Ciencia Latina Revista Científica Multidisciplinar
Septiembre-Octubre, 2023, Volumen 7, Número 5
https://doi.org/10.37811/cl_rcm.v7i5.8412

Effect of use of Certified Seed to Increase Potato (Solanum Tuberosum) Production in Ecuador

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ABSTRACT

Potato cultivation holds a significant position in Ecuador's agricultural landscape, ranking as the third most produced crop nationwide in 2022, with 19390 hectares dedicated to its cultivation. However, only 5% of the seed used by small-scale farmers is certified. Consequently, the yield from this planting material remains low at 14 $t.ha^{-1}$. Recognizing the imperative to enhance the utilization and availability of certified seed, the Korea Partnership for Innovation of Agriculture (KOPIA), in collaboration with the National Institute of Agricultural Research (INIAP), initiated the production of certified seed in automatic greenhouse. This endeavor facilitated the distribution of these seeds to small-scale farmers across seven provinces, resulting in increased production compared to the national average. The yields achieved in the years were as follows: 2016 – 25 $t.ha^{-1}$, 2017 - 24 $t.ha^{-1}$ 2018 - 20 $t.ha^{-1}$, 2019 - 18 $t.ha^{-1}$, 2020 - 21 $t.ha^{-1}$, 2021 and 2022 - 19 $t.ha^{-1}$. These represented a 52% improvement over the general national average during these years. Additionally, the certified seed's tolerance to pests and diseases led to a reduction in the use of agrochemicals, resulting the production costs remained moderate, allowing farmers to generate income. Allowing them to invest on entrepreneurship and production processes within their organizations.

Keywords: *certified seed; potato; yield; small farmers; production cost*

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Efecto del Uso de Semilla Certificada para Incrementar la Producción de Papa (Solanum Tuberosum) en Ecuador

RESUMEN

El cultivo de papa ocupa un lugar importante en el panorama agrícola del Ecuador, ubicándose como el tercer cultivo más producido a nivel nacional en 2022, con 19390 hectáreas dedicadas a su cultivo. Sin embargo, sólo el 5% de la semilla utilizada por los pequeños agricultores está certificada. En consecuencia, el rendimiento de este material de siembra sigue siendo bajo, 14 t.ha-1. Reconociendo el imperativo de mejorar la utilización y disponibilidad de semillas certificadas, la Asociación Coreana para la Innovación en Agricultura (KOPIA), en colaboración con el Instituto Nacional de Investigación Agrícola (INIAP), inició la producción de semillas certificadas en invernaderos automáticos. Este esfuerzo facilitó la distribución de estas semillas a pequeños agricultores en siete provincias, lo que resultó en un aumento de la producción en comparación con el promedio nacional. Los rendimientos alcanzados en los años fueron los siguientes: 2016 – 25 t.ha-1, 2017 - 24 t.ha-1 2018 - 20 t.ha-1, 2019 - 18 t.ha-1, 2020 - 21 t. ha-1, 2021 y 2022 - 19 t.ha-1. Estos representaron una mejora del 52% sobre el promedio nacional general durante estos años. Además, la tolerancia de la semilla certificada a plagas y enfermedades llevó a una reducción en el uso de agroquímicos, por lo que los costos de producción se mantuvieron moderados, permitiendo a los agricultores generar ingresos. Permitiéndoles invertir en emprendimiento y procesos productivos dentro de sus organizaciones.

Palabras clave: *semilla certificada; papa; producir; pequeños agricultores; costo de producción*

Artículo recibido 16 setiembre 2023
Aceptado para publicación: 25 octubre 2023

INTRODUCTION

Potatoes are globally significant, ranking as the third most cultivated crop after rice and wheat (CIP, 2023). In 2021, a total of 18132,694 hectares of potatoes were planted with an average yield of 21 tons per hectare, reaching an annual production of 376 million tons, with China as the top producer, accounting for 94 million tons of this output (FAO, 2021). Significantly, one billion people consume potatoes, and an enormous segment of the global population, particularly farmers and entrepreneurs, relies on potato production for their livelihoods (CIP, 2023).

In Ecuador, potato cultivation has been especially crucial, given the crop's adaptability to the highland region's climate conditions. In 2022, Ecuador dedicated 19390 hectares to potato cultivation, producing 251433,39 tons at an average yield of 14 tons per hectare (INEC, 2022). Four provinces – Carchi, Cotopaxi, Chimborazo, and Tungurahua – emerged as the primary potato producers, accounting for 66.5% of the national cultivation area (INEC, 2022).

However, potato production is not without challenges. Factors such as diseases, pests, and particularly seed degeneration significantly impact both the quantity and quality of potato yield. Seed degeneration refers to the decline in seed quality and yield resulting from the accumulation of pathogens and pests, especially when farmers reuse or recycle seeds (Struik &Wiersema, 1999).

Several pathogens and pests, such as Potato virus Y (PVY), *Ralstonia solanacearum* (the bacteria responsible for bacterial wilt), and *Globodera pallida* (commonly known as potato cyst nematode), contribute to the deterioration of seeds. If not addressed effectively, these diseases and pests can build up within farmers' seed stocks, leading to a decline in seed quality. In the lowlands of Colombia, experiments have demonstrated that the prevalence of PVY-infected seeds can surge by as much as 40% after a single round of on-farm propagation (de Luque et al., 1991). However, the extent of this increase is influenced by various factors, including agroecological conditions (Bertschinger et al., 2017).

Furthermore, these diseases and pests can result in significant crop yield losses. For instance, PVY can lead to average losses of 0.18 metric tons per hectare for each 1% rise in incidence (Nolte et al., 2004). Meanwhile, the Andean potato weevil (*Premnotrypes* sp.) can cause yield losses of up to 100% (Kroschel et al., 2014). These examples illustrate the substantial impact of seed degeneration on farmers' fields. Consequently, it is imperative to explore and implement strategies for managing this issue.

In an ideal scenario, seed systems should provide farmers with access to cost-effective, disease-free, disease-resistant, and high-quality seeds. However, in practice, the majority of farmers in low-income countries, such as 98% of potato growers in the Andes region, typically save seeds from the previous season to use for replanting (Devaux et al., 2014; Jaffee et al., 1992). Yields obtained from saved seeds often fall short in comparison to those achieved using improved seeds. These superior-quality seeds are produced through enhanced on-farm pest and disease management, the deployment of disease-resistant varieties, and adherence to seed certification standards. The recommended set of practices for enhancing seed systems is referred to as an integrated seed health strategy (Thomas-Sharma et al., 2016).

Scientists play a vital role in advancing seed systems by developing varieties that are not only more resistant to diseases but also possess other desirable traits for wider dissemination. By comprehending the dynamics of seed systems, scientists can formulate recommendations for improving these systems, taking into account interconnected patterns of disease transmission and socioeconomic factors across various scales.

Recognizing the need for better seed quality, the Korea Partnership for Innovation of Agriculture (KOPIA) has been active in Ecuador since 2012, with its central mission to uplift agricultural productivity by promoting certified seeds within sustainable production systems. By 2015, guided by recommendations from Korean experts specializing in hydroponics, aeroponics, and seed quality, KOPIA initiated certified seed production in an automated greenhouse, targeting the production of virus-free, disease-resistant, and pest-resistant seeds. From 2016 to 2022, these certified seeds were introduced to small-scale farmers, allowing an in-depth analysis of various factors influencing potato production in Ecuador's highlands.

METHODOLOGY

First Phase: Potato Seed Production in Automated Greenhouse

The initiative to optimize the production of virus-free, disease-resistant, and pest-resistant potato seeds started in 2015, using an automated greenhouse, with the collaboration of the National Institute for Agricultural Research of Ecuador (INIAP). In December of that year, the seed production mainly focused on cuttings, which produced faster results. During 2016 and 2017, seed production increased and started with aeroponic and hydroponic systems, including periodic evaluations to assess each stage of potato seed production. The primary performance measure, designated as a key performance indicator (KPI), was the survival rate of both cuttings and seedlings across various production areas (KOPIA, 2015-2017).

- For the initial stages, encompassing the journey from in-vitro plants to sowing trays, the benchmark survival rate was set at ≥ 95%.
- Transitioning from sowing trays to the mother plant zones, a similar survival rate of ≥ 95% was sought.
- Subsequently, from the mother plants region to hydroponic or aeroponic seed production areas, a survival rate of ≥ 85% was targeted (Villavicencio et al., 2022).

The greenhouse was equipped with state-of-the-art sensors from Priva Automation Solutions to consistently monitor and regulate vital environmental parameters—such as relative humidity, temperature, drip irrigation, air sprinklers, and fertigation — for optimal plant growth (Villavicencio et al., 2022).

Parallel to this, farming plots were established across select highland regions. An accompanying training program was instituted to facilitate knowledge transfer about the seed technology, primarily focusing on mini-tubers and seedlings, to extension services and farm leaders.

First Phase: Multiplication Plots

Between 2016 and 2017, multiplication plots were established in the following provinces in the Ecuadorian highlands, Carchi, Pichincha, Cotopaxi, Tungurahua, and Chimborazo, involving twelve farmers organizations and covering a total area of 9.46 hectares. During this period, various potato varieties were cultivated, with the majority being of superchola variety at 57.14%, followed by Libertad at 14.29%, Josefina and Fripapa at 9.52%, and Cecilia and Victoria at 4.76%. These plots sourced their seeds from the automated greenhouse, specifically utilizing hydroponics and aeroponics systems (KOPIA, 2016,2017).

The primary purpose of these multiplication plots was to obtain seed certification through a rigorous inspection process conducted by the Ministry of Agriculture and Livestock of Ecuador (MAG). To facilitate this initiative in the five provinces mentioned above, choosing training selected farmers as agricultural promoters and establishing criteria for selecting the plots essential.

Starting in early 2016, farmer training in the form of "learning plots" began in the fields. INIAP technicians led these training courses with the aim of enhancing the technical capabilities and skills of agricultural promoters through the utilization of research and technologies developed by INIAP. The duration of the course spanned seven months, allowing participants to comprehensively grasp each phase of the potato crop's phenological development. The ultimate objective of this training was to provide both theoretical and practical knowledge to the participants on the advantages of using quality potato seed and the proper management of potato crops (KOPIA, 2015-2017).

Multiplication plots were established in locations that met the following selection criteria:

- Altitude between 2,800 to 3,000 meters above sea level to reduce insect vectors of viruses.
- Four-year fallow period.
- Reliable water supply.

In addition, the farmer organizations had to be officially registered as seed multipliers by the Ministry of Agriculture and Livestock (MAG). The farmers selected underwent intensive training in theory and practical aspects of high-quality seed management. Each association also employed an agricultural and technical promoter, well-versed in multiplying cuttings and tubers (KOPIA, 2015-2017).

Second Phase: Engagement with Small-scale Farmers

After obtaining certified seed in the categories of registered and basic. From 2018 to 2022, KOPIA has involved 22 farmers' organizations which were located in Carchi, Imbabura, Pichincha, Cotopaxi, Tungurahua, Chimborazo, and Bolivar provinces. These associations produced the potato crop on 48.5 hectares. The varieties used were superchola (55.05%), Libertad (15.60%), Fripapa, chaucha amarilla, and chaucha roja (8.25%), Josefina and Superfri (1.83%), Natividad, Yana shungo, Puca shungo, Leona Negra and Clones de colores (0.92%) (KOPIA, 2018-2022).

The following selection criteria were established for farmers' organizations collaborating with KOPIA and INIAP:

- A decade's experience in potato production.
- Updated organizational statutes.
- Willingness to invest 20% of the production costs.

- Past collaboration with the Ministry of Agriculture and Livestock (MAG) or National Institute of Agricultural Research (INIAP).
- 100% of the organization's members engage in the commercialization of agricultural products.
- Affiliation to Peasant Family Farming.

Selected organizations underwent rigorous training, focusing on organizational capability enhancement, agribusiness planning, high-quality seed utilization, and integrated pest and disease management strategies for potato crops (KOPIA, 2018).

Furthermore, to gain insight into the current state of organizations and understand their needs in terms of production, a situational assessment was conducted through a survey. This diagnosis served as a foundation for obtaining a baseline understanding of the producers' circumstances. To enhance the socio-organizational skills of producers through strategic partnerships, a training program on topics related to finance was developed (KOPIA, 2018).

Additionally, to establish connections among various organizations, a logo was collaboratively designed with the slogan "weaving social ties." This logo will guide the efforts of the participating producers as they work together (KOPIA, 2018).

The KOPIA Center funded production cost such as fertilizers, seeds, pesticides, and more. INIAP produced the certified seed and extended continuous support to the farmers through periodic technician visits, imparting crucial crop management insights.

RESULTS AND DISCUSSION

First Phase: Seed multiplication

Quality assurance began at the biotechnology division of the Santa Catalina Research Station, a constituent of the National Institute of Agricultural Research (INIAP): rigorous measures eradicated viruses, fungi, bacteria, nematodes, and pests from the potato seeds. Post the in-vitro phase, potato plants were shifted to the automated greenhouse for seed multiplication.

The mother plants derived from in-vitro cuttings were crucial for potato seedling multiplication. These seedlings were then cultivated in hydroponic or aeroponic environments, generating high-quality virus-free potato seeds. At the end of 2015, Korean experts shared all the know-how related to hydroponics and aeroponics production systems with Ecuadorian technicians at INIAP, which allowed them to maintain an efficient flow of quality potato seed production (KOPIA, 2015-2017).

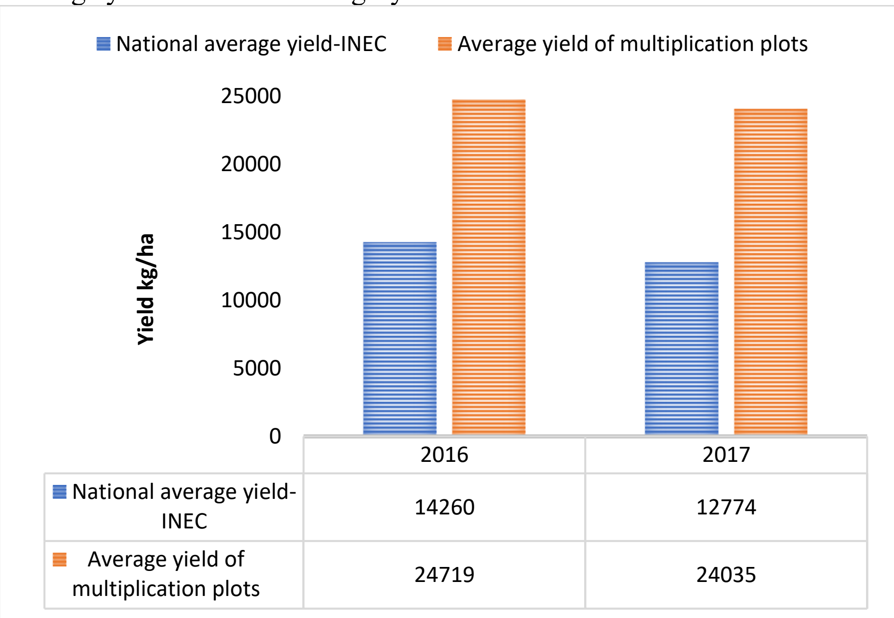
Table 1
Seed production in automated greenhouse

Number of cuttings and tubers for seed multiplication			
	2015	2016	2017
Hydroponic	0	50400	134000
Aeroponics	0	94800	380000
Cuttings	100000	123750	124850

Yield of basic category seed

Once the basic category seeds, including cuttings and mini tubers, were produced in the aeroponics and hydroponics systems, they were subsequently planted in the chosen plots in the provinces of Carchi, Pichincha, Cotopaxi, Tungurahua, and Chimborazo (KOPIA, 2016,2017). As shown in Figure 2, yields obtained from multiplication plots surpassed the national average reported by National Institute of Statistics and Censuses (INEC) (INEC, 2016,2017). The yield derived from these fields was used as the starting point for establishing the plots in the second phase. Nevertheless, when choosing the initial seeds, the focus was on those with the most favorable phenotypic and genotypic traits.

Figure 1
Average yield from basic category seed



Second Phase: Yield of certified categories seed

The producer characteristics are important to determine the productivity, in 2018 to have insight of it was ran the survey, finding the agricultural production employs 63,4% of female labor over 36,6% of men labor, the tendency of farmers´ age shows that over the 30 years old increase the interest to work on fields therefore is concentrated in the range of 51 to 71 years old with 39%. In rural areas, the education faces several barriers which are reflected in farmers who have been trained by informal learning through literacy program and 51,14% of them have completed the primary school. The household income is main factor to know the farmer´s production approach and in this case the agricultural production sales is higher by 4% than livestock production sales (KOPIA, 2018).

Subsequently, training in potato crop production was delivered using a practical "learning by doing" approach during field days. This training aimed to enhance the organizations' abilities in leadership, teamwork, communication, and decision-making, while also increasing productivity and promoting savings through topics like budgeting, savings, credit management, family assets, and financial well-being.

Additionally, sustainable agricultural practices were introduced in this phase, including the use of biofertilizers (bokashi) and crop rotation with alternative crops. These practices ensured family nutrition and provided additional income through the sale of surplus harvests.

Table 2
Socio-demographic characteristics of farmers

Provinces: Bolivar, Pichincha, Cotopaxi and Chimborazo					
	Gender		**Age**		
	Women	**Men**	**15-30**	**31-50**	**51-71**
Percentage	63,4	36,6	26	35	39
	Farmers´ household income		Farmers´ family size		
	Agricultural product sales	**Livestock product sales**	**1-3 people**	**4-5 people**	**Over 5 people**
Percentage	52	48	12,7	56,8	30,4
	Educational level				
	Non education	**Literacy program**	**Primary school**	**High school**	
Percentage	12,9	19,94	51,14	16,02	

Associations: Corazón de Totoras (Bolivar province), El Porvenir de Romerillos and Monasterio de Bellavista (Pichincha province), Artesanal de Cuturiví Chico (Cotopaxi province), Mushuk Pakary (Chimborazo province).

To establish a unique identifier for the organizations and foster connections in unconventional marketing channels, a logo was created through collaborative efforts involving representatives from these organizations and technicians. This logo was designed with the slogan "weaving social connections," aiming to showcase how collaboration among farmers can create a robust network for the collective benefit.

Within the logo, the phrase "Shamuk ñan," meaning "Future Path", was integrated. This phrase symbolized the vision of forging a solid way filled with opportunities that enhance the future well-being of farmers (KOPIA, 2018).

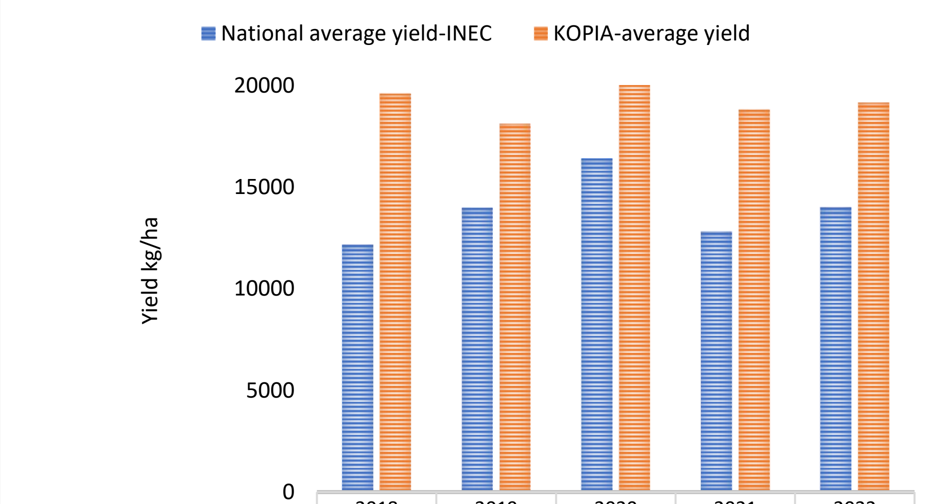
Figure 2
Logo designed by organizations and technicians

Furthermore, the data from annual reports from 2018 to 2022 confirms these findings. Notably, plots cultivated by small-scale farmers using high-quality seeds yielded crops consistently higher than the national average through five years (INEC, 2018-2022). The enhanced seed quality directly correlates with heightened resistance to the common pests, diseases, and nematodes that plague potato crops in Ecuador.

Moreover, alternative approaches for farmers to enhance their production include implementing crop management technologies, adopting environmentally-friendly cultural practices, employing integrated pest management strategies, and building resilience to climate change. These efforts were bolstered through training processes aimed at producing high-quality seeds.

In contrast, as depicted in Figure 3, in 2021, both national and KOPIA yields exhibited a slight decline compared to 2020, primarily due to adverse climatic conditions. This study underscores the critical role of weather conditions, as evidenced by specific instances: in Carchi, two plots suffered from flooding, resulting in damages exceeding 30% of the crop; Pichincha experienced damage to two plots ranging from 20% to 30% due to heavy rain, frost, hailstorms, and strong winds; in Bolivar, three plots were impacted by flooding, frost, hailstorms, and diseases, leading to yield losses of approximately 70% to 80%. Additionally, in Imbabura, three plots were affected by a fungus known as *Rosellinia sp.,* causing yield reductions of over 30% (KOPIA, 2021). According to Ministry of Agriculture and Livestock (MAG) the effect on national production to drop off in 2021 it was due to the climate adverse conditions, such as high precipitation, strong wind and low temperatures (MAG, 2022).

Figure 3
Average yield from basic, registered and certified categories seed

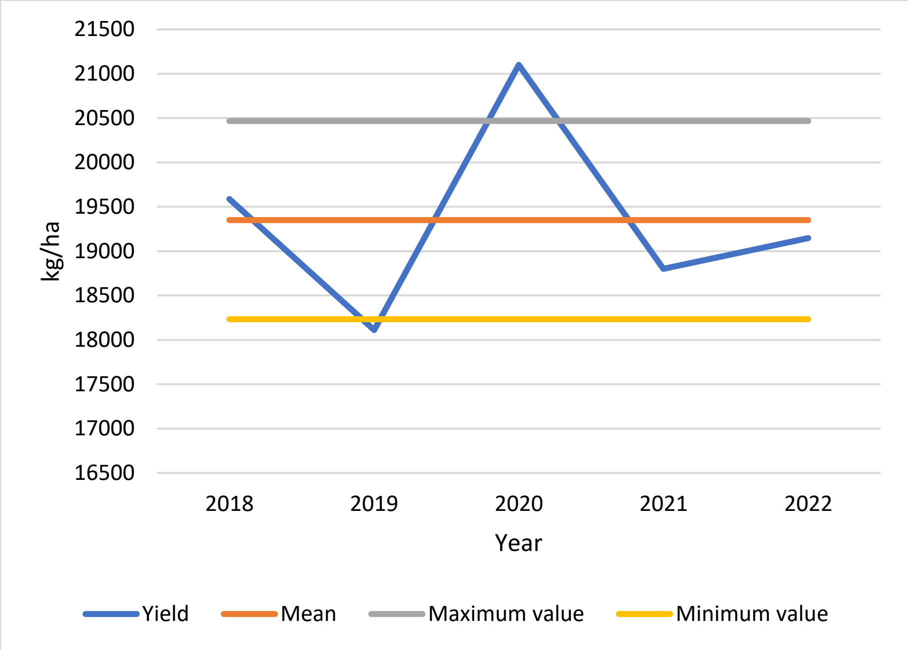


	2018	2019	2020	2021	2022
National average yield-INEC	12182	13995	16410	12822	14026
KOPIA-average yield	19587	18111	21100	18804	19149

A descriptive statistical analysis yielded the following results: the mean was found to be 19350,2 with a standard deviation of 1117,17. The maximum recorded value was 20467,37 while the minimum value was 18233,02. These values suggest that the data are concentrated around the mean.

Figure 4 presents this data, illustrating the boundary values. All data falling within this range are closely centered around the mean, while data points outside of this boundary are of lesser significance.

Figure 4
Statistical analysis of yield across the second phase



Second Phase: Cost of Production

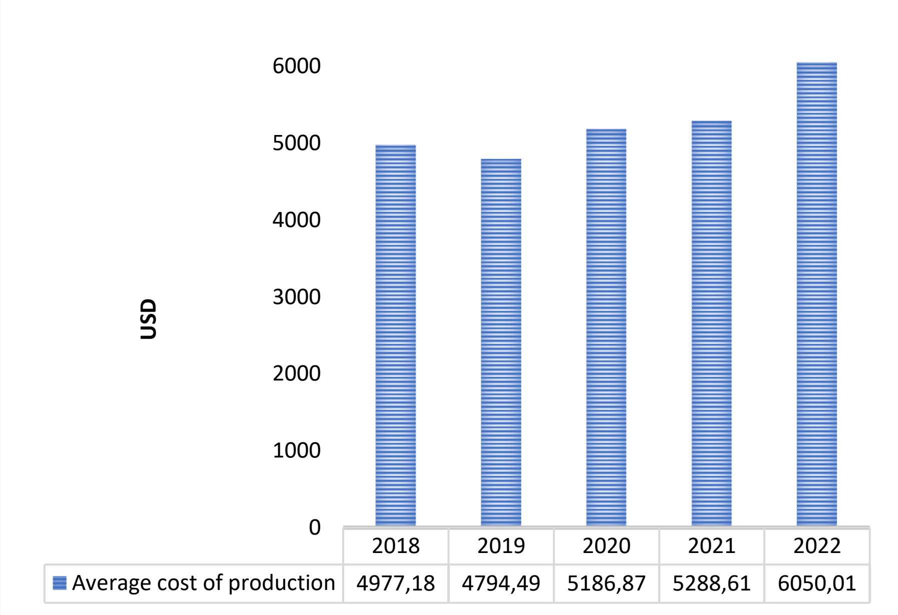
The data on production costs, gathered from annual reports spanning from 2018 to 2022, reveals a gradual upward trend over the years. In 2020, there was an slightly increase in the incidence of purple-top disease, requiring a higher usage of pesticides for control, thereby contributing to an escalation in production costs (KOPIA, 2020).

Moving to 2021, adverse weather conditions were observed in certain provinces, leading to issues like flooding, frost, hailstorms, and disease outbreaks. To address these challenges, an increased use of agrochemicals was demanded (KOPIA, 2021).

In 2022, the year took an atypical turn due to the conflict between Russia and Ukraine, resulting in a decline in both exports and imports from these nations. Ecuador's imports were notably affected, particularly due to the shortage of agricultural inputs, which had a significant impact on the agricultural sector's production. Russia, in particular, played a crucial role as a supplier of agrochemical inputs to Ecuador, accounting for 38% of the market share in 2021(Villareal, A. & Estrella, N., 2022).

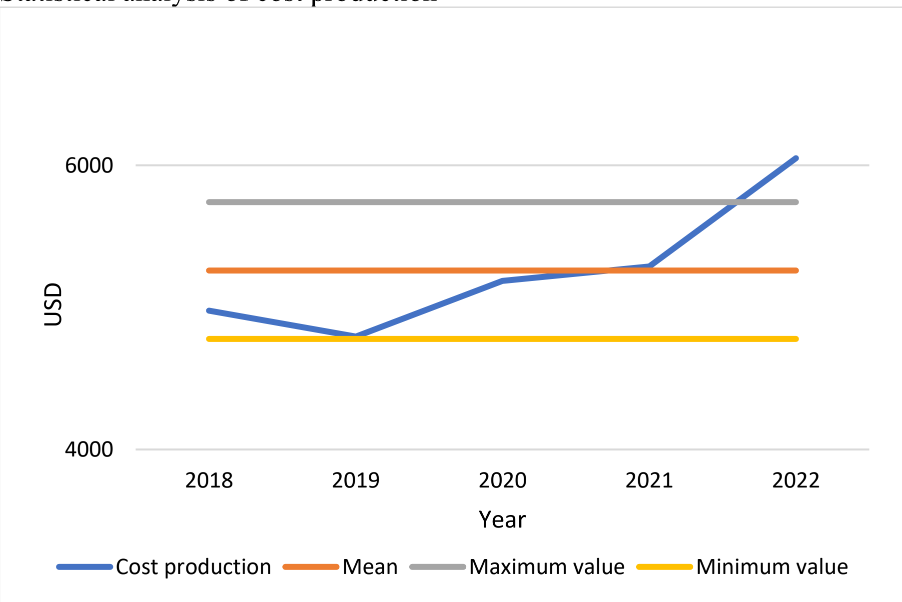
The reduced availability of agrochemicals in the market led to a surge in their prices, directly contributing to the overall increase in production costs throughout the year.

Figure 5
Average production cost during the second phase



A descriptive statistical analysis was conducted, revealing the following results: the mean was determined to be 5259,43 with a standard deviation of 481,40. The highest recorded value was 5740,83 while the lowest was 4778,04. This data is visually represented in Figure 6, which demonstrates that the data from 2018 to 2021 is concentrated around the mean. However, it's worth noting that the data for 2022 deviates slightly from these established boundary values.

Figure 6
Statistical analysis of cost production



CONCLUSIONS

KOPIA's support has been instrumental in achieving successful high-quality seed production. They designed and implemented specialized machinery for various production methods in an automated greenhouse, significantly increasing seed production in 2016 and 2017. They also established multiplication plots with high-quality seeds and advanced irrigation techniques, leading to impressive yields, surpassing national averages by 73% in 2016 and 88% in 2017.

A situational diagnosis survey revealed that over 60% of producers were women aged 51-71, with more than 50% completing primary school. These producers depended on selling agricultural products for their livelihood, helping in resource allocation.

High-quality seeds and producer training in potato cultivation resulted in yields consistently exceeding national averages, with a 61% increase in 2018 and 29% in 2019 and 2020. Even in 2021, facing atypical weather conditions, they exceeded the national average by 47%, and in 2022 by 37%. Quality seeds reduced agrochemical usage and kept production costs reasonable.

KOPIA and INIAP collaborated to produce certified seeds distributed to 455 small-scale farmers across 22 organizations in seven Ecuadorian provinces from 2016 to 2022. These associations have gained empowerment and certification as certified seed producers, allowing them to continue their initiatives and established production processes.

Acknowledgements

The National Agricultural Research Institute (INIAP), specifically its Technology Transfer Department, oversaw the implementation of the Potato Project. This initiative was financially supported by Rural Development Administration of Korea through the Korea Partnership for Innovation of Agriculture (KOPIA).

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