ORGANIC POTATO PRODUCTION WITH THE APPLICATION OF BIOAGROINPUTS IN LOS PALACIOS, CUBA †

[PRODUCCIÓN ECOLÓGICA DE PAPA CON LA APLICACIÓN DE BIOPRODUCTOS EN LOS PALACIOS, CUBA]

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SUMMARY

Background: The negative effects caused by chemical fertilizers on the environment have led in recent years to the use of ecological alternatives for the management of crops of economic interest, with the application of bioproducts. **Objective:** To evaluate the application of the EcoMic biofertilizer and the bioproducts based on *Trichoderma* and QuitoMax in the production of organic potatoes. **Methodology:** The research was carried out at Finca "El Viñedos" Los Palacios, where 1 ha of the tuber variety SPECTRA, of Dutch origin, was planted in a Red Ferralitic leached Quartzite soil and three blocks were established, in one of which potatoes were produced conventionally (control), in another it was the combination of bioproducts (QuitoMax, *Trichoderma* and EcoMic) and in the remaining only QuitoMax and *Trichoderma* was applied. For the treated blocks, applications of QuitoMax (4) and *Trichoderma* (8) were made after sprouting. **Results:** The number of tubers per plant increased by 47 and 50% in those biologically treated (QuitoMax, *Trichoderma* and EcoMic) and (QuitoMax and *Trichoderma*), respectively. A similar behavior was obtained with the block based on QuitoMax, *Trichoderma* and EcoMic in the size of the tubers (caliber) with 63% while the one treated with QuitoMax and *Trichoderma* obtained 14%; in agricultural yield it was 31 and 21%, with QuitoMax, *Trichoderma* and EcoMic standing out. **Implications:** The production of organic potatoes is possible with the application of bioproducts. **Conclusions:** With the combined application of the EcoMic biofertilizer and other bioproducts, it was possible to produce 19 t of organic potatoes on the "El Viñedo" Los Palacios farm.

Key words: yield; biofertilizer; plant; growth.

RESUMEN

Antecedentes: Los efectos negativos causados por los fertilizantes químicos al medio ambiente, han conducido en los últimos años a la utilización de alternativas ecológicas para el manejo de los cultivos de interés económico, con la aplicación de bioproductos**. Objetivo:** Evaluar la aplicación del biofertilizante EcoMic y los bioproductos a base de *Trichoderma* y QuitoMax en la producción de papa ecológica. **Metodología:** La investigación se realizó en Finca "El Viñedos" Los Palacios, donde se sembró 1 ha del tubérculo variedad SPECTRA, de origen neerlandés en un suelo Ferralítico Rojo lixiviado Cuarcítico y se establecieron tres bloques, en uno se produjo papa de forma convencional (testigo), en otro fue la combinación de bioproductos (QuitoMax, *Trichoderma harzianum* y EcoMic) y en el restante se aplicó solamente QuitoMax y *T.*

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harzianum . Para los bloques tratados, después de la brotación se hicieron aplicaciones de QuitoMax (4) y *Trichoderma* (8). **Resultados:** Se incrementó el número de tubérculos por planta en un 47 y 50% en aquellos tratados biológicamente (QuitoMax, *T. harzianum* y EcoMic) y (QuitoMax y *T. harzianum*), respectivamente, Un similar comportamiento se obtuvo con el bloque a base de QuitoMax, *Trichoderma* y EcoMic en el tamaño de los tubérculos (calibre) con un 63% mientras que el tratado por QuitoMax y *Trichoderma* obtuvo un 14%; en el rendimiento agrícola fue de un 31 y 21%, sobresaliendo el QuitoMax, *Trichoderma* y EcoMic. **Implicaciones:** Es posible la producción de papa orgánica con la aplicación de bioproductos. **Conclusiones:** Con la aplicación combinada del biofertilizante EcoMic y otros bioproductos se logró producir 19 t de papa orgánica en la finca "El Viñedo" Los Palacios.
Palabras Clave: rendimiento; fertilizante; planta; crecimiento.

INTRODUCTION

The potato (*Solanum tuberosum*) is a tuber of great demand by the Cuban population for its contribution in minerals such as potassium, phosphorus, magnesium, copper, iron, pantothenic and folic acid, rich in antioxidants, provides fiber and vitamins C, B1, B3, B6, D, hence years ago it was called "the queen of viands". It is cultivated in around 159 countries covering 17.8 million hectares, with an annual production of 375 million tons, surpassed by sugar, corn, rice and wheat, representing half of the world's production of Roots and Tubers (FAO, 2024). Since 2012, national potato production does not exceed 150 thousand tons, according to data from the National Office of Statistics and Information (ONEI). However, the yields of these crops have remained above 20 t ha^{-1}, a figure similar to the world average of 21 t ha-1 (FAO, 2024; ONEI, 2021).

A preliminary report on the 2022 potato harvest, published by the Ministry of Agriculture (MINAG, 2022), showed that of the total production plan of 120 914 t. only 77%, or 93 649 t, had been harvested, a figure even lower than in 2016 and 2021. Although crop yields have remained above 20 t ha^{-1} since 2008, the harvested area of the product has been reduced to levels below 7 000 ha, with a historic low of 2 568 ha in 2014, i.e., despite maintaining yields, the decrease in cultivated area causes less potatoes to be produced (ONEI, 2021).

This reduction is due to the lack of resources to guarantee a larger crop area, as well as the traditional way of producing the tuber, based on production systems with high inputs, agrochemicals, and various machinery. A current alternative is the use of bioproducts such as biofertilizers, bio-compost and manure that improve soil properties and fertility (Martín-Martín *et al*., 2021).

Given this situation, the transition of this system towards harmony with nature is taken into consideration, different bioproducts can be used, among them can be highlighted the use of biofertilizing products based on arbuscular mycorrhizal fungi (AMF) as well as stimulating products such as oligogalacturonides or chitin derivatives (Terry *et al*., 2022) These bioproducts work, together with bionutrients, and constitute ecological alternatives that allow an adequate nutritional balance for crops, promoting a stimulus in growth, development and agricultural yield (Terry *et al*., 2015; 2022). Also, the use of *Trichoderma* spp. presents direct and indirect mechanisms of action as a biological control agent and stimulator of plant growth (Rakibuzzaman *et al*., 2021).

Chitosan (CHT) it has shown efficacy in reducing disease incidence and increasing crop growth, yield, and quality (Chakraborty *et al*., 2020). This is why we can use CHT for dual purposes in agriculture. CHT functions as a plant growth promoter in various crops such as beans, potatoes, radish, soybean, and other crops. CHT is a poly (1,4)-2-amino-2-deoxy-β-D glucose, a de-acetylation derivative of chitin, found in arthropod exoskeletons, which includes crustaceans like lobsters, shrimps and crabs, insects, mollusk radulae, beaks of cephalopod and fish, and lissamphibian scales (Kurita, 2006). As a result of plant growth promotion, it also enhances yield. As CHT molecules are extremely hydrophilic, they reduce stress damage in plant cells by decreasing water content and accelerating several biological macromolecules activities. The results also suggested that CHT was working as a consequence of other metabolic processes rather than merely enhancing nitrogen nutritional quality or as a source of energy for the production of carbohydrates (Chakraborty *et al*., 2020).

In the municipality of Los Palacios, the tuber has not been planted since 2009 due to low yields in the province. In the case of the municipality, the historical average yield always exceeded 18 t ha^{-1}, even when the irrigation system was obsolete and required high inputs. As a strategy for potato production in the country, the planting of the tuber is resumed in the municipality of Los Palacios, in the 2019-2020 season. Having as an essential element its history in production, where it achieved 25 t ha of potato. However, in the 2021-2022 planting season, only 1 ha of potato was planted under the principles of organic production of the tuber. The seed was guaranteed and the producer was trained where the potato would be planted, as a first experience in the municipality (Argenpapa, 2020). Taking into account the above situation, the objective of the research was to evaluate the application of the EcoMic biofertilizer and the bioproducts based on *Trichoderma* and QuitoMax in the production of organic potatoes.

MATERIALS AND METHODS

Experimental Conditions

The research was carried out on the grounds of the El Viñedo farm in Los Palacios, belonging to producer Rodolfo Rodríguez Bernal. It is located at 22°36'5" LN and 83°15'34" NW. The research was carried out in 1 ha of production located south of the owner's house, where three potato production blocks were established; one of conventional production and two of agroecological production. These blocks allowed the establishment of the research variants, where a sampling design was followed, which facilitated the randomization of the samples in each block**.** Block 1) Conventional potato production (Control); Block 2) Agroecological potato production without the application of the EcoMic biofertilizer, and, Block 3) Agroecological potato production with the application of EcoMic biofertilizer. The blocks were separated by a space of 20 meters.

The soil was classified as ferrallitic red ferrallitic leached quartzite, over ferralitized weathering crust, according to Hernández *et al*. (2015). They present a clay loam texture and are characterized by a slightly acid pH (5.34), average organic matter (OM) values (3.2%). The exchangeable bases with typical contents for this type of soil and considered low, as well as the assimilable phosphorus (P), low (Mesa *et al*., 1984).

The behavior of meteorological variables during the experimental period was recorded at Meteorological Station # 317 in Paso Real de San Diego in the municipality of "Los Palacios" in Pinar del Río province, which is at an average distance of 4 km from the production area (Table 1). Average temperatures during the period ranged from 22.1 to 27.5ºC at the end of the cycle. Monthly accumulated rainfall was high, but distributed over the month and in correspondence with a relative humidity that did not exceed 79%. All this climatic behavior was considered typical for Cuban conditions and acceptable for tuber production (MINAG, 2019).

The seed potato (SPECTRA variety, of Dutch origin), with a caliber of 55-65 mm, was imported by the Cuban Ministry of Agriculture from Holland. It is a high yielding, semi-early eating variety, with very regular tubers and an attractive smooth skin (Agrico, 2022). Prior to planting, because the caliber of the seed potato was too large, it was chopped in two parts and treated with lime for scarring. The tuber (seed) was planted on January 18, 2022, at a distance of 0.20 m between tubers in the furrow and 0.90 m between furrows, and before covering the tubers, lime was applied as a phytosanitary treatment at a dose of 25 g per seed.

Irrigation in the experimental area was carried out by drip irrigation at a delivery rate of 3 L h^{-1} by micro-sprinklers. The first irrigation was carried out six days before planting (DAP), to create humid conditions for planting. Irrigation time ranged from 2-3 h with an interval of 4 days, depending on rainfall. The rest of the phytotechnical work (weed control and hilling) was carried out according to the technical instructions for potato cultivation (MINAG, 2019).

Experimental procedure

Conventional potato production (Block 1)

In the area of conventional potato production (control), based on, mineral fertilization and phytosanitary control with chemical products, a background edaphic mineral fertilization was applied at a rate of 1,490 kg ha^{-1} of complete NPK formula (12-12-17) and 20 days after sprouting, 200 kg ha^{-1} of nitrogenous mineral fertilizer (urea, 46%) were applied. Also, 11 applications of phytosanitary chemical products were made for the control of insects and diseases typical of the crop, following the phytosanitary strategy issued by the Ministry of Agriculture of Cuba (MINAG, 2019).

Agroecological potato production (Block 2 and 3)

In the agroecological production area, agronomic management was applied with several alternatives. A total of 30 t ha^{-1} of organic matter (poultry manure) was incorporated to regulate soil pH and replace mineral fertilization. In addition to the bioproducts (EcoMic, QuitoMax and *Trichoderma*).

Table 1. Behavior of meteorological variables (Jan 2022 to April 2022), monthly averages. Meteorological Station # 317 in Paso Real de San Diego.

Months	Temperature ºC			Relative humidity (%)	Precipitation (mm)
	maximum	minimum	average		
Jan	27.7	17.5	22.1	79	98
Feb	29.1	19.6	23.9	78	135
March	31.2	21.4	25.7	75	169
April	31.7	22.2	26.5	73	200

EcoMic is a biofertilizer in solid form, based on arbuscular mycorrhizal fungi, with a fungal richness of 20 spores per gram of soil. This biofertilizer is produced and commercialized by the National Institute of Agricultural Sciences of Cuba (INCA). It also produces the biostimulant QuitoMax, which has a liquid format, based on chitosan at 4 g L^{-1}. In the case of *Trichoderma harzianum* (strain 34), it is a product in solid format (rice husk), in which 5 x 10^6 conidia per gram of culture medium are suspended. This biopesticide is obtained and commercialized by the National Center of Agricultural Health of Cuba (CENSA).

In block 2, at the moment of potato tuber planting, only a mixture of *T. harzianum* and QuitoMax was applied, at a dose of 10 kg ha^{-1} and 100 mL ha^{-1}, respectively. After sprouting of the potato tuber, an application was made every 7 days, for a total of eight foliar applications. In the case of QuitoMax, four foliar applications were made with an interval of 15 days mixed with *Trichoderma* and at the same dose.

In Block 3, the same procedure was followed as in Block 2, but at the time of tuber planting, a single application of EcoMic biofertilizer at a dose of 10 kg ha^{-1} was added to the mixture of *T. harzianum* and QuitoMax.

Evaluations performed

Several evaluations related to plant growth and productivity were carried out, where 20 plants were randomly sampled in each block (1, 2 and 3; control, treatments without EcoMic and treatments with EcoMic, respectively). At 20 days after planting (DAP) of seed potatoes, a stem count per seed tuber planted was performed. Plant height was measured at two time points, at 35 and 45 DAP. The measurement was made from the soil surface to the top of the longest leaf projected in the direction of aerial growth and height values were expressed in cm. Tubers were harvested at 68 DAP and collected in previously identified bags. The total number of potatoes per plant was evaluated and the potatoes were classified according to their size, in large potatoes (>45 mm) and small potatoes (< 45 mm), using a caliper. The quantity in kg of potatoes per plant was also determined with the help of a technical scale, precision 0.001 g, and from these values the agricultural yield in t ha^{-1} was estimated.

To the results of the evaluations carried out, the data obtained were compared using Confidence Intervals for α=0.05.

RESULTS

The existing edaphoclimatic conditions were not considered as negative for the research, since they were not a variation factor.

Morphological variables of potato plants with bioproducts

It is important to note that the number of stems per plant with the application of the biofertilizer favored the survival of shoots, which subsequently formed the number of stems per plant, more rapidly. At 20 DAP, the number of shoots (stems) per plant increased in the treatment with EcoMic, with respect to the treatment without EcoMic and without differences with the control (Figure 1).

On the other hand, no differences were observed between the treatment with other bioproducts (Without EcoMic) and the control treatment. The increase in the number of sprouts in the treatment With EcoMic represented 28.9% with respect to the treatment Without EcoMic.

The difference in the number of stems caused changes in plant growth from the point of view of plant height (Figure 2). In the two moments when height was always evaluated, the treatment with EcoMic biofertilizer showed the highest values, although without differences with the control treatment. At the same time, the control treatment showed no differences with the treatment without EcoMic. The increase in plant height at 35 and 45 DAP represented 8.46 and 5.43%, respectively, compared to the treatment without EcoMic.

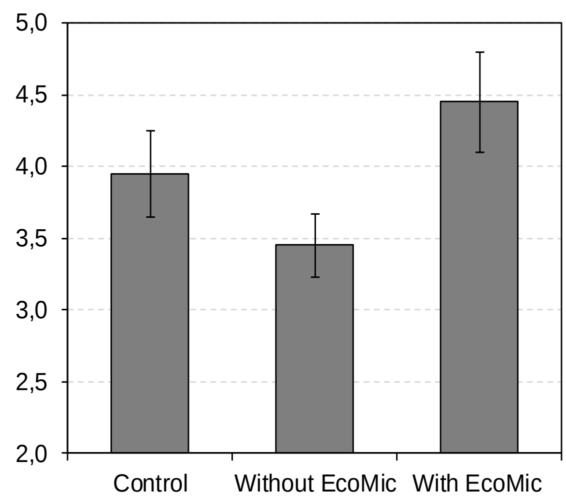

Figure 1. Number of stems per seed (tuber) under organic production conditions at the "El Viñedos" Los Palacios farm of producer Rodolfo Rodríguez Bernal. Bars above columns indicate confidence interval for α=0.05.

Tuber size is an important indicator for producers, as it influences the marketing of the crop, specifically selling prices (Mora-Quilismal *et al*., 2021). Therefore, achieving high yields and quality potato production contributes to food security. However, this depends on the edaphoclimatic conditions and the actions taken by man to obtain his crops. Harvest sampling showed a higher number of potatoes per plant in the EcoMic treatment, followed by the control treatment and in less potatoes in the treatment without EcoMic (Figure 3). The increase in the total number of potatoes per plant was 9.77% with respect to the control and 47.50% with respect to the treatment without EcoMic at the time of tuber planting.

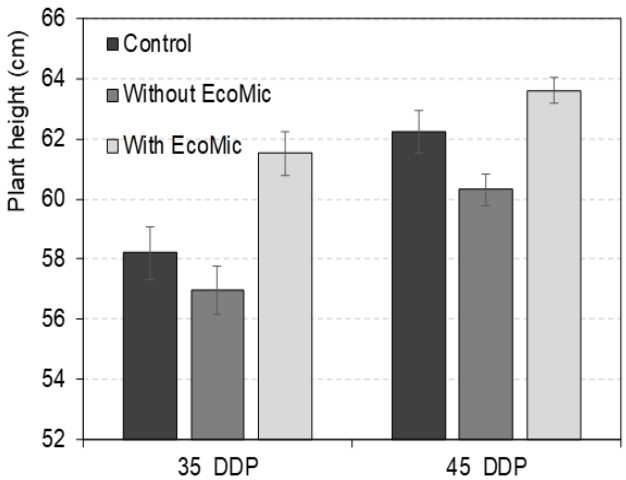

Figure 2. Height of potato plants under organic production conditions at the "Los Viñedos" Los Palacios farm of producer Rodolfo Rodríguez Bernal. Bars above columns indicate confidence interval for α=0.05.

In the EcoMic treatment at planting, 63.14% of the potatoes had a caliper >45 mm. In the treatment without EcoMic, 58.13 % of the potatoes showed a caliber greater than 45 mm. However, the control treatment showed the highest percentage of potatoes with a larger caliber, that is, 75.35% with a caliber greater than 45 mm. The production of tubers by plants indicated a positive effect of the application of the EcoMic biofertilizer, which stimulated this indicator compared to the control with mineral fertilization and the treatment without the biofertilizer; This behavior may be related to the stimulation exerted by AMF in terms of root production, which contributed to the formation of tubers (Mora-Quilismal *et al.*, 2021; Castillo *et al.*, 2016). It is also possible that the exudates of growth hormones that are produced in the microorganism-plant interaction have contributed to the formation of tubers, such is the case of the production of jasmonic acid that intervenes in tuberization (Alcantara-Cortes *et al.*, 2019). When analyzing the greater or lesser number of tubers per size, it was found that the control treatment showed the highest number of sizes, a result that corresponds to greater nutrition and growth of the tuber due to the effect of the mineral fertilization that was applied.

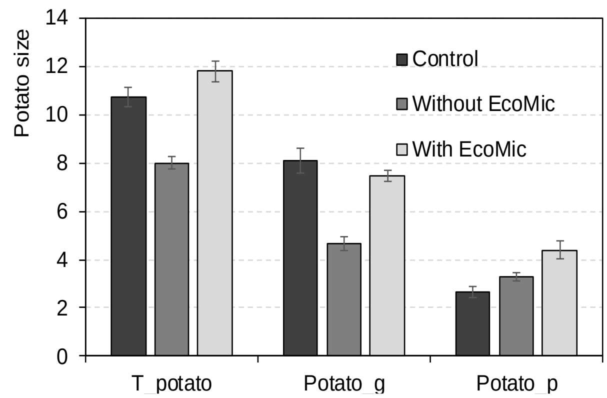

Figure 3. Total and size of potatoes, under organic production conditions at the "El Viñedos" Los Palacios farm of producer Rodolfo Rodríguez Bernal. Bars above columns indicate confidence interval for α=0.05.

Agricultural performance of potato plants with bioproducts

The application of a pool of bioproducts (*T. harzianum*, QuitoMax and EcoMic) at the time of planting and compared to the treatments without EcoMic and conventional production positively influenced the agricultural yield of potato. It was found that there were no significant differences between the control treatment and the EcoMic treatment, the latter treatment with an increase of 31.21% in agricultural yield, which represented 4.95 t ha^{-1}, compared to the treatment without EcoMic. On the other hand, the control treatment showed an increase of 36.69%, equivalent to 5.82 t ha^{-1}, with respect to the treatment without EcoMic (Figure 4).

DISCUSSION

Edaphoclimatic analysis in potato cultivation

Previous research has shown that potato cultivation in soils with ferrallitic red grouping responds positively to typical physicochemical properties (Jerez-Mompié *et al*., 2017), even when there are variations in their properties, due to anthropogenic action of man. In this sense, Martín-Alonso *et al*. (2022) assured that in Cuba the highest potato production is obtained in this type of soils, which due to monoculture and indiscriminate mineral fertilization are continuously degraded, cause for which they remain dependent on the use of mineral fertilizers and yields decrease.

In relation to the percentage of organic matter, the values correspond to a little degraded soil, even so, with the purpose of substituting mineral fertilization, organic matter was applied and incorporated at a dose of 30 t ha^{-1}. According to Ricardo-Corrales (2013) and Martín-Martín *et al*. (2021), to achieve agroecological potato production, it is necessary to apply high volumes of organic matter, depending on soil deterioration. In relation

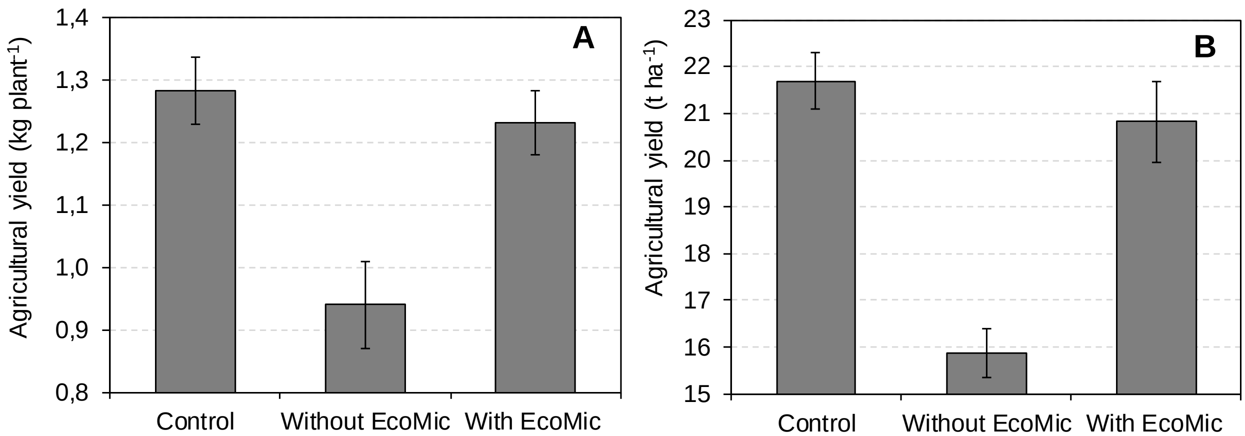

Figure 4. Agricultural yield per potato plants (A) and estimated agricultural yield per hectare (B) under organic production conditions at the "El Viñedos" Los Palacios farm of producer Rodolfo Rodríguez Bernal. Bars above columns indicate confidence interval for α=0.05.

to the percentage of organic matter, the values correspond to a slightly degraded soil, even so, in order to replace mineral fertilization, organic matter was applied and incorporated in doses of 30 t ha^{-1}, depending on the deterioration of the soil. The application of organic matter in high volumes allows the agroecological production of potatoes, so the replacement of inorganic sources with organic fertilizers, such as compost, manure or biofertilizers, should be sought, suggesting an application of 3 kg of organic matter per meter. linear (Ricardo-Corrales, 2013; Martín-Martín *et al*. 2021).

On the other hand, climatic conditions contributed to the growth and development of the crop, even when the tuber was planted outside the optimum period (January 18, 2022). According to Estévez (2007), the average values of temperature and relative humidity correspond to the needs of the crop in January and February. In the case of March and April, where the average temperature exceeded 24°C, tuberization processes are affected and therefore the biological cycle of the crop was shortened (Ricardo-Corrales, 2013, Martín-Martín and Jerez-Mompié, 2015), as occurred in this research. In this sense, Konstantinos *et al*. (2016) point out that the onset of tuberization is a process influenced by environmental factors, such as, temperature and photoperiod, mediated by the levels of endogenous growth regulators (Roumeliotis *et al*., 2012). In the case of rainfall, these were cumulatively high and did not condition the elevation of relative humidity, because they were intense, but distributed over time, thus allowing conventional (MINAG, 2019) and alternative (Martín-Martín *et al*., 2021) agronomic management, which favored the growth and development of potato plants without the extensive occurrence of pest outbreaks.

Analysis of the doses of bioproducts used

Regarding the application doses of the bioproducts used in the research (*T. harzianum,* QuitoMax and EcoMic) all were modified according to the recommendations (MINAG, 2019, Martín-Martín *et al*., 2021), as well as the times and forms of application. In the specific case of the EcoMic biofertilizer, the dose was lower, since it was applied directly in the furrow with the *T. harzianum*+ QuitoMax mixture and only 10 kg of EcoMic were applied. However, Martín-Martín *et al*. (2021) recommend dipping the seed (tuber) in a mixture of bioproduct (IHPLUS BF® and BIOBRAS-16) with 20 kg of EcoMic for 10 min, in 200 L of water, so the new form of application is novel. In the case of QuitoMax, the same authors recommends the application of a seed treatment before sowing at a dose of 50 mL ha^{-1} (Martín-Martín *et al*., 2021). However, the technical instructions for potatoes in Cuba recommends two applications, one at 30 DAP and another at 50 DAP, but with the same dose of QuitoMax (MINAG, 2019). Contradictorily, Ricardo-Corrales (2013) does not recommend the application of this biostimulant in his book "El cultivo Agroecológico de papa en Cuba". However, in this research, four treatments were carried out with the biostimulant QuitoMax in interaction with *T. harzianum*. Regarding the application of *T. harzianum* the doses of application according to recommendations of MINAG (2020) are between 2 to 10 kg ha^{-1} and in our research, we worked at a dose of 15 kg ha^{-1}, with the purpose of raising the levels of *Trichoderma* in the agroecosystems. At the same time, the benefits of this microorganism as an antagonist against phytopathogenic fungi are enhanced (Rivera-Méndez *et al*., 2018), which also has a stimulatory effect on plant growth and development (Ruiz-Sánchez *et al*., 2022).

This behavior may be due to the stimulation of plant growth from plant - AMF interaction processes, where growth hormones and secondary metabolites involved in plant growth are exuded. Other research (Castillo *et al*., 2016; Mora-Quilismal *et al*., 2021) has shown that mycorrhizal colonization in potato crop favors the number of stems.

Analysis of morphological variables of potato plants with bioproducts

It is important to highlight that the initial application of the bioproducts (*T. harzianum*, QuitoMax and EcoMic), apparently influenced the number of stems. In this sense, the stimulating effect of plant growth with the application of *T. harzianum* to seed was reported (Ruiz-Sánchez *et al*., 2022), as well as, the growth stimulating effect exerted by QuitoMax on potato crop (Jerez-Mompie *et al*., 2018). However, conventional potato production also showed higher or equal values to those achieved with bioproducts. Results that evidenced that the application of bioproducts compensated the use of chemical fertilizers.

The height of potato plants, as in other crops, depends on the production of assimilates for growth and is regulated by genetic and environmental parameters (Márquez-Vasallo *et al*., 2020). Everything seems to indicate that the application of EcoMic biofertilizer and other biofertilizers (*T. harzianum* and QuitoMax) applied to the tubers (seed) contributed to the assimilation of nutrients, as well as to improve the efficiency of the plant to achieve greater growth and development with respect to the treatment without bioproducts at the time of planting the tubers (With EcoMic).

In the research conducted by Jerez-Mompie *et al*. (2017) with the application of two moments of QuitoMax, an increase in plant growth related to plant height was found. However, in this research a similar result was obtained, but with the application of QuitoMax at four moments of the plant cycle, in combination with *T. harzianum* and EcoMic from the time of planting.

These results showed that the application of EcoMic and other bioproducts to the seed tuber at planting time favors tuber production, both in terms of total potato and potato caliber, results that are related to the number of sprouts as well as plant height. In this sense, it has been reported that phosphorus has a marked effect on tuber quality (Álvarez-Sánchez *et al*., 1999), due to its influence on cell division and, therefore, on tuber size. Therefore, it could be that the application of EcoMic has had a marked influence on the results obtained, since AMF among its benefits in the microorganism-plant interaction is the absorption and transport of phosphorus (Rivera *et al*., 2020; Felipez and Ortuño, 2021).

Tuber formation is directly related to the distribution of assimilates in the plant, which are involved in tuber growth and development (Jerez *et al*., 2015). Therefore, tuber formation in potato depends, among other things, on the availability of assimilates and the ability of tubers to accumulate them (Jerez *et al*., 2017).

Tuber size is an important indicator for growers as it influences the marketing of the crop, specifically selling prices (Mora-Quilismal *et al*., 2021). Therefore, achieving high yields and quality potato production contributes to food security. However, this depends on the edaphoclimatic conditions and the actions taken by man to obtain his crops. Sampling at harvest showed a higher number of potatoes per plant in the EcoMic treatment, followed by the control treatment and fewer potatoes in the treatment without EcoMic (Figure 3). The increase in the total number of potatoes per plant was 9.77% with respect to the control and 47.50% with respect to the treatment without EcoMic at the time of tuber planting.

Analysis of the agronomic performance of potato plants with bioproducts

Research that preceded us assured that, these bioproducts (*T. harzianum*, QuitoMax and EcoMic) applied to the potato crop in isolation cause increases in tuber production. Jerez-Mompié *et al*. (2017; 2018) in their research evidenced that the application of QuitoMax favors agricultural yield in this tuber. Mora-Quilismal *et al*. (2019) and Luna-Quecaño *et al*. (2020) reported that AMF inoculation increases the agricultural yield as well as the caliber of harvested tubers in different potato cultivars. Rakibuzzaman *et al*. (2021) reported that the application of *T. harzianum* increased the agricultural yield of potato by 23.82% with respect to the control without *Trichoderma*, when a higher concentration of *T. harzianum* was used.

In potato cultivation, other research has reported that biological fertilization with arbuscular mycorrhizal fungi also influenced crop yield (Mora-Quilismal *et al*., 2021), increasing the availability of phosphates for plants and favoring their development, not only increasing the number of tubers per plant, but also that they obtained tubers of higher quality and superior calibers, as did other studies (Restrepo-Correa *et al*., 2017).

In general, the edaphic mineral fertilization in the control treatment showed the need to fertilize the crop to achieve its growth and development and future production (MINAG, 2019). However, based on the results obtained, we can recommend the application of four applications of *T. harzianum*+ QuitoMax, as well as the application of EcoMic from the time of planting, to ensure the growth and development of potato plants in agroecological conditions.

CONCLUSIONS

It is demonstrated that it is possible to produce organic potatoes with the application of EcoMic biofertilizer and other bioproducts for the conditions of Los Palacios Cuba, equaling the agricultural yield with conventional potato production. There is a 31.21% increase in tuber yield when EcoMic and other bioproducts are applied during the physiological cycle of the plant. It is recommended to apply a combination of bioproducts (*T. harzianum*, QuitoMax and EcoMic) at the time of tuber planting in future potato production.

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REFERENCES

Agrico, 2022. *Variedad de patata Agrico*. Spectra. https://www.agricopotatoes.com/es/variedades/spectra

Alcantara-Cortes, J. S., Acero Godoy, J., Alcántara Cortés, J. D. and Sánchez Mora, R. M., 2019. Principales reguladores hormonales y sus interacciones en el crecimiento vegetal. *Nova*, 17(32), pp. 109-129. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S1794-24702019000200109&lng=en&tlng=es.

Argenpapa, 2020. *Cuba: Concluyó cosecha de papa en Los Palacios. Argenpapa*: El portal de la papa Argentina. https://www.argenpapa.com.ar/noticia/8815-cuba-concluyo-cosecha-de-papa-en-los-palacios

Castillo, C., Huenchuleo, M. J., Michaud, A. and Solano, J., 2016. Micorrización en un cultivo de papa adicionado del biofertilizante Twin-N establecido en un Andisol de la Región de La Araucanía. *Idesia (Arica)*, 34(1), pp. 39-45. https://dx.doi.org/10.4067/S0718-34292016000100005

Estévez, A., 2007. *El cultivo de la papa en Cuba*. Ediciones *INCA.* https://ediciones.inca.edu.cu/files/libros/libro_papa.pdf

Felipez, D. and Ortuño, N., 2021. La micorriza arbuscular (*Glomus fasciculatum*) en la absorción simbiótica de fósforo con variedades de papa nativa. *Revista Latinoamericana de la Papa*, 25, pp. 20–38. https://dialnet.unirioja.es/servlet/articulo?codigo=8081348&orden=0&info=link

Hernández-Jiménez, A., Pérez-Jiménez, J. M., Bosch-Infante, D. and Castro Speck, N., 2015. *Clasificación de los suelos de Cuba*. Ediciones INCA, Cuba, pp. 93.

Jerez-Mompié, E., Martín-Martín, R. and Morales-Guevara, D., 2017. Evaluación del crecimiento y composición por tamaño de tubérculos de plantas de papa para semilla. *Cultivos Tropicales*, 38(4), pp. 102-110. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0258-59362017000400015&lng=es&tlng=es

Jerez-Mompie, E., Morales-Guevara, D., Dell' Amico-Rodríguez, J. and Falcón-Rodríguez, A., 2018. El Quitomax® influye en la producción de tubérculos "semilla" de papa (*Solanum tuberosum* L.) variedad Romano. *Cultivos Tropicales*, 39(3), pp. 80-86. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0258-59362018000300011&lng=es&tlng=es

Jerez-Mompié, E., Martín-Martín, R. and Morales-Guevara, D., 2015. Comportamiento de la acumulación y distribución de masa seca en tres variedades de papa (*Solanum tuberosum* L.). *Cultivos Tropicales*, 36(4), pp. 70-76. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0258-59362015000400009&lng=es&tlng=es.

Akoumianakis, K. A., Alexopoulos, A. A., Karapanos, I. C., Kalatzopoulos, K., Aivalakis, G. and Passam,

H. C., 2016. Carbohydrate metabolism and tissue differentiation during potato tuber initiation, growth and dormancy induction. *Australian Journal of Crop Science*, 10(2), pp. 185-192. https://search.informit.org/doi/abs/10.3316/INFORMIT.030873277600434

Luna Quecaño, Juan Carlos, Zapana Pari, Juan Gregorio, Cutipa Limache, A.M. and Florida Rofner, N., 2020. Efecto de la micorriza (Glomus Intrarradices), en el rendimiento de dos variedades de papa (*Solanum Tuberosum* L.) en el Altiplano de Puno - Perú. *Revista de Investigaciones Altoandinas*, 22(1), pp. 58-67. https://dx.doi.org/10.18271/ria.2020.535

Márquez-Vasallo, Yarisyen, Salomón-Díaz, J.L. and Acosta-Roca, R., 2020. Análisis de la interacción genotipo ambiente en el cultivo de la papa (*Solanum tuberosum* L.). *Cultivos Tropicales*, 41(1). http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0258-59362020000100010&lng=es&tlng=es

Martín-Alonso, Nelson J., Llanes-Hernández, Violeta, Martín-Alonso, G.M. and Frometa-Milanés, E., 2022. Efecto del cultivo continuado en algunas propiedades de los suelos Ferralíticos Rojos Lixiviados. *Revista Ciencias Técnicas Agropecuarias*, 31(1). http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2071-00542022000100002&lng=es&tlng=es

Martín-Martín, GJ. Reyes-Ocampo, F., Medina-Salas, R., Pentón, G., Díaz, M., Alonso, O., Sánchez, T. and Hernández, L.A., 2021. *Producción de papa (Solanum tuberosum L.) en un contexto agroecológico en fincas familiares*. Editorial Estación Experimental de Pastos y Forrajes Indio Hatuey. Central España Republicana, pp. 31. ISBN: 978-959-7138-46-4

Martín Martín, R. and Jeréz Mompié, E., 2015. Evaluación del rendimiento en papa (*Solanum tuberosum* L.) a partir del comportamiento de las temperaturas. *Cultivos Tropicales*, 36(1), pp. 93-97. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0258-59362015000100012&lng=es&tlng=es

Mesa, A., Naranjo, M., Cancio, R., Martí, A., Clemente, B., Suárez, O. and Pacheco, E., 1984. *Manual de interpretación de los índices físico-químicos y morfológicos de los suelos cubanos.* Ed. Ciencia y Técnica Agrícola, La Habana, Cuba.

MINAG, 2019. *Instructivo técnico para la producción de papa en Cuba*. Ministerio de la Agricultura. Dirección de Agricultura, La Habana, Cuba, p. 58. https://docplayer.es/50285685-Ministerio-de-la-agricultura-direccion-de-agricultura-instructivo-tecnico-para-la-produccion-de-papa-en-cuba.html

MINAG, 2020. *Manual práctico para uso de bioproductos y fertilizantes líquidos*. Ministerio de la Agricultura. Dirección de Agricultura, La Habana, Cuba. https://docplayer.es/196853526-Manual-practico-para-uso-de-bioproductos-y-fertilizantes-liquidos-enero-2020.html

MINAG, 2022. *Informe preliminar de la campaña de papa 2021-2022*. Ministerio de la Agricultura. Dirección de Agricultura, La Habana, Cuba. https://www.minag.gob.cu/noticias/informe-preliminar-del-resultado-de-la-campana-de-papa-2021-2022/

Mora Quilismal, S.R., Águila Alcantara, E., Revelo Ruales, V., Benavides Rosales, H. and Balarezo Urresta, L., 2019. Combinación de dos biofertilizantes y fertilización química en la producción de *Solanum tuberosum* cv. Superchola en Andisoles ecuatorianos. *Centro Agrícola*, 46(4), pp. 44-52. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0253-57852019000400044&lng=es&tlng=es

Mora-Quilismal, S.R., Cuaical-Galárraga, E.T., García-Bolívar, J., Revelo-Ruales, V.W., Puetate-Mejía, L.M., Aguila-Alcantara, E. and Ruiz-Sánchez, M., 2021. Biofertilización con bacterias solubilizadoras de fósforo y hongos micorrízicos arbusculares en el cultivo de la papa. *Cultivos Tropicales*, 42(2). http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0258-59362021000200002&lng=es&tlng=es

Rakibuzzaman, M., Akand, M. H., Siddika, M. and Uddin, A.F.M., 2021. Impact of *Trichoderma* application as bio-stimulator on disease suppression, growth and yield of potato. *Journal of Bioscience and Agriculture Research*, 27(01), pp. 2252-2257. http://doi.org/10.18801/jbar.270121.274

Restrepo-Correa, S.P., Pineda-Meneses, E.C. and Ríos-Osorio, L.A., 2017. Mecanismos de acción de hongos y bacterias empleados como biofertilizantes en suelos agrícolas: una revisión sistemática. *Ciencia y Tecnología Agropecuaria*, 18(2), pp. 335-351.

http://www.scielo.org.co/pdf/ccta/v18n2/0122-8706-ccta-18-02-00335.pdf

Ricardo-Corrales, S., 2013. *El cultivo agroecológico de la papa en Cuba*. INCA, La Habana.

Rivera, R., Fernández, F., Ruiz, L., González, P.J., Rodríguez, Y., Pérez, E. and Ruiz Sánchez, M., 2020. *Manejo, integración y beneficios del biofertilizante micorrízico EcoMic en la producción agrícola.* R. Rivera, ed. pp. 151. Ediciones INCA, San José de las Lajas, Cuba.

Rivera-Méndez, W., Brenes-Madriz, J. and Zúñiga-Vega, C., 2018. Efectos de la aplicación de *Trichoderma asperellum* y su filtrado en el crecimiento de almácigos de cebolla (*Allium cepa*). Revista Tecnología en Marcha, 31(2), pp. 98-105. http://doi.org/10.18845/tm.v31i2.3627

Roumeliotis, E., Kloosterman, B., Oortwijn, M., Kohlen, W., Bouwmeester, H. J., Visser, R. G. and Bachem, C.W., 2012. The effects of auxin and strigolactones on tuber initiation and stolon architecture in potato. Journal of experimental botany, 63(12), págs. 4539–4547. https://doi.org/10.1093/jxb/ers132

Ruiz-Sánchez, M., Echeverría-Hernández, A., Muñoz-Hernández, Y., Martínez-Robaina, A. Y. and Cruz-Triana, A., 2022. Application of two strains of *Trichoderma asperellum* S. as a growth stimulant in rice cultivation. *Cultivo Tropicales*, 43(1), e10. https://ediciones.inca.edu.cu/index.php/ediciones/article/download/1646/3237/8800

Terry Alfonso, E., Ruiz Padrón, J., Rivera Espinosa, R., Falcón Rodríguez, A. and Carrillo Sosa, Y., 2021. Bioproductos como sustitutos parciales de la nutrición mineral del cultivo de pimiento (*Capsicum annuum* L.). *Acta Agronómica*, 70(3), págs. 266-273. https://doi.org/10.15446/acag.v70n3.86626