Aligning Strategic Objectives with Research and Development Activities in a Soft Commodity Sector: A Technological Plan for Colombian Cocoa Producers

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Abstract: Although Colombia has the potential to be a cocoa producer for fine flavor and high value markets, it is not greatly recognized as such. In spite of the government’s interest to position the country as a major specialty cocoa producer, no strategic actions have been taken to develop and strengthen this aspect of the value chain. This study structured a technology roadmap for the sector that identifies major research and development investment opportunities by examining the current challenges and weaknesses in key dimensions of the sector (e.g., postharvest technology, quality, capacity, and markets) that impinge on quality and add value to the product. These challenges are identified through a multidimensional and region-specific gap analysis that integrates the advances and technological trends developed worldwide as ideal practice scenarios. The findings of this study should help in prioritizing the investment of public and private resources in the sector in order to better position Colombia in the global specialty cocoa market.

Keywords: global value chains; specialty cocoa; cocoa-chocolate value chain; Colombian cocoa; gap analysis; R&D; technological plan; upgrading; innovation

1. Introduction

As the global cocoa system is being revolutionized through product differentiation, consumers seek to ensure that value and uniqueness are captured and preserved throughout the supply chain [1]. Thus, new specialty lines are highly valued based on the uniqueness of their flavor and aroma as well as intangible attributes, some of which are related to cocoa’s geographic origin [2]. Because cocoa’s character and quality strongly depend on genetics, climate, and soil, optimal production only naturally occurs in a few countries located within the twenty degrees north and south of the equator [3].

Traditionally, many countries within this geographic range have built their cocoa sector around an undifferentiated bulk commodity concept, where commodity companies prized quantity over quality [4]. Under this model, beans with heterogeneous traits are mixed at different postharvest stages and much of the value of the traits as well as the countries’ competitive advantage are lost. At the same time, much of the traditional knowledge regarding production management and technological options in these countries has become obsolete due to changes in the nature of value creation in global value chains [5].
In the past few decades, the source of value has shifted from tangible to intangible assets and traits and their creation, marketing, and distribution is increasingly dominated by advanced market economies [5]. This pattern of value added along the global value chain has been represented by a smiling curve, labelled the “smile of value creation”, where emerging economies are at the center of the smile, performing basic activities that largely consist of low-skill, low-cost, repetitive tasks, while advanced economies are at the left and right ends, advancing innovative agendas through basic and applied research/design on the input (left) side and coordinating and controlling marketing, sales, and brand management on the (right) marketing-distribution end [5,6].

In this global environment, emerging market economies that are able to move to higher-value activities increase their competitiveness and their share of benefits from participation in the global value chain [7–10]. This is usually done by transforming inputs into outputs more efficiently, by moving into more sophisticated product lines, and by increasing the overall skill content of their activities [11,12]. These new ways of climbing up the value chain from basic production activities that use low-cost and unskilled labor to more advanced forms of supply are referred to as upgrading or catch-up processes, which have the creation of value—through research, development (R&D), and marketing—at their core [5,13]. Scholars of international management and economic development have pointed out though that sequential or linear upgrading is often necessary, whereby weak segments of the value chain are identified and investments to build network capabilities and learning are made before investments in subsequent segments are feasible or optimal [13,14].

This work examines weaknesses of the cocoa value chain in Colombia, an emergent market economy and producer country with natural advantages for premium cocoa production yet where the great majority of stakeholders are at the center of the smiling curve of value creation. About 95% of Colombian exported beans were categorized as Fine Flavour Cocoa (FFC), and the country was ranked as the 5th largest exporter of FFC cocoa with 13,056 tons or 3.94% of the total market volume. In spite of being ranked as the fifth largest exporter of fine flavor cocoa (FFC) in the world, the country has not taken advantage of its full potential [15]. Latin American countries with similar regional conditions like Ecuador, Perú, and Dominican Republic, each has an average 20% score in the International Cocoa Organization (ICCO) ranking system, far outranking Colombia’s 3.9% and dominating almost 90% of the total FFC exports. Peru, for example, which showed similar socioeconomic and environmental conditions as Colombia in 2006, positioned itself to attain a 16.06% market participation rate, with 53,219 tons of cocoa in 2015 [2].

Previous studies of the Colombian cocoa value chain have identified quality and productivity as major bottlenecks in the sector. These bottlenecks have been found to characterize agri-food value chains in other countries that rely on a large percentage of small and medium-sized producers [16,17], but specific socioeconomic and technological challenges associated with these weaknesses have not been studied in detail [2,4,18–20]. Quality, in fact, depends strongly on harvest and postharvest activities performed by the producer segment of the value chain, with their associated practices, capacities, and technologies [21,22]. The enormous constraints that producers face to perform these activities not only prevent them from becoming competitive but also represent a major bottleneck hindering the progress and sustainability of the whole sector. Highly prominent among these constraints are lack of market access, training, associativity, collaborative networks, and financing [16,17]. The latter studies show how different competitiveness bottlenecks can be overcome when such producer constraints are removed.

This study focuses on the producer segment of the Colombian value chain, using the technology roadmapping methodology [23,24] to identify quality and competitiveness bottlenecks and proposing a plan (as a set of R&D project recommendations) that can guide policy makers to address the constraints associated with the main bottlenecks. The roadmapping methodology allows for multi-criteria appraisal of segment vulnerabilities, stakeholder constraints, and available opportunities. This methodology has been used in other contexts to plan new product developments [25] for strategic planning by large organizations and companies in areas such as technological agreements [26]; organizational plans [27]; and national policy strategies for science, technology, and
innovation [28]; and process standardization [29]. Our particular innovation is to adapt it to the analysis of the vulnerabilities of an agricultural system.

The next section provides a description of the Colombian cocoa sector in terms of its main stakeholders and organizational context to help illustrate the vulnerability of the production segment and why its upgrading is of strategic importance. The subsequent section describes the roadmapping methodology in detail and presents the primary and secondary data used for the empirical analysis. The implementation of the roadmapping process is presented in the order it was performed, in three main stages: 1) identification of market opportunities; 2) diagnostics of vulnerable value chain segment links (with data from 10 departments or regions that represent more than 80% of the cultivated cocoa areas and cocoa bean production), identification, and analysis of segment gaps/constraints through the identification of ideal scenarios; and 3) articulation of these dimensions into strategic recommendations/projects based on the analytical results.

1.1. The Colombian Cocoa Sector in Context: Stakeholders and Organizational Structure

Like other commodity value chains that operate across countries, the global cocoa value chain is characterized by a market structure controlled by a few lead firms at the downstream and a highly fragmented and competitive structure at the upstream, where a large number of small producers compete for market access and face an oligopsonic buying market. Producers and firms in countries that perform upstream activities face great challenges connected with consumer markets and sometimes function as subcontractors in captive relations. It has been evidenced that farmers in the sector who experienced persistently declining cocoa prices from the 1980s to 2008 are currently receiving just 4%-6% of the final consumer price [30].

The overall structure of the Colombian cocoa sector resembles that of other cocoa-producing countries, with production activities (cultivation, harvest, fermentation, and drying) being performed mostly by a large number of small and medium-sized producers (98% of cocoa producers in the country are in this category) [2]; commercialization of the bean performed by associations, intermediaries, and buying house representatives; and processing and marketing being performed by a reduced number of national or multinational companies (Figure 1). In addition, a handful of public, private, and nongovernmental organizations provide technical assistance and perform some research [2,4].

In spite of the general organizational similarities, the Colombian value chain has a few unique characteristics that present a set of particular challenges and opportunities for local stakeholders. One of these characteristics is that global multinational companies have very limited presence in the processing and exporting segments of the chain, where two Colombian companies—Casa Luker and Nutresa—buy over 80% of the Colombian cocoa bean production [4]. Historically, cocoa has been a part of the basic Colombian consumption basket, with widespread artisanal production and important value linked to cultural practices [31]. Thus, a second unique feature of the local market refers to the fact that the national level of per capita cocoa consumption in Colombia (1300 grams per year) is almost three times that of major producer countries such as Ecuador (500 grams per year) and Dominican Republic (500 grams/year) and more than four times that of Peru (300 grams/year), all countries with a larger participation in global fine and flavor cocoa markets [2]. A related unique characteristic then is that, unlike Ecuador, Dominican Republic, and Peru, which export 95%, 94%, and 56% of their production, respectively, Colombia only exports 19% (Figure 2).

The strong local demand for cocoa in Colombia, one of the largest Latin American consumer markets, has enabled the largest local processing and manufacturing companies (Luker and Nutresa) to upgrade into the higher levels of the local and regional value chain not only by processing beans into intermediate products (butter, powder, paste, and chocolate) and by exporting some of their production but also by deciding how to source and finance input purchases, by dominating production and local distribution networks, and by expanding some of their operations to other Latin American countries [4]. This large domestic demand has been a mixed blessing for the country, since it provides a certain level of protection from international volatility; however, it also has sheltered the local industry and prevented it from competing in higher value segments of the global chain.
For the producer segment, the concentration of power in the local processing and marketing segments has resulted in producers facing strong entry barriers to upgrade into higher segments of the value chain, having little or no ability to influence the terms of transactions or how value is created and distributed. These barriers add to the already existing power asymmetries and barriers at the downstream level of the global chain [30], increasing the producer vulnerability as well as their lack of access to consistent information on market demands, prices, and opportunities. Currently, the major activities under the producer segment are cultivation, harvest, fermentation, and drying, which as mentioned earlier are key to quality creation yet are often carried out in a traditional and rudimentary manner. Figure 3 shows the main segments of the Colombian chain and the activities performed under each. In addition, with a large proportion of cocoa farmers being small-sized producers [32], the only way they can sustainably enter the chain is by horizontally integrating to achieve larger production volumes [17]. The industry’s focus on local demand for bulk cocoa in turn has meant that cocoa premiums for quality are, for the most part, not being paid—as found by Reference [4] in several regions of the country—and, as such, little incentives for producers exist to potentiate the quality of genetic resources.

This study is set up to examine these barriers and constraints by surveying the farmers themselves as well as other stakeholders in the sector in order to obtain a more accurate understanding of the segment’s situation. In addition, the study analyzes and proposes public and private initiatives to address the main weaknesses found.

**Figure 1.** Main segments and organizational structure (companies under each segment) of the Colombian cocoa value chain.
**Figure 2.** Comparison of main features of the Colombian cocoa value chain and its natural competitors in premium cocoa markets. Sources: *[2], [33], [34], [35], [36], and [37].*
2. Methodology for the Empirical Analysis

The technology roadmapping technique supports strategic R&D planning by aiding in the process of establishing priorities among competing technological options [23,38]. Priorities are determined based on markets as well as economic and social constraints [39]. Our roadmapping process includes a multilayer graphical representation of a plan that connects producer capacities, technologies, and products with market opportunities [24]. In order to structure the roadmap for the Colombian cocoa sector specifically, adaptations were made from References [16,29,40].

A diagram that comprised our roadmapping process is presented in Figure 4. The vertical axis shows the articulation of three layers of activities required to build the roadmap: the identification of market demands and opportunities, an assessment of the weaknesses in relevant value chain segments, and the formulation of R&D strategies in the form of project proposals. The horizontal axis in Figure 4 displays the time frame of the process of understanding the sector’s past and present to formulate a future vision for each of the vertical axis dimensions.

Figure 4. Methodological guide used to build the roadmap for the Colombian cocoa value chain: relationships between selected key components and time (adapted from Reference [40]).
The following sections describe in detail the development of each phase and the tools used to obtain results.

2.1. Phase 1: Market Demands and Opportunities

2.1.1. Market Competitive Intelligence

The goal of this activity was to supply strategic marketing knowledge related to international market opportunities. Hence, the following key aspects were considered during the information search: specialized niche markets, import and export data of cocoa products, and annual import growth rates in cocoa-derived consumer countries, to identify attractive and emerging external markets. The information search was done through the following database platforms: Trade Statistics for International Business Development [37] and Sicex of Procolombia’s information center [41].

2.2. Phase 2: Current State of the Producer Segment of the Colombian Cocoa Value Chain

2.2.1. Diagnostic of Constraints and Weaknesses

The diagnostic of the cocoa sector’s weaknesses for competitiveness in high value-added market segments is tightly related to its farmers’ situation. This analysis uses primary data (see below for specifics about the data and their collection) to characterize the current situation and to determine opportunities and limitations for these stakeholders in different regions. Different dimensions that are key to upgrading in the sector were examined under two different categories or lines of action (Figure S1):

*The technological and quality line:* Quality depends strongly on harvest and postharvest segments of the value chain with their specific practices and technologies. While the genetics of the cocoa variety may determine the chemical precursors for flavor and aroma, the actual generation of these attributes in the seed occurs mostly during its transformation throughout the postharvest stage [21]. The fermentation stage is a particularly important part of quality formation that, if not carried out adequately, makes it impossible to recover the attribute afterwards [22]. As such, the variables considered in terms of their importance for the quality of the final product were harvesting, fermentation, fermentation infrastructure, drying, drying infrastructure, and bean quality. These were established taking into account previous analyses by References [3,42,43].

*The farmers’ capacities and market line:* As mentioned above, removal of the quality and competitiveness of bottlenecks requires the removal of constraints faced by stakeholders that transversely affect various segments of the value chain. The variables of the analysis considered here based on preceding studies were associativity, entrepreneurial vision, training and technical assistance, transport and merchandising infrastructure, market studies, and articulation of chain actors and research and technology transfer capabilities [16,17].

2.2.2. Construction of Ideal Practices/Scenarios

Ideal practices/scenarios are global references with which the current state of cocoa farmers is compared. These were established after carrying out the analysis of the results obtained from the application of two tools: competitive technological intelligence and benchmarking. For the first diagnostic process, a meta-analysis of secondary information was conducted to synthesize information about scientific and technological developments in the cocoa sector as they related to operations, postharvest processing, cocoa quality, or R&D capacities. The observation period was established between 1990 and 2016 and a systematic, qualitative, and quantitative assessment of relevant research articles [44] was performed through database platforms (ScienceDirect®, ISI Web of Knowledge®, and Scopus®) using the VantagePoint software. For the search, keywords were established considering the main operations and variables of the process that exert a determining influence on the quality of cocoa according to previous works [3,21,43]. Thus, the keywords included physicochemical and organoleptic properties of cocoa, storage of harvested cocoa seeds, fermentation (equipment, methods, duration, fermentation degree, microflora, aeration, microorganism cultures,
and sweating management), drying (conditions, duration, temperature, types of dryers, speed, and degree), maturity index, pod opening, microbial population dynamics during processing, quality, safety, and traceability.

For the benchmarking process, we identified those leading countries that produce and export cocoa in competition with Colombia. The benchmarking exercise was developed in three phases (see Figure 5) which involved six fundamental activities: (1) definition of the benchmarking objective, (2) identification and selection of referent countries (Ecuador, Peru, Papua New Guinea, and Malaysia) [2,15], (3) definition of evaluation criteria, (4) analysis of selected target environments, (5) identification of best practices, and (6) identification of gaps and/or challenges to establish weaknesses between the leading countries and Colombia.

![Figure 5. Benchmarking methodology. Source: Reference [45].](image)

The benchmarking was developed as shown in Figure 5. The variables selected for benchmarking were (1) production (planted and harvested area, and yield); (2) postharvest (aspects related to the physical and biochemical transformation of cocoa seeds, especially in terms of use of technologies and infrastructure); (3) associativity (cocoa farmers’ associations, training, and technical assistance—technical quality standards); (4) cocoa quality; and (5) marketing (e.g., available channels and influence of intermediaries).

2.2.3. Gap Analysis

Our gap analysis assesses the differences between the results of the primary information collected through the diagnostic of cocoa farmers in relation to the practices/scenarios defined as ideal. Figure 6 summarizes the process of gap analysis. The gap analysis reveals the aspects in which further work is required; moreover, it also allows the establishment of a strategic plan of action from which the investment—economic, human, and technological resources—is justified and must be considered to reduce the size of the gap and to achieve future objectives (i.e., improve the capabilities and competitiveness of Colombian cocoa farmers so their products can participate in specialty cocoa markets).
The diagnostic included both a quantitative and a qualitative evaluation. For the first one, the level of compliance of the cocoa farmers in each study region was evaluated in relation to the ideal practices/scenarios established for the key analysis variables defined in the technological and quality line as well as in the line of market and capacities. It was obtained from the difference between the total number of aspects that conform an ideal practice/scenario versus the number of aspects that the cocoa producers complain about according to the information reported from the surveys. The level of compliance of cocoa farmers with the ideal practice/scenario was defined on a scale from 1 to 5, where 5 is the maximum level; this corresponds to a set of aspects that theoretically must be accomplished and jointly form the ideal practice scenario. Subsequently, the difference between the maximum compliance (5) and the actual level, resulting from the quantitative evaluation, was calculated. Thereafter, according to this value, a qualitative classification of the gap was assigned. If the difference between the actual and the ideal compliance level was 1, then the gap was qualified as low; if this difference showed two levels of difference, the gap was categorized as having medium weakness. If it had three or more levels of difference, the gap was rated as high.

2.2.4. Data Sources and Data Collection

This phase entailed the collection and analysis of primary and secondary data. Primary data for a diagnostic of the current state of the value chain were collected through descriptive surveys and focal groups with representative stakeholders. Secondary data were collected for the competitive technological intelligence study and benchmarking, as described above. The analysis of the primary and secondary information was used to build ideal practice scenarios, which were subsequently used to determine the gaps throughout the value chain.

We obtained primary information on the cocoa chain from 10 of the country’s departments. In each department, we focused on the municipalities with the largest cultivated areas with cocoa trees. These regions represent a wide variety of agroecological niches in Colombia. The specific departments visited are Antioquia, Arauca, Boyacá, Cesar, Cundinamarca, Huila, Norte de Santander, Nariño, Santander, and Tolima. Approximately 80% of the Colombian cocoa producers can be found in these regions [32].

In order to select a representative sample of actors at the social level that would be employed to collect primary data, two visits were carried out in each region. A first exploratory visit was carried out in each municipality between July and December of 2015. In this first visit to all regions, a total
of 450 actors from most of the cocoa value chain links were surveyed (the surveys formats are presented in the Supplementary Materials), including input suppliers, regional cocoa committee leaders, municipal government representatives, buying agents, warehouse operators, and processors. In the case of cocoa associations, key informants and associated producers linked to the most representative cocoa organizations in the study areas were surveyed by employing focus groups to have a first approximation to the local sector dynamics. Nonassociated cocoa farmers were also identified and surveyed. Subsequently, survey instruments for the next stage of the data collection that had been prepared were adjusted. A set of questions in this survey format were applied, including questions regarding the crop’s agronomic management and transformation, access to extension and technological transfer, marketing channels, infrastructure, and associations, as well as other socioeconomic and cultural aspects. The Turning Point software (Turning technologies v 8.0.) was used during the survey process of cocoa farmers as it allows the tabulation and visualization of results obtained from the questions asked in real time.

A second visit was then carried out from November 2016 to January 2017 to survey a subsample of 220 cocoa farmers randomly selected for the survey. The sample was selected with the help of Fedecacao, the National Producer’s Association, which has the most comprehensive list of cocoa producers in the country. The selection criteria included the number of hectares of cocoa cultivated (it allows having small, medium, and large cocoa producers in the sample) and the level of technification of the farm (high, medium, or low, considering the processes and systems of production of cocoa producers). Detailed primary information on each variable of interest defined within the two strategic lines of action previously described was obtained using the participatory rural appraisal methodology and employing descriptive surveys (see the Supplementary Materials) [46]. The sections of the survey comprised two levels: the first one focused on demographic and socioeconomic aspects (i.e., education, employment, income, and access to basic public services) of the producers, and the second one focused on productive and commercial information (i.e., genetic material, agronomic management, physical and biochemical seed transformation methods and systems (postharvest processing practices and infrastructure), and agroindustrialization processing).

2.3. Phase 3: R&D Proposals to Strengthen the Capacities and the Competitiveness of Colombian Cocoa Farmers to Enter Specialty Cocoa Markets

In this phase, specific R&D proposals are identified from our competitive technological intelligence and benchmarking data, which constitute strategic actions for the cocoa sector, as they address the weaknesses identified in the previous phases of the analysis and aim to reduce the size of the gaps found. These actions are cast in terms of specific suggestions for policies/programs, development and implementation of protocols, fostering adoption of best practices and optimal equipment, and evaluation of processes, along the lines of our analysis.

3. Results and Discussion

3.1. Market Demands and Opportunities

The world demand for cocoa shows an increasing trend that is driven mainly by a growing global demand for chocolate coatings, cosmetics, and chocolate [47]. This growth in demand, coupled with climatic variables and crop diseases, has affected production in the major cocoa-producing countries, such as those in Africa, causing a product deficit [48]. This generates an opportunity for emerging cocoa producing countries and, in particular, for Colombian cocoa-growing regions.

A category of considerable interest that has been gaining prominence in the cocoa market is “specialty cocoa”, which includes fine flavor cocoa (FFC), a segment characterised by having sensory profiles with flower, fruit, caramel, walnut, and chocolate notes. In addition to the characteristics of FFC, specialty cocoa is also defined by factors that differentiate the cocoa further in terms of quality as well as social and environmental aspects of its production, such as origin, certifications obtained by their producers, traceability, and singularity [2]. The specialty cocoa market has grown very quickly in recent years. At the global scale, while the demand for cocoa is growing by 3% annually,
specialty cocoa has the highest level of growth among all cocoa segments, reaching up to 9% in annual growth in the last decade [15]. This is explained by an increase in the demand for high differentiation gourmet chocolate that is considered healthy; it is highly specialized, having its own supply and demand characteristics, and is linked to processors and consumers who demand products with consistent and differentiating attributes. The value attached to these attributes generates better income and greater welfare for producers and is not necessarily exclusively bound to the typical organoleptic properties stated by FFC [49,50]. Another advantage offered by specialty cocoa is that its prices are independent of the international cocoa market price that is fixed to the London and New York stock exchanges. Specialty cocoa can be sold for premiums of more than US $1,000 per ton, as is the case of the “Premium Cocoa of Origin” [2]. Indeed, a simple US $1 value added per kg of cocoa beans could represent an increase in stability of up to 30% with regards to the variation in sales price for bulk cocoa [51]. In addition and as mentioned by Reference [4], the value-generating activities to attract these premiums are marketing and postharvest processing; thus, any premiums will accrue to businesses conducting these activities.

In order to identify opportunities for the cocoa sector, an analysis of the cocoa global FFC market was carried out. Figure 7 illustrates potential export markets for Colombian FFC producers. The gray bars show the quantity of imported fine flavor cocoa beans plus the equivalents in fine flavor cocoa beans for cocoa-derived products (in tons). Countries that recorded in 2015 at least 1000 imported tons were considered. The points represent the price (USD/ton) offered by each country [37]. When analyzing Colombia’s perspective on the FFC market (i.e., cocoa beans, butter, cocoa paste, chocolates, and confectionery products), countries such as Switzerland, Japan, Canada, and France stand out as potential markets; in these markets—where Colombia has no noteworthy participation—specialty cocoa products have been offered the highest prices. Conversely, the Netherlands and the United States are markets where Colombian specialty cocoa could be expanded due to its attractiveness regarding volume and competitive prices [37].

**Figure 7.** Identification of potential markets for Colombian specialty cocoa: The gray bars show the quantity of imported fine flavor cocoa beans plus the equivalents in fine flavor cocoa beans for cocoa-derived products (in tons). Countries that recorded in 2015 at least 1000 imported tons were considered. The points represent the price (USD/ton) offered by each country (elaborated using data from Reference [37], accessed on 02 August 2016).

It is important to highlight that cocoa certification may represent an additional opportunity that helps Colombian cocoa cooperatives in gaining access to new markets in view that, according to References [52,53], the demand for certified cocoa is expected to continue growing. This trend is driven largely by the commitments that European and US chocolate manufacturers have made for
Agriculture 2020, 10, 141

2025. For example, Mars, Hersheys, and Ferrero have committed to using 100% certified cocoa by 2021 [52,53]. In monetary terms, the premiums for certified cocoa have been reported as ranging from 5% for UTZ-certified cocoa (certification program for sustainable farming) to 18% or more for organic certified cocoa. In this sense, higher prices (resulting from better quality products and premiums) are regarded as the main factor influencing increased income of producers, and from the cooperative perspective, enhanced bargaining power and improved organization capacity are detected as clear advantages of certification [54].

3.2. Current State and Trends of Vulnerable Links in the Producer Segment of the Colombian Cocoa Value Chain

The importance of studying the structure of the cocoa sector lies in the fact that it establishes the baseline for technical knowledge on the aspects of interest, such as the needs, weaknesses, opportunities, and capacities of cocoa farmers, and for the construction and adequate execution of integral proposals focused on solving the main identified gaps. This is framed within the lines of the analysis described earlier: technology and quality, and farmers’ capacities and market (Figure S2).

3.2.1. Technological and Quality Line

This section shows the most relevant results on the critical operating variables that influence cocoa quality significantly and that are traditionally carried out by producers to transform the seeds (i.e., harvesting and maturity index identification; seed preconditioning; and physical and biochemical transformation of these, including fermentation and drying). The variables considered in this study are identified below.

3.2.1.1. Production and Harvest

When evaluating this variable, it was found that more than 95% of the producers identify their cultivated materials using different methods and that 60% know and can designate them with a specific name, primarily those donated by the National Cocoa Federation (Fedecacao). The remaining percentage discriminates them based solely on differences in physical characteristics. In addition, we have observed the use of heterogeneous methods to identify the cocoa maturity index established by producers and based on the experience acquired empirically during the crop’s management. The most widely used method was color change, the color of the pod peel after grating (used for materials where the external color change—due to maturity—is almost imperceptible), and the presence and damage carried out by certain animals (squirrels and birds).

The total number of producers surveyed in the study indicated they were able to determine the optimum maturity state in cocoa. However, they stated that they use overripe fruits or fruit with a lower level of maturity than the optimum for the seed’s physical and biochemical transformation process because the harvest is limited to a certain day frequency (it is not carried out daily); this makes it easier to find fruits with heterogeneous maturity, and consequently, the seeds extracted from this type of pods are fermented with the seeds coming from fruits in an optimal maturity state. Furthermore, 95% of producers do not carry out a classification process and an independent transformation for various types of seeds. In addition, it was found that 98% of the producers do not show the willingness to use a tool or to apply a method that involves conventional or instrumental analysis to identify the optimum fruit ripeness index per fruit because they find this practice inefficient in terms of time and associated costs.

Eighty-four percent of the cocoa farmers surveyed stated that they classified fruits according to their health status. However, most often, fermented and dry cocoa beans are still mixed at this stage since farmers are paid per weight/volume and higher amounts of fermented and dry cocoa beans result in higher economic incomes. Thus, healthy as well as diseased pods are harvested and processed, generating low-quality cocoa. These bad practices may have a significant negative influence on the physicochemical, sensory, and microbiological quality of the seeds because, at this stage, filamentous fungi can contaminate seeds, generating deterioration and mycotoxins [55].
After the pods are harvested, the producers begin with the procedures to physically and biochemically transform the cocoa seeds.

3.2.1.2. Preconditioning Operations

After farmers harvest cocoa pods, they carry out preconditioning operations for cocoa seeds such as storing the pods to be split or draining the pulp of seeds before these are placed in the fermentation systems. The logic for the application of these pretreatments (timing and location) is generally driven by logistic aspects during harvesting, such as the extension of the planting area linked to the lack of labor availability for this type of work in most regions rather than by the awareness and consideration of the effect that this timing and logistics have on the physical and biochemical transformation of the seed and, consequently, on its quality and flavor.

Whenever possible, the producers harvest the pods, extract the seeds, and start the fermentation in the shortest period of time (1 day) to accelerate the fermentation and drying processes before taking their product to the market. Cocoa is considered an immediate source of income because it provides the main cash income to pay school fees, medical bills, and other household necessities.

3.2.1.3. Fermentation and Drying

The design and management of the fermentation and drying methods and systems used in farms are carried out in a traditional and rudimentary way, with little concern regarding food safety or quality. All of the producers surveyed stated their methods follow a traditional or farmer-recommended process; none of them referred to technical reasons for their methods choices. Table 1 shows that there is no standard control over the phenomena that occurs during fermentation, showing, for example, that the anaerobic and aerobic stages are carried out without any technical rigor. Farmers do not know the effect and importance of oxygen as a key substrate that controls the overall reaction rate of the bioprocess and, in this case, the dynamics of generating flavor precursors. Farmers were also found to mix the different genetic materials in their farms without consideration of their composition or the time suggested to obtain properly fermented cocoa beans. Similar evidence was presented by Reference [4]. In addition, the fermentation systems encountered were not built to establish the physical conditions that the seeds need to be properly fermented (e.g., neither isolation of the fermenter system from the environment to avoid contamination nor lack of flexibility in the systems to adjust for different quantities).

The fermenters’ capacity found in farms ranged from 20 kg to 1200 kg of fresh cocoa, with the most common being 400 kg. It was also observed that the farmers who reported the minimum value of fermentation mass use rudimentary systems (e.g., plastic containers that are an alternative system to the rectangular boxes are used when the fermentation mass obtained is small). The farmers with high capacity fermentation systems (i.e., between 500 kg and 1000 kg) showed management difficulties during the aeration process, as evidenced by the lack of ergonomic conditions in this type of fermenters.

Among the fermentation systems observed in this study were synthetic fiber sacks, rectangular wooden boxes of two and three levels, wood canoes, tubs with ceramic surfaces, and plastic baskets. Regarding farmers who used cleaning operations, 35% of the farmers preferred scraping, 23% preferred sweeping, and 18% preferred washing fermentation systems with water. Moreover, 23% did not perform any type of cleaning operation because they considered that it negatively influenced the microorganisms related to fermentation. At the drying stage, a low level of control was also found on the influence of the process variables because, in all the farms, the systems used to carry out the moisture reduction in the product relied directly on the environmental conditions; this of course is not favorable, especially during the rainy season, where the cocoa is subjected to a violent drying process, generating the hardening of the testa (seed coat enclosing the cocoa seed), which prevents the volatilization of the acids inside the bean and generates products with high acidity. In this case, the producer is forced to use all the sun hours available during a day to avoid the cocoa being affected by molds; this issue causes loss of quality. The technification level of the farm indicates the drying system used, which varies from the use of cement and zinc surfaces; synthetic fiber sacks without any
kind of structure that provides protection to the beans, that is, without any roof or support bases; and two structures that are used as surfaces made of dry cane (Gynerium sagittatum) and wood protected with mobile ceilings or similar to a greenhouse.

The appearance of fungi in cocoa during the drying process is an aspect that must be controlled because it negatively and significantly affects the microbiological and sensorial quality of the final product. In this regard, cocoa farmers have developed alternatives to visually eliminate microorganisms from the surface of the cocoa beans by applying the following compounds: water (used by 40% of the surveyed farmers), fresh cocoa sweatings (26%), molasses (20%), and oil (14%). Later, farmers mix and dry the beans once more, exposing them to the sun for a short period of time.

3.2.1.4. Bean Quality

From our focus groups, we found that, along the value chain, warehouse and buying agents do not discriminate for cocoa quality. They do not in take account different levels of their physical, sensory, or chemical characteristics as they acquire the cocoa beans, paying for all kinds of beans (fermented and dried) the same price. These results are consistent with the findings of References [4,58], which show that premiums for high-quality cocoa do not compensate producers adequately for the additional efforts and costs incurred when high-quality standards are desired. A similar case is reported for Ecuador and Indonesia [22,59]. In several regions in Ecuador, there is no reward at the producer’s level for investing in quality and postharvest activities; thus, different variety beans with various fermentation and moisture levels and diseases are found. It is important to mention that, in Colombia, some level of sorting at the export or wholesale intermediary stages (the local intermediaries only dry the cocoa that they buy) was identified. However, as explained by Reference [22], if the producer has not carried out an adequate fermentation process, it is impossible to recover the attributes afterwards.

In addition to the weak conditions of the transformation operations that the farmers use, the inexistence of an appropriate price differentiation system based on cocoa quality has negatively influenced farmer motivation to produce a higher-quality cocoa. Even when the cocoa price increases, producers do not capture a fair value when selling their product; added value is especially concentrated in the industrial link. Because farmers receive minimum incentive, they do not apply a better method or use a more efficient postharvest system for processing; according to farmers, the price offered does not justify this, as they do not receive significant benefits. However, farmers are aware that some subjective tests can be used to obtain good-quality fermented and dry cocoa beans in different stages of the transformation process. For example, to establish when the fermentation ends, it is common for cocoa farmers to consider the color change on the surface of the cocoa beans from white to brown, the characteristic aroma of the fermentation mass, and the cut test on a determined number of fermented beans. In the case of the drying stage, some subjective parameters evidenced were the surface color of fermented and dried beans, the “cut test” of some of the beans to observe their color and internal shape, and the “hand test” that consists of generating friction between the beans to identify its texture and the characteristic sound of a dry cocoa bean. Subjective tests do not yield homogeneous beans because the tests are not precise and their results depend on who performs the selection.

In order to infer the level of homogeneity in postharvest practices across departments and regions (potentially due to shared environmental and market characteristics), we performed a cluster analysis that created postharvest practice “types” by grouping farmers according to their similarities in postharvest practices and examined the distribution of these postharvest practice types across departments. Figure 8 presents the cocoa postharvest stages considered for the clustering.
Table 1 defines six types or clusters of postharvest practices. Cluster 1 has long fermentation and drying periods (relative to other farmers in the sample) and intermediate duration of preconditioning and aeration. Cluster 2 has long fermentation and drying periods, intermediate duration of aeration, and the lowest (zero) preconditioning time. Cluster 3 has long drying periods, low to intermediate preconditioning, and the lowest levels of fermentation and aeration time. Cluster 4 has long fermentation, intermediate preconditioning and aeration, and the lowest drying periods in the whole sample. Cluster 5 has long drying and aeration periods and intermediate times for everything else. Cluster 6 has the longest preconditioning, fermentation, and drying periods. Table 2 illustrates that postharvest practices used in producer farms have a high level of heterogeneity within and between departments. Most departments have farmers who belong to at least four of the postharvest practice cluster types. In Santander, for example, the department with the largest acreage of cocoa trees in the country (by far), most farmers belong to cluster 4 (47%), which is characterized by having the lowest drying period, along with farmers in each of the other clusters. There are similar patterns in other departments except for Narino, where we only found farmers in two cluster types; however, our sample for this department is the smallest and we are unable to infer that this is representative of the department. Thus, we use these results to show mostly that there is significant heterogeneity across Colombia.
Table 1. Groups of farmers by similarity of postharvest processing practices.

| Cluster or postharvest practice | Number of farmers using the practice | Seed preconditioning (storage days) | Operations and postharvest variables | Drying |
|---------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|--------|
|                                 |                                     |                                     | Fermentation                        |        |
|                                 |                                     |                                     | Duration of anaerobic phase (hours)  |        |
|                                 |                                     |                                     | Duration of aerobic phase (hours)    |        |
|                                 |                                     |                                     | Aeration frequency (intervals in hours) |        |
|                                 |                                     |                                     | Initial solar exposure time (hours)  |        |
| 1                               | 49                                  | 3                                   | 6                                   | 34     | 109 | 24 | 9  |
| 2                               | 40                                  | 0                                   | 6                                   | 37     | 107 | 24 | 9  |
| 3                               | 29                                  | 2                                   | 4                                   | 30     | 60  | 24 | 9  |
| 4                               | 45                                  | 2.5                                 | 6                                   | 42     | 101 | 30 | 4  |
| 5                               | 49                                  | 2                                   | 5                                   | 57     | 72  | 43 | 9  |
| 6                               | 8                                   | 8                                   | 6                                   | 52     | 92  | 32 | 9  |

Source: prepared by the authors based on the primary data acquired in this study.

Table 2. Percentage of farmers performing different types of postharvest practices (defined by clusters) across regions.

| Cluster or postharvest practice* | Antioquia | Arauca | Cesar | Huila | Nariño | Santander | Boyacá | Cundinamarca | Tolima | Norte de Santander |
|---------------------------------|-----------|--------|-------|-------|--------|-----------|--------|--------------|--------|-------------------|
| 1                               | 13%       | 32%    | 20%   | 38%   | 50%    | 25%       | 7%     | 23%          | 30%    | 33%               |
| 2                               | 41%       | 9%     | 47%   | 31%   | 0%     | 3%        | 17%    | 8%           | 13%    | 6%                |
| 3                               | 13%       | 0%     | 13%   | 15%   | 0%     | 6%        | 13%    | 8%           | 35%    | 22%               |
| 4                               | 0%        | 45%    | 0%    | 15%   | 0%     | 47%       | 11%    | 62%          | 22%    | 0%                |
| 5                               | 31%       | 9%     | 20%   | 0%    | 50%    | 16%       | 41%    | 0%           | 0%     | 39%               |
| 6                               | 3%        | 5%     | 0%    | 0%    | 0%     | 3%        | 11%    | 0%           | 0%     | 0%                |

* The type of cluster or postharvest practice can be seen in Table 1. Source: prepared by the authors based on the primary data acquired in this study.
3.3.2. Strategic Line of Chain Capacities and Market

3.2.2.1. Associativity

We found that, in different departments, there are duly organized associations of cocoa producers who have begun to carry out cocoa marketing processes, recognizing sometimes the bean quality through the payment of a small economic incentive for the fulfillment of criteria such as moisture content, bean size, and cleaning. A few of these associations carry out postharvest handling of cocoa beans in community processing centers using properly defined fermentation and drying protocols and dealing with a smaller number of intermediaries.

Several of these associations have benefited from a program that the government started implementing in 2002 (“Productive Alliances”) to help farmers join efforts and reach more volume and by linking them to a commercial ally that would purchase a significant part of the production. However, almost all of the farmers’ main commercial ally is one of the two main companies that purchase the product nationally. Only a few of the associations have direct linkages with buyers outside the country and receive additional premiums, which are invested in improvements of the farmers’ living standards and farming productivity. It should be pointed out that, although Santander is the main cocoa-producing department of the country, it also has the largest number of producers not affiliated with any association. Some farmers perceived this to be due to trust issues, yet it can also be related to the region’s largest availability of technical assistance and market access for individual farmers.

3.2.2.2. Entrepreneurship

In several regions, there is a small number of artisanal microenterprises that produce cocoa derivatives (i.e., drinking chocolate, cocoa liquor, and chocolates), though without the adequate equipment and infrastructure. Common weaknesses observed in terms of managerial and financial capacities were related to the lack of planning and agribusiness perspective, technical knowledge of agroindustrial processes, and market studies. Stakeholders were also perceived to have little to no access to information on market demands, price fluctuations, and quality standards. It is important to highlight that cocoa with a certification label is seen by some farmers as a good opportunity that helps cocoa associations gain access to new markets, yet the costs are perceived as being too high. In addition, some standards required for certification cannot be fulfilled by the farmers in certain regions. For example, for labor and safety standards, often, the person performing certain operations has to be trained in these practices yet there is no certified trainer in many regions. Despite the benefits shown by the market analysis, it was found that 81% of the farmers surveyed do not have their farms certified. Only 5% of the productive units are certified in Fair Trade or Sustainable Agriculture: Rainforest Alliance, Good Agricultural Practices, or Organic Cocoa, while 14% of the cocoa farms are in the process of becoming certified.

3.2.2.3. Training and Technical Assistance

In spite of the existence of training and technical assistance institutions in Colombia, such as the National Cocoa Federation (Fedecacao), the National Learning Service (SENA), or the Colombian Corporation for Agricultural Research (Agrosavia), their capacity and coverage is described as insufficient to attend to and to train the country’s cocoa producers. In addition, due to the lack of articulation of efforts and the lack of teamwork among these entities, cases were identified where farmers received technical assistance based on knowledge criteria that were contradictory, which created confusion and mistrust. Other research studies also report competition and little collaboration between these types of entities, creating lack of clarity in the message transferred [4, 60]. The cocoa industry has also provided training services to their clients in an effort to foster adoption of new and better agricultural practices, quality control standards, and sustainable production systems to meet the customer’s demand for higher-quality cocoa and chocolate. However, the training plans and technical assistance from these chain actors are also uncoordinated and often offer minimal or only
very particular services [16]. As reported by Reference [4], international development agencies and NGOs also play a role in providing technical assistance to cocoa growers, especially in areas with nascent supply chains. However, producers in these may be left without support when projects and funding end. See Reference [4] for a broader summary of extension efforts (technical assistance programs) recently/currently supported in Colombia.

3.2.2.4. Infrastructure and Technological Transfer

Farmers express dissatisfaction with the state of secondary and tertiary roads and stated that they must be improved to facilitate cocoa transportation and marketing. It was also observed that the cocoa storage and marketing infrastructure is insufficient and inappropriate in terms of design and operation. Similar results were found in the studies developed by References [4,58,60–62]. Similarly, farmers stated that they are not informed of technological advances or research performed by the major agricultural research institutions in the country.

3.3. Ideal Practices/Scenarios and Gap Analysis

As indicated above, the ideal reference practices/scenarios are a crucial input to highlight and construct the gaps across the regions. Tables 3 and 4 show the minimum aspects that should be considered in an ideal practice/scenario.
Table 3. Ideal practices/scenarios considered in the technological and quality strategic line.

| Harvest | Fermatation | Fermentation infrastructure | Drying | Drying infrastructure | Cocoa quality |
|---------|-------------|------------------------------|--------|------------------------|--------------|
| 1. Carrying out sanitary classification of pods, separating diseased fruits from healthy ones. | 1. Measuring process variables as temperature, pH, and degree of fermentation. | 1. The fermentation system adjusts to different quantities of fresh cocoa mass. | 1. Mixing frequently the cocoa beans in the drying bed. | 1. Separating dirt from cocoa beans. | 1. Carrying out quality tests on the cocoa beans at the end of process. |
| 2. Harvesting only ripe pods. | 2. Application of a final quality test to determine the degree of fermentation. | 2. The fermentation system is designed considering ergonomic parameters for handling. | 2. Carrying out quality tests on cocoa beans. | 2. Classifying the cocoa beans by physical quality parameters. | 3. Employing instrumental measuring equipment to carry out quality tests on cocoa beans. |
| 3. Harvesting with appropriate tools and techniques that do not damage flower cushions and trees. | 3. Using the minimum required quantity of cocoa mass to obtain a suitable degree of fermentation. | 3. The fermentation system is made of suitable materials to carry out the bioprocess (new materials could replace wood). | 4. Design and manage the drying process according to the desired characteristics of the final product. | 3. Knowing the sensory profile of the cocoa produced. | 4. Control of solar radiation times for cocoa beans. |
| 4. Harvesting specific genotypes independently. | 4. Independent transformation of cocoa varieties according to their particular characteristics. | 4. Farmers measure environmental variables in which fermentation systems are located. | 5. Measuring process variables (temperature, moisture, and drying rate). | 4. Implementing a traceability record of the cocoa produced. | 5. Measuring the adequate drainage of the sweatings generated by the process. |
| 5. Knowing and applying a preconditioning operation of pods and/or cocoa seeds before fermentation. | 5. Using starter cultures or chemical compounds and enzymes to improve the quality in the final product. | 5. The fermentation system is isolated from the environment, and it is located in a place with adequate ventilation. | 6. Measuring process variables (temperature, moisture, and drying rate). | 5. Implementing good manufacturing practices. | |
Table 4. Ideal practices/scenarios in the strategic line of capacities of the cocoa-chocolate chain and market.

| Associativity | Entrepreneurial vision of cocoa cultivation | Training and technical assistance | Transport and merchandising infrastructure | Market research | Articulation of chain actors | Research and technology transfer capacities |
|---------------|---------------------------------------------|----------------------------------|---------------------------------------------|----------------|-----------------------------|-----------------------------------------------|
| 1. Presence of first- and second-level consolidated farmers’ associations that operate efficiently. 2. Certification processes of production units led by associations. 3. Equitable resource management and benefit transfer to association members. | 1. Presence and operation of community postharvest centers and evaluation of their profitability/sustainability. 2. Presence of productive units or associations where the cocoa bean is transformed in an artisanal way or even with a low level of agroindustrialization. 3. Initiatives and capabilities for the generation of cocoa added-value products and capacity to develop market and product innovations. 4. Associations with experience in cocoa bean export to international clients. 5. Presence of cocoa companies. 6. Suppliers of appropriate and certified inputs for the cultivation of cocoa, including plant material and labor standards. 7. Existence of a business plan. | 1. Strategic training plans and technical assistance 2. Sufficient coverage for the farmers of the region. 3. Relevance of public institutions for training and technical assistance. 4. Participation of the private sector or Nongovernmental Organizations (NGOs) in the training and technical assistance processes. 5. Farmer leaders who act as transference agents of good cocoa practices. 6. Relevance of trust and social networking mechanisms and spaces. | 1. Suitable communication infrastructure in rural zones that allows product transport to buying centers. 2. Suitable places to store and market cocoa taking into account food-handling regulations. 3. Implementation of the Colombian technical standard: NTC1252. 4. Access and/or establishment of own quality control laboratories. 5. Direct sale channels. 6. Differentiation of prices by quality. 7. Conscious buying agents to purchase cocoa with minimum quality conditions. 8. Marketing legality. | 1. Performing market studies that guide the business prospects in the region. 2. Developing and updating continuously national and international market variables that guide producer’s decisions, such as prices, quantities traded, national available supply for different types of cocoa, etc. | 1. Articulated work of different actors: public entities as local and departmental governments; universities and research institutes; private sector: NGOs and financial entities for the competitiveness of the chain aligned under a strategic plan (collaborative projects and joint actions). | 1. Human resources trained in areas that contribute to the competitiveness of each value chain link. 2. Infrastructure for research and technology transfer. 3. Coordination of research, training, and educational programs targeting main sectorial demands 4. Research and transfer projects. 5. Information systems for knowledge transfer. 6. Networking support. 7. Development of research programs with impact on the chain’s competitiveness. |
3.3.1. Gap Analysis

Figures 9 and 10 show categorical measures for the gaps found across regions, constructed for each of the variables that make up the two strategic lines of the study (technological and quality, and capacities of the value chain and market) and based on the quantitative and qualitative information collected. The maximum score of 5 reflects the ideal scenario (gray line), while the black line represents the score of a region in a particular dimension. Thus, the size of the gap of a region is equal to 5 minus the score in that dimension.

As can be seen in Figure 9, the technological and quality line shows similar gap trends for all departments. The largest gaps are to be found in the dimensions related to quality and fermentation infrastructure, while harvesting, drying, and drying infrastructure are relatively and consistently better ranked. The regions with the poorest results in these two dimensions are Boyaca, Cesar, and Cundinamarca. Among the most important issues within the main gaps found were the use of outdated methods and poor transformation practices, leading to loss of cocoa quality, lack of adequate postharvest infrastructure (i.e., rudimentary processing systems that do not consider innocuousness, ergonomics, and capacity), and the high degree of market intermediation (i.e., buying agents considered a payment system that do not pay for differentiation by quality and lack of transparency), among others. Our results are similar to those reported by Reference [47] for the cocoa value chain in India. The best overall results, as evidenced by how wide the area of the hexagon is in Figure 9, correspond to Antioquia, Arauca, Narino, and Santander.

In terms of capacities and markets, our gap analysis revealed that there is much more heterogeneity in the gaps, across regions, for this group of factors of the value chain than along the technological and quality gap. Figure 10 shows that the most heterogeneous dimensions for this line relate to research and technological transfer capabilities, entrepreneurial vision of cocoa cultivation, and capacity to conduct market studies to a lesser extent. In terms of research and technological transfer capabilities, the weakest regions are Arauca, Boyaca, Cesar, Huila, and Norte de Santander, while the best ranked region along this dimension is Santander. In terms of entrepreneurial vision, the weakest are Cesar, Cundinamarca, and Norte de Santander. For the capacity to conduct market research, there is a large number of departments categorized as having a medium-low level, such as Antioquia, Cesar, Cundinamarca, Huila, Narino, Santander, and Tolima. All of the regions have their best results in the associativity dimension, perhaps due to the way the government has created incentives for cooperatives since the early 2000s [4].

The main weaknesses identified in focus groups and stakeholder surveys for this line were lack of access to information, high barriers to entry into high-value market segments, high transportation costs due to poor road infrastructure, and low level of application and transfer of technology. At an institutional level, the principal concerns stated were the execution of research projects focused on issues that did not address priorities related to the demands and main problems in the territories as well as the lack of coordination among institutions for project formulation and execution.
Figure 9. Main gaps identified in the technological and quality strategic line by region: Current situation, represented by a black line, versus best practice/scenario, represented by a gray line. Next to each variable, the qualitative assessment of the gap is indicated in parentheses: high (H), medium (M), or low (L).
Figure 10. Main gaps identified in the strategic line of capacities of the cocoa value chain and market: Regional reality (black line) versus best practice/scenario (gray line). Next to each variable, the qualitative assessment of the gap is indicated in parentheses: high (H), medium (M), or low (L).
3.4. R&D Proposals to Strengthen the Capacities and Competitiveness of the Colombian Cocoa Sector

The roadmap elaborated in this research, as a summarized scheme, can be seen in Figure 11. The map is a guiding element for the development of the Colombian cocoa sector that was built including the following elements: the articulation of the results obtained through the analysis of primary and secondary information on the current state and trends of the cocoa value chain in the country, gap analysis on technology and capacities, and the scenario that represents the opportunities and/or market demands.

3.4.1. Technological and Quality Line

The strategic proposals identified for this line through our competitive intelligence and benchmarking analyses are aimed at addressing the main gaps found in our analysis (postharvest processing and quality scopes). These proposals are aimed at the establishment of optimized and regulated physical and biochemical cocoa seed transformation processes as well as at the development and management of the bioprocess. They focus on promoting best practices and technology, providing strategic incentives to foster their adoption, establishing protocols, and performing evaluation of processes, among others.

For the postharvest dimension, programs and policies should enable access to and should foster the adoption of mechanization equipment for pod splitting (Figure S3A) [63], adjustable fermenters (Figure S3B) to be used as bioreactors that can transform different volumens of cocoa seeds and can control operating conditions [64,65], and dryers (Figure S3C) that allow for controlled environmental conditions, preferably or complementarily working with solar energy [42,66]. In addition, the sector would benefit from the development and/or adjustment of appropriate equipment and processes for the mini-chocolatier industry [21]. These technologies could be transferred and appropriated by cocoa producers through associative and entrepreneurial models [4].

In terms of research and evaluation, the sector would benefit from a dynamic approach that continuously evaluates key aspects of the postharvest process and how they influence the quality dimension in order to gain a competitive advantage addressing unique demands and fostering innovation. The key aspects identified in this realm are as follows. First, conduct a study of the profile, origin, and dynamics of the microbiota involved in the fermentation of cocoa seeds and biochemical molecules, which are precursors of sensorial attributes, and evaluation of the microorganisms’ activity in the generation of biochemical molecules. Second, conduct an evaluation of the optimization of the postharvest transformation process of cocoa seeds, through the incorporation of starter cultures and chemical and/or enzymatic catalysts [67–69]. Third, conduct an evaluation of the effect of the harvest, postharvest, and drying process conditions on the quality characteristics of the chocolate [3,21,70]. Fourth, conduct an evaluation of the effect of the processing conditions of cocoa bean (roasting, conching, etc.), on the quality characteristics of products as nibs, liquor, or chocolate [71]. Fifth, perform coordinated preconditioning, fermentation, and drying processes in order to target specific and desirable qualities of the product [43,72,73] as well as a measurement of the process progress through objective variable indicators such as pH, temperature, and concentration of biochemical markers [74,75]. At the same time, the standardization of these coordinated processes requires the development of protocols to be applied, and the identification of the desirable qualities to be targeted requires dynamic market surveillance. These protocols and targeted demands are best matched with the establishment of information systems that are transparent and accessible to all value chain actors. Sixth, conduct technological surveillance in equipment and methodologies for the industrial transformation of cocoa beans in other products with higher benefits as well as market surveillance to identify potential demands for cocoa byproducts such as pod husks, sweatings, placenta, and shells [76–78].

The geographic origin is an important aspect of quality differentiation identified, which is important for competitiveness and requires the prioritization of specific actions. In particular, the implementation of systems for the categorization of promising cocoa materials, their selection and evaluation under different agroecological conditions in different regions [79,80], the establishment of
certified plant material producers and distributors, and the development of a traceability system for cocoa processing [43].

3.4.2. Capacities and Market Line

Proposals for this line consist of strategic actions oriented toward managing the articulation process of and infusing an entrepreneurial vision in producers and associations in order to broaden the access to higher value markets. The specific weaknesses identified in our gap analysis relate to technological transfer capabilities in the sector and the entrepreneurial vision of cocoa producers (or lack thereof). Other aspects with intermediate level gaps (transportation and market infrastructure, and market research capabilities) shall also be addressed by policy and projects since these dimensions go hand in hand with the improvement of other deeper gaps. For example, technological and knowledge transfer as well as market information and research are necessary to develop an entrepreneurial vision and to create and grow entrepreneurial capacities.

Two complementary aspects of increasing these capacities correspond to the actions and policies that can be taken by the government and other institutions to enhance broad support structures for the farmers and the actions and projects aimed at strengthening the farmer associations themselves. While the government has a key role in strengthening the innovation system and links between major actors and institutions [81,82], investments by the private sector, possibly channeled through the National Cocoa Federation, are also important. In general, the successes and gaps in the country study point to a number of different investment and policy priorities: research on which associative models are best for different communities and regions and initial incentives to form a critical mass of these organizations [83], greater investment in core extension services for the transfer of knowledge and research innovations from national research institutes to the farmer associations, institutionalization and coordination of these services (possibly in partnership with local universities and national technical learning service providers), and investment in entrepreneurial and leadership capacities of farmer organizations. Improvement of infrastructure, market research, and information delivery systems should complement the abovementioned investments in addition to the current efforts to improve seed, fertilizer, and financial markets. As recognized widely, intervention and support to overcome coordination failures and kick-start nascent markets are necessary [84]. Recent research points further to the importance of establishing social and knowledge bridges between producer communities to overcome key barriers to upgrading that are rooted in the social fragmentation of producer communities [85–87]. Incentives for the coordination across national research institutes and sectorial research organizations are key as well as efforts to maintain and update public information and databases, including market research for strategic positioning of different Colombian cocoa products [4].

In terms of actions that are geared toward the improvement of entrepreneurial capacities and vision of associations, these should address the following realms: governance—members of the group should establish shared principles to work with a common vision; strengthening administrative capacities—members should pursue and manage the organization’s resources in an efficient manner and with accountability mechanisms; strengthening associative commercialization—mutual trust should be created within the organization as well as with other actors of the value chain such as buyers and with a proper understanding of the market; and business consolidation—development of entrepreneurial capacities, fulfilling commercial contracts, and building long-term relationships. In fact, entrepreneurial and community growth can go hand in hand if, as the association and the business grow under the principles of differentiation, diversification, and added value, a share of the profits and other benefits are used to improve the living conditions of the whole community [88–91]. Additionally, conversations with buyers around contractual alternatives and pricing schemes that effectively incentivize volume and quality are needed. For large buyers like Nutresa and Casa Luker, greater price differentiation by quality is most relevant; for specialty buyers, additional incentives for quality that take into account the higher postharvest costs associated with consistent fermentation and drying processes is to be addressed [4].
The strengthening of the trust and cooperation between farmer associations, the government, and other institutions and agencies will be key for the implementation and sustainability of any of the formerly mentioned initiatives (more so for rural regions in coming out of conflict situations). A key example is represented by successful technological transfer and training systems where universities and learning service institutions develop training materials with the assistance of farmers; the extension service provides trainings to the farmer association members via its training and visit system; and government agencies assist in establishing policies to guide the efforts and, jointly with farmer representatives, seek funds to support them [92].

In addition, given the significant size of the Colombian domestic market, efforts to educate local consumers about cocoa qualities and value in order to increase local appreciation for fine flavor and artisan skill could complement international incentives for quality production, particularly if the government can encourage more direct links from producers to local consumers. As suggested by Reference [4], domestic markets represent a great opportunity for farmers to increase their production volumes to produce more efficiently and profitably with enhanced quality. For example, local chocolate manufacturers could be incentivized by the government to undertake initiatives such as publicly committing to paying prices above bulk commodity for cacao; building long-term, direct relationships with cocoa producers, providing unprecedented transparency into their sourcing practices; and actively advertising skill and flavor in chocolate production. While some of these efforts may generate negative cashflow in the short run (as resources are withdrawn from low-cost production and transferred to higher value-added activities where firms may have little experience), this should not be viewed as a loss but rather as an investment in developing crucial competencies for broader participation in the global value chain and sustainable insertion of the producer segment in it [24].
Figure 11. Strategic roadmap of the Colombian cocoa sector. * The gap analysis and ** R&D proposals considered in Results and Discussion section. --- The implementation of these projects considers participatory innovation and transfer plans and the ex-ante, during, and ex-post impact evaluation of the projects in both lines.
4. Conclusions

A technological plan with specific proposals based on research/development challenges was structured for the Colombian cocoa sector. First, a diagnostic of the major challenges found in the sector for upgrading into higher-value segments of the market was performed through the collection and analysis of primary and secondary information. Primary information was collected in ten departments, which jointly grow about 80% of the cocoa produced yearly in the country. Ideal scenarios and best practices to aim for were specified before establishing the strength of the gaps in multiple dimensions for each region or department. To conclude, a set of specific proposals to help close the identified gaps was formulated. In addition, a summary of the roadmap was elaborated (Figure 11) to serve as a guiding tool for policy makers, which articulates the current state and trends of the cocoa value chain in the country, the gap analysis on technology and capacities, and the best scenarios that represent opportunities and/or market demands.

Overall, we identified that the sector could take advantage of its potential to increase its market share in premium cocoa markets by designing and managing cocoa harvesting and postharvesting processes that prioritize quality and quality differentiation geared to satisfy the needs and to meet the requirements of specialized markets. In addition to the gaps identified in postharvest processing and quality creation and maintenance through the value chain, important weaknesses were found in the areas of technological and knowledge transfer and lack of entrepreneurial vision and capacities of cocoa producers.

Addressing these gaps in the value chain will require a comprehensive and articulated policy and program implementation strategy shaped to the particularities of the different regions. This study proposed a set of policy and programs as a comprehensive strategy that would address issues from two main and complementary perspectives: actions and policies that can be taken by the government and other institutions to enhance broad support structures for the farmers and the actions and projects aimed at strengthening the farmer associations themselves. While these are presented separately, our work emphasizes that any efforts of farmer associations or of the government (and other institutions and agencies) will only be effective if they coordinate their strategies and promote their goals jointly. The experience of the Colombian coffee sector serves as an example to show how the global market dynamics for a sustainable and special quality commodity can become a major force influencing Colombian producer land use decisions [93]. The latter study found that regions apt for differentiated coffee production have experienced the greatest increases in planted area and that farmers who sold to differentiated markets were able to capture a larger portion of value added and faced lower volatility than mainstream producers.

While this work emphasized needs related to sustainably inserting the producer segment into a global supply chain that increasingly demands quality, skills, and knowledge, it will be important for future studies to complement this approach with assessments about rural development investments necessary to enhance overall rural living conditions in the country. In general, agricultural production in Colombia faces challenges related to rural outmigration, highly unequal land concentration, poor transportation infrastructure, and competition with illicit crops and nonfarming alternatives. As Reference [4] notes, nonagricultural licit and illicit alternatives strongly compete for productive resources that the cocoa sector needs, in particular, labor force. While many authors view the cocoa sector as presenting unique opportunities in the context of post-conflict development (following the signing of a peace agreement with guerrilla groups), some support the idea that Colombia has to revamp the infrastructure and sociopolitical contexts around the licit rural economy and/or legalize/regulate the existing illicit rural economy in order to exploit its full agricultural potential [4,94].

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1 Figure S1: Categories or lines of action and their variables considered for the diagnostic of the current state of the producer segment of the Colombian cocoa value chain, Figure S2: Scheme of the current state of the producer segment of the Colombian cocoa value chain under the lines of: technology and quality, and farmers’ capacities and market, Figure S3: A) Cocoa pod splitting machine. B) Adjustable fermenter systems for different cocoa seeds capacities.
and bioreactor for cocoa transformation. C) Convective dryer coupled to a renewable energy system, Survey S1: Survey to suppliers, Survey S2: Survey to cocoa farmers, Survey S3: Survey to buying agents, Survey S4: Survey to processors.

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Highlights
Diagnostic of the current state of the Colombian cocoa value chain.
Multidimensional gap analysis for the Colombian cocoa value chain was implemented.
R&D projects and policies proposed to strengthen competitiveness of the cocoa-chocolate value chain.
Technological plan for the Colombian cocoa sector: strategic projects to be developed under regional government policies for cocoa growing territories.

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