RESEARCH PAPER

Effect of Sprouted Lentil Extract as a Natural Biostimulant on the Production of Potato (Solanum tuberosum) Seed Tubers Grown Under Thermal Sleeve Conditions

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Abstract: The low potato production levels in the field phase may be due to poor-quality seeds (tubers) and the low policy prioritization of potato institutions. Controlled-environment studies have demonstrated that seed quality can be significantly improved, resulting in higher yields and increased field productivity. Thus, this study was designed to determine the optimal auxin levels in lentil solutions for seed tuber production and to compare seed tuber production and yield under thermal sleeves. Three concentrations of auxins (50, 100, and 150 g/L) were extracted from the lentils and applied directly to the plant collar in each thermal sleeve, together with a control (no treatment added). The 100 and 150 g/L dosages were the best in terms of tuber number averages (5.20 tubers for the 100 g/L and 4.20 tubers for the 150 g/L) and tuber weight per plant averages (0.150 kg per plant for 100 g/L and 0.127 kg per plant for 150 g/L) under the 0.09 m² area. Regarding the number of seed tubers per thermal sleeve, the 100 g/L dosage was outstanding, with an average of 156 seed tubers per sleeve.
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Introduction

Potato is native to southern Andean Peru and northern Bolivia. It is the most cultivated vegetable in the world, with global production of 370,436,581 tons across 17,340,986 hectares and an estimated value of nearly $ 80 billion. Production exceeds that in other Latin American countries, notably in Peru (FAOSTAT, 2021; FAO, 2024). Thanks to its adaptability, high productivity, and nutritional value, potato has for decades helped reduce food deficiencies (Devaux et al., 2021) and provide essential nutrients to daily diets (Saidi & Hajibarat, 2021). FAO predicts that the world population will exceed 9 billion by 2050, requiring increased food production (FAO, 2024). In this context, potato is also a significant crop to help satisfy global demand, as it is one of the four most consumed foods in the world (Incacari et al., 2025). The production system for potato tubers in Peru has several inherent problems, one of which is a low yield per unit area (19.5 $t\cdot ha^{-1}$, MINAGRI 2024-2025) compared with other countries (FAO, 2024). In this context, the reduction in farmers' yields indicates that the quality of seed tubers is one of the most significant factors contributing to the decline (Incacari et al., 2025). Aside from its high price, the use of low-quality certified seed is usually related to limited access to certified seed in many potato-producing countries, largely attributed to poor institutional capacity to provide certified seed and farmers' ignorance of how to obtain and manage certified seed (Aheisibwe et al., 2015; Okello et al., 2016; Forbes et al., 2020). For potato growers, certified potato seed production is crucial to producing high-quality potato plants and improving plant health, especially in high-Andean areas, where climatic factors are often challenging.

In Peru, fewer than 0.2% of farmers use certified seed; consequently, yields are limited, and crop quality is low (Devaux et al., 2021; Namugga et al., 2023). However, thin plastic mulching technology plays an important role in soil warming and reducing water loss, thereby promoting harvest (Zhang et al., 2020); it also contributes to water savings and crop protection (Rylander et al., 2020; Lamont, 1993; Díaz-Pérez, 2010). Plant development is controlled by various phytohormones, of which auxin, or indole-3-acetic acid (IAA), is regarded as one of the most relevant (Carrillo-Flores et al., 2024). Endo-hormones, or plant hormones, are signaling molecules found in various plant tissues that, when acting at certain concentrations, control and coordinate most biochemical and physiological processes, such as development, cell division, differentiation of roots and aerial organs, as well as embryogenesis and seed germination, flowering, fruit development, and abscission of foliage (Porta & Jiménez, 2019). The role of auxin in controlling root growth, as well as its close association with the adventitious rooting process, has been reported (Saidi & Hajibarat, 2021). Lentil (Lens culinaris L.), in turn, is a natural source of hormones that favor root establishment thanks to its high content of phytohormones, including auxins; experimentation has proved very effective, as exemplified by research using natural lentil roots for the propagation of fig trees (Ficus carica L.) (Mamani, 2024).

Although many studies have examined plant growth regulators and biostimulators, scientific evidence for using lentil extracts as a source of auxins to produce potato seed tubes in thermal sleeves remains limited. Most available information comes from traditional environments or from studies using synthetic regulators, leaving a knowledge gap that hinders the adoption of sustainable technologies in small-producer operations.

Based on this, it is hypothesized that applying auxin extracts derived from germinated lentil seed will increase seed tuber yield and vegetative growth of potato under the thermal sleeve method. Moreover, it is expected that an optimum dose can be identified to achieve the optimal physiological response of the crop. Hence, the following objectives were set to determine the effect of different doses of an auxin extract derived from lentils on vegetative growth and production of potato (Solanum tuberosum L.) in thermal sleeves, and to identify which dose is best able to maximize potato seed yield under the agroecological conditions existing in the Center for Agricultural Crop Research (CICA) in Huancayo, Peru.

Materials and Methods

2.1 Study site

This research was carried out at the facilities of the Center for Agricultural Crop Research (CICA) located in the Huancayo district in the Junín province of Huancayo, Junín region at 3,276 m a.s.l. (South latitude 12°2'17.75", West longitude 75°13'31.43", 2026 Google Earth Pro). The climate is temperate interandean valley type, with a mean annual temperature of 11–13 °C, precipitation occurring mainly from October to April, and a mean relative humidity of 65%.

2.2 Plant material

Seedlings were collected from sprouts of an advanced potato clone (GOP-031512.09) that produces oblong-shaped tubers with red skin and good seed potential. However, the previous selection of mother tubers was based on phytosanitary condition, uniformity, and sprout vigor, and they were then left in containers to obtain seedling tubers. The sprouts that had been removed to form seedlings were carefully separated from the emerged seedlings and transplanted to the thermal sleeves.

2.3 Obtaining the auxin extract from lentil

Bio-stimulants were collected from germinated lentil (Lens culinaris L.) using a standard germination process. For each experimental treatment, 50 g, 100 g, and 150 g of lentil seeds were weighed and placed in containers with 1 L of distilled water for 24 h of imbibition. The soaked water was then allowed to stand, and the seeds were kept moist for 10 days to germinate. On the 11th day, the soaking water containing the germinated seeds (radicles + plumules) was blended and filtered to remove solid material, yielding a related “extract”. It is worth emphasizing that the concentration of indole-3-acetic acid (IAA) may vary among lentil varieties and at different cutting stages; in this investigation, only the presence of the auxin was considered, without measuring its quantity, which is a missing piece of information in this context. Each extract was then diluted to three liters and kept at 4 °C for field application.

2.4 Thermal sleeve production system

Seed tubers were grown in high-density black polyethylene thermal sleeves—each sleeve measured 3.0 m in length and 0.90 m in width. The substrates were prepared in a 4:1 (v/v) ratio of agricultural soil to moss, with care taken to ensure good aeration and moisture-holding capacity in each sleeve. Excavated holes were then opened in a cross pattern every 0.30 m × 0.30 m, and potato seedlings were planted. One sleeve was constructed per treatment, and 30 potato seedlings were transplanted into each sleeve. A drip irrigation system provided uniform moisture across all treatments throughout the crop cycle. Pesticides were applied per plant.

2.5 Soil analysis interpretation

The interpretation table of the Official Mexican Standard (2022) indicated a sandy loam textural class, very low nitrogen status (0.19%), high available Olsen phosphorus (80.1 ppm), high available potassium (459.26 ppm), and a neutral pH (7.00 pH units) in the soil.

2.5 Fertilization

Fertigation with water-soluble fertilizer and the application of micronutrients were the methods of mineral nutrition. The nutrition program consisted of the following:

Stage	Fertilizer	Dose
First month	20–20–20 + micronutrients	20 mL plant^{-1} day^{-1}
Second month	10–55–10 + micronutrients	40 mL plant^{-1} day^{-1}
Third month	13–01–45 + micronutrients	70 mL plant^{-1} day^{-1}

All applications were performed through the drip irrigation system.

2.6 Application of treatments

During the first growth stage, lentil extract was applied directly to the base of the plant collar. Four treatments were tested:

Treatment	Description

T1	Extract obtained from 50 g L^{-1} of lentil seeds
T2	Extract obtained from 100 g L^{-1}
T3	Extract obtained from 150 g L^{-1}
T4	Control, no extract application

All applications used the same volume per plant to avoid bias associated with the amount of solution applied.

2.7 Experimental design

The experimental design was a Completely Randomized Design (CRD) with four treatments. Each treatment comprised one experimental unit, with one plant serving as the unit for the measured variables. A typical statistical model used was:

$Yij = \mu + \tau i + \varepsilon ij$

2.8 Population and sample

All plants in each thermal sleeve (population) and 5 plants per treatment (sample).

2.9 Variables evaluated

The variables for vegetative growth and seed tuber production were assessed.

Plant height (cm): Measured from the soil surface to the apex of the main stem with a graduated ruler at 90 days after transplanting.

Stem vigor: Vigor was measured as the mean diameter of the main stem using a digital caliper (vernier).

Number of tubers: All tubers were harvested, and the total tuber number was recorded.

Tuber weight: The tubers were collected from each plant, weighed on a digital scale (precision 0.01 g), and the total tuber weight recorded.

Support for 12 seed tubers produced per thermal sleeve, based on the number of tubers harvested per thermal sleeve (number of tubers per experimental unit).

2.10 Statistical analysis

All data were initially examined for outliers and for normality and homogeneity of variance using the Shapiro–Wilk and Levene tests, respectively. The effect of lentil extract doses on the variables studied was then analyzed using analysis of variance (ANOVA). Means were compared at the 5% probability level using Duncan's test when significant differences were noted ($p < 0.05$). For statistical analysis, all information was analyzed using Microsoft InfoStat 2020.

Results

3.1 Effect of lentil extract doses on vegetative growth

The vegetative growth of potato plants treated with auxin extracts from germinated lentil seeds showed significant differences depending on the applied concentration (Table 3).

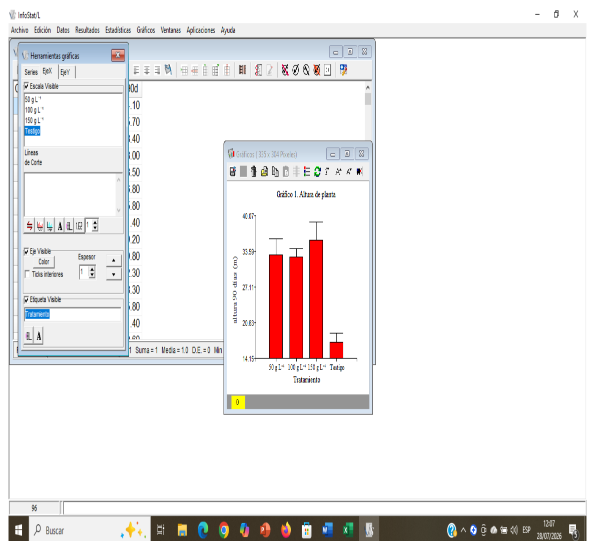
Table 3. Effect of lentil extract doses on growth and seed tuber production.

Treatment	Height (cm)	Vigor	No. tubers	Weight (kg $plant^{-1}$)
50 g L^{-1}	32.94 a	0.78 b	5.4 b	0.104 b
100 g L^{-1}	32.60 a	0.64 b	7.8 a	0.203 a
150 g L^{-1}	35.68 a	1.10 a	5.4 b	0.138 b
Control	17.04 b	0.58 b	4.6 b	0.093 b

Means followed by the same letters do not differ significantly according to Duncan's test ($p \leq 0.05$).

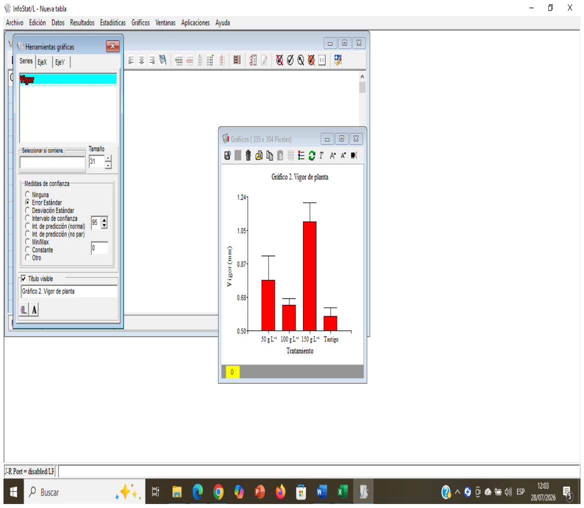
Plant height

The treatments with the highest average height were those at 150 g L^{-1} (35.68 cm) and 50 g L^{-1} (32.94 cm), which were not statistically different from each other ($p > 0.05$). The value obtained for the control treatment, on the other hand, was only 17.04 cm, which was much lower than with the application of extracts. Physiologically, the findings indicated that the application of lentil extract promoted cell elongation and stem growth, probably because it led to the presence of indole-3-acetic acid (IAA); germination also yields various other bioactive substances involved in these processes. The observed vegetative response, with an increase of almost 1.1-fold compared to the control, suggests a significant effect of the auxins.



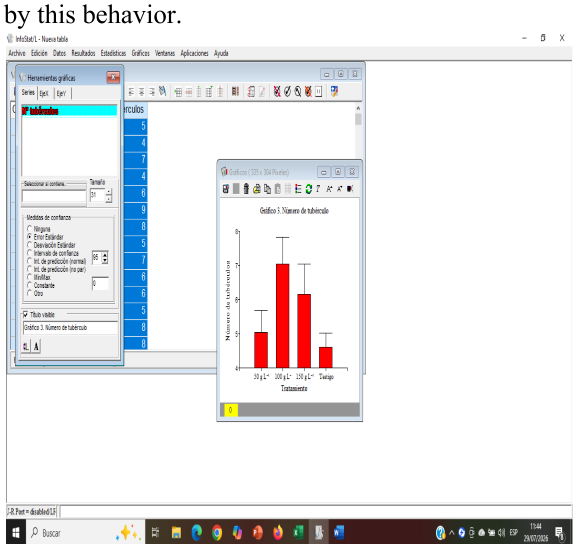
Plant vigor

Plant vigor, in turn, showed a pattern different from that observed for plant height. The 150 g L^{-1} treatment averaged 1.10, significantly exceeding the 50 g L^{-1} (0.78), 100 g L^{-1} (0.64), and control (0.58) treatments. The results show that higher extract concentrations led to greater structural development in the plant, which may positively correlate with increased vascular differentiation, root growth, and water and nutrient absorption capacity. The vigor increase is an agronomic trait that is relevant because it increases photosynthetic capacity and resource-use efficiency in the early stages of crop development.



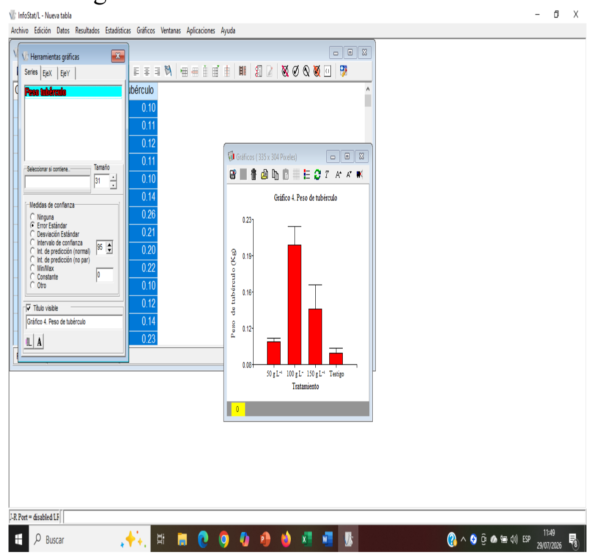
3.2 Seed tuber production

The productive response, on the other hand, exhibited a pattern that contrasted with that of vegetative growth. The maximum dose gave the best vegetative growth, but maximum tuber production was observed at the intermediate dose. Number of tubers. The following treatments showed a statistical difference ($p < 0.05$), with 100 g L^{-1} having the highest average number of tubers per plant (7.80), followed by 150 g L^{-1} (6.0) and 50 g L^{-1} (5.40). The control treatment produced only 4.60 tubers/plant, which was significantly lower. The 100 g L^{-1} dose relative to the control resulted in an increase in the number of tubers by around 100%. Thus, there is a balance between vegetative growth and the initiation and/or differentiation of the storage crop, which is optimal under the moderate extract concentration, as indicated by this behavior.



Tuber weight

The 100 g L^{-1} treatment also recorded the highest average weight (0.203 kg plant^{-1}), followed by 150 g L^{-1} (0.138 kg) and 50 g L^{-1} (0.104 kg). This was much higher than the control treatment, which recorded only 0.093 kg plant^{-1}. In practical terms, the 100 g L^{-1} dose increased tuber weight by about two times compared with the dose without any auxin application. As shown by this result, the intermediate concentration produced a greater increase in tuber biomass, whereas the higher concentration seemed to promote the production of more vegetative tissues.



3.3 Agronomic response of the doses evaluated

Overall, the results demonstrated that the potato plant's response to the lentil extract is not linear. The 150 g L^{-1} dose mainly stimulated vegetative growth, reflected in greater plant height and vigor. Concurrently, the highest dosage (100 g L^{-1}) had the highest number of tubers and seed tuber weight, suggesting better partitioning of photoassimilates to storage organs. This behavior is consistent with the known action of the physiological hormone auxin in the following way: high doses promote elongation and vegetative and reproductive growth, whereas moderate doses induce a balance between auxin and other hormones to promote tuber production and tuber filling. Agronomically, these findings suggest that increased auxin concentrations are not necessarily associated with higher yield, but that there is an optimal concentration range within which the plant most efficiently produces seed tubers.

3.4 Seed tuber production per thermal sleeve

The final evaluation of the productivity once again demonstrated that, for multiplication of seed tubers, the highest product was obtained with the treatment at 100 g L^{-1}, with an average yield of 234 seed tubers per thermal sleeve, which is the most efficient alternative under the conditions of the Center for Agricultural Crop Research (CICA). This outcome shows that using natural lentil extracts in conjunction with the thermal sleeve production system can greatly enhance seed tuber multiplication efficiency and is a technologically and economically viable option for medium- and small-scale producers committed to potato seed production.

Discussion

The results show that the application of germinated lentil seed extracts, used as a natural auxin source, significantly altered vegetative growth and seed tuber production in potato. However, the response was not linear; the highest concentration benefited vegetative growth, whereas an intermediate concentration favored tuber production. This behavior confirms that the response of potato to auxin depends on the applied concentration and the hormonal balance required to switch from vegetative growth to tuberization (Kondhare et al., 2021; Sosnowski et al., 2023). Results for plant height and vigor indicate a stimulatory effect of the lentil extract, suggesting stimulation of processes involving cell elongation and expansion at the 150 g L^{-1} dose. This is due to the activity of indole-3-acetic acid (IAA), which affects cell wall extensibility, vascular differentiation, and root system development, thereby augmenting water and nutrient uptake. Recent research indicates that auxins regulate the expression of growth-related genes and coordinate hormone transport and vegetative growth, especially in the early stages of crop development (Wang et al., 2026). Vegetative growth was highest with the 150 g L^{-1} treatment, while the highest number of tubers was produced under the 100 g L^{-1} treatment. This indicates that increased auxin availability increased aerial and root biomass but did not necessarily result in greater allocation of photoassimilates into storage organs. It has recently been shown that high auxin concentrations can impair stolon architecture and alter carbohydrate distribution, leading to smaller tubers or reduced final tuber yield when the optimal physiological concentration range is exceeded (Kondhare et al., 2021). The 100 g L^{-1} dose, in contrast, yielded the largest number and weight of tubers and produced a more balanced combination of vegetative growth and tuberization than the other doses. Tuber formation is a complex process dependent on the interaction of many hormones and carbohydrates in the plant, such as auxins, gibberellins, cytokinins, abscisic acid, and carbohydrate metabolism hormones.

The role of auxins is especially significant during stolon formation and tuber initiation, influencing cell division and the flow of sucrose to storage organs. The efficiency of tuber formation and filling will significantly increase if this regulation is maintained within an appropriate range of auxin concentrations (Wang et al., 2026). These results are consistent with recent advances in the molecular biology of tuberization. Specific auxin transporters have been shown to control the initiation of new tubers through localized increases in IAA levels in stolons. As expression of the StLAX5 gene, which promotes IAA transport, increases, stolon formation and tuber number increase, and when the gene is inactivated, both decrease significantly. The findings showed that the positive effect observed with lentil extract was supported by increased auxin availability during early-stage stolon formation. The advantage that 100 g L^{-1} gives from an agronomic point of view is especially relevant in seed tuber production programs. This dose doubled the number of tubers compared with the control and greatly increased the weight per plant (under protected conditions), which may increase the rate of seed multiplication. The effects described become essential when the fact is taken into account that the production system employed, the thermal sleeve, is designed to conserve moisture, enhance the root microclimate, and minimize fluctuations in temperature in the substrate, all of which help ensure better uniformity of crop establishment and higher physiological efficiency.

Other benefits have already been demonstrated in other protected potato production systems (Qu et al., 2024). It is also worth noting the shift from synthetic regulators to natural biostimulants. Extracts obtained from germinated lentil seeds are easy to reproduce and low-cost, enabling the production of seedlings that can be adapted to sustainable production systems and may help reduce farms' dependence on synthetic phytohormones, thereby expanding the technological alternatives available to seed producers, particularly in high-Andean areas where access to specialized inputs is restricted. However, some limitations of the study should be considered when interpreting the results. First, the amount of indole-3-acetic acid in the lentil extracts was not measured, and the observed effect is due to the combined action of bioactive compounds formed during germination. Second, the experiment used only one potato clone, so the results are not directly applicable to other potato varieties in other production systems. Similarly, the small sample size limits the ability to detect small treatment effects. Based on this, further studies should focus on the chemical characterization of the extracts, comparing several cultivars, and evaluating the effects of combined inputs on web optimization, such as natural biostimulants, fertilization, and environmental factors. In general, germinated lentil seed extracts have the potential to be a valuable alternative to plants as a potato seed tuber stimulator. The distinct responses observed in vegetative growth and yield indicate that the management of natural biostimulants in quality seed production programs should be optimized according to the applied dose. The present work therefore contributes to the existing knowledge on the use of natural biostimulants in protected potato multiplication systems and serves as a starting point for future research to validate their use in commercial production.

Policy Implications

The results of this study support the potential use of the natural biostimulant sprouted lentil extract to effectively boost the vegetative growth and seed tuber production of potatoes grown in the thermal sleeve system. The results hold significance from a policy perspective, offering a sustainable, low-cost alternative to artificial plant growth regulators that is available to small- and medium-scale potato growers, especially in areas with limited access to certified seed and chemical inputs. The government and/or agricultural extension services may provide training in the use of natural biostimulants, such as lentil extract, as a seed program component. This can be done via demonstrative plots, farmer field schools, and the integration of natural biostimulants into subsidy/support schemes. In addition, the thermal sleeve technology, together with natural ingredients, aligns with efforts to enhance resource efficiency, water management, and adaptation to climate change in agro-ecosystems, and offers opportunities to boost yield and agro-resilience for family farmers. Additionally, it is important to promote local production chains for biofertilizer raw materials and to encourage additional research into alternative natural bio inputs, as this promotes innovation and sustainability in potato seed production systems.

Scope for Future Research

Further research is warranted in several areas regarding the use of lentil extract for seed potato production, but in general, the use of a natural auxin source has shown promising results. Quantifying the active compound, such as indole-3-acetic acid, in extracts of Lentinus would help elucidate the biochemical basis of the bio stimulatory effects of these extracts. Working with various potato cultivars and other leguminous extracts could allow comparison of varietal responses and a better understanding of the dosages that optimize both coverage and yield for use in rows of other cultivars. Furthermore, longer-term trials in different agroecological regions and across various planting seasons are required to evaluate the ecological, economic, and sustainable benefits and possible environmental effects of these practices. Collectively, the potential role of synergistic mixtures of natural biostimulants, when appropriately integrated with nutrient management and improved irrigation methods, should be explored to maximize production and sustainability. Last but not least, interdisciplinary research that includes socio-economic and cost/benefit analyses would provide key insights into problems in the field and enhance the potential of these innovations to be more beneficial to smallholder farmers and the agricultural sector.

Conclusions

The results have demonstrated that using germinated lentil seed extracts as a natural source of auxin significantly improved vegetative growth and the production of potato seed tubers under thermal sleeve cultivation. The physiological response, however, was concentration-dependent and showed that there is no linear relationship between increasing dose and increasing response across all measured variables. The 150 g L^{-1} dose stimulated the most vegetative growth, as indicated by increased plant height and vigor, suggesting that higher extract concentrations more strongly stimulated cell elongation and structural development. This increased vegetative growth, however, did not translate into greater seed tuber production. The 100 g $L-1$ dose led to the highest number of tubers and the greatest weight per plant, as well as an average of 156 seed tubers per thermal sleeve, making it the agronomically most efficient dose for tuber production under the evaluated conditions for seed tuber multiplication. The results also indicate that lentil extract has an optimal concentration range that benefits the relationship between vegetative growth and tuberization, thereby promoting the optimal redistribution of photoassimilates to the storage organs. The use of natural biostimulants should, therefore, be done at technically defined dosages rather than at ever-increasing concentrations. Technologically, the use of thermal sleeves together with natural extracts from lentils makes it a more sustainable alternative for the production of quality seed tubers, especially in family farming activities where availability of synthetic regulators and certified seed is limited. Finally, it is recommended that future research quantify the concentrations of IAA found in lentil extracts, test different potato cultivars, and test this technology commercially and in various agroecological environments to confirm its use in the national certified seed production program.

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Rosa I. Pizarro Adauto	Project development and execution. Manuscript writing.
Miguel A. Beltrán Palomares	Development and evaluation of variables for data collection. Manuscript writing.
Maurino Cahuana Hidalgo	Bibliographic information collection.
Luis A. Bautista Puente	Data organization for processing.

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References

Aheisibwe, A. R., Barekye, A., Namugga, P., & Byarugaba, A. A. (2015). Challenges and opportunities for quality seed potato availability and production in Uganda. *Uganda Journal of Agricultural Sciences, 16*(2), 149–159. https://doi.org/10.4314/ujas.v16i2.1

Alcántara-Cortés, J. S., Acero Godoy, J., Alcántara Cortés, J. D., & Sánchez Mora, R. M. (2019). Principales reguladores hormonales y sus interacciones en el crecimiento vegetal. *Nova, 17*(32), 109–129. https://doi.org/10.25058/24629448.3639

Carrillo-Flores, E., Aguilera-Méndez, A., Mellado-Rojas, M. E., & Beltrán-Peña, E. (2024). Participación del transporte simplástico de las auxinas durante el desarrollo de las plantas. *CienciaUAT, 18*(2), 6–18. https://doi.org/10.29059/cienciauat.v18i2.1833

Devaux, A., Goffart, J.-P., Kromann, P., Andrade-Piedra, J., Polar, V., & Hareau, G. (2021). The potato of the future: Opportunities and challenges in sustainable agri-food systems. *Potato Research, 64*(4), 681–720. https://doi.org/10.1007/s11540-021-09501-4

Díaz-Pérez, J. C. (2010). Bell pepper (*Capsicum annuum* L.) grown on plastic film mulches: Effects on crop microenvironment, physiological attributes, and fruit yield. *HortScience, 45*(8), 1196–1204. https://doi.org/10.21273/HORTSCI.45.8.1196

Food and Agriculture Organization of the United Nations. (2024). *FAOSTAT: Crops and livestock products*. Retrieved from https://www.fao.org/faostat/en/#data/QCL

Forbes, G. A., Charkowski, A., Andrade-Piedra, J., Parker, M. L., & Schulte-Geldermann, E. (2020). Potato seed systems. In H. Campos & O. Ortiz (Eds.), *The potato crop: Its agricultural, nutritional and social contribution to humankind* (pp. 431–447). Springer. https://doi.org/10.1007/978-3-030-28683-5_12

Gao, J., Zhuang, S., & Zhang, W. (2024). Advances in plant auxin biology: Synthesis, metabolism, signaling, interaction with other hormones, and roles under abiotic stress. *Plants, 13*(17), 2523. https://doi.org/10.3390/plants13172523

Incacari, R. C., Cortez, J. W. M., & Ravelo, A. A. M. (2025). Dosis de calcio y calidad de semilla en el rendimiento del cultivo de papa (*Solanum tuberosum* L.). *Ecología Aplicada, 24*(1), 55–64. https://doi.org/10.21704/rea.v24i1.2277

Lamont, W. J., Jr. (1993). Plastic mulches for the production of vegetable crops. *HortTechnology, 3*(1), 35–39. https://doi.org/10.21273/HORTTECH.3.1.35

Mamani, E. T. (2024). Propagación de estacas de higo (*Ficus carica* L.) bajo enraizadores naturales en distintos tiempos de sumersión. *Revista de Investigación e Innovación Agropecuaria y de Recursos Naturales, 11*(1), 47–56. https://doi.org/10.53287/zecr7375iw83w

Ministerio de Desarrollo Agrario y Riego. (2025). *Valor bruto de la producción agropecuaria regional: Perfil productivo y competitivo de los principales cultivos*. Sistema Integrado de Estadística Agraria. Retrieved from https://siea.midagri.gob.pe/siea_bi/

Namugga, P., Aijuka, S., Arinda, O., Mateeka, B., & Barekye, A. (2024). Early generation seed starter materials and approaches to seed production: Challenge for improving the potato seed system in Uganda. *Crop Science, 64*(3). https://doi.org/10.1002/csc2.20969

Okello, J. J., Zhou, Y., Kwikiriza, N., Ogutu, S. O., Barker, I., Schulte-Geldermann, E., Atieno, E., & Ahmed, J. T. (2016). Determinants of the use of certified seed potato among smallholder farmers: The case of potato growers in Central and Eastern Kenya. *Agriculture, 6*(4), Article 55. https://doi.org/10.3390/agriculture6040055

Porta, H., & Jiménez, G. (2019). Papel de las hormonas vegetales en la regulación de la autofagia en plantas. *TIP. Revista Especializada en Ciencias Químico-Biológicas, 22*, 1–11. https://doi.org/10.22201/fesz.23958723e.2019.0.160

Qu, L., Huang, X., Su, X., Zhu, G., Zheng, L., Lin, J., & Xue, H. (2024). Potato: From functional genomics to genetic improvement. *Molecular Horticulture, 4*(1), 34. https://doi.org/10.1186/s43897-024-00105-3

Roumeliotis, E., Kloosterman, B., Oortwijn, M., Kohlen, W., Bouwmeester, H. J., Bachem, C. W. B., & Visser, R. G. F. (2023). Over-expression of a YUCCA-like gene results in altered shoot and stolon branching and reduced potato tuber size. *Potato Research, 66*(1), 67–84. https://doi.org/10.1007/s11540-022-09572-x

Rylander, H., Rangarajan, A., Maher, R. M., Hutton, M. G., Rowley, N. W., McGrath, M. T., & Sexton, Z. F. (2020). Black plastic tarps advance organic reduced tillage II: Impact on weeds and beet yield. *HortScience, 55*(6), 826–831. https://doi.org/10.21273/HORTSCI14793-19

Saidi, A., & Hajibarat, Z. (2021). Phytohormones: Plant switchers in developmental and growth stages in potato. *Journal of Genetic Engineering and Biotechnology, 19*(1), Article 89. https://doi.org/10.1186/s43141-021-00192-5

Sosnowski, J., Truba, M., & Vasileva, V. (2023). The impact of auxin and cytokinin on the growth and development of selected crops. *Agriculture, 13*(3), 724. https://doi.org/10.3390/agriculture13030724

Wang, T., Sun, S., Zhou, G., Yang, R., Wu, Y., Wang, Y., Wang, P., Zhao, K., Jiao, B., & Huang, B. (2026). StLAX5 regulates stolon initiation to control the tuber number and productivity of potato. *New Phytologist.* Advance online publication. https://doi.org/10.1111/nph.71253

Zhang, Y. L., Wang, F. X., Shock, C. C., & Feng, S. Y. (2020). Modeling the interaction of plastic film mulch and potato canopy growth with soil heat transport in a semiarid area. *Agronomy, 10*(2), 190. https://doi.org/10.3390/agronomy10020190

Appendices

Height at 90 days

Source of Variation	df	SS	MS	F	p-value
Treatments	3	1074.350	358.120	11.81000	0.0002
Error	16	485.170	30.320		
TOTAL	19				

S = 5.506   x̄ = 29.565   C.V. = 18.62%

Plant vigor

Source of Variation	df	SS	MS	F	p-value
Treatments	3	27.750	9.250	4.205	0.0226
Error	16	35.200	2.200		
TOTAL	19	62.950			

S = 1.483   x̄ = 6.000   C.V. = 24.72%

Number of tubers

Source of Variation	df	SS	MS	F	p-value
Treatments	3	27.750	9.250	4.205	0.0226
Error	16	35.200	2.200		
TOTAL	19	62.950			

S = 1.483   x̄ = 6.000   C.V. = 24.72%

Tuber weight

Source of Variation	df	SS	MS	F	p-value
Treatments	3	0.0371	0.0124	9.4733	0.0008
Error	16	0.0209	0.0013		
TOTAL	19	0.0580			

S = 0.036   x̄ = 0.135   C.V. = 26.71%

Photo 1. Lentil seed soaking   Photo 2. Team members

Photo 3. Obtaining potato seedlings from sprouts Photo 4. Seedling transplanting

Photo 5. Established seedlings Photo 6. Drip irrigation

Photo 7. Treatment 50 g L⁻¹ Photo 8. Treatment 100 g L⁻¹ Photo 9. Treatment 150 g L⁻¹

Photo 10. Prebasic seed tuber harvest