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Roadmapping as a Driver for Knowledge Creation: A Proposal for Improving Sustainable Practices in the Coffee Supply Chain from Chiapas, Mexico, Using Emerging Technologies

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Abstract: Technologies are essential for productive sectors to increase competitiveness and improve sustainable development. However, the technology benefits present a great delay in adoption in agricultural sectors, due to discrepancies between scientific research and local needs. This article presents a study for improving sustainability practices in the coffee supply chain, using emerging technologies, of two localities in the Frailesca region from Chiapas, Mexico, based on the current situation, expectations and actions expressed by 165 coffee producers and 12 representatives of two coffee producers' organizations. Based on Mentzer theoretical support, the technology roadmaps, knowledge management and digital compass were used to draw coffee supply chain processes to identify concrete actions and explore technologies. The results show that the technological route must be focused on renewing and improving coffee quality, getting quality certifications and access to specialized markets. Digital quality management and advanced statistical process control seem to be the appropriate emerging technologies for enhancing the acquisition of resistant varieties, proper pest management, improvement in the collection of coffee beans, the right time and way to plant a coffee plant, soil analysis and for the management of weeds and water conservation and harvesting as sustainable practices in this region. In addition, statistical correlation showed that digital technologies can be better adopted, on average, by producers with 4–6 family members, aged between 40–44 years and without additional crops. The findings propose sustainable practices linked with emerging technologies, based on a technology roadmap and knowledge management methodologies for this region.

Keywords: roadmapping; sustainability; coffee supply chain; emerging technologies; knowledge creation

1. Introduction

In today's digital era, technologies seem to be essential for productive sectors for increasing their competitiveness and improving operational management to face climate change, economic crisis and the continuously growing population in a sustainable way [1–3] Some non-desirable results of the industrial revolution were marked for unsustainable ways that cause soil and atmosphere contamination. Nowadays, in industrial modernization, knowledge is driven by technological issues such as cyber physical systems, tools and sensors, used for better management, downtime removal, waste reduction and increment of efficiency in the use of energy [4].

Nowadays a significant delay is evident in the use of technologies due to discrepancies between research and needs [5]. This is manifested in the model of conventional agriculture, which results in a vulnerable-to-change production system of small farmers, causing the destruction of natural resources [6]. However, delays in the use of technology are not present in the entire agricultural sector because it increases the yield [7]. Technology adoption depends of several factors such as profits, farm size, status of a household, distance to the nearest market, cooperative membership, and so on [8].

Agriculture 4.0, as considered in Industry 4.0, focuses on the use of technology to improve the production and efficiency in the food chain and the protection against environmental changes [9,10]. Climate-smart agricultural technology is an option to reduce climate change impacts in Rajasthan India; the study of [11] also proposed web platforms for production monitoring to increase its quality and quantity.

Agriculture engages around 1.1 billion people (31% of global employment) [12], including small producers for soil management, crop maintenance, industrialization and commercialization; however, the climate variations, technological exclusion (principally by small producers in less developed countries), non-pertinence and lack of economic resources obstruct sustainable livelihood [1].

One of the most representative worldwide crops is coffee. Today, the number of persons dependent on the coffee supply chain is around 125 million [13]. Mexico contributes around 9 million tons of coffee per year [14], 9% of worldwide production [15], and Mexico is in the ninth place regarding exportations [16].

Coffee production in Mexico involves around 500,000 producers (peasants and indigenous people) from 480 municipalities [17]. Knowledge of the coffee producer in Mexico involves beliefs, deeply rooted in their value system, expressed in a particular language and procedures for coffee plant management, from around two centuries ago [18]; therefore, small coffee producers are considered excellent for organic coffee production and important worldwide suppliers [19,20].

The supply chain, defined as those persons directly involved in upstream and downstream flows of products and/or information from a source to a customer [21], is structured in Mexico by small producers, intermediaries, industrials and marketers. Nowadays, the coffee supply chain in Mexico presents problems such as low productivity and non-economic profitability, weak technology transfers and limited value addition; these are disadvantages associated with an unsustainable coffee sector [22] and with incongruous poverty of people located in areas with the highest coffee production [23,24]. The aforementioned causes the 64% decrease in the production of coffee in Chiapas—the state with the highest production in Mexico [15]—and the increase of environmental problems [25].

Despite this scenario, for some years there have existed some regions that are recognized for their agricultural productivity, one of which is called Frailesca, in Chiapas, Mexico, and is considered to be in the process of re-adaptation. This region comprises six municipalities: Ángel Albino Corzo, El Parral, La Concordia, Montecristo de Guerrero, Villa Corzo and Villaflores [26–28]. The proposal presented in this manuscript is achieved in this region.

Literature Review

Currently, diverse methodologies related with the study of technology have been proposed to help solve problems related with sustainability, quality, innovation, health, etc. For example, the methodology of [29] exposes technology forecasting to prognosticate technology heading, the approach used by [30] identifies and compares emerging technologies through a house quality matrix and the study of [31] integrates collaborative networks by considering software agents. Most coffee studies are focused on technical approaches for recovering antioxidants, pathogen detection [32], characterization, sustainability, waste management, quality preservation [33]. A brief background has been provided in Table 1; however, sometimes, these technologies, for certain group of persons, cannot be as beneficial as others technologies are, in aspects such as technology adoption and sustainability, and this is because technology development was not initially focused on the persons that use it; therefore, there exists the necessity of having methodologies in line with technology evolution and involvement of present and future needs, a methodology that satisfies these characteristics is "roadmapping", which is considering as a part for knowledge creation and with a high potential to achieve sustainability [34].

Currently, the literature presents disadvantages of not linking the emerging technologies or combining the social aspect with the production process. This is evident in the study of [35] that just incorporates local knowledge to find resilient strategies; or the work done by [36] that incorporates field visits and econometric analysis, focusing on the analysis on just one factor such as cooperatives' impact on the adoption of sustainable practices in Nicaragua. In the same way, the work presented by [37] in which only analyzing the impact of subsidy and trade cost on technology adoption in sub-Saharan in Africa; these last two cited works give a narrow perspective of the situation of the studies, which represents a drawback.

In the work here presented, a "roadmapping"-based proposal is shown to give a wide perspective of the current situation, expectation and actions to be implemented, based on the living context of coffee producers; this work links innovation, emerging technologies and proposes sustainable practices that theoretically could be easy adopted by the farmer. "Roadmapping" is based on the interaction of stakeholders and tacit and explicit knowledge of participants, its structure includes three essential phases: (1) expectation (Where do we want to go?); (2) current situation (Where are we now?) and (3) actions to be implemented (How can we get there?) [38,39] and is also now considered a part for knowledge creation, with a high potential to achieve sustainability.

Table 1. Brief background of theoretical and empirical studies related to coffee.

Reference	Topic	Issues
[40]	Sustainability	Model for designing a sustainable coffee supply chain.
[41]	Quality	Coffee characterization for quality improvement.
[42]	Quality	Model for improving sensory properties.
[43]	Quality	Recommendations for optimal postharvest processing
[44]	Quality	Recommendations for improving coffee roasting.
[45]	Quality	Theorical recommendations for improving sensory characteristics.
[46]	Sustainability	Multi-frequency, multimode, modulated vibration technique for recovering antioxidants.
[47]	Innovation	Identification of innovation in coffee co-operatives for resilience.
[48]	Quality	Sensory and hedonic analyses for investigating the effect of coffee color.
[49]	Health	Effect of coffee consumption and the association with deaths.
[50]	Sustainability	Actions against climate change as a way of innovation.
[32]	Sustainability	Waste coffee for biodiesel production.
[51]	Health	Extracts of green coffee beans in commercial products for losing weight.
[52]	Sustainability	Practices of small farmers for climate change mitigation.
[53]	Health	Coffee's role against the apparition of colorectal and liver cancer.
[54]	Quality	Storage of coffee crop (hermetic bags) for preserving the quality.
[55]	Sustainability	Properties of coffee solid residues for improving their management.
[56]	Sustainability	Coffee technologies for evaluating environmental impact.
[57]	Quality	Model about patronages of coffee consumers (repurchase intention and habit consumer).

Sustainability development is considered in order to meet their own needs and to satisfy the necessities of the present without compromising the future generations [58]. The agri-food supply chain must involve economic, environmental and social aspects, water efficiency and social welfare [59]; this analysis is included in "roadmapping". In this sense, in Mexico, the International Coffee Organization (ICO) (n.d.) [22] considers sustainability through the creation of resistant varieties against pest and diseases or the roadmap studies for promoting strategies to adopt the appropriate technology, developed by the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SADER). In fact, current studies consider roadmapping as a driver for focusing knowledge creation correctly and enhancing sustainability [60–64].

At present, the conjunction between roadmapping and improving sustainable practices in the agriculture context considers the priorities, needs, capacities and resources of each country; however, limited access to technologies continues to be a problem for sustainable development [14]. There are some theoretical studies that have developed a roadmap involving knowledge [65], using a scientometric method and result mapping to find the necessity of reducing waste generation and greenhouse gas emissions. The study of [66] presents a roadmap framework which is environmentally friendly and based on knowledge-action topic to understand knowledge movement; the results expose the necessity to include all actors involved in the process, as well as the development of policy and more interaction between knowledge producers and potential users. Another study [67] exposes a roadmap based on knowledge management, through the installation of green-house supported by the technological advances to promote the increase of coffee productivity in Mexico, but without considering sustainability.

There are many works that include actions which help to improve sustainable strategies. For example, [68] shows that sustainable growth in agriculture will depend on the adoption of appropriate environmentally friendly technologies and recommends that the technology must satisfy the local demand and must be designed according to the specifications of the region. This is also supported by the study of [69]. In this sense, [36] discovered that cooperatives have a significant influence in practice adoption, by coffee producers of Matagalpa, Nicaragua, towards water conservation and reforestation. Another study [70] found that attitudinal difference, innovative and information-seeking behavior, subsidy and taxation were taken into account for precision agricultural technologies adoption. The research of [71] in which evaluated the adoption of technologies and expose the positive effects of a government program on technology appropriation. In addition, [72] considered the dependency of the change in market utility on technologies adoption. Failures in technological adoption are present, this was the case of the collapse of internal control systems caused by the inability and ineffective governance of the organizations, resulting in the insolvency of preserving organizational assets [73]; or the lack of a holistic approach, when attempting to implement a high-tech wheel but with an absence of technological environment to provide maintenance [74]; or the process of failure-followed-by-success, in which technological legitimacy is essential for the adoption of technologies by personal assets [75]. The aforementioned works show the necessity to have knowledge about farmers to achieve good development and technology adoption; these involve needs, human and economic issues, pertinence to cooperatives, site of farms, government programs.

In summary, the existing literature in the context of the coffee supply chain fails at the moment to include a knowledge, sustainability and technologies approach, and the reasons for that can be several and are frequently not clear; these reasons vary according to context, region and producer's knowledge, and sometimes these inclusions could be extrapolated to similar contexts. To fill these gaps, this study presents a case study that aims to get information for three localities of the Frailesca, Chiapas, Mexico. The objectives of the present study involve:

(i). To investigate the process and actors involved in the coffee supply chain.
(ii). To explore the expectations, current situation, and actions to be implement in the coffee supply chain.
(iii). To identify the appropriate emerging technology aligned with the actions to be implemented in the coffee supply chain.
(iv). To propose sustainable practices that can improve the coffee supply chain, based on detected emerging technologies.

2. Materials and Methods

2.1. Information Gathering

The integration of qualitative and quantitative research designs has, in fact, turned towards the ways of incorporating and analyzing the information. This guideline, called by [76] mixed multi-method, has been criticized for not granting a balance between the methods, but also encouraged for expanding and strengthen research [77]. In this sense, based on the use of interviews, field visits and a theoretical framework and following previous studies in the context of innovation and sustainability, a multi-method research design was adopted [76,78,79] for the analysis of the coffee supply chain, with 177 small producers, of which 165 are coffee small producers and 12 representatives of two coffee producing organizations composed of 246 and 400 coffee small producers (representatives included). Coffee producers and representatives, located from localities of Angel Albino Corzo, Jaltenango de la Paz and La Concordia in the Frailesca zone, Chiapas, Mexico, were contacted through collaborators and were notified verbally about the objective of this study and questioned about whether they wanted to participate in this study. In this sense, and in order to reach the stated objectives and to replicate the study, the information gathered during the period from May 2017 to June 2018 was developed into four stages (see flowchart in Figure 2):

1. To investigate the process and actors involved in the coffee supply chain, the first stage was implemented following the supply chain definition in [21] as a "set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances and/or information from a source to a customer", considering the producer-to-customer flow, and the organizations or individuals directly involved, to investigate the process and actors involved in the coffee supply chain. In this sense, the flow of the producer-to-customer process was explored through face-to-face questions and validated through field visits, while the actors were involved through face-to-face questions. The questions asked to producers about knowing process and actors, were formalized as follows:

    a. To investigate the flow of the process and technologies, it was asked: What are the process and technologies of the coffee supply chain, from the producer until sale to the customer?
    b. To learn about the actors involved, it was asked: Which actors are involved in the process of the coffee supply chain, from the producer until sale to the customer?

In addition, following the studies of [80–82], to assess the influence of variables, information about gender, age, family members, cultivated area, additional crops, production level and sale price were gathered in order to contextualize the socio-productive information on the coffee supply chain.

2. To explore the expectations, current situation, and actions to be implemented, the second stage was developed following the structure of the technology roadmap technique of [39], to know where we want to go, to identify where are we now, and to explore how we can get there, in the producer context, in order to extract coffee producers' tacit knowledge and make it explicit. The questions asked to producers were formalized as follows:

    a. To know where we want to go (expectation), it was asked: From your perspective, what are your expectations about the coffee supply chain?
    b. To identify where we are now (current situation), it was asked: From your perspective, what is the current situation of the coffee supply chain?
    c. To explore how we can get there (actions to be implemented), it was asked: From your perspective, which actions can be implemented in the coffee supply chain, to reach the expectations from the current situation?

To achieve a visual relationship of the roadmap technique, the investigators tagged the possible answers of the current status, expectations and actions to be implemented, following the line of [22] (see Table 2).

Table 2. Possible answers of road mapping structure.

Tag	(1) To Know Where We Want to Go	(2) To Identify Where We Are Now	(3) To Explore How We Can Get There
e1	Coffee plants renovation wanted	Having old coffee plantations	To have more quality in the coffee beans
2	Coffee quality certifications wanted	They have an exportation coffee bean	Improving interaction to obtain the renovation of coffee plants
3	Wanting to access specialized markets	Selling his coffee at the local market	Access to infrastructure programs to improve coffee quality
4	Access to roasting and grinding infrastructure	They need intermediaries	Improving interaction to have a better-quality coffee bean
5	Wanting to collaborate with academics, institutions and research centres	The interaction with actors is very little	Government programs to improve the quality of coffee plants
6	Wanting to differentiate the coffee	They have an organic certification	
7	Wanting effective actions against pest and diseases	They have problems with pest and diseases	

To stimulate coffee producers' responses and promote the conversion of tacit knowledge to explicit, the soil metaphor mentioned by [83] was used to exemplify the situation of the soil as the current situation of the coffee sector, as well as the tree analogy of thinking in the probability of the development of a tree in this soil such as the expectations and actions that could be implemented so that the tree grows healthy. This dynamic development followed the recommendations of [84] about the use of metaphor, analogy and modeling for stimulating the conversion of tacit knowledge to explicit.

3. To identify the appropriate emerging technology and linking with the actions to be implemented, in the third stage, having the roadmap results, a statistical test was developed for learning what could be the most adequate actions to be implemented, evaluating the normality of their distribution and through the frequency of the socio-productive variables and actions to be implemented considering a non-parametric test, assessing the correlation between family members, age, additional crops, gender, price production level and cultivated area (socio-productive variables) with actions to be implemented for linking the most suitable emerging technology following the value driver of digital compass [85], based on the producer's perceptions (Figure 1). This was considered for ensuring the suitability of technologies on the coffee supply chain process [9,10,86]. This point was further formalized according the next question:

    a. To identify appropriate emerging technology that links with the actions to be implemented in the coffee supply chain process, the next question was formulated: What is the most appropriate emerging technology that connects suitably with the actions to be implemented in the coffee supply chain process?

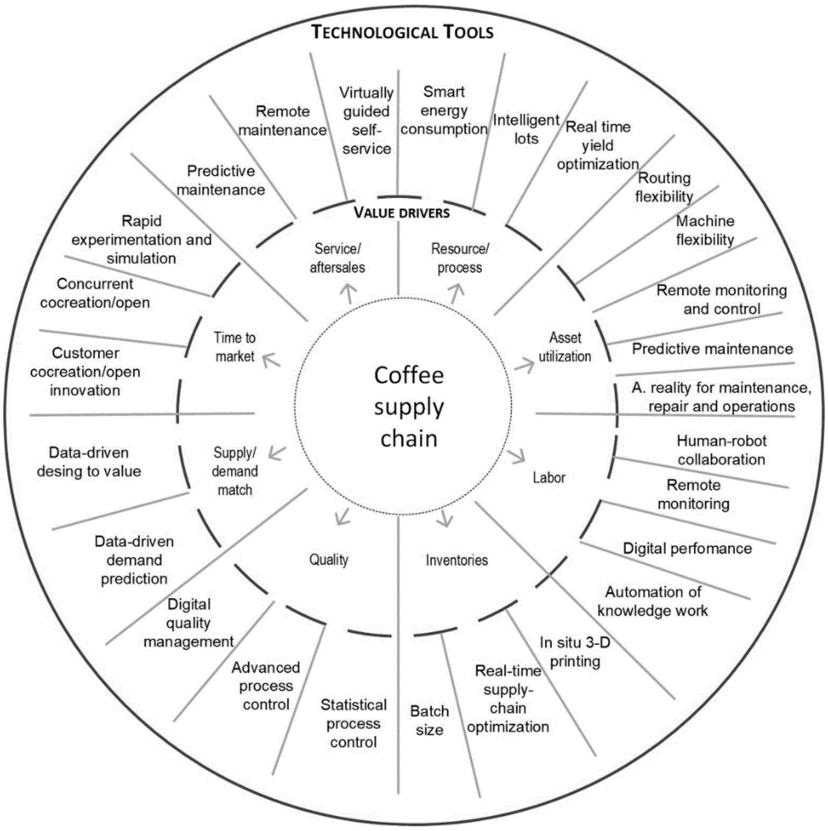


Figure 1. Digital compass.

According to [85], the digital compass is composed of eight value drivers and twenty-six technological tools and its operation lies in recommending the technology that must be used according to the needs of the chain. For example, if the need is to improve the quality, the technologies that must be used are digital quality management, advanced process control and statistical process control.

4. In the fourth stage, to propose sustainable practices that can be adopted in the coffee supply chain, a theoretical analysis was made based on roadmap results and the statistical correlation between the actions that can be implemented and the influence of socio-productive variables. In this sense, the theoretical revision was formalized following the next set of questions:

    a. How can the detected emerging technologies improve sustainable practices in the coffee supply chain?
    b. What are the sustainable practices that can be improved in the coffee supply chain, based on detected emerging technologies?

Combining the four stages, the hypothesis to check is as follows:

1. Sustainable practices can improve the coffee supply chain, identifying the suitable emerging technology, considering the statistical relationship between the actions to be implemented and the socio-productive context.

In summary, this study can be reproduced following the sequence of the flowchart represented in Figure 2, starting with a first stage with the investigation of process, technologies and actors immersed in the procedure through questions and field visits (recommended for the gathering of context information); in the second stage, we will be exploring the expectations, the current situation and the actions to be implemented considering a questionnaire (applying a metaphor and an analogy related to the nature of the chain); for the third stage, the appropriate emerging technology linked with the actions to be implemented is identified, following the value driver of digital compass based on the perception of actors; and in the fourth stage, there is a proposal of sustainable practices developing a theoretical analysis of the implementation of sustainability activities in similar contexts.

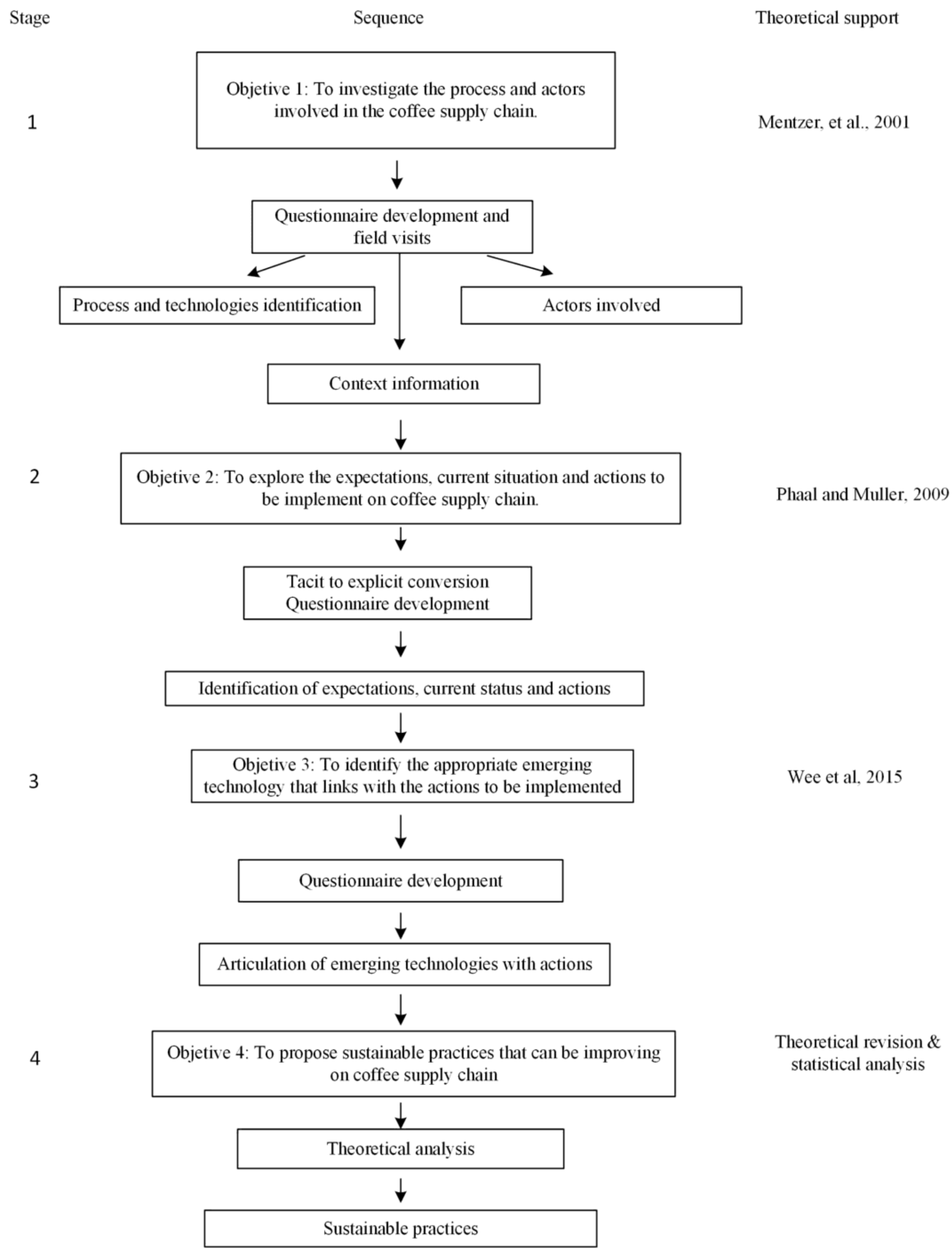


Figure 2. Flowchart of the methodology applied in the context of coffee supply chain from Chiapas, Mexico.

2.2. Information Analysis and Validity

The coffee supply chain was described according to its process, from the producer activities until the sale to the customer, including the actors. This process was validated by collaborators through a field visit.

The results of the technology roadmapping process and of socio-productive variables such as gender, cultivated area, additional crops and production level were tabulated, registered and ordered according to frequency of appearance, from the least selected registered with the number one to the registered with the highest number, following [87] and the scheme of [88], considering the success of the actions to be implemented (solutions) for linking the value driver (s) of digital compass and socio-productive information for technological adoption, age and family member variables were grouped in intervals following the line related with the characteristics of households reported in Mexico, of the National Institute of Statistics and Geography (INEGI acronym in Spanish) used in the census 2015 [89], while the sale price was based on the lowest cost reported by [67]. The analysis of frequency of appearance was done through NVIVO v11® software, while the normality and correlation of variables were accomplished using IBM® SPSS® statistics v21, through Kolmogorov–Smirnov and Spearman's rho tests, respectively.

The identity of the coffee producers was validated by the same producers and by collaborators in the field.

3. Results and Discussion

3.1. Context, Socio-Productive Information, Process, Actors and Technologies Included on Coffee Supply Chain

The municipalities of Angel Albino Corzo, The Jaltenango de la Paz (belongs to Angel Albino Corzo) and La Concordia have an altitude of 644, 634 and 540 m.a.s.l, respectively, and have a population of 26,628, 10,427 and 7641 respectively [90,91] (Figure 3).

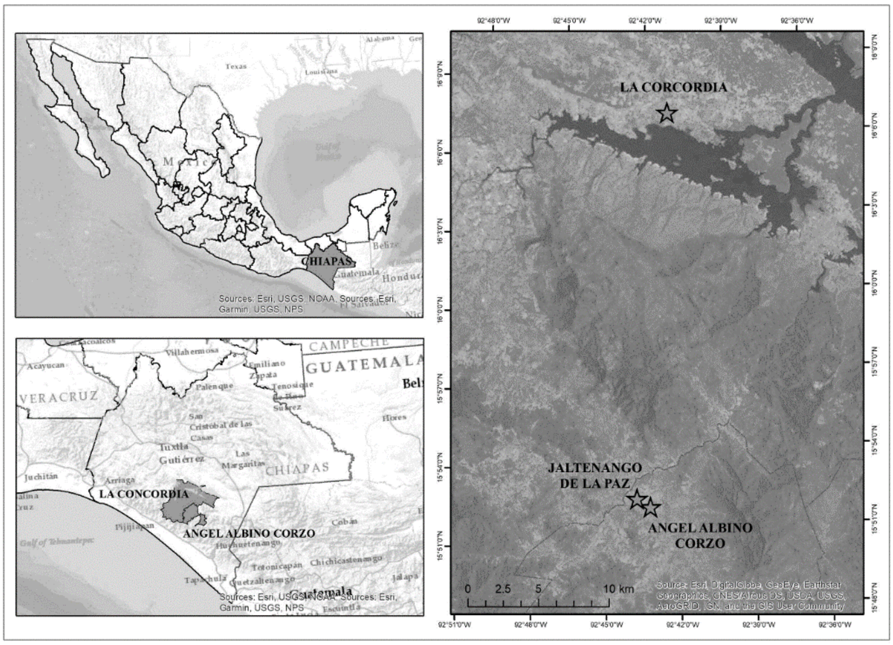


Figure 3. Location of Angel Albino Corzo, Jaltenango de la Paz and La Concordia in the Frailesca, Chiapas, Mexico.

The coffee supply chain of these three localities presents an elevated percentage of male coffee producers with 89.3% while the women are the 10.7%. This is in line with the study of [92]. Figure 4 shows the histograms of survey data obtained from producers; as can be seen, the highest frequency range of age is between 50 and 55 years, with a number of family members between 4 and 6, number of hectares per producers between 1 and 2 ha, dollar per kilogram of coffee between 1.4 and 1.6, kilograms per hectare between 184 and 684 kg and no main additional crop. Table 3 shows the average of socio-productive variables, the age average of small coffee producers is among 40–44 years old;

this means that small producers from Chiapas are younger than those reported by [93]. Family members are between 4 and 6, and the standard cultivated area is between 0.1 and 5 ha. The score for family members is higher than the value of 3.8 reported by [94], but the cultivated area is in line with their reports (1.57 Ha). The majority of producers do not have additional crops, which is in agreement with [95]. The sale price of between 1.06–2.12 US dollars per kilogram of coffee (20–50 Mexican pesos) is lower than the values of 2.52 US Dollars per kilogram reported by [96] in 2018. The coffee production level from Chiapas was between 500 and 1000 kg/ha, which is a little lower than the values of 1300 kg/ha reported by the Mexican government in 2017 [97] (Table 3) (Figure 4).

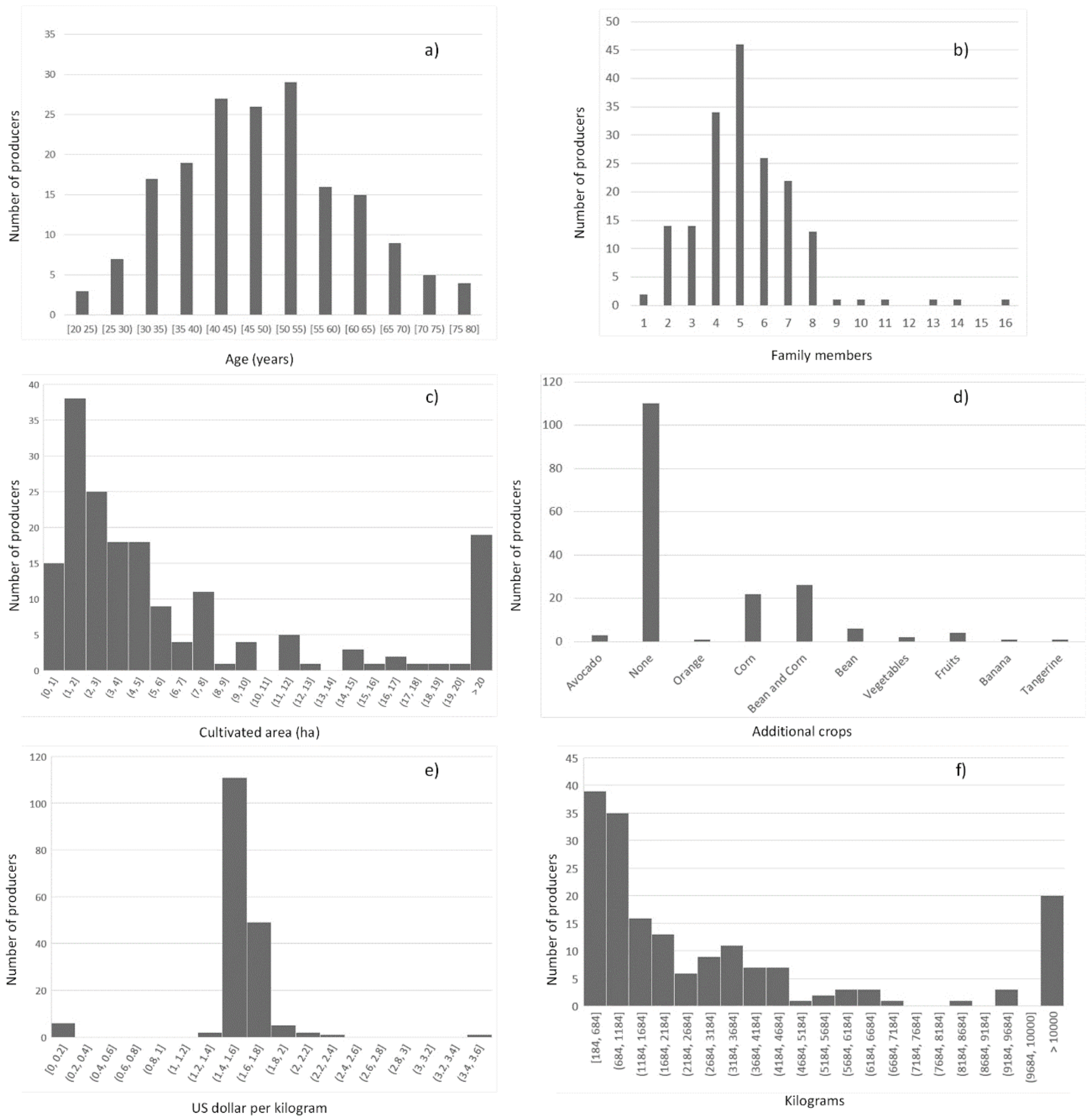


Figure 4. Histograms of the survey data: (**a**) age of producers; (**b**) family members per producer; (**c**) cultivated area per producer; (**d**) additional crops per producer; (**e**) US dollars per kilogram of coffee; (**f**) kilograms per producer.

Table 3. Socio-productive information of the local coffee supply chain.

Socio-Productive Variables	Women	Men
Small producers	10.70%	89.30%
Age (average)	40–44 years old	
Family members (average)	4–6 members	
Standard area cultivated (ha)	0.1–5 ha	
Additional crops	62.1% none	
Sale price (Kg) (average)	1.06–2.12 US dollars (20–40 Mexican pesos)	
Coffee production level	500–1000 kg p/ha	

The coffee supply chain production process is under the conventional and organic production of the Arabica species. This means that producers continue using synthetic inputs, while for the case of organic production, soil management and local inputs (natural) are the main practices [6]. The process of the coffee supply chain from Chiapas, Mexico, based on a field visit, is formalized as follows: (1) the Secretary of Agriculture, Livestock, Rural Development, Fisheries, and Food (SADER) or a private provider provides the coffee plant; (2) the small producer seeds the coffee plants; (3) the small producer prunes and fertilizes coffee plants with synthetic or natural inputs; (4) the small producer harvests the coffee bean; (5) the small producer gives their production to the organization; (6) the organization performs the wet coffee benefit; (7) the organization carries out the pulping of the coffee; (8) the organization performs the fermentation; (9) the organization executes the washing; (10) the organization performs the drying; (11) the organization sells the coffee to the intermediary in parchment presentation. The actors involved in the coffee supply chain start with government institutions or private providers; as a second actor there is the organization and in the last, the intermediaries, while technological necessities detected in coffee supply chain were in: (1) the provision of varieties resistant to pests; (2) the chemical fertilizer; (3) the manual machines for pulp removal and (4) the spaces used for fermentation, washing and drying—those are necessities required by producers and organizations in this region and, at least in this zone, the data suggest that efforts focused on technology development for agriculture need to be related, principally, to address these necessities (Figure 5).

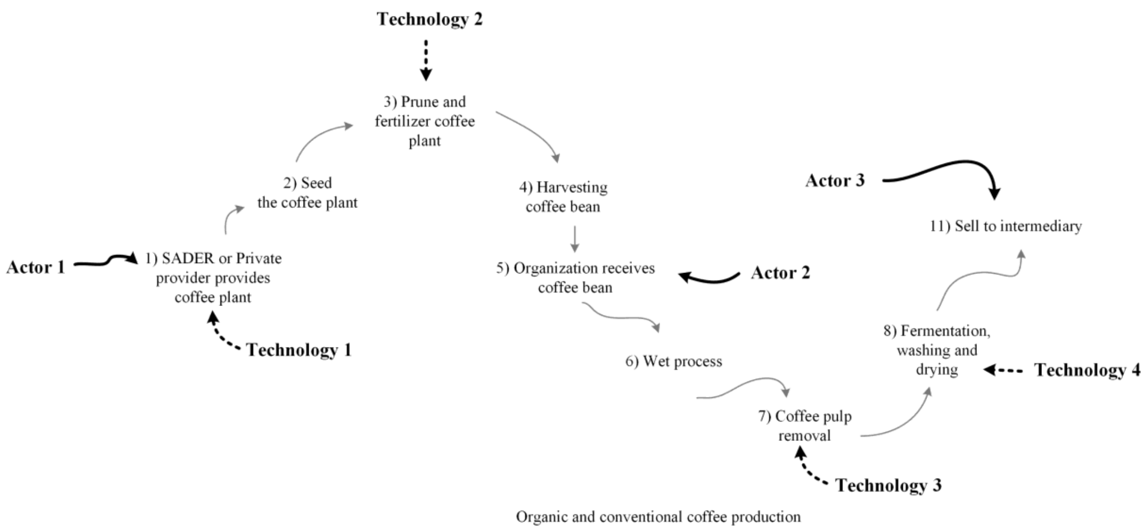


Figure 5. Mapping the process, actors and technologies of the local coffee supply chain.

The process, actors and technology of the local coffee supply chain process are in line with those reported by [67], up to the harvesting stage, and after the organization receives the coffee, the process is similar to the one reported by [98], in which there was registered coffee processing, developed by the Union of indigenous communities in the isthmus region; and with the study of [80] in which farmers in Vietnam sell their coffee production to coffee-processing factories. The alienations with these works mean that the reported results, related to strategies for improving coffee production, have high probabilities of being successfully employed by others regions with a similar coffee supply chain; however, validations studies need to be accomplished.

3.2. Expectations, Current Status and Actions for Coffee Supply Chain

For this study, producers' tacit knowledge was explicit through expectations, current status and actions to be implemented on the coffee production supply chain. The response frequency about the expectations is shown in Figure 6a, where the answer "effective actions against pest and diseases" was the least popular and "they want coffee plants renovation" had the highest score. Regarding the current situation of producers (see Figure 6b), the lowest is "they have problems of pest and diseases" and the highest—"they have old coffee plantations (60% over 15 years)". About the actions to be implemented (see Figure 6c), the lowest-scoring answer is "government programs to improve the quality of coffee plant" and the highest—"to have more quality in the coffee bean".

Figure 7 shows the roadmap including all the options considered in the current status, expectation and actions to be implemented. Figure 8 shows 3D graphs of the histogram of the five actions to be implemented depending of the current situation and expectations; as can been seen, the current situation and the expectations display a high correlation. Figure 8 can serve as a graphical guide of the better actions to be implemented, taking as reference the number of producers, the current situation and the expectations for these regions, and probably for regions of a similar social and economic context. For example, the majority of producers who want more quality in the coffee bean do so because they currently export coffee and expect to obtain a certification, which in the end will carry economic benefits (see subfigure a, correlation X_2–Y_2); as a smaller proportion, another group of producers who want more quality in the coffee bean do so because they currently sell their product to local markets and expect to enter a more specialized market (see subfigure a, correlation X_3–Y_3). Another important number of producers who want to improve the interaction to obtain the renovation of coffee plants, do so because they have old plantations and expect coffee plants renovation (see subfigure b, correlation X_1–Y_1). For a smaller number of producers, who desire to improve the interaction to obtain better quality in the coffee, have a little interaction with actors and wants to participate with academics, institutions and research centers (see subfigure c, correlation X_5–Y_5). For a similar number of producers, who request to access at infrastructure programs to improve coffee quality, have intermediaries and demand to access at roasting and grinding infrastructure (see subfigure d, correlation X_4–Y_4); while for the smallest number of producers, who ask for government programs to improve the quality of coffee plant, have problems with pest and diseases in the plant and wants effective actions against pest and diseases (see subfigure e, correlation X_7–Y_7).

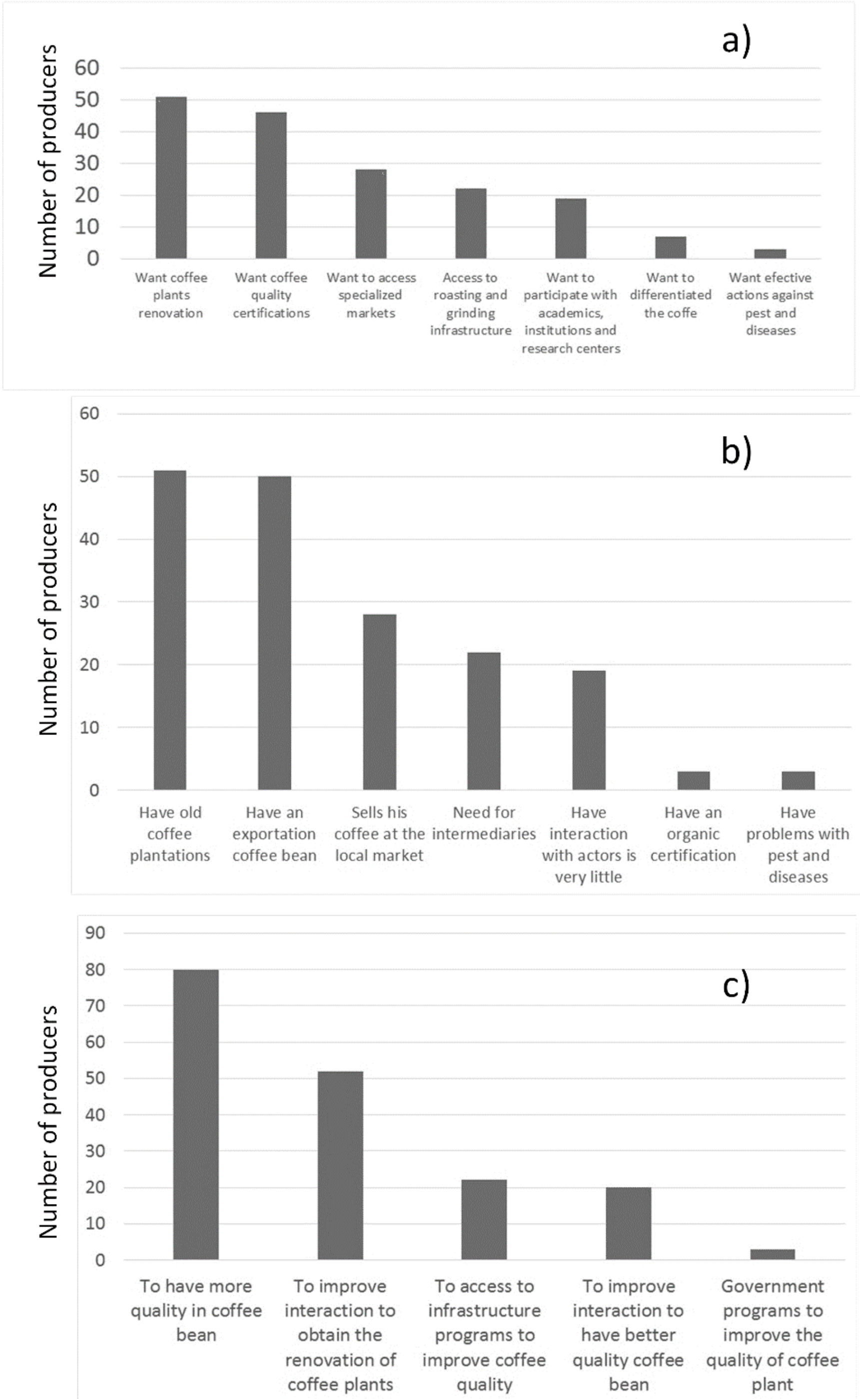


Figure 6. Responses about (**a**) expectations; (**b**) current situations; and (**c**) actions to be implemented.

Actions towards having more quality in coffee beans and plant renovation are in line with the efforts of the Mexican government, specifically by the quality set of norms and rules implemented by the Secretary of Economy (Secretaría de Economia), which are mandatory safety requirements required by law and acting as reference guide of rules to get more quality coffee beans and plants [99]. In this sense, and following the current situation of the majority of producers regarding the feeling of having exportation coffee but mainly working with the certification for organic coffee, local producers already work with the production and processing norms required by coffee international agreements; this aspect supports the expectation to get a coffee quality certification, develop a different type of coffee and gain access to specialized markets. The compliance with standards related with the criteria of altitude, region, botanical type, preparation, cup quality and bean size, shape and density registered in the coffee exporter's guide and in the Mexican norms, can be supported by the programs promoted by SADER in Mexico, which focus on supporting aspects of infrastructure, equipment, supplies and commercialization for improving the coffee sector [100], and with the knowledge of educational institutions in the region, articulating their knowledge, personnel and students through external project investment, documenting and advising actions related to improving the renovation of coffee plants principally. This should be done by considering that the majority of producers currently export their product and sell it to local markets and have the expectations of getting a coffee quality certification and entering into specialized markets and, to a lesser degree, they want to differentiate their coffee. These conclusions can be formed easily from the graphical guide showed in Figure 8. The commitment to these activities would lead to increased interaction with the government, academics, educational institutions, and research centers.

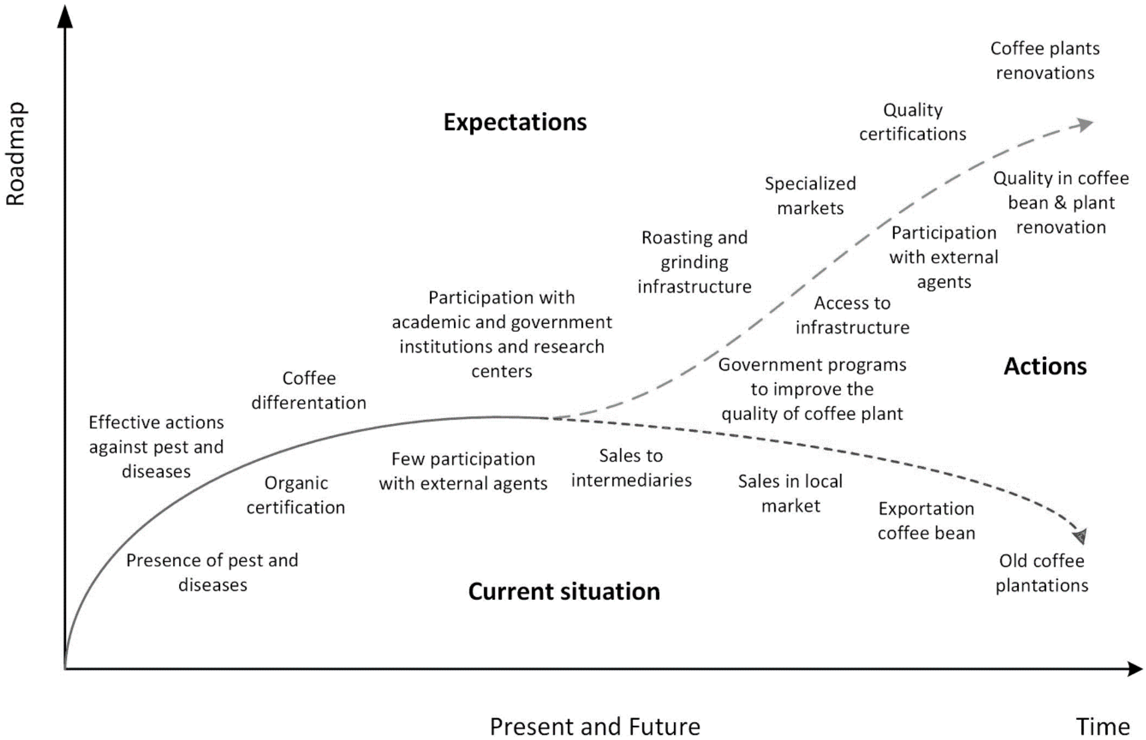
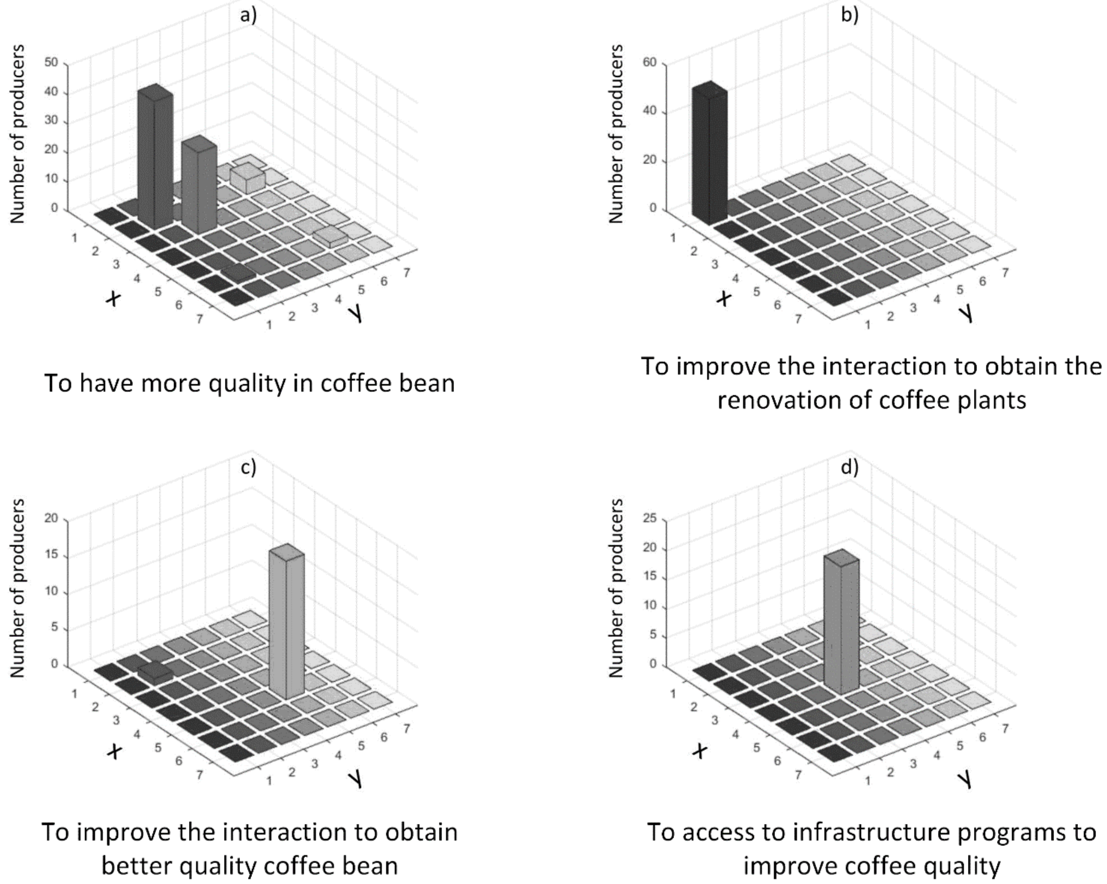
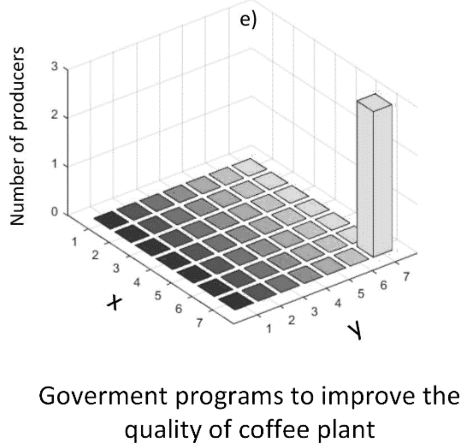


Figure 7. Description of the roadmap of the coffee supply chain from Chiapas, Mexico.

These actions are in line with the suggestion of [67] for involving network experts and sharing their knowledge in the coffee sector in Mexico, and with recommendation of ICO for Central American countries and Mexico, to develop more resistant varieties of coffee plant against pest and diseases, to access roasting and grinding infrastructure, and to build the capacity of coffee producers to improve their farm management practices [23]. In this sense, to get better economic benefits it is necessary to improve efficiency and productivity, the transferability of a governance mechanism [80], alongside collective actions for the process of increasing the quality of coffee [101].





x	Current situation
1	Have old coffee plantations
2	They have an exportation coffee bean
3	Sells his coffee at the local market
4	They need for intermediaries
5	The interaction with actors is very little
6	They have an organic certification
7	They have problems with pest and diseases

y	Expectation
1	Want coffee plants renovation
2	Wants coffee quality certifications
3	Wants to access specialized markets
4	Access to roasting and grinding infrastructure
5	Wants to participate with academics, institutions and research centers
6	Wants to differentiated the coffee
7	Wants effective actions against pest and diseases

f)

Figure 8. Actions to be implemented (according to the current situation and expectations).

3.3. Statistical Analysis

Considering the sample size, a Kolmogorov–Smirnov test was implemented to evaluate the normality of distribution. The result was statistically significant ($p < 0.05$), demonstrating an abnormal distribution [102]. Because of this finding, Spearman's non-parametric test ($-1 > r_s < 1$) [103], was executed to measure the correlation of actions to be implemented with age, gender, member per family, cultivated area, additional crops, production level and sale price per kilogram, following the statistical correlation scheme of [88]. The highest correlation result from family members and the tendencies that relate the road mapping variable with the actions to be implemented is shown in Figure 9.

Figure 10 features a graph that shows the frequency of the combination of action to be implemented, additional crops, age and family members. As can been seen, the action of "to have more quality of coffee bean" occurs most times when the producers do not have other additional crops (additional crop = none), the producers have an age around 45 years and have 5 family members; almost the same pattern is presented when the action to be implemented is "to improve interaction to obtain the renovation of coffee plants"; however, here, some producers who require this action, have a younger age than those choosing the action of "to have more quality of coffee bean"; this can be perceived visually observing the Figure 10. Figures 8 and 10 could serve as a visual guide to determine the age, family members and additional crops of the majority of producers who require some specific actions (see Figure 7), based on the current situation and expectation, in order to select the most adequate technology that could be adopted easily and rapidly by these producers in order to accomplish the expected actions. Age, family members and additional crops were selected because Table 4 shows that these variables have the highest correlation values with the actions to be implemented.

In relation with other studies, the economy benefits brought on by the management of additional crops in the coffee area are evidenced in the study done by [104], in the use of macadamia intercropping; the family members/age and sustainable practices relationship are demonstrated in [105] by detecting an average age similar to that in this study.

Table 4. Statistical analysis of the correlation between socio-productive variables on actions to be implemented.

Socio-Productive/Roadmapping Variables	Actions to be Implemented
Family members	0.658
Age	0.621
Additional crops	0.411
Gender	0.326
Price p/kg	0.033
Production level	0.026
Cultivated area	0.000

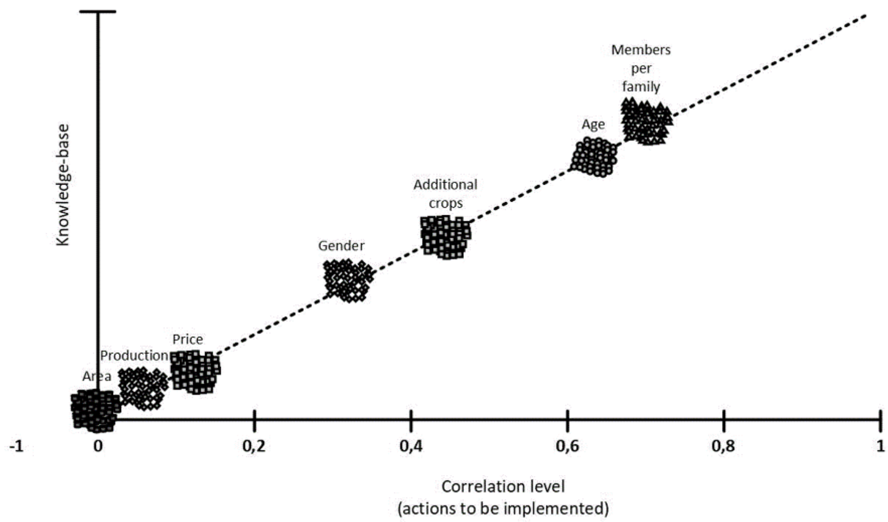


Figure 9. Graphic representation of correlation level between socio-productive variables on actions to be implemented.

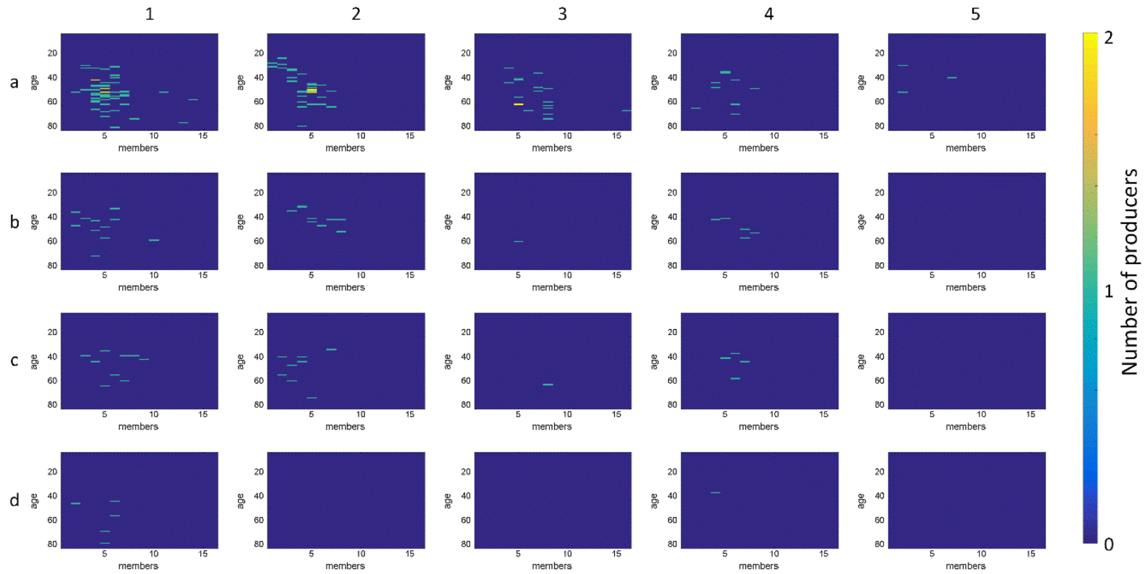


Figure 10. Actions to be implemented vs. additional crops. Explanation of columns: (**1**) To have more quality in coffee bean and plant. (**2**) Improve interaction to obtain the renovation of coffee plants. (**3**) Access to infrastructure programs to improve coffee quality. (**4**) Improve interaction to have better quality coffee beans. (**5**) Government programs to improve the quality of coffee plants. Explanation of rows: (**a**) None. (**b**) Bean and corn. (**c**) Corn. (**d**) Bean.

3.4. Improving Sustainability in the Coffee Supply Chain

The previous results show that the remoteness of the coffee productive place, majority of men producers, with an average age of 40–44 years, with coffee as unique crop, and 4–6 producer family members have the highest correlation with having a higher quality of coffee bean and the renovation of quality in coffee plants; some of these correlations can be graphically corroborated in Figure 10. The digital compass indicates that the actions to be implemented in the coffee supply chain must be related to the quality driver.

The quality driver specifies that the emerging technologies must be aligned with the use of digital quality management, advanced process control and statistical process control as the appropriate tools to begin use [85]. In this sense, the proposal for improving sustainable practices in the coffee supply chain must be developed as follows:

- Digital quality management can take an important role for producers having digital information to get more quality in coffee beans and renovation in plants, as they can manage the acquisition of the variety of coffee plant (resistant to pest and diseases) until the practices of pest management are improved, as well as the collection of maturation coffee beans, advising on when to plant the coffee plants, planting procedure, soil analysis and the control of weeds and water.

Digital management can also take an essential role for organizations in the process of wet pulp removal, fermentation and washing, for implementing the water conservation practices for re-generating and optimizing liquid levels and water harvesting for collecting rainwater as sustainable activities [37].

In an initial stage, the digital information can be shared through mobile phones and social media, exposing in a graphic way the different resistant varieties for the producer, as well as information about time, procedure and field management for planting coffee trees. In the organizational process, knowledge can be disseminated through workshops, programs and virtual assistance for improving the quality of coffee beans.

The suggestions about the acquisition of a resistant plant against pests, planting and artisanal procedures in the organization, are in line with the recommendations of the FAO [106], and of the ICO, for improving the quality of coffee [107], following the first level for adapting digital technologies in agriculture [108], while the proper pest management, soil analysis and water activities are in line with the determinants of [37] for climate change adaptation.

The digital quality management have already been implemented for small producers in a rural context from different regions in Brazil through the program "Produtor Informado" (in Portuguese), in which the producer is trained about best agricultural practices and production techniques in order to obtain a sustainable product, adopting computers and the Internet [109]. Another example is the Global Forum for Rural Advisory Services (GFRAS) which promotes rural advisory services to help and empower rural farmers and integrate them into agricultural innovation using personal computers, the Internet and mobile telephones [110].

The management programs in Mexico are still channeled directly to the producer; this is the case of the production of the wellness program, which seeks to support economically rural producers who use sustainable practices. For this purpose, digital quality management programs in Chiapas, Mexico, can help to transfer and support, in an agile way, sustainable practices for coffee producers and in this way improve the quality of plants and coffee beans, reducing the use of scarce inputs (such as water) in the wet process, fermentation or washing, or costly ones (such as fertilizer, electric light or transportation of coffee).

Advanced process control can support the renovation of plants and coffee beans as they can manage the genetic transformation of coffee [111], the use of drones with multispectral cameras for the timely detection of pest and diseases [112], or the wet process, pulp removal or during fermentation by controlling the process, using sensors for managing and monitoring the coffee process as sustainable practices, guaranteeing the homogeneity for all grains.

This recommendation is aligned with Mondal and Basu (2009) studies [113], that mention that on-line image processing, remote sensors and drones for control process, by yield monitoring, have been employed in developing countries principally by the organized farming sector; an example of this is the wireless sensor network for monitoring the coffee drying process presented by [114]. This work was done inspired by the necessity of coffee producers of Colombia in the Cauca Department, where near 500,000 small families are organized and submit their coffee beans to different types of quality control. In the coffee process, drying is one of the most important stages. The drying stage should reduce the coffee moisture to 10–12%; however, small farmers, in this region, are not able to detect when the moisture level is in the optimal range. Therefore, they proposed a wireless sensor network to study the environmental variables that affect the drying process; other examples using image-based sensors have been probed in the eLocust3 system developed by the FAO in Africa and Asia, with positive effects against plagues [115].

The coffee sector presents problems in production system organization, rural producing population, infrastructure and sustainability [116]. The development of an advanced control process in Chiapas, Mexico can impact positively coffee producers in several context-common regions, through digitally controlling the coffee process and monitoring to optimize qualities and times of coffee production. This emerging technology can also be useful in achieving the quality criteria related to altitude, bean size, color and density, roast appearance and cup quality, and also for obtaining quality certification.

- Statistical process control can be integrated along the coffee value chain to record and analyse data for improving economic and environmental sustainability. The statistical control can begin recording the number of plants received, variety, time and location of coffee plants; coffee process variables such as pest incidence, time for plantation, soil characteristics, presence of weeds, the use of water, humidity, temperature or luminosity of the wet process and fermentation time, taking advantage of remote-sensing technology. Statistical control can be used to control the incidence of pest and diseases in coffee plants for reducing process variation along organization activities. The results can be shared using interactive tools such as WhatsApp, Skype or Hangouts to meet virtually and check the statistical control with academics and experts and make the right decisions in "real time" (see Figure 11).

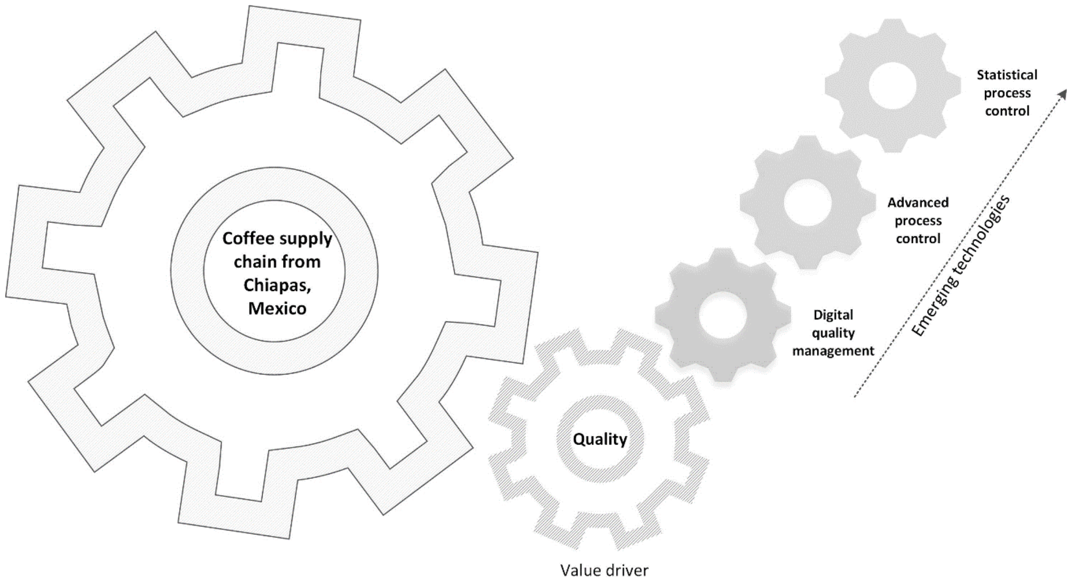


Figure 11. Representation of the coffee supply chain from Chiapas, Mexico and its alignment with the emerging technologies related with quality.

These recommendations about statistical control processes are in line with the success obtained in the manufacturing industry for improving the quality of the process and product [117,118], while the interaction system is built according to the suggestion of [119] to exploit the information and communication technologies for improving agricultural productivity and quality. Statistical control systems have already been implemented by the United States Department of Agriculture (USDA) and with the National Agricultural Statistics Service disseminating the knowledge about infrastructure, pest management practices and postharvest [120], this means that statistical control systems can be an option for Mexico.

The management of mobile devices and social media can be a means of initial introduction for the adoption of technologies, since it has been widely adopted by rural people in developing countries and can improve household living standards [121]. In fact, the benefit of the use of mobile devices such as cell phones has become evident in [122], in which the results show a reduction in the price distortion in the Mexican coffee context with a rate of about −0.544%, increasing the price margin and improving the living conditions of farmers.

In this sense, in the present day, control principles have begun to be adopted by coffee and honey small producers from Chiapas and Yucatan, Mexico, and for a large number of the producers of the Caribbean region, organizing and using an internal control system [6]. This principle can be extrapolated for monitoring crops, minimizing labor costs and also for spending less on organic fertilizer [108].

4. Conclusions

The coffee supply chains of the localities of the Frailesca, such as Angel Albino Corzo, Jaltenango de la Paz and La Concordia from Chiapas, Mexico and emerging technologies are still divided. In spite of the coffee production process still being based on human labor, coffee producers' requirements and actions to be implemented were aligned, according to the applied analysis, with quality issues. In this sense, digital quality management, advanced process control and statistical process control were the tools identified as the appropriate technological tools to improve the quality of this supply chain.

Sustainable practices such as the acquisition of a resistant variety, proper pest management, improvement in the collection of coffee beans, the right time and way for planting coffee plants, soil analysis and the management of weeds and water conservation and harvesting—each stage of the coffee supply chain process—can be improved by digital quality management, advanced process control and statistical process control tools.

These tools can have an important role in each stage of the coffee supply chain process for improving the quality coffee bean to getting farm data [123]; for differentiating local coffee from other regions to get access into specialized markets to selling to niche market buyers, as per the evidence of [84], and for increasing the interaction with external agents such as academics, government, institutions and research centers, integrating social networking and emerging technologies [124]. The most suitable and valid means of transfer seems to be using mobile devices and social media, as the first level of adapting digital technologies in agriculture [108,122].

For the above, the improvement of sustainable practices can be through digital tools, taking into account family members, age and additional crops as initial variables, for improving the quality of the coffee bean. Because of this, the study accepts the hypothesis that sustainable practices can improve the coffee supply chain, identifying a suitable technology based on the identification and statistical relationship of the actions to be implemented, within a socio-productive context. The chances of adoption increase if those coffee producers who are migrating or have migrated towards organic production are considered.

The positive impact of sustainable practices must be urgently known and evidenced to all coffee small producers in the world, from the increase in the management, quality, price to the rate of return [101,105,125,126]. Only in this way could the catastrophic projection of the reduction of the 97% suitable areas in Mexico for the year 2050 be mitigated [12]; enhancing the socio-economic situation of the coffee local producers [127] and explaining the benefits of the adoption of new processes [128].

The findings of this study attempt to contribute to the literature providing present-day information about the process, actors, technologies, expectations, current situation, and postulate actions to be implemented in the coffee supply chain process according to the requirements of coffee producers; proposing sustainable practices into the process of the coffee supply chain, linked with emerging technologies in the context of the developing economy in Chiapas, Mexico; contributing with the articulation of roadmap technique as a driver for knowledge creation exploring the knowledge of coffee small producers and offering a new method of management. In addition, this research will help the coffee supply chain in improving sustainability practices, proposing digital tools that have been applied already in similar contexts and establishing initial investment for supporting technological knowledge and decision making.

This proposal is an initial effort towards improving sustainable practices in the coffee supply chain from Chiapas, Mexico. Further research and more studies are needed which can include small farmers' needs, linked with emerging technologies, in addition to studies about the implementation of digital tools in the agriculture sector. Furthermore, a deep search of technologies, around the world, which have been successfully adopted by the producers, with similar social and economic contexts to those analyzed in this work, is necessary in order to correctly focus resources to those who develop technologies that help to adopt the actions to be implemented by the majority of producers.

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