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Advancing Agriculture with Tuber Crops: ICAR-CTCRI's Role and Achievements

Asha K.I., Asha Devi A. & Shirly Raichal Anil
Division of Crop Improvement, ICAR-CTCRI, Sreekariyam, Thiruvananthapuram-695017
*Author for correspondence: E-mail - ashakarthy@gmail.com/asha.ki@icar.gov.in

Abstract

This article highlights the indispensability of tuber crops in a global agriculture scenario and the pivotal role played by the ICAR-Central Tuber Crops Research Institute (CTCRI). Tuber crops, such as cassava and sweet potato, are vital for food security, nutrition and income generation, particularly in the developing nations. ICAR-CTCRI's dedication to tuber crop research, advanced breeding techniques and sustainable agricultural practices has significantly improved crop yields, disease resistance and nutritional quality. Its breakthroughs in development of many improved climate resilient, nutritionally rich bio-fortified, multi-trait varieties; new and relevant production and protection technologies like organic cultivation, best agricultural practices, diagnostic kits, etc., development of many value added products for the modern markets and earnest attempts at farm mechanization have transformed the lives of millions of tuber crops farmers. As we face mounting challenges in food production, ICAR-CTCRI's achievements show the urgent need for investing in tuber crop research for a sustainable future.

Introduction

The world is facing an unprecedented demographic shift, with forecasts indicating that the global population will continue to surge in the coming decades. Projections suggest that by 2030, the Earth's inhabitants will surpass 8.5 billion, and by 2050, this number is expected to reach 9.7 billion, culminating in an astonishing 11.1 billion by the turn of the century. The burgeoning youth population indicates a future with even higher growth rates, presenting both challenges and opportunities on a global scale (Sadgov, 2022).

However, such escalating population figures bring to the fore a host of concerns that necessitate urgent attention. As the global population expands, the demand for food will escalate substantially, imposing significant restrictions on agricultural production to meet the needs of billions. The gravity of this situation is underscored by predictions indicating that by 2100 more than 3 billion lives could be at risk due to food scarcity and malnutrition (UN, 2017).

The impending food crisis is not an entirely new phenomenon in human history, as certain regions have endured such challenges before. Nevertheless, projections based on the NOAA (National Oceanic and Atmospheric Administration Climate Change Program) highlight the alarming scope of the issue. Between 2010 and 2050, per capita and total food demand is projected to increase by +0% to +20% and +35% to +56%, respectively. In contrast, the population at risk of hunger is anticipated to change by −91% to +8%. Moreover, when accounting for the impact of climate change, the range of outcomes widens, presenting a more complex picture (Van Dijk et al., 2021).

Statistical estimations indicate that between 720 and 811 million people will face hunger in the world in 2020, with the middle of the projected range indicating 768 million. This suggests an alarming increase of 118 million more people grappling with hunger compared to the previous year, with the upper bound potentially reaching 161 million. The high cost of healthy diets, coupled with persistent income inequality, further aggravate the problem, rendering nutritious food out of reach for nearly 3 billion people across the globe, particularly the impoverished, across all regions (FAO et al., 2021).

In 2019, approximately 3 billion people across the globe, particularly the impoverished, faced significant challenges accessing healthy diets due to their prohibitively high costs. This issue was exacerbated by persistent income inequality, affecting populations in all regions. Although there was a slight improvement from 2017, the situation was expected to deteriorate in 2020 due to the far-reaching impact of the COVID-19 pandemic.

Addressing this crucial challenge requires a fundamental shift towards adopting healthy diets that also take sustainability into account. By doing so, we can potentially achieve a reduction in both health-related expenses and the costs associated with climate change by the year 2030 (FAO et al., 2021).

Climate change poses a significant challenge to the sustainable production of agricultural crops. It is characterized by substantial changes in various meteorological elements, such as temperature and precipitation, which have been observed over long periods. This phenomenon has far-reaching implications for global food security, as it has already had a substantial impact on agricultural production worldwide (Dhankar and Foyer, 2018). The negative environmental impacts are intensified in current cropping systems due to low diversity and high input intensity. Climate-related yield instabilities are observed to be higher in grain legumes but lower in tubers and cereals (Wang and Huang, 2004).

The combination of drought and high temperature has been observed to have more damaging effects on crops compared to individual stresses. Important crops like wheat and maize have experienced decreased global yields from 1981 to 2010 relative to previous years (Iizumi et at., 2018). It is projected that atmospheric CO_2 levels will continue to increase and potentially reaching 730-1000 ppm by the end of the 21st century, leading to a rise in global temperatures and significant climate changes (Balasooriya et al., 2018).

Elevated temperatures due to climate change can accelerate the metabolic activities of insect pests, increasing the frequency of crop damage and high levels of CO_2 will make food crops more susceptible to insects and various pathogens (Naqvi et al., 2022). Overall, the effect of climate change on crops will remain detrimental.

Traditional food production practices have long demonstrated their resilience to highly variable ecological and climatic conditions, supporting local communities, especially those in remote or inland areas, with localised food sources (Marrero and Mattei, 2022). However, the decline in local food production has left structural susceptibilities to food insecurity, particularly in imported food distribution systems exposed to climate risks. Unfortunately, shifting away from starchy root crops, fruits, coconuts and seafood have led to a heavy reliance on rice, canned meats and sugar, contributing to malnutrition and adiposity (Hughes and Marks, 2010).

Tuber crops hold a significant position as a vital food source, ranking third after cereals and legumes. For approximately one-fifth of the global population, these crops are either a staple food or a crucial part of their dietary intake. Their exceptional characteristic lies in their remarkably high rate of dry matter production per day, making them significant contributors to caloric intake. Particularly for small-scale and marginalized farmers, especially within tribal communities, tuber crops form an essential aspect of dietary habits and play a crucial role in ensuring food security (Kennedy et al., 2018).

Agronomically, root and tuber crops offer substantial advantages as staple foods due to their remarkable adaptability to various soil and environmental conditions. Moreover, they can thrive in a diverse range of farming systems, requiring minimal agricultural inputs for successful cultivation. The versatility in their growth patterns allows for the adoption of cultural practices that are tailored to the specific production systems. Looking back through history, archaeological findings point to a profound historical reliance on starchy plants like cassava, yautía and maize. This reliance eventually paved the way for the advancement of root crop horticulture and gardening, solidifying the importance of tuber crops in the evolution of the global food system, particularly in securing food resources for the developing world (Chauhan et al., 2022). The emphasis on starchy roots in diets reflects the need for energy-dense foods with short growing seasons and protection from natural disasters underground (Marrero and Mattei, 2022).

Origin of a Sole Institute for Tropical Tuber Crops - an Indian Scenario

The research efforts on cassava commenced in 1942, under the leadership of Dr. A. Abraham, the economic botanist of the erstwhile State of Travancore. Initially, the focus was on varietal improvement, with financial support from the Government of Travancore-Cochin. The aftermath of the Second World War created a pressing need for food security, accelerating tuber crop research, particularly in Kerala. The Indian Council of Agricultural Research (ICAR) recognized Kerala's potential and started funding the cassava research project, alongside A. P. Cess Funds. The research station, originally located at "Maracheenivila," meaning the cassava field, was later shifted to Sreekariyam after the area transformed into a residential neighborhood (Kumar, 2018).

ICAR-Central Tuber Crops Research Institute HQ at Thiruvananthapuram, Kerala

Regional Station, ICAR- Central Tuber Crops Research Institute at Bhubaneswar, Odisha

During the 1940s, cassava gained prominence as an industrial raw material for starch and sago production. The establishment of ICAR-CTCRI in 1963 with eleven staff members in Thiruvananthapuram marked a significant milestone in tuber crop research. Before this, Cytogenetic research on tuber crops was carried out by the erstwhile Travancore University starting from 1953. With a growing team, the laboratory cum office moved from Thycaud to Sasthamangalam and later to Vazhuthacaud in 1964. On 1 April 1966, the administrative control of the Institute was transferred from the Government of India to ICAR (Kumar, 2018). In 1972, the Institute found its permanent home in a new building in Sreekariyam, now extending to an area of 48.19 hectares. The Institute comes under the aegis of the Indian Council of Agricultural Research under the Ministry of Agriculture and Farmer's Welfare, Government of India. In 2023, the Institute celebrated its 60th Foundation Day (Diamond Jubilee Celebration).

The Institute also has a Regional Station (RS) located at Bhubaneswar, Odisha which was established in 1976. The RS concentrates on research on sweet potato and aroids catering to the needs of the Eastern and North Eastern Regions of the country. They also deal with the major issues related to improvement, production, protection and utilization of tropical tuber crops and also fulfill the socio-economic commitments of the farming communities in this region.

The All India Coordinated Research Project on Tuber Crops (AICRP TC) was started at ICAR-CTCRI in 1968 for testing and popularizing the location-specific tuber crop technologies in various parts of India. It has at present 21 Centres including ICAR-CTCRI HQ and the Regional Station.

The Institute was established with the vision of root and tubers for ensuring better health, wealth generation and inclusive growth. The main mission of the Institute is to integrate root and tuber crops as sustainable farming system components to ensure food and nutritional security of the nation and livelihood improvement of rural population. The Institute has a broad mandate of generating information on research of tropical tuber crops that will help to enhance productivity and improve the utilization potential. The two main mandates are: a) Basic, strategic and applied research on genetic resource management, crop improvement, sustainable production and utilization of tropical tuber crops and b) Co-ordinate research and validation of technologies through AICRP on Tuber Crops.

In acknowledgment of its outstanding endeavors, ICAR-CTCRI was honored with the prestigious Sardar Patel Outstanding Institution Award in 2005, conferred by the Indian Council of Agricultural Research (ICAR). This accolade lauded the Institute's significant impact on improving tropical tuber crops and its innovation in developing cost-effective production technologies. Apart from this, the Institute has been bestowed with many other awards over the period of the 60 years of its existence. Many MoUs exist with renowned National and International Institutions to strengthen research and education on tuber crops.

Improvement of tuber crops through conventional and non-conventional approaches

Being the National Active Germplasm Site (NAGS) for tuber crops and to safeguard the genetic diversity of tuber crops, a comprehensive field gene bank was established, housing 5542 accessions, encompassing various tuber accessions comprising landraces, cultivars, natural hybrids and wild relatives of various tuber crops viz., cassava, sweet potato, greater yam, lesser yam, African yam, aerial yams, wild yams, taro, tannia, elephant foot yam, arrowroot, coleus, yam bean, etc. Around 50 different species of agriculturally important tuber crops are being conserved in the institute field gene bank.

The valuable germplasm collection housed in the institute gene bank was used for the development of more than 70 different improved varieties having various traits of interest through selection or hybridization. Genes were introgressed to develop new and improved varieties like Cassava Mosaic Disease (CMD) resistant cassava, β-carotene enriched sweet potato, anthocyanin enriched sweet potato and greater yam, compact tuber shape in greater yam, non-acrid elephant foot yam and good storing variety in taro. Sree Shilpa, a greater yam variety is a World's first hybrid in this crop. Sree Shubra, an African yam variety has found its way in the Limca Book of World Records for the maximum yield from one plant. Sree Dhanya, a natural mutant, is the World's first dwarf white yam.

The role of non-conventional methods like tissue culture and biotechnology is also notable. Many important tuber crop accessions are conserved

Sree Reksha a high yielding CMD resistant cassava variety

Bhu Krishna a purple fleshed anthocyanin enriched sweet potato variety

Bhu Sona an orange fleshed β carotene enriched sweet potato variety

Sree Neelima the anthocyanin enriched greater yam variety

Dwarf yam Sree Swetha

Sree Hira a novel taro variety with long cormels and maintained in the *In Vitro* Active Genebank (IVAG) of the institute and micropropagation protocols have been standardized for almost all the crops. Marker assisted selection is done for various traits like CMD, Postharvest Physiological Deterioration (PPD) and starch in cassava, dwarfness in yams, taro leaf blight (TLB) in taro, etc. Studies on development of waxy cassava through gene editing are being undertaken along with bioinformatics work for overall improvement of the various crops

Improvement in field management practices

In addition to biotechnological advancements, ICAR-CTCRI has made significant strides in the development of agro-techniques tailored to various tuber crop production systems. These techniques encompass quality planting material production, sustainable nutrient management approaches like Integrated Nutrient Management (INM), Site-Specific Nutrient Management (SSNM) and organic management practices. SSNM technology for fertilizer recommendations at individual fields based on native soil fertility, yield target and nutrient interactions was developed. The on-station calibrated technology using the Quantitative Evaluation of Fertility of Tropical Soils (QUEFTS) model has been successfully tested by conducting validation experiments across major cassava growing environments of India (Byju and Jaganathan, 2023). The integration of micro-irrigation and drip fertigation technologies has also been instrumental in optimizing water usage and enhancing crop yields, soil fertility and overall farm income (ICAR-CTCRI, 2021).

The other major areas include, standardization of agro techniques of new varieties and for non- traditional areas for tropical tuber crops, soil nutrient dynamics under cassava in long term fertilizer experiment, physiological studies of tuber crops with special emphasis on climate change, cropping systems involving tuber crops, low input management strategy for tropical tuber crops, soil conservation studies for cassava growing hilly tracts of India, studies on carbon sequestration potential of tropical tuber crops, rapid multiplication methods via mini sett techniques, pro-tray propagation methods, vertical farming, etc.

On-field detection and disease diagnostics

ICAR-CTCRI has established a robust and comprehensive biotechnology program, focusing on the development of innovative diagnostic tools for viral and fungal diseases, as well as transgenic plants with enhanced resistance to CMD. Work is also going on to combat the menace of sweet potato weevil through biotechnological approaches. This program is aimed at bolstering the productivity and economic viability of tuber crops in diverse production systems across the country. Notably, ICAR-CTCRI has devised effective strategies to combat cassava mosaic disease, cassava tuber rot, taro leaf blight, collar rot of elephant foot yam, anthracnose of greater yam and sweet potato weevil. These integrated crop protection measures serve as crucial resources for the farming community, offering practical solutions during challenging times.

Furthermore, ICAR-CTCRI has successfully ventured into the domain of bio-pesticides

Biopesticides *Menma*, *Nanma* and *Shreya* developed by ICAR-CTCRI using cassava as a base to manage the banana pseudostem weevil. Pilot plant for the extraction of active principle from cassava leaves was made-up at ICAR-CTCRI with the technical support of Indian Space Research Organization (ISRO-DRDO). Three bio-formulations developed at ICAR-CTCRI and arbitrarily named as *Nanma*, *Menma* and *Shreya,* have proven to be successful alternatives in the farmers' fields, showcasing the Institute's commitment to environmentally friendly and sustainable agricultural practices (Kumar, 2018). Efforts are on to tackle the white fly, mealy bug and nematode problems in tuber crops fields' through various integrated approaches.

Food Products

CTCRI efforts to make conventional new generation food such as pasta, spaghetti and noodles from fortified cassava and sweet potato which are enriched with fibre and protein is noteworthy. The institute also focuses on items like fried chips, muffins, cookies, papads, nutrijelly, nutri-shreds and pop-ups, rice analogues from cassava and sweet potato.

Sweet potato chips from bio-fortified lines

Pasta from bio-fortified sweet potato flour

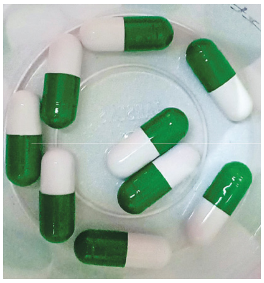
Functional pasta from tuber crops

Bakery products from tuber crops

Industrial Products/Processes

High quality starch based cassava flour, sago from reconstituted cassava based dry starch, wax coating technology for fresh cassava tubers, thickening agent from food grade modified starches of cassava, RS4 (Modified starch) and RS5 (Starch-lipid complex) type resistant starches of cassava and sweet potato, cassava starch based nano composite films for food wrapping application, encapsulated sweet potato and purple yam anthocyanins are some of the major industrial products developed from tuber crops. Cassava starch factory effluent treatment plant, cassava bio-ethanol production technology, cassava starch based biodegradable plastics are also notable achievements. Large number of entrepreneurship development programmes is organized on value addition in tuber crops for farmers and young entrepreneurs from different states of India. The trainees from individual farmers/entrepreneurs, representatives from self-help groups/Kudumbasree unit's/farmers clubs/ FPOs/ stakeholders of One District One Product scheme are the beneficiaries. Innovative extension model 'Village incubation centre' is spread in all the north eastern states of the country for ensuring livelihood security of tribal people (Byju and Jaganathan, 2023).

Super absorbent polymer



Sweet potato anthocyanin capsules

Utilization of value addition

The Institute's efforts in crop utilization have led to significant value addition and diversification of technologies. These advancements extend to the industrial sector with products like superabsorbent polymers, graft copolymerized starches, cold water miscible starch, solid adhesives and pasta products contributing to the economic growth and enhanced applicability of tuber crops in various industrial applications. The Institute has made significant contributions in the development of innovative and sustainable technologies related to tuber crops. A comprehensive program has been established, focusing on the creation of cassava starch composite-based biodegradable films and adhesive formulations for the corrugation and paper industries. These advancements not only address environmental concerns but also showcase the Institute's commitment to industry-specific applications.

In recent years, ICAR-CTCRI has shown promising results in the development of functional food products derived from cassava, sweet potato, yams and elephant foot yam. Moreover, the Institute has successfully enhanced anthocyanin recovery from yams and sweet potato, contributing to the growing interest in functional foods with potential health benefits. Products like leaf protein concentrate for fish feed, minimally processed cassava and elephant foot yam have been developed. Processing machinery viz., chipping machines, raspers, starch extraction units and feed granulators are in constant demand from clients. Additionally, in-depth surveys have been conducted to estimate the demand projections for cassava starch, considering its significant use in the paper industry. The findings indicate an increasing demand for cassava starch, highlighting its importance as a versatile industrial resource.

To take home these technologies to the farming community and the entrepreneurs, the Techno-incubation centre was created with the financial support from the Small Farmers' Agribusiness Consortium, Department of Agriculture, Government of Kerala for promoting entrepreneurships to enhance the value of these treasures of soil.

Lab to land outreach program

The Institute's commitment to bridging the gap between research and practical application is exemplified by its outreach programs. The Lab to Land Programme (LLP) initiated in 1979, aimed to establish direct connections between technology generators such as the Institute and farmers, enabling the transfer of cutting-edge agricultural technologies to the fields. Through LLP, approximately 1600 farmers from Kerala, Tamil Nadu, and Orissa benefited, contributing to enhanced agricultural practices in the regions. While the LLP concluded in 1996, its impact remains evident in the improved farming methods and increased productivity among the beneficiaries.

Furthermore, ICAR-CTCRI has implemented the Institution-Village Linkage Programme (IVLP) since 1996, catering to 1000 farm families. This program has witnessed more than 80 technological interventions, assessed in collaboration with farmers, to ensure their relevance and effectiveness. However, it is noteworthy that the IVLP is presently limited to the Chenkal village in Thiruvananthapuram district, Kerala. Nonetheless, the program's targeted approach has resulted in valuable insights and contributed to the sustainable development of agriculture in the region (ICAR-CTCRI-2023).

Technology transfer

The Institute has provided valuable techno-economic feasibility reports for prospective entrepreneurs on various tuber-based products including cassava starch, sago, sago wafers, cassava flour, fried food products, arrowroot starch, cold water miscible starch, liquid adhesive and sweet potato pasta. These reports serve as valuable resources for entrepreneurs seeking to venture into the tuber crop industry. ICAR-CTCRI's efforts have not only focused on technological advancements but also extended to studying the market systems of tuber crops including cassava, sweet potato, elephant foot yam, taro and yams. The research has identified different market channels and estimated price spreads providing insights into the marketing dynamics of tuber crops throughout the country.

The adoption and dissemination of tuber crop production technologies among tribal communities in Kerala, Tamil Nadu, Andhra Pradesh, Orissa and Chhattisgarh have been key focus areas for the ICAR-CTCRI. Additionally, the Institute has taken a proactive approach to test and popularize improved cassava varieties through on-farm trials in five districts of Tamil Nadu, namely Tirunelveli, Salem, Namakkal, Erode and Dharmapuri starting from 1997. The success of these trials is evident with the high-yielding variety H-165 gaining popularity in the Mekkara region of Tirunelveli district, and varieties Sree

Visakham and Sree Jaya becoming prominent in the Salem region, particularly for consumption purposes (ICAR-CTCRI, 2023).

Improved tuber crop varieties developed by ICAR-CTCRI have gained popularity in various states across India, especially in Kerala, Tamil Nadu, Odisha, Bihar, Uttar Pradesh, and Gujarat. These developments have been facilitated through the Rashtriya Krishi Vikas Yojana (RKVY) and other government schemes, emphasizing the importance of research-driven agricultural interventions in driving rural development.

To ensure the effectiveness and relevance of tuber crop technologies, ICAR-CTCRI has adopted a participatory approach involving farmers. Through farmers' participatory programmes, the Institute assesses and refines the generated technologies, fostering better adoption and acceptance among farmers. In this regard, four varieties, two each in cassava (Sree Jaya and Sree Vijaya) and sweet potato (Sree Arun and Sree Varun), have been released and well-received by the farming community (ICAR-CTCRI, 2021).

Information technologies

Innovative tools showcase the Institute's commitment to leveraging technology for the betterment of the farming community and the sustainable growth of the tuber crops sector. A digital hub has been created through the Institute's official website, accessible at http://www.ctcri.org. This comprehensive online platform provides detailed insights into the Institute's multifaceted activities and offers various online facilities, including a sales counter and discussion forum, fostering knowledge dissemination and engagement with stakeholders.

"Variety Identifier," has been meticulously designed to assist scientists and extension workers in accurately identifying different varieties of cassava, a perennial woody shrub with an edible root. By relying on morphological attributes, this tool empowers experts to make informed decisions regarding the diverse range of cassava varieties, optimizing their research and extension efforts.

"Oushadham," is an online diagnostic system tailored to address the disease, pest and nutrient-related issues affecting tuber crops. The "Tuber Information Cafe (TIC)" serves as a comprehensive hub of vital information on various tuber crops which offers valuable insights into production, protection, improvement and utilization strategies for different tuber crops. As a knowledge repository, TIC proves indispensable to farmers, researchers, and stakeholders alike, fostering informed decision-making and sustainable practices.

Recognizing the vital role of marketing in ensuring the livelihood of farmers and other stakeholders, ICAR-CTCRI launched the "Tuber Crops Online Marketing" (TOMS) initiative in 2015. This platform provides valuable support to farmers, processors, and industrialists engaged in tuber crops."Sree Vishakham Cassava Expert is a web-based expert system which specifically targets cassava farmers and seeks to provide practical solutions to their challenges. It offers valuable insights into disease and pest diagnosis, nutrient advisory, and online marketing.

To make available the numerous technologies developed for the improvement, production, protection and utilization of tuber crops, a database system namely TUBERTECH was designed and developed. This database stores the information about the technologies and has seven fields meant for different aspects of the technology namely technology name, description, advantages, pre-requisites for introduction, limitations, picture and any other information.

"SIMCAS", a growth model for cassava was developed to simulate the growth of cassava using the weather data as the driving variables. To conduct an experiment the user should feed both weather data and plant coefficient data. A program for installing this software was also developed.

Another growth simulation model of sweet potato named MADHURAM was developed to simulate the growth of sweet potato. Vegetative developmental days (VDD) and reproductive developmental days (RDD) were calculated to predict crop phenology. The software performs simulation using the weather data, genetic coefficient data and fertilizer data which the user loads.

SPOTCOMS is a process model for simulating growth of sweet potato growth which is a modification of the earlier sweet potato growth simulation model MADHURAM. Here, crop phenology was predicted as a function of growing degree days (GDD). For computing solar radiation, photosynthesis and partitioning of dry matter, methods used in MADHURAM model was followed. The software performs simulation using the weather data, genetic coefficient data and fertilizer data which the user loads.

The latest in the series is the E-crop or the electronic crop. This electronic device is developed to simulate the crop growth real-time in the field based on weather, soil moisture and nutrient status; calculates nutrient and water requirements and generates agro-advisory for the crop at a daily time scale. This device gives periodical advices as SMS to the growers about water and nutrient (nitrogen, phosphorus and potassium) requirements. The device has been successfully demonstrated for various crops like cassava, sweet potato, elephant foot yam and banana and the growers could achieve higher yields with a saving on nutrients and water up to 50%. Reducing yield gap and improving nutrient use efficiency pay rich dividends to the farmers besides significant savings on costly inputs thereby reducing carbon footprint and global warming. Recently this IoT device has been granted patent by the Indian Patent Office.

Technology management and commercialization

A key aspect of ICAR-CTCRI's accomplishments lays in its technology management endeavors, facilitated by the Institute Technology Management Unit (ITMU). The active pursuit of Intellectual Property (IP) activities has led to the successful commercialization of various technologies, focusing on value addition. Through consultancy, licensing, and contract research modes, the Institute has effectively transformed innovative discoveries into practical applications, furthering the impact of its research (ICAR-CTCRI, 2023).

Conclusion

In today's world, the importance of tropical tuber crops cannot be overstated, as they hold immense potential to address the pressing challenges of food security, nutrition, and sustainable agriculture. With a rising global population, climate change, and shifting dietary preferences, the demand for resilient and nutritious crops is greater than ever. Tropical tuber crops, such as cassava, sweet potato, and yams, exhibit remarkable adaptability to diverse agro-climatic conditions and offer a rich source of carbohydrates, vitamins, and minerals. Furthermore, their ability to thrive in marginal lands utilizing minimal water and chemical inputs makes them valuable assets in promoting sustainable farming practices and reducing environmental impacts. Emphasizing research and development in tropical tuber crops is thus crucial to harness their full potential and ensure food and nutritional security for present and future generations.

In this context, the role of ICAR-CTCRI emerges as pivotal. The institute's dedication to tuber crop research, varietal improvement, biodiversity conservation, and resource management has significantly contributed to the advancement of tropical tuber agriculture. Its efforts in maintaining an extensive field gene bank with diverse accessions have safeguarded the genetic diversity of these crops, providing a valuable resource for crop breeding and trait enhancement. Moreover, ICAR-CTCRI's initiatives in promoting the utilization of tubers as industrial raw materials have opened new avenues for economic growth and agro-industrial development. As a leading research institution, ICAR-CTCRI continues to play a crucial role in disseminating knowledge, supporting farmers, and collaborating with stakeholders to realize the full potential of tropical tuber crops.

The future of tubers is promising and holds tremendous possibilities. With ongoing research and advancements in breeding technologies, the development of improved and resilient varieties with enhanced nutritional content is within reach. As the world grapples with the challenges of climate change, water scarcity, and diminishing arable lands, the significance of tropical tuber crops will only grow. Their resilience and adaptability can contribute to climate-smart agriculture, ensuring food security in the face of changing environmental conditions. Additionally, their potential as alternative sources for biofuels and industrial applications further enhances their importance in a sustainable bio-economy. By continuing to invest in research, technology dissemination, and capacity-building efforts, ICAR-CTCRI and other research institutions can collectively shape a future where tropical tuber crops play a pivotal role in achieving global food and nutritional security, fostering economic development, and advancing sustainable agriculture practices.

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