for traditional linkage analysis are often unavailable for natural populations. To enhance mapping population resolution, large populations of recombinant inbred lines that have undergone multiple rounds of random mating have been created for various plant species, including maize. These rounds of mating increase the potential number of recombination events. Despite these efforts, the resolution for many QTLs remains several centimorgans, which corresponds to hundreds of genes. Additionally, the low number of alleles sampled per locus in each population makes it challenging to capture the full spectrum of genetic diversity available in many plant species.

Genetic linkage maps developed based on segregating families, as described above, have been valuable for plant geneticists and breeders. However, there are three limitations associated with this approach

1. It requires the growth of three generations before linkage analysis is possible.
2. Very large segregating populations are needed to achieve a high resolution map.
3. The molecular markers may be specific (polymorphic) to only one particular crossing family.

Consequently, this method is time-consuming and demands substantial effort, resulting in a relatively low-resolution map. High resolution is essential for applications like Marker-Assisted Selection (MAS) and other endeavors such as gene cloning in proximity to the marker.

II. Association mapping

One hallmark of twentieth century genetics will be the tremendous strides made in understanding how individual genes control simple traits (phenotypes). However, the fruits of the revolution in molecular genetics will likely be seen in this century, when the genes and alleles that control complex traits (quantitative trait loci - QTL) are identified and understood. Currently, F_1-derived mapping populations are the key tool for identifying the genetic basis of quantitative traits. An alternative is to use natural populations to map traits by means of association analysis. Association analysis, has been used extensively to dissect human diseases, most notably Alzheimer's disease and cystic fibrosis. This approach has recently been extended to plants, thereby increasing mapping resolution substantially over the current capabilities of standard mapping populations. There has been a resurgence of interest in LD, owing largely to the belief that association studies offer substantially greater power for mapping common disease genes than do traditional linkage studies, and that LD can offer a shortcut to genome wide association studies. LD between two loci in natural populations is affected by all the recombination events that have happened since the two alleles appeared in some individuals of the population.

Association analysis has the potential to identify a single polymorphism within a gene that is responsible for the difference in phenotype. In addition, many plant species have high levels of diversity for which association approaches are well suited to evaluate the numerous alleles available. LD plays a central role in association analysis. The distance over which LD persists will determine the number and density of markers, and experimental design needed to perform an association analysis. For these reasons, it is important to understand LD and to determine the extent of LD in the species under investigation (Flint *et al*., 2003).

An analysis by linkage study, the number of pedigrees required to map the genes of minor effect that probably underlie susceptibility to common diseases would be prohibitively large. In these circumstances, for common disease alleles, they advocated the use of population based tests of association (Fig.3). In their conception, several unrelated markers in every known gene would be tested for an association with the disease. This in itself would entail the genotyping of a vast number of markers, and there would be no guarantee that the causative variant would be included. The number of markers to be tested could range from the ~50,000 non-synonymous coding SNPs (cSNPs) to the ~7 million SNPs with both alleles above 5% frequency.

An immediate question is whether a susceptibility locus could be implicated by detecting an indirect association, through LD, between a nearby marker and the disease. If disequilibrium were extensive, the number of markers used in a genome-wide test of association could be reduced, without an unacceptable probability missing the association. Even variants that are not present in the screen would be assayed indirectly through LD with nearby markers. This approach is known as LD mapping. If this strategy is to be applied successfully, we need to understand the behaviour of LD and, in particular, gain some insight into how far usable levels of disequilibrium extend in the human genome, and how much this varies from one region or population to another. Answers to these questions will determine whether LD mapping of susceptibility genes can be carried out with a feasible number of markers, although feasibility is an ever-moving target as SNP genotyping technologies improve.

Measures of linkage disequilibrium

Although the measure D captures the intuitive concept of LD, its numerical value is of little use for measuring the strength of and comparing levels of LD. This is due to the dependence of D on allele frequencies. As a result, several alternative measures based on D have been devised. Comparing different reports on the extent of LD is complicated by the fact that several measures are in common use, and although all are based on Lewontin's D, they have very different properties and measure different things. The two most common measures are the absolute value of D and r^2 and other three more measures are used.

1. The absolute value of D is determined by dividing D by its maximum possible value, given the allele frequencies at the two loci. This has the useful property that D= 1 if, and only if, two SNPs have not been separated by recombination (or recurrent mutation or gene conversion) during the history of the sample. In this case, at most three out of the four possible two locus haplotypes are observed in the sample (Fig.1). The case of D= 1 is known as complete LD. Values of D< 1 indicate that the complete ancestral LD has been disrupted. However, the relative magnitude of values of D< 1 has no clear interpretation. In addition, estimates of D are strongly inflated in small samples, even for SNPs with common alleles, but especially for SNPs with rare alleles. So, high values can be obtained even when markers are in fact in linkage equilibrium. Because the magnitude of D depends strongly on sample size but, samples are difficult to compare. Therefore, statistically significant values of D that are near one provide a useful indication of minimal historical recombination, but intermediate values should not be used for comparisons of the strength of LD between studies, or to measure the extent of LD.

2. The measure r^2 (Δ^2) is in some ways complementary to D, and has recently emerged as the measure of choice for quantifying and comparing LD in the context of mapping. It is the correlation of alleles at the two sites, and is formed by dividing D^2 by the product of the four allele frequencies at the two loci. $r^2 = 1$ if, and only if, the markers have not been separated by recombination

and have the same allele frequency. In this case, exactly two out of the four possible two-locus haplotypes are observed in the sample (such as A, *B* and a, *b* in Fig.1). The case of $r^2 = 1$ is known as perfect LD. In this case, observations at one marker provide complete information about the other marker, making the two redundant. Intermediate values of r^2 are easily interpretable. Consider two loci: one locus is functionally associated with disease and the other is a nearby marker in LD with the susceptibility locus. To have the same power to detect the association between the disease and the marker locus, the sample size must be increased by roughly $1/r^2$ when compared with the sample size for detecting association with the susceptibility locus itself. Put more simply, the value of r^2 is related to the amount of information provided by one locus about the other. Notably, this property correctly takes into account differences in allele frequencies at the two loci. However, it also means that two markers that are immediately adjacent might show different r^2 -values with a third marker, and that a low pairwise r^2 -value is not necessarily indicative of high ancestral recombination in the region. r^2 also shows much less inflation in small samples than does D.

The interpretation of r^2 in terms of the power to detect an association leads to the concept of useful LD. Sample size is usually limiting in association studies (because of the cost and effort that are involved in patient recruitment, phenotyping and genotyping), and large increases in sample size to compensate for weak LD between a marker and the susceptibility locus are impractical. Values of $r^2 > 1/3$ limit the required increase in sample size to no more than threefold, and should probably be taken to be the minimum useful values. Much higher D-values are generally needed to indicate similarly useful levels of LD, because of the tendency of D to overestimate the magnitude of LD. In particular, the 'half-length' of D (the distance at which it falls to 0.5) greatly overstates the range over which LD is useful for mapping.

3. Additional confusion arises from descriptions of LD in terms of p-values in a test of significant departure from linkage equilibrium between loci. Because p-values depend strongly on sample size, they cannot be used to compare

LD between studies with different sample sizes. Furthermore, even very low levels of LD can be statistically significant in a sufficiently large sample. For example, an r^2 -value of 0.01 can be statistically significant in a sample of 1,000 chromosomes. Because weak deviations from linkage equilibrium might extend over considerable distances, p-values can create a misleading impression that LD extends over great distances, when the actual level of LD present at such distances is typically far below that which is useful for mapping.

4. Another approach for quantifying LD is through the population recombination parameter $4N_e r$ (alternatively denoted by c , $4N_e c$ or C), where r or c is the recombination rate across the region of interest and $4N_e$ is the effective population size. This approach avoids reliance on pairwise measures of LD, which differ from marker to marker, and facilitates comparisons between regions. In practice, estimation of $4N_e r$ from genotyping data is computationally challenging the theory of optimal estimation is not fully worked out and estimators rely on assumptions about demography and selective neutrality. The theoretical and intuitive appeal of $4N_e r$ as a measure of the extent of historical recombination in a region is certain to keep this an active area of research, and the use of this measure should become increasingly common as methods to compute it improve. In summary, current research strongly favours the use of r^2 as a pairwise measure of LD in the context of association studies. As a rough rule of thumb, r^2 –values above 1/3 might indicate sufficiently strong LD to be useful for mapping. Statistically significant values of D that are near one can indicate regions of low historical recombination, but intermediate values of D should be avoided as measures of LD. The population recombination parameter $4N_e r$ shows considerable promise for quantifying the strength of LD in a region, pending further theoretical and computational development.

5. Another methodology proposed for association mapping is a *whole genome scan*. This term indicates probing the genome with sufficient number of markers to detect regions associations with the phenotype of interest. An alternative is to use a small number of genes already suspected of being involved in the trait

of interest. The choice of whole genome scan type association mapping vs. candidate gene approach will depend on the extent of linkage disequilibrium in the population. If the level of LD is low, whole genome scan may be impractical because of the excessive number of markers required. In this case, specific SNPs could be targeted by identifying candidate genes for the trait using microarray analysis of some other means. However, if the LD is extensive, measured in tens of even hundreds of kb, whole genome scans are feasible, but the resolution may be limited (Rafalski, 2002).

Properties of Linkage Disequilibrium map

A linkage disequilibrium map is expressed in linkage disequilibrium (LD) units (LDU) discriminating blocks of conserved LD that have additive distances and locations monotonic with physical (kb) and genetic (cM) maps. There is remarkable agreement between LDU steps and sites of meiotic recombination in the one body of data informative for crossing over, and good agreement with another method that defines blocks without assigning an LD location to each marker. The map may be constructed from haplotypes or diplotypes, and efficiency estimated from the empirical variance of LD is substantially greater for the metric based on evolutionary theory than for the absolute correlation r, and for the LD map compared with its physical counterpart. The empirical variance is nearly three times as great for the worst alternative (r and kb map) as for the most efficient approach (ρ and LD map). According to the empirical variances, blocks are the best defined by zero distance between included markers. Because block size is algorithm-dependent and highly variable, the number of markers required for positional cloning is minimized by uniform spacing on the LD map, which is estimated to have 1 LDU per locus, but with much variation among regions. No alternative representation of linkage disequilibrium has these properties, suggesting that LD maps are optimal for positional cloning of genes determining disease susceptibility (Zhang *et al*., 2002).

Factors influencing linkage disequilibrium

Mutation and recombination might have the most evident impact on linkage disequilibrium (LD), but there are additional contributors to the extent and distribution of disequilibrium.

Most of these involve demographic aspects of a population, and tend to sever the relationship between LD strength and the physical distance between loci.

Genetic drift. This phenomenon describes the change in gene and haplotype frequency in a population every generation owing to the random sampling of gametes that occurs during the production of a finite number of offspring. Frequency changes are accentuated in small populations. In general, the increased drift of small, stable populations tends to increase LD, as haplotypes are lost from the population. Such populations might be suitable for disease-gene mapping, with the idea that genetic drift will accentuate disease and marker allele frequency differences between cases and controls. However, the applicability of this phenomenon to gene mapping has not been well characterized.

Population growth. Rapid population growth decreases LD by reducing genetic drift.

Admixture or migration. LD can be created by admixture, or by migration (gene flow), between populations. Initially, LD is proportional to the allele frequency differences between the populations, and is unrelated to the distance between markers. In subsequent generations, the 'spurious' LD between unlinked markers quickly dissipates, while LD between nearby markers is more slowly broken down by recombination. In theory, this would allow the mapping of disease genes in hybrid populations without using many genetic markers. Several admixed populations, such as African Americans and Hispanic Americans, have been characterized with this application in mind, but the success of this approach will depend heavily on the time since admixture occurred, the frequency differences of the disease of interest in the parental populations and the allele frequency differences. So, the diseases and circumstances for which this mapping approach will be feasible might turn out to be quite rare and exceptional.

Population structure. Various aspects of population structure are thought to influence LD. Population subdivision is likely to have been an important factor in establishing the patterns of LD in humans, but most of our limited knowledge comes from the study of model organisms. An interesting recent study of *Arabidopsis* indicated that extreme inbreeding can produce high levels of LD without a substantial reduction in levels of variation. This neglected area would benefit from intensified study in humans.

Natural selection. There are two primary routes by which selection can affect the extent of disequilibrium. The first is a hitchhiking effect, in which an entire haplotype that flanks a favoured variant can be rapidly swept to high frequency or even fixation. Although the effect is generally milder, selection against deleterious variants can also inflate LD, as the deleterious haplotypes are swept from the population. The second way in which selection can affect LD is through epistatic selection for combinations of alleles at two or more loci on the same chromosome. This form of selection leads to the association of particular alleles at different loci. Although this has provided a major motivation for historical studies of LD in *Drosophila* genetics, as a means of detecting the action of (epistatic) natural selection, it has not yet been shown to alter LD in humans.

Variable recombination rates. Recombination rates are known to vary by more than an order of magnitude across the genome. Because breakdown of LD is primarily driven by recombination, the extent of LD is expected to vary in inverse relation to the local recombination rate. It is even possible that recombination is largely confined to highly localized recombination hot spots, with little recombination elsewhere. According to this view, LD will be strong across the non-recombining regions and break down at hot spots. Although there are intriguing indications that this reflects the situation for some regions, the generality of the hot-spot phenomenon, the strength of recombination in and outside hot spots, and the length distributions of these regions remain to be determined.

Variable mutation rates. Some single-nucleotide polymorphisms, such as those at CpG dinucleotides, might have high mutation rates and therefore show little or no LD with nearby markers, even in the absence of historical recombination.

Gene conversion. In a gene conversion event, a short stretch of one copy of a chromosome is transferred to the other copy during meiosis. The effect is equivalent to two very closely spaced recombination events, and can break down LD in a manner similar to recombination or recurrent mutation. It has recently been shown that rates of gene conversion in humans are high and are important in LD between very tightly linked markers.

Examples in LD mapping in plants

Association analysis recently emerged as a powerful tool to identify QTL in plants. The first association study of a quantitative trait based on a candidate gene was the analysis of flowering time and the dwarf 8 (*d8*) gene in maize. This putative transcription factor has been implicated as playing a role in the "Green Revolution" varieties of wheat, and the Arabidopsis ortholog has been shown to play a role in regulating flowering time variation (Remington *et al*., 2001). The sugary1 (*su1*) gene in maize is responsible for the production of naturally occurring varieties of sweet corn. In a recent survey of allelic diversity at this locus, association methods were used to map the mutation to a single nucleotide (Whitt *et al*., 2002) even though approximately 150 mutations were segregating within the 12 kb this locus. There was little recombination within the locus, but the association survey found diverse alleles that were key to resolving the functional mutation to a single nucleotide. Biochemical and molecular studies confirmed that the identified nucleotide is the functional cause.

In a natural population of sea beet, *Beta vulgaris* ssp. Maritima, association of AFLP markers with each other, and with the annual growth habit trait were reported. Growth habit in beet, whether the plant requires vernalization prior to bolting, is determined by a single gene, the bolting (B) gene. Two of 440 genome wide AFLP markers were significantly associated with the B gene. However, when three markers that were located within 1.5 cM of the B gene were tested, only one showed weak association. This finding indicates very significant LD in this population of a self-incompatible species (Rafalski *et al*., 2002).

Sugarcane (*Saccharum* spp.) exhibits extensive long range LD, approximately 10 cM. This is not surprising considering the bottleneck in the breeding history of modern sugarcane cultivars. The majority of modern cultivars were derived from the interspecific cross between *S. officinarum* and *S. spontaneum*, followed by multiple back crosses to *S. officinarum*. Because sugarcane is propagated vegetatively, the resulting cultivars generally resulted from fewer than 10 meiosis since the first interspecific cross. In this study, LD was investigated between RFLP loci in 59 cultivars. The majority of the locus pairs in significant LD were physically linked on the same chromosome. However, 14% of the cases of significant LD involved loci on different chromosomes. Jannoo *et al.,* (1999), reported that the overall estimate of LD may be exaggerated because of the polyploid nature of sugarcane. Most of the pairs of loci in LD are derived from an *S. spontaneum* parent reflecting the phenomenon of homeologus pairing.

Conclusion

The extent of LD is population-dependent as well as expected to vary as a function of recombination frequency along the genome, mating system, and population history including selection. Therefore, LD measured in a wild population may be dramatically different from that observed in a breeding population that has been through a genetic bottleneck. In genetically more restricted elite maize populations there is significant LD extending to a several kb distances at least at some loci. Inbred species, such as soybean, are likely to exhibit more extensive LD than outbreeding species, such as pine.

We expect trait allele association studies in crop plants will develop rapidly in the next several years and will result in a much better understanding of the allelic diversity of breeding populations. Recently, in maize an association between the Dwarf8 gene and flowering time variation in 92 maize inbred lines using a candidate gene approach. Scientists corrected for possible sub-structuring of the population under study using the approach. Such association genetic methodologies for mapping complex traits in existing populations will be further developed and will allow rapid and sensitive mapping of simple and complex traits. The advantages of association mapping in terms of resolution, speed, and allelic range are complementary to the strengths of F_2-based QTL mapping, namely, marker efficiency and statistical power. Plant genomics is beginning to allow the merger of molecular and biochemical approaches with quantitative genetics, and LD will likely play a key role in this merger. Association mapping may play an important role in identifying and evaluating the basis of quantitative variation in a wide range of species. But the key to designing and carrying out these association analyses is a thorough understanding of the LD structure across a wide range of species. For identifying cross specific markers for each trait is very difficult, considering the volume of crosses breeders make. To over come this problem, a strategy be established to trace the genes from germplasm first and then confirming at crosses level (bottom up approach) instead from a cross to germplasm (top down approach). For that germplasm survey of different ecotypes of each species with molecular markers and associating these markers with phenotype(s) may be used as alternative strategy for gene mapping.

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