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Economic feasibility and sustainability of post-harvest processing routes for agroforestry coffee in Campinas, Brazil

Viabilidade econômica e sustentabilidade de vias pós-colheita do café agroflorestal em Campinas-SP

Viabilidad económica y sostenibilidad de las vías de procesamiento poscosecha del café agroforestal en Campinas, São Paulo, Brasil

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Abstract:
The choice of coffee post-harvest processing route affects costs, sale value, water use and effluent generation, which calls for an integrated decision on farms that grow coffee in agroforestry systems (AFS). This study compares the economic feasibility of the dry, semi-washed and washed routes on an agroforestry coffee farm in Campinas, São Paulo, Brazil, considering beverage quality and the socio-environmental effects of each route. It is a quantitative case-modelling study, with assumptions and a spreadsheet fed by a semi-structured interview with the farm staff, the farm's feasibility spreadsheet and a questionnaire answered by four local coffee shops. Costs were split into CAPEX and OPEX and assessed through NPV, IRR and payback over the 2025–2049 horizon, with a minimum attractive rate of return of 14% per year, accompanied by a sensitivity analysis of the selling price. All three routes proved feasible, with NPVs of R$ 179.8 thousand (dry), R$ 485.2 thousand (semi-washed) and R$ 1.73 million (washed) and IRRs of 20.6%, 28.9% and 52.4%. The wet routes outperform the dry route above about R$ 63/kg of roasted coffee, but they use more water and generate effluent with a high organic load. The farm is advised to start with the dry route and migrate gradually to the wet routes in the first harvests, provided that demand is confirmed and the effluent is properly managed.

Keywords:
Specialty coffee. Agroforestry system. Post-harvest. Economic feasibility. Sustainability.

Resumo:
A escolha da via de processamento pós-colheita do café afeta custos, valor de venda, uso de água e geração de efluentes, o que exige uma decisão integrada em propriedades que cultivam café em sistema agroflorestal (SAF). Este estudo compara a viabilidade econômica das vias seca, semiúmida e úmida em uma propriedade de café agroflorestal em Campinas-SP, considerando a qualidade da bebida e os efeitos socioambientais de cada via. Trata-se de uma modelagem de um caso de abordagem quantitativa, com premissas e planilha alimentada por entrevista semiestruturada com a equipe da fazenda, pela planilha de viabilidade da propriedade e por questionário aplicado a quatro cafeterias da região. Os custos foram separados em CAPEX e OPEX e avaliados por VPL, TIR e payback, no horizonte de 2025 a 2049, com TMA de 14% a.a., e acompanhados por análise de sensibilidade ao preço de venda. As três vias mostraram-se viáveis, com VPL de R$ 179,8 mil (seca), R$ 485,2 mil (semiúmida) e R$ 1,73 milhão (úmida) e TIR de 20,6%, 28,9% e 52,4%. As vias úmidas superam a seca a partir de cerca de R$ 63/kg de café torrado, mas consomem mais água e geram efluente de alta carga orgânica. Recomenda-se iniciar pela via seca e migrar gradualmente para as vias úmidas nas primeiras safras, condicionando a migração à confirmação da demanda e ao manejo do efluente.

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Palavras-chave:
Café especial. Sistema agroflorestal. Pós-colheita. Viabilidade econômica. Sustentabilidade.

Resumen:
La elección de la vía de procesamiento poscosecha del café afecta los costos, el precio de venta, el consumo de agua y la generación de efluentes. Esto requiere una decisión integrada en las fincas que cultivan café en sistemas agroforestales (SAF). Este estudio compara la viabilidad económica de las vías seca, semihúmeda y húmeda en una finca de café agroforestal de Campinas, São Paulo, Brasil, teniendo en cuenta la calidad de la bebida y los efectos socioambientales de cada vía. Se trata de una modelización cuantitativa de un caso, cuyos supuestos y hoja de cálculo se nutrieron de una entrevista semiestructurada al personal de la finca, de la hoja de cálculo de viabilidad de la propiedad y de un cuestionario respondido por cuatro cafeterías de la región. Los costos se separaron en CAPEX y OPEX y se evaluaron mediante el VAN, la TIR y el plazo de recuperación para el período 2025–2049, con una tasa mínima aceptable de rendimiento del 14 % anual y un análisis de sensibilidad al precio de venta. Las tres vías resultaron viables, con un VAN de R$ 179,8 mil (seca), R$ 485,2 mil (semihúmeda) y R$ 1,73 millones (húmeda) y una TIR del 20,6 %, 28,9 % y 52,4 %, respectivamente. Las vías húmedas superan a la seca a partir de aproximadamente R$ 63 por kilogramo de café tostado, pero consumen más agua y generan efluentes con alta carga orgánica. Se recomienda comenzar por la vía seca y pasar gradualmente a las vías húmedas en las primeras cosechas, siempre que se confirme la demanda y se gestione adecuadamente el efluente.

Palabras clave:
Café de especialidad. Sistema agroforestal. Poscosecha. Viabilidad económica. Sostenibilidad.

1. Introduction

Coffee is among the world's most widely consumed beverages and one of the most important agricultural commodities in international trade (FAO, 2025). Brazil is the world's largest coffee producer and exporter and the second-largest consumer (Brasil, 2022). This position makes it necessary to reconcile the economic performance of coffee farming with the conservation of natural resources in light of the pressure that agricultural expansion exerts on native ecosystems (Brasil, 2025).

Agroforestry systems (AFS) integrate coffee plants with tree species and other crops, diversify the production environment and contribute to biodiversity conservation and ecosystem services such as nutrient cycling. Studies of agroforestry coffee show predominantly positive effects of diversification on sustainability. These effects depend on establishment and management, with potential trade-offs between productivity and conservation (Nesper et al., 2019; Teixeira et al., 2022).

At the same time, the specialty coffee market values sensory attributes influenced by post-harvest processing. In the dry route, the whole cherry dries with its pulp and mucilage. In

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the washed route, the pulp and mucilage are removed before drying, with fermentation. In the semi-washed route (pulped natural), the pulp is removed and the mucilage is retained (Gonzalez, 2004; Oliveira et al., 2013). These routes differ in how they shape the physical, chemical and sensory attributes of the beverage (Hameed et al., 2018), and in infrastructure requirements, water use and effluent generation. These differences affect investment, operating costs and hence the feasibility of each alternative (Vegro; Fronzaglia; Veiga Filho, 2009; Rattan et al., 2015).

On an agroforestry coffee farm, the choice of route extends beyond technical considerations. The wet routes tend to add more value to the product but use more water and generate effluent with a high organic load. If this effluent is improperly treated, it can undermine the environmental goals that motivate the AFS. The literature reviewed generally treats the economic feasibility of agroforestry coffee (Mangabeira et al., 2009; Siqueira et al., 2020) separately from the effects of processing on quality and the environment (Rattan et al., 2015; Hameed et al., 2018). This raises the research question: which post-harvest processing route for coffee grown in an agroforestry system is best suited to achieving economic feasibility while ensuring quality and socio-environmental sustainability?

The objective is to compare the economic feasibility of the dry, semi-washed and washed routes on an agroforestry coffee farm in the Campinas region of São Paulo, Brazil, using NPV, IRR and payback, and to compare the economic outcomes with beverage quality and the socio-environmental benefits and risks of each route. Answering this question helps guide the grower on when to invest in higher-value routes, given that production will initially focus on the dry route, and on the market and environmental management conditions supporting the decision. After the introduction, the article presents the theoretical background (Section 2), method (Section 3), results and discussion (Section 4), and conclusions (Section 5).

2. Theoretical background

This section presents the concepts and scientific principles needed to understand sustainable coffee production and the factors influencing its quality and market value. It addresses two topics: agroecology and agroforestry systems as alternatives for sustainable production, and post-harvest practices, processing and coffee quality assessment. The section thus describes both the characteristics of the production system and the practices carried out

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after harvest, providing a theoretical basis for examining their possible links with final product quality and economic feasibility.

2.1 Agroforestry systems and sustainable coffee production

Agroecology provides ecological principles for studying, designing and managing productive agroecosystems that conserve natural resources and are culturally appropriate, socially equitable and economically feasible (Altieri, 1998). Agroforestry systems put these principles into practice by combining forest species and crops in a single area, sometimes with livestock (Reis, 2018). They seek to emulate the layered structure of a natural forest, making better use of light and supporting nutrient cycling (Silva et al., 2019; Santos et al., 2024).

In agroforestry coffee, well-managed tree cover reduces exposure to frost, excess radiation, high temperatures and strong winds. It also improves soil fertility and reduces nutrient leaching (Vaast et al., 2006). Shade increases the uniformity of ripening and bean size (Lunz et al., 2007). At Fazenda Ouro Verde in Unaí, Minas Gerais, Teixeira (2024) reports higher yields, longer-lived coffee plants, less biennial bearing and the possibility of growing a second commercial product in the same area. The case also illustrates challenges: intensive management, a need for specialized technical assistance and a long maturation period.

2.2 Post-harvest processing, quality and impacts of the processing routes

In the Brazilian literature, the term beneficiamento refers both to post-harvest preparation through the dry, washed or semi-washed routes and to the operation that converts dried cherries into green coffee by hulling and separating the beans (EMBRAPA, 2004). This study uses the term in the first sense. Post-harvest handling is among the stages most influential for quality, since several factors can damage the beans and alter their chemical composition (Bassetto; Espirito Santo, 2016). Figure 1 shows the layers of the cherry removed or retained by each route.

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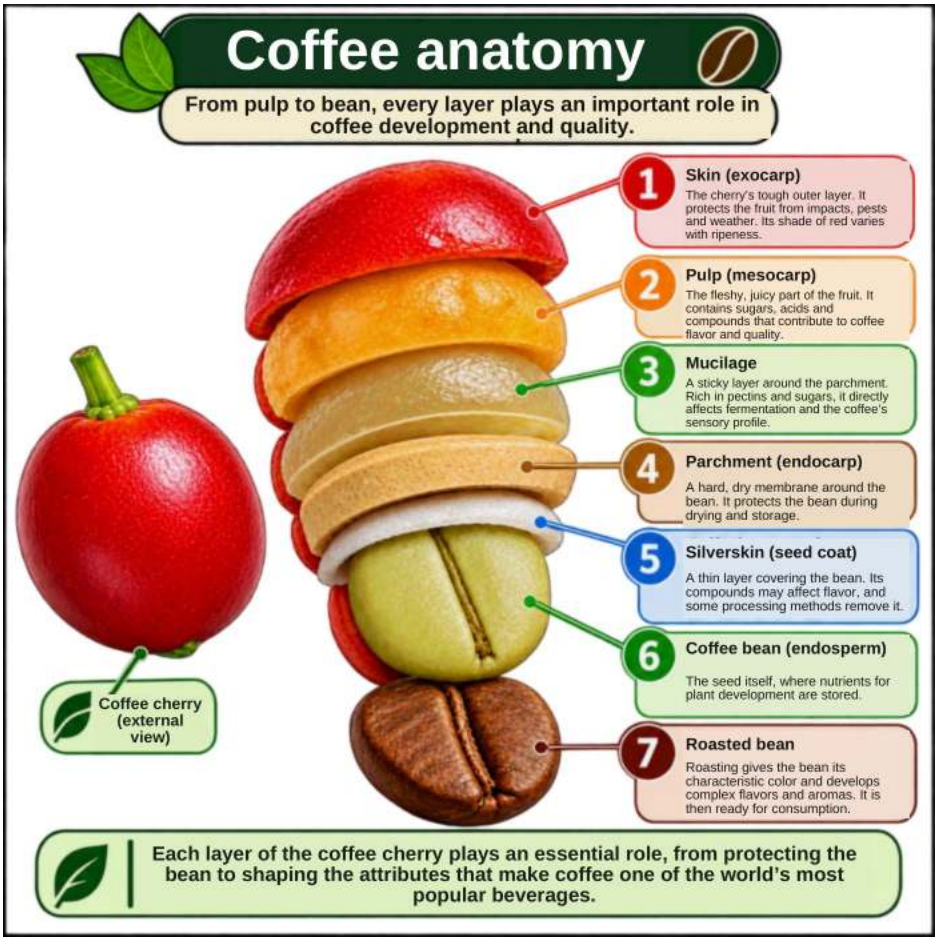
Figure 1 – Detailed anatomy of the coffee bean



Source: Prepared by the authors with support from ChatGPT (OpenAI), based on Gonzalez (2004) and EMBRAPA (2004).

In the dry route, natural coffee dries with the pulp and mucilage, which impart sweetness and produce the pronounced body and aroma characteristic of Brazilian coffees. In the washed route, the pulp and mucilage are removed before drying, with fermentation, yielding a milder beverage with less pronounced body and aroma. With pulped natural coffee (semi-washed route), the pulp is removed and the mucilage remains, preserving sweetness similar to that of natural coffee (Gonzalez, 2004). In routes that use water, washing removes floating cherries and impurities, improving the beverage but increasing water consumption (Vegro; Fronzaglia; Veiga Filho, 2009).

Drying has the greatest influence on quality and cost, and final moisture should be between 11% and 13% (EMBRAPA, 2004). Drying patios are cheaper and common among small producers, but take more time and space and are susceptible to moisture increases caused by rain. Mechanical dryers reduce dependence on weather and shorten drying time, increasing batch uniformity (Vasconcelos, 2025).

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The routes also have socio-environmental implications. The washed and semi-washed routes consume more water and generate wastewater rich in organic matter (Soares et al., 2015): 3 to 5 liters per liter of cherries during pulping and mucilage removal (Matos; Lo Mônaco, 2003, as cited in Rigueira et al., 2010). This effluent cannot be discharged into bodies of water without treatment (Brasil, 2011). The dry route omits these stages but depends more on weather and drying infrastructure, increasing labor requirements (Vasconcelos, 2025).

The reference for the specialty coffee market is the Specialty Coffee Association (SCA) protocol. Coffees scoring 80 or above on a 100-point scale are considered specialty if they have no primary defects and at most five secondary defects in a 350 g sample. Cupping evaluates fragrance and aroma, flavor, aftertaste, acidity, body, balance, sweetness, clean cup and uniformity (Roasters App, 2026). In agroforestry coffee, shade can enhance sensory potential (Mancuso; Soratto; Perdoná, 2013), but that improvement generates value only if processing preserves it and the grower can reach markets that reward it.

2.3 Economic assessment of farm investments

The corporate finance literature divides business expenditures into CAPEX (capital expenditure), investment in capital goods that generate productive capacity over several periods, and OPEX (operating expenditure), the recurring outlays required to keep that capacity in operation (Assaf Neto, 2020). In cost accounting, this corresponds to the distinction between investment and period costs (Martins, 2018).

Feasibility is assessed by net present value (NPV), the sum of cash flows discounted at a minimum attractive rate of return (MARR), less the initial investment; internal rate of return (IRR), the rate that sets NPV to zero and is compared with MARR; and simple or discounted payback, the time required for cumulative cash flows to recover the investment (Casarotto Filho; Kopittke, 2000; Assaf Neto, 2020). The indicators work best together. NPV shows the value created, IRR shows the percentage return and discounted payback shows the duration of exposure to risk (Assaf Neto, 2020).

Because projections are uncertain, sensitivity analysis recalculates indicators while varying the least certain inputs, generally price, volume and costs, to identify the project's margin of safety (Casarotto Filho; Kopittke, 2000). In coffee production, uncertainty is increased by climate variability, which reduced agroforestry yields in Espírito Santo during the 2015–2017 drought (Siqueira et al., 2020), and by coffee price volatility (Mendoza et al., 2025).

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3. Method

This is applied, quantitative research of a descriptive and explanatory nature, intended to investigate the problem by detailing processes and identifying the factors behind them (Gil, 2019). It takes the form of a model of a single case, Fazenda do Lapa, an agroforestry coffee farm being established in the Joaquim Egídio district of Campinas, São Paulo, Brazil. The farm plans to produce coffee, avocados, pecans and mahogany in the same area. The model details the costs and processes of the three post-harvest routes and uses them to calculate feasibility indicators. Coffee quality is treated as an assumption.

3.1 Data collection

Farm data were collected through a semi-structured interview with the farm team (Appendix B). The interview identified existing equipment and infrastructure, feasible processing routes, inputs, labor, energy use, maintenance, processing capacity and the target quality standard. The farm also provided the feasibility spreadsheet for its realistic scenario (Fazenda do Lapa, 2026).

The buyer market was mapped using a questionnaire (Appendix A) answered by owners or staff of four coffee shops in the Sousas district near the farm, three specialty shops and one traditional shop. It addressed purchase volume, quality standards, preferred processing routes and willingness to pay for agroforestry coffee. It was developed with support from Gemini (Google) based on Mendes et al. (2020) and Moori, Bido and Oliveira (2011), reviewed by the author and not statistically validated. With four respondents, the survey is not representative of the regional market. The responses serve as price references for the model.

3.2 Model and assumptions

The model was built in a spreadsheet based on the farm's own spreadsheet. Each route's costs were itemized and split into CAPEX (machinery, equipment, infrastructure and modifications) and OPEX (labor, energy, maintenance and other recurring costs). The assumptions were:

a) a 2025–2049 horizon, with 2025 as year zero, amounts in constant Brazilian reais and zero residual value;
b) a MARR of 14% per year, using the Selic rate as a reference;

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c) costs shared across the four crops split equally, with one-quarter allocated to coffee;
d) in the dry route, 50% of coffee sold in 60 kg bags at R$1,800 per bag and 50% roasted and sold in 1 kg packages at R$70/kg; in the semi-washed and washed routes, all coffee roasted and packaged at R$80/kg and R$150/kg, respectively, based on prices reported by the coffee shops;
e) a roasting yield of 0.85, with roasting and packaging costs proportional to packaged volume;
f) for the wet routes, an additional 0.3 labor-days and 5.77 kWh per bag (Incaper, 2009), with electricity priced at R$0.72/kWh (K2 Power Energia, 2026) and approximately R$1,000 per year for pulper and tank maintenance;
g) effluent reused for irrigation, with the only cost being environmental licensing at establishment.

Socio-environmental benefits and risks were not measured on the farm. They were assessed qualitatively from the literature for the aspects on which routes differ: water use, effluent, by-products, income and labor.

3.3 Indicators and sensitivity analysis

NPV (Equation 1), IRR (Equation 2), and simple and discounted payback were calculated. For constant annual cash flow, simple payback is given by Equation 3.

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+i)^t} \quad (1)$$

$$0 = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} \quad (2)$$

$$Payback = \frac{I_0}{CF} \quad (3)$$

where:

CF_t = cash flow in period t;

t = period;

i = discount rate (MARR);

n = total number of periods;

I_0 = initial investment;

CF = annual net cash flow.

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The project is feasible when NPV is positive and IRR exceeds MARR. Maximum capital at risk, the largest cumulative negative cash flow balance, was also calculated to measure the capital required before the investment is recovered.

To test robustness, we calculated the minimum packaged coffee price per kilogram at which the wet routes outperform the dry route, the maximum share of common costs that maintains nonnegative NPV, and the sensitivity of wet-route NPV to selling price. We also calculated the incremental NPV of switching from the dry route to the wet routes in different years, using the dry route through the preceding year and making the new investment in the year of transition.

4. Results and discussion

Figure 2 summarizes the stages of each route and the equipment required. Harvesting, receiving, sorting and washing are common to all three. The wet routes add pulping. The washed route also adds fermentation and parchment washing, which generates effluent.

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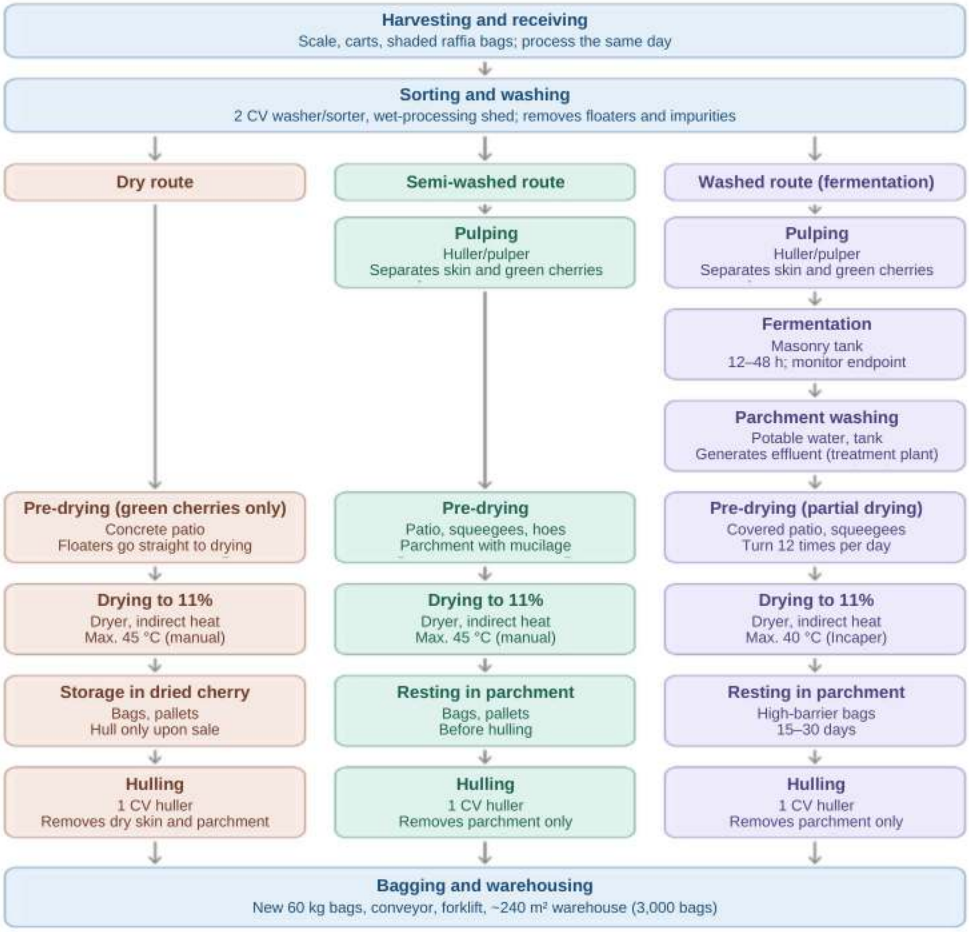
Figure 2 – Coffee processing for the three post-harvest routes and equipment required



Source: Prepared by the author based on Eletrobras and Embrapa (2015) and Incaper (2009).

Table 1 shows the coffee shops' responses. Prices range from R$20/kg at the traditional shop to R$150/kg at the specialty shop that prefers the washed route. Only one shop would pay a premium for agroforestry origin (11% to 20%), and two accept fermented coffees in experimental batches. The model's prices of R$80/kg and R$150/kg for the semi-washed and washed routes come from shops C3 and C2, respectively.

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Table 1 – Coffee shop responses to the questionnaire

Coffee shop	Type	Purchases (kg/month)	Price paid (R$/kg)	Minimum SCA score	Customers' preferred route	Accepts fermented coffee	AFS coffee premium
C1	Traditional	5	20	< 80	Dry	No	0%
C2	Specialty	15	150	84 to 86	Washed	Experimental batches	0%
C3	Specialty	5	80	84 to 86	Semi-washed	Experimental batches	11% to 20%
C4	Specialty	35	Not reported	> 87	No preference	No	0%

Source: Prepared by the author from survey data (2026).

Table 2 shows CAPEX and OPEX by route. CAPEX differs little across routes: the wet routes require R$12,300 (semi-washed) and R$13,100 (washed) more than the dry route, equivalent to 5.7% and 6.1%. The pulper and licensing account for 93% and 88% of those differences. The Compacta Pinhalense machine, which cleans, hulls and grades the coffee, and the washer cost R$85,000 together, representing 72% of direct CAPEX, and are shared by all three routes.

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Table 2 – CAPEX and OPEX by item in the modeled scenario, 2025–2049 (R$)

Item	Dry route	Semi-washed route	Washed route
Direct coffee CAPEX			
Arara coffee seedlings	13,690	13,690	13,690
Raised drying beds (materials and labor)	11,000	11,000	11,000
Drying patio expansion (+70 m²)	5,833	5,833	5,833
Compacta Pinhalense	55,000	55,000	55,000
Washer/sorting tank	30,000	30,000	30,000
Moisture meter and scale	2,500	2,500	2,500
CAPEX specific to wet routes			
Small pulper	0	6,000	6,000
Fermentation tank	0	0	800
Water reservoir	0	800	800
Environmental licensing and fees	0	5,500	5,500
Effluent treatment (reused for irrigation)	0	0	0
Shared CAPEX (1/4 allocation)			
Infrastructure (dam, irrigation, fence, nursery)	36,731	36,731	36,731
Establishment (soil preparation, labor, inputs)	24,297	24,297	24,297
Equipment (subsoiler, sprayer, fertilizer spreader, harrow)	33,500	33,500	33,500
Shared seedlings and seeds	2,980	2,980	2,980
Total CAPEX	215,532	227,832	228,632
Direct coffee OPEX			
Harvesting, drying, hulling and bagging labor	660,000	660,000	660,000
Marketing and logistics	330,000	330,000	330,000
Roasting and packaging	746,000	1,492,000	1,492,000
Additional labor (0.3 labor-days per bag)	0	37,630	37,630
Pulper energy use	0	7,222	7,222
Pulper and tank maintenance	0	22,000	22,000
Shared OPEX (1/4 allocation)			
System maintenance labor	360,000	360,000	360,000
Maintenance materials	120,000	120,000	120,000
Maintenance from April to December 2025	13,093	13,093	13,093
Maintenance inputs	75,049	75,049	75,049
Photovoltaic power	47,053	47,053	47,053
Total OPEX	2,351,195	3,164,047	3,164,047
Total cost (CAPEX + OPEX)	2,566,727	3,391,879	3,392,679
CAPEX share of total cost	8.4%	6.7%	6.7%

Source: Prepared by the author based on the feasibility spreadsheet from Fazenda do Lapa (2026).

The larger difference is in OPEX. The wet routes cost an additional R$812,852 (+35%), of which R$746,000 (92%) comes from roasting and packaging. All coffee is packaged in those routes, compared with half in the dry route. OPEX accounts for 92% to 93% of total costs, making the outcome more sensitive to cost per bag than to investment. Coffee's share of shared

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costs is R$712,704 (R$97,509 in CAPEX and R$615,195 in OPEX), reflecting equal allocation across four crops.

Table 3 presents the indicators for each route. All three have positive NPV and IRR above MARR, with returns ranking washed, semi-washed and dry. The dry route has the narrowest margin: IRR is 6.6 percentage points above MARR and discounted payback takes almost 11 years. Compared with the dry route, the wet routes increase average revenue from 2031 to 2049 by R$121,000 (semi-washed) and R$429,000 (washed) per year, with R$39,000 in additional annual costs.

Table 3 – Economic indicators for coffee in the modeled scenario (MARR of 14% per year)

Indicator	Dry route	Semi-washed route	Washed route
Revenue per 60 kg bag (R$)	2,685	4,080	7,650
Average operating cash flow, 2031–2049 (R$/year)	125,963	207,254	515,683
Maximum capital at risk (R$)	333,815 (2029)	333,119 (2028)	283,939 (2028)
NPV (R$)	179,835	485,222	1,727,148
IRR (% per year)	20.6	28.9	52.4
Simple payback	7.3 years (2033)	6.2 years (2032)	4.6 years (2030)
Discounted payback	10.8 years	7.6 years	5.1 years
Incremental NPV over the dry route (R$)	–	305,388	1,547,313
Minimum price to outperform the dry route (R$/kg)	–	62.79	62.83
Maximum share of common costs with NPV ≥ 0	41%	68%	180%

Source: Prepared by the author from the spreadsheet model.

Because the semi-washed and washed routes cost nearly the same, differing by the R$800 fermentation tank, the R$1.24 million NPV advantage of the washed route comes entirely from the R$150/kg price versus R$80/kg. At the same price, the difference would be R$540. The maximum allocation reveals another weakness of the dry route: it remains viable only if coffee absorbs no more than 41% of shared costs, compared with 68% for the semi-washed route.

Because the outcome for the wet routes depends on prices reported by only two coffee shops, NPV sensitivity to the packaged price per kilogram was analyzed (Table 4 and Figure 3). Each R$1/kg increase or decrease changes wet-route NPV by about R$17,700. The wet routes outperform the dry route at R$62.8/kg or more and cease to be viable (negative NPV) below about R$52.7/kg.

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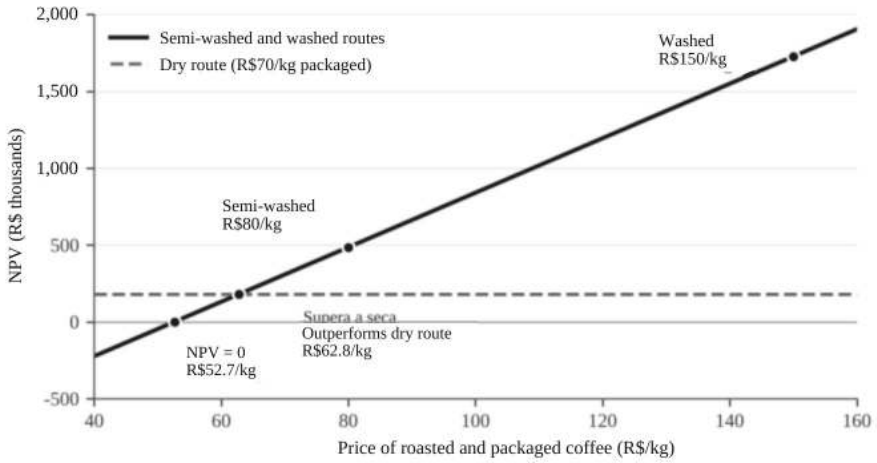
Table 4 – Sensitivity of wet-route NPV to the price of roasted and packaged coffee

Price (R$/kg)	Wet-route NPV (R$)	Incremental NPV over the dry route (R$)	Status
50	−47,000	−226,800	Negative NPV
52.7	0	−179,800	Feasibility threshold
62.8	180,100	≈0	Matches the dry route
70	307,800	128,000	Outperforms the dry route
80	485,222	305,388	Semi-washed price (C3)
100	840,100	660,300	Outperforms the dry route
120	1,194,900	1,015,100	Outperforms the dry route
150	1,727,148	1,547,313	Washed price (C2)

Source: Prepared by the author from the spreadsheet model. Intermediate values were linearly interpolated between the model NPVs at R$80/kg and R$150/kg and rounded to the nearest hundred reais. The approximately R$540 difference between the semi-washed and washed routes at the same price was ignored.

Figure 3 – Wet-route NPV as a function of the price of roasted and packaged coffee



Source: Prepared by the author from the spreadsheet model (MARR of 14% per year).

Even at the same price as packaged dry-route coffee (R$70/kg), the wet routes outperform the dry route by about R$127,000 because all of their coffee is sold roasted. The R$150/kg price can fall by up to 58% before the washed route falls behind the dry route. The main risk is therefore the ability to sell the entire roasted volume from the wet routes (about 4.4 metric tons per year), which the model did not test, rather than the price per kilogram itself.

Given the small additional investment for the wet routes, the model simulated switching from the dry route in different years (Table 5). Production remains low in 2028 and 2029 (14 and 28 bags), making these the least costly years to test the new routes. Switching in 2030 instead of 2028 costs R$16,000 (semi-washed) and R$109,000 (washed) in NPV. At full production of 82 to 91 bags, the cost of waiting increases and reaches R$397,000 for the washed route if the switch takes place in 2032.

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Table 5 – Incremental NPV over the dry route by year of transition (R$)

Year of transition	Semi-washed	Washed	Cost of waiting since 2028: semi-washed	Cost of waiting since 2028: washed
2028	305,388	1,547,313	–	–
2029	302,918	1,511,175	2,470	36,138
2030	289,403	1,438,533	15,985	108,780
2031	270,453	1,318,073	34,935	229,240
2032	236,691	1,150,581	68,697	396,732
2034	176,309	857,507	129,079	689,806
2036	129,847	631,997	175,541	915,316

Source: Prepared by the author from the model's cash flows, using the dry route until the preceding year and the semi-washed or washed route thereafter. The investment for the new route is made in the year of transition.

The suggested sequence is to adopt the semi-washed route first, which requires the pulper (R$6,000), reservoir and licensing, and then the washed route, which adds the fermentation tank (R$800) and control of fermentation time and temperature. A gradual switch allows testing reuse of the effluent for irrigation and monitoring spring discharge and infiltration before increasing the processed volume.

A specialist assessed a dry-processed sample of the farm's Arara coffee from the 2026 harvest. It scored 86.25 on the SCA scale, with zero defects and the maximum score (10.00) for uniformity, clean cup and sweetness (Arcanjo, 2026). Other scores were 8.50 for aroma, 8.25 for flavor, 7.50 for aftertaste, 8.00 for acidity, 8.25 for body, 8.00 for balance and 7.75 overall. The recorded descriptors were pure honey, a hint of roses, silky body, juicy citrus acidity, a short finish, very slight astringency and slight sourness.

The score exceeds the 80-point specialty coffee minimum and falls in the 85–89.99 range classified as excellent (Gregorio, 2026). The outcome is consistent with the effect of shade, which moderates temperature and wind and favors a milder beverage (Mancuso; Soratto; Perdoná, 2013), and supports the assumption that the coffee can be sold as specialty. Because the assessment used a single dry-route sample, the model offers no evidence that the wet routes increase the score. Their advantage is based on the value perceived by coffee shops, the process and the agroforestry origin.

AFS benefits such as reduced erosion, greater infiltration, more soil carbon and organic matter, and greater biodiversity (Pavan et al., 2018; Kuyah et al., 2019; Muchane et al., 2020; Solis et al., 2020) stem from the production system and apply equally to the three routes. They do not differentiate the choice. Box 1 includes only the aspects on which the routes differ.

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Box 1 – Socio-environmental aspects that distinguish the post-harvest routes

Aspect	Dry route	Semi-washed route	Washed route	Basis
Water for processing	Washing and cherry sorting only – low	Washing and pulping – moderate	Washing, pulping and parchment washing – high	3–5 L of wastewater per liter of cherries (Matos; Lo Mônaco, 2003, cited in Rigueira et al., 2010)
Effluent load	Almost none, no pulping – low	High with pulp and mucilage – high	Greater with fermentation water (inference) – very high	COD of 6,000–7,000 mg/L, about 80 times the 90 mg/L limit (Gonçalves et al., 2006)
Risk to springs	No effluent applied to soil – low	Requires control of effluent applied in irrigation – moderate	Requires a closed loop, dilution and application away from springs – high	Excess effluent can impair infiltration (Bebé et al., 2006)
By-products	Dried husks used as fertilizer	Skin and pulp for composting	Skin, pulp and mucilage for composting	Prezotti et al. (2012); Oliveira (2022)
Local labor	Monitoring during drying. Roasting and packaging half of production	Roasting and packaging all production and 0.3 extra labor-days per bag	As in the semi-washed route, plus fermentation control	Ribaski (2007); model assumptions

Source: Prepared by the author based on the sources cited in the box.

The box highlights the central trade-off: for water and effluent, the socio-environmental ranking is dry, semi-washed and washed, the reverse of the economic ranking. This risk was not quantified as a cost because the model assumed effluent reuse for irrigation without recurring cost. If treatment is required, its additional cost will reduce the wet routes' advantage, although that advantage is considerable (R$305,000 and R$1.55 million in incremental NPV).

5. Conclusion

This study compared the economic feasibility of dry, semi-washed and washed post-harvest processing for agroforestry coffee on a farm in the Campinas region of São Paulo. Under the assumptions adopted, all three routes are feasible. The washed route has the highest return (NPV of R$1.73 million and IRR of 52.4%), followed by the semi-washed route (R$485,000 and 28.9%) and the dry route (R$180,000 and 20.6%). The ranking is reversed for water use and effluent load.

In answer to the research question, the washed route is the most suitable for this case. Although the dry route is feasible with lower water-related risk at the outset, the time to recover capital is much longer than for the washed route. Thus, provided that effluent from the washed route is managed in a closed loop and demand is confirmed, the return will be higher and faster.

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Beverage quality (86.25 points) supports sales as specialty coffee, but it was assessed only for the dry route.

The results describe scenarios contingent on assumptions, rather than forecasts. The main limitations are constant prices and zero residual value, equal allocation of shared costs, zero effluent cost, prices reported by four coffee shops without firm orders, sale of all roasted coffee without demand modeling, absence of a learning curve during the switch, and sensory assessment of just one dry-route sample. Future work should measure spring discharge and soil infiltration, convert coffee shops' interest into contracts, conduct sensory assessments of coffee from the wet routes and extend sensitivity analysis to yield, MARR and sales volume.

Statement on the use of artificial intelligence

The author used Gemini (Google) to assist with developing the questionnaire for the coffee shops, ChatGPT (OpenAI) to produce the illustration in Figure 1 based on the cited sources, and Claude (Anthropic) to assist with editing the text, translating the title and abstracts, and creating Figures 2 and 3. The author reviewed all content and assumes full responsibility for the text, data and conclusions.

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Appendix A – Questionnaire on the buyer market and willingness to pay for agroforestry coffee

Market survey: commercial feasibility and preferences of specialty coffee buyers in the Campinas region, São Paulo

Dear participant,

This questionnaire forms part of a final-year research project in Production Engineering. It seeks to identify quality requirements, purchase volumes, processing preferences and willingness to pay for specialty coffee grown in an agroforestry system (AFS) in the Campinas region of São Paulo. All information provided will remain strictly confidential and will be analyzed exclusively in aggregate.

1. Company identification and profile

1.1 Registered company name / trade name (optional):

_____

1.2 Time in the specialty coffee market: _____ years

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1.3 What is your position in the company? _____

2. Purchase volume and demand

2.1 What average volume of coffee does your company buy per month? Roasted whole bean: _____ kg/month

2.2 What average price does your company currently pay per kilogram of specialty coffee (green or roasted)? R$ _____

2.3 How often do you usually purchase coffee to replenish your stock?

( ) Weekly

( ) Every two weeks

( ) Monthly

( ) Quarterly / once per harvest

3. Required quality standard

3.1 What minimum score on the SCA (Specialty Coffee Association) scale is required for the coffee your company buys?

( ) Below 80 points (commercial / superior)

( ) 80 to 83 points (standard specialty)

( ) 84 to 86 points (high-quality specialty)

( ) Above 87 points (top specialty / microlot)

3.2 Rate the importance (1 = low importance to 5 = extremely important) of the following quality attributes in your purchasing decision:

Traceability to farm and origin: [ ]

Sensory score (SCA): [ ]

Uniform screen size and absence of defects: [ ]

Organic / agroforestry certification: [ ]

Sustainability and socio-environmental appeal of production: [ ]

4. Preferred post-harvest processing route

4.1 Which processing method has the greatest acceptance and demand among your customers?

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( ) Dry route (natural coffee, dried with skin and pulp)
( ) Semi-washed route (hulled / pulped / pulped natural)
( ) Washed route with induced fermentation
( ) No preference, provided the desired sensory score is achieved

4.2 Would your company buy coffee processed using alternative methods or fermented coffee if it had a distinctive sensory profile?
( ) Yes, with strong preference
( ) Yes, in experimental batches
( ) No

5. Willingness to pay

5.1 Given that coffee produced in an agroforestry system (AFS) combines high sensory quality with biodiversity conservation and carbon neutralization, what maximum premium over your usual price would your company pay for this product?
( ) 0% (willing to pay only the market price for conventional specialty coffee)
( ) Between 5% and 10% above the market price
( ) Between 11% and 20% above the market price
( ) More than 20% above the market price

Thank you for your cooperation!

Appendix B – Semi-structured interview guide for Fazenda do Lapa

Guide used with farm staff to collect input data for the feasibility model (Section 3.2).
Interviewee / position: _____ Date: ___/___/2026

Section 1 – Production and marketing

1.1 What coffee output (bags per year) is expected for each harvest from the start of operations through full production?
1.2 How does the farm plan to sell coffee (60 kg bags or roasted and packaged coffee), and in what proportions?
1.3 Which crops share land and infrastructure with coffee, and how are common costs allocated?

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Section 2 – Processes and equipment

2.1 Which post-harvest stages can the farm carry out for the dry, semi-washed and washed routes?
2.2 What machinery, equipment and facilities are in place or planned (drying patios, washer, huller/pulper, fermentation tank, reservoir, moisture meter and scale), and what does each cost?
2.3 What are the equipment's processing capacity and energy consumption? What is the energy source and the rate paid?

Section 3 – Water and effluent

3.1 How much water is available for coffee processing?
3.2 How would wastewater from the wet routes be handled, and what environmental licensing requirements apply?
3.3 How should processing be coordinated with the protection and restoration of the farm's springs?

Section 4 – Labor, inputs and maintenance

4.1 How many labor-days are needed per bag for harvesting, drying, hulling and bagging, and how much extra time would pulping and fermentation require?
4.2 What inputs and annual maintenance costs are expected for the equipment and the agroforestry system?

Section 5 – Quality

5.1 What coffee quality standard is the farm targeting (SCA score)?
5.2 Has a farm coffee sample undergone sensory assessment? What score did it receive and which processing route was used?

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