

Paradoxes and challenges of sustainability in family-based garlic production: a qualitative analysis based on the Triple Bottom Line concept in the Contestado region (SC), Brazil

Paradoxos e desafios da sustentabilidade na produção de alho na agricultura familiar: uma análise qualitativa baseada no conceito Triple Bottom Line na região do Contestado (SC), Brasil

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ABSTRACT

Family farming plays a strategic role in promoting food and nutrition security and sustainable rural development in Brazil. Garlic production in the Contestado region, Santa Catarina State, represents an agricultural activity marked by significant paradoxes and sustainability challenges. This study analyzes the sustainability of garlic production from the perspective of the Triple Bottom Line (TBL) framework, encompassing its economic, social, and environmental dimensions. A qualitative, descriptive study was conducted in 2024 using semi-structured interviews with ten family farmers and six extension specialists and researchers, complemented by field observations and document analysis. The findings indicate that, despite the high economic importance and strong sociocultural embeddedness of garlic production, its sustainability is constrained by interconnected factors. Economically, the main challenges include high production costs, price volatility, and dependence on external inputs. Socially, garlic farming contributes to community cohesion and the preservation of traditional knowledge but faces challenges related to family succession and rural youth outmigration. Environmentally, limitations persist in the adoption of sustainable practices, particularly regarding soil management and reduced reliance on agricultural inputs. The integrated analysis highlights paradoxes between the economic importance of garlic production and its environmental constraints, as well as between its cultural significance and the fragility of intergenerational continuity. These findings suggest that enhancing the sustainability of garlic production requires integrated strategies that reconcile economic, social, and environmental dimensions through more coordinated public policies, broader access to appropriate technologies, strengthened extension services, and greater recognition of local production.

Keywords: Rural development; Economic viability; Generational succession; Soil management.

RESUMO

A agricultura familiar desempenha papel estratégico na segurança alimentar e nutricional no desenvolvimento rural sustentável no Brasil, tendo a produção de alho na região do Contestado, em Santa Catarina, como exemplo de atividade marcada por paradoxos e desafios. Este artigo analisa a sustentabilidade dessa cultura sob a perspectiva do modelo *Triple Bottom Line* (TBL), que integra dimensões econômica, social e ambiental. A pesquisa qualitativa e descritiva, foi realizada em 2024 e utilizou entrevistas semiestruturadas com dez agricultores familiares e seis técnicos e pesquisadores, além de observações de campo e análise documental. Os resultados evidenciam que, embora o alho apresente elevada relevância econômica e forte enraizamento sociocultural, sua sustentabilidade é limitada por fatores interdependentes. Na dimensão econômica, destacam-se os elevados custos de produção, a volatilidade de preços e a dependência de insumos externos. Na dimensão social, a atividade contribui para a coesão comunitária e a preservação de saberes tradicionais, mas enfrenta dificuldades relacionadas à sucessão familiar e à saída de jovens do meio rural. Na dimensão ambiental, observam-se limitações na adoção de práticas sustentáveis, especialmente no manejo do solo e na redução do uso de insumos. A análise integrada revela paradoxos entre a relevância econômica da atividade e suas limitações ambientais, bem como entre sua importância cultural e a fragilidade de sua continuidade geracional. Conclui-se que a sustentabilidade da produção de alho depende de ações integradas que conciliem estas dimensões, incluindo políticas públicas mais articuladas, ampliação do acesso a tecnologias apropriadas, fortalecimento da assistência técnica e valorização da produção local.

Palavras-chave: Desenvolvimento rural; Viabilidade econômica; Sucessão geracional; Manejo do solo.

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Introduction

The persistence of hunger and food and nutrition insecurity underscores the structural limitations of contemporary agrifood systems. According to *The State of Food Security and Nutrition in the World* (FAO, 2024), approximately 733 million people experienced hunger in 2023, jeopardizing the achievement of Sustainable Development Goal 2 (Zero Hunger). If current trends continue, an estimated 582 million people will still be affected by chronic undernourishment by 2030. Against this backdrop, family farming plays a strategic role in advancing food and nutrition security and sustainable development through the integration of economic, social, and environmental dimensions, as conceptualized by the Triple Bottom Line (TBL) framework.

In Brazil, family farming is one of the cornerstones of food and nutrition security, contributing substantially to domestic food supply, agricultural diversity, and the social reproduction of rural households (Leite and Leite, 2022). Nevertheless, the sector faces persistent challenges associated with production intensification, dependence on external inputs, and limited competitiveness in agricultural markets (Tiozo and Bertolini, 2021; Silva and Peixinho, 2023).

In the state of Santa Catarina, garlic production is concentrated in the Contestado region, which accounts for more than 60% of the state's total output (EPAGRI, 2022). Predominantly based on family farming, garlic production combines income generation with strong cultural embeddedness, as production practices are transmitted across generations and continuously reinterpreted (Lima, 2021). However, the competitiveness of regional garlic production has been increasingly undermined by rising production costs, environmental degradation associated with the intensive use of agricultural inputs, and competition from imported garlic, particularly from China, Argentina, and Spain (FAO, 2021; EPAGRI, 2022; CONAB, 2024a). In the Santa Catarina Highlands, the estimated 2025/26 garlic harvest reached 8,635 metric tons, representing a 19% increase over the previous season. The municipalities of Curitibanos, Fraiburgo, Lebon Régis, and Frei Rogério, where this study was conducted, are the region's leading producers, accounting for approximately 80% of the state's garlic production and involving more than 2,000 farming families (EPAGRI, 2026).

These dynamics are closely associated with the process of conservative agricultural modernization, which intensified agricultural production without addressing structural inequalities, thereby increasing technological dependence and placing additional pressure on the profitability of family farming (Noronha et al., 2023). Although garlic production offers high economic returns per hectare and holds considerable sociocultural significance, it also reveals important paradoxes concerning profitability, environmental sustainability, and the long-term viability of rural livelihoods (Khan et al., 2024).

Against this background, this study examines the sustainability challenges and paradoxes associated with family-based garlic produc-

tion in the Contestado region of Santa Catarina through an integrated analysis of its social, economic, and environmental dimensions, drawing on the TBL framework (Elkington, 1998; Nogueira et al., 2023).

Theoretical framework

Family farming and pathways to sustainability

Agricultural modernization driven by the Green Revolution from the 1960s onward resulted in substantial gains in productivity but also generated significant negative externalities, including soil degradation, environmental contamination, increasing dependence on external inputs, and persistent inequalities in rural areas. Despite these challenges, family farming remains a strategic pillar of food and nutrition security, accounting for approximately 70% of the food consumed in Brazil (Maciel et al., 2022).

Beyond its economic importance, family farming contributes to the conservation of natural resources through production diversification, sustainable soil management, and the adoption of agroecological practices that strengthen the autonomy of rural households and enhance the sustainability of production systems (Antonio and Assis, 2024). In doing so, it reinforces food sovereignty and promotes sustainable rural development (Mior et al., 2021). However, its capacity to adopt sustainable practices and access differentiated markets varies according to factors such as access to public policies, social capital, agricultural extension services, and the level of productive organization (Grisa and Schneider, 2014; Lourenço et al., 2023).

Diversified production systems generally exhibit greater economic and environmental resilience, whereas specialized systems that rely heavily on external inputs tend to be more vulnerable to market fluctuations and climatic variability (Mior et al., 2021; Maciel et al., 2022). Within this context, analytical approaches capable of capturing the complexity of family farming production systems by integrating their economic, social, and environmental dimensions become essential.

The TBL framework provides a valuable analytical lens for assessing sustainability in agricultural systems by integrating these three dimensions in a balanced manner and informing both production practices and public policies aimed at strengthening rural development (Loviscek, 2021; Oftedal et al., 2021; Maciel et al., 2022).

Connecting people, planet, and profit in family farming

The TBL concept, proposed by Elkington (1998), expands the traditional notion of organizational performance by incorporating social (*people*) and environmental (*planet*) dimensions alongside economic performance (*profit*). Within the context of family farming, this framework enables the simultaneous assessment of economic viability, the social reproduction of rural households, and the conservation of natural resources (Nogueira et al., 2023).

Recent studies, however, indicate that the practical implementation of the TBL framework in agricultural systems faces significant

challenges. Oftedal et al. (2021) and Nogueira et al. (2023) argue that economic considerations frequently outweigh social and environmental concerns, particularly under conditions of strong pressure to maintain profitability. Conversely, studies on agroecological systems report a more balanced integration of the three dimensions, although such systems are often characterized by smaller production scales and limited market opportunities (Buralli et al., 2021).

Operationalizing the TBL framework requires the development of indicators capable of capturing the complexity of family farming production systems. In this regard, indicators such as net profit margin, income stability, the retention of family labor, intergenerational farm succession, and soil quality are essential for a comprehensive assessment of sustainability (Maciel et al., 2022).

From an economic perspective, sustainability is associated with value addition, access to differentiated markets, and the strengthening of collaborative marketing networks (Rêgo and Godoi, 2022). From a social perspective, key aspects include job creation, intergenerational farm succession, and the retention of rural families, despite persistent structural constraints related to access to land, credit, and agricultural extension services (Tonezer et al., 2022). From an environmental perspective, production intensification in the absence of sustainable management practices tends to exacerbate negative impacts such as soil degradation, biodiversity loss, and the excessive use of chemical inputs, thereby reducing the resilience of agroecosystems (Khan et al., 2024). Accordingly, practices such as efficient water management, the rational use of agricultural inputs, production diversification, and the adoption of agroecological principles are fundamental to balancing the economic, social, and environmental dimensions of sustainability (Buralli et al., 2021; Antonio and Assis, 2024).

Taken together, the TBL framework provides a valuable foundation for understanding the sustainability challenges facing family farming by highlighting the interdependencies and trade-offs among economic performance, social well-being, and environmental conservation.

Garlic production in the Brazilian context

Garlic production occupies a strategic position within Brazil's agrifood system owing to both its high domestic consumption and the country's dependence on imports. Brazil is among the world's largest garlic consumers, with an estimated annual per capita consumption of approximately 2 kg. However, domestic production remains insufficient to meet national demand, making the country heavily reliant on imports, particularly from China, Argentina, and Spain (FAO, 2021; CONAB, 2024a). This dependence exposes the garlic value chain to fluctuations in international markets and to competition from lower-priced imports (EPAGRI, 2024).

Whereas countries such as China achieve yields exceeding 20 metric tons per hectare through intensive technological adoption, mechanization, and large-scale production, Brazilian garlic production exhibits greater variability and is more sensitive to climatic and

structural constraints (FAO, 2021). Within Brazil, garlic production is concentrated in states such as Minas Gerais, Goiás, Bahia, and Santa Catarina. Regions characterized by higher levels of technological development generally achieve greater productivity and production efficiency, whereas family farming systems, predominant in Santa Catarina, face greater challenges related to production scale, input costs, and dependence on manual labor (Carvalho et al., 2022; Uekubo et al., 2024).

In Santa Catarina, particularly in the Contestado region, garlic production has become historically established through the combination of favorable soil and climatic conditions, cultivar adaptation, and the accumulation of locally developed technical knowledge. Beyond its economic importance, garlic production has a strong sociocultural dimension, contributing to income generation and supporting the retention of rural families (Figueiró and Renk, 2019; EPAGRI, 2022).

Sustainability of garlic production

Among the various production systems within family farming, garlic production stands out in the state of Santa Catarina, particularly in the Contestado region. Despite its economic and cultural significance, the sector faces climatic, structural, and market-related challenges that undermine its competitiveness (Carvalho et al., 2022). Garlic production is highly labor- and input-intensive, and production costs have increased substantially in recent years. Its vulnerability is further exacerbated by climate instability and by the financial and technological constraints faced by family farmers (EPAGRI, 2024).

Conservation practices, such as crop rotation, cover cropping, and green manuring, are widely recognized for their contributions to soil conservation and the sustainability of production systems. However, their adoption remains limited due to insufficient agricultural extension services, restricted access to appropriate technologies, and the economic constraints faced by producers (Antonio and Assis, 2024).

These limitations are further intensified by growing economic pressures on garlic production. The replacement of traditional garlic-growing areas with crops offering higher short-term returns, such as soybean, highlights the tension between short-term economic strategies and the long-term sustainability of production systems (EPAGRI, 2024). In addition, competition from imported garlic, particularly from China, Argentina, and Spain, further intensifies these pressures despite the implementation of antidumping¹ measures. In Santa Catarina, production costs have increased by approximately 300% in less than a decade, compromising the economic viability of many family farmers (CONAB, 2024a; Uekubo et al., 2024).

¹ Dumping refers to the practice of exporting goods at prices lower than those charged in the exporting country's domestic market or below production costs, thereby constituting a form of unfair competition. To protect domestic production, Brazil has imposed antidumping duties on garlic imports from China since 1995 through the application of an additional tariff on imported products (Gecex Resolution No. 181, March 30, 2021).

Although the TBL framework is widely used as an analytical reference, its application to agricultural systems remains subject to important limitations. Studies indicate that, in practice, economic considerations often prevail over social and environmental concerns, particularly in contexts characterized by strong pressure to maintain profitability (Ofstedal et al., 2021; Nogueira et al., 2023). By contrast, agroecological systems tend to achieve a more balanced integration of these dimensions, albeit generally at a smaller production scale (Burralli et al., 2021).

Taken together, these findings suggest that the effective implementation of the TBL framework in family farming depends on structural conditions that enable the reconciliation of economic viability with sustainable practices, a challenge that remains unresolved across many agricultural production systems.

Methodology

This study adopts a qualitative, applied, and descriptive-analytical research design. Its empirical focus is family-based garlic production in the Contestado region of Santa Catarina, analyzed through the TBL framework. A qualitative approach was chosen because it enables an in-depth understanding of farmers' perceptions, practices, and strategies, emphasizing analytical depth and interpretive rigor rather than statistical representativeness (Sousa and Santos, 2020; Sampaio and Lycarício, 2021).

The study included ten family farmers engaged in garlic production, who were purposively selected according to the following criteria: direct involvement in garlic production, a minimum of five years of farming experience, eligibility under Law No. 11,326/2006, and location in the municipalities of Curitiba and Frei Rogério, which account for a substantial share of regional garlic production. Participants were selected to ensure diversity in production scale, cultivation systems, and marketing strategies. In addition, six extension specialists and researchers affiliated with the Santa Catarina Agricultural Research and Rural Extension Agency (EPAGRI) [*Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina*] and the Federal University of Santa Catarina (UFSC) [*Universidade Federal de Santa Catarina*] were interviewed to enable data triangulation. Data were collected through semi-structured interviews, document analysis based on reports published by EPAGRI and CONAB, and field observations recorded in a field journal.

Data collection was conducted between June and September 2024 through individual semi-structured interviews based on a protocol inspired by the MADERUS methodology (Nepomoceno et al., 2023), an instrument developed to assess sustainability among family farming households. The interviews addressed the economic, social, and environmental dimensions of sustainability. All interviews were audio-recorded with participants' informed consent and subsequently transcribed verbatim. To ensure anonymity, family farmers were

identified by the letter "A" (A1–A10), whereas extension specialists and researchers were identified by the letter "T" (T1–T6).

Two interview guides were developed for the study, both organized into four thematic sections: the social, economic, and environmental dimensions, and rural sustainability. The interview guide designed for extension specialists and researchers comprised twenty questions, evenly distributed across the four sections. The guide administered to family farmers also consisted of twenty questions but provided more detailed coverage of the social and economic dimensions.

The number of participants was determined according to the principle of theoretical saturation (Baumgartner, 2022). Data collection and analysis were conducted concurrently, and interviews lasted 50 minutes on average. Following the tenth interview with family farmers, the main themes, including production costs, economic challenges, farm succession, environmental practices, and market relations, began to recur without the emergence of new substantive insights, indicating that theoretical saturation had been achieved.

The use of theoretical saturation is consistent with the qualitative research literature, which emphasizes that sample adequacy should be assessed based on the analytical depth and interpretive richness of the empirical material rather than on its proportionality to the study population. As Baumgartner (2022) argues, once sufficient analytical depth has been achieved, sample size becomes a secondary consideration.

The municipalities of Curitiba and Frei Rogério comprise 674 family farming establishments, of which 317 cultivate garlic, representing approximately 47% of all family farms in the study area (EPAGRI, 2023).

The data were analyzed using content analysis (Bardin, 1977), with the support of QDA Miner software. The analytical process comprised three stages: (i) pre-analysis, involving an initial reading and organization of the empirical material; (ii) data coding and exploration, which resulted in 47 initial categories (Table 1) that were subsequently grouped into four analytical categories associated with the social, economic, and environmental dimensions of family farming; and (iii) data treatment, inference, and interpretation, conducted in dialogue with the theoretical framework (Sampaio and Lycarício, 2021). The bibliographic references were identified and managed using Rayyan and Zotero.

The study strictly adhered to the ethical principles established by National Health Council Resolution No. 466/2012, ensuring participant anonymity and the confidentiality of all information collected. Ethical approval was granted by the Research Ethics Committee (REC) under approval number 7.001.068, issued on August 12, 2024.

Results and discussion

Data analysis was based on the triangulation of evidence obtained from semi-structured interviews with family farmers, extension specialists, and researchers, complemented by a review of the scientific literature on garlic production and sustainability in family farming.

Table 1 – Data analysis categories.

Category	Code	Count	% of codes	Cases	% of cases
Social Dimension	Family	26	2.90	10	62.50
	Education	24	2.70	10	62.50
	Occupation	28	3.25	10	62.50
	Health	15	0.70	10	62.50
	Infrastructure and Technology	13	1.50	9	56.30
	Satisfaction with Rural Life	20	2.30	11	68.80
	Farm Succession	16	3.50	16	100.00
	Extension and Technical Assistance	31	3.50	15	93.80
	Community and Cooperatives	13	41.50	9	56.30
	Social Sustainability	20	2.30	7	43.80
	Social Challenges and Constraints	38	4.30	6	37.50
	Social Strategies and Initiatives	30	3.40	6	37.50
	Social Indicators and Metrics	12	1.40	6	37.50
	Identification with Garlic Farming	12	1.40	8	50.00
Economic Dimension	Labor	20	2.30	13	81.30
	Farm Characteristics	12	1.40	10	62.50
	Income	12	1.40	9	56.30
	Marketing	18	2.00	11	68.80
	Farm Management	14	1.60	11	68.80
	Crops Produced	25	2.80	11	68.80
	Credit and Financing	23	2.60	10	62.50
	Investments	14	1.60	10	62.50
	Profitability	17	1.90	8	50.00
	Productivity	13	1.50	7	43.80
	Economic Challenges and Constraints	63	7.10	11	68.80
	Economic Strategies and Initiatives	21	2.40	7	43.80
	Economic Sustainability	12	1.40	6	37.50
	Economic Indicators and Metrics	11	1.20	6	37.50
Environmental Dimension	Public Policies	8	0.90	5	31.30
	Geographical Indication	6	0.70	4	25.00
	Water Sources	10	1.10	10	62.50
	Energy Sources	11	1.20	10	62.50
	Soil Management Practices	19	2.10	13	81.30
	Pesticides, Insecticides and Herbicides	27	3.10	13	81.30
	Waste and Residues	11	1.20	10	62.50
	Environmental Challenges and Constraints	53	6.00	12	75.00
	Environmental Strategies and Initiatives	28	3.20	7	43.80
	Environmental Sustainability	16	1.80	6	37.50
TBL	Environmental Indicators and Metrics	7	0.80	5	31.30
	Research Areas	8	0.90	6	37.50
	Sustainable Strategies and Practices	29	3.30	16	100.00
	Garlic versus Other Crops	16	1.80	8	50.00
	Partnerships	14	1.60	37	37.50
	Impact on the Rural Community	8	0.90	5	31.30
	Sustainability of Garlic Production	13	1.50	5	31.30
	Sustainability of Family Farming	10	1.10	5	31.30
	Challenges for Family Farming	2	0.20	12	12.50

Source: Uekubo et al. (2024).

Sixteen interviews were analyzed using content analysis, enabling the identification of empirical categories organized according to the economic, social, and environmental dimensions of the TBL framework. These findings were further supported by field observations and document analysis.

This analytical approach ensured greater alignment between the theoretical framework and the empirical evidence, revealing that family-based garlic production in the Contestado region constitutes a production system characterized by interrelated challenges. Although garlic production is of considerable economic and sociocultural significance to the region, its sustainability is constrained by factors such as market volatility, rising production costs, and weaknesses in intergenerational farm succession. Together, these factors expose the tensions among economic viability, social reproduction, and environmental conservation.

The analysis of the interview data enabled the identification and systematization of the principal challenges faced by family farmers, as presented in Table 2.

The findings indicate that the sustainability of garlic production is constrained by interrelated economic, social, and environmental limitations that reinforce one another. These results corroborate previous studies identifying the growing economic pressure on family farming resulting from rising production costs and the instability of agricultural markets (Carvalho et al., 2022; Khan et al., 2024). Likewise, the difficulties associated with intergenerational farm succession observed among the interviewees are consistent with the findings of Tonezer et al. (2022) and Figueiró and Renk (2019), who identify rural youth outmigration as one of the principal challenges to the continuity of family farming in Brazil.

Economic dimension: potential profitability and structural vulnerability

The economic dimension emerged as the central theme in the interviews, reflecting farmers' concerns regarding the economic viability of garlic production. As one participant explained, "Garlic production is profitable, but production costs are very high. If market prices fluctuate, profitability quickly becomes uncertain" (A1).

Although garlic production is recognized for generating a high gross production value per hectare, the data presented in Table 3 indicate that the continuous increase in production costs has substantially reduced producers' profit margins. This finding is consistent with Carvalho et al. (2022), who identified agricultural inputs, labor, and field operations as the main cost components of garlic production in Brazil. Furthermore, data from CONAB (2024b) reveal an upward trend in production costs over recent years, further eroding the profitability of garlic production.

This situation is compounded by fluctuations in farm-gate prices, which interviewees identified as a major source of economic uncertainty. The interviews revealed that producers face considerable difficulty in forecasting the profitability of garlic production and planning long-term investments in the face of high market volatility. As one participant remarked, "We plant without knowing what price we'll get for our crop" (A4). This perception is consistent with the CONAB (2024a) analysis, which reports substantial seasonal fluctuations in garlic prices, and with the findings of Carvalho et al. (2022), who highlight producers' high exposure to market conditions and fluctuations in production costs.

The integrated analysis of the data reveals a growing mismatch between rising production costs and the prices received by producers,

Table 2 – Main sustainability challenges of garlic production in family farming.

Dimension	Main Challenges
Economic	High production costs; price volatility; dependence on external inputs; competition from imported garlic; limited access to credit.
Social	Rural youth outmigration; challenges related to family farm succession; labor-intensive production; low social recognition of agricultural activity.
Environmental	Intensive use of agrochemicals; limited adoption of sustainable practices; technical and financial constraints; lack of incentives.

Table 3 – Production costs of garlic cultivation in Santa Catarina, Brazil (R\$ ha⁻¹)

Cost item	2016	2017	2018	2019	2020	2021	2022	2023	2024
Machinery operations	2,860.69	3,127.52	3,212.29	3,345.13	5,583.62	8,381.24	9,743.43	9,526.38	9,529.50
Temporary labor	12,035.04	13,285.04	15,655.45	15,487.50	18,817.50	18,505.00	25,650.00	24,037.50	34,860.00
Farm manager	44.00	46.84	47.72	49.88	52.24	55.00	60.60	66.00	70.60
Seed garlic	10,220.00	11,620.00	14,280.00	14,280.00	28,440.00	35,460.00	23,220.00	23,760.00	41,400.00
Fertilizers	4,869.00	5,224.00	5,741.13	7,374.00	7,259.04	18,034.01	17,776.98	13,579.31	12,278.76
Agrochemicals	2,624.65	2,953.53	3,165.80	3,173.65	4,996.65	6,765.03	7,067.10	6,116.28	6,244.84
Other inputs	1,727.70	2,086.50	2,400.00	3,265.00	2,850.00	5,845.00	5,030.00	5,291.50	4,707.00
Total garlic production cost	34,381.08	38,343.43	44,502.39	46,975.16	67,999.05	93,045.28	88,548.11	82,376.97	109,090.70

Source: CONAB (2024b).

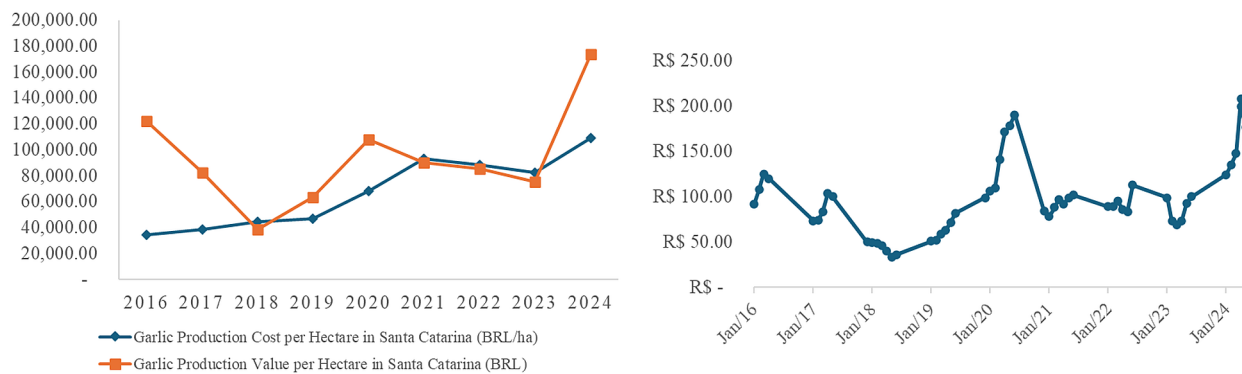


Figure 1 – Comparison of production costs, selling prices, and producer returns.
Source: CONAB (2024b); EPAGRI (2024).

indicating a progressive compression of profit margins over time, as illustrated in Figure 1. This trend is primarily driven by increasing expenditures on agricultural inputs and labor, intensifying producers' dependence on external factors and further increasing the economic vulnerability of family farmers.

A comparison between Santa Catarina (Figure 2) and Goiás (Figure 3) highlights structural differences in their production systems. Whereas garlic production in Santa Catarina is predominantly based on family farming, characterized by smaller production scales, greater reliance on family labor, and more limited access to capital and technology, production in Goiás is dominated by commercial farming operations, which benefit from more technologically advanced production systems, larger-scale operations, and a greater capacity to spread production costs.

The comparison between the two states is essential for understanding the structural differences between these production contexts and corroborates previous studies showing that family farmers generally face greater constraints in accessing capital, technology, and economies of scale (Grisa and Schneider, 2014; Maciel et al., 2022). These findings therefore suggest that the economic viability of garlic production de-

pends not only on market prices but also on the structural and institutional conditions that support different production models.

Social dimension: community cohesion and the challenges of intergenerational farm succession

From a social perspective, the findings indicate that garlic production plays an important role in maintaining local identity and strengthening community cohesion. As reported by the interviewees, "Garlic farming has been part of our families for generations, this is how we've always learned to do it" (A2), and "During the harvest, neighbors are always willing to help one another" (A5). These accounts suggest that garlic production extends beyond its economic function, serving as a social practice that reinforces community ties and supports the intergenerational transmission of traditional knowledge. This finding is consistent with Figueiró and Renk (2019), who emphasize the role of traditional agricultural activities in preserving cultural identity and reciprocal social relationships within rural communities in the state of Santa Catarina.

However, these positive social attributes are challenged by structural constraints, particularly regarding intergenerational farm succes-

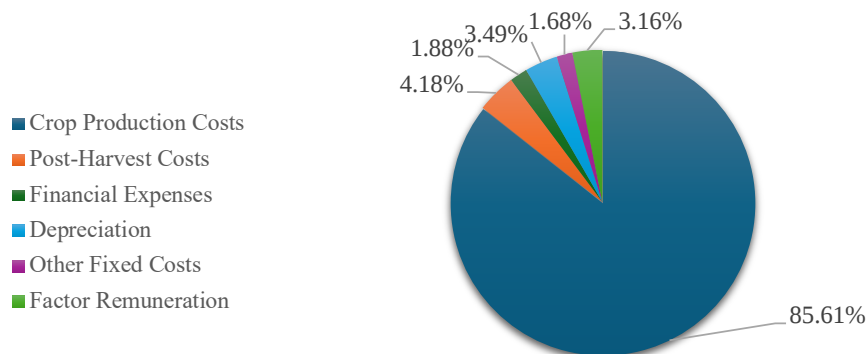


Figure 2 – Production costs of garlic in Santa Catarina.
Source: Uekubo et al. (2024, p. 90).

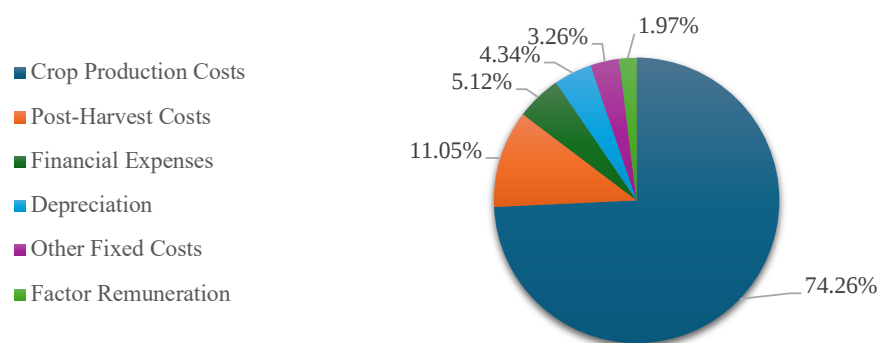


Figure 3 – Production costs of garlic in Goiás.

Source: Uekubo et al. (2024, p. 90).

sion. The qualitative data indicate that the continuity of garlic production is threatened by rural youth outmigration, as illustrated by one participant's observation: *"Young people don't want to continue farming—they'd rather move to the city"* (A7). This finding corroborates the results reported by Tonezer et al. (2022), who identify intergenerational farm succession as one of the principal challenges facing the continuity of family farming in Brazil. Similarly, Silva and Peixinho (2023) argue that limited income prospects, quality-of-life constraints, and the low social recognition associated with agricultural work reduce younger generations' willingness to remain in rural areas.

According to one of the extension specialists interviewed (T2), rural youth outmigration cannot be explained solely by economic factors. Deficiencies in infrastructure and quality of life, combined with the search for greater income stability in urban areas, reduce the attractiveness of farming as a livelihood. Moreover, changing expectations regarding work—particularly the rejection of labor-intensive activities and the growing preference for technology-based occupations—underscore the need to modernize agricultural production systems. In this context, expanding access to agricultural extension services and rural training programs could make farming more attractive and competitive, particularly for younger generations. Studies conducted by the Brazilian Agricultural Research Corporation (EMBRAPA) [*Empresa Brasileira de Pesquisa Agropecuária*] (2020) and Mior et al. (2021) demonstrate that access to innovation, technical knowledge, and appropriate technologies encourages families to remain in rural areas and strengthens the sustainability of agricultural production systems.

Taken together, these findings indicate that garlic production simultaneously promotes social cohesion while remaining vulnerable to structural challenges, revealing the tension between its cultural significance and the difficulties associated with its long-term continuity. This situation undermines the social reproduction of family farming and reinforces the need for public policies aimed at improving living conditions in rural areas, expanding rural infrastructure, and encouraging younger generations to remain in farming.

Environmental dimension: barriers to the transition toward sustainable practices

From an environmental perspective, the findings reveal a growing awareness of the importance of sustainability, yet significant barriers remain to the adoption of effective sustainable practices. As one farmer explained, *"We know we need to take better care of the soil, but we don't always have the means to do so"* (A3), illustrating the gap between environmental awareness and practical implementation.

Soil management emerged as one of the principal challenges identified in the interviews. According to the extension specialists interviewed (T1; T2), the intensive soil preparation required for garlic production promotes soil degradation and erosion, particularly during periods of heavy rainfall. Soil loss is perceived not merely as an environmental problem but as the loss of productive capital, thereby threatening the long-term sustainability of the activity (T5; T6). This perception is consistent with the findings of Tiozo and Bertolini (2021), who warn that intensive management practices increase the risk of natural resource degradation in agricultural production systems.

Although technical alternatives such as minimum tillage and conservation systems inspired by no-till farming are available, their adoption remains limited due to operational constraints, low acceptance among both farmers and agricultural workers, and restrictions associated with mechanization (T1; T2). Likewise, dependence on fertilizers and pesticides remains high, largely because of climatic conditions that favor the occurrence of crop diseases. Although progress has been made in the adoption of biological products, important challenges remain regarding their effectiveness, the technical knowledge required for their application, and the need for preventive crop management (T2).

The interviews also identified crop rotation, soil cover, and production planning as promising strategies for reducing environmental impacts. However, the implementation of these practices remains incipient, constrained by technical, economic, and cultural barriers, as well as by limited participation in training initiatives and agricultural extension programs (T1). This finding differs, at least in part, from the

results reported by Buralli et al. (2021), who observed a more balanced integration of the economic, social, and environmental dimensions in agroecological systems, albeit generally at smaller production scales.

The findings further demonstrate that the environmental sustainability of garlic production cannot be analyzed in isolation, as it is directly conditioned by the economic viability of the activity. Consequently, the transition toward more sustainable production systems depends on the combined effects of technological innovation, institutional support, and market incentives, including the recognition and appreciation of products with lower environmental impacts. These results reinforce the limitations identified by Oftedal et al. (2021) and Nogueira et al. (2023), who argue that profitability requirements frequently hinder the balance among the economic, social, and environmental dimensions proposed by the TBL framework.

Integrating the three dimensions: understanding the sustainability paradoxes

An integrated analysis of the economic, social, and environmental dimensions demonstrates that the sustainability of family-based garlic production is shaped by strong structural interdependencies. The findings indicate that the challenges identified do not occur in isolation; rather, they reinforce one another, creating a system of interconnected tensions that conditions the long-term continuity of the activity.

From an economic perspective, rising production costs and price volatility reduce profit margins and increase uncertainty, thereby limiting farmers' capacity to invest. This finding is consistent with Carvalho et al. (2022) and CONAB (2024a), who identify increasing production costs and market instability as key factors undermining the profitability of garlic production. These economic constraints directly affect the environmental dimension by limiting the adoption of conservation practices and more sustainable technologies, which often require higher initial investments or involve greater operational complexity.

At the same time, economic instability and working conditions influence the social dimension by contributing to rural youth outmigration and weakening intergenerational farm succession. This finding is consistent with the studies of Tonezer et al. (2022) and Silva and Peixinho (2023), who identify generational succession as one of the principal challenges to the continuity of family farming in Brazil. The search for greater income stability and improved living conditions in urban areas further reinforces this trend, undermining the social reproduction of family farming.

The environmental dimension, in turn, also influences the other two. Soil degradation and dependence on external agricultural inputs tend to increase production costs while reducing the resilience of production systems, thereby intensifying economic vulnerability. A similar relationship was identified by Tiozo and Bertolini (2021), who demonstrated that natural resource degradation compromises the economic sustainability of agricultural systems dependent on intensive management practices.

Within this context, two central paradoxes emerge. The first concerns the coexistence of garlic production's considerable economic importance with its reliance on a production model that simultaneously intensifies environmental pressures and increases production costs. The second lies in the contrast between the crop's strong socio-cultural significance for local identity and the growing difficulty of ensuring its long-term continuity due to its declining attractiveness to younger generations. This paradox reinforces the observations of Figueiró and Renk (2019), who emphasize the cultural value of family farming while also highlighting the social transformations that increasingly threaten its long-term reproduction.

Overall, the findings demonstrate that the sustainability of garlic production cannot be understood through isolated analytical dimensions but instead requires integrated approaches that simultaneously consider its economic, social, and environmental determinants. The TBL framework proved to be an appropriate analytical lens for revealing these interrelationships and the sustainability paradoxes that characterize family farming. At the same time, the findings corroborate the limitations identified in previous studies, according to which economic considerations tend to prevail over social and environmental concerns under conditions of strong pressure to maintain profitability (Oftedal et al., 2021; Nogueira et al., 2023).

In the case examined here, the need to ensure the economic viability of garlic production frequently constrains the adoption of more environmentally sustainable practices and influences decisions affecting intergenerational farm succession and the retention of young people in rural areas. Consequently, the effective implementation of the TBL principles depends not only on farmers' decisions but also on supportive structural conditions, institutional support, agricultural extension services, and public policies capable of reducing the tensions among the three dimensions of sustainability, as likewise observed in studies of more sustainable agricultural production systems (Buralli et al., 2021).

Conclusions

This study examined the sustainability challenges and paradoxes associated with family-based garlic production in the Contestado region of Santa Catarina through the analytical lens of the TBL framework. By triangulating evidence from interviews with family farmers, extension specialists, and researchers, together with a review of the relevant literature, the study provided a comprehensive understanding of the interdependence among the economic, social, and environmental dimensions of garlic production.

The findings demonstrate that although garlic production is characterized by considerable economic importance and strong sociocultural embeddedness, its long-term sustainability is constrained by persistent structural weaknesses. From an economic perspective, rising production costs, price volatility, and dependence on external agricultural inputs reduce both profitability and economic pre-

dictability. From a social perspective, despite its contribution to community cohesion and the preservation of traditional knowledge, intergenerational farm succession remains a major challenge owing to rural youth outmigration and the declining attractiveness of farming as a livelihood. From an environmental perspective, although some progress has been achieved, current efforts remain insufficient to overcome dependence on chemical inputs and the risks associated with natural resource degradation.

The integrated analysis of these three dimensions revealed the central paradoxes that characterize family-based garlic production. On the one hand, garlic production represents an economically important activity with strong cultural significance. On the other hand, it faces structural constraints that compromise its long-term sustainability. Two paradoxes stand out in particular: the economic–environmental paradox, reflected in the tension between potential profitability and dependence on external inputs; and the social–economic paradox, expressed in the contrast between the cultural importance of garlic production and its declining attractiveness to younger generations.

These findings reinforce the need for integrated approaches to promoting sustainability in family farming by recognizing the interdependence among the three dimensions of the TBL. From a practical perspective, they highlight the importance of more coordinated public policies, strengthened agricultural extension services, greater incentives for the adoption of appropriate technologies, and increased support for locally produced garlic.

From a theoretical perspective, this study demonstrates that applying the TBL framework to family farming makes it possible to identify not only individual sustainability indicators but also the tensions and interdependencies among the economic, social, and environmental dimensions that shape the long-term continuity of agricultural production systems.

Finally, this study is subject to certain limitations. Its findings are based on a specific geographical context and on a qualitative research design, which does not allow for statistical generalization. Future research should therefore expand the analysis to other garlic-producing regions and incorporate quantitative and comparative approaches to advance understanding of the factors influencing the sustainability of garlic production in Brazil.

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