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Análisis del rendimiento de la producción de la papa en los departamentos de Antioquia, Boyacá y Cundinamarca, Colombia

Analysis of the performance of potato production in the departments of Antioquia, Boyacá and Cundinamarca, Colombia

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ABSTRACT

Introduction: this study sought to analyze the yield of potato production in the departments of Antioquia, Boyacá, and Cundinamarca, Colombia, in 2021. The objective of the research was to identify if there are significant differences in the yield of potato crops between these departments.

Methodology: the research was carried out by applying an ANOVA (Analysis of Variance) model on a sample of 494 agricultural yield data extracted from a database from the Rural Agricultural Planning Unit (UPRA).

Results: the results obtained reveal that Cundinamarca obtained the highest average yield of 19.67 (T/ha) and the lowest dispersion of the data, which could indicate the existence of greater stability in its production. On the other hand, Antioquia is the department with the lowest average yield, 15.26 (T/ha), and the highest variance, indicating greater heterogeneity in yields compared to the other departments.

Conclusions: the ANOVA analysis developed confirmed the hypothesis of the existence of significant differences between the performances of the three departments.

Keywords: agriculture, comparative analysis, cultivation, productivity.

JEL classification: L11, L16.

RESUMEN

Introducción: el presente estudio buscó analizar el rendimiento de la producción de papa en los departamentos de Antioquia, Boyacá y Cundinamarca, Colombia, durante el año 2021. El objetivo de la investigación fue poder identificar si existen diferencias significativas en el rendimiento de los cultivos de papa entre estos departamentos.

Metodología: la investigación se realizó mediante la aplicación de un modelo ANOVA (Análisis de Varianza) sobre una muestra de 494 datos de rendimiento agrícola, extraída de una base de datos proveniente de la Unidad de Planificación Rural Agropecuaria (UPRA).

Resultados: los resultados obtenidos revelan que Cundinamarca obtuvo el mayor rendimiento promedio de 19.67 (T/ha) y la menor dispersión de los datos, lo que podría indicar la existencia de una mayor estabilidad en su producción. Por otro lado, Antioquia es el departamento con menor rendimiento promedio, 15.26 (T/ha), y la mayor varianza, lo que indica una mayor heterogeneidad en los rendimientos en comparación con los otros departamentos.

Conclusiones: el análisis ANOVA desarrollado confirmó la hipótesis de existencia de diferencias significativas entre los rendimientos de los tres departamentos.

Palabras clave: agricultura, análisis comparativo, cultivo, productividad.

Clasificación JEL: L11, L16.

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INTRODUCTION

The potato is an essential food, not only for its nutritional value and versatility in cooking but also for its ability to grow in diverse climates and environmental conditions (Benalcázar-Sánchez & Urresta-Yépez, 2024). The potato is a tuber that provides carbohydrates, vitamins, and minerals (Sifuentes-Ibarra et al., 2023). Thus, it has established itself as a key food for the production and consumption of the world's inhabitants, making its contribution essential to achieving food security. By 2023, global potato production was estimated to be around 375 million tons. This growth reflects a

slight increase compared to recent years, with nearly 18 million hectares of productive land used for this purpose (National Potato Development Fund, 2024). This development has been driven primarily by China, which accounts for 26% of global production.

This situation has also been reflected in Colombia, which, while it has reached 27th place as a producer (Corpus Arrieta, 2019), is a product considered key to boosting the nation's rural economy (Barrientos et al., 2014; Mishra et al., 2024). This situation is reflected in its high domestic consumption, which has allowed it to become a staple food for farmers. This sector involves 100 000 farming families in the country, as well as transporters and supply chain workers, and therefore provides, both directly and indirectly, more than 350 000 jobs in Colombia (ICA, 2024).

In this sense, it has become a key product for Colombian agriculture, providing a source of income and livelihood for rural communities, as well as for their extended value chain (Ordinola & Devaux, 2021). This is because, even though it is a transitory crop, it provides economic stability due to the high seasonal demand for the product, especially in the Andean region (Desalegn, 2021). Consequently, the potato is not only one of the crops that most contribute to food security in Colombia due to its price and accessibility, but it is also a vital source of employment in the producing regions (Unidad de Planificación Rural Agropecuaria - UPRA, 2021).

Given this importance, the government and various non-governmental organizations, such as Fedepapa, have promoted initiatives to modernize the sector to improve productivity through more efficient and sustainable agricultural practices. In Colombia, the departments of Antioquia, Boyacá, and Cundinamarca are the primary producers (Fondo Nacional de Fomento a la Papa, 2024), and each of them has agroclimatic characteristics that affect potato productivity, generating variations in its yield.

Crop yield is an agricultural indicator that reflects the amount of production obtained from a given crop area. This yield is generally expressed in kilograms or tons per hectare, allowing farmers and analysts to understand the effectiveness of their agricultural practices. However, yield is not a static value; it is subject to the influence of various factors that can affect its variability. These factors include climatic conditions, soil properties, and plant genetic characteristics, which can cause significant differences in results from one crop cycle to the next (Seminario Cunya et al., 2021).

Agricultural yield is calculated by dividing a crop's total production by the area under cultivation. This result is measured in metric tons per hectare (MT/ha) and is determined by both the density of plants planted per hectare and the individual productivity of each plant. Therefore, high planting density does not always guarantee high yields; optimal growing conditions are essential for each plant to develop properly and reach its full potential.

Evaluating agricultural yield allows farmers and agricultural policymakers to make informed decisions about resource management. A high yield not only indicates that land is being used efficiently but also suggests that available resources, such as water, nutrients, fertilizers, and pesticides, are being used to the best possible advantage. This approach translates into increased food production and the ability to meet the population's food demand (Duchenne-Moutien & Neetoo, 2021).

In this sense, the purpose of this analysis is to identify which of the three departments presented had the highest yield in 2021, using an agricultural database that provides detailed information on production in these regions. For this purpose, the ANOVA (Analysis of Variance) model was used by the authors, which made it possible to determine whether there are significant differences in yield between the three departments. This model provides data that allow a better understanding of production variations and the factors influencing the performance of each region.

Therefore, this document provides insight into the variability in potato yield and offers recommendations for improving the factors affecting potato production in Colombia. It is important to remember that, starting in 2020, agricultural production in Colombia was affected by the COVID-19 pandemic, which caused changes in crop yields, including potatoes. For this reason, the base year of 2021 is used due to its current importance.

METHODOLOGY

El presente trabajo siguió una metodología de carácter cuantitativo, al centrarse en el análisis de datos numéricos sobre la productividad de la papa, en los departamentos de Antioquia, Boyacá y Cundinamarca. De igual forma, tuvo un alcance descriptivo, al ofrecer una descripción de las principales características que afectaron las variables definidas, las cuales se muestran en la tabla 1, sin pretender generar experimentos o cambios en estas.

Table 1.
Variables used in the research

Variables	Description
Department	Describe the sample departments of Colombia: Cundinamarca, Antioquia, and Boyacá.
Performance	Describe the production quantity in hectares (h).

Source: own elaboration

To conduct the research, the database available at the Rural Agricultural Planning Unit (UPRA) (EVA) was used. The data were organized and standardized from this database to focus on the potato production yields of the three established departments. To this end, these yields were evaluated by the researchers and compared using an analysis of variance (ANOVA) model.

The ANOVA model, analysis of variance, is a statistical method used to examine differences in the means of three or more groups. This model is used to test the null hypothesis (Ho), which states that three or more population measures could behave similarly, against the alternative hypothesis (Ha), which states that at least one of the measures is different (Chen et al., 2022).

Thus, the ANOVA model made it possible to compare potato production yields in the departments of Antioquia, Boyacá, and Cundinamarca during 2021, seeking to determine whether there were significant differences between yields. In this regard, the yields for each of the departments to be compared were extracted from the UPRA database, where 494 data points were distributed, as shown in table 2.

Table 2.
Distribution of performance data by department

Department	Data number
Antioquia	82
Boyacá	226
Cundinamarca	186
Total	494

Source: own elaboration

Finally, after obtaining the performance behavior of each of the departments, we proceeded to analyze them and determine first if there was any relationship between the variation in performance in each one and, on the other hand, we sought to observe which of these three departments has a better performance compared to the others and what reasons generated this phenomenon.

RESULTS

As shown in table 3, which shows the analysis of variance (ANOVA) performed on the yields of each of the three departments evaluated (Antioquia, Boyacá, and Cundinamarca), some significant differences were found from the averages obtained in each of the departments. Mainly, an observed average yield of 15.2698 (T/ha) for Antioquia, 16.1062 (T/ha) for Boyacá, and finally 19.6743 (T/ha) for the department of Cundinamarca. Thus, the latter department obtained the highest average yield. Thus, it can be inferred that Cundinamarca stood out as the most productive department in terms of yield compared to the other departments evaluated. On the other hand, it can also be stated that Antioquia is the department with the lowest average.

Table 3.
Analysis of means and variances between the 3 departments (Antioquia, Boyacá and Cundinamarca)

Groups	Account	Sum	Average	Variance
Performance Antioquia	82	1252.13	15.26987805	53.0791197
Performance Boyacá	226	3640	16.10619469	34.1873872
Performance Cundinamarca	186	3659.42	19.67430108	23.3447551

Source: own elaboration

In addition to the analysis of averages, the analysis of variances is noteworthy, revealing interesting patterns for the research. It is observed in the data that Antioquia presented the highest variance compared to the other departments, with a value of 53.0791. This result could indicate greater dispersion in yields within the department of Antioquia. Meanwhile, Boyacá and Cundinamarca presented variances of 34.1874 and 23.3446, respectively. Authors can infer that Cundinamarca not only has the highest average yield within the study but also the lowest dispersion in the data obtained. This finding, in turn, could be associated with greater stability or consistency in potato crop yields in this department.

The ANOVA model, as shown in Table 4, yielded an F value of 25.7164, which, when compared to the critical F, is considerably higher with a value of 3.0140. Furthermore, the probability value or P-value was 2.3909e-11, which at first glance is significantly lower than the significance level taken in the research of 5% (0.05). This result leads to the rejection of the null hypothesis (Ho) of equality in average yields among the three departments in the research on potato production yields. Therefore, it is found that when analyzing the yield of potato crops with the ANOVA model, there are significant differences between the yields obtained in Antioquia, Boyacá, and Cundinamarca.

Table 4.
Analysis of the hypotheses obtained from the ANOVA model against the performance of the departments evaluated

Origin of the variations	Sum of squares	Degrees of freedom	Mean of squares	F	Probability	Critical value for F
Between groups	1708.523974	2	854.261872	25.7163991	2.39099E-11	3.014084671
Within groups	16310.31759	491	33.21856942			
Total	18018.84156	493				

Source: own elaboration

Based on the above, the results of the analysis show that the department of Cundinamarca stands out both in terms of average yield and consistency in potato production, positioning it as the most efficient department in terms of yield in this study. On the other hand, it should be noted by readers that although Antioquia shows a lower yield compared to the other departments evaluated, its greater variance suggests considerable heterogeneity in the data. This finding could indicate the need for a more in-depth analysis to understand the sources of variability in this department. Finally, Boyacá, with an intermediate yield, can be inferred to be in a relatively balanced production situation, although with considerable variance, as in the department of Antioquia.

DISCUSSION

The objective of this research was to analyze potato production yields in the departments of Antioquia, Boyacá, and Cundinamarca using a variance-variance (ANOVA) model to determine whether there was a direct relationship between the yields evaluated for each of the potato crops in these departments. An analysis of the results obtained from the research revealed quite significant differences between the average yields of the three departments evaluated, which could suggest that potato crop yields may vary depending on the region in which they are produced.

The ANOVA analysis performed previously revealed an F value of 25.7164, which is higher than the critical F value of 3.0140. However, this result is accompanied by an extremely small p-value (2.3909e-11), a value that is lower compared to the significance level of the research (5%). These results are statistically significant for the research conducted, as they provide sufficient evidence to reject the null hypothesis (Ho) initially postulated. In this regard, it indicated that there were no differences in potato crop yields between the three departments. Therefore, this result could suggest that the observed yield differences cannot be caused by random factors, but rather, these yields could be linked to regional factors that impact yield, such as climate, soil quality, and access to water.

From a comparative research perspective, it can be stated that Cundinamarca not only has the highest average yield of 19.67 tons per hectare (T/ha) but also has the lowest dispersion compared (Variance = 23.34). This finding could indicate that its yields may be more stable than those of other departments. In contrast, Antioquia had a very low average yield (15.26 T/ha) compared to the other departments evaluated and the most significant dispersion in its data (Variance = 53.07), which may suggest that potato production yields for this department are more heterogeneous. Finally, Boyacá obtained an intermediate average yield of 16.10 (T/ha) and a variance of 34.18, which shows a more balanced situation for the Boyacá territory in terms of yield, although with considerable dispersion for the research.

These results obtained from the ANOVA on potato production yield reveal differences, which could be explained

by climatic factors in these regions (Raymundo et al., 2018) or soil type (Setiawan & Inayati, 2020). Another factor to consider could be the methods used for potato cultivation (Buckseth et al., 2022), which could influence the observed yields. Thus, Cundinamarca, which had a higher yield and lower variance compared to the other regions, could benefit from its better agronomic conditions or more efficient cultivation techniques (Stark et al., 2020).

Thus, the findings allow us to identify that, for this study, there is indeed a significant relationship between potato crop yields in Antioquia, Boyacá, and Cundinamarca. These results are relevant not only from an academic perspective but also for the agricultural sector, which could use this information to determine strategies that can be employed by stakeholders to optimize potato production in different regions of the country.

It is worth mentioning that the significant differences found in potato yield between Antioquia, Boyacá, and Cundinamarca likely reflect the influence of specific agroclimatic factors in each department (Grados & Schrevens, 2019; Sandhu, 2022). However, a study is needed in each department on the ideal agronomic conditions for proper potato cultivation, such as fertile soils and standardized agricultural management practices.

In this sense, previous studies have shown that consistency in practices such as crop rotation or irrigation control directly influences the stability of agricultural yields (Restrepo, 2023). Likewise, the soil conditions, stable climate, and homogeneous agricultural resources tend to show less dispersion in yield (Ordinola & Devaux, 2021), reasons that would explain the differences between Cundinamarca and other departments.

For its part, Antioquia, with greater variance and the lowest average yield, may be facing a series of agroclimatic challenges, such as altitude variations due to its geographic location, significant differences in soil quality compared to other departments, and access to water resources (Grados & Schrevens, 2019). Similarly, dispersion indicates a lack of standardization in growing conditions or the use of variable agricultural inputs. This contrast could be due to factors such as the fragmentation of crop plots or the lack of access to modern irrigation, fertilization, and pest control technologies for crops in Antioquia compared to Cundinamarca and Boyacá (Gallo-García et al., 2021; King et al., 2020).

Furthermore, it is possible to infer that annual climate variability, including rainfall and average temperature in each region, plays an important role in potato production (Grados & Schrevens, 2019). Identifying excessive rainfall or high levels of precipitation, phenomena that can cause diseases such as late blight, which significantly affect potato yield (Tiwari et al., 2021), could be one of the main factors driving the variability in production in each region. Thus, the lower variance in Cundinamarca could be due to better irrigation management or climatic conditions that favor the crop during the growth cycle. In turn, climate variability in Antioquia (Cure et al., 2022) could be contributing to the dispersion in yields observed in the research, suggesting the need for more detailed climate monitoring and the development of resilient practices to mitigate the effects of adverse climate events.

Likewise, one of the most significant challenges for farmers is proper water management, especially during times of drought, such as the one the country has been experiencing since 2024 (Vaca Agudelo, 2024). Therefore, it is necessary to review and optimize strategies for the potato growth cycle, as constant and controlled irrigation of the crop is required (Sánchez D. & Meza A., 2015). This challenge is especially relevant during the tuber formation phase since if the water supply is insufficient, the harvest may be limited. Furthermore, excess water can damage roots and cause diseases due to moisture. All of this makes irrigation systems crucial for farmers to achieve optimal and efficient production without compromising crop quality (Djaman et al., 2021).

Furthermore, proper water management not only improves the current harvest but also contributes to the conservation of natural resources, ensuring that the land remains productive in the future (Haverkort & MacKerron, 2023). This comprehensive approach seeks not only to increase crop yields but also to ensure that the potato continues to be a key source of income and food in the country, based on an environmental and social responsibility approach.

However, even in this context, it is important to highlight the potato's ability to thrive in conditions of water scarcity. Thus, with appropriate cultivation techniques, this tuber can be grown even during periods of drought, making it even more valuable in regions where access to water is a constant challenge. This makes the potato a strategic resource from a sustainable development perspective (Sapakhova et al., 2023).

Emphasis is also placed on the findings obtained directly related to the implementation of standardized agricultural practices, as these practices could improve yields in regions with greater variability, such as Antioquia and Boyacá. Consequently, the adoption of pest control measures, as well as the use of soil-specific fertilizers, could

help reduce the heterogeneity in yields across regions. For the Colombian agricultural sector, these practices not only improve productivity but can also strengthen the long-term sustainability of agricultural resources.

On the other hand, although the ANOVA model developed in the research allows for the identification of statistically significant and comparative differences in yields, the analysis does not directly consider specific factors that could influence agricultural productivity. Examples of this could be the seed variety used, fertilization techniques, or access to agricultural technology in each department. These factors, which the ANOVA does not consider, can vary significantly within departments, contributing significantly to the observed heterogeneity in yields, especially in the department of Antioquia. Therefore, the inclusion of these variables in a multiple regression analysis is recommended in future research, as it could help identify the magnitude of the impact of each factor on potato yield in the studied regions.

CONCLUSIONS

Based on the ANOVA results, it is concluded that there are significant differences in potato crop yields between the three departments analyzed, which allows us to reject the null hypothesis of equality regarding yields proposed at the beginning. This finding highlights the influence of specific regional factors in each of the departments studied. Specifically, agroclimatic variations, agricultural practices, and the availability of technology stand out as factors that may contribute to the productivity disparities found.

Identifying these factors is essential primarily to understanding how local environments can affect potato crop yields and suggests that not all agronomic practices are uniformly applicable nationwide. Furthermore, the yield stability observed in Cundinamarca shows that both the higher average yield and the lower variance may be due to efficient agricultural management and favorable agroclimatic conditions. Therefore, this department could serve as a model for future research to optimize practices in any region of Colombia, applying techniques such as standardized irrigation and fertilization control, in addition to improving the selection of potato varieties adapted to the variable climatic conditions specific to each region.

The high variance in Antioquia is also a relevant result, indicating dispersion in yield. This finding suggests that Antioquia could benefit from greater standardization in its agricultural methods, thus optimizing productivity and reducing variability. This is also the case in Boyacá, a region with intermediate yield and variance. Gradual improvements in crop management techniques could be considered, with special emphasis on controlled irrigation strategies and soil conservation practices that increase yield stability.

Finally, this study paves the way for future research focused primarily on identifying specific determining factors in potato yield in Colombia, including further investigations involving soil studies, seed varieties used, water resource availability, and innovative cultivation technologies. A longitudinal analysis would be valuable to observe whether potato yield differences persist over the years, particularly under changing climatic conditions, or change significantly.

Furthermore, the results of this study provide an initial basis for the design of adaptive agricultural policies that more implicitly consider the particular conditions found in each region. Thus, these findings are crucial not only for increasing productivity but also for optimally ensuring economic stability in rural areas and moving toward sustainable food security in Colombia.

Therefore, this research provides a guideline for future research aimed at identifying the specific factors affecting potato production in each department of the country to improve potato productivity and thus reduce variability in yields obtained over a given period, thereby optimizing agricultural development in these key regions of the country.

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FINANCING

DECLARATION OF CONFLICTS OF INTEREST
None

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