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Regional relationships between inherent coffee quality and growing environment for denomination of origin labels in Nariño and Cauca, Colombia

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ABSTRACT

International markets are increasingly signaling demand for quality-differentiated coffee, which the Colombian Coffee Growers Federation (FNC) proposed to exploit to identify those regional coffees that would fulfill the requirements to be classified as denomination of origin. The objective of this study was to develop and implement a sound, robust and repeatable approach with and for the FNC to identify regional causal relationships between coffee quality and environmental characteristics as bases for labels of denomination of origin. Environmental differences between coffee-growing areas in the departments of Cauca and Nariño were statistically significant for several characteristics, including the number of dry months, annual precipitation and diurnal temperature range. The dominant varieties (Caturra and Colombia) did not show major differences in quality attributes, and were pooled for the analyses with the environmental data. There are significant differences in biochemical and sensorial product characteristics between the two departments. The spatial patterns in product characteristics exhibit a non-random, regionally-changing structure that is related to those in the environmental data. The generated results provided ample evidence to support the application for regionally-based denominations of origin. Recommendations were derived to help mainstreaming the developed approach and thereby facilitate policy decisions for its use in other geographies and with other crops. Furthermore, the importance of systematic interdisciplinary institutional collaboration for large-scale denomination of origin projects was corroborated for food policy dialogue and decision making. It seems plausible that producers of high-quality products within other commodities are likely to follow the FNC in seeking denomination of origin for their goods. The presented approach is crucial to facilitate policy.

Introduction

The International Coffee Agreement, which had contributed to maintaining producers' prices for almost 40 years, collapsed in the early part of the 1990s. By the end of the decade, structural changes in the coffee-producing sector aggravated the prevailing boom – bust price fluctuations of the market and producers' prices fell to less than half those of 10 years before (Coggins, 1995). Coffee producers worldwide were confronted with their worst-ever crisis, with costs in many production systems higher than the prices that growers obtained for their coffee. Small-holder producers, such as those in Colombia, were particularly hard hit.

The market success of the international specialty coffee industry, including rapidly increasing numbers of small- to medium-sized roasters of high quality coffee beans and several chains of upmarket coffee houses, provides evidence that many coffee drinkers are becoming more discerning about beverage quality, and are prepared to pay for it (Pendergrast, 1999). Colombia produces a mild Arabica coffee that is widely sought by the cognoscenti, contrasting strongly with coffee from non-mild Arabica producers elsewhere. The Colombian Coffee Federation (FNC) is one of the few producers' associations worldwide that could execute a concerted strategy that would benefit its predominantly small-holder

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producers. Accordingly the FNC embarked on two activities, the Juan Valdez cafes as part of their marketing campaign, directed towards raising the awareness of consumers to Colombian coffee, and a scientific program to provide the basis for declaration of specific Colombian regional coffees for denomination of origin.

This paper reports investigations undertaken to support applications for denomination of origin, which would serve to place regional Colombian coffees in a position from which they would be difficult to dislodge – providing an example of how a producers' association may enter global markets that have been inaccessible to them previously. This is a deliberate policy initiative on the part of the FNC to place Colombian regional coffees formally in unique market positions. It is internationally relevant because this is the first time that the denomination of origin concept has been applied to coffee at the national and sub-national level. Moreover, it has the potential to improve the livelihoods of more than half a million (www.federaciondecafeteros.org) of small-holder coffee producers in the Colombia highlands.

International markets are increasingly signaling demand for differentiated products. The farming sector is looking to these differentiated products as higher value options to increase on farm-gate income. Niederhauser et al. (2008) define high value crops as crops that return higher gross margins per hectare and per unit labor input than traditional commodities. Some high value crops are difficult or expensive to produce. Examples include cashew and lulo, an Andean fruit, which are consistently high priced. Secondly, there are crops where the high value is obtained by differentiating the quality of the final product. The differentiation can be based both on perceptual differences and on actual, measurable product differences, such as inherent quality (Niederhauser et al., 2008). Porter (1986) identifies differentiation as one of four key marketing strategies. Labels of origin, including geographical indications (GI) and denominations of origin (DO), are examples for product differentiation based on inherent quality characteristics. There is growing consumer demand for these products (Marsden et al., 2000; Van der Ploeg and Renting, 2000). These concepts are particularly relevant for Colombian coffee, which is all mild washed Arabica. This coffee has gained a global reputation due to the environmental conditions, the quality control and the support systems that have been designed by the Colombian coffee growers. These ensure that Colombian coffee can reliably meet the quality requirements of consumers. The Andes Mountains, which cross the country from south to north, and thereby separate the Amazon basin from the Pacific and Atlantic coastlines, and create together with the impact of the oceans and the Amazon exceptional growing conditions and geographic patterns that permit to coffee harvest throughout the year in diverse and distinct growing environments. Colombia is therefore uniquely positioned for labels of origins that differentiate coffee regionally.

Labels of origin are usually state-granted product protection schemes. They hold the potential of re-linking particular products to the social, cultural and environmental aspects of particular places, distinguishing them from mass-produced goods (Barham, 2003). The European Union declared two kinds of protection for local foods and food products linked to a territory, namely the "Protected Geographical Indication" (PGI) and the "Protected Designation of Origin" (PDO) (European Commission, 2007). The PGI status applies to agricultural products or foods that originate in a region, specific place, or country, and that possess a specific quality, reputation or other characteristic of that geographical area. The PDO status is applied to products that originate in a specific region, place, or country, and have qualities or characteristics that are essentially or exclusively due to a particular geographical environment. For the PDO, the link between product and origin is essential, and the entire production process must take place in the defined geographical area, while it is sufficient that either production, or processing or preparation take place in the delimitated origin of a PGI. European regulations (EC) n. 510/2006 on the protection of Geographical Indication and Designation of Origin for agricultural products and foodstuffs, (EC) n. 1898/2006 laying down rules of implementation of 510/2006, and (EC) n. 628/2008 outlining detailed rules of implementation of (EC) n. 510/2006 stipulate the requirements that must be fulfilled in applications for labels of origins in the European Union. The applicant is requested to provide an explanation how the characteristics of the defined geographical area affect the final product, including a description of causal interactions. National legal frameworks differ between countries or country groups, but the concept that products have specific characteristics related to their geographical origin is common to most systems.

These modern day legal instruments are conceptually linked to the use of terroir in French wine production. The modern Appellation d'Origine Controlée (Name with a Controlled Origin, AOC) is built on the terroir concept and has been evolving in recent years along with EU recognition of labels of origin. Historically, terroir refers to an area or terrain, usually rather small, whose soil and microclimate impart distinctive qualities to wines produced there. A great deal of knowledge about the local terrain is needed for success, as well as respect for local natural conditions that can be expressed through the wine. This tie has been developed through decades of winemaking based on observation of what made wines from different regions or vineyards different from each other (Van Leeuwen and Seguin, 2006). A number of questions remain open. How to establish the tie between product and its area of origin where no long tradition exists, where the history is brief and our knowledge of growing environments is only evolving? Can evidence in lieu of documented long term observations be generated through short term acquisition and analyses of product, environmental and production system information? Lack of accurate natural resource information with high spatial and temporal resolution prevented the application of such analyses for large geographical regions. Recent advances in both the availability of environmental information and analytical methods have created new opportunities for researchers to emulate the traditional reporting of relationships between environment and product quality within shorter time frames. With new geospatial natural resource databases, particularly site-specific daily weather data for any place in the tropics as well as high-resolution terrain and topography models and geo-referenced product quality data, it is now possible to identify relationships between quality and site. Unfortunately, reliable soil information from field measurements at the required scale is still scarce.

Despite the advances in quantitative soil mapping techniques, most soil maps continue to be produced using conventional techniques (Cook et al., 2008). The usefulness for decision making of such maps is restricted (Oberthür et al., 1996). Terrain and its topography are paramount in natural-resource management for its influence on numerous physical processes associated with the distribution of soil properties, plant growth, vegetation structure, decomposition rates, biomass accumulation, and ecologic niche formation (Gessler et al., 1995, 2000). Topography has been used in our analyses as an easily measured surrogate for less easily measured soil variables. Research on coffee in Colombia was for many years focused on improving productivity of coffee, and quality was largely associated with bean size and the absence of blemishes (Cadena, 2005). Although varieties were tested for cupping quality little attention was paid to the effects of variation in growing conditions and management on cupping quality due to the FNC focus at the time on a uniform homogeneous high quality product. Furthermore, research traditionally tends to disaggregate the world into the effects of separate variables (Thompson and Scoones, 1994), while it is the dynamic, changing and often chaotic juxtaposition of variables that drives the relationships between environment and product quality (Läderach et al., 2009, 2011). As an alternative to traditional research approaches, Cock and Luna (1996), provided initial evidence on how commercial databases could be used to relate production and quality of sugarcane to specific site characteristics and management practices. A similar approach was used by Edwin and Masters (2005), to determine which cocoa varieties and management were the most appropriate for Ghanaian conditions. Spatial correlation analyses provide the analytical framework to implement this approach. Läderach et al. (2009, 2011) demonstrate how spatial patterns of coffee quality can be derived from an analysis of geographically-indexed data on coffee quality from farms and environmental data that are not only available at each farm location but also for the whole area under consideration. The factors that led to statistical patterns of likely association between environmental factors and product quality were uncovered to determine an odds-ratio that predicts product quality outcomes, given presumed causal environmental factors. The whole approach benefits from mining data, which is the process of knowledge discovery in databases.

The objective of research underlying this paper was to conceptualize and implement an approach for systematic spatial correlation analyses between environmental production factors and product quality information, so that specific production factors can be identified that link the territory under study and the characteristics of the product. The purpose of the paper is therefore to illustrate a repeatable methodology for large regions with environmentally contrasting conditions that is suitable to support the application process for labels of origin by generating in reasonable time and with sufficient integrity the evidence for causal relationships between product quality and environmental characteristics. The method was developed during the first phase of a national program to identify regional labels for the EU registered PGI "Café de Colombia", and is demonstrated with data from coffee growing regions of the Colombian departments of Cauca and Nariño. This paper introduces the conceptual approach, describes the sources of information, the field sampling method and the equipment, the applied analyses and results, and finally identifies in the discussion the embedding institutional requirements for such an approach and reviews the first phase to derive lessons and recommendations for the future.

Data and methods

Colombian coffee growing departments of Cauca and Nariño

The Cauca department has 29,308 km^2 with a population of 1,182,000 people (DANE, 2005). The department is located in south-western Colombia, with a lowland coastal region, two cordilleras of the Andes and a central inter-Andean valley where much of the coffee cultivation is concentrated. The economy of Cauca is mainly based on agricultural production, with the main crops being sugar cane, maize, beans and cassava. Marine fishing is semi-industrialist and extracts shrimp, prawn, sardine and tuna. In Cauca 68,000 ha are used for coffee production. There are over 85,000 coffee farmers, of which 97.4% of them have less than 3 ha of farm land. The Nariño department in southwestern Colombia borders to the north with Cauca and with Ecuador located on its southern border. Its population of about 1,579,000 people is concentrated principally in the volcanic Andean highlands above 1500 m. The department covers about 30,000 km^2, and the economy is based almost exclusively on agriculture. Besides coffee, which is grown on 27,600 ha, wheat, sugarcane, beans, cocoa, plantain and potatoes dominate the agricultural production, and bananas are cultivated in the Pacific lowlands. There are more than 33,000 coffee farmers, with about 96% of them having less than 3 ha of farm area. Small-scale farms (<5 ha) and especially micro-scale farms (<1 ha) are highly dependent on incomes from coffee cultivation. Small-scale farms use 84% of their area for coffee production. Approximately 50% of small-scale farmers have no other income apart from coffee revenues (García, 2003). García (2003) simulated the heterogeneity of different types of small-scale farmers: those with more than 3.8 ha can increase productivity to cover family expenditures and labor costs, micro-scale farms (<0.5 hectares) are not able to generate coffee revenues that will cover costs. These latter households need additional revenues from other activities. Small-scale farms with an average of 1.8 ha can improve productivity mainly by using unpaid family labor.

Environmental information

Terrain attributes such as elevation, aspect and slope in the areas of those departments were generated and mapped with 90 m resolution from the digital elevation model (DEM) of the shuttle radar topography mission (SRTM) made available through the CSI-CGIAR at http://srtm.csi.cgiar.org (Jarvis et al., 2008). Climate information was generated using WorldClim and MarkSim data. WorldClim (Hijmans et al., 2005) is a global database of climate variables in grid format. The data layers were generated on 1 km^2 resolution through interpolation of average monthly climate data from 15,000 to 47,000 weather stations during the years 1950–2000. Variables extracted from WorldClim included monthly total precipitation, and monthly mean, minimum, and maximum temperature. Annual average precipitation, annual average temperature, and dry month per year were generated from these. The distribution of the annual precipitation is important. Recommended are adequate rainfall during berry development, and a dry season of about 3 months towards the harvest period to obtain best quality beans (Wintgens, 2004). Dry months were defined as months with less than 90 mm of precipitation. Annual average diurnal temperature range was also calculated from WorldClim. As relative humidity varies diurnally and also between seasons, dew point was mapped. Dew point is the temperature at which air becomes saturated and produces dew and is a direct measure of the absolute amount of water vapor in the air. Dew point maps were calculated using the method of Linacre (Linacre, 1977). Rain days per year can be estimated by Marksim using the WorldClim data as input for each cell. MarkSim uses a third-order Markov function to generate rainfall data (Jones and Thornton, 2000).

Coffee sampling

Model- or design-based approaches (e.g. Brus and De Gruijter, 1997), were difficult to use to generate the field data as operational constraints (length of the harvest, field travel times, accessibility of farms) prevented their implementation. We used a purposive non-probability approach with proportional quota sampling to ensure that the most representative groups in the population could be assessed. The difference between non-probability and probability sampling is that non-probability sampling does not involve a complete random selection. That does not mean that non-probability samples are not representative of the population, but it implies that one cannot depend on the rationale of probability theory, and has to find other ways to show that one sampled the population adequately.

The consultation process with the regional offices of the coffee growers' federation concluded that up to 400 farms could be sampled in the Cauca/Nariño region given the length of the harvest and the accessibility of farms. Prior knowledge generated by similar work in the departments of Cauca, Huila and Nariño (Läderach et al., 2006), was used to identify the specific environmental characteristics on which to base the sampling quota. Key environmental factors linked to coffee beverage characteristics including altitude of the growing area, diurnal temperature range, annual average temperature, dew point, and annual average precipitation were considered. Some of these characteristics are obviously highly correlated. Altitude and diurnal temperature range are less correlated in the target region, and were used to allocate samples. Combinations of altitude and diurnal temperature range were identified, and the two departments were stratified accordingly in 10 and 12 different sampling domains for Cauca and Nariño Departments, respectively. Stratification was only implemented in regions that were identified as coffee growing zones. The target was to sample about 15 farms per unit in Cauca and 10 farms per unit in Nariño. The actual farm identification was based on production system files held by the FNC and its Departmental Coffee Growers' Committees. The FNC has implemented a national coffee sector information system (SICA, Sistema de Información Cafetera), which identifies coffee growing regions at the farm level, including production system characteristics.

Field extension agents visited all farms before sampling to stimulate social interactions with producers, to explain sampling routines and to elucidate complementary information. If farms were not representative of the dominat cropping system within the sampled strata, no longer cultivating coffee or simply not accessible then the nearest available farms were sampled (Table 1). Information on farmers' agronomic and post-harvest management was captured using a questionnaire.

Sample processing

All sample sites were identified by the latitude, longitude, and elevation in the center of each sampled coffee field using a Trimble ProXR global positioning system (GPS) device with OmniSTAR real-time correction. Samples were taken during the harvest season by the field team. Samples were delivered to a mobile post-harvest processing unit stationed at a site central to a number of farms immediately after harvesting for wet processing and drying. Damaged, green and infected berries, stones, leaves and other artifacts were removed before de-pulping and removal of mucilage in a specially modified J.M. Estrada Model 100 unit. The samples were fermented separately for 5 h in buckets, and then dried in a metal closet with four floors of drawers, each of which perforated on the bottom. The drier was fitted onto the mobile processing unit. Air was heated to 40 °C with gas and blown into the bottom of the closet. The dryer has the capacity to process 24 samples of 1–1.5 kg at the same time and emulates the process of industrial dryers. Samples were dried until they reached a humidity of 10–12%. The dried samples were stored at 18° C until the cupping process.

Table 1
Sampling units in the coffee growing areas of Cauca and Nariño, their classification criteria, and number of analyzed samples (total n_{Cauca} = 135, total $n_{Nariño}$ = 155). Only a part of the unit area grows coffee. More samples were taken but not included in the analyses due to bean damage or because they were not Caturra or Colombia varieties.

	Sampling unit code, area in (ha)	Diurnal temperature range in (°C)	Altitude in (m)	Number of analyzed samples
Cauca department				
1	61,224	1	1	8
2	36,549	1	2	15
3	34,788	2	2	9
4	41,658	2	3	20
5	82,203	3	3	24
6	79,314	3	2	14
7	114,879	3	1	6
8	38,576	1	4	17
9	44,219	1	3	22
Nariño department				
1	16,474	1	4	15
2	11,908	1	3	7
3	8195	1	2	6
4	8256	2	4	13
5	9567	2	1	14
6	14,600	3	1	2
7	7267	3	2	15
8	10,239	3	3	22
9	9035	4	1	13
10	7373	4	2	15
11	6738	1	1	9
12	16,172	3	4	24

Physical product quality analyses

The parchment beans were milled and the percentage and weight of bean and husks determined. The density of the beans was calculated after humidity was measured. Thereafter beans with primary and secondary defects were quantified, and their weight and percentage recorded. Any beans with defects were then removed by hand. The defect-free beans were sieved and the bean size distribution determined using standard sieves from 14/64 inch to 18/64 inch.

Biochemical analyses

Biochemical analyses of green bean samples were performed by near infrared spectroscopy (NIRS). NIR reflectance spectra were collected using a scanning monochromator NIR systems spectrophotometer (model 6500, Perstrop Analytical Inc., 1201 Tech Road, Silver Spring, MD 20904, USA) driven by ISISCAN v.2.71 and the mathematical processing by WINISI III (v.1.50e) software (Intrasoft Intl., LLC, RD109, Sellers Lane, Port Matilda, PA 16870, USA). The analyses were performed on green coffee (3 g) after grinding to pass a 1.0 mm sieve. For each sample, a NIR spectrum was acquired in reflectance (R) mode (Downey and Boussion, 1996). The prediction values (in percent of dry matter) for caffeine, trigoneline, and chlorogenic acid were done using the calibration equations developed from laboratory reference data by the coffee research center CENICAFE of the FNC.

Sensory analyses

Samples of 250 g of beans were roasted in a laboratory roaster the day before the beverage assessment. All samples were roasted for 11 min with an initial temperature of 200 °C to a standard reddish-yellow color. Roasted beans were ground to the recommended intermediate particle size immediately before the beverage quality assessment. Sensory beverage quality assessment was done by cupping of the coffee liquid prepared for each sample: water (150 ml at 97 °C) was poured on 10 g of ground coffee in each of five cups. The sensory attributes evaluated were fragrance, aroma, acidity, aftertaste, body, flavor, sweetness, preference and final score. The attributes were rated on a scale of 1–10 with 0.5 point increments, using the cupping protocol of the Specialty Coffee Association of America (Lingle, 2001). The samples were assessed by a panel of five professional cuppers, and their consistency was evaluated using discriminant function analyses.

Summary statistics

Summary and Bonferoni statistics were computed for all the data. Multivariate statistics, including cluster analyses, principle component analyses, and discriminant analysis were applied. Hair et al., 1992, provide general information about these techniques. All the environmental data and the biochemical and physical information on product quality used in this study were measured on an interval or ratio scale. Information of sensorial quality was measured on a quasi-interval scale. Such data have been commonly used in similar studies (Decazy et al., 2003; Avelino et al., 2005; Vaast et al., 2006).

Spatial Bayesian probability analyses

Various modeling approaches exist to identify suitable niches for specific crops, and one such approach has been used to create a spatial decision support system (SDSS). The tool, crop niche selection in tropical agriculture (CaNaSTA) (Whitsed et al., 2010), was initially developed based on the well known Expector methods, to identify niches of forage species to smallholder farm in the tropics (Corner et al., 2002). The engine used to develop CaNaSTA is Bayesian probability modeling to define prior and conditional probability distributions and to combine these to calculate posterior probabilities for each possible outcome. The CaNaSTA algorithm creates conditional probability tables of all predictor variables against response variable categories. In the case of coffee, predictor variables included climate and topographic factors and the response variables were sensorial, physical or biochemical coffee quality characteristics (Läderach et al., 2009). The primary model output is a discrete probability distribution at each location. The probability distribution consists of the probability that the response variable is in each potential state. This information can be used to create maps showing the most likely response value ('Most likely'). The values in the probability distribution can also be weighted to produce a suitability value ('Score'). Finally, a certainty value can be displayed as a map ('Certainty'), derived from the number of occurrences in the data with a particular combination of predictors and responses, and can assist in the interpretation of the results. Once locations have been identified where a particular response is likely, further analysis can be carried out to determine which predictor variables are important. These driving factors can be either positive or negative, and can help with the analysis of specific conditions required for specialty coffee. Analysis of driving factors attempts to identify the variable classes that disproportionately contribute to high values in the probability surface (positive driving factors) and low values in the probability surface (negative driving factors).

Results

Differences in the growing environments

All environmental variables, apart from altitude, aspect and dew point are significantly different (at $p < 0.05$, Bonferoni test) between Cauca and Nariño. Although differences in altitude were not statistically significant, it is noteworthy that the Nariño sites have a much wider range of altitudes (Table 2, Fig. 1). Wider ranges in both altitude and dew point in Nariño show that they are more heterogeneous than those in Cauca. Cauca has a defined but short dry period, in contrast with Nariño, which has seasonal climate with a pronounced dry period. Moreover, and associated with the longer dry season, rainfall in general is substantially lower in Nariño than in Cauca. The altitude map (Fig. 2) shows that the altitudinal ranges are roughly similar in both regions but the patterns of spatial distribution are very different. In Cauca there are extensive contiguous regions of similar altitude. In contrast, in Nariño altitude varies greatly over short distances. It is important to note that there are regions of lower altitude in the Western Cordillera just south of the border between Cauca and Nariño Departments that open up a corridor to the southwest between the coffee growing regions and the Pacific. The distribution of dry months between Cauca and Nariño demonstrates strong spatial patterns and a clear difference between the two regions. However they also confirm that the Bolívar district of Cauca has a stronger affinity for Nariño than for the other coffee producing areas in Cauca. It also demonstrates that the Inza district on the eastern side of the Central Cordillera is highly variable.

Table 2
Environmental differences between the coffee growing areas of Cauca and Nariño Departments as measured at the sampling sites.

Variable	Mean	Min[1]	Low Q[2]	Med[3]	Up Q[4]	Max[5]
Cauca						
Altitude (masl)	1758	1373	1645	1781	1871	2088
Slope (°)	12	1	5	11	18	34
Aspect (°)	177	1	78	185	279	359
Rainfall (mm per year)	2069	1580	1793	2170	2261	2575
Dry months per year	2	0	1	2	2	4
Diur. temp. range[6] (°C)	10.8	9.5	10.5	11.0	11.3	11.4
Dew point (°C)	12.5	11.0	11.9	12.3	13.3	15.0
Mean temperature (°C)	18.5	16.8	17.8	18.2	19.3	21.6
Solar rad.[7] (MJ m^{-2} d^{-1})	24.4	19.0	24.0	25.0	25.0	25.0
Nariño						
Altitude (masl)	1748	1222	1520	1750	1961	2235
Slope (degrees)	15	2	9	14	19	35
Aspect (degrees)	196	3	102	202	293	355
Rainfall (mm per year)	1612	1330	1523	1611	1684	2232
Dry months per year	3	0	3	4	4	4
Diur. temp. range[6] (°C)	9.9	9.3	9.7	10.0	10.2	10.5
Dew point (°C)	12.6	5.6	11.7	12.8	13.9	17.9
Mean temperature (°C)	18.1	10.6	17.2	18.3	19.4	23.2
Solar rad.[7] (MJ m^{-2} d^{-1})	24.2	20.0	24.0	24.0	25.0	25.0

1 – minimum, 2 – lower quartile, 3 – median, 4 – upper quartile, 5 – maximum, 6 – diurnal temperature range, 7 – solar radiation.

Cluster analysis was used to derive clusters that provided coherent grouping for each region (Fig. 2). Sites in the Bolívar district of southern Cauca are environmentally more similar to Nariño than to the other sites in Cauca and were therefore included with the Nariño data for the clustering exercise. Clustering was spatially more consistent in Cauca than in Nariño (apart from cluster 1), with the clustering clouds in Cauca showing little variation between the component sites of each cluster. Nevertheless, groupings do emerge also for Nariño. The points from the Bolívar district of southern Cauca fall in cluster 2. Cluster descriptions are provided in Table 3.

Differences in coffee quality characteristics between the two departments

Discriminant analysis was carried out to test the consistency of the cuppers with original data and standardized cupping data, both of which gave the same results. In the ideal case, applying for example the discriminant function derived for cupper 4 to the data would classify all predicted samples as cupped by cupper 4. Lower numbers of correctly classified samples result in lower percentages of cupping accuracy and are an indicator for low cupping consistency by the respective cupper. Only 33–61% of the samples were correctly scored. Only one cupper demonstrated acceptable cupping consistency and therefore all subsequent analyses were done on scores of this cupper.

Secondly, varietal differences were screened (Table 4). The data consisted of 108 samples of the variety Caturra and 27 samples of the variety Colombia in Cauca. In Nariño, Caturra was represented by 106 samples, and Colombia by 49 samples. In Cauca, there were no significant differences ($p < 0.05$, multivariate Bonferoni test) for bean size between varieties, although the Caturra variety had smaller beans (sieve sizes 17 and less) than the Colombia variety. Colombia has more beans in the sieve size 18, and moreover its size distribution tends to be more homogenous. In Nariño, there were no significant differences ($p < 0.05$). Unlike Cauca there were no

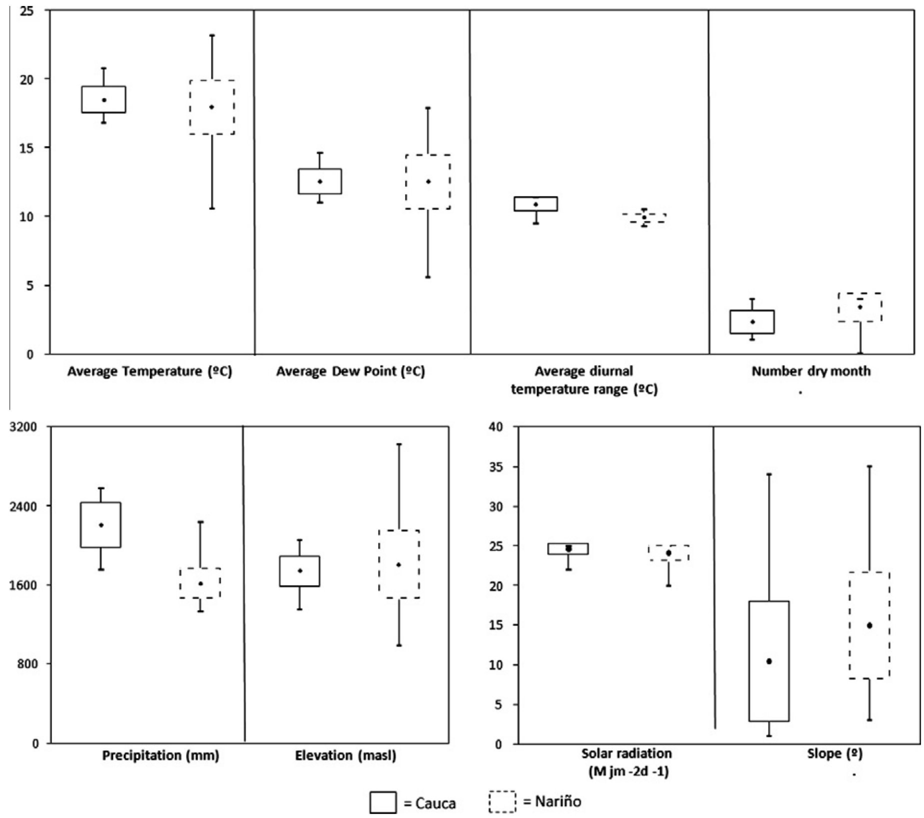

Fig. 1. Environmental differences between origins. All environmental variables, apart from altitude, aspect and dew point are significantly different (at $p < 0.05$, Bonferoni Test) between Cauca and Nariño.

clear trends, although the size values did not differ very much from those in Cauca. Also for biochemical characteristics, there were no significant differences ($p < 0.05$) in Cauca between the varieties. Caffeine ranged from 1.03% to 1.49%, trigonelline from 0.69% to 1.17%, and chlorogenic acids from 4.67% to 6.88%. Ranges for the Colombia variety tended to be smaller than for the Caturra variety. Values for caffeine and trigonelline were somewhat higher in Cauca than in Nariño, while chlorogenic acids were somewhat lower. Although the differences were small in Nariño for biochemical characteristics, the Colombia variety had significantly more caffeine ($p < 0.05$) than the Caturra variety. Caffeine ranged from 0.94% to 1.45%, trigonelline from 0.61% to 1.02%, chlorogenic acids from 4.68% to 7.60 %. Ranges for both varieties were similar. Percentages of caffeine and trigonelline were lower and of chlorogenic acids higher than in Cauca. Once again, there were no significant sensory differences for Cauca between varieties. The Colombia variety tended to have higher mean values for quality characteristics than the Caturra variety, however Caturra again had wider ranges and for this reason had individual samples that had higher scores in sensory characteristics than the best Colombia samples. As in Cauca, there were no statistically significant sensory differences between varieties (Bonferoni $p < 0.05$). The Colombia variety also tends to have higher mean scores than the Caturra variety, however Caturra once more has wider ranges and thereby has individual samples that are better than the best Colombia samples. The differences between the best samples of Colombia and the best samples of Caturra tend to be even higher in Nariño than in Cauca.

In Cauca, both varieties are grown in very similar production environments (Table 4). Altitudes ranged from 1370 m to almost 2100 m, average annual temperatures (largely reflecting altitude) from almost 22 °C to as low as 16.8 °C with the mean diurnal range varying from about 9.5 to 11.5 °C. Rainfall varied from 1600 mm to as much as 2600 mm, with an average of two dry months each year. Unlike in Cauca, the production environments for the two varieties are very different in Nariño (Table 5). The Bonferoni test shows that altitude, aspect, precipitation, diurnal temperature range, dew point and temperature are all significantly different ($p < 0.05$). The coffee rust resistant Colombia variety is grown in environments with lower altitudes, less slope and higher temperatures all of which favor higher volume production. In contrast, the Caturra variety is grown at higher altitudes, steeper slopes and lower temperatures, where rust is less prevalent. The small differences in biochemical properties between the varieties in Nariño are likely due to the different growing environments and not due to varietal differences. It was therefore concluded that both varieties are actually very similar in their performance. The following spatial analyses are conducted jointly for both varieties.

Spatial distribution patterns of product quality as reflection of environmental differences

To illustrate how environmental factors have specific influences on product quality the spatial patterns in these relationships are explored using Bayesian spatial probability analyses, with the two important characteristics of acidity and flavor as examples. The analyses are conducted for each region individually to calculate maps of the spatial distribution of the product quality characteristics. Then, environmental characteristics that enhance the product quality characteristics are identified. Fig. 3 shows the probability that beans produced in Cauca and Nariño have high flavor and high acidity content. Important in the context of these analyses is the fact that Cauca has consistently different probability values than Nariño. This represents the regionalization of the results from the point based statistics. The maps in Fig. 3 show

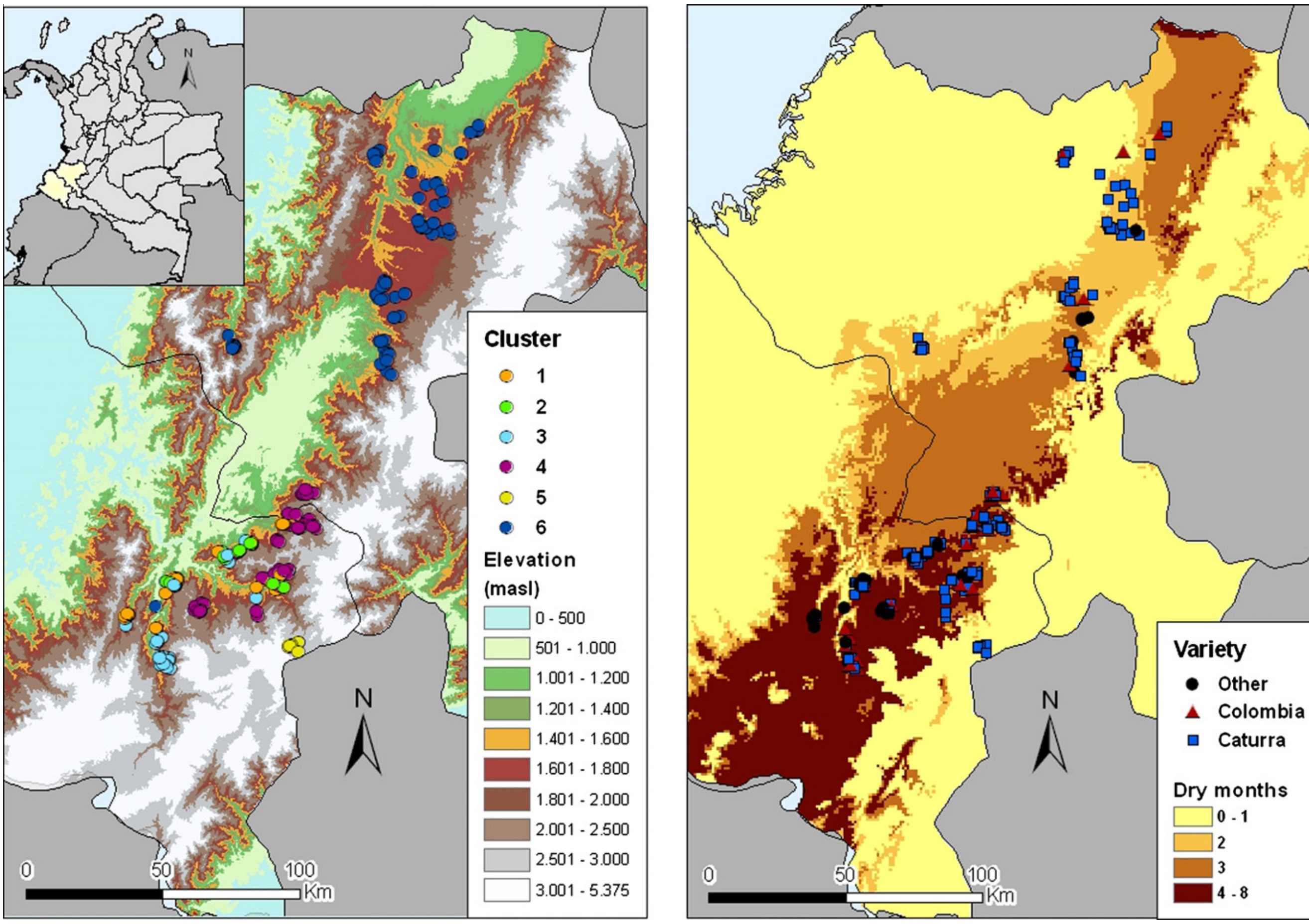

Fig. 2. Spatial differences in growing conditions. A cluster analysis of the environmental factors at the samples sites overlaid on a relief map (right map) and the spatial distribution of the sampled varieties overlaid on a dry month map (left map). Location of the departments of Cauca and Nariño (small map).

Table 3
Selected, differentiating factors between the environmental clusters in coffee growing areas of Cauca and Nariño, and in brackets their median values. Median values are given in masl for altitude, in mm for rainfall, in degrees for slope and aspect, in degrees Celsius for dew point, and as the number of dry months for seasonality.

Cluster	Cauca*	Nariño*
1	Mid altitude (1774), low rainfall (1646), steep slopes (18), moderate dew point (12.5), little seasonality (1)	High altitude (2041), low rainfall (1480), low dew point (11.7), strong seasonality (3.9), slope aspect (130)
2	Mid altitude (1734), mid rainfall (2191), low slopes (8), moderate dew point (12.5), moderately seasonal (2.2)	High altitude (1957), moderate rainfall (1732), low dew point (11.7), strongly seasonal (3.6), slope aspect (200)
3	High altitude (1980), high rainfall (2560), moderate slopes (14), low dew point (11.7), little seasonality (1.1)	Mid altitude (1727), low rainfall (1557), moderate dew point (13.1), strong seasonality (3.7), slope aspect (180)
4	Low altitude (1521), high rainfall (2463), steep slopes (19), high dew point (14), moderate seasonality (2.1)	Low altitudes (1475), moderate rainfall (1648), moderate dew point (14.4), moderate seasonality (2.9), slope aspects (250)

the homogenous nature of the probability distribution for acidity and flavor in Cauca except for regions in higher altitudes and regions in the Inza district and on the Pacific side of the cordillera. The maps highlight the fact that in the Nariño region the environmental characteristics change over short distances.

Table 6 lists those environmental factors that enhance the product quality characteristics. Annual precipitation, dew point and altitude are important in Cauca for acidity, and dew point, daily mean temperature and altitude for flavor development. In Nariño, average diurnal temperature range, dry months, slope degrees, and annual precipitation are key factors for acidity, while annual precipitation, slope degrees and dry months are critical for flavor development. In the interpretation of these values it becomes apparent that different ranges of environmental characteristics have different impacts and different environmental characteristics influence different product quality characteristics. This probably implies that product qualities are enhanced by a set of different environmental characteristics that can partly compensate one another. Finally, while it can be noted that different environmental characteristics have different impacts in the two regions on product quality, it also illustrates the site specific causal nature between product and environmental characteristics.

Discussion

The regional differences in environmental and product quality characteristics between the coffee growing areas in the two Colombian regions of Cauca and Nariño, as redefined, were generally significant in statistical terms. Considering the magnitude of the differences in sensorial characteristics, they are also important in

Table 4
Mean and median (med) values for selected product quality characteristics of the Colombia and Caturra varieties in the coffee growing areas of Cauca and Nariño (Cauca $n_{Colombia}$ = 108, $n_{Caturra}$ = 27; Nariño $n_{Colombia}$ = 106, $n_{Caturra}$ = 49).

	Cauca				Nariño			
	Caturra		Colombia		Caturra		Colombia	
Variable	Mean	Med	Mean	Med	Mean	Med	Mean	Med
Screen size 12[a]	0.7	0.3	0.3	0.2	0.4	0.3	0.4	0.3
Screen size 18[a]	61.1	55.7	75.0	64.0	64.7	61.1	64.2	62.5
Screen size 17 + 18[a]	132.2	138.9	139.6	141.3	137.3	138.0	135.4	140.8
Caffein[b]	1.27	1.27	1.30	1.32	1.15	1.15	1.19	1.18
Trigonelline[b]	0.92	0.93	0.92	0.92	0.78	0.78	0.75	0.75
Chlorogenic acid[b]	6.05	6.06	6.05	6.09	6.01	6.02	6.02	6.02
Fragrance/aroma[c]	6.5	7.0	6.4	6.5	5.7	6.0	5.7	6.0
Flavor[c]	5.8	6.0	6.1	6.0	5.4	5.5	5.6	6.0
Aftertaste[c]	5.8	6.0	6.1	6.0	5.4	5.5	5.5	6.0
Acidity[c]	5.9	6.0	6.2	6.5	5.4	5.5	5.7	6.0
Body[c]	5.9	6.0	6.2	6.0	5.4	5.0	5.7	6.0
Sweetness[c]	5.6	6.0	5.7	5.5	5.1	5.0	5.2	5.0

[a] in gram.
[b] in percent of dry matter.
[c] on a scale from 0 to 10 with 0.5 increments.

commercial terms. These differences of the environmental and product quality characteristics are not random but have a clearly expressed spatial structure. Moreover, the spatial structures in the data of both the environmental and the product quality characteristics are correlated.

The introduced method thereby provided the evidence to support a denomination of origin process. The development of the approach provided ample opportunity to identify several aspects during this phase that can be improved for the upcoming stages in other coffee producing regions of Colombia, and for similar work on different crops and / or elsewhere in the world. It is important for producing countries to understand the institutional requirements in order to firmly ground the research component within the institutional grower support network. Riveros et al., 2008, reporting on several denomination of origin case studies in Latin America, revealed that most of these generate at least partial evidence for relationships between environment and product but rarely advance beyond this stage. Time requirements to implement a large-scale approach for denominations of origin, and the capacity to successfully manage institutional multi stakeholder processes is often underestimated.

In the following sub-sections we address pertinent questions of institutional, operational as well as administrative requirements for the implementation of the proposed approach.

Institutional requirements to enable the collective multi stakeholder approach

The recognition of a protected appellation is usually based on a legislative act, which concludes an administrative procedure involving representatives of the producers concerned and the administration (Höpperger, 2007). The declaration of an assembly of a producers' association expressing a producers' decision to apply for an appellation commences this process. A code of practices has to be elaborated by the actors belonging to the production system seeking protection (Galtier et al., 2008), and importantly, a collective negotiation process has to take place to communicate the benefits that arise from the relationship between a product and its production environment in its precisely delimitated boundaries. In this project, the FNC coordinated the application process for its growers (Gallego Gómez, 2008). Colombia's coffee growers have a long history of developing strategies to protect and promote their coffee (World Intellectual Property Organization, 2007). The FNC has a democratic hierarchy based on 356 Municipal Committees elected at the community level, which in turn elect 15 Departmental Coffee Growers' Committees, which elect a National Coffee Congress (Bentley and Baker, 2000). For the described approach the FNC can count on an institutional network that includes the ALMACAFE S.A laboratories and dry mills, as well as 38 cooperatives which have close to 500 buying stations nationally, a national extension service and the prestigious research institution CENICAFE, Centro Nacional de Investigaciones del Café (Gallego Gómez, 2008).

Operational requirements to implement the collective multi stakeholder approach

The developed approach is grounded in a process that started in December 2004, when the FNC presented the Colombian government (Superintendencia de Industria y Comercio, División de Signos Distintivos) with an application to recognize Colombian coffee growing areas and "Café de Colombia" as a Denomination of Origin in Colombia. In February 2005, the Colombian government granted the recognition of "Café de Colombia" as a "Denomination of Origin". In 2005, "Café de Colombia" became the first product from a non-EU nation that applied for recognition as Protected Geographical Indication in the EU, and from October 2007 onwards "Café de Colombia" has had legal protection in all European Union member states (European Database of Origin and Registration DOOR dossier number CO/PGI/0005/0467). The application was prepared by a team including the international advisor to the FNC executive management, the technical FNC management and the directorate of intellectual property, the legal department, and CENICAFE, under the direct leadership of the FNC's CEO. The process was approved in the National Coffee Congress, by the National Coffee Committee and by the FNC Board of Directors, and was then widely socialized through the FNC communication channels, creating the basis and necessary foundation for the described regional DO extension. During the registration process of "Café de Colombia", the concepts and ideas were socialized with FNC's Departmental Coffee Growers' Committees and subsequently communicated to producers. For the regional extension, FNC management consolidated in two workshops in 2005 an extended, international interdisciplinary team with intellectual property professionals, environmental, agronomic and social scientists, coffee quality expertise and marketing representatives. This phase was introduced in 2005 and 2006 to the directors, technical managers and the extension service coordinators of the Departmental Coffee

Table 5
Environmental differences between growing environments of Caturra and Colombia varieties in the coffee growing areas of Cauca and Nariño Departments (Cauca $n_{Colombia}$ = 108, $n_{Caturra}$ = 27; Nariño $n_{Colombia}$ = 106, $n_{Caturra}$ = 49).

Cauca	Caturra						Colombia					
Variable	Mean	Min[1]	LQ[2]	Med[3]	UQ[4]	Max[5]	Mean	Min[1]	LQ[2]	Med[3]	UQ[4]	Max[5]
Altitude (masl)	1750	1373	1630	1774	1870	2088	1759	1384	1638	1791	1869	2047
Slope (°)	13	1	5	11	19	34	12	3	7	10	15	33
Aspect (°)	179	3	90	189	274	359	192	1	79	158	304	358
Rainfall (m per year)	2064	1580	1723	2168	2261	2575	2088	1598	1801	2174	2299	2569
Dry months per year	2	0	1	2	2	4	2	0	2	2	3	4
Diur. temp. range[6] (°C)	10.8	9.7	10.5	11.0	11.3	11.4	10.7	9.5	10.4	10.7	11.2	11.3
Dew point (°C)	12.6	11.0	12.0	12.4	13.4	15.0	12.6	11.0	12.0	12.3	13.4	14.6
Mean temperature (°C)	18.5	16.8	17.9	18.3	19.3	21.6	18.5	16.8	17.8	18.4	19.5	20.7
Solar rad.[7] (MJ m^{-2} d^{-1})	24	19	24	25	25	25	25	22	24	25	25	25

Environmental differences between growing environments of Caturra and Colombia varieties in Cauca and Nariño Departments (Cauca $n_{Colombia}$ = 108, $n_{Caturra}$ = 27; Nariño $n_{Colombia}$ = 106, $n_{Caturra}$ = 49).

Nariño												
Altitude (masl)	1814	1385	1666	1826	1987	2168	1629	1408	1491	1573	1712	2091
Slope (°)	16	3	10	16	21	35	14	9	8	13	21	29
Aspect (°)	206	2	112	238	308	355	196	3	106	201	282	346
Rainfall (mm per year)	1635	1331	1561	1628	1717	2025	1569	1330	1524	1616	1631	1755
Dry months per year	3	0	3	4	4	4	3	2	3	3	4	4
Diur. temp. range[6] (°C)	10.0	9.3	9.8	10.0	10.1	10.5	10.1	9.6	9.9	10.2	10.3	10.5
Dew point (°C)	12.1	5.6	11.5	12.3	13.2	15.7	13.2	11.0	12.4	13.4	13.9	14.6
Mean temperature (°C)	17.6	10.6	17.0	17.9	18.7	21.3	18.8	16.3	17.9	19.1	19.6	20.4
Solar rad.[7] (MJ m^{-2} d^{-1})	24	20	23	24	25	25	24	22	24	25	25	25

1 – minimum, 2 – lower quartile, 3 – median, 4 – upper quartile, 5 – maximum, 6 – diurnal temperature range, 7 – solar radiation.

Growers' Committees. The internal departmental communication of concepts and project implementation plans was conducted by the extension service coordinator. Field work commenced in 2006 with meetings of the field team and local FNC extension agents. Field work and data interpretation required environmental scientists for data modeling and analyses, experienced agronomists to interpret the results within the context of the relevant coffee production systems, as well facilitators to support the implementation. Adequate financial resources had to be procured for the required human resources as well as for the logistics of the field operations. Progress report meetings were held throughout the year, results were communicated to the Departmental Coffee Growers' Committees when they became available and a final report was submitted at the end of 2006 in a special meeting of the FNC management team. The insights from extensive research of various years by Colombian and international research organizations into the relationships between environment and coffee quality that preceded this project were indispensible feasibility studies for the success of this program.

Reconciling environmental and administrative boundaries

The organizational structure of the FNC follows largely that of the political department boundaries in Colombia. The proposed delimitations for regional denominations of origin for coffee follow environmental processes that underlie coffee quality, and therefore are not always identical with administrative boundaries. The results indicate that the two environmental domains do not fit perfectly with the Department boundaries, with for example Bolivar region in Cauca belonging more closely to the Nariño domain. During 2007 and 2008 a process was initiated to come to an arrangement about inclusions/exclusions of certain geographic coffee growing areas from one department into the other. Separate discussions took place between the FNC directorate of intellectual property, and each executive board of the Departmental Coffee Growers' Committees of Cauca and Nariño. The locally elected coffee growers subsequently convened internal meetings to decide whether (a) not to continue the regional denomination of origin process, to (b) continue and adjust the denominations to political boundaries, or (c) to accept the implications that arise from denominations that account for environmental processes. Both departments accepted the latter option, and finalized agreements in a joint meeting at FNC headquarters.

Quantifying local and seasonal variability in product quality

The presented approach builds on climate and topography information as the main predictors for regional coffee quality (Läderach et al., 2009). Topography is a strong predictor for soils information, and the understanding that soil patterns and topography are closely correlated at the scale required for this work enables the representation of soil attributes through landscape positions (Conacher and Dalrymple, 1997; Moore et al., 1991; McKenzie and Ryan, 1999; White et al., 2000). Local land and soil management can, however, have an influence on factors affecting agricultural productivity (Pauli et al., 2009; Yamamoto et al., 2009), and likely also on coffee quality (Bosselmann et al., 2009) It is important to note that this variability in quality does not prevent the implementation of denominations of origin, as it is expected that quality will locally deviate somewhat from the regional quality profile. It was impossible to quantify this impact in this short-term study as the sampling scale has to coincide with the intrinsic scale of the process structure. Changing the spatial scale of analyses results in new interactions and relationships as changes in the organization of the studied phenomena are encountered (Nelson et al., 2007). For this reason, a repeat sampling of coffee and monitoring of soils and climate on a well-selected sub-set of farms was designed to quantify the magnitude of the short range variability in coffee quality introduced by soil fertility management and to define the climatic representativeness of a particular growing season.

Conclusions

We have demonstrated that Colombian regional coffees are indeed unique with characteristics that can be readily identifiable and justify the classification of denominations of origin. The imple-

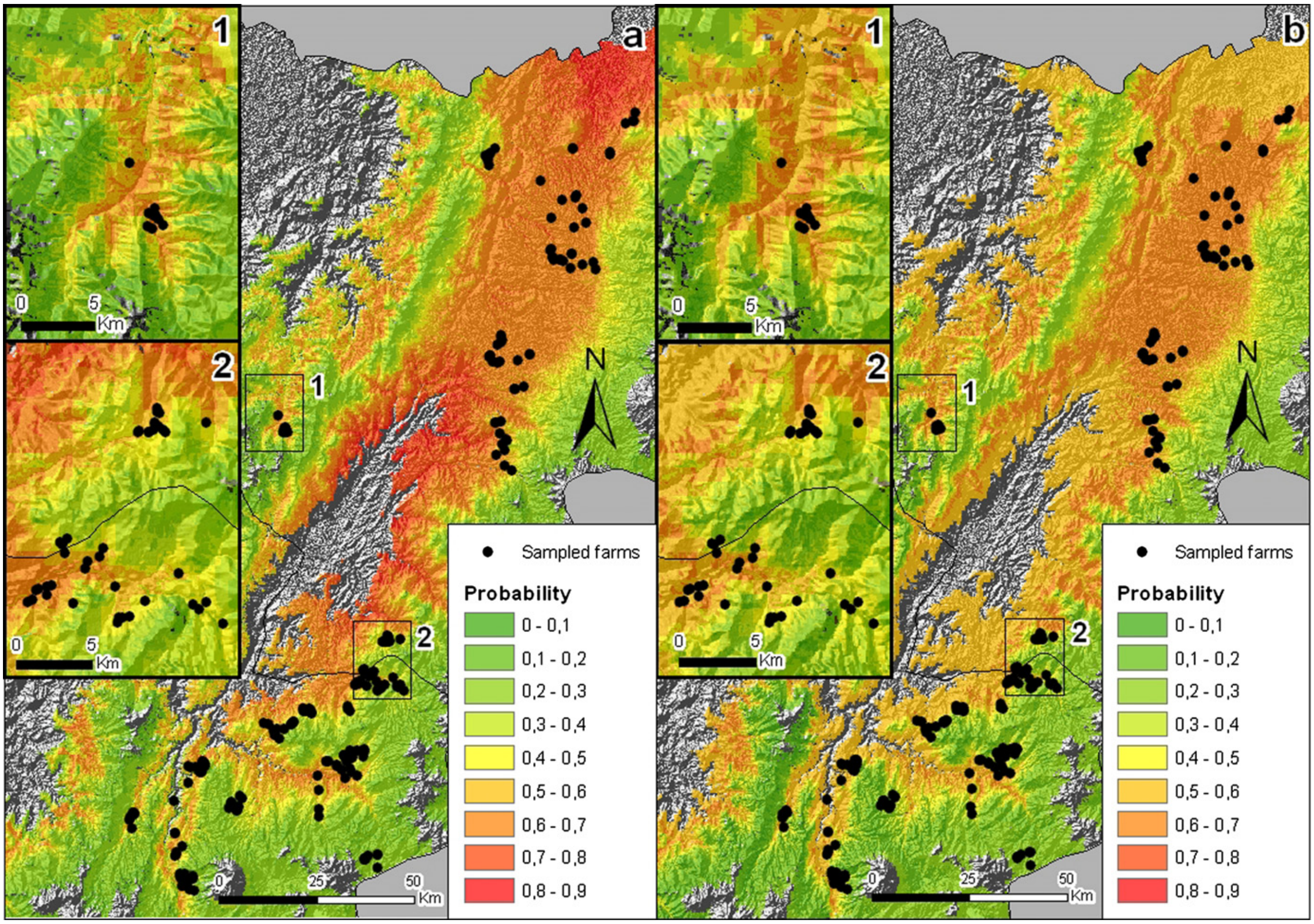

Fig. 3. Identification of high quality niches. Probability of the beans produced in Cauca and Nariño to have high acidity (left map) and high flavor (right map) content.

Table 6
The environmental factors, and their ranges, that enhance product quality (flavor, acidity): higher factor importance values imply increased importance.

Variable	Factor range	Factor importance
Factors that enhance acidity in Cauca		
Average annual precipitation (mm)	1746–1912	3.56
Average daily dew point (°C)	12.3–13.0	2.56
Altitude (masl)	1611–1730	2.47
Altitude (masl)	1731–1849	2.45
Average annual precipitation (mm)	2077–2243	2.42
Factors that enhance flavor in Cauca		
Average daily dew point (°C)	11.0–11.6	2.89
Altitude (masl)	1730–1849	2.83
Average daily dew point (°C)	11.6–12.3	2.72
Average diurnal temperature range (°C)	16.8–17.6	2.68
Altitude (masl)	1611–1730	2.67
Factors that enhance acidity in Nariño		
Average diurnal temperature range (°C)	10.5–12.2	3.29
Average annual precipitation (mm)	2081–2232	2.88
Dry months per year	1	2.75
Slope (°)	0–19	2.70
Dry months per year	0	2.59
Factors that enhance flavor in Nariño		
Average annual precipitation (mm)	2081–2232	3.26
Dry months per year	1	3.18
Dry months per year	0	2.98
Average annual precipitation (mm)	1931–2081	2.75
Slope (°)	0–2	2.41

mentation of the denomination of origin coffee concept is a deliberate policy initiative on the part of the FNC to market and protect Colombian regional coffees. The initiative will further aid the removal of Colombian coffees from the commodity coffee market and contribute bilateral trading relations partly decoupled from those of the world's coffee bourses. It consolidates the elite status of Colombia's small-holder producers and has substantial impact on their livelihoods.

The FNC have been pioneers in the field of identifying the unique characteristics that differentiate Colombian regional coffees from the bulk commodity product traded at the New York Board of Trade, and trading floors elsewhere. This initiative is of international relevance because it is the first time that the denomination of origin concept has been applied to coffee at the national and sub-national level. An important consideration for international food policy is to what extent does this indicate a direction for producers of high quality in other commodity products to follow? It is easy to see this as a trend, such as organically-produced foods, whose impact is more generally local, that may extend more generally to commodity products, with implications for future global trading patterns.

Labels of origin have often and traditionally been used with wine and spirits, but are now also applied to other foods. In September 2009 the European Database of Origin and Registration (DOOR) listed more than 850 agricultural farm products and foodstuffs PDO, PDI or TSG (Traditional Specialty Guaranteed) labels, and about 350 applications for registration. Café de Colombia is the first non-EU product. There are nationally registered coffee labels, as for instance the Pico Duarte Coffee from the Dominican Republic, Café Veracruz in México (www.cafeveracruz.com.mx) or the Jamaica Blue Mountain Coffee. To our best knowledge, none of these has attempted to develop systematically a denomination over a large contrasting geographical area, the feasibility of which has been documented here.

The differences in environmental and product quality characteristics between the Colombian coffee growing regions of Cauca and Nariño provided the evidence to initiate an administrative procedure to obtain denominations of origins for the coffee growing regions of both Departments. In April 2009, the FNC submitted the first regional dossier to the Superintendencia de Industria y Comercio to obtain the regional denomination of origin Nariño. A few months later the application for Cauca was also submitted. Currently, the FNC produces, with support of the Multilateral Investment Fund of the Inter-American Development Bank, videos and other visual documentation material that will illustrate to producers, clients and consumers the relationships between environment and quality attributes based on these findings. These materials will become accessible through the www.cafedecolombia.com website to strengthen further demand and thereby generate higher premiums for local coffee growers in the future.

The rise and growth of the Specialty Coffee sector in the past 20 years has been remarkable and is largely driven by new consumer awareness and appreciation for coffees of known quality. Demand for these coffees is growing underlined by the recent entry into the market of large restaurant chains and large traditional coffee roasters. Specialty coffees use three basic pathways into markets including a differentiation only by geographical origin (Neilson, 2007), differentiation based on sensoric characteristics of excellent taste quality (Daviron and Ponte, 2005), and characterization by compliance and emphasis of environmental and social process standards (Ponte, 2004). Labels of origin can potentially integrate elements of all of these approaches and are therefore well positioned to increase further the participation of Colombian coffees within the market place for specialty coffee. This study documented, however, that success hinges on a multi-stakeholder process under the umbrella of a national sector development strategy that is fully endorsed by governmental, producers and industry institutions. For example, consideration was required concerning several specific geographic areas. It was argued to include the Bolívar district and surrounding municipalities of southern Cauca in the Nariño DO. The Bolívar district is environmentally and in product quality terms more similar to those of Nariño than of Cauca. The collective decision making process was able to address these issues. The Cauca Department municipalities of Bolivar, Mercaderes and Florencia were included in the Nariño DO.

At the geographical scale of the department, the environmental characteristics that affect coffee product quality are mainly climatic with the exception of altitude. A cautionary note, which is important in this context, is that for any sub-denominations within the regions, other environmental characteristics such as aspect, slope and soils will become more relevant compared with those that are identified at the regional scale. This is related to the concept of ecological fallacy (Robinson, 1950). The lack of soil data and the lack of knowledge about the relationships between soil characteristics and specific coffee quality characteristics obstructs the establishment of origin labels for smaller areas. Further research to understand these relationships better is recommended. Similarly, research generating insights into the interactions of small scale climate patterns with other environmental and production factors will strengthen the implementation of the developed approach elsewhere and at different geographical scales.

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