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Sustainable Potato Production in the Mountain Area of Ecuador, an Approach to Increase Productivity with Small Scale Farmers

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Abstract

Ecuador potato crop is family based production system. Potato production has two roles in their economy, the first is providing food for their families and the second is a source of income for the household. However small scale farmers have limited access to local markets and most of the sales are through intermediates' who purchase directly in the field at the lowest price possible. Potato production challenges for the small-scale farmers are among others availability of quality potato seed, direct sales, purchase of agrochemical inputs to maintain their crops and lack of education. In 2021, only 4% of potato farmers used certified seed. Potato yield is still low around 16.1 t·ha^{-1}, in the last 10 years the total potato cultivated area was reduced by at least 50%. The farmers produce "Bokashi" and other organic fertilizer and these are effective to improve soil fertility and plant health. Homemade bio-pesticides reduce agrochemical pesticides. The Decision Support System (DSS) is a handheld device to control late blight, minimizes fungicide applications and improve fungicide rotation. In 2018 *Candidatus Liberibacter solanacearum* (Lso), the causal agent of zebra chip, and its vector, the potato psyllid *Bactericera cockerelli*, together created havoc for farmers and researchers. Promotion of early potato varieties INIAP—Libertad is an alternative to lower the impact of this newest pest.

Keywords

Potato, Yield, Small-Scale Farmers, Agro-Ecological Production, Quality Seed

1. Introduction

Ecuador potato production area is located in the Andean region, between 2200 to 3600 altitude. This area is considered a tropical highland. The ecosystem is an important regulator of water cycles, and it is sensitive to the increase in temperature [1]. The population in this area has low scale economy; poverty levels are critical and face food insecurity. The male migrates to the urban areas with hope to bring economic resources for their families. This migration has a direct impact on the rural economy, and fields are abandoned or managed by women.

In the highland, the potato farms are family-based, adverse factors such as climate change, and monocropping [2], seed availability, and limited access to financial system make them more difficult to produce. Potato in Ecuador is a staple food, this crop is important for food security and source of income [3] for small scale farmers [4]. It contributes approximately 6% of the share of agriculture's gross domestic product [5].

Potato productivity in Ecuador is considered low when compared with their neighboring countries, according to reports from the Agricultural Ministry (MAG) in 2020 the average yield is 16.41 $t \cdot ha^{-1}$ [6]. The total cultivated area was reduced by at least 50% when compared to 2011 [7].

Potato farmers have limited access to quality seed due to the high price. Only 6% of the farmers used certified seed [5]. However farmers implement different practices such as saving seed from previous harvest and this lead to seed degeneration, pest spread and diseases [8]. Seed degeneration is defined as the reduction in seed quality and yield due to the accumulation of pathogens and pests in/on the seed tubers [9]. The seed is recycled (*i.e.*, propagated over consecutive cycles of on-farm multiplication) [10].

In 2018, Ecuador reported the presence of *Candidatus Liberibacter solanacearum*, the pathogen that causes Zebra chip disease, and phytoplasmas vectored by leafhoppers and causing purple top or hop-burned disease. At the time, the farmers and researchers did not how to control the disease and the losses were over 60%, [11].

This is an opportunity to have an approach to improve potato production in tropical mountains. All agricultural practices to increase potato yield and productivity need to be developed and well adapted to the area. The agricultural practices such as water harvesting, reforestation, use of bokashi [12], organic fertilizers and homemade biopesticides need to minimize the impact on the ecosystem and landscape [4].

Meeting Ecuador Potato Farmers

More than 82.000 farmers work in the potato sector, 53% are middle-aged males [6]. Only 4% of the farmers use certified seed, and 76% of the cultivated area is managed by family members [6].

Education

61% have primary school, and 20% have no education [6]. And this limits

their ability to have written records, understand production cost, and crop yield and learn new and improved agricultural practices.

Aging population

Young male farmers are migrating to nearby cities, and farming is not appealing to them. The land is being managed by old parents or his wife, who don't have decision power. 44% of potato farmers from the collaborative project are 51 years old or older, [13].

Women and potato farming

They are key players in the potato production especially in the seed system, variety selection, and storage [14]. 63% farmers participating in the collaborative project KOPIA-INIAP from 2018-2021 were women [15].

Traditional cultivation methods

Small-scale potato farmers follow traditional cultivation practices, because they cannot afford to purchase quality seed and pesticides among other inputs. They plow the field down hillside, and this practice is common in the north side of Ecuador, degrading the soil fertility and causing erosion [13].

Limited access to markets

Small-scale potato farmers in Bolivar, Cotopaxi and Chimborazo provinces live in the highlands above 2600 meters above sea level (masl). Their homes and fields are far away from the market. Unfortunately, small-scale farmers access their fields in motorbikes or llamas (*Lama glama*) due to poor road conditions. The farmers have lost their negotiation power and they sell their products to the first purchaser.

All the time the purchasers go to the farmer organizations and communities in trucks, harvest the field and pay below the production cost [13].

Farmer organizations

They are family-based, largely unorganized. The farmer organization does not have an administrative and accounting system implemented. Lack of production and business plans [13].

Seed supply system

There are two systems to supply seed potatoes, the informal and the formal potato seed system [16]. The formal system is established according to the country law certification, the seed is categorized based on the type of potato seed: breeder, basic, registered, certified and commercial [17]. The informal system is when farmers produce quality seed, and they are not registered as seed producers.

Phase 1: Implemented in 2015-2017: Optimize seed production processes of initial category in the automated greenhouse and seed distribution to seed multipliers.

The goals for the first phase were:

Greenhouse optimization and production of virus-free potato seed.

Crop-integrated management training for farmers and extension services.

Introduction of new technologies for small scale farmers and potato seed producers.

In the Highland areas of Ecuador potato production is the main source of income for small and medium-size farmers, currently less than 9% of the potato farmers use certified seed therefore national productivity is the lowest in the Andean Region currently the productivity is 12.79 $t \cdot ha^{-1}$ [17].

Potato seed virus-free production began at the Biotechnology Department in Santa Catalina Research Station at INIAP. The automated greenhouse received the potato virus-free *in-vitro* plants and started the multiplication of small cuttings throughout the autotrophic-hydroponic system to produce mother plants. The mother plants became the starting material to produce seedlings to multiply basic potato seed either in the hydroponic or aeroponics areas in the greenhouse.

One of the goals of the KOPIA-INIAP Potato Project was to introduce high-quality potato seed to small-scale potato farmers.

Phase 2: Implemented in 2018: Increase productivity in the highlands of Ecuador with potato quality seed production and strength agribusiness.

The objectives for the second phase were:

Strengthen potato production system using virus-free potato seed.

Validate low environmental impact technology.

Implementation of small agribusiness to aid family income.

It was considered a pilot phase. The participant farmers were surveyed to develop an economic-social baseline. The data collection was done in 5 provinces. The rapid market analysis was an important tool to implement small agribusiness and training leaders in marketing skills [13].

Phase 3: Implemented in 2019-2021: Farm Village model, the establishment of agri-business with farmers of the Rural Family Farming Organizations (AFC), in seven provinces of Ecuadorian Highlands working in the potato sector.

The goals for the third phase were:

Empower and strengthen farmer organization.

Implementation of agribusiness in seven provinces.

Strengthening local capacities and implementation of sustainable production systems.

The farm village model "*Saemaul Undong* (SMU) was implemented in Korea in 1965-1980 during one of the most critical socio-economic changes caused by migration of the rural youth to the cities [18]: "(*i*) *establishing democratic leadership in the nation's rural communities*, (*ii*) *increasing household income through modernization of agricultural production and mobilization of rural resources including labor, and* (*iii*) *encouraging self-help efforts by residents of rural communities*", [19]. In this phase of the project, we worked on 2nd objective of the SMU, and scaled up all technologies disseminated to potato farmers in the last 2 phases from 2015 to 2018.

The project was implemented in 7 provinces. A total of 252 rural family farmers were direct beneficiaries.

2. Methodology

Each phase of the project had its own methodology.

2.1. In the First Phase

Evaluation and performance of the automated greenhouse were key to optimizing virus-free potato seed production. The production process was evaluated at the greenhouse level. Survival rate of the cuttings and seedlings was the key performance indicator (KPI) in different production areas.

From the *in-vitro* plants to the sowing trays the acceptable survival rate was no less than 95%. From the sowing trays to the mother plants area the acceptable survival rate was at least 95%. And from the mother plants area to either hydroponic or aeroponic seed production areas the acceptable survival rate was no less than 85%.

The automated system works using sensors to monitor and control every environmental parameter for the good growth of the plants. The greenhouse relative humidity, temperature, drip irrigation, air sprinklers, and ferti-irrigation is controlled by Priva Automation Solutions.

In 2015, a group of Korean experts in hydroponic and quality potato seed production and management worked together with INIAP to improve performance and production of the greenhouse. Among their recommendations were reduction of labour employees and the implementation of equipment and machinery to improve efficiency in the potato seed production system [17].

A training program was developed to aid extension services and farm leaders to learn and disseminate the seed technology (mini-tubers and seedling). Farming field schools and learning plots were implemented in all 5 provinces [17].

2.2. Second Phase

Setting a baseline study of the socio-economic conditions was a key activity to know the potato farmers in this study. The survey had a pre-design questionary about their education level, access to new technology, production area, main crops, economic wealth, livelihood status and access to local markets [20].

A formal training program was designed for farmers in family finance, leadership training, working together, communication skills and solidarity economy implemented with external consultants and other non-government organizations [13].

The Rapid Market Analysis is an important tool for assessing market potential at the early stages of the business. The market potential is based on the quantity that could be produced and the net price to producers, [21].

Participating farmers had a key role to develop a distinctive logo for their products. Meetings with farmer organization leaders, INIAP extension services and the external marketing consultant helped to build the logo [13].

The short marketing circuits were an alternative for the inclusion and empowerment of rural agricultural family farming. It promotes associated, sustainable

and fair production, [22].

Learning plots were implemented for all groups of farmers to continue with the production of quality potato seed [13].

An external consultant group trained INIAP extension services on different methodologies to teach farmers. The program is called "Visualisation in Participative Programs" (VIPP), [23].

2.3. Third Phase

The "Farm Village Model" involved a total of 16 farmer organizations in 7 provinces. Six farmer organizations from 2018 and 10 new farmer organizations joined in the first semester of the "Farm Village Model". The new organizations were surveyed to have a socio-economic baseline study. The survey was the same pre-design questionary used in 2018.

The information helped to develop a training program for the farmers in associativity, strengthening farmer association, family finance and saving boxes, potato production, use of environmentally friendly technologies, and formulation of biopesticides and organic fertilizer.

It was considered the scaling-up process to introduce virus-free potato seed, environmentally friendly technology to reduce chemical pesticides, homemade organic fertilizers and biopesticides, and strengthen agribusiness for farmers.

The decision support system (DSS) developed by the International Potato Center [24] was used to control late blight. The use of organic fertilizers was an alternative to reduce chemical fertilizer [25]. Home-made biopesticides were an opportunity for farmers to reduce synthetic pesticides, considering that biopesticides are easily biodegradable, exhibit various modes of action, are less expensive and have lower toxicity to humans and non-target organisms [26].

The Business Model CANVAS (BMC) is a strategic planning tool to illustrate a new business. This template gives an overall situation of the business and it might speed up the problem-solving processes [27].

3. Results

Automated Greenhouse optimization or the first phase of the project, the production of high-quality seed began at the biotechnology department in Santa Catalina Research Station of the National Institute of Agricultural and Livestock. Potato seed was cleaned of PXY, PVY, PVX and PLVR viruses to ensure quality potato seed. Once, the *in-vitro* potato plants were cleaned and free of viruses, the *in-vitro* potato plants were taken to the automated greenhouse for seed multiplication. The *in-vitro* potato plants were cut. The cuttings had grown into mother plants. The mother plants become a starting material to multiply potato seedlings.

The seedling produced basic potato seed free of virus either in the hydroponic or aeroponic areas. The production process evaluation was carried out during the first 3 months of the project implementation.

Among the findings, soil substrate removal and disinfection from the hydro-

ponic production area were done by 11 people. A vacuum machine type aided soil substrate removal. The use of this machine resulted in reduction of 3 people. The soil substrate disinfection was time-consuming and involved at least 5 labour workers per day. The use of a cauldron and the big-bag system was reduced to 3 people. The equipment and machinery used for disinfection and removal of the soil substrate reduced the number of workers from 11 to 6 [17]. The project was carried out in 2 years, in 5 provinces and the total production area was 12 hectares divided in 5.7 Ha of potato cuttings and 6.3 Ha of potato seed mini tubers. A total of 215 small farmers and 90 extension services were trained in potato seed production [17].

In the second phase of the project a total of 82 surveys were carried out within the farmer organizations. The results reported that 67% were women, and 33% were men. 14% of the farmers finished high school, and only 40% finished elementary school. 36% of the farmers were 51 years old or older. 64% of the interviewed farmers said, that their income was below the minimum wage for the country. 40% of the farmers had less than 1 hectare [13].

Farmers divided their work by gender, males migrate to the nearby cities to have another source of income for the family, and the land was either managed by their wives, sisters, or elderly parents. All of the farmers reported having their own property, however, they said that access to the local market is restricted.

Because, the project was focused to open new market opportunities for farmers, a total of 244 surveys for quick market analysis were carried out in Quito, Riobamba and Guaranda [13]. The quick market analysis reported data and analysis informed that 46% of the people would like to receive agroecological baskets produced by small-scale farmers [13]. The agroecological basket included the following products: aromatic herbs, vegetables, potatoes, onions, corn, and beans. The people were willing to purchase every 2 weeks, and the sale price for each basket was 15 US dollars, including delivery, [13]. They also recommended creating a logo to identify and promote the products sold at the farmers markets and the restaurant services. The restaurants and hotels were also open to purchasing their local products and the demand was established for 2.5 tons of fresh potatoes per week [13].

The development of the logo was done with the support of an external consultant, farm leaders and extension services who participated and designed the logo and slogan "*Shamuk-ñan*" it means "Future Road" [13].

A total of 5.2 potato hectares were implemented with the farmers. In all field plots, government-certified seed was used to produce farmers' quality seed to be distributed among the farmers inside the association or to sell to local farmers. The average yield in this production area was 20 $t \cdot ha^{-1}$ [13], and the government reported in the national average was 16.28 $t \cdot ha^{-1}$ [4].

Each organization implemented its own saving box, and all the organizations started their own small agri-business with the support of the KOPIA-INIAP project [13].

The Farm Village Model, follows the Korean rural development model "*Saemaul Undong* (SMU)" which is a community-based development initiative that allows unprecedented success in transforming rural areas by changing the agricultural concept of the productive sector towards a new vision [19].

KOPIA and INIAP carefully adapted these fundamental pillars of Korean Rural Development to the local conditions of small-scale potato farmers in Ecuador. It had the following strategic axes: associativity, increased productivity, use of technologies such as quality seeds, promoting the use of early potato varieties, environmentally friendly potato production, financial education, opening of differentiated markets, and empowerment of youth and women.

252 farmers were working in this phase of the project [15]. 60% of the farmers were women [15]. A total of 55 hectares of commercial potato field plots and potato seeds were implemented in the project, and the average yield was calculated to 20 $t \cdot ha^{-1}$ [15]. Farmers increase their income because of potato productivity and they open new markets. The productivity increased an average of 22% when compared with 2020 national estimated productivity reported by the Agricultural Ministry (MAG) at 16.41 $t \cdot ha^{-1}$ [7].

Implementation of small business with farmers was not easy. The farmers received training in all areas like accounting, finance, saving boxes and management, and good manufacturing practices. The most relevant business was implemented in Carchi, Cotopaxi, Chimborazo, and Tungurahua. The Carchi farmers focused to produce high-quality potato seed, right now they are working to receive government registration as potato seed producers.

Cotopaxi farmers received from the project 2-grain millers and storage facility. The organization provided milling services for the community.

Chimborazo farmers distributed and sold organic vegetables to Riobamba city and implemented a novel potato production to reduce soil erosion and optimization of water management. Tungurahua famers received from the project a grain miller and a small toaster to produce wheat flour; they have local registration as small businesses. The product had received the national food registration to sell nationwide.

In 2020, KOPIA Ecuador received an award from UN SDG—Ecuador in the category "SDG-2 Zero Hunger" because this Farm Village model complies with the goals for this objective [15].

4. Conclusions

In this article, we aimed to summarize the implementation of the collaborative KOPIA-INIAP project from 2015 to 2021.

Increasing potato productivity needs the intervention of all involved in the potato agri-food system, government officials, researchers, farmers and industry. The government seed producer certification is complicated, and all bureaucratic steps make it impossible for small scale farmers.

It is important to find alternatives for small-scale farmers to receive and conti-

nuously replace potato seeds to maintain yield and reduce potato seed degeneration.

Agro-ecological potato production is possible at lower scale. Introduction of new potato varieties adapted to the local area is necessary to continue working with potato farmers to increase yield.

Small-scale famers need to work together and organize themselves in farmers association. Access to different type of markets like solidarity markets, alliances with restaurants and food potato industry becomes an opportunity for small scale farmers to increase income.

Farmers need a better understanding of accounting systems, taxes and family finance, and training in this area is urgently needed. Implementation of small agri-business will aid rural family income. We all need to work to have a better potato agri-food system.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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