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RESEARCH ARTICLE

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AHP choice in cocoa post-harvest technology for small-scale farmers

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Abstract

Ensuring that the post-harvest process yields good quality cocoa is a relevant research question. However, the literature currently lacks detailed studies of producers' criteria for post-harvest technology selection. There is therefore a need for research that examines technology choice based on several criteria. This is the aim of our paper. We defined a cocoa post-harvest technology selection model to assist small producers in Ecuador. To do so, we employed the Analytical Hierarchy Process (AHP) to assess the following criteria: quality, processing cost and technology adoption capability. By considering only quality, we first performed a preliminary assessment of nine post-harvest technologies yielded by all possible combinations of fermentation and drying methods. Under the criterion "quality", results show that no post-harvest technology is preferable to another. This implies that quality differences between producers do not derive from technology choice but rather from the rigour with which producers perform fermentation and drying processes. After adding the criteria "processing cost" and "technology adoption capability", we performed the analysis again. This multi-criteria approach offered a better way to approximate small farmers' real needs when selecting technology for cocoa post-harvest. Although quality was the highest-valued criterion, high scores attributed to some technologies in the other two criteria offset scores for quality. Thus, processing cost and technology adoption also emerged as relevant factors for small holders.

Additional key words: multi-criteria decision; fermentation; drying; quality; costs; Ecuador.

Introduction

Ecuador is the world's largest producer of fine aroma cocoa (*Theobroma cocoa*), providing 70% of global output for this highly specialised market. Ecuador accounts for 4% of worldwide cocoa production. Consumption of this product is forecast to grow at 5 to 10% annually in coming years (Central Bank of Ecuador, 2012). Figures from the Central Bank of Ecuador (2012) show that cocoa bean exports contribute 1.6% to the Ecuador's Gross Domestic Product (GDP), with 0.3% of GDP coming from processed cocoa production. Cocoa production has a 12% share of Ecuador's agricultural GDP and affects 4% of the country's employment.

Nevertheless, 59% of national cocoa production comes from smallholdings no larger than 10 hectares. Remaining production comes from medium-scale farmers (whose holdings cover areas between 10 and 50 ha, 31%) and large-scale farmers (areas larger than 50 ha, 10%). Most producers cultivate native cocoa, also known as 'Nacional' (Oracz & Nebesny, 2014). This native cocoa represents 70% of Ecuador's exports (Anecacao, 2013).

A key factor in determining cocoa quality is the post-harvest stage. This begins with the fermentation

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Abbreviations used: AHP (analytical hierarchy process); CR (consistency ratio); CRD (completely randomised design); GDP (gross domestic product); INEN (Ecuadorian Standardisation Institute; *Instituto Ecuatoriano de Normalización*); LSD (least significant difference).

process. Fermentation is essential for developing flavour characteristics and precursors of colour in the bean (Camu *et al*., 2007; Nielsen *et al*., 2007; García-Armisen *et al*., 2010; Papalexandratou *et al*., 2011b). During the second stage, cocoa beans are dried to reduce moisture. Drying is followed by the oxidative phase, which begins with fermentation and ends with formation of aroma and flavour compounds (Braudeau, 1991; Jinap *et al*., 1994; Cros & Jeanjean, 1995; Wood & Lass, 2001). Drying also contributes to reducing cocoa bitterness and astringency, mitigating the risk that beans develop undesirable odours (Mossu, 1992). Although this process appears to be standard, different methods of fermentation and drying exist. Fermentation methods are heap, boxes and bags and there are three drying methods: racks, concrete floors and solar dryers.

Papalexandratou *et al*. (2013) claimed that recent research on cocoa fermentation processes has been inconclusive. They argued that a number of fermentation methods exist, and that their adoption varies according to regional and production practices (Papalexandratou *et al*., 2011a). Thus, additional criteria, besides bean quality, are important when deciding which post-harvest technology to employ.

In addition to quality, other criteria determine which post-harvest technology to employ. These criteria include cost of the post-harvest process and ability to adopt new technologies. We therefore sought to define a multi-criteria selection model for cocoa post-harvest technology. Our aim was to develop a process that could be implemented by small farmers in the province of Manabí (Ecuador). To achieve this aim we applied the Analytical Hierarchy Process (AHP). AHP is a measurement theory (Saaty, 1986, 1988, 1990; Saaty & Vargas, 1987; Xu, 1988; Golden & Wang, 1989) applicable to decision-making. AHP can be used to describe general decision processes by decomposing complex problems into multi-level hierarchical structures of objectives, criteria, sub-criteria and alternatives. Aznar & Caballer (2005) and Roig-Tierno *et al*. (2013) stated that the AHP method does not require quantitative information about alternatives because it is based on decision makers' value judgments. Thus, AHP offers an improvement on the current scenario, whereby small farmers in Ecuador lack information on costs and ease of technology adoption, and information is incomplete for experts or decision makers. AHP methodology has become an important tool for decision-making, and evidence of its importance has been shown by Stokes & Tozer (2002), Shrestha *et al*. (2004), Karami (2006), Aznar & Estruch (2007), Kim *et al*. (2010), Ning *et al*. (2011), Zhang *et al*. (2011), Chavez *et al*. (2012), Tayfun & Mevlut (2013), amongst others.

Within our general research aim, we established the following specific objectives: 1) to evaluate, in terms of quality alone, alternative post-harvest techniques consisting of combinations of cocoa bean fermentation and drying methods; 2) to use AHP methodology to select the best cocoa post-harvest technology by examining quality, cost and technology adoption capability. We drew on the expertise of national experts to assess these criteria. These objectives allowed us to determine whether decisions based only on quality would lead to different results from multi-criteria decisions.

Material and methods

Cocoa post-harvest technologies have generally been assessed in terms of bean quality only. In recent years, however, the need to study post-harvest phenomena from a holistic point of view has grown. Thus, assessing trade-offs between quality and other criteria is important (Castro-Tanzi *et al*., 2012). We therefore applied two methods. First, we assessed different technologies according to their quality. Second, we assessed the same technologies from a multi-criteria approach (quality, costs and technology adoption). We then compared results.

Description of additional criteria

Converting a cocoa harvest into a marketable product is a genuine production process, where technology, capital and labour costs sometimes outweigh costs of the agricultural phase (Alarcón, 2011). For cocoa, removing cobs from trees and trading dried cocoa beans entails a transformation process and thus incurs costs. Measurement and classification of costs in post-harvest cocoa is complex because farmers are often unaware of actual costs: Variability of volumes and availability of resources for producers affect total cost. Cost is nevertheless a key criterion when deciding which post-harvest technology to adopt.

Adoption is the result of a sequence of decisions (Gatignon & Robertson, 1991) on whether to implement an innovation. Lindner (1987) approached the issue of adoption as part of a process in which decision makers have prior knowledge before making their decision. Sidibé (2005) defined agricultural technology adoption as the quest for a balance between new technology and other activities, assuming farmers have complete information about technology and its potential. Authors of studies in several fields have concluded that technology adoption is an essential criterion when deploying technology. In agriculture, studies in many fields have addressed technology adoption. Studies on rice (Mariano *et al*., 2012), irrigation (Abdulai *et al*., 2011), sustainable agriculture (Lee, 2005), and soil conservation (Roco *et al*., 2012), amongst other fields, have all shed light on the issue. In all such studies, technology adoption has been explored from the producer's point of view. In cocoa cultivation, producers adopt and implement post-harvest technologies, so technology adoption is also an important criterion.

Post-harvest technology evaluation according to quality

Research scenario

Our research was conducted in the "Fortalezas del Valle" Association Collection Centre, located in Calceta, Bolivar County, province of Manabí, Ecuador. The structural fieldwork phase was conducted in both the dry season, between November and December 2012 (rainfalls of 5.3 mm and 36.1 mm, respectively), and in the wet season, between January and March 2013 (rainfalls of 267.6 mm, 163.8 mm and 372.1 mm, respectively, for the three months). We chose these periods to account for possible climactic influences on cocoa fermentation and drying.

Experimental design

To evaluate quality we considered two basic factors: type of fermentation (F) and type of drying (S). Methods for *type of fermentation* were heap (F1), bags (F2) and boxes (F3). Methods for *type of drying* were solar dryer (S1), concrete floors (S2) and racks (S3). Fermentation methods were paired with drying methods to create nine post-harvest technology combinations.

For the experiment, we used a completely randomised design (CRD) with three replicates for each technology. Several physical variables were evaluated for each technology in both dry and wet seasons. For each season, 27 technologies were evaluated. For each technology, we used 30 kg of fresh cocoa.

Percentage of fermentation

We employed the INEN standard 176 (INEN, 2006) method to measure the percentage of fermentation. We thus performed a cut test by dividing longitudinally into two halves 100 beans taken at random from each dry sample. The cut test could thus be used to measure the percentage of good fermentation, percentage of medium fermentation, percentage of total fermentation and percentage of violet beans. This method has been documented by INEN (2006), based on measurements from INEN STANDARD 176 and ISO 950 (INEN, 2006).

Seed index

The seed index was analysed by accurately weighing the beans. We first weighed 100 fermented and dried beans randomly sampled for each of the technologies. This number was divided by 100 to yield the seed index in grams. This operation was repeated twice per sample to give an average for this index.

Percentage of testa and cotyledons

For this test, we first took a 30 g sample of beans. Testa was removed manually to separate it from cotyledons. Cotyledons were then weighed separately and this value was subtracted from 30 g to determine the weight of testa. The final weight was divided by 30 and multiplied by 100 to yield the percentage of testa.

Statistical analysis

An analysis of variance (ANOVA) was performed to find significant differences between factors and technologies. We set a significance level of 5% ($p < 0.05$) for all comparisons. Physical variables used to measure quality were percentage of fermentation, seed index, and percentage of testa and cotyledons.

Multi-criteria (AHP) evaluation of post-harvest technologies according to quality, costs and technology adoption

We performed a second round of analysis to evaluate technology selection, adopting a multi-criteria approach to do so. We used the AHP method, developed by Saaty (1980), as a flexible system for multi-criteria decision analysis. Formulation of the decision problem in a hierarchical structure was the first step. The hierarchy (objective-criterion-sub-criterion-alternative) was constructed so that elements at the same level were of the same order of magnitude and could interact with some or all elements at the next level. In a typical hierarchy, the highest level is the decision problem or goal. Once the hierarchical model was built, pairwise comparisons between these criteria and alternatives were made. Thus, experts in the decision process assigned numerical values (from 1-9) according to their preferences (Saaty, 1980).

The hierarchy of our decision problem was as follows (Fig. 1): (i) the objective was to select the best technology; (ii) criteria were quality, processing cost and technology adoption capability; (iii) alternatives corresponded to nine post-harvest technologies yielded by all possible combinations of fermentation and drying methods.

This process yielded three clusters. Each cluster's central axis corresponded to one fermentation method (heaps, bags or boxes). In each cluster, the fermentation method was matched with all drying alternatives (solar dryer, concrete floors and racks). Each cluster was therefore represented by a 3×3 matrix. Thus, under this approach, each fermentation alternative was combined with all drying alternatives. This allowed us to determine the best alternative for each cluster.

Eight national experts provided the study data. They were selected from a group of more than 20 experts with experience in R&D in cocoa production, post-harvest processes and cocoa quality. They were selected according to years of experience and willingness to participate in our project. We ensured the group of experts was heterogeneous to foster a range of views and judgments (Wedley *et al.*, 1993). Amongst the experts were academics and employees in private corporations. We used a questionnaire to collect data from selected experts. This process allowed us to perform a pairwise assessment of technologies using Saaty's scale (1980). We explained the purpose and content of the questionnaire to each expert. Experts then responded to the questionnaire. To merge individual judgments into a single representative judgment for the entire group, we used the geometric mean, as recommended by Saaty (2008). This method maintained the reciprocity property of the trials.

In each pairing, an acceptable range for experts' judgments was also established. This avoided inconsistency. The consistency ratio (CR), which can vary depending on the size of the matrix, was used to establish this range. As stated in the literature, the CR is 0.05 for a 3×3 matrix, 0.08 for a 4×4 matrix, and 0.1 for all $n \times n$ matrices with $n \geq 5$ (Saaty, 2000; Cheng & Li, 2001). A CR value less than or equal to the threshold value implies that the evaluation within the matrix is acceptable, and that the matrix represents a good level of consistency in comparative judgments. Conversely, a CR value greater than the threshold value suggests some inconsistency in comparative judgments, and that the evaluation process should be checked. An acceptable consistency index helps ensure reliability in the decision-making process. Because matrices in this study were 3×3, a range of less than 5% consistency was established, as previously stated (Saaty, 2000).

In the second round, the best overall results for each cluster were selected and evaluated. This yielded the best post-harvest technology overall.

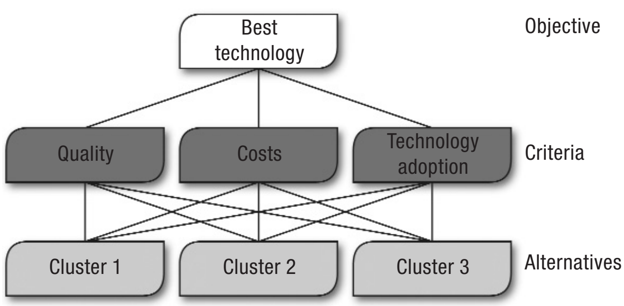

Figure 1. AHP structure for this study.

Results

Choice of post-harvest technology according to quality

To maintain consistency across all data, factors and post-harvest technologies were separately evaluated to test for statistically significant differences between technologies. Table 1 displays results for the dry season. Duncan ANOVA at 5% yielded results that show

Table 1. Analysis of variance for fermentation and drying methods during dry and wet seasons

Season	Factors	% Good	% Medium	% Total	% Violet	Seed index	% Testa	% Cotyledons
Dry	Type of fermentation							
	Boxes	22.67	62.44	85.11	14.89	120.76	15.02[a]	84.98[b]
	Heap	22.44	59.11	81.44	18.33	114.9	14.8[a]	85.20[b]
	Bags	19.78	57.78	77.56	23.56	122.37	13.63[b]	86.37[a]
	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	Type of fermentation							
	Boxes	62.22	25.33	87.67	12.00	113.82[c]	15.24	84.76
	Heap	61.22	22.44	84.00	16.00	118.50[b]	15.06	84.98
	Bags	58.22	26.33	85.67	14.33	121.67[a]	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	113.61[b]	14.40[b]	85.60[a]
	Concrete floors	59.67	25.44	86.22	13.78	118.86[a]	14.52[b]	85.48[a]
	Solar dryer	64.22	22.56	86.11	13.89	121.52[a]	16.24[a]	83.76[b]
	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

The percentages marked by a letter are significantly different from other values in the same column under Duncan ANOVA ($\alpha = 0.05$) with a confidence level of 95%.

no significant differences between types of fermentation or between types of drying for the 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, type of fermentation (heap, bags or boxes) and type of drying (solar dryer, concrete floors or racks) did not appear to have any significant impact on quality.

Table 2 displays the results for post-harvest technologies in the dry season. The results indicate no significant differences between technologies for the variables *percentage of good fermentation*, *percentage of medium fermentation*, *percentage of total fermentation*, *percentage of violet beans*, *seed index*, *percentage of testa and cotyledons*.

For the wet season, results from Duncan ANOVA at 5% (Table 1) show that there were no significant differences between types of fermentation or between types of drying for the variables *percentage of good fermentation*, *percentage of medium fermentation*, *percentage of total fermentation* and *percentage of violet beans*. In contrast, seed index differences between different types of fermentation and drying are highly significant. Seed index does not just depend directly on the post-harvest process. It also depends on genetic variability in native 'Nacional' cocoa in Ecuador (INEN, 2006). There were significant differences between drying types in terms of percentage of cotyledons and testa. For type of fermentation, however, no differences between these variables' distributions emerged.

For the wet season (Table 2), there were no significant differences between technologies for the variables *percentage of good fermentation*, *percentage of medium fermentation*, *percentage of total fermentation*, *percentage of violet beans*, *percentage of testa and cotyledons*. However, results imply significant variability in seed index. As explained earlier, this variable also depends heavily on genetic variability between seeds.

Table 2. Analysis of variance for post-harvest technologies during dry and wet seasons

Season	Technologies	% Good	% Medium	% Total	% Violet	Seed index	% Testa	% Cotyledons
Dry	Boxes-Racks	24.67	60.33	85	15	128.39	14.02	85.98
	Boxes-Concrete floors	22.67	64	86.67	13.33	114.9	15.59	84.41
	Boxes-Solar dryer	20.67	63	83.67	16.33	118.99	15.45	84.55
	Heap-Racks	24.33	59	83	16.67	123.62	14.79	85.21
	Heap-Concrete floors	22	66.00	88	11.67	122.37	14.38	85.62
	Heap-Solar dryer	21	52.33	73.33	26.67	119.4	15.22	84.78
	Bags-Racks	19.33	62	81.33	18.67	122.26	14.09	85.91
	Bags-Concrete floors	23.67	61	84.67	18.67	126.8	13.09	86.91
	Bags-Solar dryer	16.33	50.33	66.67	33.33	118.04	13.71	86.26
	Standard error	3.86	6.36	6.65	6.79	5.43	0.65	0.65
	Probability	0.85	0.70	0.40	0.45	0.70	0.17	0.17
Wet	Boxes-Racks	55.33	27.33	82.67	16.33	110.67[f]	19	85.70
	Boxes-Concrete floors	62.33	28	90.33	9.67	111.62[ef]	14	85.81
	Boxes-Solar dryer	69	20.67	90	10	119.17[cd]	17.23	82.77
	Heap-Racks	62	20.33	82.33	17.67	114.63[e]	14.65	85.35
	Heap-Concrete floors	58	21	82.33	17.67	121.57[bc]	15.14	84.86
	Heap-Solar dryer	63.67	26	87.33	12.67	119.30[cd]	15.4	84.60
	Bags-Racks	56	30.67	90	10	115.53[de]	14.27	85.73
	Bags-Concrete floors	58.67	27.33	86	14	123.39[ab]	14.22	85.78
	Bags-Solar dryer	60	21	81	19	126.10[a]	16.09	83.91
	Standard error	4.12	4.16	2.43	2.53	1.26	0.78	0.78
	Probability	0.43	0.53	0.056	0.085	<0.0001	0.15	0.15

The percentages marked by a letter are significantly different from other values in the same column under Duncan ANOVA ($\alpha = 0.05$) with a confidence level of 95%.

All results seem to indicate that different types of fermentation and drying yielded beans whose quality was statistically non-significantly different. Likewise, if implemented correctly, all nine post-harvest technologies were shown to yield beans whose quality was statistically non-significantly different. These results reflect the fact that variability in bean quality depends less on technology than on producers' rigour in stirring and mixing the beans during fermentation. In other words, statistically speaking, no post-harvest technology yielded a better quality product than any other. This finding is consistent with that of Amores (2009). Indeed, Papalexandratou *et al*. (2013) asserted that recent research on cocoa fermentation processes has been inconclusive. Interestingly, there is high variability at production unit level and a low degree of standardisation amongst producers. This variability arises because producers choose a fermentation method depending on cocoa type and local production unit practices (Papalexandratou *et al*., 2011a).

To conclude the results section, we now offer some comparisons of significant differences between the most relevant variables' mean values for each season (dry and wet). Variables with significant results are *percentage of good fermentation* and *percentage of medium fermentation*. Fig. 2a shows a least significant difference (LSD) of 7.7 percentage points between seasons for percentage of good fermentation. Fig. 2b shows an LSD of 5.1 percentage points for percentage of medium fermentation. These results suggest that time of year had an impact on cocoa quality. The wet season yielded better good fermentation rates than dry. We obtained these results under controlled conditions, however, and these conditions were the same for both periods.

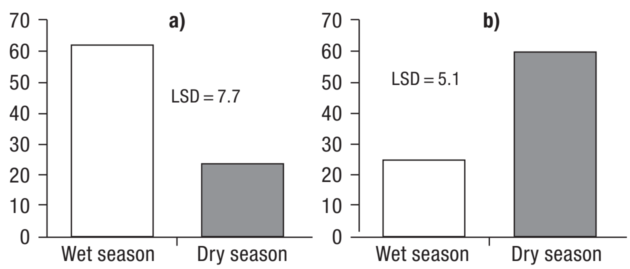

Figure 2. Comparison of significant means for percentage of (a) good fermentation and (b) medium fermentation as a function of time of year.

Table 3. Minimum, maximum and geometric mean values from experts' evaluations of quality, costs and technology adoption

Criteria	Minimum	Maximum	Geometric mean
Quality	0.400	0.747	0.487
Costs	0.119	0.458	0.330
Technology adoption	0.082	0.200	0.142

Anonymous individual answers are available upon request.

AHP choice of post-harvest technology according to quality, costs and technology adoption

Results per cluster

First, experts gave an individual assessment of each criteria: quality, costs and technology adoption. Of these criteria, the most valued criterion was quality, with a geometric mean of 0.487, followed by cost (0.330) and finally technological adoption (0.142) (Table 3).

Table 4 shows the evaluation of different technology pairs. When fermentation in boxes was combined with solar dryer, concrete floors and racks, results show that the highest quality technology was boxes-solar dryer with a geometric mean of 0.515. This score was considerably higher than that of boxes-racks (0.247) and boxes-concrete floors (0.207). For cost, the best combination was boxes-racks (0.426). In other words, this technology had the lowest cost. Nevertheless, boxes-concrete floors yielded a score of the same magnitude (0.421), which was much higher than that of boxes-solar dryer (0.134). This order reflects small-scale farmers' preference for low-cost technologies to avoid the burden of a large financial outlay. The best result for technology adoption was boxes-concrete floors (0.565), well above scores for boxes-racks (0.261) and boxes-solar dryer (0.165). This order reflects ease of technological adoption (from high to low) because small-scale farmers prefer technologies that are easy to adopt. Finally, the best technology combination overall was boxes-concrete floors with a score of 0.338. This score was nonetheless close to that of boxes-solar dryer (0.327) and boxes-racks (0.310). The best technology (boxes-concrete floors) received the highest ratings in assessment of costs and technology adoption.

When fermentation in heap was combined with solar dryer, concrete floors and racks, we found the best

Table 4. Minimum, maximum and geometric mean values of experts' evaluations of technologies

	Technologies	Quality			Costs			Technology adoption			Overall		
		Min	Max	Geom. M	Min	Max	Geom. M	Min	Max	Geom. M	Min	Max	Geom. M
Cluster of fermentation in boxes	Boxes-Racks	0.179	0.376	0.247	0.320	0.540	0.426	0.200	0.333	0.261	0.229	0.373	0.310
	Boxes-Solar dryer	0.333	0.709	0.515	0.109	0.163	0.134	0.136	0.250	0.165	0.203	0.565	0.327
	Boxes-Concrete floors	0.113	0.333	0.207	0.297	0.558	0.421	0.500	0.625	0.565	0.206	0.456	0.338
Cluster of fermentation in heap	Heap-Racks	0.240	0.493	0.353	0.238	0.528	0.374	0.330	0.655	0.432	0.274	0.485	0.384
	Heap-Solar dryer	0.200	0.550	0.238	0.078	0.200	0.130	0.097	0.150	0.117	0.134	0.307	0.182
	Heap-Concrete floors	0.200	0.550	0.353	0.333	0.625	0.471	0.250	0.547	0.427	0.264	0.552	0.412
Cluster of fermentation in bags	Bags-Racks	0.157	0.528	0.285	0.320	0.540	0.396	0.258	0.458	0.330	0.199	0.402	0.329
	Bags-Solar dryer	0.333	0.600	0.465	0.105	0.163	0.127	0.105	0.143	0.125	0.207	0.470	0.295
	Bags-Concrete floors	0.128	0.333	0.204	0.297	0.558	0.461	0.416	0.637	0.530	0.273	0.420	0.354
Best technologies by cluster	Boxes-Concrete floors	0.196	0.550	0.447	0.169	0.405	0.213	0.169	0.200	0.192	0.262	0.458	0.334
	Bags-Concrete floors	0.196	0.493	0.263	0.114	0.400	0.330	0.200	0.400	0.364	0.279	0.400	0.320
	Heap-Concrete floors	0.200	0.311	0.251	0.400	0.4993	0.426	0.400	0.600	0.432	0.263	0.388	0.337

Anonymous individual answers are available upon request.

quality technology to be heap-concrete floors, which yielded a geometric mean of 0.353. This was followed by heap-racks (0.351) and heap-solar dryer (0.237). The technology considered by experts to have the lowest cost was heap-concrete floors (0.471). The next cheapest was heap-racks with a much lower score of 0.374. Likewise, this technology scored much more highly than heap-solar dryer did (0.130). Results for the best technologies in terms of adoption were very close, mirroring the results for quality. In descending order, scores were 0.431 for heap-racks, 0.427 for heap-concrete floors and 0.117 for heap-solar dryer. Overall, there was a narrow margin between experts' preferences for the first two technologies. Experts rated heap-concrete floors best with a geometric mean of 0.412. This was followed by heap-racks (0.384) and heap-solar dryer (0.182). The best technology (heap-concrete floors) scored most highly in quality and cost. Notably, although heap-racks received the highest score for technology adoption, the score for heap-concrete floors was only marginally lower.

When fermentation in bags was combined with solar dryers, concrete floors and racks, the best geometric mean for the quality criterion was bags-solar dryer (0.465). There was a considerable difference between this score and the average for bags-racks (0.285). Finally, the lowest score was for bags-concrete floors with 0.204. For cost, the best result was for bags-concrete floors with 0.461. This was followed by bags-racks with 0.396 and bags-solar dryer (0.127), which scored much lower than the other two technology combinations. For technology adoption, experts clearly favoured bags-concrete floors (0.530) over bags-racks (0.330) and bags-solar dryer (0.125). Overall, there was a narrow margin between the top two technologies (bags-concrete floors and bags-racks). However, the best score was for bags-concrete floors with 0.354, followed by bags-racks with 0.329 and finally bags-solar dryer with 0.295. Although bags-concrete floors yielded the best average, bags-solar dryer had the best score for quality. Bags-concrete floors therefore yielded better results in costs and technology adoption, and thus yielded the best overall score of all technologies in the last cluster.

Overall results

By taking the best result of each cluster, we constructed another matrix to repeat the assessment process and find the best technology overall. Technologies chosen from their clusters were boxes-concrete floors, bags-concrete floors and heap-concrete floors (Table 4). For all three clusters, the type of drying was the same, namely concrete floors, because it was cheap and was the easiest technology to adopt.

For quality, the technology with the best score was boxes-concrete floors (0.447), far ahead of bags-concrete floors (0.263). The lowest scoring technology (heap-concrete floors) received a score of 0.251. For cost, the best technology was heap-concrete floors with a geometric mean of 0.426, followed by bags-concrete floors (0.330) and boxes-concrete floors (0.213). For technology adoption, the highest geometric mean was that of heap-concrete floors (0.432), followed by bags-concrete floors (0.364) and boxes-concrete floors (0.192). Table 4 shows these results.

Overall, the highest value corresponded to heap-concrete floors (0.337), followed by boxes-concrete floors (0.334), and finally bags-concrete floors (0.320). The overall technology scores were very close to one another. The best technology (heap-concrete floors) had high scores for cost and technology adoption. In contrast, for quality, there was a big difference in relation to the highest score (boxes-concrete floors).

Unlike evaluation based on quality alone, AHP offers a means of using multiple criteria to classify cocoa post-harvest technologies. Because we carried out our analysis by cluster, our method yielded the best technology for every fermentation technique. AHP also revealed the best technology according to each criterion. We were thus able to determine the best technology in terms of quality, costs, technology adoption and overall. Although quality was the most important criterion, a combination of the other two criteria in fact contributed to a higher final score. Thus, cost and technology adoption are also important for small producers in Ecuador.

Discussion

The first specific objective of our study was to evaluate the quality of different post-harvest techniques. These post-harvest techniques consisted of a combination of cocoa fermentation and drying methods. For physical variables, results show that no significant differences between factors or technologies emerged. In other words, statistically, no post-harvest technology yielded better quality beans than any other technique. We may therefore conclude that quality differences between producers derive from the way producers carry out fermentation and drying. However, our analysis did reveal significant differences between the times of year, with post-harvest in the wet season leading to better results.

The second objective of the study was to use AHP to assist in decision-making when choosing a cocoa post-harvest technology. In this multi-criteria model, we evaluated quality, cost and technology adoption. Results are not only conclusive in terms of quality, but also reveal the best scores according to cost and technology adoption, as well as overall. The most-valued criterion for experts was quality, followed by cost and then technology adoption. This finding is consistent with Amores (2009), who reported his findings on chemical, physical and, above all, sensory quality parameters, which depend on agroecological and agronomic factors. The author found that these quality parameters are representative in cocoa evaluation. However, we considered two additional criteria because differences in post-harvest costs and technology adoption are significant in small-scale production. The results of the cluster assessment are as follows: (i) for fermentation in boxes, the best technology was boxes-concrete floors; (ii) for fermentation in heap, the best technology was heap-concrete floors; (iii) for fermentation in bags, the best technology was bags-concrete floors; finally, (iv) the best technology overall was heap-concrete floors. Although experts considered quality most important, it was not necessarily decisive in the selection of the best technology. This is because high scores attributed to some technologies in the other two criteria offset the score for quality.

This study raises awareness of the role of additional criteria when choosing post-harvest technologies for cocoa production. Our article therefore fills a research gap. After considering costs involved in the process, as well as ease of adopting a given technology, the method we employed in this study better reflects the reality for small-scale producers when making practical decisions. Use of the AHP method to assess multiple criteria marks an innovation in this field. Furthermore, this method is advantageous in that it does not require quantitative information because it is based on expert opinion rather than numerical data. Nonetheless, we must accept limitations related to subjective information, selection of experts, and cost and time for experts. Without such multi-criteria decision frameworks, however, decisions would be more discretionary. This method also offers a transparent way to test the significance of policy objectives.

We omitted other socio-economic and environmental factors such as environmental impact, private earnings and prices (quality is closely related to market value). Nevertheless, the method developed in this article can be extended to incorporate new criteria. In fact, in the future, scholars could identify other criteria to include in the model. These may include marketing, which may be separated into sub-criteria such as access to markets, producer bargaining power and volume of applicants. The use of new methods such as fuzzy logic or the Analytic Network Process (ANP) may also provide insight into this research issue.

We are aware that producing high-quality cocoa can bring many benefits. In light of our research findings, however, it would be advisable for those responsible for policies governing 'Nacional' cocoa trade in Ecuador to consider supporting technology adoption and reducing post-harvest technology cost in small-scale production.

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