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A Systemic Approach to the Product Life Cycle for the Product Development Process in Agriculture

Franciele Lourenço [1], Marcelo Carneiro Gonçalves [2], Osiris Canciglieri Júnior [1], Izamara Cristina Palheta Dias [1], Guilherme Brittes Benitez [1], Lisianne Brittes Benitez [3] and Elpidio Oscar Benitez Nara [1,*]

1 Industrial and Systems Engineering Graduate Program, Pontifical Catholic University of Paraná, Curitiba 80215-901, Brazil; francielelourenco@gmail.com (F.L.); osiris.canciglieri@pucpr.br (O.C.J.); izamara.dias@pucpr.edu.br (I.C.P.D.); guilherme.benitez@pucpr.br (G.B.B.)
2 Mechatronic Systems Graduate Program, University of Brasilia, Brasilia 70910-900, Brazil; marcelo.goncalves@unb.br
3 Environmental Technology Graduate Program, University of Santa Cruz Do Sul-Unisc, Santa Cruz Do Sul 96815-900, Brazil; lisianne@unisc.br
* Correspondence: elpidio.nara@pucpr.br

Abstract: For a long time, a company's Product Development Process (PDP) was seen as supporting the operations department, although PDP decisions and mistakes have a considerable impact on market performance. This is critical even in agriculture where bad habits and practices in the PDP can lead rural producers to great losses. Therefore, this research investigates the effect of the PDP on the market performance of rural products (bananas) in the southern region of Brazil, based on two analyses: (i) how sustainability practices support the PDP phases and (ii) how the phases of the Product Life Cycle Assessment (LCA) mediate sustainability practices and PDP phases. This study presents a quantitative analysis using Confirmatory Factor Analysis (CFA) and hierarchical ordinary least squares (OLS) regression of data obtained from a survey of 110 rural producers who directly participate in the banana production and planning process in southern Brazil. Our results show that sustainability practices support the PDP, and we confirm that the product development and post-development phase has an effect on market performance. In addition, we identify that in the pre-development phase of the PDP, dealing with rural products (bananas), the maturity stage of the LCA mediates sustainability. In the PDP development phase, we conclude that rural families who develop economic and environmental practices with their products, which are in the market growth phase may have reduced results. As for the post-development phase of the PDP, we conclude that when companies invest in environmental and social practices, there is a complete mediation of the effect, where these practices lose strength if the product is in the introductory and maturity phases in the market. In an original matter, our study contributes to demonstrating the value of the product life cycle for the Product Development Process in agriculture using sustainability practices through a systemic approach, filling the gap in the literature due to a lack of integrated research on these areas seen.

Keywords: sustainability practices; life-cycle assessment; product development process; market performance; systemic approach; agricultural products

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1. Introduction

The authors of [1], highlight the use of management processes based on a systemic approach in the management of organizations, which aim to perceive organizations in a more comprehensive way, integrating their various activities through a verification of the horizontal view of customer satisfaction. In this way, it is possible to obtain relevant insights to improve market performance in companies by analyzing different areas together. In this work, we opted for a theoretical lens for this systemic approach due to the objective of this

study, which is to consider different topics of research such as the Product Development Process, Life-Cycle Assessment, and sustainability.

Sustainability is divided into three practices: economic, environmental, and social. Refs. [2,3] report that the economic and environmental practices of sustainability have been the most common issues in the manufacturing industry, while the social practices have been neglected; their results confirmed these practices. Understanding the relationship between these sustainability practices in companies is essential for demonstrating to decision makers that it is necessary to find a balance between these three pillars. Individually, this task becomes more difficult, so this study proposes an analysis of sustainability interconnected with the phases of the Product Development Process (PDP) and a Life-Cycle Assessment (LCA), that is, making use of a systemic approach.

As for the PDP, [4], organizations from countries that classify themselves as developed usually make use of the innovative aspect of new products as a strategy to circumvent the problem of economic crises or increase their revenues, which consequently contributes to an increase in market performance, from the increase in the product portfolio. The authors of [5,6], see that new business competition is focused on the development of new products; therefore, it forces this area to be dynamic and flexible in organizations [7]. In the view of [8,9], it is reported that the process of developing new products is a risky activity because, just as it can bring about success, being converted directly into profits for the company, it can also be a failure, which is implied in lost expenses and investments.

One way to evaluate the PDP is through the Life-Cycle Assessment (LCA). The LCA is an approach that aggregates all the business processes related to products and allows companies to control all the information about their products throughout the life cycle, from initial conception until discard [10,11]. The LCA is an integrated approach for managing data throughout the life cycle of a product: from specification, design, manufacturing, distribution, and maintenance to recycling [12,13]. By enabling process optimization and integration and reducing costs, the LCA can manage data concerning a product and all the internal and external factors involved in the development of said product. Ref. [12] the considers LCA as a system that supports the evolution and change in data during the product life cycle.

The globalized reality of organizations is increasingly competitive, and understanding what actions are necessary to be performed internally and externally in companies is not a matter of choice but of survival. This study sought to contribute strategically to an increase in market performance of rural producers in southern Brazil. These producers are responsible for production and trade in the Brazilian banana market. This market stands out for having great social and economic relevance, serving as a source of income for many rural producer families, which allows for the generating of jobs in the countryside and in cities and for the promoting of development of the regions directly and indirectly involved in this production, whether nationally or internationally [14].

Brazil is the fourth largest banana producer in the world, and annually harvests 7 million tons of the fruit for the domestic market. Currently, cultivation areas are concentrated in the south, southeast and northeast regions of Brazil. Banana production has an important social role, since this fruit can be produced all year around, which presents benefits for the generation of employment and income for rural producers [15].

From this context, it becomes relevant to assess how the social, environmental, and economic practices of sustainability are associated with the pre-development, development, and post-development stages of banana production, with the intention of allowing those involved to achieve greater market performance. In addition, it is important to know how the LCA phases are associated with the PDP and sustainability practices in order to contribute to the improved market performance of these banana producers. Evaluating these relationships in an integrated way necessitates the use of a systemic approach as it allows the measuring of the impact on the entire system from the combination and interrelationships of its subsystems to enable effective decision-making.

To achieve the aim of this research, the following specific objectives were formulated: (i) identify and collect relevant data through a survey provided to banana producers in the southern region of Brazil; (ii) describe and detail the research methodology adopted, including the process for treating and analyzing the collected data; and (iii) address and respond to the main research questions related to sustainability in agriculture, the Life Cycle Assessment, the Product Development Process, and market performance.

To achieve the first specific objective, a survey was conducted with banana producers in the southern region of Brazil. Subsequently, to address the second specific objective, the following steps were taken: (i) the treatment and analysis of the database; (ii) the formulation of hypotheses for the research; (iii) the proposition of a conceptual model relating to the topics of sustainability, the Life Cycle Assessment, the Product Development Process, and market performance; (iv) the application of an econometric study using a Confirmatory Factor Analysis (CFA) and a hierarchical ordinary least squares (OLS) regression; (v) validation of the hypotheses raised; and (vi) the application of methods for response bias, endogeneity, and robustness to the results. Finally, for the third specific objective, an analysis of the main contributions and practical implications was conducted.

As a contribution, it was possible to verify how the area of sustainability, integrated with the PDP and the LCA, can contribute to improved market performance for banana producers. Moreover, a preliminary study was carried out by [16], who carried out a systematic review of the literature to verify relevant papers that addressed the themes of sustainability, the Life-Cycle Assessment (LCA), and the Product Development Process (PDP) using a construct technique. As a result, no study was found for these topics, thus a gap in the literature was established for carrying out the research.

2. Theoretical Background

2.1. Product Development Process (PDP) and Market Performance

The PDP is conceptually defined as the complete process needed to take a product from concept to market availability. It also can introduce an old product to a new market or renew an existing product. This includes identifying a market need, conceptualizing a solution and the product itself, product development, launching the product, and collecting feedback. Currently, there are several PDP models; they vary in relation to the number of subprocesses or activities needed for development, and their stages go through the generation of the concept, the product design, the preparation for production, and the product launch into the market [6]. Even though PDP models can be different from one company to another [17], all types of businesses stand by the fact that demand must be big enough to make creating and launching a new product worthwhile. In other words, the company's decision to meet the needs of the final customer is driven by where the company is in terms of product life cycle management.

Regardless of the different approaches to the PDP, in this context, the PDP is approached as one aspect of strategic product planning through incorporating environmental issues into corporate culture and business decision-making for sustainability. The main approaches in the literature on sustainable product development are focused on single products and do not consider product architecture and implications during the stages of use and final disposal [18]. For this reason, there is increasing pressure on the timing of the product launch into the market, which comes into conflict with the analytical approach normally required when using conventional environmental management accounting (EMA) tools such as the Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) [19]. Refs. [18,20,21] say that there are several existing methods focused on improving the sustainability performance of products, and the most frequent topic approach used in product development is the Life-Cycle Assessment (LCA). An LCA is designed to measure a product's impacts at all stages of its life cycle, considering the relative importance of the specific indicators selected previously [18]. Moreover, rather than focusing on explaining the definition and conceptualization of the PDP, this research explains and supports PDP

initiatives and LCA implementations for an improved environmental performance and sustainable market performance.

2.2. Product Life-Cycle Assessment (LCA)

The life cycle of a product comprises all the stages that the product goes through, from its conception to its final disposal after use. In simple terms, the product life cycle stages are introduction, growth, maturity, and decline. References to the product life cycle started appearing around the beginning of 2000, and since then, the concept has developed as organizations have also had to adapt to this evolution. Life Cycle Assessment is a technique for assessing the environmental practices associated with a product over its life cycle [21]. The most important applications are following: (i) the analysis of the contribution of the life cycle stages to the overall environmental load, usually with an aim to prioritize improvements of products or processes; and (ii) the comparison between products designed for internal use. The LCA is a primarily anthropocentric approach focused on processes that occur in the techno sphere (economies and societies) and (even if only partially) in their environment. Therefore, the effects of natural resource consumption are quantified based on the balance between what human activities remove and what remains [22].

Global awareness of product life cycle issues and the competitive advantages of implementing end-of-life recovery strategies such as reuse, remanufacturing, and recycling are prerequisites for more sustainable business actions [23]. Ref. [24] compliments this notion by saying that the LCA is an analysis technique used to assess the environmental loads of products or production processes. The LCA also aims to compare the potential environmental impacts associated with products, processes, systems, or supply chains throughout their life cycle [24]. Therefore, it allows for the optimization and integration of processes and cost reduction; In this way, it can manage the data related to a product and all the internal and external factors involved in the development of said product, that is, it is seen as a system that supports the evolution and change in data during the product life cycle [25]. In general, the LCA deals with the behavior of products and/or services, from their launch to their decline, i.e., it concerns the set of production line stages, which may vary from one product to another, given their characteristics, such as sales, marketing, profit, and so on.

This is why it is important that companies have full knowledge regarding the management of their business, and also about design tools, data warehouse systems, and support systems for the maintenance, repair, and disposal of products [26]. One of these tools is eco-design, which gathers a large amount of design information and covers the product life cycle from the raw material acquisition phase to the recycling and disposal phase in order to predict its effects on the environment [27].

The LCA is indirectly concerned with the origins of resources and materials, as their provenance can influence its results [28]. Therefore, Ref. [29] investigated product life cycle issues and end-of-life recovery management to support product design decision-making by adopting closed-loop material flow. Consequently, the LCA considers the aggregative inputs, such as resources and utilities, and undesirable outputs in relation to environmental effects that span the entire product life cycle [19]. One of these inputs is product designers, who can quantify the environmental impacts of their designs, selecting the designs that have the most critical factors for developing a green brand [19]. Thus, the model's emphasis on decision-making is in line with recent developments in the field of sustainability accounting [30,31]. So, one of the premises that can be integrated with sustainability accounting is long-term product design decisions. Product design decisions can significantly affect future financial and environmental performance [32]. Therefore, we must consider information systems, conceptual designs, and time to market, among others, which can collaborate through more accurate, reliable, complete, and relevant information to support the initial stages of product design selection [19].

2.3. Sustainability

It is known that the concept of sustainability, although questioned, worrying, and considered current by many, is a concern that has persisted since the 1970s. Therefore, it is not only seen as a problem of today. Facing the challenges of sustainability is necessary because we need, according to [33], to understand that this is an issue of relationships and a way of thinking, and not only an issue of technology. Without natural resources, a business will not survive, and we need to get out of our comfort zone and understand that ethical behavior brings economic gains. This cannot be undertaken just for financial reasons, but also for man's existence and survival.

Discussions about sustainability have been growing day by day since humanity's awareness of environmental problems and the scarcity of natural resources. As sustainability officially emerged through the World Commission on Environment and Development (WCED), its goal was to disseminate this concept and propose a global agenda to raise awareness. Several events took place, such as Stockholm (1972), WCED, Copenhagen (1980), the Brundtland report (1987), Rio (1992), and the Kyoto Protocol, among others. The impacts are often masked by substitution agreements or financial compensation, yet the resources required are not fully repaid, nor do they guarantee the continuity of humanity. More importantly, concerns are being configured and reconfigured, especially when it comes to decision making. Organizations yearn for sustainable alternatives to maintain their strategic and competitive position in the market. Strategic actions have been developed based on product design. In the last decade, sustainability has become a key emphasis in product design, focusing on the integration of environmental, and social economic concerns [29].

Identifying ways to improve the sustainability of production systems using sustainability assessment tools such as the LCA requires a broad set of metrics that demonstrate impacts relative to planetary boundaries [34]. "Sustainability assessment covers the organization's entire supply chain, including stakeholder interests and end-of-life instructions for products" [35]. More action is required to promote an understanding that the environment is not something that serves only to exploit and generate wealth. Regarding the concept of sustainability, Ref. [36] states that it does not need to be concerned with the development or the protection of the environment, but rather what kind of development should be implemented from now on, since after the creation of clean technologies—the new competitive advantage in the market—these will be complementary to development and the environment. For this reason, the three dimensions of sustainability are divided into the following: environmental, economic, and social.

Ref. [36] characterizes the dimensions as follows: the environmental dimension is seen as a production model compatible with the ecosystem, that is, it produces/consumes while maintaining the self-repair capacity or resilience of the ecosystem. The economic dimension, aims to increase the efficiency of production and consumption, with increased natural resource savings through technological innovation, i.e., eco-efficiency. The last dimension is the social dimension, which is a sustainable society, presupposing that there is social justice and that all citizens have the minimum necessary for a dignified life. Regarding the use of resources, another important point is the life cycle of products, with phases ranging from development (start/design), introduction to the market, product growth and maturity, and product decline. It turns out that every product (good or service) generates some negative impact on the environment, in any of the stages of its existence, including resource extraction, production, distribution, consumption, and post-use. Although the concept of sustainability is advocated for from a political perspective, in general, economic practices are given more significance than environmental and social practices, the latter often being ignored. This explains the fact that decision-making values business opportunities (economic dimension) and uses environmental capital only in an exploitative way, which in turn "forces" organizations to be environmentally responsible (the environmental dimension). If sustainable development initially focused more on the environmental dimension, gradually, obligations concerning the social and economic

dimensions were added [35]. Financial and non-financial factors should also be taken into consideration in relation to the costs and benefits of environmental issues. This can thus be achieved by including quantitative and qualitative data from a broader, cross-company perspective in environmental impact assessments [18].

Therefore, organizations should implement various strategies according to the interests of their stakeholders and best practices to make their processes environmentally efficient and socially and economically viable [35]. However, what we have been noticing is a reconfiguration of interests, taking into consideration that the three dimensions of sustainability, sustainable development, sustainability, and corporate social responsibility are themes that have constantly been growing in current discourses, leading to new goals and strategies to achieve multiple objectives, but involving only one main target—environmental sustainability, counting on the engagement of those involved and focusing on the three dimensions.

Furthermore, the PDP is driven by the LCA, and sustainability can be considered as a trend in all organizational activities so that when developing products, companies think about economic, social, and environmental practices at all stages of production, with the aim of making the supply chain more sustainable, long-lasting and with possibilities for profit generation. Consequently, market performance will depend on the behaviors exercised by the company, which must take into consideration the generation and dissemination of information from different areas within the organization. This is crucial to guarantee success, high competitiveness, and profitability.

2.4. Framework-Based Systemic Approach

According to [37], the systemic framework-based approach is based on systems theory, which consists of a multi and interdisciplinary study of systems and is the process in which one seeks to understand how agents/resources/sub-systems influence each other from a macro view of the process. According to the same author, currently, international guidelines and regulations lead to changes in human activities. Thus, changes in human activities are caused by external forces, such as economic crises or natural disasters.

One of the principles of the systemic approach, according to [38] is that the whole is greater than the parts. For example, the family is larger than its members. Based on this principle, the systemic approach is interested in the relationships between the most diverse systems and sub-systems to better understand the functioning of the whole. The systems approach was introduced in the mid-1960s and was defined as "an organized and united whole, composed of two or more independent parts, components or subsystems".

From this context, it is understood that a macro view of any system is fundamental; however, understanding the interrelationships and mediations that exist in each sub-system allows us to improve the efficiency of the system.

In this work, we opted for the theoretical lens of the systemic approach due to the objective of this study being to consider different topics of this research, consecrated in the literature, such as Product Development Process, the Life-Cycle Assessment and sustainability. They are completely different areas, which when analyzed together, based on their relationships and connections, it is possible to obtain important insights to improve the market performance of organizations.

3. Hypotheses Development

Our literature review, carried out in the article by [16], on how the areas of sustainability, the PDP, and the LCA contribute to an increase in market performance, showed that the literature still lacks a framework that relates these areas using a systemic approach.

Thus, we intended to contribute by showing how these areas are related and how they can increase market performance for farmers in southern Brazil. This is represented in our conceptual model, seen in Figure 1. Figure 1 illustrates how PDP-related sustainability practices contribute to market performance of banana producers. In addition, Figure 1

demonstrates how the LCA can mediate sustainability and PDP practices to allow banana producers a greater competitive advantage in terms of market performance.

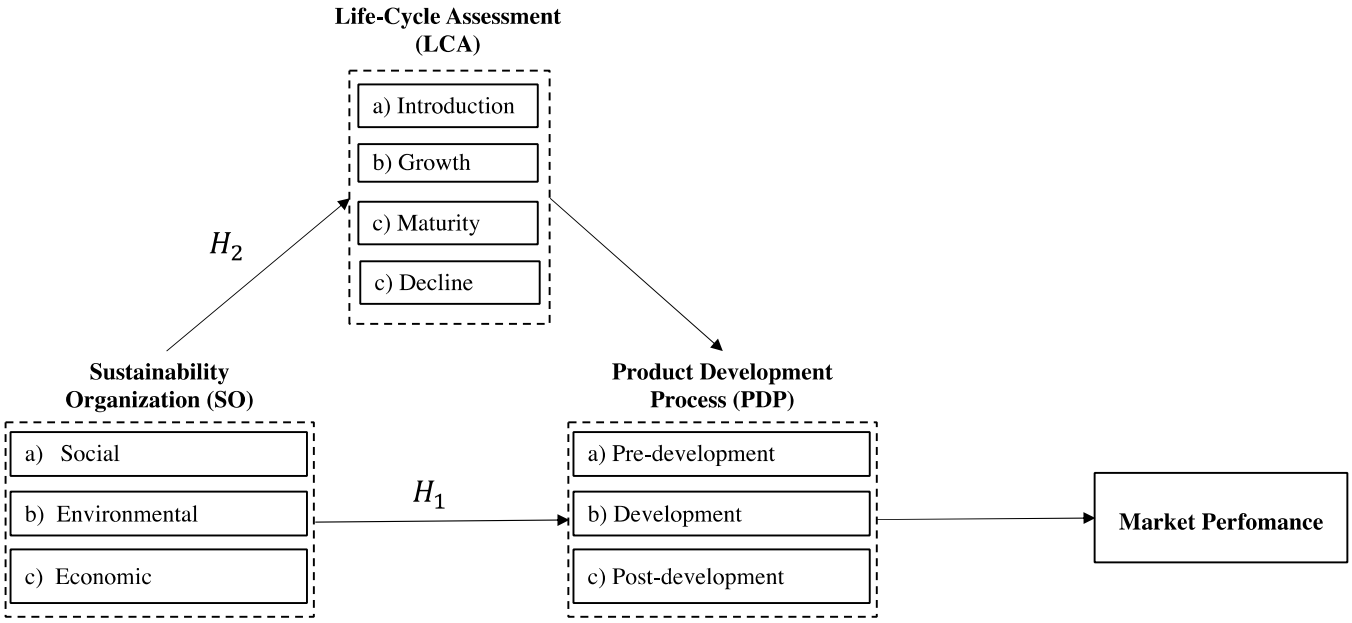


Figure 1. Conceptual framework. Source: Authors.

The development of the hypotheses of this paper considered the most relevant needs for the interviewees (banana producers), that is, what would be the main contributions that the study could provide to them in terms of planning involving the areas of sustainability, the Life-Cycle Assessment, the Product Development Process and market performance.

The conceptual model of this research was related as follows:

From the conceptual model, it is possible to raise hypotheses to validate them at the end of the research, using an econometric study, based on the collection of responses from the banana producers interviewed. As previously mentioned, strategic hypotheses were selected to investigate throughout the research. Two hypotheses were raised and presented in the following sections.

3.1. Organizational Sustainability and Product Development Process

The literature on sustainability practices and the PDP, described in [16], has already recognized the use of these areas for the creation of a conceptual model, however, it was not linked to market performance for rural producers. In this way, we use a systematic approach of these areas to allow rural banana producers to verify how the social, environmental, and economic practices related to the PDP phases are related, leading to an increase in market performance. Thus, we proposed the following general hypothesis to represent these three dimensions in the production chain of banana producers:

H1: *Organizational sustainability has a positive association with the Product Development Process (PDP), leading to improved market performance for banana producers.*

Hypothesis H1 seeks to identify whether there is a positive association between the sustainability construct, involving all its practices including economic, environ-mental, and social, and the phases of the Product Development Process (PDP) leading the company to improved market performance. In other words, we sought to investigate which sustainability practices related to the PDP phases, pre-development, development, and post-development, would lead banana producers to obtain efficiency in terms of market performance.

3.2. Life-Cycle Assessment, Organizational Sustainability, and Product Development Process

The literature recognizes the use of LCA phases connected to PDP phases, ac-cording to [16]; however, they do not analyze the LCA as a mediator between sustain-ability practices and PDP phases leading to improved market performance. We under-stand that these relationships are important for obtaining competitive advantages from agricultural products; thus we formulated the following general hypothesis to represent the possible mediation of the LCA between sustainability and the PDP.

H2: *The Life-Cycle Assessment (LCA) mediates the relationship between sustainability and the Product Development Process (PDP), leading banana producers to improved market performance.*

Hypothesis H2 seeks to identify whether the phases of the product life cycle can mediate the relationship between sustainability practices and the product development phases, leading the company to improved market performance. This hypothesis then involves three constructs with different variables. The product life cycle (LCA) construct has the phases of introduction, growth, maturity, and decline; the sustainability construct has three practices, economic, environmental, and social; the Product Development Process construct has three phases: pre-development, development, and post-development. With this, we sought to understand whether the LCA phases can mediate sustainability practices with the PDP phases, which promote efficiency in terms of market performance for banana producers.

4. Research Method

4.1. Sampling

The main interviewees for this study were executives from banana producers in southern Brazil, responsible for managing product planning and development. The banana production market has great socioeconomic relevance, especially after the COVID-19 pandemic, where the world economy went into recession and unemployment levels worsened. In economic terms, the banana production market is an important source of income for several rural families in the south, southeast and northeast regions of Brazil. In social terms, this market has the advantage of its production being continuous throughout the year and adaptable to different climatic conditions and soil characteristics, generating employment for several agricultures. Currently, Brazil occupies the fourth position in the world for banana production and according to [39], the amount of bananas produced in Brazil was approximately 7 million tons and has growth estimates over the next few years.

During the quarantine, caused by the COVID-19 pandemic, the Brazilian population underwent changes aimed at concerns related to health, safety, and finances [40]. In terms of health, the population started to have a healthier lifestyle and eating habits. According to [15], banana was the most consumed fruit in Brazil, as it is a versatile fruit, rich in potassium, vitamins, and fiber. In this context, in terms of social-economic impacts and changes in consumption patterns in Brazil, the development of studies related to increasing the performance of rural products (banana) becomes increasingly necessary to guide producers on the relevant aspects that impact on them obtaining a competitive advantage in the market.

A survey was then developed online to collect data for the study. Once the research was created, the authors invited researchers and industry experts to test the research. This was performed to ensure the face validity, readability, and comprehensibility of the scales, in addition to ensuring that key informants could answer all survey questions. Changes were made to the scales to reflect feedback from participants. Once the changes were made, a pre-test was sent to 12 potential respondents, 100% of whom completed the survey. The response rate for the pre-test was the total of potential respondents. Modifications were made to the questionnaire based on the pre-test, after which the final questionnaire was set. In the final survey, 217 producers were contacted and 110 responded, giving a response rate of 50.69 percent.

Regarding the representativeness of the sample, it is important to emphasize that the interviewees were selected among the members of the Banana Producers Association of the southern region of Brazil. This choice was made due to their central position within the banana production chain in the region and their significant representativeness in the market. The association has a registry of 217 active members, who were approached to participate in the research. Considering the specific focus of this study on product development practices in the banana industry, the members of this association represent a relevant and specialized sample of the study's target audience.

To pre-qualify respondents, they were asked if their job involved working with the PDP. This is because our interviews and discussions with industry experts indicated that producers working with the PDP would be able to answer the questions in our survey. Only those who indicated working with the PDP were invited to respond to the survey.

The questionnaire consisted of 71 questions in total, divided into five main blocks. The first block of questions had a total of 11 questions on socioeconomic practices. For the construction of the socioeconomic profile, the following aspects were addressed: name and personal contact, if banana farming is their only activity, level of education, if they are registered with the Association of Banana Producers of the southern region of Brazil, age, number of employees who work directly in the banana plantation and annual revenue. The objective was to know the descriptors of the respondents and be able to trace their profiles. Blocks 2, 3, 4, and 5, respectively, referred to the following constructs: sustainability, the Life-Cycle Assessment (LCA), the Product Development Process (PDP), and market performance.

No specific profile of respondents was selected to reduce bias and increase sample randomization. An endogeneity test and a self-selection bias test were conducted (Section 4.6). The questionnaire was sent five times to respondents via Google Forms from March 2022 to July 2022. Our sample, according to Table 1, was mostly composed of respondents who participate in companies with an annual revenue of BRL 100 million to 200 million (51%), where most have completed high school (32%), 64% do not still participate in the banana producers' association, and most are between 20 and 30 years old (25%).

Table 1. Sample Composition.

	Description	**%**
Revenue	More than BRL 200 million	19
	Between BRL 100 million and 200 million	51
	Between BRL 50 million and 100 million	19
	Between BRL 10 million and 50 million	6
	Less than BRL 10 million	5
Scholarity	Incomplete elementary school	13
	Complete elementary school	22
	Incomplete high School	17
	Complete high School	32
	Incomplete undergraduate	5
	Complete undergraduate	11
Participation of the banana producers association	More than 10 years	9
	Between 5 and 10 years	8
	Between 3 and 5 years	4
	Between 1 and 3 years	7
	Less than 1 year	8
	No participation	64
Age	More than 71 years	1
	Between 61 and 70 years	7
	Between 51 and 60 years	16
	Between 41 and 50 years	17
	Between 31 and 40 years	34
	Between 20 and 30 years	25

4.2. Measures and Survey Instruments

The survey was developed based on consolidated constructs in the literature. The constructs were as follows: sustainability, the Life-Cycle Assessment (LCA), the Product Development Process (PDP), and market performance. The sustainability construct includes issues of economic, environmental, and social practices. The Life-Cycle Assessment construct includes questions about the introduction, growth, maturity, and decline phases of the product. The Product Development Process construct includes questions regarding the pre-development, development, and post-development phases of the product. The market performance construct includes issues related to marketing and operational performance.

The items used in the measurement of each construct and their respective references are shown in Table 2. In addition, factor loadings are also presented.

Table 2. Measurement validation.

Items	Factor Loadings
Sustainability—Economic (SUS1) [41]	
We develop practices for crop growth.	0.51
We develop actions aimed at controlling and managing business risks.	0.45
We develop practices to increase planting/cultivation production.	0.67
We have developed practices to optimize processes (e.g., accelerate planting/pest control) in our business.	0.82
Sustainability—Environmental (SUS2) [41]	
We develop practices in accordance with environmental legislation.	0.56
We have developed practices for product disposal.	0.90
We promote the recovery, conservation and sustainable management of environmental resources.	0.66
We develop practices for environmental preservation (e.g., less use of pesticides).	0.65
Sustainability—Social (SUS3) [41]	
We develop practices for social inclusion.	0.53
We develop practices to comply with labor standards.	0.72
We develop practices for occupational health in the field.	0.64
We develop professional management practices and human resources.	0.62
Life-Cycle Assessment—Introduction (LCA1) [42]	
We develop economic performance indicators before cultivation.	0.76
We carry out studies of the soils until the harvest of the products.	0.73
We develop a prior market study of the product to be cultivated/that we wish to cultivate.	0.89
We develop studies of the environmental impacts of our harvest (e.g., RIMA).	0.55
Life-Cycle Assessment—Growth (LCA2) [42]	
We develop a growth study of our products after the beginning of the process (e.g., growth in planting/cultivation).	0.68
We develop a follow-up study plan during the growth stage of our products.	0.66
We develop technology investment projects during the growth stage of our products.	0.57
We develop practices to improve the market entry of our products during their growth stage.	0.67
Life-Cycle Assessment—Maturity (LCA3) [42]	
We develop innovation practices to ensure the maturity of our product in the market.	0.82
We develop a productivity study of our products.	0.79
We develop a study to improve our products and processes in the maturity stage.	0.66
We develop partnerships for the maintenance of qualified workforce in the maturity stage.	0.63
Life-Cycle Assessment—Decline (LCA4) [42]	
We develop practices for the discontinuation of the product in the market.	0.82
We develop analysis of the life cycle of our products after the end of their cycle.	0.79
We develop techniques to prepare for the next generation of products when we notice poor returns in the market.	0.66

Table 2. *Cont.*

Items	Factor Loadings
Product Development Process—Pre-Development (PDP1) [43]	
We carry out market prospecting for the selection of the product to be cultivated.	0.71
We carry out labor prospecting for cultivation in the initial stage of production.	0.52
We carry out studies of the quality of the soils for the cultivation of the product in the initial stage of production.	0.56
We develop a production method at the initial stage of production.	0.81
Product Development Process—Development (PDP2) [43]	
We develop practices for the standardization of cultivation during its production.	0.71
We develop production processes and means during cultivation.	0.64
We develop good production/cultivation practices during production.	0.62
We develop ways to improve process efficiency during production.	0.68
Product Development Process—Post-Development (PDP3) [43]	
We monitor the consumption of our products after the sale.	0.71
We carry out studies on the reuse of our products after the sale.	0.64
We carry out studies of new markets for our products after the sale.	0.62
Market Performance (MP) [43]	
The response to the market has improved in the last 3 years.	0.76
We have managed to keep it on the market for the last 3 years.	0.57
Customer loyalty has increased in the last 3 years.	0.49
Demand has increased in the last 3 years.	0.71

For identification, in the sustainability construct, the acronyms SUS1, SUS2, and SUS3 were used, referring to the three sustainability practices in the economic, environmental, and social spheres, respectively. For the Life-Cycle Assessment (LCA) construct, the acronyms LCA1, LCA2, LCA3, and LCA4 were used, referring to the phases, introduction, growth, maturity, and decline of the product, respectively. For the Product Development Process construct, the acronyms PDP1, PDP2, and PDP3 were used, referring to the pre-development, development, and post-development phases of the product, respectively. Finally, for the market performance construct, the acronym MP was used.

In terms of the sustainability construct, five questions were used for each economic, environmental, and social practiceHowever, one question from each group was eliminated after analyzing the loading factor; it did not meet the standard of being greater than 0.5. However, for reasons of resilience and reference in the literature, we chose to keep a question related to economic practice, which presented a loading factor of 0.45, as we judged that it was important this remain in the analysis. The author who inspired this construct was [41].

For the Life-Cycle Assessment construct, for each phase of introduction, growth, maturity, and decline, five questions were applied. However, one question from each group was eliminated; after analyzing the loading factor, it did not meet the standard of being greater than 0.5. Except for the decline phase, two questions were eliminated. The author who inspired this construct was [42].

For the Product Development Process construct, for each phase of pre-development, development, and post-development of the product, five questions were applied. However, one question from the pre-development phase was eliminated, and for the development and post-development phases, two questions from each were eliminated after analyzing the loading factor which did not meet the standard of being greater than 0.5. The author who inspired this construct was [43].

In terms of the performance construct, five questions were used for each performance rating, both marketing and operational. However, one question from each group was eliminated; after analyzing their loading factors, they did not meet the standard of being greater than 0.5. The author who inspired this construct was [44].

For the market performance construct, five questions were used. However, one question was eliminated after analyzing its loading factor; it did not meet the standard of being greater than 0.5. The author who inspired this construct was [44].

Regarding the dependent variable, the market performance construct was used. This construct was added as a dependent variable because it seeks to analyze the fulfillment of hypotheses 1 and 2 that lead to improved market performance.

We measured all the questions of the constructs using the Likert scale, which it has a range of 1 (strongly disagree) to 5 (strongly agree).

Only 5 control variables were selected: banana producer, scholarly low, scholarly high, revenue low, and revenue high. All were evaluated with a binary scale [0.1]. For the banana producer control variable, we sought to identify respondents for which banana farming is their only activity. For the control variable on scholarly, the low level represents those who reached elementary school, and the high level represents the respondents who started an undergraduate course. For the control variable associated with revenue, the low level represents receipts up to BRL 50 thousand, and the high level is above BRL 200 thousand.

Table 2 presents each item by research construct. Items with factor loadings below 0.5 were not reported except for the item referring to the economic practice of sustainability, which was chosen to remain as mentioned above.

4.3. Variable Operationalization, Reliability, and Validity of Measures

To analyze the unidimensionality, a Confirmatory Factor Analysis (CFA) was performed. Our model showed the goodness of fit as the reference values for the Comparative Fit Index (CFI), the Root Mean Squared Error of Approximation (RMSEA), the Average Variance Extracted (AVE), the Composite Reliability (CR), and Cronbach's Alpha fell in the acceptable values [45], as shown in Table 3.

Table 3. CFA Metrics.

Construct	AVE	CR	Alpha	RMSEA	CFI	TLI
Sustainability—Economic (SUS1)	0.40	0.71	0.66	0.070	0.964	0.936
Sustainability—Environmental (SUS2)	0.49	0.79	0.83			
Sustainability—Social (SUS3)	0.40	0.72	0.71			
Life-Cycle Assessment—Introduction (LCA1)	0.55	0.83	0.78	0.078	0.951	0.930
Life-Cycle Assessment—Growth (LCA2)	0.42	0.74	0.74			
Life-Cycle Assessment—Maturity (LCA3)	0.54	0.82	0.84			
Life-Cycle Assessment—Decline (LCA4)	0.51	0.75	0.70			
Product Development Process—Pre-Development (PDP1)	0.43	0.75	0.81	0.072	0.971	0.951
Product Development Process—Development (PDP2)	0.44	0.76	0.78			
Product Development Process—Post-Development (PDP3)	0.66	0.85	0.84			
Performance—Market Performance	0.41	0.73	0.67	0.051	0.985	0.971
Performance—Operational Performance	0.44	0.78	0.78			

Ensuring consistency within the CFA requires diligent focus on key metrics such as the Root Mean Square Error of Approximation (RMSEA), the Comparative Fit Index (CFI), the Tucker–Lewis Index (TLI), the Average Variance Extracted (AVE), Cronbach's Alpha, the Composite Reliability (CR), and the Factor Loading.

The Root Mean Square Error of Approximation (RMSEA) serves as a parsimony-adjusted index, with values approaching zero indicating favorable fits. Typically falling

between 0.03 and 0.08, RMSEA values are commonly accepted. Thus, it is essential to note that all construct values fell within this range.

The Comparative Fit Index (CFI) evaluates the fit of a target model against that of an independent or null model. Recommendations suggest values exceeding 0.90, indicating adherence. It is observed that all constructs achieved this threshold [46].

The Tucker-Lewis Index (TLI), suitable for small samples, is recommended to exceed 0.90 or surpass 95 [47]. Accordingly, all constructs demonstrated adherence.

The Average Variance Extracted (AVE) gauges the proportion of variance captured by a construct relative to the variance attributed to measurement error. The literature suggests an AVE threshold of up to 0.5. Note that for each item of the construct, the majority had an AVE below 0.5, except for PDP3, LCA1, LCA 3 and LCA4; however, they were close to 0.5. Cronbach's Alpha, a reliability measure ranging from 0 to 1, sets acceptability thresholds at 0.60 to 0.70. It assesses questionnaire answer correlation by analyzing respondent responses, presenting an average correlation between questions [48]. Hence, it is observed that all items within the constructs surpassed the lower limit. Composite Reliability, similar to Cronbach's Alpha, evaluates internal consistency across scale items [49]. It is noteworthy that the CR value was sufficient, surpassing the threshold of 0.70.

Table 4 presents the correlation matrix between the independent variables of the model. The independent variables are those belonging to the sustainability, LCA, and PDP constructs. As the market performance construct is the response variable, it was not reported in the matrix. The control variables were included in the analysis to verify the existence of a relationship between the variables. The acronyms for the control variables were reported as Control 1, Control 2, Control 3, Control 4, and Control 5, representing, respectively, banana producer, scholarity low, scholarity high, revenue low, and revenue high. The independent variables of the constructs were reported as SUS1, SUS2, SUS3, AVC1, AVC2, AVC3, AVC4, PDP1, PDP2, and PDP3, which represent, respectively, economic, environmental, social, introduction, growth, maturity, decline, pre-development, development, and post-development.

This Table 4 shows the correlation coefficients for the different variables. It is a powerful tool for summarizing a large dataset and identifying and visualizing patterns in the data provided. The relationships that were significant, i.e., had p-values lower than 0.05 or lower than 0.01, were reported in parentheses next to their respective coefficients. In addition, in Table 4, the descriptive statistics of the model were reported using the techniques of mean and standard deviation. Input values were non-standard values of variables. Data normality was tested by Kurtosis and Asymmetry techniques, also reported at the end of Table 4.

Analyzing the results as the control variables, we can see that Control variable 2 had a negative correlation and significance with Control variables 3, 4, and 5, while Control variable 4 had a positive correlation and significance with Control variable 3. Control variable 5 had a negative correlation and significance with the LCA1, PDP1, and PDP2 constructs.

The SUS1 construct had a positive correlation and significance with all other constructs, except for PDP3. All other constructs (SUS2, SUS3, LCA1, LCA2, LCA3, LCA4, PDP1, PDP2, and PDP3) showed positive correlation and significance.

Therefore, it was possible to observe how the constructs were strongly correlated when combined pairwise.

The average of the control variables presented values between 0 and 1 due to the nature of the answers being binary. The mean of the independent variables was around 3, since non-standard values were used, that is, from the Likert scale from 1 to 5. The construct with the greatest deviation was the LCA3 construct.

Table 4. Bivariate correlation matrix.

Independent Variables		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Control_1	-														
2	Control_2	0.139	-													
3	Control_3	−0.186	−0.321 (p = 0.001)	-												
4	Control_4	−0.106	−0.193 (p = 0.043)	0.238 (p = 0.012)	–											
5	Control_5	0.167	−0.256 (p = 0.007)	0.035	−0.170	–										
6	SUS1	0.167	0.156	−0.138	−0.105	−0.044	–									
7	SUS2	−0.124	−0.028	−0.020	0.068	−0.138	0.420 (p = 0.000)	–								
8	SUS3	0.028	0.054	−0.019	0.168	−0.172	0.467 (p = 0.000)	0.386 (p = 0.000)	–							
9	LCA1	−0.162	0.101	0.009	0.061	−0.225 (p = 0.018)	0.398 (p = 0.000)	0.627 (p = 0.000)	0.607 (p = 0.000)	–						
10	LCA2	−0.131	0.082	0.043	0.098	−0.163	0.367 (p = 0.000)	0.444 (p = 0.000)	0.638 (p = 0.000)	0.73 (p = 0.000)	–					
11	LCA3	0.075	0.173	−0.032	0.026	−0.171	0.481 (p = 0.000)	0.389 (p = 0.000)	0.670 (p = 0.000)	0.565 (p = 0.000)	0.697 (p = 0.000)	–				
12	LCA4	0.036	0.144	−0.027	0.005	−0.179	0.326 (p = 0.001)	0.356 (p = 0.000)	0.550 (p = 0.000)	0.589 (p = 0.000)	0.646 (p = 0.000)	0.88 (p = 0.000)	–			
13	PDP1	−0.67	0.120	0.021	0.082	−0.257 (p = 0.007)	0.455 (p = 0.000)	0.534 (p = 0.000)	0.650 (p = 0.000)	0.663 (p = 0.000)	0.695 (p = 0.000)	0.702 (p = 0.000)	0.614 (p = 0.000)	–		
14	PDP2	−0.079	0.062	−0.057	0.125	−0.240 (p = 0.012)	0.543 (p = 0.000)	0.544 (p = 0.000)	0.482 (p = 0.000)	0.588 (p = 0.000)	0.609 (p = 0.000)	0.528 (p = 0.000)	0.559 (p = 0.000)	0.669 (p = 0.000)	–	
15	PDP3	−0.034	0.023	−0.030	0.114	−0.052	0.083	0.248 (p = 0.009)	0.286 (p = 0.002)	0.429 (p = 0.000)	0.276 (p = 0.004)	0.415 (p = 0.000)	0.373 (p = 0.000)	0.255 (p = 0.007)	0.111	–
	Mean	0.6455	0.3455	0.1636	0.1091	0.1909	3.8295	3.9477	3.6341	3.7614	3.6727	3.7455	3.4606	3.7659	3.8182	2.3697
	SD	0.48056	0.47769	0.37164	0.31318	0.39482	0.61324	0.69739	0.85179	0.77325	0.80262	0.9055	0.86733	0.82206	0.7434	0.0856
	Skewness	−0.617	0.659	1.844	2.543	1.595	0.019	−0.266	−0.901	−0.962	−1.199	−0.848	−0.522	−0.5	−0.684	0.25
	Kurtosis	−1.65	−1.595	1.425	4.547	0.553	0.158	−0.496	1.069	1.256	1.347	−0.066	0.014	0.013	0.942	−1.100

The normality of the independent variables was examined using the metrics of Skewness and Kurtosis values. Besides these, there are other methods such as Shapiro–Wilk, Kolmogorov–Smirnov (K-S), and Anderson–Darling tests (for small samples). The results suggest that our independent variables were normally distributed since all values were between [−2.58, +2.58], which represents 0.01 of significance [45], except for the "Control_4"; however, this will not be a problem since it is a control variable and not a main model variable.

4.4. Response Bias

To assess the model's consistency, Harman's test was employed [50]. This post hoc factor analysis is often utilized to determine if a significant portion of data variation can be attributed to a single factor. Harman's test collects data for both dependent and independent variables. An Exploratory Factor Analysis (EFA) is conducted on all construct items to examine the total variance. If a factor extracts more than 50% of the total variance, it indicates the presence of common method bias in the study [45,50].

Consequently, it is evident that the extracted variance did not exceed 50% (48.9%), suggesting the absence of multicollinearity within the construct. Therefore, we inferred that response bias was unlikely to be a concern in this study.

4.5. Endogeneity and Robustness Checks

Endogeneity is an issue that we should be concerned about in regression analyses because if the independent variables are not exogenous, they are strongly correlated to the error term. Endogeneity occurs when one or more independent variables are affected by other variables within the model. In addition to bias, another major problem that can arise is inconsistency; in this case, our estimates did not converge to the population parameter [51]. It is impossible to eliminate 100% of endogeneity in the model; however, it is possible to mitigate its existence in the econometric model [51].

For the selection of the endogenous variable, it is necessary that it has no direct influence on Y (the model dependent variable). Instrumental variables are exogenous variables used in the model to correct other variables that should be independent but are endogenous. Therefore, an instrumental variable is a third variable, which is used in regression analyses when there is a presence of endogenous variables.

To examine endogeneity and self-selection bias, we conducted a two-stage least squares (2SLS) regression analysis using Stata 16. In this approach, we utilized all independent constructs associated with the PDP in our model during the hierarchical regression stages. We selected the banana producers' operational performance to instrument our independent variables; this variable was chosen because it has no direct link to the independent variable of marketing performance. According to the tests, the independent variables showed that our measuring instrument was strong (p-value < 0.05 and the minimum F-value was 9.91, so above 3, as the literature recommends).

Hence, we examined whether the independent variables should be treated as endogenous and necessitate instrumentation in the 2SLS regression model. Utilizing Stata's stat endogenous procedure and Durbin and Wu-Hausman statistics, we evaluated the consistency of the estimators. The test results indicated that the hypothesis of exogeneity for the independent variable could not be rejected during regression estimation, as all p-values exceeded 0.05.

To ensure the consistency of the model, we perform a robustness check on the model. We performed this to establish whether the results of our regression analysis could vary by (i) removing control variables, (ii) including a new construct, and (iii) analyzing individual predictors.

In the first approach, we removed Control variables 1, 2, 3, 4, and 5 to check if our predictors were influenced by demographics. We found stable results because they did not show significant changes in the coefficients of our model; in addition, all significance relationships remained the same without the presence of control variables.

For the second approach, we included a construct called operational performance which produced the values of RMSEA = 0.051, CFI = 0.985, AVE = 0.44, Cronbach = 0.78, and CR = 0.78. The construct items were as follows: (i) productivity has increased in the last three years (0.76), (ii) cultivation methods have improved in the last three years (0.56), the production period between start and end (lead time) has improved in the last three years (0.48), and harvest assertiveness has improved in the last three years (e.g., we planted 100 and harvested them all) (0.80). We expected to obtain a significant effect of the new construct with the PDP and LCA phases as it was associated with production over the last three years. The approach showed a direct effect of the new construct on the PDP phases and partially on the LCA phases.

The third approach was considered from the individual analysis of the relationship of effects between each construct; in Table 4, we found consistency with our main results. The control variables did not show significance, in general, when compared with the predictor variables. In comparing the predictor variables, we found a strong relationship of significance, in general, between them.

4.6. Data Analysis

We performed a hierarchical least squares regression set on the model to test the hypotheses. We normalized our independent variables using a mean-centering Z-score to test for all relationships (Table 5). In the first stage of the hierarchical regression, we analyzed all the direct effects of the control variables (Control 1, Control 2, Control 3, Control 4, and Control 5) and the sustainability construct in its economic (SUS1), environmental (SUS2), and social (SUS3) practices in the product life cycle in all its phases of introduction (LCA1), growth (LCA2), maturity (LCA3), and decline (LCA4).

In the second stage of the hierarchical regression, we analyzed all the direct effects of the control variables and the PDP in its three phases of pre-development, development, and post-development (PDP1, PDP2, and PDP3).

In the third stage of the hierarchical regression, we analyzed all the direct effects of the control variables, sustainability, and the LCA on the PDP. In the fourth stage of the hierarchical regression, we analyzed all the direct effects of the control variables, the sustainability variables, the LCA variables, and the PDP variables on market performance. No direct relationship was made from the market performance variables because it was a set of dependent variables in the model. Thus, our model had five control variables and ten independent variables.

We checked the assumptions of normality, linearity, and homoscedasticity in our regression analysis. We analyzed normality via Kurtosis and Skewness values. Linearity was investigated by plotting a partial regression for the independent variables, while homoscedasticity was visualized by examining standardized residual plots against the predicted values. Table 5 presents the results of the hierarchical regression. Table 6 presents the effects of mediation. The mediation analyzed in this paper was between the sustainability variables and the PDP variables, which were mediated by the LCA variables, leading to market performance.

For presenting the mediation effects, we employed the process macro from [52]. To evaluate these effects, we computed the indirect effects of the relationships as recommended by [53]. A process analysis facilitated bootstrapping to examine the indirect effects. Bootstrapping is a resampling method used to approximate the normal distribution in the sample of a statistical survey, enabling the calculation of the population mean from the sample redistribution (central limit theorem). This method is more robust and powerful than Sobel's z-test for testing mediation effects [54]. We utilized 5000 bootstrap samples in line with suggestions from [53].

Table 5. Results of regression analysis.

(A)

Independent Variable	1st Main Stage								2nd Main Stage					
	LCA1		LCA2		LCA3		LCA4		PDP1		PDP2		PDP3	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Dummy01	−0.224	−0.197 (0.000)	−0.186	−0.214 (0.099)	0.167	0.090	0.095	0.077	−0.051	−0.074	−0.077	−0.125	−0.073	−0.020
Dummy02	0.137	0.155	0.164	0.151	0.262	0.220	0.184	0.177	0.155	0.144	0.016	−0.013	0.067	0.102
Dummy03	0.020	0.109	0.084	0.156	0.065	0.151	0.050	0.113	0.091	0.181	−0.163	−0.069	−0.165	−0.127
Dummy04	0.075	−0.137	0.198	−0.042	0.089	−0.155	−0.008	−0.244	0.129	−0.084	0.252	0.216	0.441	0.238
Dummy05	−0.343 (0.09)	−0.110	−0.219	−0.001	−0.335	−0.097	−0.358	−0.155	−0.462 (0.032)	−0.229	−0.392 (0.045)	−0.239	−0.042	0.113
SUS1		0.014		0.035		0.134 (0.091)		0.000		0.090		0.263 (0.000)		−0.136
SUS2		0.339 (0.000)		0.166 (0.0160)		0.112		0.153 (0.063)		0.239 (0.000)		0.220 (0.001)		0.217 (0.069)
SUS3		0.331 (0.000)		0.434 (0.000)		0.497 (0.000)		0.415 (0.000)		0.388 (0.000)		0.124 (0.056)		0.282 (0.022)
LCA1														
LCA2														
LCA3														
LCA4														
PDP1														
PDP2														
PDP3														
F-Value	1.626	17.548 (0.000)	1.080	11.559 (0.000)	1.223	13.358 (0.000)	0.980	6.878 (0.000)	1.680	15.558 (0.000)	1.628	11.824 (0.000)	0.398	1.755 (0.095)
R2	0.073	0.582	0.049	0.478	0.056	0.514	0.045	0.353	0.075	0.552	0.073	0.484	0.019	0.122
Adjusted R2	0.028	0.548	0.004	0.437	0.010	0.476	−0.001	0.301	0.030	0.517	0.028	0.443	−0.028	0.053
Change in R2	0.073	0.509 (0.000)	0.049	0.429 (0.000)	0.056	0.459 (0.000)	0.045	0.308 (0.000)	0.075	0.477 (0.000)	0.073	0.411 (0.000)	0.019	0.103 (0.010)

(B)

Independent Variable	3rd Main Stage									4th Main Stage			
	PDP1			PDP2			PDP3			MP			
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 4
Dummy01	−0.051	−0.074	−0.041	−0.077	−0.125	−0.078	−0.073	−0.020	−0.032	−0.040	−0.126	−0.073	−0.052
Dummy02	0.155	0.144	0.043	0.016	−0.013	−0.073	0.067	0.102	−0.094	0.037	−0.015	−0.018	−0.004
Dummy03	0.091	0.181	0.101	−0.163	−0.069	−0.122	−0.165	−0.127	−0.231	−0.066	−0.028	−0.045	−0.021
Dummy04	0.129	−0.084	−0.019	0.252	0.216	0.271	0.441	0.238	0.438	0.142	0.182	0.130	0.053

Table 5. *Cont.*

(B)													
Independent Variable	**3rd Main Stage**									**4th Main Stage**			
	PDP1			**PDP2**			**PDP3**			**MP**			
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Dummy05	−0.462 (0.032)	−0.229	−0.192	−0.392 (0.045)	−0.239	−0.211	−0.042	0.113	0.276	0.047	0.080	0.039	0.079
SUS1		0.090	0.051		0.263 (0.000)	0.271 (0.000)		−0.136	−0.218		0.243 (0.000)	0.217 (0.000)	0.182 (0.001)
SUS2		0.239 (0.000)	0.149 (0.028)		0.220 (0.001)	0.155 (0.019)		0.217 (0.069)	−0.063		−0.039	−0.027	−0.068
SUS3		0.388 (0.000)	0.141 (0.063)		0.124 (0.056)	−0.043		0.282 (0.022)	−0.082		0.032	0.006	0.000
LCA1			0.054			−0.026			0.703 (0.000)			−0.050	−0.108
LCA2			0.166 (0.075)			0.237 (0.010)			−0.492 (0.004)			0.201 (0.010)	0.178 (0.026)
LCA3			0.211 (0.035)			−0.120			0.612 (0.001)			0.123	0.066
LCA4			0.038			0.243 (0.004)			−0.012			−0.268 (0.000)	−0.313 (0.000)
PDP1													0.114
PDP2													0.124 (0.063)
PDP3													0.086 (0.085)
F-Value	1.680	15.558 (0.000)	15.448 (0.000)	1.628	11.824 (0.000)	12.122 (0.000)	0.398	1.755 (0.095)	4.186 (0.000)	0.199	3.829 (0.001)	4.686 (0.000)	4.685 (0.000)
R2	0.075	0.552	0.656	0.073	0.484	0.600	0.019	0.122	0.341	0.009	0.233	0.367	0.428
Adjusted R2	0.030	0.517	0.614	0.028	0.443	0.550	−0.028	0.053	0.260	−0.038	0.172	0.289	0.336
Changed in R2	0.075	0.477 (0.000)	0.104 (0.000)	0.073	0.411 (0.000)	0.116 (0.000)	0.019	0.103 (0.010)	0.219 (0.000)	0.009	0.223 (0.000)	0.134 (0.001)	0.061 (0.023)

Unstandardized beta coefficients are reported. since the main variables were standardized previous to the regression.

Table 6. Indirect effects (bootstrapping outcome).

Interactions (LCA as Mediators)	Bootstrap Outcome			95% Confidence Interval		Total and Direct Effects	Sig.	Conclusion
	Mean	SD	Sig.	LLCI	ULCI			
SUS1 → LCA1 → PDP1	0.0833	0.0438	0.0126	0.0044	0.1757	Total Effect	0	Complete
SUS1 → LCA2 → PDP1	0.605	0.0382	0.0735	−0.0084	0.1447			
SUS1 → LCA3 → PDP1	0.1373	0.0557	0.0033	0.0362	0.255	Direct Effect	0.1482	
SUS1 → LCA4 → PDP1	0.0071	0.0369	0.7996	−0.0625	0.0882			
SUS2 → LCA1 → PDP1	0.078	0.0642	0.1174	−0.047	0.2087	Total Effect	0	Partial
SUS2 → LCA2 → PDP1	0.0807	0.0444	0.0464	0.0062	0.1802			
SUS2 → LCA3 → PDP1	0.1192	0.0443	0.0007	0.0377	0.2099	Direct Effect	0.017	
SUS2 → LCA4→ PDP1	0.0063	0.0371	0.8325	−0.0577	0.0923			
SUS3 → LCA1 → PDP1	0.1184	0.0573	0.0194	0.0062	0.234	Total Effect	0	Partial
SUS3 → LCA2 → PDP1	0.085	0.0643	0.1449	−0.0284	0.2248			
SUS3 → LCA3 → PDP1	0.1771	0.0708	0.0062	0.0327	0.3121	Direct Effect	0.0468	
SUS3 → LCA4 → PDP1	0.0081	0.0602	0.862	−0.0951	0.1414			
SUS1→ LCA1 → PDP2	0.0389	0.0473	0.2353	−0.0394	0.1497	Total Effect	0	Partial
SUS1 → LCA2 → PDP2	0.0796	0.0408	0.0184	0.0096	0.1656			
SUS1 → LCA3 → PDP2	−0.059	0.056	0.197	−0.1735	0.0521	Direct Effect	0	
SUS1 → LCA4 → PDP2	0.0738	0.0462	0.0091	0.0009	0.1799			
SUS2 → LCA1 → PDP2	0.0063	0.0878	0.9162	−0.1394	0.208	Total Effect	0	Partial
SUS2 → LCA2 → PDP2	0.1004	0.0482	0.0186	0.0173	0.2034			
SUS2 → LCA3 → PDP2	−0.0044	0.0422	0.9026	−0.0895	0.0766	Direct Effect	0.0007	
SUS2 → LCA4 → PDP2	0.0673	0.0487	0.0336	−0.0028	0.1841			
SUS3 → LCA1 → PDP2	0.1014	0.0732	0.0671	−0.0412	0.2484	Total Effect	0	No mediation
SUS3 → LCA2 → PDP2	0.1145	0.0715	0.0748	−0.0167	0.2658			
SUS3 → LCA3 → PDP2	0.0078	0.0798	0.9112	−0.1449	0.1684	Direct Effect	0.6065	
SUS3 → LCA4 → PDP2	0.0932	0.0725	0.0704	−0.238	0.257			
SUS1 → LCA1 → PDP3	0.2476	0.0749	0	0.117	0.4063	Total Effect	0.3894	No mediation
SUS1 → LCA2 → PDP3	−0.1712	0.0707	0.0045	−0.3259	−0.0522			
SUS1 → LCA3 → PDP3	0.2707	0.0832	0.0011	0.1243	0.4482	Direct Effect	0.0177	
SUS1 → LCA4 → PDP3	−0.0074	0.0598	0.8815	−0.1356	0.1062			
SUS2 → LCA1 → PDP3	0.385	0.1142	0.0004	0.1675	0.6264	Total Effect	0.009	Complete
SUS2 → LCA2→ PDP3	−0.2017	0.0746	0.0071	−0.3564	−0.0635			
SUS2 → LCA3 → PDP3	0.1703	0.0746	0.008	0.0445	0.3358	Direct Effect	0.4292	
SUS2 → LCA4 → PDP3	0.0087	0.0664	0.8743	−0.1326	0.1338			
SUS3 → LCA1 → PDP3	0.347	0.0871	0.0002	0.1837	0.5251	Total Effect	0.0024	Complete
SUS3 → LCA2 → PDP3	−0.2706	0.1044	0.0117	−0.4775	−0.0663			
SUS3 → LCA3 → PDP3	0.3107	0.1139	0.0084	0.0952	0.5428	Direct Effect	0.4965	
SUS3 → LCA4 → PDP3	0.0143	0.0976	0.866	−0.1976	0.1882			

5. Results

We used ten independent variables, divided into the sustainability, LCA, and PDP constructs, in a hierarchical analysis of each model. We performed a model with four hierarchical stages, where the first stage included the analysis of the direct effect of the control variables and sustainability on the LCA. The second stage included the analysis of the direct effect of the control variables and sustainability on the PDP. The third stage included the analysis of the effect of the control variables, sustainability, and the LCA on the PDP. The fourth stage included the analysis of the direct effect between the control variables, sustainability, the LCA, and the PDP on market performance.

The model's dependent variable was market performance, which included four items. In Table 5, we can see that all models were significant when analyzing the *p*-value at levels 0.01, 0.05, and 0.1, with the R square changing significantly when analyzing the *p*-value at levels 0.01 and 0.05 at all stages in the hierarchical process.

As a final result from each step of the model, we had the following metrics: LCA1 construct (F = 17.548, $p < 0.01$), LCA2 (F = 11.559, $p < 0.01$), LCA3 (F = 13.358, $p < 0.01$), LCA4 (F = 6.878, $p < 0.01$), PDP1 (F = 15.558, $p < 0.01$), PDP2 (F = 11.824, $p < 0.01$), PDP3 (F = 1.755, $p < 0.1$), and the market performance construct (F = 4.658, $p < 0.01$). All showed significant values at p-value levels 0.01 and 0.1; as for the F-value, only PDP3 was below 3, the others all showed acceptable values.

Unstandardized coefficients are reported in Table 5 because all scale values were standardized with the Z-score because they represent standardized effects.

Table 6 presents the estimates of standardized errors, significance level, and their corresponding lower (LLCI) and upper level (ULCI) confidence intervals. All values found were within the 95% confidence interval, showing the efficiency of the indirect effects of bootstrapping, except in the analysis between SUS3 and PDP2, and SUS1 and PDP3, mediated by the LCA, as there was no mediation since they were left out in the lower and upper range. Finally, Table 7 summarizes the evaluation of the hypotheses. It is concluded that hypothesis H1 was supported in the research, and hypothesis H2 was partially supported.

Table 7. Hypotheses evaluation.

Hypotheses	Outcome	Supported Relationship
H1: Organizational Sustainability → Product Development Process (PDP)	Supported	SUS1 → PDP1 (B = 0.090, p = 0.396), SUS1 → PDP2 (B = 0.263, p = 0.000), SUS1 → PDP3 (B = −0.136, p = 0.286), SUS2 → PDP1 (B = 0.239, p = 0.000), SUS2 → PDP2 (B = 0.220, p = 0.001), SUS2 → PDP3 (B = −0.217, p = 0.069), SUS3 → PDP1 (B = 0.388, p = 0.000), SUS3 → PDP2 (B = 0.124, p = 0.056), SUS3 → PDP3 (B = −0.282, p = 0.022).
H2: Organizational Sustainability → Life-Cycle Assessment (LCA) → Product Development Process (PDP)	Partially Supported	SUS1 → LCA1 → PDP1 (p = 0.0126) SUS1 → LCA3 → PDP1 (p = 0.033) SUS2 → LCA2 → PDP1 (p = 0.0464) SUS2L → LCA3 → PDP1 (p = 0.007) SUS3 → LCA1 → PDP1 (p = 0.0194) SUS3 → LCA3 → PDP1 (p = 0.0062) SUS1 → LCA2 → PDP2 (p = 0.0184) SUS1 → LCA4 → PDP2T (p = 0.0091) SUS2 → LCA2 → PDP2 (p = 0.0186) SUS2 → LCA1 → PDP2 (p = 0.0004) SUS2 → LCA2 → PDP3 (p = 0.0071) SUS2 → LCA3 → PDP3 (p = 0.0008) SUS3 → LCA1 → PDP3 (p = 0.0002) SUS3 → LCA2 → PDP3 (p = 0.0117) SUS3 → LCA3 → PDP3 (p = 0.0084)

It was possible to conclude that hypothesis 1 was supported in this study, however, as for hypothesis 2, it was partially supported. In the next section (Discussion) the main insights of the results and the hypotheses in it are specified.

Analyzing Table 5, regarding the first stage of the 12 possible combinations between the constructs in model 02, 8 were significant. Significant relationships were found between SUS2, SUS3, and LCA1; SUS2, SUS3, and LCA2; SUS1, SUS3, and LCA3; SUS2,SUS3, and LCA4.

As for the second stage of the nine possible combinations between the constructs in model 02, seven were significant. Significant relationships were between SUS2, SUS3, and PDP1; SUS1, SUS2, SUS3, and PDP2; and SUS2, SUS3, and PDP3.

As for the third stage of the 21 possible combinations between the constructs in model 03, 12 were significant. Significant relationships were between SUS2, SUS3, LCA2, LCA3 and PDP1; SUS1, SUS2, LCA2, LCA4 and PDP2; and SUS1, LCA1, LCA2, LCA3, and PDP3. As for the fourth stage of the 14 possible combinations between the constructs in model 04,

7 were significant. Significant relationships were between SUS1, LCA2, LCA4, PDP2, PDP3, and MP.

The F test is a statistical test that is used in hypothesis testing to check whether the variances of two populations or two samples are equal or not. The general significance F test indicates whether the regression model provides a better fit than a model that does not contain independent variables. After analyzing the value of F in the first stage, all models (only level 2 models since these are the combination of model 01 variables) were significant with p-values lower than 0.01. For the second stage, all models (level 2 models only, as mentioned above) were also significant, with the model referring to the variables PDP2 and PDP3 at a level of 0.05, and PDP1 at a level of 0.01. For the third stage, all models (level 3 models, as these include the combination of models 1 and 2) were significant at a level of 0.01. For the fourth stage, the model (model at level 4 only, as it includes models 1, 2, and 3) was significant at a level of 0.01. Therefore, we can confirm that all models were significant when considering the constructs in the bigger picture.

R square is a statistical measure that represents the proportion of the variance of a dependent variable that is explained by an independent variable. The model with the highest R squared in the sample was in the third stage in the variable PDP1 (0.65), followed by PDP3 (0.60) of the same stage, and LCA1 of the first stage (0.58).

The adjusted R-squared serves as a corrected measure of goodness of fit for linear models. Regarding the ranking of explanatory proportions of the independent variables, it mirrored that of the R-squared. Overall, no significant disparities were observed between the R-squared and adjusted R-squared in the models.

Finally, the last metric was the R-changed. It represents how much a model improves with the addition of more predictor (independent) variables in a hierarchical regression. In the first and second stages, with only two models, where model 01 represents the presence of only the control variables, the R-changed was not significant; however, when we added the independent variables, the model became significant. In stages 2 and 3, it is noted that in the first models, with only the control variable, the models were not significant; however, from model 02 onwards, when we inserted independent variables, the model became significant.

With this, all analysis requirements were checked in the database to perform the regression analysis. Finally, multicollinearity was evaluated for our independent variables [45]. To assess the mediation of effects, we calculated the indirect effects of the relationships as suggested by [53]. Table 6 presents the results.

Analyses of the sustainability constructs were carried out in all its practices, economic (SUS1), environmental (SUS2), and social (SUS3), and the PDP construct in all its phases, pre-development (PDP1), development (PDP2), and post-development (PDP3), being mediated by the LCA construct in all its phases, introduction (LCA1), growth (LCA2), maturity (LCA3), and decline (LCA4), generating a total of 36 combinations.

The first combination between SUS1 and PDP1 was mediated by the LCA construct in all its phases; significance was obtained only in the combinations, [SUS1 → LCA1 → PDP1] and [SUS1 → LCA3 → PDP1] as they presented significant p-values and the zero point was not included in the lower (LLCI) and upper (ULCI) confidence level ranges. However, when analyzing the direct effect of the combinations, it was observed that the *p*-value was not significant, which is concluded as a complete mediation since the direct effect of the variable x was not significant, and the mediation was significant. The same analysis was repeated for the other combinations.

It is important to highlight that two groups did not present any mediation, namely the combinations of SUS3 and PDP2 being mediated by LCA in all its phases (LCA1, LCA2, LCA3, and LCA4), and the combinations of SUS1 and PDP3 being mediated by LCA, also in all its phases. Finally, Table 7 presents the results of the hypotheses and the research conclusions.

6. Discussion

The literature does not focus on carrying out a systemic approach to the areas of the PDP, the LCA, and sustainability, and how these relationships can contribute to improved market performance in the case of rural producers in southern Brazil.

The existing literature on sustainability has focused on evaluating the three sustainability practices (economic, environmental, and social) in business development without considering aspects of product development or even the phases of the product life cycle [16]. It is possible to notice these gaps in [55], who evaluated the relationship between national participation in green entrepreneurial activity and sustainability practices. These gaps were also noticed in [56], who explored the relationship of sustainability reporting with corporate reputation in the context of public policies, and in [57], who analyzed the relationship between information technologies and sustainability practiced by G-7 economies. Therefore, it is noted that this study aimed to fill this gap by developing an empirical analysis of sustainability practices and the PDP and the LCA. Although our study aimed to obtain improved market performance of rural producers in the southern region of Brazil, it is possible to contribute to this gap, in terms of theoretical and empirical progress, by analyzing in an integrated way these three important areas for the development of market performance.

The existing literature on the PDP also presents a gap in terms of integration with the areas of sustainability and the phases of the LCA [16]. This becomes evident in [58], who analyzed the relationship of lean practices in the assembly of factories with the Product Development Process and the information technologies used. This also becomes evident in [59], who investigated the impact of product customization on the perceived satisfaction of the sellers' relationship and on the subsequent expectations of relationship continuity.

This gap becomes more worrying when considering [16], who investigated the literature on the LCA, since most papers related to this area do not portray the importance of product development and its environmental impacts throughout its life cycle. The literature on the LCA has been focused on the application of economic factors, that is, only the economic practice of sustainability. To exemplify this drawback in the literature, Ref. [60] applied a cost and Life-Cycle Assessment to estimate the economic costs of gasoline generators used to generate electricity in urban areas of Sub-Saharan Africa. Therefore, previous studies have focused on evaluating these areas separately and have not integrated them in a systemic approach; in this way, this study contributed to further expand the application of empirical methods associated with an integrated view of the areas of sustainability, the PDP, and the LCA, and how they drive market performance.

The existing literature has largely overlooked the interconnectedness of Product Development Processes (PDPs), the Life-Cycle Assessment (LCA), and sustainability practices, especially in the context of rural producers in southern Brazil. While previous studies have assessed sustainability practices in business development, they often neglect to integrate these practices with the PDP and the LCA. For instance, studies such as [55–57] examined various aspects of sustainability, but without considering their implications for product development or the product life cycle. Additionally, the literature on the PDP lacks integration with sustainability and the LCA, as demonstrated by [58,59], which explored product development aspects without considering their environmental impacts. This study addresses these gaps by providing a comprehensive analysis that integrates sustainability practices with the PDP and the LCA, thereby contributing to a deeper understanding of how these interconnected areas influence market performance. By filling these gaps, our study extends the existing literature by demonstrating the importance of adopting a systemic approach to sustainability, the PDP, and the LCA in promoting market performance among rural producers in Brazil.

Furthermore, articles related to the product life cycle [61–70] offer a comprehensive view of the Life-Cycle Assessment across various industries and contexts. From analyzing the life cycle of mineral fertilizers to managing plastic waste and the environmental impact of construction material production, these studies highlight the importance of

understanding the full life cycle of products to guide sustainable practices and reduce environmental impacts.

On the other hand, articles on sustainability [71–80] explore a wide range of topics, from maximizing solar energy generation to managing waste associated with respiratory treatment. These studies demonstrate the growing interest in sustainable solutions and innovations in various areas, including renewable energy, air quality, and sustainable agricultural practices. They offer valuable insights for addressing contemporary environmental challenges and promoting global sustainable development.

Finally, articles on the Product Development Process (PDP) [81–95] present a wide variety of approaches and techniques to optimize product development and improve market performance. From using advanced machine learning techniques to integrating sustainable practices into the PDP, these studies highlight the importance of innovation and efficiency in the Product Development Process. They provide valuable insights for companies seeking to enhance their competitiveness and respond to market demands effectively and sustainably.

The literature review revealed a significant gap in the integrated approach to Product Development (PDP), Life-Cycle Assessment (LCA), and sustainability, especially in the context of rural producers in southern Brazil. However, to further strengthen the theoretical contribution and originality of this study, we conducted a comprehensive content analysis using the Scopus database. This analysis involved searching for four key descriptors: Product Development Processes, Product Life-Cycle Assessments, sustainability, and market performance. Out of the 56 initially identified works, we applied additional filters to narrow down the results to publications in scientific journals and limited the temporal scope to the last five years (2020–2024), resulting in 16 articles relevant to our research. We grouped these articles according to their similarity into eight application areas for a clearer analysis, as follows:

1. Sustainable Manufacturing: Ref. [35] explored the implications of sustainable manufacturing in the context of Industry 4.0.
2. Environmental Assessment and the Circular Economy: Ref. [96] proposed a green public procurement model for the environmental assessment of constructive systems, while Ref. [97] focused on defining strategies to adopt levels for bringing buildings into the circular economy.
3. Valorization and Waste Management: Ref. [98] investigated the valorization of seafood side-streams through the design of new holistic value chains, Ref. [22] explored scenarios and prospective Life-Cycle Assessments for the sustainable reprocessing and valorization of sulfidic copper tailings, and Ref. [99] provided a technical description and performance evaluation of different packaging plastic waste management systems.
4. Energy Sustainability: Ref. [100] proposed a framework for the sustainable evaluation of thermal energy storage in the circular economy.
5. Life-Cycle Assessment: Ref. [101] conducted a life cycle sustainability assessment of short-chain carboxylic acid from municipal bio-wastes.
6. Sustainable Agriculture: Ref. [102] implemented ecolabelling for improving the sustainability of the agri-food supply chain, specifically focusing on hard sheep's milk cheese, while Ref. [103] assessed the ecological sustainability of aquafeed by conducting an energy assessment of novel and underexploited ingredients.
7. Green Chemistry and Biotechnology: Ref. [104] assessed the feasibility and sustainability of a surfactin production process through a techno-economic and environmental analysis; Ref. [105] investigated bioplastic feedstock production from microalgae with fuel co-products, using a techno-economic and life cycle impact assessment; and Ref. [106] studied sustainable lactic acid production from lignocellulosic biomass.
8. Construction and Architecture: Ref. [107] conducted a cost and environmental impact assessment of stainless steel microscale chemical reactor components produced using conventional and additive manufacturing processes, Ref. [108] evaluated the environmental sustainability of hemp as a building material through a Life-Cycle Assessment,

and Ref. [18] emphasized the role of modular architecture principles (MAPs) in the development of sustainable open architecture products.

These studies offer a comprehensive view of the interactions between sustainability, PDP, LCA, and market performance across various industries and contexts. By considering their findings together with our empirical analysis, we can enrich our understanding of the importance of an integrated approach to promoting sustainable practices and improving market performance among rural producers in Brazil.

In the study, we identified that hypothesis H1 ("Sustainability has a positive association with the Product Development Process (PDP) leading the company to Market Performance") was supported by the quantitative analysis using the CFA and the least squares regression (OLS) hierarchical, for sustainability in socio-environmental practices at all stages and for the three pillars of the PDP in the development stage. Therefore, this means that sustainable practices support product development (presented in the 2nd main stage) and, later, we confirmed that the development and post-development phase influence market performance (presented in the 4th main stage). We also identified that this makes sense, as the pre-development phase is the product planning stage that has no direct effect on the market performance of rural producers. The development phase concerns production and the post-development phase deals with customer contact and maintenance, having a direct relationship with market performance. With this, we conclude that H1, in general, was supported. We had only one exception for economic practices in the pre-development and post-development phase of rural products.

As for hypothesis H2 ("The Life-Cycle Assessment (LCA) mediates the relationship between Sustainability and Product Development Process (PDP) leading the company to Market Performance"), we identified that in the pre-development phase of the PDP, dealing with field products (bananas) the LCA maturity stage mediates sustainability. While economic practices are fully mediated, environmental and social practices are partially mediated. We concluded that rural families that develop sustainable practices may have reduced results in the replanning of their products if these products are already at a mature stage in the market. The same phenomenon can be observed for economic and social practices in the product introduction stage and for environmental practices in the growth stage. In addition, we identified that in the PDP development phase, we concluded that rural families that develop economic and environmental practices with their products in the market growth phase may have reduced (but still significant) results if their product is in the development phase. The same is true for economic practices in the decline phase. As for the post-development phase of the PDP, we concluded that when companies invest in environmental and social practices, there is a complete mediation of the effect, where these practices lose strength if the product is in the introduction and maturity phases in the market. This fact can be confirmed in the day-to-day undertakings of organizations, as only economic practices are relevant to performance and this means that with these stages in which the business is still incipient or is mature in the market, they end up reducing the socio-environmental effects. On the other hand, when the product is in the growth phase in the market and the families are dealing with post-development, we have a complete competitive mediation, that is, the sign of the growth effect is inverted (negative); this means that if the families develop socio-environmental practices in the growth phase, they will be mediated by this phase which, consequently, will bring negative results in post-development. As the product post-development stage is mainly related to after-sales, the development of socio-environmental practices during this stage can lead to higher costs for rural producers, which may have undesired (negative) results in after-sales practices. Therefore, we concluded that hypothesis H2 was supported in the maturity phase mediating sustainability in economic, environmental, and social practices and in the pre-development phase. It was also supported in the introductory phase by mediating environmental, social and pre-development practices. In addition, it was possible to observe that it was supported in the growth phase, mediating environmental practices in the pre-development phase. We can see that H2 was also supported in the growth phase, mediating economic and

environmental practices, and in the development phase. In addition, we had support for H2 in the decline phase, mediating economic practices, and in the development phase. Finally, this hypothesis was also supported in the introduction, growth, and maturity phase, mediating the environmental and social practices, and in the post-development phase.

In summary, this study empirically contributed to show rural producers (of bananas) that hypothesis H1 was supported in the research and hypothesis H2 was partially supported, allowing them to manage their activities in a strategic and competitive way in the rural market.

We propose expanding the discussion to include the potential policy implications and practical applications of the study's results. Specifically, we plan to delve into how the identified positive impact of sustainability practices on the Product Development Process (PDP) and market performance can inform policymaking aimed at promoting sustainable agricultural practices. By elucidating how the integration of sustainability principles into the PDP can enhance market performance for rural producers, we can provide valuable insights for policymakers seeking to develop strategies for fostering sustainable development in the agricultural sector. Additionally, we can discuss the importance of leveraging these findings to guide decision-making processes at both organizational and governmental levels, ultimately contributing to the advancement of sustainable agriculture practices and the achievement of global sustainable development goals.

7. Conclusions

Our study created a theoretical model through an empirical validation of sustainability, LCAs, the PDP, and market performance. As a contribution to the field, and according to [16], it was observed from a systematic review of the literature that there are no articles referring to an analysis that uses a systemic approach based on frameworks in the areas of sustainability, LCAs, the PDP, and the market performance of banana producers in southern Brazil.

A post hoc test was performed to validate the positive associations that formed the hypotheses of this research through a robustness analysis and an endogeneity test. We also demonstrated that sustainability practices have a positive association with the phases of the Product Development Process. Furthermore, we saw that the LCA phases partially mediate the sustainability constructs and the Product Development Process phases that lead to an improvement in banana producers' market performance.

The results presented are directly related to the theoretical lens that was used in this research; a systemic approach based on frameworks. Different areas of research were analyzed, which we can understand as subsystems according to the principle of this theoretical lens, where the objective was to understand how they are related and how together they can improve the market performance of rural producers in the banana sector of Brazil. This contradicts what has been observed in recent years regarding an isolated analysis of the PDP, seen only as an operations support department, as we know that decisions and mistakes in the PDP have a direct impact on the performance capacity of organizations.

Our study contributes to the sustainable development goals [109] proposed by the 2030 Agenda for the Sustainable Development of the United Nations [110,111]. The ONU and its partners work to achieve their sustainable development goals, which are 17 ambitious and interconnected goals which envision the main challenges to be overcome to achieve the development of partner countries and, consequently, the world. In summary, the goals represent a call for the world to develop actions that end poverty, protect the environment and climate, and bring peace and prosperity to people.

Our study is directly related to goal 12, which deals with "Responsible Consumption and Production", more specifically items 12.2 and 12.6 which deal, respectively, with the following: "By 2030, achieve sustainable management and efficient use of natural resources" and "Encourage companies, especially large and transnational companies, to adopt sustainable practices and integrate sustainability information into their reporting

cycle". It was identified in our study that sustainable practices help in product development, and that the stages of development and post-development stages of the product have a direct effect on the market performance of banana producers.

An important limitation of our study is its restriction to rural banana producers only in the southern region of Brazil; however, according to [110,112] 70% of the sum of products and services generated by agribusiness come from the agricultural sector. Although these producers are representative of the agricultural sector, other geographical regions and agricultural crops may offer valuable insights into sustainable practices and market performance. Therefore, future research could benefit from using a more diverse sample of agricultural producers from different regions of the country.

Additionally, our study suggests analyzing new constructs and verifying other hypotheses and relationships that may influence market performance. This includes investigating specific factors such as soil quality, water resource management practices, and innovative agricultural technologies that may have a significant impact on the competitiveness of rural producers. Thus, future studies could focus on identifying and evaluating these additional constructs for a more comprehensive understanding of the determinants of market performance in the agricultural sector [112,113].

Furthermore, we suggest analyzing the introduction of moderating variables into these constructs and conducting a structural equation analysis with information from neural networks. This approach will allow for a deeper understanding of the complex relationships between the various factors influencing the market performance of rural producers. Therefore, future studies could explore advanced statistical analysis methods to investigate these relationships with more detail and accuracy. These more sophisticated analyses may help identify specific strategies to enhance the performance and sustainability of rural producers in the market.

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