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Yam Biotechnology Innovation: A Contribution to Local Food Sovereignty

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Triple Helix (TH) model is a crucial instrument for introducing innovations in agricultural systems and products, encompassing university and governmental production sectors. Thus, the present research aims to assess the efficacy of implementing a biotechnological innovation in yam (*Dioscorea* spp.) cultivation by applying TH model. The components under consideration were for the educational, governmental, and production sectors. Awareness and training activities were identified as critical for the establishment, management, propagation, diversification, and agricultural extension of the selected yam clones. A total of 25 training activities were considered favorable in response to 675 participants. Their impact on local governmental actions enabled creating three categorized mass seed multiplication units involving 175 people. The project commenced with acquiring 7 500 plants subsequently acclimatized *in vitro*, whose processes yielded 60 000 seeds planted in the field. The survival rate was 96%, and yields were 60 t/ha^{-1} for urban and 50 t/ha^{-1} for suburban agricultural systems. These values were higher than those obtained through the traditional method (10 t/ha^{-1}). The organoleptic tuber analysis from the improved seeds demonstrated superior flavor, appearance, and texture indicators with a 25% increase in acceptance compared to the traditional system. Therefore, HT model allowed evaluating the yam biotechnological innovation effectiveness, demonstrating its applicability to other agricultural systems and products in Cuba and internationally, thereby contributing to food sovereignty.
Keywords: Categorized seed production, food production, local development, plant biotechnology.

INTRODUCTION

Currently, food security includes not only food availability but also its nutritional quality that ensures the most desirable effects on health, in such a way that healthy product availability is increasingly in demand (Li *et al*., 2023). Yam tuber (*Dioscorea* spp.) is considered one of the healthiest and valued as a basic food due to its nutrient and high protein contents, which is generally higher than other food tubers (Wanasundera and Ravindran,1994). Additionally, yam has a high secondary metabolite content with pharmacological properties to help prevent certain non-serious diseases, particularly, some related to erectile dysfunction (Hess and Boehmer, 2020). The annual world consumption of yam is 18 million tons (Mt), with 15 Mt (83.33%) consumed in West Africa. Yam is an important food and income source for local economy in rural Cuban areas, the Americas, and insular Caribbean (Mendoza-Crespo and Ortiz-Velásquez, 2020). In most countries that make up the tropical and subtropical belts of the world, yam phytochemical profile and its potential are considered as a strategy in food security. Nonetheless, dearth of information prevents integration into strategies for regional development and public policies on food and resource sustainability (Otálora *et al*., 2024).

Considering the above, public policies for managing science, innovation, and technology transfer to the agricultural sector have been poorly attended and sometimes difficult to estimate and implement in production practice (Kaiba *et al*., 2020). Specifically, issues related to technological innovation in yam cultivation are limited, making this product-system an

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important model for strengthening local food sovereignty (Borges García and Reyes Avalos, 2022). Moreover, in a globalized world, the conceptual model development has a high incidence and high adaptability to regional models, which is very important, especially in those where knowledge and innovation contribute directly or indirectly to local development (Núñez Jover *et al*., 2019; Almaguer Torres *et al*., 2023). On the other hand, models that include human resources are increasingly relevant to evaluate the real effect of agronomic improvements (capacities, skills, abilities, attitudes, and aptitudes) that best adapt to local conditions (Gatto, 2020).

Furthermore, models are necessary and valuable tools for small producers to know the limitations of production processes and scope of adopting new technology, including the different marking phases (Villalobos *et al*., 2017; Plataforma Articulada para el Desarrollo Integral Territorial, 2020). At this point, acknowledging the interconnection between the university, productive sector, and government as an avenue is crucial for enhancing knowledge management and innovation; thereby, local development contributes through a participatory approach to social impact (Pérez, 2022). Innovative modelling processes, specifically the Triple Helix (TH) model, involves a quantitative-qualitative estimation and a complementary descriptive phase. Productivity, quality, and level of adoption are based on the theoretical concepts of Etzkowitz and Leyersdorf (Bonilla-Jurado *et al*., 2023). According to Amaral *et al*. (2023), evaluating economic-sociological variables leads to more accurate innovation measurements of innovation adaptation and model effectiveness.

In adapting a TH model, agricultural yield is considered the most important quantitative component because it expresses the physiological plant responses per unit of quantity or mass and is commonly used to estimate the model adaptation efficiency (Navas Olmedo *et al*., 2023). Nevertheless, socio-economic theory frequently excludes the quantitative analysis components, such as the level of technology acceptance, impact of awareness actions on productivity, and value added by the effect of innovation, unless explicitly identified as subjective (Bryda and Costa, 2023). Thus, both variables, qualitative (production, profits, performance, protein quality, etc.) and qualitative (palativity, level of acceptance, market acceptance, etc.) must be analyzed for a better understanding of the model (Luengo and Obeso, 2013). Therefore, the aim of the present study is to assess the effectiveness of adopting a biotechnological innovation in yam cultivation in the Jiguaní region of Cuba, using a Triple Helix model.

MATERIALS AND METHODS

***The theoretical-methodological basis of the Triple Helix model*:** Yam crop was chosen due to its nutritional significance as a food security source for the local population. The University of Granma, Bayamo, Cuba conducted the research based on the theoretical concepts of the Triple Helix (TH) model (Boza *et al*., 2021; Bonilla-Jurado *et al*., 2023). The experimental phase took place in Jiguaní Municipality, Granma Province from 2018 to 2022. The TH methodology and theoretical framework model was based mainly on three components (helices); (i) Educational institution as a generator of knowledge (University of Granma, Cuba); (ii) Productive sector as the beneficiary of the improvement, and (iii) Government as manager and complementary support. The model was adjusted considering quantitative (yield in tons/ha) and qualitative variables (organoleptic and nutritional properties, added value of the harvest and the level of acceptance of yam). The model adjustments were considered based on three critical points; (i) Improvements in production; (ii) Adequate innovation transfer; and (iii) Appropriation efficiency by producers (Navas Olmedo *et al*., 2023).

***Model components*:** The TH model considers three operational axes (helices) to study its adaptability and effectiveness: educational institution as the axis of knowledge generation and innovation; producers as the executor and beneficiary; and government as the management and financing axis. The actions of the educational institution are estimated based on technology transfer and the corresponding methodology generation (Gutiérrez-Ortega *et al*., 2022). The survival of seed, agronomic valuation, and impact of the integrative model on producers were considered in terms of improvements associated with innovation (Morse and McNamara, 2015). The model considered and adjusted disposition of plant material, training workshops, field days, specialized advice, extension events, dissemination, and institutional strengthening. Governmental actions included contributing to a space-like mass propagation unit (MPU), managing public policies for productive projects and financing. Consumers evaluated the quality of yam tubers based on their organoleptic characteristics for estimating the added value of the product.

***Acquiring plant material as a product-system*:** The plant material used in this study was obtained through *in vitro* yam cultivar propagation, including Caballo, Caraqueño, Criollo, Chino Blanco, Belep, and Blanco de Guinea. The propagation was performed at the Centro de Estudios de Biotecnología Vegetal (CEBVEG), University of Granma, Cuba. The acclimatization of the plant material was conducted in a semi-controlled plant reproduction center attached to CEBVEG for a period of eight months. As a result of this stage, 7 500 kg of fresh and healthy tubers were obtained, which were then fragmented into portions weighing 125 ± 2 g, resulting in a total of 60 000 certified seeds. These seeds were then planted on a fluvisol soil, at a rate of 20 000 plants/ha^{-1}, covering an area of 3 hectares (ha).

***The experimental units*:** The experimental field phase involved establishing three yam MPUs for sowing categorized seed from *in vitro* culture. One hectare was selected in the Canaán Farm (N 20° 21' 57.786", W 76° 25' 49.223") and 1 ha in the Cruz Alta Farm (N 20° 21' 57.74", W 76° 25' 48.187"), both belonging to the urban agriculture system; additionally, 1 ha was established in the Jatía La Yaya production pole (N 20° 23' 16.71", W 76° 28' 31.687") (suburban agriculture system). In each of the three locations under study, a conventional mass propagation unit (The seeds used for sowing were derived from tuber fragments of non-biotechnologically improved plants, with an average mass of between 100 and 150 grams) was used as the control. The crop was managed agronomically according to yam technical instructions in all the experimental units (Ministerio de la Agricultura, 2008).

***Efficiency estimation model*:** The increase in percentage (progression) was estimated using the equation: Δ (%) = SPE (100)/SInt, where Δ represents increase; SPE = standardized production system response (conventional), and SInt = integrative system response (innovation). The model efficiency adoption was determined by the formula: E = [Δr+ΔVag]x[p], where E = integrative system efficiency in percentage; r = yield increase efficiency; Vag = value added efficiency, and p = model appropriation probability. Gutiérrez-Ortega *et al*. (2022) considered both quantitative variables, such as production and quality, and qualitative variables related to value added and product acceptance, specifically quality.

***Variables*:** The study evaluated the independent variables related to educational institutions (EI), productive sector (PS), and the government (Gov) in relation to the increase (Δ) in quantifiable results and qualitative data on model adoption (E). The variables measured were yield (kg/ha^{-1}), value added (vag), and level of acceptance of the model by producers (p). The qualitative variables were related to the training processes, which included workshops, meetings with producers to raise awareness, technical advice on crop management, specialized advice in terms of pest management and control, and three extension programs on the application of these methodologies by teachers from the University of Granma. Quality organoleptic analysis was performed on freshly cooked tubers of the Caballo clone using both traditional and innovative methods on mashed and small (5-8 cm) pieces of cooked tuber. Appearance (including shape, texture, and color) and flavor were taken into account, with categorical ranges of excellent, good, fair, and bad. The texture of the material was evaluated according to the following categories: hard, semi-hard, and soft.

***Additional variables to be considered for the model*:** The qualitative variables estimated in the model evaluation were complementary and integrated to the qualitative variables. The educational institutional actions in relation to technology transfer were generating methodologies, implementing workshops, specialized advice, and new knowledge adjustment generated to be adapted to regional needs. The actions associated with the producers in terms of the adoption were quantified by the number of interested parties and the formation of organized units (cooperatives, producer societies, private initiatives, etc.) as an impact of the integrative model. The qualitative components related to government were management actions, such as financial facilities, module donation and governmental extensionist.

RESULTS

***The implementation and subsequent adjustment of the Triple Helix Model*:** The efficiency of adopting biotechnological innovation in yam cultivation was evaluated in the territory of Jiguaní, Cuba by implementing the model. The study was of a mixed type, involving both quantitative and qualitative variables. Additionally, a complementary descriptive phase estimated productivity, adapted to the model, and measured the level of interest in the innovation. The aim is to ensure the effective technology transfer for producing categorized yam seeds as an alternative support to local food security (Fig. 1).

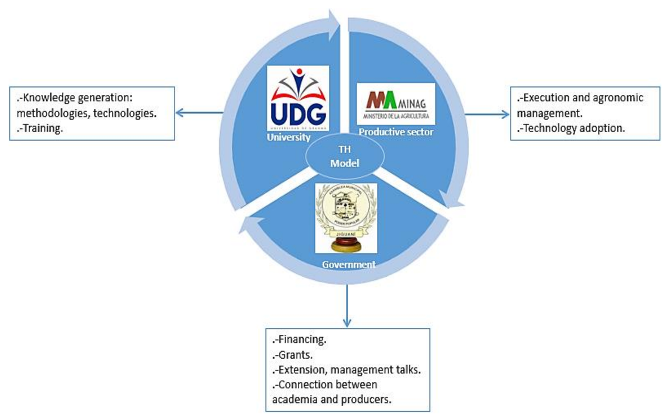

Figure 1. The Triple Helix Model University-Government-Productive sector for transferring production technology categorizing yam seeds in Jiguaní, Granma, Cuba.

Twenty-six training activities were developed, responding to 675 participants. The greatest impact was achieved during the field day with an attendance of 215 people. The government implemented 27.14% of the total actions, including six extension activities and two management talks with a total of 175 participants. These activities had a positive impact on staff awareness and training activities that were classified based on their origin with the largest number of participants attending field days (215). They were followed by 100 specialized consultancy actions, 95 workshops and management talks, 90 conferences, and finally 80 extension actions with the smallest number of participants (Tab. 1).

Table 1. Presents a summary of the awareness-raising and training activities carried out from 2018 to 2022 in the municipality of Jiguaní, Granma, Cuba.

Activities[1]	Amount	Participants[2]
University actions		
Workshops	6	95
Conferences	6	90
Specialized consultancies	3	100
Field work	2	215
Subtotal	17	500
Government actions		
Infrastructure donation	1	2
Extensionism	6	80
Management talks	2	95
Subtotal	9	177
Total	**26**	**677**

[1]Workshop: practical technical activity related to crop management (agronomic management). Conference: theoretical academic activity related to crop management (soil and seed preparation and planting). Specialized consultancies: field work according to the needs of the crop and producer. Extensionism: work of governmental departments (unpaid) related to crop management and commercialization. Management talks: face-to-face activities related to management for marketing and obtaining financing.[2]The participants were the registered attendees at each event. In the case of participants in the infrastructure, a minimum of two of them was taken to form a rural production society.

Acceptance level of the triple helix model**:** The awareness-raising program and training activities constituted a fundamental element for the successful model execution, which included holding six workshops, six conferences, six extension activities, three specialized consultancies, two field work and management talks, as well as an infrastructure donation. The participating population was made up of professionals, specialists, technicians, Granma University agronomy students, and producers (Fig. 2).

The impact on the agricultural performance variable**:** The adaptation of the model to the experimental conditions evaluated constituted a key quantitative variable, where performance is a primary focus. The 60 000 categorized seeds planted in 3 ha exhibited a survival rate of at least 98% and yield of 60 t/ha^{-1} (6 kg/plant^{-1}) in the urban agriculture system and 50 t/ha^{-1} (5 kg/plant^{-1}) in suburban agriculture, 10 months after the crop was planted in the field (Fig. 1B). Seed survival ranged from 98 to 100% with clones demonstrating adequate adaptability to soil and climate conditions. The Criollo (99%) and Caraqueño (100%) clones showed the highest survival and adaptability values.

Organoleptic properties associated with added value: The organoleptic tuber characteristics were analyzed at zero and 60 days of storage. The biotechnologically improved seeds exhibited superior performance in all indicators, including flavor, shape, and texture, compared to the traditional seeds. According to the TH model used, an increase in performance of 68% was observed with innovation compared to 4% through the traditional route. Quality doubled (2.12 times) when the innovation was used compared to the control, while the highest variable performance value increase due to innovation (12%) was recorded compared to the control (0.2%). Finally, the highest value of the variable performance increase was recorded in innovation (14) compared to control (2) (Table 2).

Figure 2. **Production technology transfer results of the categorized yam seeds in Jiguaní Municipality, Cuba, through a triple helix (TH) model (university-productive government-sector). The results are presented in four sections: (A) Awareness-raising and training activities for producers through advice; (B) Quantitative variables of yam yield and quality; (C) Yield of 8 kg/plant^{-1} with seeds from *in vitro* plants; and (D) Obtaining certified seeds with a survival rate of at least 98% and greater capacity to adapt to soil and climatic conditions.**

Table 2. Indicators related to the performance and quality of the TH system-product innovation model in yam cultivation.

MODEL	YIELD[1] (t/ha^{-1})		QUAL-ITY[2]	INCREASE (Δ)[3] (%)	
	initial	final	(p/TP)	Δ yield	Δ value-added
Control	5	5.2	40/100	4	0
Model TH	5	8.4	85/100	68	112.5

[1]The initial performance was taken as the average of the two years prior to the innovation.[2]The estimated quality of yam as a commercial product was estimated according to the acceptance of the organoleptic properties, where p = acceptance to pay 20% more than the base value of the product; **TP** = total ratings.[3] The level of increase for the two variables evaluated (performance and quality) were estimated with the formula **Δ (%)** = 100 **(vf-vi)/vi** increment, where **vf** = final value and **vi** = initial value.

DISCUSSION

The university and the productive sector, previously distinct institutional spheres, now collaborate in the development of new technologies for the benefit of society. A new social contract is emerging between the university and society at large, in which public funding is subordinated to a more direct contribution to the economy. In this context, it is being questioned whether economic development has become a function of the university in addition to teaching and research. As the university crosses traditional boundaries through its links with the productive sector and industry, it becomes evident that there are ways of making these boundaries compatible with each other, thus achieving its objectives (Yoda and Kuwashima, 2020).

Triple helix (TH) models have historically been difficult to document, especially in the integrative part of the quantifiable and qualitative values, and even less have the final effects on the food security chain been studied and their impact on local development. Thus, the TH model is adequate to measure the impact on technology adoption to quantitative (and qualitative) values, where each part of the helix works has been observed as a management action measure. The university integration and local government knowledge management have facilitated the generation of technologies and innovation processes in yam cultivation, thereby strengthening food production at municipal level. Government management represents a strategic component from this mechanism integration from the public policy agenda to infrastructure management and extension activities. In this context, Olabuénaga-Ruiz (2007) mentioned that these indicators are necessary elements to appropriately measure the level of adopting innovation technologies. Quantitative variables are those that have historically represented the level of effectiveness of technological transfer, especially those related to the most measurable effects, such as production and profits (Luengo and Obeso, 2013). In terms of yield, Degras *et al*. (1986) posited that the potential yield of commercial yam varieties is about 8.0 kg/plant^{-1} (80 t. ha^{-1}) with performance even lower in other productive systems in America, where the performance ranges from 2.5 to 4 kg/plant^{-1}.

However, the present study finds a direct correlation between some quality variables and the acceptance level of innovation, especially those related with the organoleptic properties. Cabrera Jova *et al*. (2010) observed an 86.5% survival rate 42 days after yam cultivation (cv. Pacala Duclos) establishment under field conditions in agricultural areas. These areas belong to the Instituto de Investigaciones en Viandas Tropicales (INIVIT), located in Santo Domingo, Villa Clara, Cuba. Their values are lower than those observed in the present investigation with the application of the TH model. The level of acceptance of the TH model with the yield indicators was higher than 61%, compared to the control, while with the qualitative indicators, 45 people agreed to pay 20% more than the standard value of the product, which means a 112.5% increase (Tab. 2). In this regard, Reyes Avalos *et al*. (2019) and Borges García *et al*. (2020) demonstrated that the organoleptic properties of yam tubers from biotechnological seeds achieved acceptance levels greater than 90% when subjected to different analysis techniques. Additionally, the organoleptic and appearance criteria agreed with those reported by Pacheco *et al*. (2020).

Consequently, biotechnological innovation represents a valuable social tool for the introduction of new yam clones and the enhancement of productivity and culinary values. Thereby, the added-value of the product-system increased. The results in the present study coincide with González de la Fe (2009), who mentioned that TH model can be a pivotal instrument for continuous improvement and competitiveness, contributing in a measurable way to food security and social well-being effect. Furthermore, additional components can increase the efficiency of the model, such as private initiative, cooperatives between small and medium-sized enterprises (SMEs) and interaction of local suppliers (Boza *et al*., 2021).

In relation to density, Borges García *et al*. (2018b) reported 15% increase, considering that yam yields are related to plantation densities, especially when the seeds are *in vitro* seedling. Rodríguez *et al*. (2017) evaluated different densities in yam (cv. Belep) and observed the highest production with four seeds per nest (3.33 kg/plant^{-1}), followed by three (2.81 kg/plant^{-1}), while with one seed, 1.86 kg/plant^{-1} of fresh tuber mass was achieved. Borges García *et al*. (2020) posited that the sustainable yam (cv. Criollo) production from aerial bulbils derived from *in vitro* plants exhibited a high degree of adaptation and survival, with a minimum threshold of 85%. Recently, Borges García *et al*. (2018a) demonstrated the multiplication and survival potential of bulbils with a minimum weight of 80 g (cv. Criollo) derived from *in vitro* plants cultivated in the first crop cycle.

Based on this experience, it is important to ensure the high-quality seed production, either through traditional breeding methods or innovations in cultivation techniques (Rodríguez *et al*., 2018) derived from technological transfer strategies. The present study identified the *in vitro* seed multiplication technique potential for yam mass production that could result in availability of certified planting material at a reasonable benefit/cost. This result could be achieved by having seed available in June agricultural period and extending to November, which is the optimal time for establishing this plant species in the insular Caribbean.

Given the complexity of these systems and understanding each of their parts, the results in the present study are in accordance with various researchers who argue that agricultural innovations with native products in Mexico (nopal) can be adjusted to TH model but with the need for more research (Ramírez-Arpide *et al*., 2019; Chávez-Román *et al*., 2023).

Furthermore, a recent study by Rodríguez-Deméneghi *et al*. (2023) examined the potential of biotechnological innovations in the cultivation of vanilla in Mexico. The research demonstrated that biotechnological techniques could be a key alternative to increase crop production and mitigate the negative effects caused by the low genetic variability in this species. These techniques include the use of tissue culture, molecular markers for the study of somaclonal variation, and asymbiotic germination of seeds under *in vitro* conditions. When considered collectively with agroindustrial strategies, these techniques represent a promising avenue for sustainable vanilla production. However, it is recommended that multidisciplinary studies be conducted to gain a comprehensive understanding of the phenomena involved in vanilla production and utilization, as well as to address the challenges encountered in this process.

However, another crucial part of adapting innovations in the correct quantitative and qualitative variable interaction for a better estimate of yam cultivation improvement and for better assessment of regional development (Mondo *et al*., 2021; Reyes Avalos and Borges García, 2021) and ensuring long-term acceptance and their integration into productive practice by farmers (Boza *et al*., 2021).

In this context, the necessity of developing awareness and training programs involving direct actors have been highlighted to achieve yam crop diversification and sustainable production (Borges García *et al*., 2015, Vallejo Zamora *et al*., 2016, Reyes Avalos and Borges García, 2021). On the other hand, evidently the implementation mechanisms of the innovation processes generated by educational institutions are complex. However, the success of local development strategies should depend on government support and guidance for integrating all actors to obtain the most favorable results (Vallejo Zamora *et al*., 2016; Torres Paez *et al*., 2022). The results in the present study agree with the need to include the three helices in the TH model. However, considering other actors when making decisions is important, including small producers, technicians, students, and academic staff from higher educational institutions and the government. The goal is that everyone contributes to planning, establishment, management, propagation, and advice of the system-product up to its commercialization and contribute to food security strategies for the region and country.

Finally, future research should focus on fostering dialogue between universities, the productive sector, and the government on agricultural innovation and food sovereignty. This dialogue should aim to develop research that addresses the challenges faced by companies and the productive sector, where applied research processes are conducted. By generating an innovative culture between academia, producers, and government, research results can be transformed into solutions to problems faced by different sectors of society (Holroyd, 2020).

Conclusions: The present study demonstrates the interrelationship between the knowledge generation by the university, role of the productive sector and government management, and agricultural innovation establishment with social relevance. The TH model enables the yam product-system yield effectiveness, improvement and quality as a contribution to local food security. Therefore, the use of the TH model in other innovative systems-products in Cuba or the rest of the world is considered possible.

Conflict of interest: The authors declare no conflict of interest.

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SDG's addressed: Zero Hunger,Quality Education, Decent Work and Economic Growth.

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