

PRODUCTION AND MARKETING OF ECOLOGICAL AND STANDARDIZED GARLIC POWDER: A TECHNICAL-ECONOMIC ANALYSIS

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Received 07.06.2024.
Revised 25.11.2024.
Accepted 17.12.2024.

Keywords:

Garlic powder, Solar energy, Technical-economic study, Ecological industrial plant

ABSTRACT

A technical-economic study was designed and developed to analyze the standardized production and marketing of garlic powder. This study addresses the issues of variable quality garlic powder production and its environmental impact by designing an ecological industrial plant that uses solar energy for drying and utilizes agricultural residues from garlic processing for compost production. The process is divided into four units: raw material preparation unit, raw material processing unit, garlic powder production unit, and finally, the compost production unit. The methodology included process design, line balance analysis, and plant layout as part of the technical study, along with the application of surveys and a cost analysis of implementation as part of the economic study. To validate the product's marketability, surveys were conducted with 73 households and 68 food companies in Arequipa, assessing their interest in an ecological seasoning. The results showed high acceptance of the product with 90% of households and 40% of companies interested in its use and purchase due to its quality and ecological production process. The conclusions highlight the feasibility of the plant design and its potential in the condiments and food additives market, responding to the growing demand for healthy and ecological products.



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1. INTRODUCTION

Garlic (*Allium sativum*) is one of the world's oldest herbaceous crops (Worku & Mehari, 2018). It is commonly used for culinary purposes and is valued for its therapeutic and medicinal properties, possessing a distinctive flavor resulting from complex biochemical reactions. The main compound responsible for its characteristic flavor is primarily non-volatile sulfur-containing amino acids (thiosulfates), with alliin or S-allyl-cysteine sulfoxide being the predominant

precursors of garlic's flavor. Additionally, these sulfur compounds are responsible for its anticancer, antidiabetic, anti-inflammatory, antimicrobial, antioxidant, cardioprotective, and immunomodulatory properties (Martins et al., 2016).

In Peru, garlic production reached 84,601.28 tons in 2023, with a yield per hectare of 10.79 tons/ha; meanwhile, production in Arequipa reached 57,809.51 tons, with a yield of 13.55 tons/ha, representing more than 68% of national production (Ministry of Agriculture

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and Irrigation, 2024). Garlic production is intended for both domestic consumption and export in fresh and processed forms; however, garlic cultivation is adversely affected by overproduction, leading to low prices and creating a risk of loss for farmers due to product deterioration (Condor et al., 2019).

Primarily, the deterioration is due to the high moisture content in garlic, exceeding 65% (wet basis), which can trigger microbial, enzymatic, and chemical reactions, making garlic prone to rapid and undesirable changes such as germination and rot. (Guo et al., 2023). To extend the shelf life of garlic, maintain its nutritional value, and add value for better marketing, appropriate processing methods can be used to reduce the moisture content of garlic (Feng et al., 2021).

Currently, natural and artificial methods are used for drying foodstuffs (Magaña et al., 2019). The main objective of the different methods is the removal of the largest amount of water from the food through a flow of hot air passing through the product (Espinoza, 2016). In Arequipa, both natural and artificial methods are used for drying garlic.

Drying garlic by the natural or traditional method, mostly applied by local farmers, consists of direct exposure of the product to the sun's rays and air currents. This method entails multiple drawbacks, including contamination of the product by particles carried by wind, rain, and insects (Baloushi et al., 2020), exposure of the product to attacks by rodents and insects (Asmat & Carreño, 2018), direct dependence on climatic conditions, making it impossible to dry the product during the rainy season, and the long duration of the drying process (Milón et al., 2024). The traditional method of drying by direct exposure to the sun does not allow for the control of variables that intervene in the process, such as air flow, solar radiation, product humidity, and drying air temperature (Dandy et al., 2019), affecting product quality when the natural color is lost, vitamins are destroyed, nutritional value is lost, odor components are lost, flavor is lost or undesirable flavors appear, and undesirable changes in texture occur (Champawat et al., 2019).

On the other hand, in artificial drying processing, generally used by industrial companies, fossil fuels are used (Espinoza, 2016), gas produced from wood combustion, and electrical energy to heat the air (Ortiz et al., 2020). The production cost under this methodology is high due to its initial and operating costs, limiting its use (Hernández et al., 2017). Additionally, it is considered a source of pollution (Palacio et al., 2016) because it generates deforestation and air pollution (Hernández et al., 2017), emits greenhouse gases equivalent to CO₂ that cause global warming and climate change (Hernández et al., 2017).

Locally, different investigations have been conducted in Arequipa regarding garlic drying. A first investigation

evaluated the prefeasibility of a plant in Arequipa for the production of a dehydrated onion and garlic seasoning, whose production process involved drying previously chopped garlic with a size of 1 x 1 cm in an industrial electric tray dehydrator at a temperature of 70°C for 2.5 hours, parameters under which color and smell were preserved for commercialization with dehydrated onion in sachets in a ratio of 20 g and 30 g of garlic and onion, respectively (Cruz, 2018).

Another study evaluated the production of garlic powder through a dehydration process of garlic flakes with a thickness of 2 mm using hot air at a temperature of 60°C and a constant air velocity of 3 m/s, obtaining a product with preserved smell and taste characteristics (Del Rio et al., 2019). Nationally, other authors evaluated garlic drying in a cabin dehydrator at 60°C for a period of 6.5 hours powered by a propane gas heat source and at a speed of 0.5 m/s in a plant in Ayacucho, obtaining garlic powder of a yellowish-white color and without odor (Ucharima, 2013).

Therefore, the design and development of low-cost and energy-efficient dryers is a challenge for the production of high-quality food. Due to the energy crisis, food processing must consider the application of renewable energy to replace conventional unit operations, which use intensive fossil fuels, in order to harness solar energy, an attractive source for its efficiency, profitability, low cost, and rural applicability (Mohana et al., 2020).

Additionally, it is worth mentioning that during harvesting and processing activities, a wide variety of solid agricultural waste is generated, coming from roots, leaves, and stems that are not used and become waste without any utility, generating accumulation and therefore a negative environmental impact (Espinoza, 2016). An alternative for this waste is its recovery for compost formation, whose main advantage is low operating costs, in addition to presenting advantages in minimizing environmental pollution (Chávez & Rodríguez, 2016).

The objective of this study is to present the design of an ecological industrial plant for the standardized production of garlic powder, through the evaluation of the technical and economic aspects of the plant. This analysis aims to demonstrate the feasibility and market potential of producing and marketing high-quality ecological garlic powder, responding to the growing demand for healthy and environmentally friendly products.

2. METODOLOGY

2.1. Process Design

The design of an ecological industrial plant for the standardized production of garlic powder involves a series of stages of the production process which are

grouped into four constituent units: Raw Material Preparation Unit, Processing Unit, Garlic Powder Obtaining Unit and finally the Compost Obtaining Unit. (Figure 1).

Firstly, the Raw Material Unit consists of raw material preparation activities consisting of the reception, cleaning and cutting of stems; then the selection of garlic bulbs is made in order to separate those in poor condition using a sorting machine and then continue with the shelling of garlic bulbs that will allow the separation of the bulbs into garlic clove. Finally, the collection of solid agricultural waste generated in the previous stages such as roots and stems are carried out.

For its part, the Processing Unit consists of the activities of peeling, washing and severing garlic clove. Once the garlic bulbs have been shelled, the shells of the garlic

clove are removed for this purpose, a peeling machine is used; then proceed to remove the dirt in a washing machine to finally make the slice in garlic flakes using a garlic slicer machine.

In the Garlic Powder Production Unit, raw material processing activities such as the dehydration of garlic powder are considered, an activity whose purpose is to remove moisture from the product and then proceed with the grinding in a grinding machine. Once obtained with the final product, dehydrated garlic powder, packaging and packaging is proceeded.

Finally, the Compost Collection Unit includes the activities of drying, forming, fermenting and packaging of the solid waste generated during the first unit. The process design is shown in Figure I.

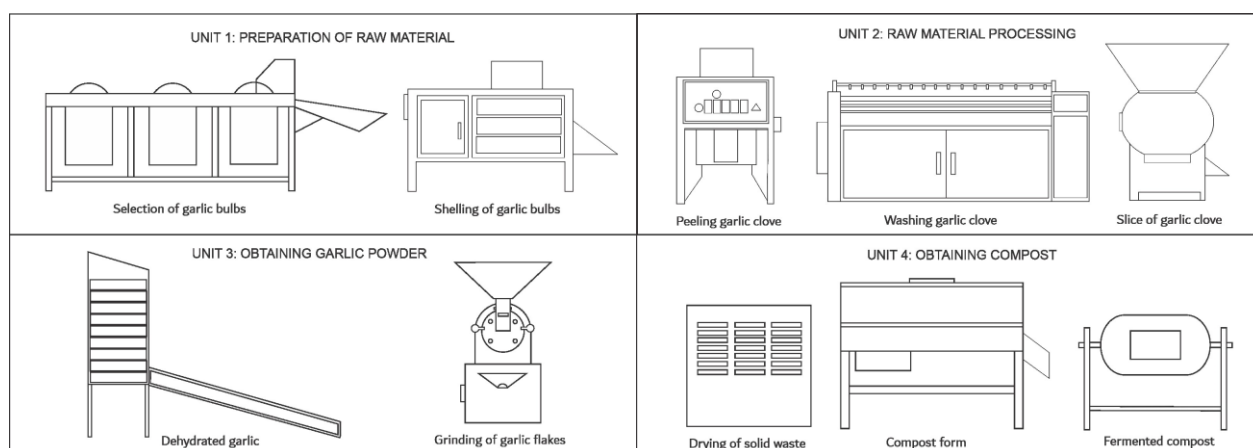


Figure 1. Production process of powder garlic

The process design also considered the optimal distribution of the plant to facilitate solar drying and the reuse of agricultural waste. Additionally, a line balance analysis was conducted, and the optimal number of workstations and personnel needed for the production process was calculated. Finally, the plant size and production capacity were determined, evaluating the area distribution and plant modeling.

2.2. Market Study

The market study focused on analyzing the acceptance of ecological garlic powder among two market segments: households in Arequipa and companies in the food industry. For households, 73 units were selected in the province of Arequipa through a sample proportional to the population density of the districts. For companies, 68 entities in the food industry, including restaurants, bars, cantinas, and producers of meat and meat products, were segmented using the finite population formula.

Two main instruments were designed and applied for data collection. Surveys for households were conducted using questionnaires with open and closed questions,

distributed virtually through Google Drive forms. On the other hand, structured interviews were conducted with companies using a specific question guide, which allowed for the collection of detailed information on the use of garlic powder as an additive in food production.

Finally, the collected data were analyzed to evaluate product acceptance, identify the characteristics of the target market, and develop marketing mix strategies, including price, product, place, and promotion.

2.3. Economic Study

The economic study focused on evaluating the financial viability of the production and commercialization of organic garlic powder. First, production costs were determined for two presentations: 20-gram packets and 50-gram packets. This included calculating fixed costs such as electricity, water, and labor, and variable costs such as raw materials and supplies. Administrative and sales expenses, as well as the necessary investment in machinery and equipment, were also considered.

Production capacity was established based on the processing capacity of the machinery and the cycle time

of each production process activity, determining that 2.65 kg of fresh garlic are needed to produce 1 kg of garlic powder. The selling price was determined using a cost-based method and the average market price.

To evaluate the investment, costs in infrastructure, machinery, and other assets necessary for the plant's operation were analyzed. Key economic indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Benefit/Cost (B/C) ratio, and payback period were calculated, demonstrating the financial viability of the project.

3. RESULTS

3.1. Determination of the Plant Location

For the determination of the plant location, two possible locations on an agricultural land of 5 hectares were evaluated taking into account certain factors: proximity to the raw material, proximity to basic services, accessibility to the plant, availability of surface area, proximity to the finished product warehouse and administrative and operational costs. Once the evaluation of the best localization alternative was carried out through the factor weighting method, alternative 1 was determined as the optimal location. (Table 1)

Table 1. Weighting of factors

Localization factors	Weighting%	Alternative 1 (entry)		Alternative 2 (rear)	
		Qualification	Score	Qualification	Score
Proximity to raw material	21%	5	1.05	1	0.21
Proximity to the source of water, electricity and drainage	13%	5	0.65	1	0.13
Accessibility to the plant	21%	5	1.05	1	0.21
Surface area availability	17%	3	0.51	3	0.51
Proximity to the finished product warehouse	13%	5	0.65	1	0.13
Administrative and operational costs	17%	5	0.85	1	0.17
Total	100%		4.76		1.36

3.2. Plant Distribution

The evaluation of the plant distribution was carried out. To this end, the activities that make up the production process were related in order to identify the need for closeness.

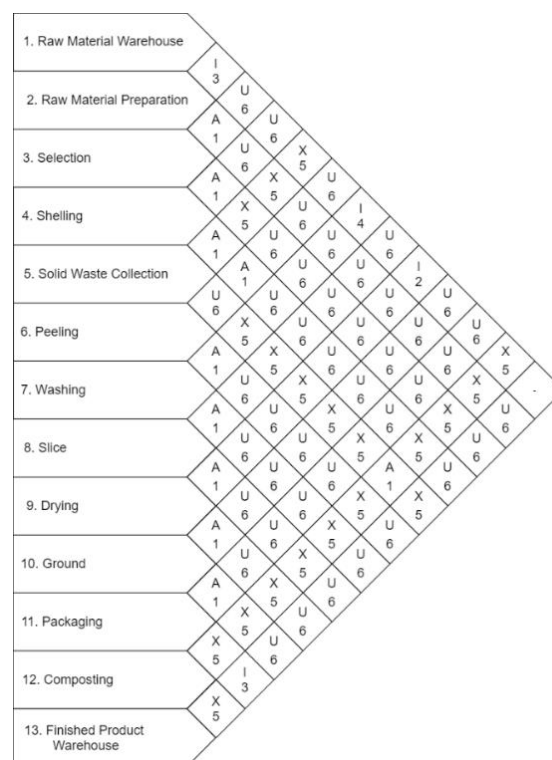


Figure 1. Relational table of activities

The results obtained are graphically illustrated in a relational diagram of activities. (Figure 3).

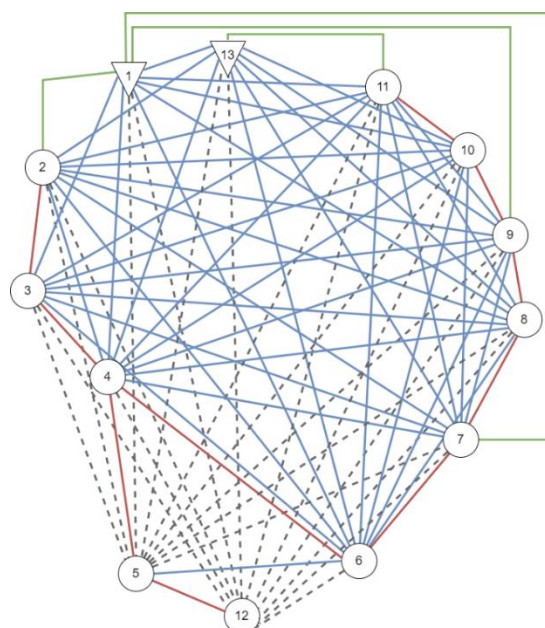


Figure 3. Relational diagram of activities

3.3. Calculation of the Total Area

In order to determine the physical space for the activities of the garlic powder production process, the Guerchet method was used. The calculation of the total surface was made according to the partial surfaces: Static Surface (Ss), Gravitational Sur-face (Sg) and Evolution Surface (Se). In addition, the coefficient of evolution (k) was considered, which relates the average height of the moving and static elements equal to 1.10. (Table 2)

Table 2. Calculation of total area

Elements	Ss (m2)	Sg (m2)	Se (m2)	St (m2)
		Ss x N	(Ss + Sg)k	n(Ss+Sg+Se)
<i>Static</i>				
Garlic bulb sorter	0.48	0.96	1.24	2.68
Garlic bulb sheller	0.2	0.6	0.69	1.49
Garlic clove peeler	0.3	0.9	1.03	2.23
Garlic clove washer	0.9	1.8	2.32	5.02
Garlic clove slicer	0.16	0.48	0.55	1.19
Garlic flake grinder	0.16	0.48	0.55	1.19
Solid waste dryer	0.22	0.66	0.75	1.63
Solid waste mixer	0.55	1.65	1.89	4.09
Compound Reactor	1.22	2.44	3.15	6.81
<i>Mobile</i>				
Garlic flake dryer	2.60	5.20	6.70	14.50
Operators	0.5	1	1.29	8.36
Total				49.18

Additionally, the physical space required for the development of manual activities equal to 16 m2 was considered. The minimum required area was determined to be 65.18 m2.

3.4. Line Balance and Number of Operators

In order to determine the optimal number of workstations and personnel, a line balance was carried out. For this, the duration of the activities of the production process was considered in Table 3.

Table 3. Precedence of activities

Description	Activities	Precedence	T/C (h)	T/C(min)
Raw Material Preparation	A		1.50	90
Selection Process	B	A	0.71	43
Shelling Process	C	B	0.69	42
Peeling Process	D	C	0.66	39
Washing Process	E	D	0.60	36
Cutting Process	F	E	0.63	38
Drying Process	G	F	72.00	4320
Grinding Process	H	G	0.15	9
Packaging	I	H	11.57	694
T/C Total			88.51	5311

A total duration of 88.51 hours was identified. Likewise, the takt time and number of operators were calculated using formulas (1) y (2).

Takt Time (hours/lot):

$$\text{Takt Time} = \frac{\text{Time for production available per month}}{\text{Monthly production required}} \quad (1)$$

Takt Time = 74.06 hours/lot

Number of Operators:

$$\text{Number of Operators} = \frac{\text{Total product cycle time}}{\text{Takt Time}} \quad (2)$$

Number of Operators = 1.20 operators

Once the minimum number of stations has been defined, the assignment of activities to the stations is carried out according to the time they require. (Table 4)

Table 4. Assignment of activities

Unit	Available Tasks	Task	Time	Acum Times	Time available	Allocation
I	A	A	1.50	1.50	74.06	
	B	B	0.71	2.21	71.85	Yes
	C	C	0.69	2.90	71.16	Yes
	D	D	0.66	3.56	70.50	Yes
	E	E	0.60	4.16	69.90	Yes
	F	F	0.63	4.79	69.27	Yes
II	G	G	72.00	72.00	2.06	Yes
	H	H	0.15	72.15	1.91	Yes
III	I	I	11.57	11.57	62.50	Yes

Finally, the line balance analysis has yielded a total of 3 work-stations. Station I covers the activities of preparation of raw material until cutting, station II contemplates the activities of drying and grinding and finally the last station contemplates the activity of packaging.

3.5. Plant Size

For the determination of the plant size, the % of waste obtained by each activity of the process resulting from the material balance was considered, additionally the cycle time (h) of each activity and processing capacity of the machinery (kg/h) that makes up the production line, determining that for the production of 1 kg of garlic powder 2.65 kg of fresh garlic is necessary.

Therefore, the plant size has been determined according to the production capacity, this being 214 kg per month and 2563 kg per year.

3.6. Market Study

To determine the sample population of households in Arequipa that will be part of the study, formula (3) was used to calculate the sample size for infinite populations, as the population size is greater than 10,000. In addition, to determine the sample population of the market for companies dedicated to the food industry, formula (4) for finite populations was used.

$$n = \frac{Z^2 * p * q}{e^2} \quad (3)$$

$$n = \frac{N * Z^2 * p * q}{e^2 * (N-1) + Z^2 * p * q} \quad (4)$$

The sample population for both households and food industry market was calculated in Table 5.

Table 5. Calculation of the Sample – Household and Food Industry Market

Variable	Description	Household Market	Food Industry Market
N	Population Size	327 760	957
Z	Confidence Level	1.96	1.96
e	Margin of Error	0.05	0.05
p	Probability of Success	0.95	0.95
q	Probability of Failure	0.05	0.05
n	Mínimum Sample Size	73	68

The survey conducted among household decision-makers in Arequipa revealed that 68% are female and 32% are male, with most decision-makers being adults aged 18-35. Socioeconomic levels vary, with 23% in NSC1 (upper middle class) and smaller percentages in other levels. While 58% use garlic powder, 42% do not, citing preferences for fresh garlic or unawareness of garlic powder. Weekly purchases are most common (40%), and popular brands include Batán (43%) and bulk options (24%). A significant 99% are willing to buy ecologically produced garlic powder. Preferences for packaging lean towards glass jars (62%), with varied preferences for product size and potential condiment combinations. Most prefer to purchase from local markets, and 85% favor social media for advertising. Overall, there is strong potential for marketing ecologically produced garlic powder, with 90% of respondents likely to purchase it. Figure 4 illustrates the purchasing preference for garlic powder in the household market.

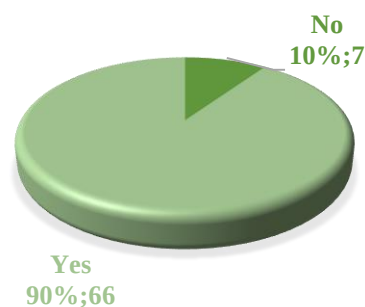


Figure 4. Preference for Purchasing Organic Garlic Powder – Household Market

Based on the surveyed companies in Arequipa, 90% belong to the restaurant, bar, and cantina sector, followed by 7% in accommodation and food services, and 3% in meat production and meat products. Only 21% of companies use garlic powder, with 18% in the restaurant sector and 3% in meat production; no usage was observed in accommodation and food services. Liquid garlic is an alternative, used by 72% in the restaurant sector and 7% in accommodation services. For supplier selection, 43% prioritize product quality and price, 29% prioritize quality alone, and 14% prioritize both quality and certification. Bulk garlic powder is used in meat production, while 42% of restaurants use the Batán brand and 58% prefer bulk. Meat producers purchase 50-60 kg monthly, while restaurants buy daily and weekly in various quantities. Bulk bags are preferred by meat producers, while 83% of restaurants buy packets. Average monthly spending on garlic powder is 186 soles for restaurants (5 kg) and 440 soles for meat producers (55 kg). In terms of willingness to purchase, 80% of accommodation services, 100% of meat producers, and 34% of restaurants would buy garlic powder after testing. Most accommodation services prefer local markets, meat producers prefer direct delivery, and restaurants favor local markets or delivery. Figure 5 illustrates the purchasing preference for garlic powder in the food industry market.

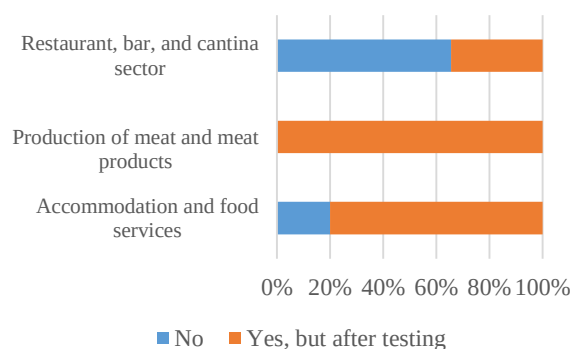


Figure 5. Preference for Purchasing Organic Garlic Powder – Food Industry Market

3.7. Production Costs and Selling Price

A costing has been made that considers the cost of producing garlic powder to be marketed in presentations of 20 and 50 gr and its sale price, as shown in Table 6.

Table 6. Cost of production and selling price

Indicator	Envelope of 50 gr	Envelope of 20 gr
<i>Unit cost of production</i>	1.01	0.61
<i>Sale Price</i>	4.90	2.40

3.8. Economic Evaluation of the Project

For the economic evaluation of the project have been considered, the level of production in number of units of both presentations, the fixed costs (electricity, water, labor direct and indirect) and variable costs (raw materials and inputs), administrative and sales expenses, investment in machinery, investment in tangible and intangible assets, as shown in Table 7.

Table 7. Production and investment data

Production capacity	Kg/Lot	26.7
	Kg/year	2, 563
	Envelopes of 50 gr/year	40, 992
	Envelopes of 20 gr/año	25, 632
Tangible Assets	Infrastructure(soles)	45, 000.00
	Machinery and Equipment (soles)	219, 480.89
	Other (soles)	10, 218.89
Intangible Assets	Adaptations of infrastructure (soles)	3, 037.32
MOI	Soles/year	18,132.84
MOD	Soles/year	30, 660.98
Electric Power and Water	Soles/year	3,170.82
Administrative Expenditure	Soles/year	24, 569.72
Cost of Sales	Soles/year	16, 940.00

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The project demonstrates profitability through favorable economic indicators, as shown in Table 8.

Table 8. Economic indicators

Economic Indicator	Value
NPV	S/. 229, 689.91
IRR	34%
B/C	1.20
Recovery period (years)	3.94

4. CONCLUSION

An ecological industrial plant has been designed to facilitate the standardized processing of garlic powder through the use of solar energy and precise control of parameters during the drying stage. This ensures the production of garlic powder with excellent organoleptic characteristics, including optimal color, aroma, taste, and preserved nutritional properties.

The ecological industrial plant includes a dedicated production line for the reuse of agricultural solid waste generated during garlic powder production. This waste is repurposed as raw material for composting, promoting sustainability and reducing environmental impact.

The market analysis indicates strong demand for ecologically produced garlic powder, with a significant proportion of consumers willing to purchase the product. The positive reception among potential buyers and the growing preference for sustainable products highlight the market potential and justify further investment in production and marketing strategies.

The project demonstrates profitability through favorable economic indicators derived from the established cost of production and competitive selling price. This financial viability underscores the project's potential for long-term success.

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