



## **Phenolic Content and Financial Analysis Simulation of Anaerobically Fermented Robusta Coffee (*Coffea canephora*) Instant Powder Using Polysaccharide Carriers**

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### **Abstract**

*This study aimed to analyze the total phenolic content (TPC), added value, and financial feasibility of anaerobically fermented Robusta coffee instant powder using maltodextrin as a carrier at a concentration of 6% (A2B3). The experiment employed a factorial Completely Randomized Design involving gum arabic and maltodextrin at concentrations of 0%, 4%, and 6%. Total phenolic content was analyzed using analysis of variance followed by a 5% HSD test, while financial feasibility was evaluated using the B/C ratio, NPV, and IRR. Added value and the remuneration of production factors were assessed using the Hayami method. The A2B3 treatment produced a TPC of 4.75%, indicating high retention of measurable phenolic compounds after spray drying. The financial simulation resulted in a B/C ratio of 1.04, an NPV of Rp39,034,664, and an IRR of 23.89%, exceeding the simulated 8% discount rate. The Hayami analysis showed a conversion factor of 0.235, an added value of Rp10,175/kg, and an added-value ratio of 34.64%, classified within the medium category. A2B3 also generated the highest annual output of 2,115 kg and annual profit of Rp30,213,000. These findings indicate that 6% maltodextrin can support phenolic retention, processing value addition, and positive financial performance under the simulated production conditions.*

**Keywords:** Anaerobic Fermentation, Gum Arabic, Maltodextrin, Phenolic, Robusta Coffee.



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## **INTRODUCTION**

Coffee is one of the most widely consumed beverages and contains various bioactive compounds, including caffeine, chlorogenic acids, trigonelline, and phenolic compounds (Makiso et al., 2024). These compounds contribute to the characteristic chemical properties of coffee and are associated with its biological and antioxidant potential (Hernández-Ayala et al., 2024). Robusta coffee (*Coffea canephora*) is an important species for the coffee industry and is widely utilized in commercial coffee production. Compared with Arabica, Robusta is generally characterized by a stronger and more bitter sensory profile, which creates opportunities for processing strategies that can modify its sensory and functional characteristics. The presence of phenolic and other bioactive compounds also provides a basis for developing value-added Robusta coffee products. Processing innovations can therefore support the diversification of Robusta coffee products while maintaining or utilizing its potentially valuable bioactive components (Liczbiński & Bukowska, 2022).

Fermentation is one processing approach that can modify the chemical and sensory characteristics of coffee through microbial activity and biochemical transformations. In *Coffea canephora*, fermentation involves complex microbial interactions that can influence the composition of metabolites and characteristics of the resulting coffee (Bernardes & Coelho, 2024). Anaerobic fermentation provides a controlled environment in which oxygen availability is restricted, allowing microbial and biochemical processes to proceed under different conditions from conventional fermentation. These conditions can influence microbial communities, chemical composition, and sensory quality of coffee (Pereira et al., 2022). Changes associated with anaerobic fermentation may subsequently affect the volatile profile and sensory characteristics of coffee across different processing stages (Pholtaisong et al., 2025). Fermented coffee can further be processed into instant coffee, providing a convenient product form with potential for broader utilization. The conversion of coffee extract into powder requires an appropriate drying technology, and spray drying is widely applied

because it rapidly transforms liquid feed into a stable powder through atomization and contact with heated air (Kumoro et al., 2024).

Spray drying is particularly relevant to coffee processing because its relatively short drying period can facilitate the production of powders while limiting prolonged exposure to heat. However, drying conditions may affect the physicochemical characteristics and retention of heat-sensitive compounds in the final product. The incorporation of carrier or wall materials can improve powder formation and provide protection for bioactive compounds during the drying process (Díaz-Montes, 2023). Maltodextrin is commonly used as a carrier material because of its high solubility, low viscosity, and suitability for spray-drying applications (Zhang et al., 2018). Gum arabic is another widely used material that can contribute to film formation, emulsification, and stabilization of encapsulated compounds. Differences in the characteristics of carrier materials can consequently influence the physicochemical properties and encapsulation performance of spray-dried powders (Toprakçı et al., 2024).

The selection and concentration of carrier materials are important factors in determining the characteristics of spray-dried powders because the wall matrix affects compound retention, powder structure, and overall encapsulation performance. Gum arabic and maltodextrin have distinct functional properties that may produce different outcomes when used as coating or carrier materials (Hay et al., 2025). Variations in carrier composition have also been shown to influence the protection and stabilization of bioactive compounds during spray drying. Such differences are relevant when the target compounds include phenolic substances that may be affected by processing conditions. Total Phenolic Content (TPC) represents the overall amount of phenolic compounds detected in an extract and can be used as an indicator for evaluating phenolic characteristics of the resulting powder (Araújo et al., 2022). The concentration of carrier material may therefore need to be considered alongside the preservation of phenolic compounds when developing fermented coffee powder. Evaluation of TPC can provide complementary information for determining how different carrier formulations affect the functional characteristics of the final product.

Beyond physicochemical and phenolic characteristics, the economic feasibility of producing instant coffee powder is an important consideration in evaluating the applicability of a processing formulation. Spray-drying operations involve expenditures related to energy, raw materials, labor, equipment, maintenance, and packaging, which collectively influence production costs (Tinoco-Caicedo et al., 2020). The use of carrier materials also affects the quantity of auxiliary materials required and can consequently contribute to differences in processing expenditure. Techno-economic evaluation can be used to assess the relationship between processing inputs, production costs, and potential economic value of a processed product (Shofinita et al., 2021). Previous research has also demonstrated the potential economic value associated with processing and fermentation technologies for Robusta coffee (Nurhaliza et al., 2024). Therefore, an evaluation of product characteristics alone may not sufficiently describe the feasibility of a spray-dried fermented coffee product. Integrating TPC evaluation with financial analysis can provide a more comprehensive basis for assessing different carrier formulations in the production of anaerobically fermented Robusta coffee instant powder.

Research on carrier materials in spray drying has been conducted extensively for food products and extracts containing bioactive compounds. However, limited studies have specifically integrated phenolic evaluation and financial analysis in the development of instant powder from anaerobically fermented Robusta coffee. The use of gum arabic and maltodextrin at different concentrations may produce different effects on the characteristics and economic requirements of the resulting powder. A combined assessment is therefore needed to examine product quality alongside the financial implications of formulation and processing. This study evaluates the Total Phenolic Content of anaerobically fermented Robusta coffee instant powder produced using different concentrations of gum arabic and maltodextrin. The study also conducts a financial analysis simulation to examine the economic considerations associated with the production process. The findings are expected to provide an integrated basis for evaluating carrier formulation in the development of value-added instant coffee products.

## RESEARCH METHODS

This study employed an empirical factorial Completely Randomized Design (CRD) to develop and evaluate instant powder from anaerobically fermented Robusta coffee (*Coffea canephora*) using

polysaccharide carriers. The experimental design consisted of two factors, namely carrier type (A), comprising gum arab (A1) and maltodextrin (A2), and carrier concentration (B), comprising 0% (B1), 4% (B2), and 6% (B3), resulting in six treatment combinations. The fermented Robusta coffee extract was processed into instant powder by spray drying after the addition of the respective carrier formulations, considering that wall materials can influence powder formation and the protection of bioactive compounds during drying (Díaz-Montes, 2023). The resulting powders were evaluated for Total Phenolic Content (TPC), while the experimental data were subjected to analysis of variance (ANOVA) at a 5% significance level to assess the main effects of carrier type, carrier concentration, and their interaction. When significant differences were detected, treatment means were further compared using the Honestly Significant Difference (HSD) test at the 5% significance level, and the financial simulation was constructed for all six treatments using investment costs, fixed costs, variable costs, production capacity, selling price, and annual cash flow based on an adapted Robusta coffee processing framework (Nurhaliza et al., 2024). The simulation assumed a production capacity of 100 kg of coffee feed per batch, 90 production batches per year, a five-year evaluation period, an 8% discount rate, and a residual equipment value of Rp5,000,000, with electricity and thermal energy included as major operating-cost components because spray drying is associated with substantial energy requirements in instant coffee production (Tinoco-Caicedo et al., 2020).

**Table 1. Value-Added Calculation Variables**

| No.                                           | Variable (Output, Input, Price)   | Notation / Calculation               |
|-----------------------------------------------|-----------------------------------|--------------------------------------|
| <b>Output, Input, and Price</b>               |                                   |                                      |
| 1                                             | Output (kg)                       | (1)                                  |
| 2                                             | Raw material input (kg)           | (2)                                  |
| 3                                             | Labor (JKO/production)            | (3)                                  |
| 4                                             | Conversion factor                 | $(4) = (1) / (2)$                    |
| 5                                             | Labor coefficient                 | $(5) = (3) / (2)$                    |
| 6                                             | Output price (Rp/kg)              | (6)                                  |
| 7                                             | Labor wage (Rp/JKO)               | (7)                                  |
| <b>Profit Calculation</b>                     |                                   |                                      |
| 8                                             | Raw material price (Rp/kg)        | (8)                                  |
| 9                                             | Other input contributions (Rp/kg) | (9)                                  |
| 10                                            | Output value (Rp/kg)              | $(10) = (4) \times (6)$              |
| 11a                                           | Added value (Rp/kg)               | $(11a) = (10) - (9) - (8)$           |
| 11b                                           | Added-value ratio (%)             | $(11b) = (11a) / (10) \times 100\%$  |
| 12a                                           | Labor income (Rp/kg)              | $(12a) = (5) \times (7)$             |
| 12b                                           | Labor share (%)                   | $(12b) = (12a) / (11a) \times 100\%$ |
| 13a                                           | Profit (Rp/kg)                    | $(13a) = (11a) - (12a)$              |
| 13b                                           | Profitability (%)                 | $(13b) = (13a) / (11a) \times 100\%$ |
| <b>Remuneration for Factors of Production</b> |                                   |                                      |
| 14                                            | Margin (Rp/kg)                    | $(14) = (10) - (8)$                  |
| 14a                                           | Labor income (%)                  | $(14a) = (12a) / (14) \times 100\%$  |
| 14b                                           | Other input contribution (%)      | $(14b) = (9) / (14) \times 100\%$    |
| 14c                                           | Profit (%)                        | $(14c) = (13a) / (14) \times 100\%$  |

Validation of the experimental results was performed through statistical testing of TPC, whereas the economic model was evaluated using the Benefit-Cost Ratio (B/C), Net Present Value (NPV), Internal Rate of Return (IRR), and Hayami value-added indicators. The B/C ratio was calculated as the present value of total benefits divided by the present value of total costs, with a value greater than one indicating that simulated benefits exceed costs, while NPV was calculated from discounted annual net cash flows over the five-year evaluation period and interpreted relative to zero (Shofinita et al., 2021). IRR was estimated through interpolation between discount rates producing positive and negative NPV values and was compared with the assumed 8% discount rate, while the Hayami method quantified added value by incorporating output, input, labor, product price, raw-material price, and other input

contributions (Nurhaliza et al., 2024). The Hayami calculation was applied separately to A1B1, A1B2, A1B3, A2B1, A2B2, and A2B3, with the calculation variables and equations presented in Table 1 and the resulting added-value ratio classified as low when below 15%, medium when 15–40%, and high when above 40%. Financial assumptions were explicitly documented for raw materials, carrier materials, labor, energy, packaging, water, maintenance, transportation, equipment investment, and selling price so that the simulation could be reproduced and subsequently recalibrated using commercial operating data. The combined evaluation of TPC, factorial statistical testing, financial feasibility, and Hayami value addition was used to establish methodological robustness by connecting the experimental performance of carrier formulations with their simulated economic implications rather than assessing powder quality through phenolic content alone.

## RESULTS AND DISCUSSION

### Total Phenolic Content of Anaerobically Fermented Robusta Coffee Instant Powder

The total phenolic content (TPC) of the anaerobically fermented Robusta coffee instant powder varied according to carrier concentration, whereas the numerical difference between gum arabic and maltodextrin at the same concentration was comparatively limited. As shown in Figure 1, the TPC values were 1.30% for A1B1, 3.25% for A1B2, and 4.82% for A1B3, while the corresponding maltodextrin treatments yielded 1.30%, 3.21%, and 4.75%, respectively. The increase from the control treatment to the 4% and 6% carrier treatments indicates that the drying formulation was associated with greater retention of measurable phenolic compounds in the resulting powder. This pattern is particularly relevant because coffee contains diverse phenolic constituents that contribute to its antioxidant characteristics, although their measurable concentration can be altered by processing conditions (Hernández-Ayala et al., 2024). Anaerobic fermentation may also modify the chemical composition of coffee through microbial activity and biochemical transformation before the extract enters the drying stage (Pereira et al., 2022). The TPC results therefore need to be interpreted as an outcome of the combined fermentation and spray-drying system rather than as evidence that carrier addition generated additional phenolic compounds.

Figure 1 demonstrates a progressive increase in TPC as carrier concentration increased from 0% to 6% for both carrier types. The gum arabic series increased from 1.30% in A1B1 to 3.25% in A1B2 and subsequently to 4.82% in A1B3, while the maltodextrin series increased from 1.30% in A2B1 to 3.21% in A2B2 and 4.75% in A2B3. At 4% concentration, the difference between gum arabic and maltodextrin was only 0.04 percentage points, whereas the difference at 6% was 0.07 percentage points. Such small differences suggest that carrier concentration was more strongly reflected in the observed TPC pattern than the distinction between the two polysaccharide materials under the experimental conditions. Polysaccharide carriers can form a protective matrix around bioactive compounds during spray drying, reducing their direct exposure to heat, oxygen, and other processing stresses (Buljeta et al., 2022). The effectiveness of this protection depends on wall-material characteristics, feed composition, and drying conditions, so the observed pattern should be interpreted as formulation-specific rather than universally applicable to all coffee powders (Díaz-Montes, 2023). Similar evidence from coffee-derived extracts has shown that spray drying with suitable carrier materials can support the preservation of phenolic and antioxidant compounds in the dried powder (Araújo et al., 2022).

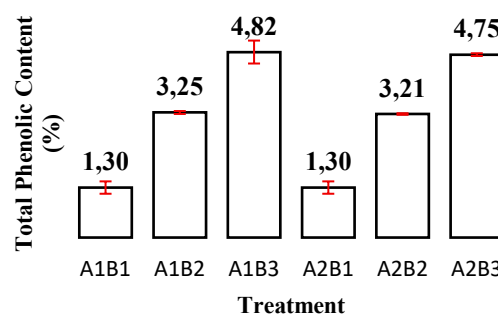


**Figure 1. Total Phenolic Content of Anaerobically Fermented Robusta Coffee Instant Powder**

The statistical evaluation further clarifies the concentration effect identified in Figure 1. Table 2 presents the mean TPC values aggregated according to carrier concentration, showing  $1.30 \pm 0.19\%$  for B1,  $3.23 \pm 0.03\%$  for B2, and  $4.79 \pm 0.14\%$  for B3. The different superscript letters assigned to the three treatments indicate statistically significant differences at the 5% HSD level. The HSD value of 0.24 establishes that the observed separation among concentration levels exceeded the threshold required for distinguishing the treatment means. The increase of approximately 1.93 percentage points from B1 to B2 and 1.56 percentage points from B2 to B3 indicates that the concentration effect was substantial within the tested formulation range. This statistical pattern strengthens the interpretation that carrier concentration was an important experimental factor associated with TPC retention, rather than the numerical differences being attributable solely to experimental variation. Comparable spray-drying research has demonstrated that changes in carrier formulation can alter the retention and physicochemical characteristics of phenolic-rich powders, although the direction and magnitude of the response depend on the material system and process parameters (Sid et al., 2023).

**Table 2. LSD 5% Post-Hoc Test Results on the Effect of Carrier Concentration on the Total Phenolic Content of Anaerobically Fermented Robusta Coffee Instant Powder**

| Treatment | Mean (%) $\pm$ SD | LSD 5% = 0.24 |
|-----------|-------------------|---------------|
| B3        | $4.79 \pm 0.14$   | a             |
| B2        | $3.23 \pm 0.03$   | b             |
| B1        | $1.30 \pm 0.19$   | c             |

Description: Values followed by the same letter in the same column show no significant difference.

The concentration-dependent increase can be interpreted through the role of polysaccharides as wall-forming materials during spray drying. A higher carrier concentration increases the proportion of solid material available to form the drying matrix, which can alter the physical environment surrounding phenolic constituents as water is rapidly removed from the feed. Maltodextrin is widely applied as a carrier because of its ability to facilitate powder formation and protect sensitive compounds during drying, while gum arabic can provide film-forming and encapsulation properties that contribute to compound retention (Zhang et al., 2018; Díaz-Montes, 2023). The present data show that both materials produced a similar directional response, with the 6% treatments producing the highest TPC values. This similarity is consistent with research indicating that gum arabic and maltodextrin can both function as protective matrices, although their interactions with bioactive compounds and their effects on powder properties may differ according to formulation and drying conditions (Toprakçı et al., 2024). The result also indicates that the presence of a carrier should not automatically be interpreted as an increase in the intrinsic phenolic concentration of the coffee extract, because the carrier itself is not being treated as a phenolic source. Instead, the higher measured TPC may reflect improved recovery or reduced degradation of phenolic constituents during conversion from liquid extract into dry powder.

The TPC response is also relevant to the chemical characteristics of anaerobically fermented Robusta coffee. Fermentation under oxygen-limited conditions can modify microbial communities and chemical composition, creating a precursor matrix whose subsequent behavior during drying may differ from that of non-fermented coffee extracts (Bernardes & Coelho, 2024). Pereira et al. (2022) reported that self-induced anaerobic coffee fermentation affected microbial communities, chemical composition, and sensory quality, indicating that fermentation should be considered an integral stage of the final product profile. In the present experiment, however, the fermentation stage was held constant across treatments, while carrier type and concentration were varied during powder production. The observed differences in TPC can therefore be interpreted primarily within the context of the spray-drying formulation rather than as evidence of different fermentation effects among treatments. Phenolic compounds in coffee are chemically diverse and may undergo oxidation, degradation, transformation, or altered extractability during thermal processing, making their final measurable concentration dependent on processing history (Liczbiński & Bukowska, 2022). The protective function of the carrier matrix provides a plausible mechanism for reducing losses during drying, but confirmation of individual phenolic compounds would require compound-specific analytical techniques beyond the aggregate TPC measurement used here.

The relatively close TPC values between gum arabic and maltodextrin at equivalent concentrations provide an additional indication that carrier concentration was the more prominent factor under the tested conditions. At 4%, the TPC difference between A1B2 and A2B2 was only 0.04%, and at 6%, the difference between A1B3 and A2B3 was 0.07%, while both carrier types produced the same 1.30% value without carrier. These small differences suggest that replacing one polysaccharide carrier with the other did not produce a pronounced change in measurable TPC when concentration was held constant. Previous studies have nevertheless shown that carrier composition can influence encapsulation efficiency, phenolic retention, powder recovery, and other functional properties, meaning that similar TPC values do not necessarily imply identical technological performance (Mutavski et al., 2025). Differences in molecular structure, solubility, viscosity, film-forming behavior, and interaction with the target compounds may become more apparent when other quality attributes are considered (Hay et al., 2025). The present findings therefore support a distinction between the statistical effect of carrier concentration and the comparatively small numerical difference between carrier types for TPC. Such distinction is important because a formulation may produce similar phenolic retention while differing in powder yield, processability, moisture characteristics, encapsulation efficiency, or economic cost.

From an applied product-development perspective, the TPC results establish that increasing carrier concentration from 0% to 6% was associated with improved measurable phenolic retention in anaerobically fermented Robusta coffee instant powder. The 6% treatments reached 4.82% for gum arabic and 4.75% for maltodextrin, representing increases of approximately 271% and 265%, respectively, relative to the 1.30% control value. The magnitude of this difference provides a meaningful basis for subsequent economic evaluation because additional carrier material introduces formulation costs that must be considered alongside the resulting powder yield and product value. Spray-drying studies have emphasized that carrier concentration influences not only bioactive-compound preservation but also powder recovery and product characteristics, creating a direct connection between formulation design and process economics (Pınarbaşı et al., 2026). The TPC findings consequently provide one component of the formulation-performance assessment, while the financial simulation determines whether the additional processing and material requirements can be supported under the assumed production conditions. The interpretation remains limited to the measured TPC parameter because antioxidant activity, individual phenolic profiles, encapsulation efficiency, moisture content, and powder recovery were not included as response variables in the reported experiment. The subsequent economic analysis can therefore use these TPC results as a quality-related indicator while independently evaluating production costs, value addition, and financial feasibility across the six treatment combinations.

### Investment and Production Cost Structure

The financial simulation began with the identification of the investment requirements needed to support production of anaerobically fermented Robusta coffee instant powder. The simulated initial investment amounted to Rp85,000,000 and consisted of processing, extraction, fermentation, packaging, weighing, storage, and supporting equipment. The spray dryer represented the largest single investment component at Rp35,000,000, indicating that the drying stage was the dominant capital requirement in the proposed processing system. This allocation is consistent with the technological role of spray drying as a core unit operation for converting liquid extracts into stable powder products and with the relatively substantial equipment and energy requirements associated with the process (Kumoro et al., 2024). The economic importance of the spray dryer is also supported by exergoeconomic analysis showing that energy consumption and system performance are important determinants of the economic characteristics of spray-drying operations in instant coffee production (Tinoco-Caicedo et al., 2020). The remaining investment was distributed among equipment such as the grinder, roasting machine, fermentation tank, extraction vessel, sealing machine, weighing scale, moisture meter, cold storage, water-heating equipment, and packaging support.

**Table 3. Simulated Investment Cost**

| Equipment      | Unit Price (Rp) | Quantity | Total (Rp) |
|----------------|-----------------|----------|------------|
| Spray dryer    | 35,000,000      | 1        | 35,000,000 |
| Coffee grinder | 4,000,000       | 1        | 4,000,000  |

|                         |            |   |                   |
|-------------------------|------------|---|-------------------|
| Coffee roasting machine | 15,000,000 | 1 | 15,000,000        |
| Fermentation tank       | 3,000,000  | 1 | 3,000,000         |
| Extraction vessel       | 5,000,000  | 1 | 5,000,000         |
| Sealing machine         | 3.0000.000 | 1 | 3.0000.000        |
| Digital weighing scale  | 1.0000.000 | 1 | 1.0000.000        |
| Moisture meter          | 2,000,000  | 1 | 2,000,000         |
| Cold storage            | 5,000,000  | 1 | 5,000,000         |
| Water heating           | 5,000,000  | 1 | 5,000,000         |
| Packaging support       | 2,000,000  | 1 | 2,000,000         |
| <b>Total Investment</b> |            |   | <b>85,000,000</b> |

The investment structure shown in Table 3 indicates that the proposed production system requires a relatively concentrated capital allocation at the drying stage rather than an even distribution across all processing activities. This condition is important because the spray dryer determines not only the physical conversion of the extract into powder but also a substantial part of the energy demand and production capacity of the system. A high-cost drying unit can improve processing capability, yet its economic contribution depends on how effectively the equipment is utilized over the production year. Tinoco-Caicedo et al. (2020) demonstrated that the performance and energy characteristics of spray-drying systems have direct implications for economic efficiency, particularly in instant coffee applications. The investment requirement should therefore be evaluated together with production volume rather than considered solely as an initial expenditure. In the present simulation, the equipment is assumed to support 90 production batches per year, which provides the utilization basis for distributing investment-related economic consequences across the projected production period. The resulting structure also explains why changes in output volume can substantially influence the subsequent B/C ratio, NPV, and IRR calculations.

In addition to the initial investment, the production system incurred fixed costs that did not directly change with the treatment formulation. As presented in Table 4, the annual fixed cost was Rp18,000,000, consisting of production-room rental of Rp6,000,000, permanent labor of Rp8,000,000, administration of Rp2,000,000, and insurance and licensing/tax expenses of Rp2,000,000. Permanent labor represented the largest component of the fixed-cost structure, followed by production-room rental. Maintaining these expenditures as fixed assumptions allows the financial simulation to isolate the effects of treatment-specific variable costs and production output. Such separation is relevant in processing feasibility analysis because investment and fixed expenditures must be distinguished from costs that increase as production intensity or formulation requirements change (Shofinita et al., 2021). The fixed-cost structure also means that higher production volumes can distribute the annual burden of these expenditures over a greater quantity of saleable powder.

**Table 4. Fixed Costs**

| <b>Cost Component</b>       | <b>Annual Cost (Rp/year)</b> |
|-----------------------------|------------------------------|
| Production-room rental      | 6,000,000                    |
| Permanent labor             | 8,000,000                    |
| Administration              | 2,000,000                    |
| Insurance and licensing/tax | 2,000,000                    |
| <b>Total</b>                | <b>18,000,000</b>            |

Variable costs displayed a clearer differentiation among the six treatment combinations because carrier concentration directly affected the formulation requirement. As shown in Table 5, raw-material expenditure remained constant at Rp108,000,000 per year for all treatments, while carrier, labor, energy, packaging, water, and maintenance costs varied according to the formulation assumptions. The carrier cost was zero in both 0% treatments, increased to Rp3,060,000 for A1B2 and Rp2,448,000 for A2B2, and reached Rp4,590,000 for A1B3 and Rp3,672,000 for A2B3. These values indicate that gum arabic generated higher formulation expenditure than maltodextrin at the same concentration, with differences of Rp612,000 at 4% and Rp918,000 at 6%. The result illustrates that carrier selection has an economic consequence even when the corresponding TPC values are relatively close, because the

cost of achieving a given formulation performance is not necessarily equivalent between materials. Research comparing polysaccharide carriers has likewise shown that gum arabic and maltodextrin can produce different processing and powder characteristics, making carrier selection a technological as well as an economic consideration (Sid et al., 2023).

**Table 5. Annual Variable Costs**

| Treatment | Raw Material (Rp) | Labor (Rp) | Carrier (Rp) | Energy (Rp) | Packaging (Rp) | Water (Rp) | Maintenance (Rp) |
|-----------|-------------------|------------|--------------|-------------|----------------|------------|------------------|
| A1B1      | 108,000,000       | 21,600,000 | 0            | 10,800,000  | 9,000,000      | 1,800,000  | 3,150,000        |
| A1B2      | 108,000,000       | 22,950,000 | 3,060,000    | 10,800,000  | 9,000,000      | 1,800,000  | 3,150,000        |
| A1B3      | 108,000,000       | 24,300,000 | 4,590,000    | 10,800,000  | 9,000,000      | 1,800,000  | 3,150,000        |
| A2B1      | 108,000,000       | 21,600,000 | 0            | 10,800,000  | 9,000,000      | 1,800,000  | 3,150,000        |
| A2B2      | 108,000,000       | 22,140,000 | 2,448,000    | 10,800,000  | 9,000,000      | 1,800,000  | 3,150,000        |
| A2B3      | 108,000,000       | 23,490,000 | 3,672,000    | 10,800,000  | 9,000,000      | 1,800,000  | 3,150,000        |

The variable-cost structure further shows that energy expenditure was maintained at Rp10,800,000 per year across all treatments, making it one of the principal common operating costs after raw materials and labor. Although energy was held constant in the base simulation, actual energy consumption in spray drying can vary with feed solids, viscosity, moisture removal requirements, drying conditions, and equipment utilization. Wall-material concentration can alter feed properties and drying behavior, which may subsequently affect energy demand and powder recovery under commercial operating conditions (Díaz-Montes, 2023). Maltodextrin has also been described as a carrier capable of facilitating spray drying because of its functional properties and suitability for producing dried powders from bioactive-rich materials (Zhang et al., 2018). Consequently, the constant energy assumption should be regarded as a controlled financial-simulation parameter rather than a universal representation of industrial energy consumption. The assumption is useful for comparing treatments on a common basis, while future scale-up analysis should incorporate treatment-specific energy measurements and actual equipment performance.

The cost results indicate that the economic implications of carrier addition cannot be evaluated independently from production output and product quality. Increasing carrier concentration raised formulation-related expenditure, but the same treatments also produced higher TPC values and higher simulated output quantities than the control treatments. This creates a trade-off in which additional material costs may be economically justified if they contribute to greater powder recovery, marketable output, or product value. Nurhaliza et al. (2024) similarly emphasized the importance of integrating processing technology, business finance, and value-added analysis in evaluating fermented Robusta coffee processing. The present cost structure provides the basis for that integration because investment, fixed expenditure, variable expenditure, and treatment-specific carrier costs are subsequently incorporated into the financial feasibility calculations. The economic performance of each treatment therefore depends not only on minimizing production cost but also on whether the additional formulation expenditure is accompanied by sufficient increases in saleable output and revenue. This relationship becomes particularly important when comparing A1B3 and A2B3, where the 6% formulations generated the highest TPC values while also requiring the highest carrier expenditures within their respective carrier groups.

### Financial Feasibility Based on B/C Ratio, NPV, and IRR

The financial feasibility simulation was conducted to determine whether differences in production output, selling price, and treatment-specific production costs could support the investment required for anaerobically fermented Robusta coffee instant powder. The B/C ratio provides an initial comparison between the present value of benefits and the present value of costs over the five-year evaluation period. The results show that the simulated B/C ratios ranged from 0.78 to 1.04 across the six treatment combinations, indicating substantial variation in economic performance among formulations. The lowest ratios were observed for A1B1, A2B1, A1B2, and A2B2, while the 6% carrier treatments produced ratios exceeding or approaching unity. This pattern is consistent with the principle

that value-added processing must generate sufficient additional product value to compensate for processing, material, labor, energy, and capital costs (Nurhaliza et al., 2024). The financial interpretation therefore needs to consider the interaction between formulation cost and the amount of saleable instant powder generated by each treatment.

The detailed B/C calculations are presented in Table 6, where the 6% treatments generated the highest present-value benefits relative to their corresponding costs. A1B3 recorded a B/C ratio of 1.01, while A2B3 produced 1.04, compared with 0.78 for both 0% treatments and 0.92 and 0.96 for A1B2 and A2B2, respectively. The higher ratios of the 6% formulations correspond with their greater simulated annual output and revenue, suggesting that the additional carrier expenditure was accompanied by an increase in economically saleable product. The difference between A1B3 and A2B3 is also noteworthy because the maltodextrin treatment generated a slightly higher B/C ratio despite the formulation containing the same 6% carrier concentration. This result reflects the combined effect of carrier cost, production output, and the assumed selling price rather than the TPC result alone. Similar relationships between carrier formulation, powder production, and economic value have been observed in spray-dried bioactive products, where processing performance influences the economic attractiveness of the final product (Araújo et al., 2022; Edson et al., 2023).

**Table 6. B/C Ratio**

| Treatment | Annual Revenue (Rp) | PV Benefit (Rp) | PV Cost (Rp)  | B/C Ratio |
|-----------|---------------------|-----------------|---------------|-----------|
| A1B1      | 194,000,000         | 779,585,747     | 997,733,514   | 0.78      |
| A1B2      | 232,200,000         | 930,510,187     | 1,015,341,366 | 0.92      |
| A1B3      | 258,750,000         | 1,036,516,638   | 1,026,840,371 | 1.01      |
| A2B1      | 194,400,000         | 779,585,747     | 997,733,514   | 0.78      |
| A2B2      | 241,560,000         | 967,881,953     | 1,009,663,732 | 0.96      |
| A2B3      | 264,375,000         | 1,058,975,632   | 1,019,940,968 | 1.04      |

The B/C results are further supported by the NPV analysis, which incorporates the timing of cash flows and the assumed 8% discount rate. As shown in Table 7, A1B1 generated an NPV of -Rp287,187,767, while A1B2 remained negative at -Rp84,831,179. A1B3 generated a positive NPV of Rp9,676,267, whereas A2B1 and A2B2 produced negative values of -Rp218,147,267 and -Rp41,781,780, respectively. The A2B3 treatment generated the highest NPV at Rp39,034,664, indicating the largest positive difference between the present value of projected benefits and costs under the stated assumptions. The transition from negative to positive NPV at the 6% carrier level indicates that the increase in projected revenue was sufficient to offset the additional production and investment burden within the simulation period. Such sensitivity to output and processing efficiency is expected in spray-drying systems because energy consumption, equipment utilization, and product recovery can substantially influence the economic balance of the process (Tinoco-Caicedo et al., 2020).

**Table 7. NPV**

| Treatment | Annual Net Benefit (Rp) | NPV (Rp)     |
|-----------|-------------------------|--------------|
| A1B1      | -34,200,000             | -287,187,767 |
| A1B2      | -810,000                | -84,831,179  |
| A1B3      | 22,860,000              | 9,676,267    |
| A2B1      | -34,200,000             | -218,147,267 |
| A2B2      | 9,972,000               | -41,781,780  |
| A2B3      | 30,213,000              | 39,034,664   |

The NPV pattern demonstrates that a treatment can generate positive annual operating income while still producing a negative investment NPV over the evaluation period. This condition is evident in A2B2, which has an annual net benefit of Rp9,972,000 but an NPV of -Rp41,781,780. The result occurs because the annual cash inflow is not sufficient to compensate for the initial investment and the time value of money at the assumed discount rate within five years. A1B3, in contrast, produces an

annual net benefit of Rp22,860,000 and a positive NPV of Rp9,676,267, although its margin of economic feasibility remains relatively narrow. The difference between A1B3 and A2B3 also indicates that higher output and revenue can substantially strengthen investment performance when additional carrier costs remain proportionate to the resulting production gain. Previous techno-economic evaluations of value-added food processing have similarly demonstrated that production capacity, processing efficiency, and operating costs can determine whether technically viable processing becomes financially sustainable (Shofinita et al., 2021).

The IRR results provide another perspective by measuring the implied rate of return generated by the projected cash flows. Table 8 shows that A1B3 produced an IRR of 12.35%, while A2B3 produced an IRR of 23.89%, both exceeding the simulated discount rate of 8%. IRR was not defined for A1B1, A1B2, A2B1, and A2B2 because their projected cash flows did not generate sufficient recovery of the investment and their NPVs remained negative. The difference between the two positive-IRR treatments indicates that the cash-flow structure of A2B3 provides a larger return relative to the initial investment under the specified assumptions. This result is compatible with the B/C and NPV patterns, in which A2B3 also produced the highest B/C ratio and NPV. The consistency among these indicators provides stronger evidence for interpreting the financial simulation because the three measures evaluate economic performance from complementary perspectives rather than relying on a single metric.

**Table 8. IRR**

| <b>Treatment</b> | <b>IRR</b>                            |
|------------------|---------------------------------------|
| A1B1             | Not defined; NPV remains negative     |
| A1B2             | Not defined; NPV remains negative     |
| A1B3             | 12.35%; Above simulated discount rate |
| A2B1             | Not defined; NPV remains negative     |
| A2B2             | Not defined; NPV remains negative     |
| A2B3             | 23.89%; Above simulated discount rate |

The combined B/C, NPV, and IRR results indicate that the economic performance of the six formulations is highly dependent on the relationship between carrier concentration and saleable output. The 6% treatments produced the strongest financial indicators, corresponding with the highest TPC values and the largest simulated powder outputs reported in the experimental results. This association suggests that formulation changes capable of improving product recovery may have economic consequences beyond the improvement of a single quality parameter. Research on polysaccharide carriers has shown that carrier composition and spray-drying conditions can affect encapsulation performance, powder characteristics, and bioactive-compound retention, which can ultimately influence the usable yield of the process (Pınarbaşı et al., 2026). Nevertheless, the present financial results represent a simulation based on fixed assumptions for production capacity, energy expenditure, selling price, investment period, and other operating parameters, rather than a guarantee of commercial profitability. Changes in coffee raw-material prices, carrier prices, drying efficiency, powder recovery, market price, equipment utilization, or annual production volume could materially alter the calculated indicators. The results consequently provide an economic scenario for comparing the six formulations and establish a basis for subsequent value-added analysis rather than representing a universal financial outcome for industrial production.

### **Hayami Value Added and Remuneration of Production Factors**

The Hayami value-added analysis was applied to determine the economic value generated from converting anaerobically fermented Robusta coffee into instant powder and to examine its distribution among labor, other inputs, and profit. All treatments used the same raw-material input of 100 kg per production cycle, while the resulting powder output differed according to carrier type and concentration. This difference in output provides an important basis for evaluating the efficiency of the processing system because the same quantity of raw material generated different quantities of saleable powder. The conversion factor increased from 0.180 in A1B1 and A2B1 to 0.215 and 0.220 at 4% carrier concentration and to 0.230 and 0.235 at 6% concentration. Higher conversion factors indicate that a

greater proportion of the raw-material input was transformed into instant powder, which is economically relevant because recovery directly affects the quantity available for sale. Carrier materials can influence feed characteristics, drying behavior, and powder recovery, making formulation an important determinant of the economic performance of spray-dried products (Díaz-Montes, 2023).

The detailed Hayami results in Table 9 show that A2B3 produced the highest output at 23.50 kg from 100 kg of input, followed by A1B3 at 23.00 kg. The two control treatments produced only 18.00 kg, while A1B2 and A2B2 generated 21.50 and 22.00 kg, respectively. The increase in conversion factor across carrier concentrations indicates that the carrier-containing formulations were associated with greater output recovery than the treatments without carrier. The output value consequently increased from Rp21,600/kg in the control treatments to Rp25,800/kg for A1B2, Rp26,840/kg for A2B2, Rp28,750/kg for A1B3, and Rp29,375/kg for A2B3. This relationship demonstrates how improved conversion efficiency can increase the economic value generated from a fixed quantity of raw material. Research on spray-dried bioactive powders has similarly shown that carrier selection can influence powder recovery and the physical characteristics of the final product, which subsequently affects processing efficiency (Sid et al., 2023).

**Table 9. Hayami Value-Added Analysis**

| Variable                                                | A1B1    | A1B2    | A1B3    | A2B1    | A2B2    | A2B3    |
|---------------------------------------------------------|---------|---------|---------|---------|---------|---------|
| 1. Output (kg)                                          | 18.00   | 21.50   | 23.00   | 18.00   | 22.00   | 23.50   |
| 2. Input (kg)                                           | 100.00  | 100.00  | 100.00  | 100.00  | 100.00  | 100.00  |
| 3. Manpower (JKO/production)                            | 8.00    | 8.50    | 9.00    | 8.00    | 8.20    | 8.70    |
| 4. Conversion factor                                    | 0.180   | 0.215   | 0.230   | 0.180   | 0.220   | 0.235   |
| 5. Manpower conversion                                  | 0.080   | 0.085   | 0.090   | 0.080   | 0.082   | 0.087   |
| 6. Output Price (Rp/Kg) $\frac{1}{2}$ dan $\frac{1}{4}$ | 120,000 | 120,000 | 120,000 | 120,000 | 120,000 | 120,000 |
| 7. Labor Wages (Rp/JKO)                                 | 30,000  | 30,000  | 30,000  | 30,000  | 30,000  | 30,000  |
| 8. Raw material price                                   | 18,000  | 18,000  | 18,000  | 18,000  | 18,000  | 18,000  |
| 9. Other Input Contributions                            | 900     | 1,150   | 1,300   | 900     | 1,050   | 1,200   |
| 10. Output Value (Rp/Kg)                                | 21,600  | 25,800  | 28,750  | 21,600  | 26,840  | 29,375  |
| 11a. Added value                                        | 2,700   | 6,650   | 9,450   | 2,700   | 7,790   | 1,175   |
| 11b. Added Value Ratio                                  | 12.50   | 25.78   | 32.87   | 12.50   | 29.02   | 34.64   |
| 12a. Labor income                                       | 2,400   | 2,550   | 2,700   | 2,400   | 2,460   | 2,610   |
| 12b. Labor Section                                      | 88.89   | 38.35   | 28.57   | 88.89   | 31.58   | 25.65   |
| 13a. Profit                                             | 300     | 4,100   | 6,750   | 300     | 5,330   | 7,565   |
| 13b. Profitability Level                                | 11.11   | 61.65   | 71.43   | 11.11   | 68.42   | 74.35   |
| 14. Margin                                              | 3,600   | 7,800   | 10,750  | 3,600   | 8,840   | 11,375  |
| 14a. Labor income (%)                                   | 66.67   | 32.69   | 25.12   | 66.67   | 27.83   | 22.95   |
| 14b. Other Input Contributions (%)                      | 25.00   | 14.74   | 12.09   | 25.00   | 11.88   | 10.55   |
| 14c. Profit (%)                                         | 8.33    | 52.56   | 62.79   | 8.33    | 60.69   | 66.51   |

The added-value results show a clear distinction between the control and carrier-containing treatments. The added-value ratio was 12.50% for both A1B1 and A2B1, placing these treatments in the low category under the applied classification of less than 15%. The ratio increased to 25.78% for A1B2, 29.02% for A2B2, 32.87% for A1B3, and 34.64% for A2B3, placing all carrier-containing treatments in the medium category of 15–40%. This progression indicates that the addition of polysaccharide carriers increased the economic contribution generated through processing relative to the value of the resulting product. The highest added-value ratio recorded for A2B3 corresponds with its highest conversion factor and output value, reinforcing the relationship between processing recovery and value creation. Similar findings have been reported in value-added evaluations of processed Robusta coffee, where processing technology can substantially alter the economic value obtained from the same agricultural raw material (Nurhaliza et al., 2024). The results also demonstrate that increasing the processing value of coffee does not necessarily require a high added-value category, since the carrier-containing treatments already shifted the product from the low to the medium classification.

Labor remuneration showed a different pattern from total added value. Labor income increased from Rp2,400/kg in the control treatments to Rp2,550 and Rp2,460/kg at 4% carrier concentration and

Rp2,700 and Rp2,610/kg at 6% concentration. Although the nominal labor income increased, its percentage share of added value declined considerably as carrier concentration increased. The labor share fell from 88.89% in both control treatments to 38.35% in A1B2 and 31.58% in A2B2, before reaching 28.57% in A1B3 and 25.65% in A2B3. This pattern indicates that the increase in generated value was proportionally larger than the increase in labor remuneration. The changing distribution is important because greater processing value allows a larger portion of the economic surplus to remain after labor costs have been accounted for. Hayami analysis is particularly useful for identifying this relationship because it separates the absolute income received by labor from the proportion of total added value allocated to labor (Nurhaliza et al., 2024).

The profitability results provide further evidence of the economic effect of higher carrier concentrations. Profit increased from Rp300/kg in A1B1 and A2B1 to Rp4,100/kg in A1B2, Rp5,330/kg in A2B2, Rp6,750/kg in A1B3, and Rp7,565/kg in A2B3. Profitability levels followed the same pattern, increasing from 11.11% in the controls to 61.65% and 68.42% at 4% concentration and 71.43% and 74.35% at 6% concentration. The increasing profit levels indicate that the additional costs associated with carrier-containing formulations were accompanied by a greater increase in economic value generated by processing. A2B3 recorded the highest profitability level, consistent with its highest conversion factor, output quantity, and output value. The result is relevant to the functional role of carrier materials because effective encapsulation can contribute to the preservation of bioactive compounds and improvement of powder properties during spray drying (Mutavski et al., 2025). Studies using gum arabic and maltodextrin as coating materials similarly demonstrate that carrier formulation affects the characteristics and stability of bioactive-rich powders, which can influence their potential value as processed products (Toprakçı et al., 2024).

The remuneration of production factors illustrates how the margin generated from processing was distributed among labor, other inputs, and owner profit. As shown in Table 11, the margin increased from Rp3,600/kg in the control treatments to Rp7,800/kg and Rp8,840/kg at 4% concentration and Rp10,750/kg and Rp11,375/kg at 6% concentration. Labor remuneration accounted for 66.67% of the margin in the control treatments but decreased to 32.69% and 27.83% at 4% concentration and 25.12% and 22.95% at 6% concentration. The contribution of other inputs also declined proportionally, from 25.00% in the controls to between 10.55% and 14.74% in the carrier-containing treatments. In contrast, the proportion attributed to owner profit increased from 8.33% in the controls to 52.56–60.29% at 4% concentration and 62.79–66.51% at 6% concentration. This distribution indicates that increasing processing output generated a progressively larger economic margin, within which the relative share attributable to owner profit became more substantial. The result is consistent with the concept that value-added processing can redistribute the economic contribution of agricultural commodities by creating additional value beyond the original raw-material price.

**Table 11. Remuneration of Production Factors**

| Indicator                     | A1B1  | A1B2  | A1B3   | A2B1  | A2B2  | A2B3   |
|-------------------------------|-------|-------|--------|-------|-------|--------|
| Margin                        | 3,600 | 7,800 | 10,750 | 3,600 | 8,840 | 11,375 |
| Labor remuneration (%)        | 66.67 | 32.69 | 25.12  | 66.67 | 27.83 | 22.95  |
| Other input contribution (%)  | 25.00 | 14.74 | 12.09  | 25.00 | 11.88 | 10.55  |
| Owner profit remuneration (%) | 8.33  | 52.56 | 62.79  | 8.33  | 60.29 | 66.51  |

The annual simulation connects the Hayami results with the broader financial performance of the six formulations. Table 10 shows that annual output increased from 1,620 kg in the control treatments to 1,935 kg for A1B2, 2,070 kg for A1B3, 1,980 kg for A2B2, and 2,115 kg for A2B3. Annual revenue consequently ranged from Rp194,400,000 for A1B1 and A2B1 to Rp264,375,000 for A2B3, while A1B3 generated Rp258,750,000. A2B3 also produced the highest simulated annual profit at Rp30,213,000, followed by A1B3 at Rp22,860,000. The higher annual revenue and profit correspond with the higher conversion factor and value-added performance observed at the 6% carrier concentration. Spray-drying research indicates that carrier materials can influence powder recovery and the preservation of bioactive compounds, making formulation and process efficiency important considerations when translating laboratory performance into economically valuable products (Araújo et al., 2022). The combined Hayami and annual financial results therefore show that greater conversion

of raw material into marketable powder can strengthen both value creation at the processing level and economic returns at the annual production level. The consistency of this pattern with the B/C, NPV, and IRR results further indicates that formulation performance, powder recovery, and production economics are closely interconnected in the simulated processing system.

## CONCLUSION

The anaerobically fermented Robusta coffee instant powder showed a clear increase in total phenolic content with increasing polysaccharide carrier concentration. The TPC increased from 1.30% in the 0% carrier treatment to 4.82% with 6% gum arabic and 4.75% with 6% maltodextrin, while the statistical analysis confirmed significant differences among carrier concentrations. The relatively small differences between gum arabic and maltodextrin at equivalent concentrations indicate that carrier concentration had a more pronounced effect on TPC than carrier type under the experimental conditions. The financial simulation showed that investment requirements were dominated by the spray dryer, with total initial investment reaching Rp85,000,000 and annual fixed costs of Rp18,000,000. Among the six treatments, A1B3 and A2B3 generated B/C ratios above 1, while their NPVs were positive at Rp9,676,267 and Rp39,034,664, respectively, with IRRs of 12.35% and 23.89%. These findings indicate that increasing carrier concentration was associated with improved phenolic retention, greater powder conversion, and stronger financial performance within the assumptions of the simulation.

The Hayami analysis further demonstrated that carrier addition increased the conversion factor and economic value generated from the same 100 kg raw-material input. The conversion factor increased from 0.180 in the control treatments to 0.230 for A1B3 and 0.235 for A2B3, while the added-value ratio increased from 12.50% to 32.87% and 34.64%, respectively. The 4% and 6% carrier treatments were classified within the medium added-value category, whereas the control treatments remained in the low category. A2B3 produced the highest output, annual revenue, annual profit, and profitability level, indicating a strong association between processing conversion and economic value creation. The results also show that the relative share of labor remuneration decreased as added value increased, while the proportion allocated to owner profit became larger in the higher-concentration treatments. Overall, the integration of TPC, financial feasibility, and Hayami value-added indicators demonstrates the potential of polysaccharide-assisted spray drying to improve the technical and economic characteristics of anaerobically fermented Robusta coffee instant powder under the specified production assumptions.

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