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Multi-Criteria Methodology: AHP and Fuzzy Logic in the Selection of Post-Harvest Technology for Smallholder Cocoa Production

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Abstract

Ecuador supplies 70% of the world's fine aroma cocoa (Theobroma cacao). This paper defines a model of post-harvest technology selection, adapted to small producers, using two multi-criteria models that evaluate the quality, processing cost, and technology adoption capability of each technology. To achieve this result, a preliminary assessment of nine post-harvest technologies is performed, considering only the quality criteria. We then apply the analytical hierarchy process and fuzzy logic methodologies considering the other criteria (processing cost and technology adoption capability). The models provide alternative methods to achieve solutions that reflect the reality of small cocoa producers' decision-making processes.

Keywords: cocoa, small-scale agriculture, post-harvest, analytical hierarchy process, fuzzy logic.

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Introduction

Cocoa post-harvest technology is essential for generating value added for small producers. The postharvest is relevant to Ecuador since the country provides 70% of the world's supply of the 'fine and flavour' cocoa products. The Central Bank of Ecuador (2013) reports that the export of cocoa beans and processed cocoa contributes 1.9% of the country's GDP, representing up to 4% of the employment. In 2012 export volume reached 174,560 metric tons (MT). Almost 60% of the production of fine and flavour cocoa comes from small holders, so decisions on post-harvest operations become relevant for a pro-development export strategy.

Post-harvest operations begin with collection, followed by fermentation and finally drying, prior to marketing.Quality has been considered a relevant criterion for selecting post-harvest technology, because its relevance to determine the price of cocoa in the international market (Amores 2009). However, technology selection in agriculture and post-harvest remain a challenge for small farmers when other economic and social objectives must be considered (Giordano and de Fraiture 2014, Namara et al. 2014). In recent years, an increasing need has emerged to study phenomena from a holistic point of view. Thus, it is important to assess the trade-offs that exist between the quality of the production and other criteria (Castro-Tanzi et al. 2012). In cocoa postharvest, selection criteria such as the processing costs or the technology adoption capability are typically overlooked, which justifies the need for widening the scope of technology selection from a single criterion (quality) to multi-criteria decision analysis (MCDA), including other objectives beyond quality. This paper intends to show the use of MCDA in this context by comparing methodologies that orient postharvest operations in rural areas of Ecuador. This evaluation is carried out considering three criteria: quality, cost of postharvest operations (first processing) and capability of technology adoption by small holders. The last two criteria are considered because small scale production differences are significant in postharvest costs and technology adoption.

Development studies underline the need for enhancing human capabilities to adopt technologies (Ooesterlaken and Hoven 2012). Technology adoption must be eased by the implementation of selection methodologies that are understandable by users and adapt to their characteristics. In this paper, the problem of postharvest selection for small cocoa producers is approached through MCDA that may shed new light on the selection of the best post-harvest technology. This study defines a cocoa post-harvest technology selection model that is suitable for small farmers in the province of Manabi (Ecuador), by applying two alternative multi-criteria methodologies; namely, the analytical hierarchy process (AHP) and fuzzy logic. This is carried out through the following steps: 1) analyse post-harvest techniques that combine fermentation and drying of cocoa beans by using the single criterion of quality. 2) evaluate AHP to choose the best cocoa post-harvest technology, drawing on national experts' assessment, and 3) evaluate fuzzy logic in selecting the best post-harvest technology according to the three aforementioned criteria. Therefore, technology selection in cocoa postharvest is considered with one single criterion method (quality optimization) and two multi-criteria methods (AHP and fuzzy). Though MCDA has been widely used in the environmental management and agriculture (Sipahi and Timor 2010) there is a lack of contributions of MCDA applied to the selection of postharvest technologies by small producers, in particular in cocoa transformation.

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Ecuadorian cocoa producers employ a wide range of post-harvest technologies. Our paper will first confirm what other studies have shown when the single quality criterion is applied. Then MCDA includes, in addition to quality, the other two criteria: post-harvesting costs and technology adoption capability and the paper evaluates how retained solutions are sensitive to the multi-criteria method. Both methods are evaluated considering their adequacy for managers or policy-makers work in a context marked by small-scale production.

The paper has the following structure. Section 2 describes cocoa postharvest main fermentation and drying technologies and justifies the use of multiple selection criteria. Section 3 considers the single quality analysis, followed by Section 4, which describes the methodological basis for the MCDA including AHP and Fuzzy logic models. Section 5 presents the results of the post-harvest technology selection the alternative methods and provides with a comparative assessment of solutions and methods. Finally, Section 6 lays out the conclusions of the analysis.

Criteria and Techniques

Papalexandratou et al. (2011b) show that postharvest operations of the cocoa are crucial in developing flavour and colour in the beans. However, Papalexandratou et al. (2013) claim that producers choose postharvest methods depending on the region of origin and practices in the production unit. In other words, besides quality of the output of fermentation and drying operations, other objectives play an important role in the decision of the post-harvest technology by small holders. In this paper, we consider two additional criteria: post-harvesting cost and technology adoption capability. Both criteria are justified as relevant for small holders. We don't neglect the influence of other criteria to approach the selection of post-harvest technologies, such as expected profit, price, and other social, environmental and cultural considerations. Nevertheless, for the purpose of this paper, we aim at showing how MCDA can be applied when data are insufficient and expert assessment is required (Macharis et al. 2004; Scheffler et al. 2014). Expected profit and price are both criteria that can be related to quality and to costs, so we chose to work with orthogonal criteria, with low correlation among them (Savoska and Loshkovska 2014).

Cocoa post-harvesting implies technology, capital, and labour costs that sometimes exceed those of the agricultural phase. This process involves an increase in the value of goods as a result of processing and other services. The specific case of cocoa (from extracting the pod from the tree to trading dry cocoa beans) involves a process of transformation and therefore involves costs, which justifies the inclusion of this criterion in the MCDA.

Technology adoption is the result of a sequence of decisions (Gatignon and Robertson 1991), with the ease of adoption informing the selection of a technology, based on prior knowledge. Sidibé (2004) defines technology adoption as a balance between new technologies and traditional activities. Agricultural research has underlined the relevance of technology adoption capability, in particular in rural areas with significant presence of small holders (Lee 2005; Abdulai et al. 2011; Mariano et al. 2012). In all cases, the subjects of technology adoption are producers, who have their own economic and socio-cultural traits. In this study, as the producer must adopt and implement a post-harvest technology, the technology adoption capability becomes a relevant criterion, which is expressed in this investigation through experts' assessment.

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Cocoa post-harvest techniques by small holders in Ecuador consist of a combination of fermentation and drying methods, as the result of a sequential processing process. The fermentation stage is relevant to generate the antecedents of chocolate's aroma and flavour. The type of fermentation affects the quality of the fermented bean (Braudeau 1991, Puziah et al. 1998). The fermentation process may take place in numerous ways, but the traditional methods used by small producers are heap, bags, and boxes (Braudeau 1991).

Later, the drying stage reduces moisture, and the subsequent oxidation phase, which begins during fermentation, completes the maturing process of the aroma and flavour compounds (Jinap et al. 1994, Cros and Jeanjean 1995). During the drying stage, air enters the testa, oxidising part of the polyphenols that remain. This phase marks the continuation of internal biochemical reactions that stimulate the development of flavour and aroma in well-fermented cocoa beans. Concentrations of volatile fatty acids that affect bean quality (Páramo et al. 2010) are also eliminated in the drying phase. During the drying stage, moisture drops to 6 or 7%, the level necessary for storage (Braudeau 1991, Wood and Lass 2001). As in fermentation, there are three traditional drying methods: solar dryers, concrete floors, and racks.

In summary, small producers usually resort to three possible fermentation methods (boxes, heaps and bags) and three possible drying methods (solar dryers, concrete floors, and racks). The combination of the two steps gives rise to nine post-harvest technologies. In the following pages, alternative methods to evaluate technologies are proposed.

Selection Based on Quality

Technology assessment was first carried out using only the single quality criterion, based on the measurement of relevant indicators. The research took place in the Fortalezas del Valle Association collection centre, located in Calceta, Ecuador. The fieldwork was conducted in the dry season of 2012 and the wet season of 2013. The type of experiment followed a completely randomized design, selecting three replicates for each technology. Physical variables for each of the nine combinations were measured in both the dry and wet seasons. In total, 27 samples for each season were assessed, using 10 kilos of fresh cocoa in each sample. The physical variables considered in the empirical research were: percentage of fermentation (good, medium, total, and percentage of violet beans), seed index, and percentage of testa and cotyledons. All these physical indicators are based on measurements from NORMA INEN 176 and ISO 950 (INEN 2006).

To maintain consistency across all data, factors and post-harvest technologies were separately evaluated to test for statistically significant differences between technologies. In the dry season (Table 1), the results of the Duncan ANOVA at 5% revealed an absence of significant differences in the type of fermentation and type of drying for the following variables: percentage of good fermentation, percentage of medium fermentation, percentage of total fermentation, percentage of violet beans and seed index. However, significant results emerged for percentage of testa and cotyledons. Thus, the type of fermentation factor (heap, bags, boxes) or the type of drying (solar dryer, concrete floors, racks) exerts no marked or significant impact on quality. The analysis also considered differences between technologies based on the mixing of fermentation and drying methods (eg. boxes – racks, bag – solar dryer, etc.) which were not found significant.

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In the wet season, the results from the Duncan ANOVA at 5% (Table 1) revealed no significant differences in the type of fermentation and type of drying for the following variables: percentage of fermentation (good, medium, total and violet beans). However, the differences in seed index for distinct types of fermentation and types of drying were highly significant. Note that this variable is not directly dependent on post-harvest techniques, as seed index is also influenced by the study material itself due to the inherent genetic variability of the native *Nacional* cocoa in Ecuador. There are also significant differences between drying types in terms of the percentage of cotyledons and testa. For the type of fermentation, however, no significant differences between these variables emerge. With respect to analysis extended to technologies based on combination of methods (not displayed in Table 1) results implied no significant differences for any variables except for the seed index. As explained above, this variable depends heavily on the genetic variability between seeds.

Table 1. Quality indicators by type of fermentation and type of drying

Dry Season[a]

	Factors	Percentage of Fermentation % Good	% Medium	% Total	% Violet	Seed Index	% Testa	% Cotyledons
Type of fermentation	Boxes	22.67	62.44	85.11	14.89	120.76	15.02a	84.98b
	Heap	22.44	59.11	81.44	18.33	114.9	14.8a	85.20b
	Bags	19.78	57.78	77.56	23.56	122.37	13.63b	86.37a
	Standard error	2.08	3.49	3.63	3.68	3.07	0.38	0.38
	Probability	0.56	0.62	0.35	0.26	0.90	0.03	0.03
Type of drying	Racks	22.78	60.44	83.11	16.78	124.76	14.30	85.7
	Concrete floors	22.78	63.67	86.44	14.56	121.35	14.35	85.65
	Solar dryer	19.33	55.22	74.56	25.44	118.81	14.79	85.21
	Standard error	2.08	3.49	3.63	3.68	3.07	0.38	0.38
	Probability	0.41	0.24	0.07	0.11	0.40	0.61	0.61

Wet season[a]

	Factors	Percentage of Fermentation % Good	% Medium	% Total	% Violet	Seed Index	% Testa	% Cotyledons
Type of fermentation	Boxes	62.22	25.33	87.67	12.00	113.82c	15.24	84.76
	Heap	61.22	22.44	84.00	16.00	118.50b	15.06	84.98
	Bags	58.22	26.33	85.67	14.33	121.67a	14.86	85.14
	Standard error	2.33	2.43	1.73	1.74	0.96	0.45	0.45
	Probability	0.46	0.51	0.34	0.28	<0.0001	0.83	0.83
Type of drying	Racks	57.78	26.11	85.00	14.67	113.61b	14.40b	85.60a
	Concrete floors	59.67	25.44	86.22	13.78	118.86a	14.52b	85.48a
	Solar dryer	64.22	22.56	86.11	13.89	121.52a	16.24a	83.76b
	Standard error	2.33	2.43	1.73	1.74	0.96	0.45	0.45
	Probability	0.15	0.55	0.86	0.90	<0.0001	0.01	0.01

[a] The percentages marked by a letter are significantly different from other values under the Duncan ANOVA (α = 0.05) with a confidence level of 95%.

Source. Authors own elaborations based on experimental data

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The results are consistent with Amores (2009), although Papalexandratou et al. (2013) indicate that recent research on cocoa fermentation is inconclusive. These results support the hypothesis that the variability of the final quality of the bean depends less on the technology selected and more on the producer's individual performance and environmental conditions. Even if technologies are not decisive for quality, to reach the minimum standards some technologies are more easily implemented than others.

Papalexandratou et al. (2011a) and Lefeber et al. (2011) assert that variability within the production unit and the low degree of standardisation among producers is a consequence of there being several fermentation methods, depending on the region and local practices. These results confirm that, using only the criterion of quality to determine the optimal post-harvest technology is not a far-reaching guide for managers or policy makers in small-scale contexts. Due to the technological diversity, it is therefore necessary to expand the assessment criteria. In the following sections, two additional criteria (processing cost and technology adoption capability) are evaluated using multi-criteria methodologies.

Methodologies for MCDA

In the previous section, technology assessment was based on a single statistical analysis of quality data from the field. We extended the selection problem to consider MCDA with other two methodologies (AHP and fuzzy logic) that allow to enlarging the criteria to consider post-harvest costs and technology adoption capability. MCDA was based on experts' evaluations. In order to facilitate the interpretation of the MCDA in the technology selection for small producers, we avoid mixing AHP and fuzzy in the same MCDA model, as it is carried out by fuzzy-AHP (FAHP) methods (Anojkumar *et al.* 2014).[1]

AHP Methodology

AHP is a measurement theory (Saaty 1980, 1982, 1986) that attempts to describe a general decision operation by decomposing a complex problem into a hierarchical multi-level structure (objectives, criteria, sub-criteria, and alternatives) for decision-making (Saaty and Sagir 2009). The strength of the AHP is that it brings together a diverse group of people to make complex decisions. This methodology is appropriate for everyday decisions and can provide a guideline for the selecting technologies. The AHP methodology has been used successfully in the field of agriculture for sire selection (Stokes and Tozer 2002), the adoption of irrigation methods (Karami 2006), and in the assessment of farming activities for tobacco diversification (Chavez *et al.* 2012), among others. We didn't find reference to MCDA using AHP applied to cocoa postharvest.

The hierarchy of our decision problem has the following structure (Figure 1): (i) The objective is to select the best technology; (ii) the criteria are: quality, processing cost, and technology adoption capability; and (iii) the alternatives are nine post-harvest technologies. Pairwise

[1] According to Zhü (2014) fuzzy AHP does not give a generally accepted method to rank fuzzy numbers and a way to check the validity of the results.

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comparisons were then made between these criteria and alternatives, attributing numerical values (from 1 to 9) to identify preferences (Saaty 1980). This process yielded three clusters, whose central axis consists of each of the three fermentation methods (bags, heaps and boxes), which were matched with the drying alternatives (solar dryer, concrete floors, and racks). A 3x3 matrix shows the best alternatives for each cluster.

To provide data for the AHP process, we consulted eight experts with experience in research and development on cocoa production, postharvest, and quality belonging to well-known national cocoa institutions. To merge individual judgments into one representative judgment for the group, the geometric mean was used as by Saaty (2008). The best result for each cluster passed to a second round of assessment to give a final overall result with the best post-harvest technology. In each pairing, an acceptable range of expert judgments was established to avoid inconsistency. This range is measured by the consistency ratio (CR). In this research we used 0.05 for a 3x3 matrix. If the value of CR is equal to or less than this value, the assessment within the matrix can be acceptable (Cheng and Li 2001).

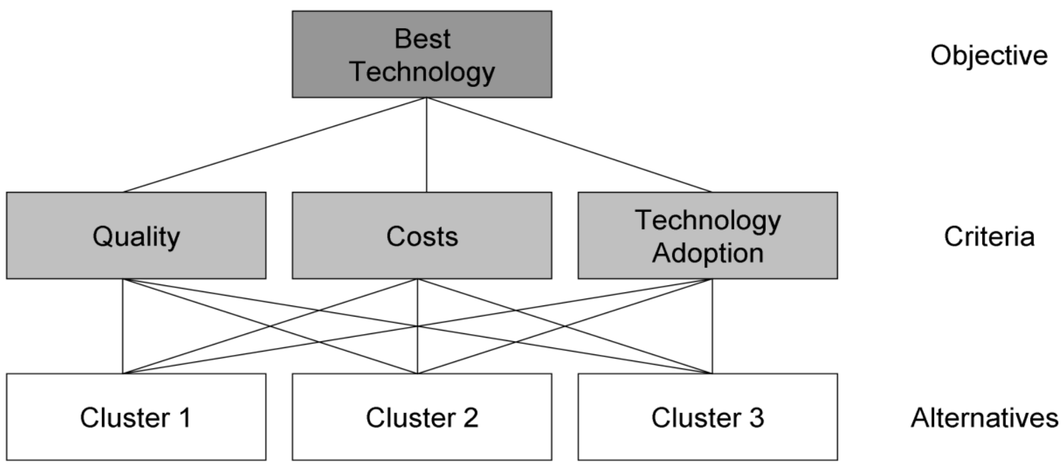

Figure 1. AHP structure for this study

Fuzzy Logic

Fuzzy logic has already been used successfully in the field of agribusiness and agricultural economics (Odetunji and Kehinde 2005, Atthajariyakul and Leephakpreeda 2006). Its methodological basis can be found in Zadeh (1965, 1966) who defines the fuzzy set A in X by a membership function fA (x) that associates each point in X with a real number in the interval [0,1], where fA (x) is the degree of membership of x in A. The closer the value of fA (x) to 1, the greater the degree of membership of x in A.

Fuzzy logic assessment uses a logical sequence of linguistic labels. Labels in our case must adapt to the assessment of post-harvest technologies. For quality the labels used were: 'very good',

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'good', 'fair', and 'bad', classification that draws on preliminary information from the NORMA INEN 156 (2006) for the classification of cocoa bean quality. For the other two criteria considered (costs and technology adoption), we worked with the same national experts as for the AHP. For processing cost, all experts agreed on three linguistic labels: 'high', 'medium', 'low', taking into account the heterogeneity of the target group (small farmers). Experts described the technology adoption capability as 'easy', 'moderate', or 'difficult' to implement. The output variable consisted of the assessment of the nine post-harvest technologies. The labels were 'excellent', 'very good', 'good', 'fair', or 'poor'.

To allow the evaluation, 36 rules were generated—the result of combining the inputs of all variables with potential outputs (Table 2, see Appendix). The fuzzy rules are those set out by Mamdani (Mamdani and Assilian 1975). Applying fuzzy rules gave rise to fuzzy output sets. The next step was defuzzification, which consisted of transforming these fuzzy outputs into the final set. These values yield the levels of membership of the input values to the different fuzzy sets. The centroid method was used, with three input variables in a 1x3 matrix, a 1x1 output matrix, and 36 rules.

Results and Discussion

We present first the main findings of the cocoa postharvest selection by using first, AHP, and second, fuzzy logic. Then we compare the solutions and evaluate the methodologies having regarded a set of methodological criteria that relate to the adequacy of these methods to the studied problem and other contexts.

Selection of Post-Harvest Technologies using AHP

Experts conducted an individual assessment of each criterion. Quality received the best rating, with a geometric mean of 0.49, followed by processing cost (0.32), and technology adoption capability (0.13) (Table 3). These results are consistent with Amores (2009), who reports that the post-harvest is relevant for marketing a product, taking chemical, physical, and, above all, sensory quality parameters to be the most representative when assessing cocoa. However, the expert assessment confirmed the view that post-harvest costs and technology adoption are not negligible.

Table 3. Preliminary assessment of criteria

Criteria	**Minimum**	**Maximum**	**Geometric mean**
Quality	0.40	0.75	0.49
Costs	0.12	0.46	0.32
Technology adoption	0.07	0.20	0.13

Source. Authors own elaborations based on expert assessment

When boxes are combined with solar dryer, concrete floors, and racks (Table 4), the results reveal that, for the quality criterion, the best technology is boxes-solar dryer with a geometric mean of 0.51. For the cost criterion, the best result is that of the combination boxes-racks, with score of 0.43, which implies that this technology has the lowest cost. The easiest technology to

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adopt is boxes-concrete floors (0.56). In the overall assessment, the best technology combination is boxes-concrete floors (0.34). This technology attains its highest ratings for the criteria of costs and technology adoption.

The peer review was extended to technologies for the cluster of fermentation in heaps and bags (Table 4). When heaps are combined with solar dryers, concrete floors, and racks, we find that the best technology combination is heap-concrete floors, with a geometric mean of 0.40. It also achieves the best average in the assessment of quality criteria and processing costs in the heaps cluster. Finally, when fermentation in bags is combined with solar dryers, concrete floors, and racks, the best score belongs to bags-concrete floors, whose geometric mean is 0.34 in the overall assessment. In the bags cluster, this technology attains its highest ratings in the assessment of costs and technology adoption criteria, prevailing over the technology considered the best in terms of quality (bags-solar dryer).

Table 4. Assessment of the fermentation clusters

Technologies by Fermentation Cluster	Criteria											
	Quality			Costs			Technology Adoption			Global		
	Min	Max	Geom. M.	Min	Max	Geom. M.	Min	Max	Geom. M.	Min	Max	Geom. M.
Boxes-Racks	0.18	0.38	0.25	0.31	0.53	0.43	0.20	0.32	0.25	0.23	0.36	0.31
Boxes-Solar dryer	0.32	0.71	0.51	0.11	0.15	0.12	0.14	0.24	0.16	0.20	0.56	0.33
Boxes-Concrete floors	0.10	0.32	0.21	0.30	0.56	0.41	0.50	0.62	0.56	0.21	0.46	0.34
Heap-Racks	0.23	0.48	0.34	0.24	0.53	0.36	0.32	0.65	0.43	0.26	0.48	0.37
Heap-Solar dryer	0.20	0.54	0.24	0.08	0.20	0.12	0.10	0.14	0.12	0.12	0.31	0.17
Heap-Concrete floors	0.20	0.54	0.34	0.32	0.62	0.46	0.24	0.55	0.42	0.25	0.54	0.40
Bags-Racks	0.16	0.53	0.28	0.31	0.53	0.40	0.26	0.46	0.32	0.20	0.39	0.33
Bags-Solar dryer	0.32	0.60	0.46	0.10	0.15	0.13	0.10	0.13	0.12	0.21	0.46	0.29
Bags-Concrete floors	0.13	0.32	0.20	0.30	0.56	0.45	0.42	0.64	0.52	0.26	0.41	0.34

Source. Authors own elaborations based on expert assessment

Taking the best result of each cluster, we constructed a further matrix (3x3), which we used to repeat the assessment process and derive the best overall technology. The three technologies chosen from their clusters were: boxes-concrete floors, bags-concrete floors, and heap-concrete floors (see Table 5). For all three clusters, the type of drying is the same because it is relatively cheap and easy to adopt. For the quality criteria, boxes-concrete floors was the highest-scoring technology (0.45). For the cost criterion, the best technology is heap-concrete floors with an average of 0.43. For the criterion of technology adoption, the highest geometric mean is that of heap-concrete floors with 0.42. Finally, the overall evaluation assigns the highest value to heap-concrete floors (0.34), followed by boxes-concrete floors (0.32), and finally bags-concrete floors (0.31).

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Table 5. Assessment of the best technologies by cluster

Technologies	Criteria											
	Quality			Costs			Technology Adoption			Global		
	Min	Max	Geom. M.	Min	Max	Geom. M.	Min	Max	Geom. M.	Min	Max	Geom. M.
Boxes-Concrete floors	0.20	0.55	0.45	0.17	0.40	0.20	0.17	0.20	0.20	0.25	0.46	0.32
Heap-Concrete floors	0.19	0.30	0.24	0.40	0.50	0.43	0.40	0.60	0.42	0.25	0.39	0.34
Bags-Concrete floors	0.20	0.50	0.25	0.10	0.40	0.33	0.20	0.40	0.35	0.28	0.40	0.31

Source. Authors own elaborations based on expert assessment

The overall technology scores are very close to each other, although for different reasons, which justifies MCDA in cocoa postharvest. The best technology (heap-concrete floors) has the highest score because of high scores in the cost and technology adoption criteria. In contrast, for the quality criterion, there is a considerable difference in relation to the highest score (boxes-concrete floors). Therefore, quality matters but it is not enough to indicate the best technology, when other relevant criteria are considered in the analysis.

Selection of Post-Harvest Technologies using Fuzzy Logic

Consulting the same group of experts, the degree of membership of the variables and their ranges was classified (Table 6). Fuzzy sets, as well as degrees of membership for each set, were formed for each of the four input and output variables.

Table 6. Ranges of the input and output variables

	Variables	Label	Range
INPUTS	Quality	Bad	0-30
		Fair	20-60
		Good	50-80
		Very Good	70-100
	Cost	Low	0-30
		Medium	20-70
		High	60-100
	Technology Adoption	Easy	0-30
		Moderate	20-70
		Difficult	60-100
OUTPUT	Technology Assessment	Poor	0-30
		Fair	25-50
		Good	45-70
		Very good	65-90
		Excellent	85-100

Source. Ranges established by experts

The experts assessed each technology according to the three criteria (quality, cost, and adoption), leading to the indicated linguistic classification (the first three columns of Table 7).The results of

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the technology assessment were obtained following fuzzy rules and processing the expert data (the last column of Table 7). The technologies that experts deem ‘excellent’, taking into account all the criteria, were: (i) fermentation in bags and drying with concrete floors; and (ii) heap fermentation and drying with concrete floors. Both combinations employ the same type of drying. Heap fermentation and drying with racks receives the next highest rating (‘very good’).

For the quality criteria, fuzzy results are consistent with the results when only the quality criteria is considered, as only one technology is classified as fair (bags-racks). Therefore, for the quality criterion, all technologies offer the same output quality if they are properly implemented. Differences emerge when the other criteria are also considered. The technologies that have a good rating for processing cost and technology adoption capability are the same as above (heap-concrete floors and bags-concrete floors).

Table 7. Technology assessment using fuzzy logic

Technologies		**Quality**	**Cost**	**Technology Adoption**	**Technology Assessment**	
Fermentation	*Drying*				*Numeric*	*Linguistic*
Heap	Solar dryer	Good	Medium	Moderate	57.5	Good
	Concrete floors	Good	Low	Easy	94.9	Excellent
	Racks	Good	Low	Moderate	77.5	Very Good
Bags	Solar dryer	Good	Medium	Moderate	57.5	Good
	Concrete floors	Good	Low	Easy	94.9	Excellent
	Racks	Fair	Medium	Easy	37.5	Fair
Boxes	Solar dryer	Good	High	Moderate	57.5	Good
	Concrete floors	Good	Medium	Moderate	57.5	Good
	Racks	Good	Medium	Moderate	57.5	Good

Source. Authors own elaborations based on expert assessment

Comparative Evaluation

This paper follows the interest of others (Anojkumar et al. 2014) to compare Multi Criteria Decision Making in order to choose best alternatives. Comparing the three methods (Table 8) reveals a key difference. The single analysis of quality indicators is quite demanding in data but it does not provide with an unambiguous solution to the selection of post-harvest technology. When small holders are at stake, policy makers would need better guidelines for orienting one type of technology or another. AHP and Fuzzy Logic provide a more accurate assessment of technologies using management goals that fit better to the challenges faced by small producers, who in reality make *ad hoc* decisions according to more than one criterion. The three methods use a variety of data sources. The quality assessment used in this paper was quite demanding in statistical data, whereas the multi-criteria methods are based on experts’ evaluations. It is clear, on the other side, that the quality criterion is less subjective than the MCDA applied to this case.

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Table 8. Comparison of methodologies

	Single Criterion Statistical Method	AHP	Fuzzy Logic
Criteria	*Quality*	*Quality, cost, adoption*	*Quality, cost, adoption*
Approach to the reality of small farmers	Low	High	High
Input data	High demanding (field work)	Low demanding (experts' evaluations)	Low demanding (experts' evaluations)
Subjectivity	Low	High (can be reduced in the expert selection)	High (can be reduced in the expert selection)
Methodological basis	Statistical analysis of field data	Formation of hierarchies and the use of peer assessment	Formation of fuzzy sets and rules
Results	No significant differences	Heap-concrete floors	Heap-concrete floors Bags-concrete floors
Possibility for ranking and prioritising	Low	High	High
Level of detail	Low	Medium	High
Extrapolation to new situations	Low	Low	High
Transference to policy makers	Current situation	Potential situation	Potential situation

Source. Authors own elaborations

The MCDA performed in this paper used two alternative selection methods. The methodological basis of AHP is the formation of hierarchies and the use of peer assessment to make decisions (selection of the best technology). In contrast, fuzzy logic focuses on the formation of fuzzy sets and rules, using criteria to determine an output result. In this case, the output variable is the classification of technology assessment into the categories of 'excellent', 'very good', 'good', 'fair,' or 'poor'. Despite their differing methodologies, the results of the two techniques arrive at the same conclusion; namely, that the best post-harvest technology is heap-concrete floors. Both methodologies also give the researcher the possibility for ranking and prioritising the different technologies (Mikhailov 2004). An advantage of the fuzzy method is that it uses linguistic evaluations, which means greater detail during analysis. Furthermore, fuzzy controllers are created during the process. Input data of these controllers could be modified and obtain new results without asking experts again (Odetunji and Kehinde 2005).

The information provided by comparative MCDA allows policy makers to ensure that technology promotion is oriented to improve access for small farmers. Applying a multi-criteria approach to examining the cocoa smallholder sector highlights the reality faced by producers as well as its potential growth (Giordano and de Fraiture 2014).

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Conclusions

Producers make decisions based on multiple criteria, an inherent part of human judgment when making choices. Assessing criteria (in this case quality, processing costs, and technology adoption capability) for the choice of cocoa post-harvest technology with multi-criteria methodologies like AHP and fuzzy logic is therefore closer to the reality of the actual choices made by producers. Hence, any technological improvement plan must take into account all of the above criteria on account.

The first specific objective of this study was to assess alternative post-harvest technologies, combining fermentation and drying techniques of cocoa beans under a single quality criterion. This analysis revealed no significant differences, in terms of physical metrics of cocoa quality, between the two factors (i.e., type of fermentation and type of drying) and technologies. In other words, statistically speaking, under the criteria of quality, claims to have a better post-harvest technology are ambiguous. Differences between the quality of different producers' cocoa are not dependant on the technology selected.

The research considered MCDA to take into account the criteria of quality, post-harvesting costs, and technology adoption capability. AHP attached the quality criterion the greatest weight, but quality was not always decisive when selecting the best technology because some technologies receive high scores for the other two criteria, thereby offsetting the quality criterion score. Fuzzy logic yielded results that are similar to those of the AHP methodology, indicating that the experts' judgments are coherent. Moreover, fuzzy logic results were also consistent with the statistical results of the first analysis (in terms of quality), as the results of the fuzzy logic analysis were similar to the ratings of the quality criterion for eight of the nine technologies.

Other socio-economic and environmental benefits, such as, environmental impacts, private earnings or prices, are not considered (quality is closely related to its market value). However, the way has been paved for new criteria in next steps. Finally, our findings lead to an important research question: what is the optimal multi-criteria methodology? The answer lies in the quality of the data provided by experts and the scope of the research aims. As a closing remark, policymakers can apply MCDA to develop cocoa policies taking into account the relevance of these multiple criteria, and having discriminatory elements beyond the single criterion of quality. In the same way, managers can also benefit from MCDA when cooperative forms of production are carried out.

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Appendix

Table 2. Fuzzy rules

Rules No.	If QUALITY is	and COST is	and TECHNOLOGY ADOPTION is	Then TECHNOLOGY ASSESSMENT is
1	Very Good	High	Easy	Good
2	Very Good	High	Moderate	Good
3	Very Good	High	Difficult	Fair
4	Very Good	Medium	Easy	Very Good
5	Very Good	Medium	Moderate	Very Good
6	Very Good	Medium	Difficult	Good
7	Very Good	Low	Easy	Excellent
8	Very Good	Low	Moderate	Excellent
9	Very Good	Low	Difficult	Very Good
10	Good	High	Easy	Good
11	Good	High	Moderate	Good
12	Good	High	Difficult	Fair
13	Good	Medium	Easy	Very Good
14	Good	Medium	Moderate	Good
15	Good	Medium	Difficult	Fair
16	Good	Low	Easy	Excellent
17	Good	Low	Moderate	Very Good
18	Good	Low	Difficult	Good
19	Fair	High	Easy	Fair
20	Fair	High	Moderate	Fair
21	Fair	High	Difficult	Poor
22	Fair	Medium	Easy	Fair
23	Fair	Medium	Moderate	Fair
24	Fair	Medium	Difficult	Fair
25	Fair	Low	Easy	Good
26	Fair	Low	Moderate	Fair
27	Fair	Low	Difficult	Fair
28	Bad	High	Easy	Poor
29	Bad	High	Moderate	Poor
30	Bad	High	Difficult	Poor
31	Bad	Medium	Easy	Poor
32	Bad	Medium	Moderate	Poor
33	Bad	Medium	Difficult	Poor
34	Bad	Low	Easy	Fair
35	Bad	Low	Moderate	Poor
36	Bad	Low	Difficult	Poor

Source. Authors own elaborations

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