FACULTY OF
BIOSCIENCE ENGINEERING

BIOPHYSICAL CONTROL ON COCOA QUALITY IN SANTANDER, COLOMBIA

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Acknowledgements

So here we are.

The final words of a chapter in life.

All my life, I've been sitting behind a desk, listening to someone who's told me things. I didn't know why or for what. But well, you have to learn it and prove that you get it by passing tests, exams,... it's been 25 years now, and here I am, once again, behind a desk, writing my last words on this computer that I've come to know and appreciate. Quite difficult but also very beautiful times have been endured during those years, but now it’s time to move on, and to pursue and realize my own success, my own “Personal Legend”.

For this masterthesis, I’ve been to Colombia on my own. Very scary at first, but it was the first time I could fully enjoy working for the university, and it was even more surprising that I could have so much fun while working on one of my most important projects. I could finally understand why I’ve endured all those years: living and working in this incredible Colombian culture with such heart-warming people was an eye-opener.

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Un grand merci à vous tous.

Be 

Summary

The global demand for high quality cocoa is increasing. Despite the fact that there are techniques and knowledge available to manage cocoa cultivation effectively, the quality of the beans varies widely. There is a need for standardization in order to assure high quality in the long term. Colombia demonstrates a high quality and high potential yield and are on track to meet the needs of growing demand. This thesis investigates the influence of farming practices, soil properties and altitudes on the quality of fermented and dried beans in San Vicente de Chucurí and Rionegro, two municipalities located in Santander, Colombia.

With that objective, in each municipality, 21 farmers were investigated on different altitudinal ranges. The 42 farmers were questioned by means of a socio-economic survey about their farming practices, while soil and dried bean samples were taken. The soil was analyzed for its chemical properties and the beans for their quality attributes. These attributes include the bean mass, the moisture, the pH and titratable acidity, the protein content, the fat content, and the fermentation index. In addition, the cadmium in the soil and in the beans was investigated.

Overall, the beans were at a high quality according to the 'Norma Tecnica Colombiana' NTC 1252, but the majority of farmers had a considerably low productivity. Using the linear mixed effect model statistics, it was found that multiple significant soil predictors had an influence on the bean quality. However, due to the time and scope of this thesis and the lack of research on the effect of soil on bean quality, few causal links could be established.

In terms of cadmium content, both San Vicente and Rionegro had cadmium in their soil, but only San Vicente had beans in which the cadmium content exceeded the maximum limit level set by the European Commission.

Resumen

La demanda mundial de cacao de alta calidad está aumentando. A pesar de que existen técnicas y conocimientos para gestionar eficazmente el cultivo del cacao, la calidad de los granos varía ampliamente. Existe la necesidad de estandarización para asegurar una alta calidad a largo plazo. Colombia demuestra una alta calidad y un alto rendimiento potencial y está en camino de satisfacer las necesidades de la creciente demanda. Esta tesis investiga la influencia de las prácticas agrícolas, las propiedades del suelo y las altitudes sobre la calidad de los granos fermentados y deshidratados en San Vicente de Chucurí y Rionegro, dos municipios ubicados en Santander, Colombia.

Con ese objetivo, en cada municipio se investigaron 21 agricultores en diferentes rangos altitudinales. Se interrogó a los 42 agricultores mediante una encuesta socioeconómica sobre sus prácticas agrícolas y se tomaron muestras de suelo y granos secos. El suelo fue analizado por sus propiedades químicas y los granos por sus atributos de calidad. Estos atributos incluyen la masa del grano, la humedad, el pH y la acidez titulable, el contenido de proteínas, el contenido de grasa y el índice de fermentación. Además, se investigó el cadmio en el suelo y en los granos.

En general, los granos eran de alta calidad según la Norma Técnica Colombiana NTC 1252, pero la mayoría de los agricultores tenían una productividad considerablemente baja. Utilizando las estadísticas del modelo de efectos mixtos lineales, se encontró que múltiples predictores de suelo significativos tenían una influencia en la calidad del grano. Sin embargo, debido al tiempo y alcance de esta tesis y a la falta de investigación sobre el efecto del suelo en la calidad del grano, se pudieron establecer pocos vínculos causales.

En términos de contenido de cadmio, tanto San Vicente como Rionegro tenían cadmio en su suelo, pero sólo San Vicente tenía granos en las que el contenido de cadmio superaba el nivel máximo establecido por la Comisión Europea.

Samenvatting

Wereldwijd neemt de vraag naar cacao van hoge kwaliteit toe. Ondanks het feit dat er technieken en kennis beschikbaar zijn om de cacaoteelt effectief te managen, varieert de kwaliteit van de bonen sterk. Er is behoefte aan standardisatie om op lange termijn een hoge kwaliteit te kunnen garanderen. Colombia laat een hoge kwaliteit en een hoog potentieel zien en ligt op schema om aan de behoeften van de groeiende vraag te voldoen. Deze dissertatie onderzoekt de invloed van landbouwpraktijken, bodemeigenschappen en hoogten op de kwaliteit van gefermenteerde en gedroogde bonen in San Vicente de Chucurí en Rionegro, twee gemeenten in Santander, Colombia.

Met dat doel werden in elke gemeente 21 boeren op verschillende hoogten onderzocht. Aan de hand van een sociaal-economisch onderzoek zijn de 42 boeren ondervraagd over hun bedrijfsvoering, terwijl bodem- en bonenmonsters zijn genomen. De bodem werd geanalyseerd op zijn chemische eigenschappen en de bonen op hun kwaliteitskenmerken. Deze kenmerken zijn onder andere de bonenmassa, het vochtgehalte, de pH en titreerbare zuurgraad, het eiwitgehalte, het vetgehalte en de fermentatie-index. Bovendien werd het cadmiumgehalte in de bodem en in de bonen onderzocht.

In het algemeen waren de bonen van hoge kwaliteit volgens de "Norma Tecnica Colombiana" NTC 1252, maar de meeste boeren hadden een aanzienlijk lage productiviteit. Aan de hand van de statistieken van het lineaire mixed effect model werd vastgesteld dat meerdere belangrijke bodemvoorspellers een invloed hadden op de kwaliteit van de boon. Door de tijd en omvang van deze dissertatie en het gebrek aan onderzoek naar het effect van de bodem op de kwaliteit van de bonen konden echter weinig causale verbanden worden vastgesteld.

Wat het cadmiumgehalte betreft, hadden zowel San Vicente als Rionegro cadmium in hun bodem, maar alleen San Vicente had bonen waarvan het cadmiumgehalte het door de Europese Commissie vastgestelde maximumgehalte overschreed.

Résumé

La demande mondiale de cacao de haute qualité est en hausse. Bien qu'il existe des techniques et des connaissances pour gérer efficacement la culture du cacao, la qualité des fèves présente de grandes variations. Il est nécessaire de procéder à une normalisation afin d'assurer une qualité élevée à long terme. La Colombie fait preuve d'une grande qualité et d'un rendement potentiel élevé et est en position de répondre aux besoins de la demande croissante. Ce mémoire examine l'influence des pratiques agricoles, des propriétés du sol et de l'altitude sur la qualité des fèves fermentées et séchées à San Vicente de Chucurí et Rionegro, deux municipalités situées à Santander, en Colombie.

Dans cet objectif, dans chaque municipalité, 21 agriculteurs ont été étudiés sur différentes altitudes. Les 42 agriculteurs ont été interrogés au moyen d'une enquête socio-économique sur leurs pratiques agricoles, tandis que des échantillons de sol et de fèves séchées ont été prélevés. Le sol a été analysé pour ses propriétés chimiques et les fèves pour leurs attributs de qualité. Ces attributs comprennent la masse de la fève, l'humidité, le pH et l'acidité titrable, la teneur en protéines, la teneur en matières grasses et l'indice de fermentation. De plus, le cadmium dans le sol et dans les fèves a été étudié.

Dans l'ensemble, les fèves étaient de bonne qualité selon la Norma Tecnica Colombiana NTC 1252, mais la majorité des agriculteurs avaient une productivité considérablement basse. À l'aide des statistiques du modèle linéaire à effets mixtes, on a constaté que de multiples prédicteurs significatifs du sol avaient une influence sur la qualité de la fève. Cependant, en raison du temps et de la portée de ce mémoire et du manque de recherche sur l'effet du sol sur la qualité des haricots, peu de liens de cause à effet ont pu être établis.

En ce qui concerne la teneur en cadmium, aussi bien San Vicente et Rionegro contenaient du cadmium dans leur sol, mais seul San Vicente avait des fèves dont la teneur en cadmium dépassait la limite maximale fixée par la Commission européenne.

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1. Introduction

Cocoa (*Theobroma cacao L*) is a crop of significant global economic importance, from its beginnings in agricultural countries, to its production within the confectionery industry, to the billions of consumers it reaches throughout the world. Originally cultivated in Latin America, cocoa is currently produced in other parts of the world including Africa, Asia, and the Pacific Islands. The current global production consists of more than 4 million tonnes annually. About 89% of the worldwide cocoa supply is provided by seven countries. In order of highest to lowest production outputs, these countries are: Ivory Coast, Ghana, Indonesia, Nigeria, Cameroon, Brazil and Ecuador (ICCO, 2017), with West African farmers on their own responsible for 63% of global production (ICCO, 2017).

More than 90% of the world's cocoa is produced by smallholder farmers, usually on a subsistence basis. Due to insufficient resources in management knowledge and crop production, smallholder farmers are not able to reach the full potential of the land they cultivate (Cacaonet, 2012). Global demand for cocoa is projected to increase to 5 million tonnes in 2020, about 2–3% higher than current production levels. In order to meet the increasing global demand for cocoa, the yield gap must be closed to sustainably optimise cocoa production on smallholder farms without increasing the land area used for this production (Cacaonet, 2012; ICCO, 2012).

The increasing demand for cocoa is not limited only to quantity, but also on quality and single origin cocoa, as opposed to bulk cocoa. As with coffee and wine, this trend is increasingly being observed in the cocoa sector. The traceability and transparency of the processes from bean to bar are receiving increased scrutiny from the global consuming markets. There is increased interest from consumers in knowing where the cocoa beans used to make their chocolate comes from, consequently giving more value to the small plantation and the single origin bean (Regout and Ogier, 2013).

While Colombia possesses only 1.5% of the global cocoa market, it was qualified by the International Cocoa Organization (ICCO) in 2010 as a producer of high quality 'fine or flavour' cocoa and has the potential to fulfil the increasing demand for single origin 'fine or flavour' cocoa (FEDECACAO, 2017; ICCO, 2017). While there has been a high number of government-, university-, and privately-funded research initiatives surrounding small-scale farming, the interactions between ideal soil conditions, altitude, climatic conditions and farm management needed to increase the production of high quality cocoa beans remains unclear (van Vliet and Giller, 2017).

The objective of this research is to investigate the influence of biophysical factors on the quality of cocoa beans produced in Santander, Colombia. The department of Santander accounts for 38% of the national production. The study focused on three aspects of biophysical factors on cocoa bean quality. These included: first, the influence of location and altitude of the cocoa farms; second, the correlation between soil fertility, farm management practices, and the altitude of the farms with cocoa bean quality; third, the impact of the cadmium present in the soil on the beans.

2. Literature Review

2.1 History of cocoa

Cocoa (*Theobroma cacao*) originated more than 2000 years ago in the Amazon basin. The plant was given the botanical name of *Theobroma cacao*, derived from the Greek word 'ambrosia' - meaning 'cocoa, food of the gods' - in 1737 by the Swedish botanist Carolus Linnaeus (Alvim, 1984; Anon, 2008).

According to Coe *et al.* (1996), the early history of cocoa cultivation dates back to 600AD in the lowlands of south Yucatán. The Maya and Aztecs at this time primarily consumed cocoa as a spiritual beverage, mixing the beans with hot water, maize and chili peppers in order to form a spicy fermented alcoholic drink called *xocoatl* (Presilla, 2001). Cocoa beans were also highly prized as a currency for trading (Afoakwa, 2010). The cultivation of cocoa later spread to Asia, Africa, and the Caribbean, and is currently grown in a number of Pacific islands, including Papua New Guinea, Fiji, Solomon Islands, Samoa, and Hawaii (Hebbar et al., 2011).

Cocoa was introduced to Europe by the Spanish, who invaded and conquered the Aztec empire in present-day Mexico in the 16th century (Anon, 2011a). The first export of cocoa from Colombia to Europe took place in 1580 (García, 1997). This Cocoa was seen as premium quality with bitter red-coloured beans but very sweet and full of aromas.

2.2 Cocoa in the world

More than 4 million tons of cocoa beans are produced worldwide annually (ICCO, 2017; Statista, 2017), and about 89% of this comes from just seven countries. From highest to lowest production outputs, these countries are: Côte d' Ivoire, Ghana, Indonesia, Nigeria, Cameroon, Brazil and Ecuador (ICCO, 2017), with West African farmers responsible for 63% of global production. In addition, reports by the World Cocoa Foundation (WCF) demonstrate that 90% of the world's cocoa is produced by smallholder farmers in developing countries, usually on 2–5 ha land (World Cocoa Foundation, 2012).

Cocoa is mainly cultivated in areas between 10°N and 10°S of the equator (figure 1.1), and responds well to relatively high temperatures, between 18 and 32°C throughout the year (ICCO 2018). Also known as the humid tropics, these regions are characterized by a hot and humid atmosphere with a relative humidity between 70% and 100% and an annual rainfall level between 1500 and 2000 mm.

<u>Cocoa producing countries around the world</u>

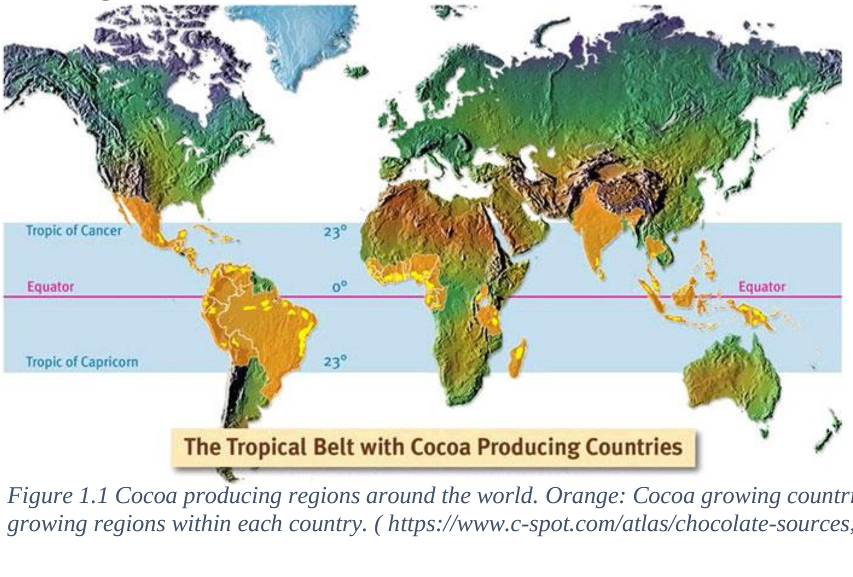

Figure 1.1 Cocoa producing regions around the world. Orange: Cocoa growing countries and Yellow: cocoa growing regions within each country. (https://www.c-spot.com/atlas/chocolate-sources, 2018)

2.3 Importance of cocoa

About 40 million people worldwide are economically and socially dependent on the cultivation of cocoa (WCF, 2018). As stated, cocoa is mostly produced by smallholder farmers, and the low productivity and small farm areas often make it difficult to provide even basic needs for farmers and their families despite a high global cocoa demand. The farmers tried to address this issue by expanding cocoa cultivation area, which led to deforestation and a decrease in productivity per hectare (Eskes, 2010; Kongor *et al.*, 2017). Today, different programs such as Cocoalife and FairTrade exist with the aim of providing education for farmers, introducing new technologies and varieties into cocoa agriculture, increasing production, improving management efficiency, improving the fair trade cocoa system, and preserving biodiversity and the environment (Mondelez International, 2016; FAOSTAT, 2017; ICCO, 2017; World Cocoa Foundation, 2018).

The worldwide production, demand and consumption of cocoa have all increased significantly since the last century (FAOSTAT, 2017; ICCO, 2017; Statista, 2017). At 5 762 600 ha and 2 671 298 tons respectively in 1994, the cultivation area and production mass of cocoa almost doubled by 2016 (10 196 725 ha and 4 466 574 tons). Today, 0.7% of the total arable land in the world - or 7% of the global permanent crops area - is occupied by cocoa (FAOSTAT, 2017).

The consumption of chocolate products has also been increasing yearly. The world's biggest chocolate consumers are Europeans, with Switzerland in the lead (8.8 kg/person/year). In contrast, the consumption in producing countries is much lower – in Colombia it is at just 0.9 kg/person/year (Statista, 2015). The biggest producers of chocolate products in the world are Mars Inc (USA), Ferrero Group (Luxembourg/Italy) and Mondelez (USA) with annual net sales of $18, $12, and $11.6 billion US Dollars respectively (ICCO, 2018). Cocoa beans, the primary products of chocolate derivate products, are thus playing a large economic role in the US and European food sector (ICCO, 2018).

Cocoa is considered as an excellent crop for reforestation. It tolerates and even needs shade trees such as timber wood and other crops, which are beneficial both for environmental and economic aspects (Ruf and Zadi, 1998; Hartmann and Petersen, 2004). In addition, it has a much higher positive impact on biodiversity, ecosystem services, and on the carbon stock compared to other plantations (De Beenhouwer, Aerts and Honnay, 2013; Somarriba *et al.*, 2013; Jacobi *et al.*, 2014). A well-managed agroforest cocoa farm with a good shade structure can regulate pests and diseases, provide a habitat for numerous forest dependent species, and allow for human income and consumption. In light of deforestation and climate change, cocoa-based agroforests are not a substitute for natural rainforests, but their value should not be underestimated (Somarriba *et al.*, 2013; Deheuvels *et al.*, 2014).

2.4 Cocoa varieties

There are four main cocoa varieties: Criollo, Trinitario, Forastero and Nacional.

Criollo beans are mostly found in South and Central America and are known for their fine chocolate flavour. However, they have relatively low yields and are very susceptible to pests and diseases (Lass, 2001). These beans are white and characterized by their low fermentation time (2-3 days) and low pH, which might easily affect the flavour profile. This variety has a mild or weak chocolate flavour and is used in high quality dark chocolate production.

Forastero or bulk cocoa is found in 95% of the cocoa market. It is a highly productive and resistant variety that finds its origins in the Amazon region but is now cultivated all over West Africa. The dried beans demonstrate a generally higher pH than Criollo beans (Ortiz de Bertorelli *et al*, 2009). This results in strong chocolate used in the production of milk chocolate, which forms the largest part of the chocolate market worldwide (CAOBISCO/ECA/FCC, 2015).

Trinitario cocoa is a hybrid of the Criollo and Forastero varieties, resulting in a highly productive and resistant cocoa variety. Its introduction has already replaced most of the criollo trees which were susceptible to diseases. The flavour of this type of cocoa is recognized by its fruity and floral touches (Afoakwa et al., 2008; Wood and Lass, 2008). Together with Criollo, these varieties are known as “fine or flavour” cocoa (Rusconi and Conti, 2010; ICCO, 2014).

Nacional is only found in Ecuador and is also considered as “fine or flavour” cocoa.

In 1850, fine flavour cocoa beans, principally produced in Latin America and the Carribean area, were estimated to take 80% of the worldwide production. But in 1900 the production lost 50% of its market share and by 1977, fine flavour cocoa only constituted about 7.2% of global cocoa. Currently, fine flavour cocoa is estimated to constitute less than 5% of the world production (Criollo <2% and Trinitario <5%) while bulk cocoa largely dominates the market (Toxopeus, 2001; Wood and Lass, 2008).

2.5 Cocoa in Colombia

Colombia represents ca. 1.5% of global cocoa production. In 2016, a yield of 60 535 tons of cocoa beans were produced over 175 000 ha of land at an altitude ranging between 0 and 1200 m above sea level (masl) (FEDECACAO, 2017; ICCO, 2017). Most cocoa farmers in Colombia cultivate between 3–5 ha land with an annual productivity of 400 kg ha^{-1} of dry cocoa beans. The low productivity is in part due to a lack of high-technology levels used for farming, the age of the trees, and the pests and diseases such as Monilia (*Moniliophtora roreri*), responsible for up to 60% of total loss (Evans, 1981).

Cocoa is cultivated in four different regions in Colombia, each distinguished by different agroecological characteristics. Due to the differences in environmental variables in each region, different management strategies and cocoa varieties are needed for sustainable production in each region. The first region is the tropical rainforest zone (a.o.Arauca, Nariño, the pacific coast). This region is characterized by average temperatures between 26 and 30°C, annual precipitation above 2600 mm, altitude levels ranging between 0 to 500 masl, loamy soils and a plane topography. The second region covers the dry inter Andean valleys (a.o. Huila, Atlantic Coast), with characteristics mostly similar to the tropical rainforest region, except for the precipitation levels which are less than 1500 mm in this area. The Andes zone (a.o. Antioquia,Tolima), the third region, has an average temperature range from 23 to 26°C, annual precipitation of 1500–2000 mm, with the landscape going from 500 to 1200 masl. This region is known for its high soil fertility. Finally, the Santanderean mountains (Santander and Norte de Santander) have average temperatures between 23 and 28°C, annual precipitations between 1500–2500 mm with mainly clay to clayey loam soils (FEDECACAO, 2016). With 38 % of the Colombian cocoa production, Santander is the most productive region, followed by 8.9% in Antioquia and 8.3% in Arauca (see figure 1.2).

The vast majority of cocoa beans produced in Colombia are of the fine or flavour variety. The fine or flavour cocoa in Colombia comes from Criollo and Trinitario cocoa varieties. The latter is also called hybrid and is the predominant type of cocoa in Colombia. The best materials of this type are selected, cloned and recommended by the national federation of cocoa cultivators in Colombia (FEDECACAO). The so-called common cocoa is the one that comes from natural hybrids (Sanchez and Rojas, 2013). Each cultivar or clone is usually selected for its flavour characteristics, production rate and resistance against pests and diseases.

90 000 ha of agricultural land in Colombia today is planted with traditional cultures (i.e. plantation with only Trinatario and Criollo or hybrids) which have a potential yield of up to 800 kg/ha/year. In contrast, cocoa clones are cultivated on 30 000 ha and can produce up to 2500 kg/ha/year (Villamil *et al.*, 2013).

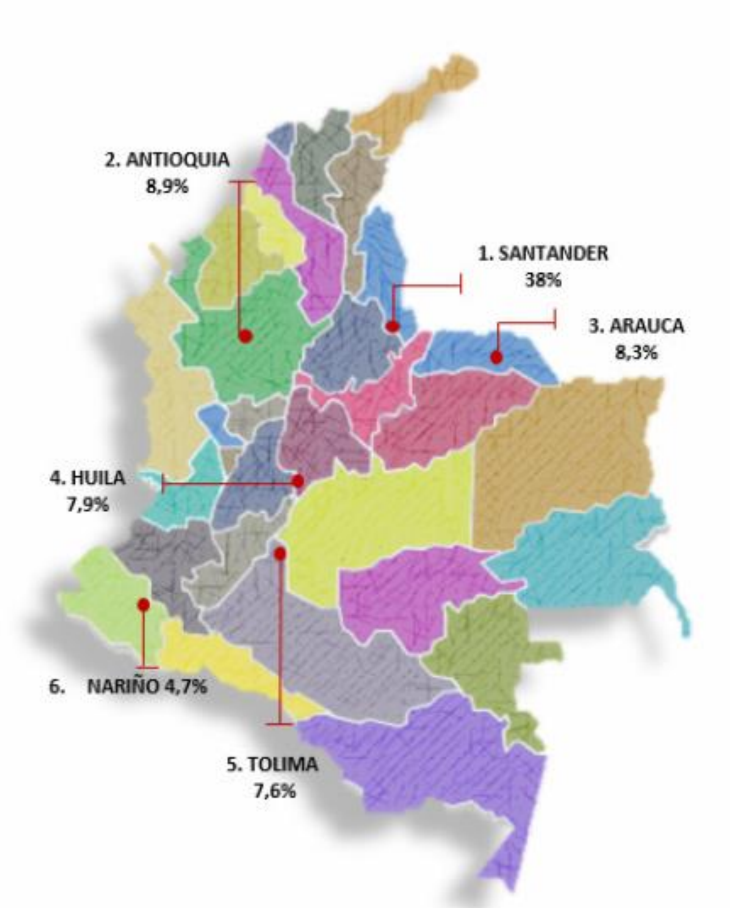

Figure 1.2: Colombian cocoa production per department. Source FEDECACAO, 2017

2.6 Factors potentially influencing the quality of cocoa beans

The quality of a cocoa bean is determined by its physical characteristics, such as the mass of the bean, the amount of fat, etc. and its flavour components. While the latter is more subjective, it is the most essential factor for the consumption of chocolate (Afoakwa *et al.*, 2008).

In this section, the factors, important in the cocoa cultivation and potentially influencing the quality of the dried cocoa beans will be briefly reviewed. The listed factors will follow the chronology of the processes from seed to exportable product. In section 2.7, the different quality tests and their possible relations with these factors will be explained.

2.6.1 Environmental Factors

2.6.1.1 Climate

To guarantee a good and healthy cocoa cultivation, the fulfilment of the following climatic requirements is indispensable:

Temperature

A temperature range of 23-28°C provides optimal growth and development (Sys *et al.*, 1993). Further, day and night temperature variations should not exceed 9°C: the day temperature should not exceed 38°C and night temperature should not go below 15°C (FEDECACAO, 2016).

Precipitation

A good distributed precipitation between 1800 and 2500 mm throughout the year is needed for good fructifications and abundant yields. Dry periods of more than 2 months will have a negative impact on production. In regions where precipitation is less than 1500 mm per year irrigation methods will be needed (Sys *et al.*, 1993; Wood, 2001).

Humid Relativity

Since the cocoa tree finds its origin in the tropical rainforests, a high relative humidity is needed for good growth. A relative humidity of 80% is considered optimal, but even 70% is sufficient to ensure a good development of the trees (ICCO, 2013; FEDECACAO, 2016).

2.6.1.2 Soil

Cocoa is a demanding crop in terms of soil nutrient requirements (Wessel, 1971). These nutrients are crucial for the development of the tree and help with flowering, pod maturity, and the rate of photosynthesis, among other things (Okali and Owusu, 1975). Sys *et al.* (1993) have found that the ratio of potassium (K) and sodium (Na) over magnesium (Mg) and calcium (Ca) should be near 1/50 to obtain a good crop growth.

In addition, the pH of the soil is important, again in terms of the availability of nutrients. A pH between 6.0 and 7.5 is reported for an optimal uptake of nutrients (Wood and Lass, 2008). Once the pH falls below 5.2, the risk of a soil acidity complex can affect the cocoa tree. This is a combination of aluminium toxicity and a fixation of calcium, magnesium and phosphorus onto iron and aluminium, thus making it unavailable for the plant. To counteract that, chicken dung, green manure, and basalt applications increase soil pH and reduce Al toxicity (Shamshuddin *et al.*, 2004). Ofori-Frimpong *et al.* (2007) have found that cocoa cultivation acidifies the soil with the time.

An organic matter above 3% is needed for optimal levels (Sys *et al.*, 1993). The main nutrients in the organic matter are carbon (C) and nitrogen (N). The soil organic matter (SOM) will play a key role in the fertility of the soil as well as on the structure (Wessel, 1971; Wood, 2001).

In addition, the texture of the soil plays a role in the retention of water and nutrient. Loamy soils would be optimal in terms of both water and nutrient availability for the crop. Clayey soils hold more organic matter and nutrients, which positively influence the roots development. On the other hand, clayey soils have a high water holding capacity, meaning the water in the soil is not easily available for the crop and thus has a negative effect on aeration and drainage. In contrast, sandy soils have good drainage and good aeration but contain less organic matter. These soils have much lower water holding capacity, so crop roots would tend to grow deeper. Generally, the roots attain a depth of 1.5m or deeper to prevent drought stress (Wessel, 1971; Wood, 2001).

Considering the soils and climate of Santander, Colombia (see section 2.5 Cocoa in Colombia), this area is very suitable for the cultivation of cocoa (Pimiento and Vega, 2006; Uribe *et al.*, 2011).

2.6.2 Farming practices

As mentioned earlier, 95% of the global cocoa production comes from Forastero (bulk) cocoa (Fowler, 1994). Different studies found high significant variations in bean quality attributes. Knowing that 90% of cocoa production is carried out by smallholder farmers possessing on average 3-5 hectares of land and considering the large variation in quality within the same variety, it can be assumed that farming practices have a big impact on the final quality of the beans. To counteract this problem, and to obtain reliable and constant quality within a region, farming practices should be optimized and standardized (Saltini, Akkerman and Frosch, 2013).

The national federation of cocoa cultivators in Colombia, FEDECACAO, is working towards the goal of guaranteeing good and reliable quality of all Colombian cocoa beans by standardizing all farming practices. For this purpose, cocoa training courses are offered to farmers, and cocoa technicians are sent to cocoa farms in order to give them adapted and adequate technical, administrative and financial advice (Pimiento and Vega, 2006). The ideal farming practices and conditions which Fedecacao promotes will be described in the next paragraphs.

It is important to clarify what steps the cocoa bean undergoes before being exported and how this influences the quality. Following this, the measured bean quality parameters, and how they in turn influence the quality of the bean and final product, will be explained.

2.6.2.1 Pre-harvest

Before the cocoa tree produces a good quantitative and qualitative yield, ready to be harvested, a lot of work is involved. This includes pruning, pest and disease control, fertilizing and more.

Cultivars

First of all, it is important to work with appropriate cultivars based on the climate and the soil. The cultivated varieties are of crucial importance for both quantity and quality of cocoa bean production, as each variety possesses different properties such as: resistance properties (against pests and diseases (especially Monilia (*Moniliphthora roreri*)); physical properties (bean mass, yield per year); and flavour properties, due to differences in content in terms of sugars, proteins and polyphenols; which result in a variety of flavour profiles (see table A.4 in annex) (Clapperton *et al.*, 1994; Afoakwa *et al.*, 2008; Villamil *et al.*, 2013).

Pruning

Pruning consists of finding an equilibrium between the vegetative and fruit production of the plants, which is of major importance for an optimal yield. It is recommended to prune the cocoa trees twice a year. This eliminates the low producing parts of the tree, regulates the height, and opens up the cultivation, enhancing the aeration and light interception. All of this creates unfavorable conditions for potential pests and diseases (Hutcheon, 1976; Govindaraj K & Jancirani P, 2017). The first and main pruning should be executed at the end of the dry season (from December to February), and a second one should be done between August and September (FEDECACAO, 2016).

Pests and disease control

The main diseases in Santander are Monilia (*Moniliphthora roreri), "*Escoba de Bruja" or "Witches Broom disease" (*Moniliophthora perniciosa),* Phytopthora (*Pythophthra palmivora*) and "el Mal de Machete" or Ceratocystis (*Ceratocystis fimbriata*) transmitted by the insect of the genus *Xyleborus sp.* (Lass, 2001)

The common pests in Santander include ants (*Atta cephalotes*) that eat the leaves of the cocoa trees and ants of the genus *Acromyrmex* which, contrarily to the others, do not have predefined walking routes. The latter are more difficult to control (Pimiento and Vega, 2006; FEDECACAO, 2016). The *Xyleborus spp* perforate the stem and branches of the cocoa tree and transmit the *Ceratoscystis* disease. Thrips or *Selenothrips rubrocinctus* are mainly found on the pods and leaves. Chinche negro (*Mecistorhinus pallesceus*) will leave black dots on the pod and finally the *Sinantedum theobromal* or 'pasador del fruto' are the larvae of a little butterfly on the pod that make holes in the pod. Bacteria and fungi, who flourish in humid environments, will enter through these openings and cause damage to the beans (Entwistle, 2001).

These pests and diseases cause a lot of yield damage and thus economic loss especially when not well controlled (Bateman, 2015). The best way to avoid those pests is through prevention. A primordial practice for that, is pruning, which will aerate the plantations and make the environment less suitable for pests and diseases (i.e. less warm and humid). Other cultural, biological and chemical methods can be used to control those pests and diseases. Some cultivars have a higher resistance against Monilia, e.g. CCN 51 and ICS 95 (see table A.4 in annex) (Quintana *et al.*, 2015). Insecticides and fungicides are very rapid and efficient but expensive and potentially hazardous to human health and environment due to residues of biocides and heavy metals (Adejumo, 2005). Finally, contaminated pods and other organic material should be removed and not be recycled in the cultivation (Adejumo, 2005; CAOBISCO/ECA/FCC, 2015; FEDECACAO, 2016)

Fertilizer application

Since the cocoa tree has high nutrient requirements, fertilization is often applied to fulfill these needs. The most essential nutrients needed are nitrogen (N), phosphorus (P) and potassium (K). The names of the different fertilizers are based on this composition e.g. NPK 15/15/15. If there are two more numbers, those will refer to the proportion of calcium (Ca) and magnesium (Mg) present in the fertilizer. Sys *et al.* (1993) proposed amounts of each elements to produce 1 ton of beans per ha (table 1.1).

Table 1.1: Fertilizer application to produce 1 ton of beans/ha mentioning the nutrietns and the minimal and maximal limits in kg/ha/growing cycle (Sys et al, 1993)

Nutrient	Minimal application (kg/ha/growing cycle)	Maximal application (kg/ha/growing cycle)
N	35	60
P_2O_5	25	50
K_2O	55	75

2.6.2.2 Harvest

Harvesting is done throughout the year, but two seasons bear considerably more yield than the other two. In Colombia, the main harvest season is from April to June, and the mid harvest season occurs between November and January. These seasonal patterns of production tend to coincide with the bimodal rainfall pattern in Santander, two periods where the monthly rainfall exceeds 100 mm.

Fedecacao recommends only harvesting fully ripe pods two times per month in the main and mid seasons (resp. April – June and October- November), corresponding with the bimodal rainfall pattern, and every 20 days the rest of the year. Once harvested, the farmers should split the pods the same day and leave the husks in the cultivation, leaving out diseased or contaminated ones. Harvesting ripe pods has a positive effect on the flavour of the beans; however, the composition does not change from less ripe pods (Felperlaan and Linnemann, 1997)

2.6.2.3 Post-harvest

Storage

Several studies recommend storing pods before fermentation to obtain an improvement in the final flavour, especially for cocoa beans with strong acid flavours. Pod storage reduces the sucrose, glucose, ethanol and acetic acid content and increase the pH in the fermented cocoa beans, resulting in lower acidic flavours in the final product. A significant downside of storing pods is that if this process is not well controlled, mould can easily occur and result in a substantial production loss (Tomlins *et al.*, 1993;

Ortiz de Bertorelli, Graziani de Farinas and Rovedas L, 2009). Pod storage is not recommended by Fedecacao (FEDECACAO, 2016).

Fermentation

The fermentation of the cocoa beans is essential to obtain the characteristic flavour and taste of chocolate developed during this 6-day process (Afoakwa *et al.*, 2013).

Method of fermentation

While the heap method is mostly used in West- Africa, the box method is recommended in South America. This method enables a more defined and controlled fermentation. Other methods include the platform and basket method, but those are less used in South America.

The chemical changes in the heap method are more uniform, and more brown beans are present compared to the (wooden) box method. The less uniform fermentation in the boxes will lead to incomplete usage of sugars or a high proportion of brown beans (Tomlins *et al.*, 1993; Guehi *et al.*, 2010).

Fermentation process (see schematic representation in figure 1.3 and 1.4)

The actual fermentation begins by throwing all beans that still contain pulp in a heap, or wooden box or other recipient/ substrate. The mound of all those beans will create a low oxygenated environment with a low pH (3.6) due to the citric acid present in the pulp. This environment is ideal for the colonization of yeast, which will then convert the pulp carbohydrates into alcohol. After 24 hours, the quantity of yeast will decline and the lactic acid bacteria (LAB) will increase. The function of the LAB is to convert glucose into lactic acid. After 36h, the amount of LAB is maximal, and the pH increases again due to the production of non-acidic products. After two days of fermentation. the LAB give way to the acetic acid bacteria (AAB), which are obligated aerobic bacteria and will produce an exothermic reaction by oxidizing ethanol to acetic acid, followed by an oxidation of the acetic acid to CO_2 and H_2O. Those reactions cause an increase of temperature that reaches up to 50°C on the 4th day and provoke the hydrolysis and diffusion of the proteins present in the beans. As a result, the AAB is of crucial importance for the formation of flavour precursors. After 6 days of fermentation, the AAB decreases and the beans are ready to be dried to prevent the development of aerobic spore bacteria, which cause off-flavours and affects the pH (Schwan and Wheals, 2004).

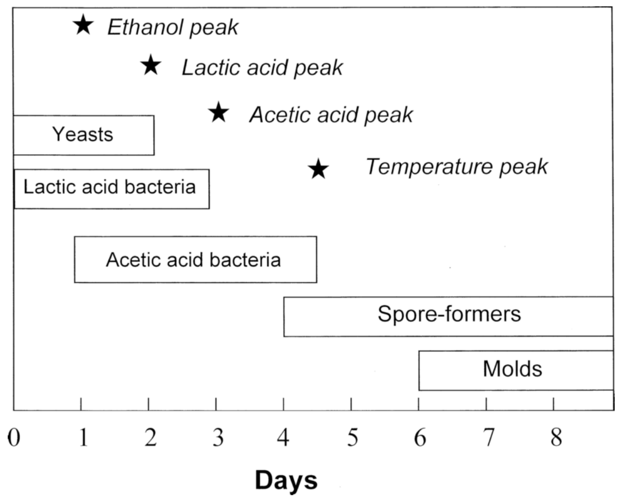

Figure 1.3: Schematic of a microbial succession during cocoa bean fermentations. The open boxes indicate the periods during the fermentations when a particular microbial group is most abundant and/or important. The stars indicate the timing of peaks of metabolites and temperature. SOURCE: Schwan and Wheals, 2004.

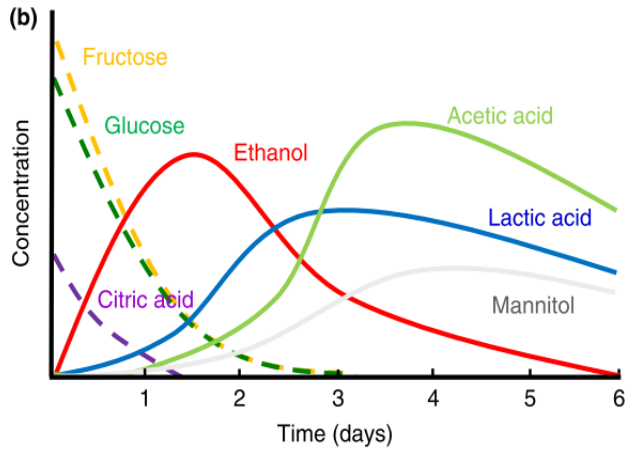

Figure 1.4: Community dynamics of a spontaneous cocoa bean fermentation process (De Vuyst and Weckx, 2016).

The proteins in the beans – and more specifically, the globulin fraction (43%) of these proteins – are important for the flavour quality. During the proteolysis, or enzymatic degradation of the proteins, the vicilin class globulines are converted into amino acids and peptides, which are essential for the flavour formation (Emmanuel Ohene Afoakwa *et al.*, 2013; Voigt, Textoris-Taube and Wöstemeyer, 2018). The proteolysis is induced by acetic acid after a day of fermentation (Ziegleder, 2017).

The duration of the fermentation has an important impact on the flavour quality of the beans as well. Since unfermented beans will not have had the time to fully develop their flavour precursors and the acids (citric, lactic and acetic) will not be completely reduced, the acidity of the beans will remain high. In addition, the polyphenols, which through oxidation produce the colour of the beans (black, brown or red) will not be totally reduced and will cause an astringent and bitter aroma. On the other hand, over-fermented beans will develop aerobic spore bacteria, which cause off-flavours (Schwan and Wheals, 2004; Afoakwa *et al.*, 2008; Saltini, Akkerman and Frosch, 2013).

Drying

After 6 days of fermentation, the beans need to be dried to reduce the moisture of the cocoa bean to 6 - 8%. The moisture content should not exceed 8% - at this point, the risk of mould growth and bacteria is high. A moisture content below 6% can make the bean very fragile and more susceptible to disintegration during transportation (Wood, 2008). During the drying process, the oxidation of polyphenols continues, accentuating the brown color of the beans and ameliorating the flavour. The remaining acetic acids continue to be reduced and the pH will slightly increase (Tomlins *et al.*, 1993; Afoakwa *et al.*, 2008). In addition, the speed of drying has a big impact on the final flavour quality of the beans. If the drying is done too rapidly, the acetic acids will not be able to be reduced or to quit the bean by evaporation; on the other hand, if the drying is too slow, the acidity of the beans will be too low and the presence of moulds will affect the flavour (Tomlins *et al.*, 1993; Bonaparte, Alikhani and Madramootoo, 1998; Hii *et al.*, 2006).

2.7 Quality aspects

This section will be divided in two chapters: the quality aspects in terms of flavour, and the quality aspects in terms of physical characteristics.

While the literature provides a lot of information about how the postharvest management and cocoa genotype contribute to the quality of cocoa beans, no work has investigated the effect of soil on the flavour quality of cocoa beans.

2.7.1 Flavour or organoleptic characteristics

The basic flavour of the cocoa bean depends on the variety. That is to say that fine or flavour cocoa will have a mild nutty flavour if it originates from the Criollo variety, while Trinitario beans have a full chocolate flavour (Wood, 2008). On the level of cultivars, each genotype of cocoa has a specific taste, which is described for at least 26 cultivars in Colombia by Fedecacao and the Industrial University of Santander (UIS) (Villamil *et al.*, 2013).

The most important (off-)flavour factors are: mouldy, under fermentation, acidity and smoke.

The cut test score, fermentation index, pH & Acidity and moisture are parameters that give an indication of the quality of the flavour in the cocoa bean and will be described in the following paragraphs.

2.7.1.1 Cut Test

The cut test is a well-known method to evaluate the presence of defects in the fermented and dried cocoa beans. Two major off flavours are detected: mouldy and unfermented beans. In addition, insect damaged beans, slaty beans, germinated beans, and flat beans are also taken into account. A sample of 300 beans are taken and put in a Guillotine to slice the bean into two equal parts. In the natural light, the inspector checks and counts the number of slaty, purple, and insect damaged beans and takes notations. The Cut test is evaluated by grades defined by the International Cocoa Standards, indicating the maximum percentage of beans of a certain category within one cut test (table 1.2).

Table 1.2: International grade standards (Maximum percentage by count). SOURCE: Anon (1970)

	Mouldy	***Slaty***	***Insect damaged, Germinated, and Flat***
Grade I	3	3	3
Grade II	4	8	6

2.7.1.2 Fermentation Index

Contrary to the cut test, the fermentation index gives an objective indicator for the degree of fermentation. The beans are considered well-fermented when the index is ≥ 1 (Pettipher, 1986). This is to avoid overfemented and mouldy beans with unpleasant smells, as well as insufficiently fermented beans, characterized by an astringent flavour or unpleasant taste (Jinap and Dimick, 1990).

2.7.1.3 pH and Acidity

The pH determines the level of sourness in the bean and is a good indicator for the fermentation status (Afoakwa *et al.*, 2015). Romero-Cortes *et al.* (2013), found that the pH could be used as a first indicator to evaluate the quality of fermentation. However, the pH is not an assurance of good chocolate flavour, and should be confirmed by the fermentation index (Romero-Cortes *et al.*, 2013).

It is important to remember that pH and titratable acidity are not the same: pH is defined as the logarithm of the hydrogen ion concentration while the titratable acidity (wt/wt) is usually stated in the total content of the predominant acids within a food product. In the dried and fermented cocoa beans, those acids are acetic, citric, and oxalic acids (Dimick, 1990; Tomlins, Baker and McDowell, 1990; Icontec, 2003). The "Norma Tecnica Colombiana" NTC 1252 of cocoa beans suggest an optimal pH between 4.5 – 5.5 for dried cocoa beans, and a total content of the organic acids (among others: acetic acids, citric acids and oxalic acids) between 1.2% - 1.6% (Icontec, 2003).

The pH of the dried cocoa bean is influenced by a several factors:

First, the **variety** can influence the pH. According to Ortiz de Bertorelli, Graziani de Farinas and Rovedas L (2009), a higher pH is noted on Forastero beans compared to Criollo beans. This affects the flavour profile of the end product: Forastero beans make less bitter, less astringent, and less acid chocolate than Criollo or Trinitario (Clapperton *et al.*, 1994).

The **storage** also has an impact on the pH and total acidity of the beans. A well-controlled storage diminishes the pulp volume and thus shortens the anaerobic phase, resulting in a reduction of the sucrose, glucose, ethanol and acetic acid content and an increase in the pH of the fermented cocoa beans. This leads to a low acidity and better cocoa flavours (Afoakwa *et al.*, 2015). The negative aspect here is that a great loss can easily occur due to mouldy beans if this is not well controlled (Tomlins et al., 1993; Ortiz de Bertorelli, Graziani de Farinas and Rovedas L, 2009).

Even the **fermentation method** (i.e. in a heap, wooden boxes, platforms or baskets) has an influence on the pH and acid formation of the beans. The wooden boxes or "cajones" are reported by Guehi *et al.*, (2010) as having low uniformity, resulting in a high pH, relatively low concentrations of sugars, (due to an incomplete usage of sugars) ethanol and acetic acids, and a high presence of defective beans.

The **fermentation** and **drying** process will increase the pH as mentioned earlier.

2.7.1.3 Moisture content

The moisture content is used in both flavour definition and as a physical aspect for the quality. As explained in paragraph 2.6.2.3 under "**Drying** time", the moisture affects both the physical aspects of the bean (disintegration) and the flavour profile of the bean (mouldy flavours, which is an important off-flavour) (Wood, 2008).

With an insufficient drying of the beans, **moulds** can appear earlier on damaged pods caused by pests and disease and overfermented beans, as well as with climatic conditions when the beans are sun dried (Wood, 2008).

2.7.2 Physical Characteristics

The physical characteristics take into account the yield of the edible part of the bean. While the flavour aspects look more into the quality of the edible part, the physical aspect looks at the quantity. It is important that the physical aspects stays consistent over time in order to have reliable and qualitative beans to sell (CAOBISCO/ECA/FCC, 2015).

2.7.2.1 Bean count

The bean count gives an indication of the size and mass of the beans. This is done by weighing 100 grams of cocoa beans and counting the number of beans. The bean mass is calculated by dividing the number of beans by the exact mass. The larger the bean mass, the higher the amount of useable material (cocoa nibs) and the higher the cocoa butter content. The smaller the beans, the bigger the proportion of the shell and the less cocoa butter it will contain. According to the International Organization for Standardization (ISO) 2451, large beans are considered as having a bean count of less or equal to 100, medium bean between 101 and 120 beans and small beans containing more than 120 beans per 100 grams (Icontec, 2003). In terms of bean weight, the beans should have a mass of 1.0-1.2g (Icontec, 2003).

The bean size is determined by the **variety**: Trinitario has the biggest beans, followed by Criollo and Forastero (Clapperton *et al.*, 1994).

The **rainfall** and thus the time of harvest also has an impact on the bean weight. Thus, during the main harvest, the beans will have the biggest and heaviest beans due to the intense rainfall over the previous months (Toxopeus and Wessel, 1970).

2.7.2.2 Protein content

As described in section 2.6.2.3 under '**fermentation**' the proteins present in the beans are partly responsible for the production of the flavour precursors as the free amino acids and peptides. This means the protein content should decline with the fermentation time. According to Rohsius *et al.* (2006), high quality beans should contain approximatively 8 – 14 mg/g dry matter of total amino acids. Afoakwa *et al.* (2015), also report a decrease in protein content during the **storage** as during the **drying**.

The amount of proteins present in the beans also depends on the cocoa **genotype** (Clapperton *et al.*, 1994; Afoakwa, 2010).

Protein in Colombian regional materials can range from 11.49±1.12 to 12.52±0.18%.

2.7.2.3 Fat content

Depending on the **variety**, about half of the bean weight consists of fats which are inherent in the beans and are not affected by the fermentation process (Rohsius, Matissek and Lieberei, 2006; Afoakwa *et al.*, 2008; Afoakwa, 2010; De Vuyst and Weckx, 2016). The more fat in the beans, the more cocoa butter can be extracted. Cocoa butter is the most valuable part of the cocoa bean (Wood, 2008). The fat content in the beans has no standards nor optimal value. Thus, the percentage of fat may vary between materials: however, most available materials usually vary between 46 and 60% (CAOBISCO/ECA/FCC, 2015).

Colombian cocoa beans possess high fat content compared to varieties measured in Trinidad, Venezuela, Mexico, and Ecuador, resulting in more cocoa butter which is one of the most costly ingredients in the cocoa beans (Liendo, Padilla and Quintana, 1997; Cueto *et al.*, 2007; Puyutaxi *et al.*, 2009). In Colombia, the ranges of fat content are considered as high for a fat content between 60.4 and 60.9%, medium for 56.7 – 59.8% and low for 55.2 – 55.4% (Icontec, 2003).

2.7.3 Cadmium

Cadmium is a heavy metal that occurs naturally in the soils coming from industrial or agricultural sources (pesticides, fertilizers, etc.). This heavy metal is problematic: \although the intake by humans is relatively low, it is retained in the kidney and liver for 10 to 30 years. The accumulation of cadmium leads to renal dysfunctions, bone demineralization and increases the risk of cancer in the lung, bladder and breast ((Alexander *et al.*, 2009).

The source of cadmium is the earth's crust, and it always occurs in combination with zinc. The propagation of cadmium is mainly done by rivers through weathering rocks, by volcanoes and forest fires and by human activities as an inevitable by-product of zinc, lead and copper extraction. The production and application of artificial phosphate fertilizers will end up in surface water or streams which can be transported over great distances when absorbed by sludge. This will, on his turn, contaminate other soils and surface waters (Lenntech, 2018).

Latin America is infamous for having naturally high levels of cadmium in the soil which can be reflected in the cocoa beans. The availability of cadmium in the soil depends on the physical and chemical properties of the soil, the variety and the agricultural practices of the farmer and may so vary a lot from farm to farm (CAOBISCO/ECA/FCC, 2015; Gramlich *et al.*, 2017). Kirkham (2006) reviewed that pH levels and the organic matter content are the most important factor that controls the uptake. An increase of both pH levels and phosphate and zinc reduce the uptake of cadmium. While an increase in the organic matter content, sludged soils, soil salinity and clay content in the topsoil increase the Cd uptake (Smolders, 2001; Barančíková, Madams and Rybàr, 2004; Gramlich *et al.*, 2017). More than that, the sulfate and chloride salts of Cd have very high solubilities in water, which can influence the availability for plants (Henderson, 1997; Sharma and Sachdeva, 2015).

Starting in January 2019, the European Commission will set maximum limits in the concentration of cadmium in chocolate products (see table 1.3).

Table 1.3: Maximum permitted levels of cadmium in cocoa and derived products by the European Commission

Specific cocoa and chocolate products	**Maximum permitted cadmium levels (mg/kg)**
Milk chocolate with < 30 % total dry cocoa solids	0,10 as from 1 January 2019
Chocolate with < 50% total dry cocoa solids; milk chocolate with ≥ 30 % total dry cocoa solids	0,30 as from 1 January 2019
Chocolate with ≥ 50 % total dry cocoa solids	0,80 as from 1 January 2019
Cocoa powder sold to the final consumer or as an ingredient in sweetened cocoa powder sold to the final consumer (drinking chocolate)	0,60 as from 1 January 2019

Next to conventional methods used for soil remediation, alternatives can be applied such as phytoremediation, which is a more cost effective and environmental friendly green technology. This method uses the capacity of some plants to accumulate and tolerate high levels of heavy metals, also called ‘Hyperaccumulators’ (Krämer, 2005). Since the cadmium in the soil is present in large areas in Latin America, this method can be promoted to diminish the levels of cadmium in the soils.

For cocoa farmers it is recommended to remove the contaminated parts of the tree (pods, pruning material, etc.) from the cultivation, to lime the soils in order to increase the pH, to apply only phosphate fertilizers that have been checked to ensure it does not contain high Cd levels, and to increase the organic matter of the soil (CAOBISCO/ECA/FCC, 2015)

3 Materials and methods

3.1 Study sites

The study was conducted from August to October 2017 in two municipalities in Santander. This was just before one of the two major cocoa harvest periods in Colombia[1].

The first municipality, San Vicente de Chucurí (figure 3.1), also known as the "cocoa capital of Colombia", is a high producing region, contributing ca. 26% of the national production. About 55% of the total population (34 640 inhabitants) are farmers living outside the village. The average annual temperature is 25.3 °C and the town has an average annual rainfall of 1820 mm. The climate in San Vicente de Chucurí is classified as Af or tropical rainforest climate according to the Köppen-Geiger climate classification (climate-data.org, 2018). The main soil types in San Vicente de Chucuri are humic Cambisols (CMu) and umbric Leptosols (LPu) in the high altitudes (see figure 3.5 and table 3.1).

Rionegro (figure 3.2) on the other hand, consist of 27 114 inhabitants and produces only half as much as San Vicente. Although traditionally a coffee producing town, attacks of the "roya" *Hemileia vastatrix* (fungus) and the coffee borer beetle "broca" *Hypothenemus hampei* (insect) pests forced the inhabitants to quit the coffee cultivation and start cocoa cultivation. The climate in Rionegro is also an Af or tropical rainforest climate (Köppen-Geiger classification) with a mean annual temperature of 24.9 °C and an average annual precipitation of 1620 mm (climate-data.org, 2018). The main soil types in Rionegro are gleyic Arenosols (ARg) (see figure 3.5 and table 3.1).

Both San Vicente and Rionegro possess soils with a warm, humid climate, with a relief that is steep to very steep, little to moderately developed and generally unsaturated (Instituto Geografico Agustin Cadozzi, 1983); .

Figure 3.1: San Vicente de Chucuri (6°52'55"N 73°24'43"O), Santander, Colombia

Figure 3.2: Rionegro(7°15'51"N 73°08'58"O), Santander, Colombia

[1] Colombia, as other countries with a bimodal climate pattern, has two big harvest seasons. The first going from April to June, and the second from November to December (Wood et al, 2008).

3.2 Data collection

3.2.1 Selection of farmers

An altitudinal transect was chosen in each municipality (Low: 0-600 masl; Mid: 600-900 masl; High: 900-1200 masl). Two neighbouring villages were then selected in each of the altitudinal range. A total of 7 farms were randomly selected for the 2 villages in each altitudinal range (i.e. 7 farms for each altitude, 21 farms in each municipality and 42 farms in total for the whole survey) (figures 3.3 - 3.4). Together with a technician of Fedecacao, the 21 farms in each municipality were visited and marked with a unique code. Each codename SV0XX and RN0XX stands for a farm while SV and RN refer respectively to San Vicente and Rionegro. The highest range (900-1200 masl) corresponds with the codenumbers 001 to 007, the medium range (600-900 masl) with 008 to 014 and the lowest with 015 to 021. The geographical coordinates were determined with the GPS (Garmin GPSmap 60CSx) in addition to their altitude.

An overview of the mean annual temperature, annual precipitation and soil types are put in table 3.1

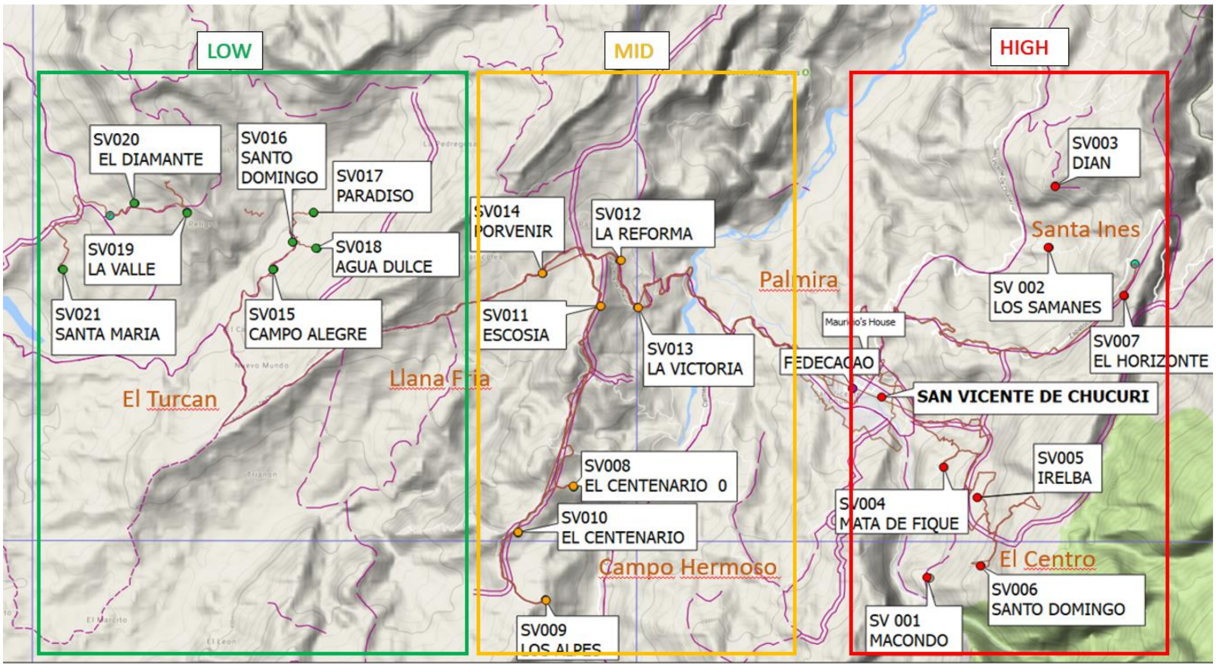

Figure 3.3: Selected farms in San Vicente de Chucurí, Santander, Colombia, with names of selected villages. Red: High altitudes; Orange: Mid altitudes; Green: Low altitudes.

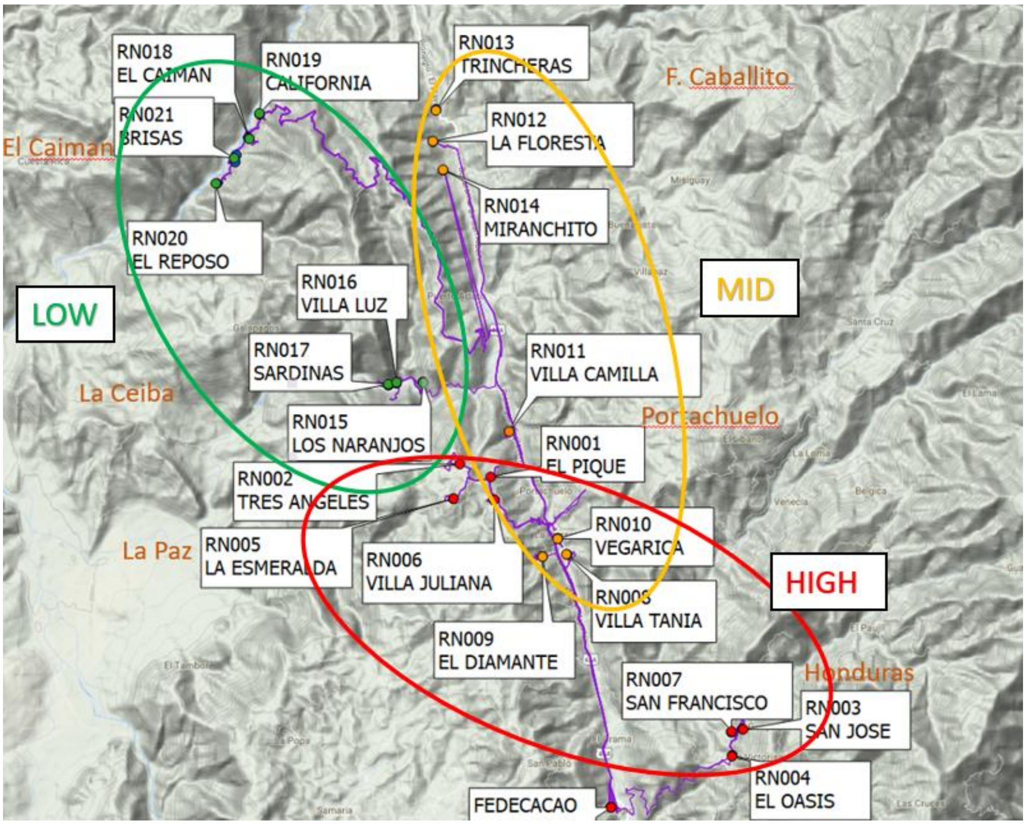

Figure 3.4: Selected farms in Rionegro. Santander, Colombia, with names of selected villages. Red dots: High altitudes; Orange dots: Mid altitudes; Green dots: Low altitudes.

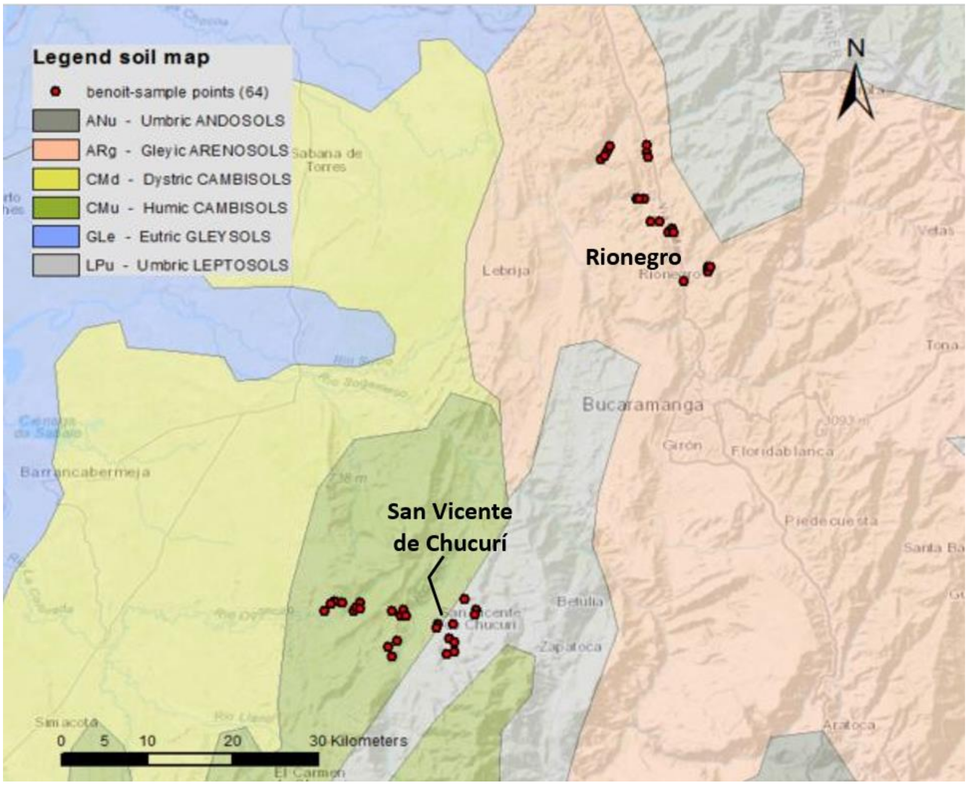

Figure 3.5: Soil type in San Vicente de Chucurí: SVHigh: Umbric Leptosol, SVMid&SVLow: Humic Cambisol; Rionegro: Gleyic Arenosols. WRB classification. (SOURCE: ISRIC, http://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/436bd4b0-7ffc-4272-be57-686b7d7eea7d)

Table 3.1: Soil type in each location (WRB) and Climatic data from the two regions in each altitude. (SOURCES: ISRIC, data.isric.org and www.worldclim.org)

	ALTITUDES		
	HIGH	***MID***	***LOW***
SAN VICENTE DE CHUCURÍ			
Soil type	Umbric Leptosols	Humic Cambisols	Humic Cambisols
Mean Annual Temperature (°C)	21.5	24.0	25.6
Precipitation (mm/year)	1522	1776	2174
RIONEGRO			
Soil type	Gleyic Arenosols	Gleyic Arenosols	Gleyic Arenosols
Mean Annual Temperature (°C)	22.8	23.5	25.9
Precipitation (mm/year)	1640	1621	2061

3.2.2 Survey

A socio-economic survey was conducted with the selected farmers using a semi structured questionnaire. The following information were collected during the survey:

1) Demographic characteristics (e.g. gender, age, educational level, experience of farmers in cocoa cultivation)
2) Farm characteristics (e.g. size of the farm and cocoa cultivation, age of cocoa trees, cocoa varieties planted)
3) Farm management practices (e.g. weed, pests and diseases control, fertilization application)
4) Post-harvest practices (e.g. information about harvest, pod storage, fermentation and drying)
5) Training of the farmers
6) Income and expenditure of the households and the farms

The complete survey questionnaire is provided in the Appendix.

3.2.3 Soil sampling

Soil samples were taken in each selected farm for analysis. The upper organic and fermentation layer were removed, and soil was sampled at a 0–30 cm depth with an auger. This process was repeated 10 times at different spots for each farm. The distribution of the sampling was at random over the whole area, by asking the farmer to look for 10 representative plots where the cocoa trees grow. At the end, all samples were mixed to form a composite sample per farm. The composite soil was air dried, sieved to 2 mm, stored in a plastic zip-bag and labelled as in the survey (SV0XX & RN 0XX). The soil samples were sent to Ghent University for analysis.

3.2.4 Bean sampling

In order to have as less as possible variation in time between the moment of harvest and the transportation to Ghent, Belgium, the cocoa beans were sampled by the farmers themselves. The prepared samples were recollected at the end of the month of October. The samples consisted of 2.5 kg dried cocoa beans per farm, all varieties mixed.

3.3 Laboratory analysis

3.3.1 Soil analysis

Dried soil samples were ground with a ball mill to obtain fine, homogeneous samples and used for analysis.

3.3.1.1 pH

Both pH KCl and pH H_2O were measured with a 1:2.5 soil: liquid mixture. Exactly 25 mL 1M KCl and distilled water respectively was added to 10.0 grams of air-dried fine soil sample. The mixtures were shaken for 2 hours and measured with a pH electrode.

3.3.1.2 Soil exchangeable bases

The soil sample (2.0g) was extracted with 1M NH_4OAc solution at pH 7. The soil solution was shaken for 2 hours and the solid was separated by centrifugation (10 min at 6000 min^{-1}). The addition of NH_4^+ in excess to the soil, displaced the rapid exchangeable alkali and alkaline cations from the exchange sites of the soil particles. The concentrations of Na, K, Ca, Mg and Al were subsequently analyzed by ICP-OES.

3.3.1.3 Carbon (C) and Nitrogen (N) percentages and Isotopes

For analysis of %N and %C and their isotopes, all 42 soil samples were used. Samples for $\delta^{15}N$ and $\delta^{13}C$ analyses were prepared by weighing duplicate 1.2 ± 0.12 mg (1.08-1.32 mg) subsamples into tin foil capsules. The N and C isotopes were assayed by combustion of the whole material to N_2 and CO_2 gases in an Elemental Analyzer - Isotope Ratio Mass Spectrometer (EA-IRMS) (20–22, SerCon, Cheshire, UK) using helium as carrier gas. The gases were separated on a packed molecular sieve GC column and sent sequentially to the inlet of a PDZ Europa ANCA-SL (Automated Nitrogen Carbon Analyzer - Solids and Liquids) interfaced with a SerCon 20-22 IRMS and with SysCon electronics (Sercon, Cheshire, UK) in continuous flow mode. The isotope ratios were measured relative to laboratory standards, which are adjusted to the sample size and have been calibrated against international standards by IAEA -. The final delta unit is expressed relative to international standards VPDB (Vienna PeeDee Belmenite) for 13C and AIR for 15N.

3.3.1.4 Bio-available P

The resin method was used to measure the bioavailable P in the soil. First, resin strips were regenerated by using 0.5M $NaHCO_3$ (pH 8.5). A one gram sample was shaken during 16 hours with 2 resin strips in 30 mL MilliQ water, followed by a shaking of 20 hours with 20 mL 0.5M HCl. The HCl solution was then used to measure the bioavailable phosphorus present in the soil sample using a Phosphate Colorimetric Assay Kit.

3.3.1.5 Total Cadmium

The total concentration of heavy metals present in the soil was determined with aqua regia. About 0.5g of soil was diluted with 3:1 volume of HCl and HNO_3 and placed on the hot plate for 2 hours. The mixture was filtered, and the filtrate was used in the ICP OES.

3.3.1.6 Bio-available Cadmium

For the plant available concentration of heavy metals in the soil, 10.00 g of air dried soil was added to 50mL of .0.01M CaCl2 (extraction medium). After shaking for 2 hours, the filtered extract was acidified with some drops of nitric acid. The bio-available cadmium and other heavy metals were measured using the ICP-OES.

3.3.2 Bean analysis

3.3.2.1 Bean count

For the analysis of the bean count, 100 grams of beans were weighed for each sample irrespective of size but excluding flat beans. The number of beans were counted for every 100 grams to determine the bean count. A triplicate determination was done for every sample.

$$Bean\ count = \frac{Number\ of\ beans}{Mass\ of\ whole\ beans} * 100$$

From that analysis, the average bean mass can also be calculated.

3.3.2.2 Cut test

The cut test was done by placing 50 beans on the guillotine, an equipment which cut lengthwise through the middle of the bean to expose the cut surface of the cotyledons. Both halves were examined in daylight for slaty beans, purple beans, brown beans, purple-brown beans, germinated beans, mouldy beans or other defects. The number of these types of beans were counted and expressed as percentage of the total number of beans used. In total 150 beans were cut per sample. The percentage count of each colour attribute was used to calculate the cut test score as:

$$Cut\ test\ score = (10\ x\ \%\ Brown) + (5\ x\ partly\ purple/Brown) + (0\ x\ \%\ purple\ and\ slaty)$$

Hereafter all the sliced beans were winnowed by hand and milled with a stainless-steel grinder into powder for the other analyses.

3.3.2.3 pH and titratable acidity

Ten grams of ground cocoa beans was homogenized in 90 ml hot distilled water, stirred for about 30 s and filtered using Whatman No. 4® filter paper and cooled to 20–25ºC. Twenty-five (25) ml aliquot of the resulting filtrate was used to measure the pH with a pH meter probe in duplicate. Titratable acidity was determined on the 25 mL filtrate by titrating to an end point pH of 8.1with 0.1 N NaOH solution.

While the pH measures the “strength” of acid in a solution, also called “active acidity”, titratable acidity deals with measurement of the total acid concentration contained within a food (also called total acidity). Titratable acidity is a better predictor of acid’s impact on flavour than pH and will be calculated as follow (S.S. Nielsen, 2014):

$$\%\ acid\ \left(\frac{wt}{wt}\right) = \frac{N * V * Eq\ wt}{W * 1000} * 100$$

Where: N = normality of titrant, usually NaOH (mEq/ml)

V= volume of titrant (ml)

Eq. wt. = equivalent weight of predominant acid (mg/mEq)

W = mass of sample (g)

1000 = factor relating mg to grams (mg/g) (1/10 = 100/1000)

3.3.2.4 Moisture content

Empty moisture cans, filled with acid wash sand and a glass rod were placed in an oven overnight. The next day, the cans were placed in a desiccator to cool. Once cooled, the filled cans were weighed (w1) and 5 grams of sample were added (w2) and placed back in the oven for 4h. The cans were removed from the oven after 4h, placed in the desiccator and weighed (w3) once cooled. This process was repeated until the mass (w3) was constant.

The moisture content was calculated as follows:

$$\%Moisture\ content\ (wt/wt) = \frac{(w1 + w2) - w3}{w2}$$

3.3.2.5 Fermentation index

The fermentation index (FI) was determined according to the method of Gourieva & Tserevitinov (1979), with slight modifications. A mixture of 50 ml of methanol:hydrochloric acid (97:3) solution was added to 0,50 g of grinded cocoa nibs. The mixture was cooled in a refrigerator for 30 min at 4°C. Then, by filtration, through a Whatman No.40 filter paper, under slight low vacuum a clear filtrate was obtained. This was made up to volume in 50 ml volumetric flask. The fermentation index was obtained by calculating the ratio of absorbance at 460 nm and 530 nm using a UV-Visible spectrophotometer (Varian, USA). All the samples were analysed in duplicate.

3.3.2.6 Protein content

Quantification of protein content was performed by measuring total nitrogen using the Kjeldahl method.

$$\%\mathrm{N} = N\ HCl \times \frac{corrected\ acid\ volume}{g\ of\ sample} \times \frac{14\ \mathrm{g\ N}}{mol} \times \frac{100}{1000}$$

Where: *N HCl = normality of HCl in mol/1000ml*
Corrected acid vol. = (ml std. acid for sample) – (ml std. acid for blank)
14 = atomic weight of nitrogen

A factor is used to convert percent N to percent crude protein. Most proteins contain 16% N, so conversion factor is 6.25 (100/16 = 6.25) (Nielsen and Chang, 2014)

3.3.2.7 Fat content

The fat content was extracted using Soxhlet method (Nielsen and Chang, 2014). Percent fat was calculated as:

$$\%Fat\ on\ dry\ weight\ basis = \left(\frac{g\ of\ fat\ in\ sample}{g\ of\ dried\ sample}\right) * 100$$

3.3.2.8 Total bean Cadmium

Aqua Regia digestion was applied for the extraction of the heavy metals in the beans. 1.000g of bean sample was diluted in 2 mL distilled water, 3 mL concentrated hydrochloric acid and 1mL concentrated nitric acid, covered with a watch glass and allowed to react overnight. The next morning it was boiled progressively for 2 hours, cooled, and filtered. The filtrate was diluted to 50 mL and placed into the ICP-OES.

3.4 Statistical analysis

All statistical analyses were conducted with R version 3.4.3 (R Core Team, 2017).

Descriptive analysis was done for the survey results.

To look at the influences of regions and the three altitudinal ranges on the beans and soil parameters a two-way ANOVA statistic test was used. Region (Rionegro and San Vicente) and altitude (High, Mid, Low) were defined as the factors (or main effects or independent variables). The soil and bean parameters of each farm were used as dependent variables. The same for the differences between the different locations (RNHigh, RNLow, …) on the bean, climate and soil parameters. This was done with the "multcomp" package (Torsten Hothorn, Frank Bretz and Peter Westfall, 2008).

To assess the direct impact of the soil, the management and abiotic factors on the bean parameters, lmerTest (Kuznetsova A, Brockhoff PB and Christensen RHB, 2017) was used, performing a linear mixed models effects analysis. As fixed effects, we entered the abiotic factors (i.e altitude, annual precipitation and mean annual temperature), soil parameters (i.e. pH H2O, pH KCl, N, C, Exch Al, Exch Ca, Exch K, Exch Mg, Exch Na, Phosphorus and ECEC) and the farming practices (i.e. surface of cocoa, age of the cocoa trees, pruning frequency per year, pesticide applied per year, fungicide applied per year, storage time, fermentation time and drying time). The region where the farm was located (SV/RN) was set as a random intercept. Residual plots were inspected to check assumption violations and general model fit. The full model was checked for deviations from homoscedasticity or normality. The approximate P-values were calculated using a Satterthwaite approximation for each parameter and a multiple stepwise regression was done manually using the Akaike's information criterion (AIC) as stopping criterion, which penalizes for the number of predictor variables that are retained in the model. The best model (based on AIC) was inspected on multicollinearity by calculating the variance inflation factors (VIF). Every variables with a VIF higher than 3 were removed and the single variables with the strongest Pearson correlation with the response variable was retained (Zuur, Ieno and Elphick, 2010).

4. Results & Discussion

The outcome of the 2-way ANOVA and mixed effect layers can be found in annex (tables A.2 and.3). All outcomes and mentioned statistics are based on the 42 investigated farms, situated in Rionegro (RN) (blue) and San Vicente de Chucurí (SV) (orange), in Santander, Colombia.

- Regions: Rionegro (RN) and San Vicente de Chucurí (SV)
- Altitudinal ranges: High (>900 masl), Mid (600 – 900 masl), Low (<600 masl)
- Locations: RNHigh, RNMid, RNLow, SVHigh, SVMid, SVLow

4.1 Climate

Suitable temperature and precipitation are primordial for cocoa yield. According to Sys et al (1993) the most optimal mean annual temperature for cocoa is around 23 -28 °C and the most optimal annual rainfall is between 1600 and 2500mm (Sys *et al.*, 1993; Wood and Lass, 2008). In table 3.1 the mean annual temperatures (MAT) and annual precipitations are presented in the different altitudinal ranges from both regions. So, according to Sys *et al.* (1993), the optimal values, the most suitable areas in terms of optimal climatic conditions are encountered in the low altitudes.

4.2 Survey

4.2.1 Demographic characteristics

Table 4.1 shows that the majority (83%) of the farmers were men. More than 90% of those male farmers had an age over 40 years and 40.5% of them were even older than 60 years. Most of these farmers had almost no education: more than 75% of all farmers did not make it further than primary school. The majority contributed most of their lives to the cultivation of cocoa., 71% of the farmers have spent more than 20 years on cocoa.

*Table 4.1: Demographic characteristics of surveyed farmers (**in** %) in Rionegro and San Vicente de Chucurí, Colombia*

	Total (n=42)	**Rionegro (n=21)**	**Low (n=7)**	**Mid (n=7)**	**High (n=7)**	**San Vicente (n=21)**	**Low (n=7)**	**Mid (n=7)**	**High (n=7)**
Gender									
Male	83	76	86	57	86	90	86	86	100
Female	17	24	14	43	14	10	14	14	0
Age of Farmers (yrs)									
21 – 40	7	5	0	0	14	9.5	0	14	14
41 – 60	52.5	52	71	57	29	52.5	71	43	43
>60	40.5	43	29	43	57	38	29	43	43
Educational Level									
None	12	18	14	29	14	5	14	0	0
Primary	64	62	86	43	57	67	71	57	71
Secondary	19	15	0	14	29	24	14	43	15
Higher Education	5	5	0	14	0	5	0	0	14
Cocoa farming years									
1-10	15	15	0	14	28	15	43	0	0
11-20	14	24	14	28	29	5	0	0	14
21-30	24	15	43	28	14	34	29	28	0
>30	47	46	43	30	29	46	28	72	86

4.2.2 Farm characteristics

In the hilly topography of Santander, a clear difference has been observed between the farm area of the high and low altitudinal ranges (figure 4.1). In the high altitudinal range almost all the farm area was used for cocoa cultivation whereas in the low range more than half of the farm area was dedicated to other activities such as cattle, pisciculture and other crops. This might be due to the warm and humid climate conditions where *Monilia* and other diseases are more likely to occur. Between the regions, larger cocoa areas were observed in San Vicente de Chucurí with an average total farm size of 14 ha (on average 6.5 ha dedicated to cocoa) and Rionegro with 9.5 ha on average of which 3.5 ha of this land was used for cocoa. (figure 4.2).

The farms were in general quite old. About 40% of the farms were older than 30 years. Meanwhile there was a trend in the number of varieties planted in cocoa: high altitudes had significantly ($p< 0.05$) more cocoa varieties than the low range (figure 4.3 - table 4.2). The main cocoa varieties are plotted in figure 4.4. The cultivar CCN 51 was found in 95% of the farms in SV and 80% of the farms in RN. ICS cultivars were also popular in those two regions (61% SV, 76% RN). All main varieties were found in both regions and were typically found in mid and high altitudes while low altitudes had principally hybrids and CCN 51 (figure 4.5). Table 3.1 shows that low altitudes have a more humid and warmer microclimate. This will increase the presence of pests and diseases. This brings us to an apparent paradox: according to Sys *et al.* (1993), the low altitudes have the most optimal climate conditions for the cultivation of cacao, but since a lot of high quality cocoa varieties are susceptible to diseases like Monilia (ICS 39, ICS 60, FSV 41, EET 8), cultivating this quality varieties in this altitudinal range would be unsuitable and less profitable, due to the aforementioned increased presence of pests and diseases. As a result, the lower regions cultivated mostly the CCN51 and hybrid varieties, while the high altitudes farmers could afford to cultivate a broader spectrum of cultivars, with better physical characteristics (see table A.4 in annex). This introduced cultivar from Ecuador, CCN 51, was intermixed with the regional cultivars and is known for its high productivity and resistance against diseases. However, despite its productivity and robustness, CCN 51 does not meet the fine flavour requirements because of its less desirable organoleptic quality and thus reduces the overall quality of the region (Boza *et al.*, 2014).

Information about the properties of the most present varieties (i.e. resistance against Monilia, bean count, yield, etc.) can be found in table A.4 (annex).

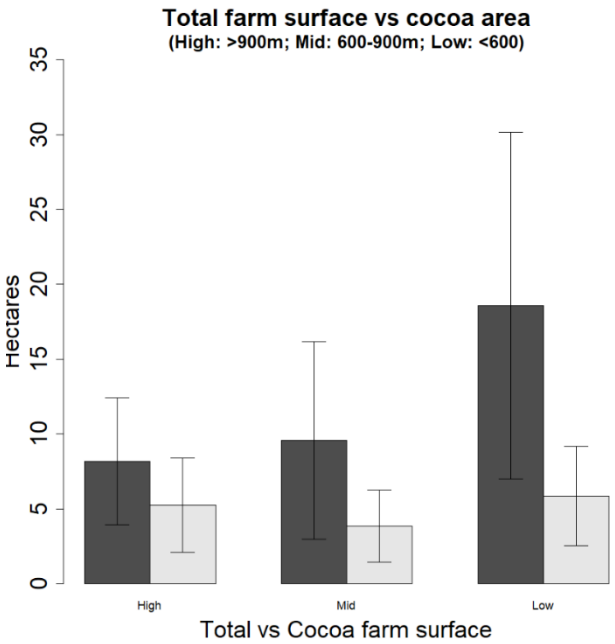

Figure 4.1: Barplots comparing the distribution of the total farm area in ha (dark bars) with the area dedicated to cocoa cultivation, going from High (left) to Low (right) altitudes in San Vicente and Rionegro.

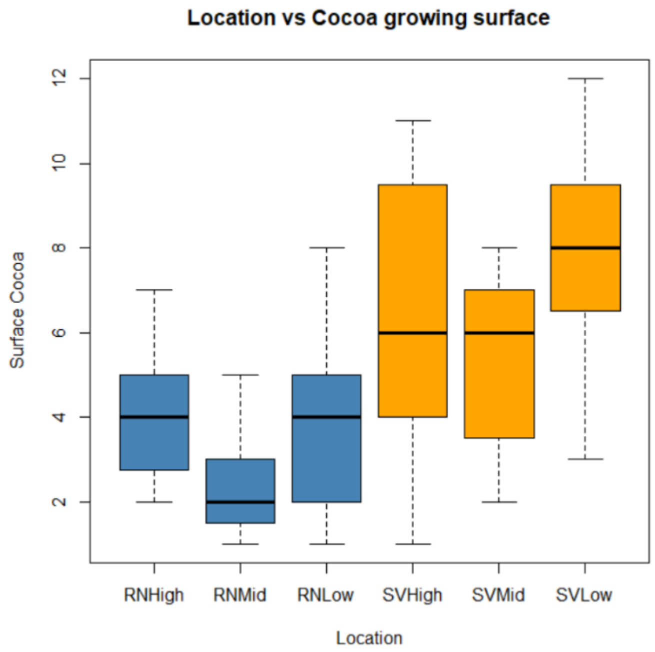

Figure 4.2: Boxplots showing distribution of cocoa area (ha) in each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl)

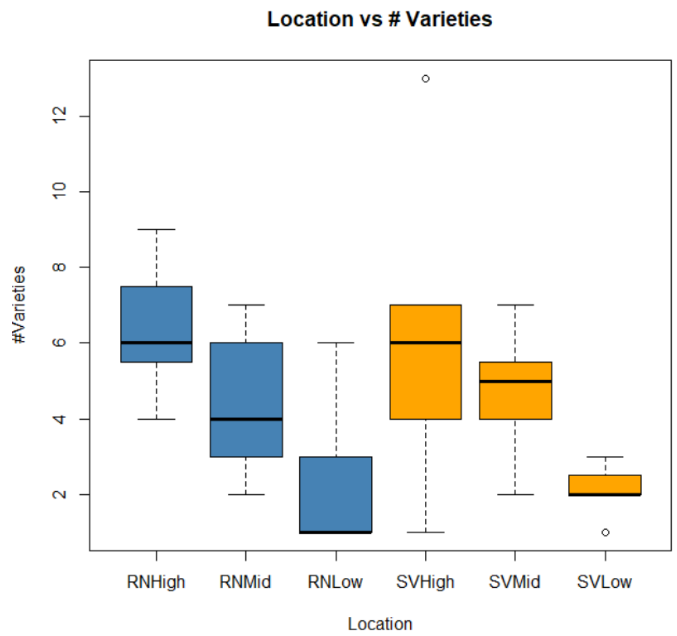

Figure 4.3: Boxplots showing distribution of the number of cocoa varieties in each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl

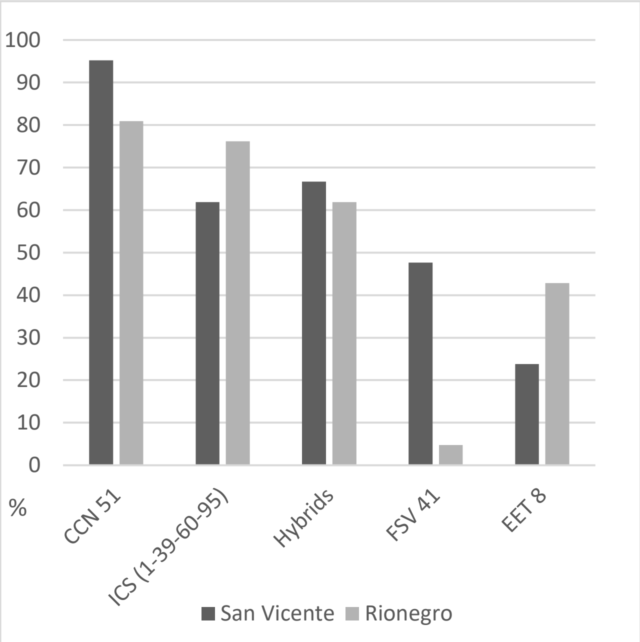

Figure 4.4: Percentage of varieties present in each region (dark: San Vicente, light: Rionegro). The Y-axis gives the presence of each variety per farm. A presence of 100% means the cultivar was present at all farmers in that region

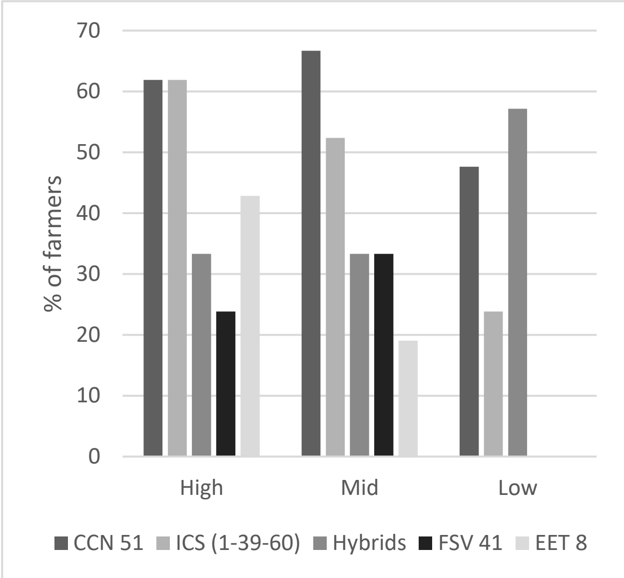

Figure 4.5: Distribution (in %) of the main varieties according to the altitude (High: >900 masl, Mid: 600-900 masl, Low: <600 masl).). The Y-axis gives the presence of each variety per altitude. A presence of 100% means the cultivar was present at all farmers at the given altitude

Table 4.2: Farm characteristics from surveyed farms (in %) in Rionegro and San Vicente de Chucurí, Colombia

	Total (n=42)	**Rionegro (n=21)**	**Low (n=7)**	**Mid (n=7)**	**High (n=7)**	**San Vicente (n=21)**	**Low (n=7)**	**Mid (n=7)**	**High (n=7)**
Age of farm (years)									
1-10	19	14	0	0	43	24	42	14	14
11-20	24	24	0	43	29	24	29	0	43
21-30	17	10	0	29	0	24	29	14	29
>30	40	52	100	29	29	28	0	72	14
Cocoa Varieties planted									
0-2	29	24	57	14	0	33	71	14	14
3-4	26	29	29	43	14	24	29	14	29
5-6	26	29	14	29	43	24	0	57	14
>6	19	19	0	14	43	19	0	15	43

4.2.3 Farm Management

The maximum recorded **productivity** in both regions was 2000 kg per ha in 2016. Figure 4.6 shows that 50 % of the farms had a production of maximum 600 kg ha^{-1}. About 17% had a production which yields more than 1000 kg/ha and only 2% produced more than 1500 kg ha^{-1}.

83% of the farmers **fertilized** their cocoa cultivation. As can be seen in table 4.3, it was only in the low altitudinal range that farmers tended not to fertilize. Figure 4.7 shows the proportion of farmers (in %) using pesticides and fertilizers. The percentage is based on 7 farms per altitudinal range and per region. The most used herbicide was glyphosate. Attakil was mostly used as insecticide since ants were the major problem. All the farmers applicated fertilizers through the soil. Mostly two times a year, sometimes only one or three times. The relatively high absence of fertilizing on the low altitudes (< 600 m asl) is surprising. Some farmers used organic "homemade" fertilizers from their chicken and cattle, while the others bought NPK(Mg) fertilizers as 18/18/18, 17/6/18/2 (mostly in San Vicente) and 15/15/15 (mostly in Rionegro). Depending on the used fertilizer, the quantity went from 100 to 5000 g/plant. Fertilizers should be applied according to recommendations and checked for cadmium level, especially where soil Cd levels are known to be high (see section 4.4.8 Cadmium) (Bateman, 2015).

By talking about the pests and diseases it is important to clarify that only the main threats were reported during the survey. The main cocoa diseases are listed per region and altitudinal range in figure 4.8. The major diseases are the Broom Disease or "Escoba de Bruja" or Witches (*M. perniciosa*), Monilia (*Moniliophtora roreri*) and black pod disease (*Phytophtora palmivora*) (see figure 4.9). With 86% and 95%, Rionegro seemed more susceptible to respectively the witches broom disease and Monilia. The latter dominated in both regions (90%) and occurred also at 100% in both low ranges. Phytophtora was less present and more distributed over the farms. On the other hand, pests were also a threat, yet they affected the farms less than the diseases did. The main pests were ants (86% of presence) followed by the capsids (*Distantiella theobroma*) (36%). Another main pest was the cocoa fruit borer (*Carmenta theobromae*): 24% in Rionegro and absent in San Vicente. Squirrels and woodpeckers were also not well received.

Multipurpose trees are trees, which serve more than one function. Besides being a tree that aids in the biodiversity and the shade of the cocoa trees, they also generate extra income for the farmers. The main multipurpose trees include fruit trees like plantains (*Musa spp.*), citrus (*Citrus spp.*), avocado (*Persea spp.*), and shade trees which can be used as timber in the future: Matarraton (*Gliricidia sepium*), Cedro (*Cedrella odorata*), Nauno (*Albizia guachapele*), Moncorro (*Cordia gerascanthus*), Anaco (*Erythrina sp*). The results in table 4.3 shows that all farmers planted at least 2 other species and that it was common to see at least 5 or more shade trees intercropped with the cocoa trees.

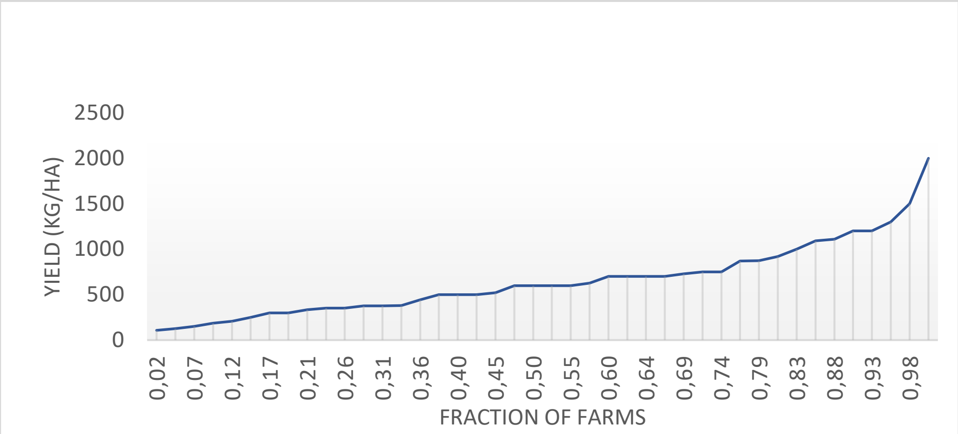

Figure 4.6: Cumulative representation of the total yield in kg per hectares. The value of 1 on the x-as represents 100% of the farms.

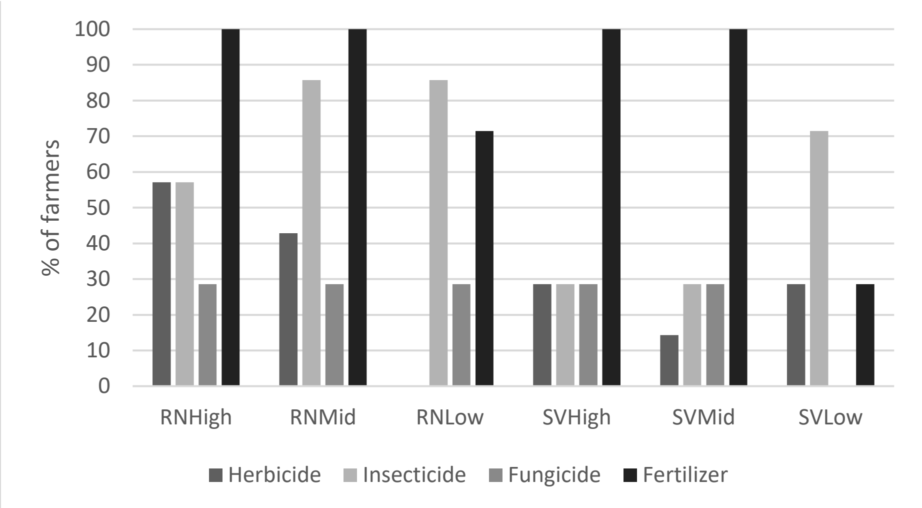

Figure 4.7: Use of pesticides and fertilizers in Rionegro and San Vicente de Chucurí, Santander, Colombia. Divided into the different locations (High: >900 masl, Mid: 600-900 masl, Low: <600 masl). The Y-axis gives the presence of each pesticide or fertilizer per farm. A presence of 100% means the pesticide or fertilizer was applied by all farmers in that location

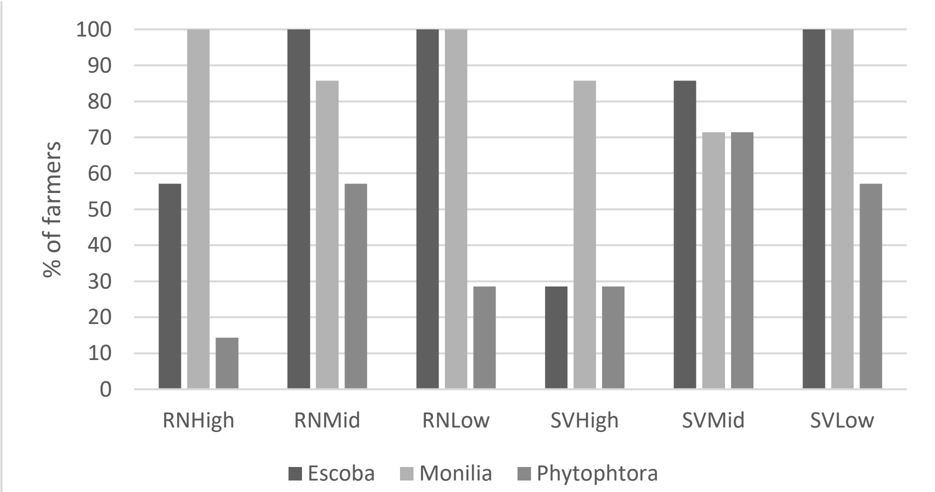

Figure 4.8: Distribution of major diseases in the different locations. The y-axis represents the presence of the different diseases in the different locations. 100% means (in % of farms per region and altitudinal range (High: >900 masl, Mid: 600-900 masl, Low: <600 masl). The Y-axis gives the presence of each disease per farm. A presence of 100% means the disease was present at all farmers in that location

Figure 4.9: Pictures of pests and diseases seen on field:
Top row, left to right: Monilia, Witches Broom disease, Phytopthora;
Bottom row, left to right: Capsids, Ants, woodpecker

Table 4.3: Management practices from surveyed farms in Rionegro and San Vicente de Chucurí, Santander, Colombia

	Total (n=42)	Rionegro (n=21)	Low (n=7)	Mid (n=7)	High (n=7)	San Vicente (n=21)	Low (n=7)	Mid (n=7)	High (n=7)
Fertilizer application									
Yes	83	95	71	100	100	88	29	100	100
No	17	5	29	0	0	12	71	0	0
Major Diseases									
M. perniciosa	79	86	100	100	57	71	100	86	29
Monilia	90	95	100	86	100	86	100	71	86
Phytophtora	43	33	29	57	14	52	57	71	29
Major Pests									
Capsidos	36	24	29	14	29	48	0	57	86
Carmenta	12	24	0	14	57	0	0	0	0
Xileborus	29	14	0	0	43	43	14	43	71
Ants	86	95	86	100	100	76	100	57	71
Number of multipurpose trees									
2-4	12	19	29	14	14	5	0	0	14
5-6	38	38	57	43	14	38	43	29	43
7-8	26	19	0	14	43	33	43	43	29
>9	24	24	14	29	29	24	29	29	14

4.2.4 Post-Harvest Management

The outcome of the postharvest techniques is summarized in table 4.4.

The pod storage time never exceeded 8 days, however high-altitude farms contributed the most to the 1-2 days storage. One day storage means the farmers ferment the beans in less than 24 hours after harvesting it. FEDECACAO recommended to keep the storage time as short as possible (FEDECACAO, 2016), while literature states pod storage can have a positive influence on the bean flavour, but only when well controlled because the risk of moulds increases considerably(Tomlins *et al.*, 1993; Saltini, Akkerman and Frosch, 2013). More than 50% of all the farmers exceeded the recommended time.

The management of the fermentation process consists of two stages: first, the number of days of fermentation, secondly the number of turnings during the fermentation. In Rionegro, 81% ferment their beans for 5-6 days while the majority in San Vicente apply to 6-8 days fermentation. The majority in RN and SV apply 3-5 turnings per fermentation (71% and 48%). Notice that the turnings in San Vicente are almost the same as in Rionegro, yet the fermentation time is higher (figure 4.8).

Despite the fact that literature favors heaps as method of fermentation, 90 % of the farmers fermented the harvested beans in wooden boxes as recommended by FEDECACOA (Tomlins *et al.*, 1993; Guehi *et al.*, 2010). As can be noticed in figure 4.10 and in table 4.5, the fermentation time varied a lot (3 to 9 days) but with a peak on the 6th day. The duration of fermentation will have an impact on the flavour of the cocoa beans since it generates the different flavour precursors and the amount of amino acids. Beans that are fermented too long, also called over-fermented beans will reduce the flavour precursors and the pH will decrease which will result in the development of off-flavours. Under-fermented beans on the other hand, will have a high amount of polyphenols, which will result in an increased astringency, bitterness and antioxidant capacity (Saltini, Akkerman and Frosch, 2013).

All the farmers in San Vicente, without exceptions used their roof ("elba" - figure 4.12) for drying the beans. While in Rionegro, only 43% did. These farmers primarily put the beans on the ground, which is not recommended especially when domestic animals and livestock run freely (figure 4.13). All farmers however, used the sun for drying the beans, which gives better results compared to artificial drying (Bonaparte, Alikhani and Madramootoo, 1998). The end of the drying time was decided by the farmer, based on his own criteria (a well-known criterion is when the beans crack by squeezing them) often after 3 to 5 days depending on the weather.

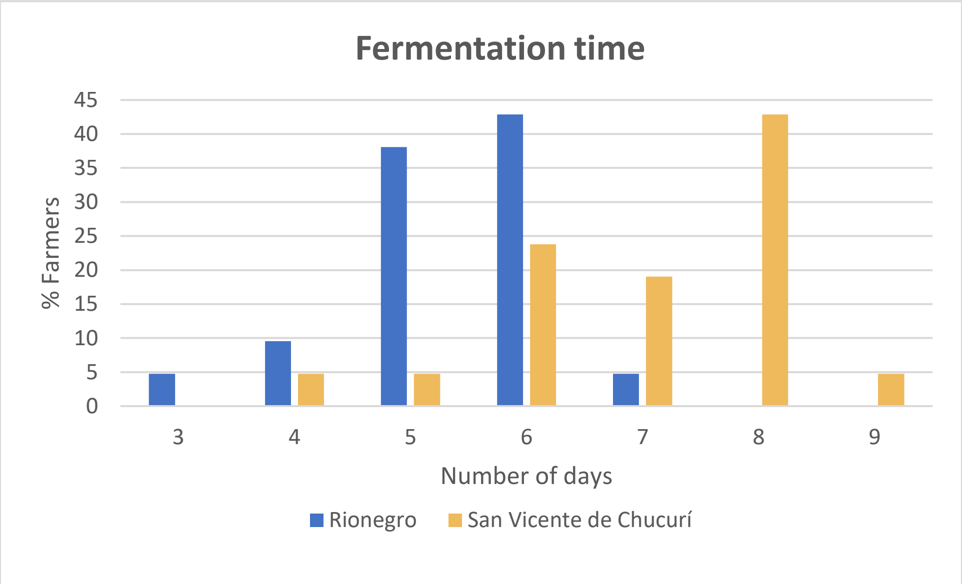

Figure 4.10: Histogram showing distribution of the applied fermentation time in each region (Rionegro (blue), San Vicente (orange))

Table 4.4: Post harvest practices from surveyed farms (in %) in Rionegro and San Vicente de Chucurí, Santander, Colombia

	Total (n=42)	Rionegro (n=21)	Low (n=7)	Mid (n=7)	High (n=7)	San Vicente (n=21)	Low (n=7)	Mid (n=7)	High (n=7)
Pod Storage (Days)									
1-2	43	48	29	43	71	38	14	29	72
3-4	31	33	43	29	29	29	43	29	14
5-6	7	5	14	0	0	10	14	14	0
7-8	19	14	14	29	0	24	29	29	14
Fermentation (Days)									
<5	10	14	29	14	0	5	0	0	14
5-6	55	81	71	86	86	29	43	29	14
>6	36	5	0	0	14	67	57	71	71
Turnings									
0-2	17	10	29	0	0	24	29	14	29
3-5	60	71	57	57	100	48	57	43	43
>5	24	19	14	43	0	29	14	43	29
Drying (Days)									
3	21	29	43	29	14	14	29	14	0
4	57	62	57	57	72	52	57	57	43
5	19	5	0	0	14	33	14	29	57
6	2	5	0	14	0	0	0	0	0

Figure 4.11: wooden boxes used for fermentation in Santander, Colombia

Figure 4.12: "Elba" or roof (on wheels) for drying the fermented cocoa beans. the rooftop is mobile, so it can protect the beans if it rains

Figure 4.13: Drying the beans on the ground; not recommended especially for hygienic reasons

4.3 Soil

An overview of the soil parameters can be seen in table A.1.1 (annex) and in the boxplots (figure 4.14 – 4.16), divided into the different locations.

4.3.1 pH, Nutrients and cadmium

Both **pH-H_2O** and **pH-KCl** were similar in all locations and ranges. The majority of the pH-H_2O had values between 4.5 and 6.0 and pH-KCl between 3.5 and 4.5.

The **carbon content** in the topsoil (0-30cm) had a significant higher percentage at high altitudes ($P<0.01$). Looking at the two investigated regions, San Vicente had a higher carbon percentage compared to Rionegro ($P<0.01$). SVhigh was the location with the highest amount of carbon with significant differences compared to RNLow ($P<0.01$), RNMid ($P<0.05$) and SVLow ($P<0.05$).

The boxplots in figure 4.15 show clearly a trend of decreasing carbon content in the upper soil with a decrease in altitude.

The **nitrogen content** followed the same trend as carbon, but with a higher significance towards region ($P<0.001$) than altitudes ($P<0.05$). As a result, the **C/N** ratio had very significant higher values at high altitudes relative to the low ones ($P<0.001$) and was also higher in Rionegro ($P<0.05$). Similarly to the % C the SVhigh location was higher than RNLow ($P<0.01$), RNMid ($P<0.01$), RNHigh ($P<0.01$), SVLow ($P<0.01$) but also SVMid was significantly higher than RNLow ($P<0.05$).

The **exchangeable Al** was only significantly higher in the high altitudes compared to the low ones ($P<0.05$) while **exchangeable Mg** was higher in the low altitudes ($P<0.05$). The SVLow transect had also significantly more exchangeable magnesium than SVHigh ($P<0.01$), SVMid ($P<0.01$) and RNHigh ($P<0.05$). **Exchangeable Ca, K, Na, and the ECEC** were similar in all different locations.

The mid altitudes ($P<0.05$) and San Vicente ($P<0.01$) had higher values for the **bio-available Phosphorus.** Also, the SVMid transect shows significant higher levels than RNHigh ($P<0.01$), RNMid ($P<0.01$), SVLow ($P<0.01$), RNLow ($P<0.05$) and SVHigh ($P<0.05$).

For both the **total cadmium** as the plant **available cadmium**, San Vicente showed higher values ($P<0.05$) without any significant differences between the altitudes. Cadmium will be discussed in section 4.4.8.

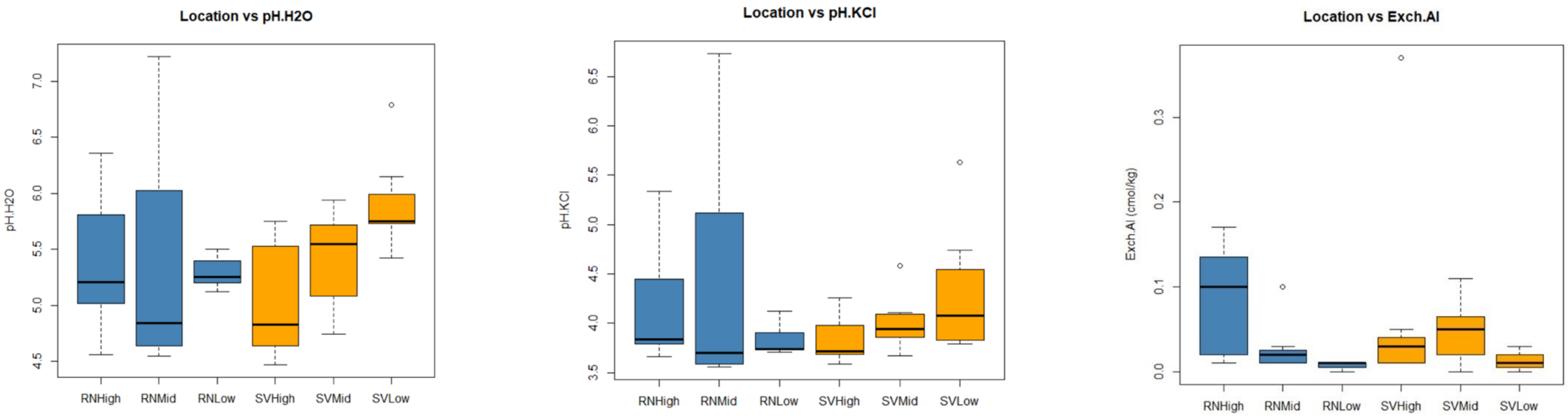

Figure 4.14: Boxplots showing distribution of the pH and exchangeable aluminium in the topsoil (0-30 cm) of each location (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl). Letters represent statistical differences (P<0.05) between the locations using a two- way ANOVA. If no letters are present, it means no significant differences were found.

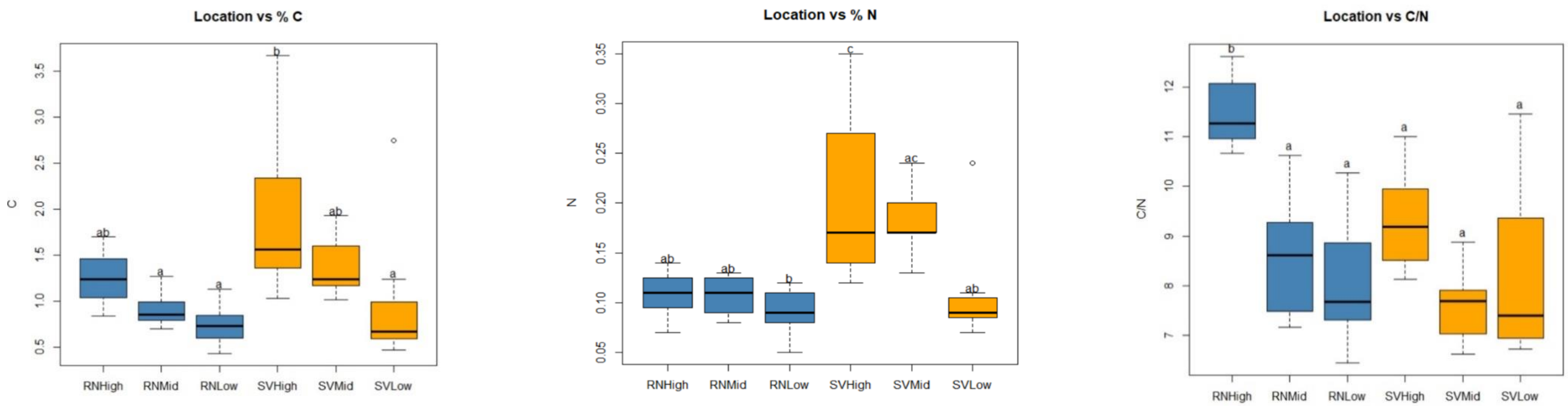

Figure 4.15: Boxplots showing distribution of carbon, nitrogen content and C/N ratio in the topsoil (0-30 cm)of each location (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl). Letters represent statistical differences (P<0.05) between the locations using a two- way ANOVA. If no letters are present, it means no significant differences were found.

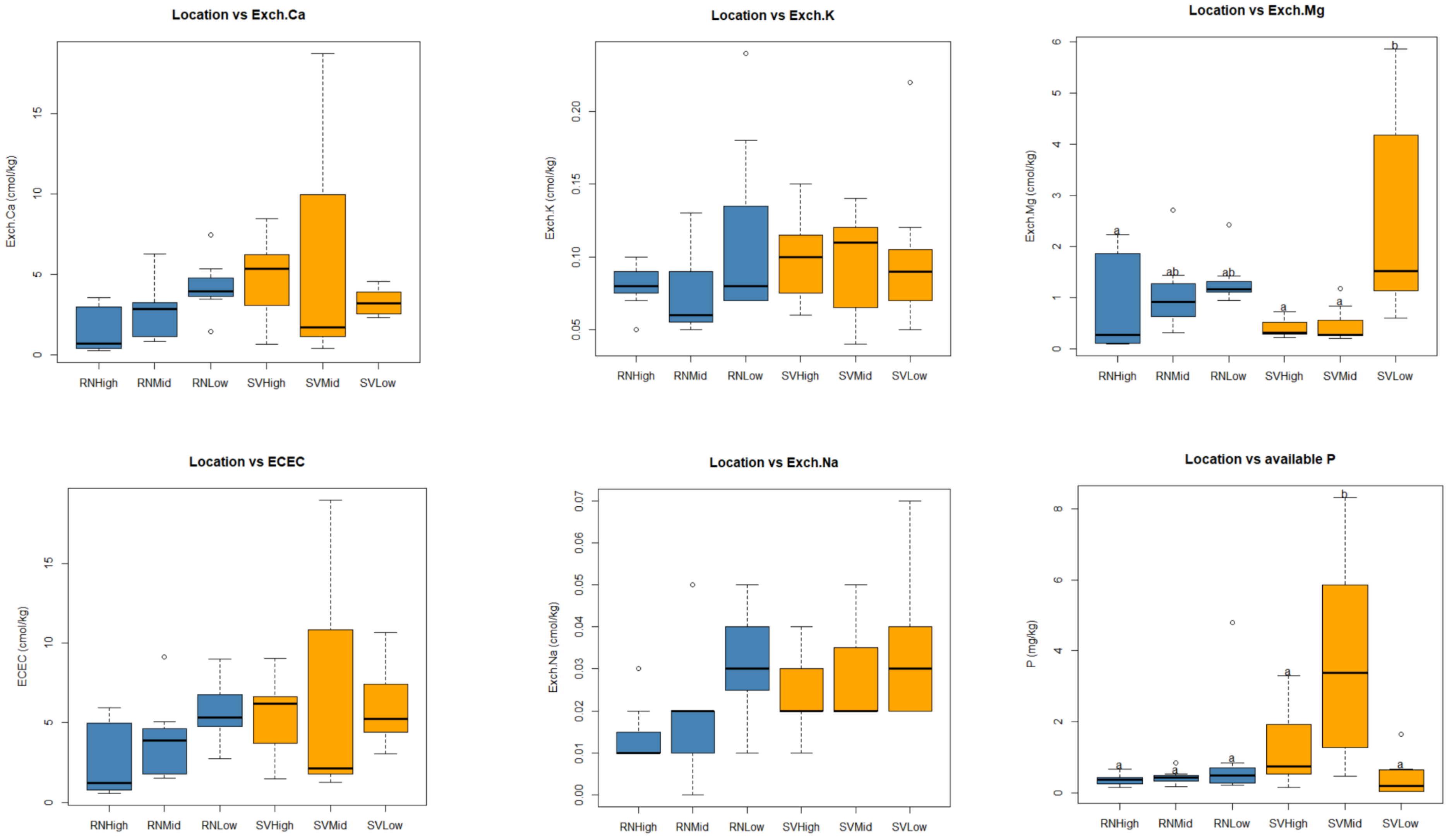

Figure 4.16: Boxplots showing distribution of the different nutrients present in the soil (0 – 30cm) of each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 masl), Mid (600-900 masl) and Low (<600 masl). Letters represent statistical differences (P<0.05) between the locations using a two- way ANOVA. If no letters are present, it means no significant differences were found

4.4 Beans

An overview of the bean parameters can be seen in table A.1.2 (annex) where the significant differences between the different locations can be observed, based on the 2-way ANOVA.

4.4.1 pH and Titratable Acidity

The pH of the beans, together with the acidity content did not show any significant differences between locations and altitudes. The pH ranged between 4.7 and 6.5 while the titratable acidity between 0.36% and 1.37%

The pH of the beans could be explained (R^2=0.25) by the following soil parameters: **pH-H_2O**, **exchangeable Al**, **exchangeable K** (negatively correlated), **exchangeable Mg** and **available P,** according to the mixed effects model. The titratable Acidity had no significant predictors.

While the literature indicates that the farming practices (as storage, fermentation and drying processes) are of crucial importance for the pH and the amount of acids in the beans, the mixed effect model did not show any significant predictor in the management effect.

The "Norma Tecnica Colombiana" NTC 1252 of cocoa beans, suggest an optimal pH between 4.5 – 5.5 for dried cocoa beans and a total content of the organic acids (among others: acetic acids, citric acids and oxalic acids) between 1.2 - 1.6% (Icontec, 2003). These values were calculated through High-Performance Liquid Chromatography (HPLC) which estimate all the organic acids in the beans. This is a more accurate determination than titratable acidity. As a result, the titratable acidity which is only determined by dominant acids in the bean, will have lower values. While the average acidity of each location is almost similar (table A.1.2), large variations are noted on farm level (figure 4.17)

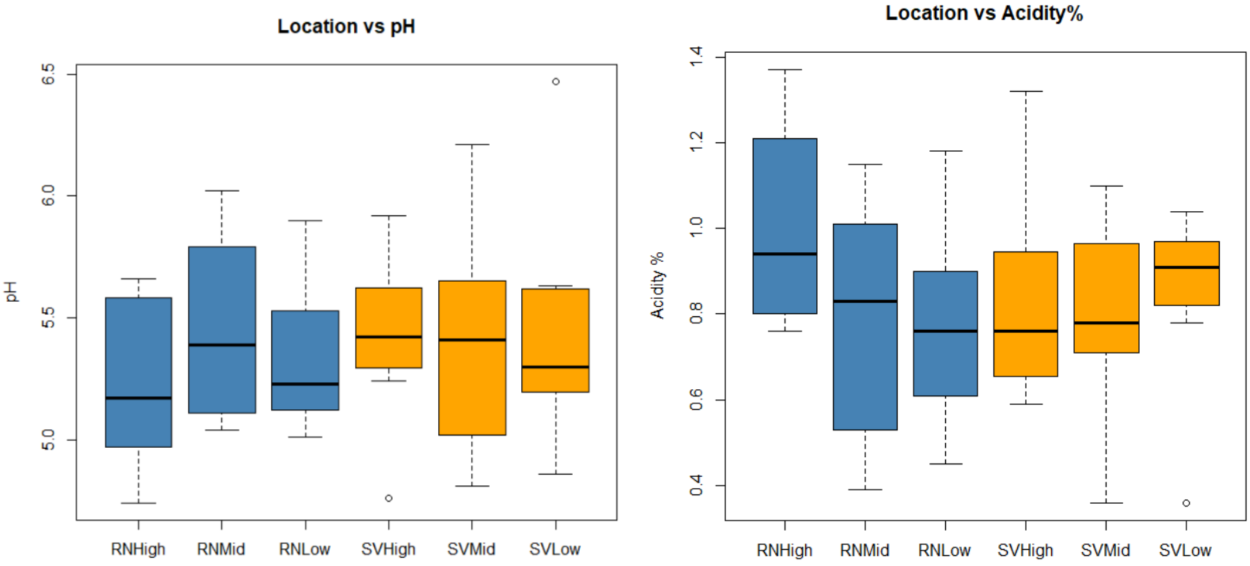

Figure 4.17: Boxplots showing distribution of the pH and titratable acidity present in the soil (0 – 30cm) of each region (first three: Rionegro (blue), Last three: San Vicente (orange)) for the three altitudinal ranges: respectively High (>900 masl), Mid (600-900 masl) and Low (<600 masl). Letters represent statistical differences (P<0.05) between the locations using a two- way ANOVA. If no letters are present, it means no significant differences were found

Soil effect

Very little is known about the influence of the soil properties on the pH of the beans after fermentation and drying.

A hypothesis could be that, as the **pH** of the soil is optimal (between 6 and 7.5) it would have a positive influence for the nutrient uptake. Sys *et al.*, (1993) found a ratio for optimal nutrient uptake K+Na/Mg+Ca to be near 1/50. Figure 4.18 shows a clear influence of the soil pH on the ratio, with a soil pH from 5 having a ratio near to 1/50 (=0.02) and confirms the optimal nutrient uptake corresponding with a soil pH between 5 and 7. Since most of the soils are acidic (between 5- 6), the farms are concentrated around that range. An optimal assimilation of nutrients suggests a good development of the fruits, assuming other factors not being limiting.

The pH of the bean is further influenced by the storage, the fermentation and the drying process. Therefore, the pulp of the bean plays a big role due to its high content of citric acid. The sugars, present in the pulp are converted in alcohol and organic acids during the fermentation which on their turn diffuse into the bean. A high amount of acid diffusing into the pulp will lead to a production of acid beans (Schwan and Wheals, 2004; E. O. Afoakwa *et al.*, 2013; Maïmouna Kouamé, 2015).

Potassium (**K**) represents about 70% of the minerals contained in the cocoa sap of xylem and is important for the translocation of the carbohydrates. Since K is easily and largely absorbed when available, the higher the pH in the soil, the less K will be absorbed relative to **Mg** and Ca, since the ratio will be smaller than 1/50 (see figure 4.18). In the same way, if the soil pH is lower, the ratio will be higher than 1/50 and relatively more K will be absorbed. More potassium means more translocation of carbohydrates. This results in potentially higher sugar contents in the pulp of the beans which, on their turn will be converted in organic acids during fermentation. Figure 4.19 indicates a positive correlation between the pH-H_2O and the pH in the beans, yet further research is needed to confirm this hypothesis.

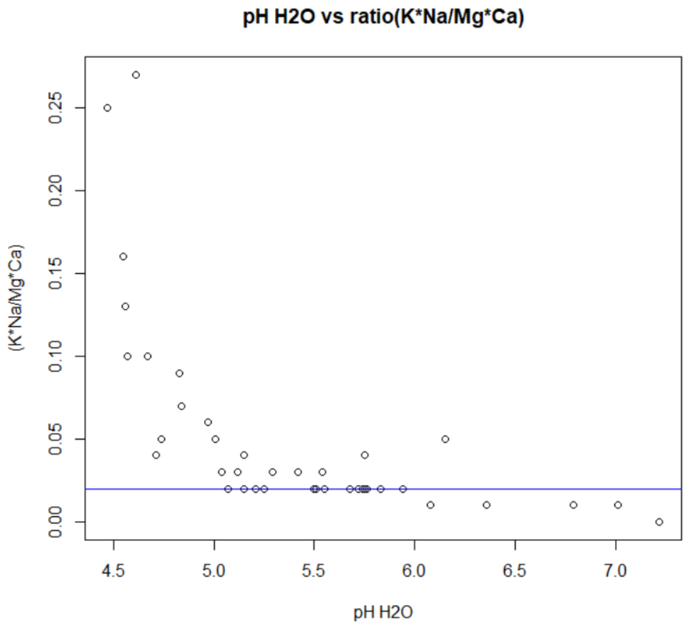

*Figure 4.18: Relation between pH-H2O and optimal uptake ratio K*Na/Mg*Ca. Blue line is the optimal value of the ratio (Sys et al, 1993).*

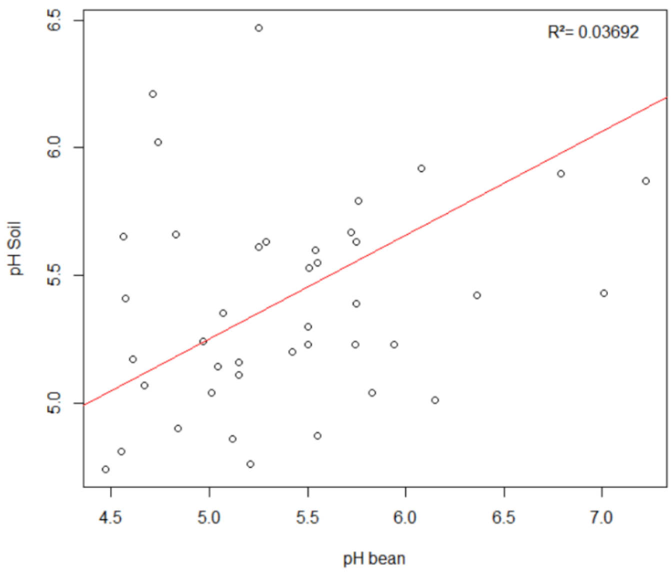

Figure 4.19: Correlation between pH bean and pH soil. Diagonal line represent the trendline with R^2.

4.4.2 Protein content

The beans in Rionegro had a higher **protein %** than in San Vicente (*P<0.01*). The protein content in the beans was found between 10.4% and 13.9%. Altitude did not have a significant effect on the protein content in the beans. The location of RNMid had a significantly higher average protein content than in SVmid (*P<0.01*) and SVlow (*P<0.05*) and the same for RNMid compared to SVMid (*P<0.01*).

Management effect

The linear mixed effect model (LME) (table A.2 in annex) showed a negative relation between the **fermentation time** and the protein content in the dried and fermented bean (R^2= 0.19). The proteins present in the fresh beans are converted into amino acids and peptides by enzymatic degradation. The latter are flavour precursors which are primordial in the flavour formation. The longer the time of fermentation, the more proteins will be degraded into flavour precursors. This is confirmed by the fact that Rionegro fermented their beans for a shorter period than San Vicente (*P*<0.001) (see figures 4.20 – 4.21). So, assuming the dried and fermented beans of each region initiated the fermentation with the same amount of proteins, the apparent effect of one more day of fermentation will result in a decrease of ca. 0.4 % in protein content in the beans and thus more conversion into flavour precursors. Consequently, San Vicente produce more flavoured beans and thus of likely better quality.

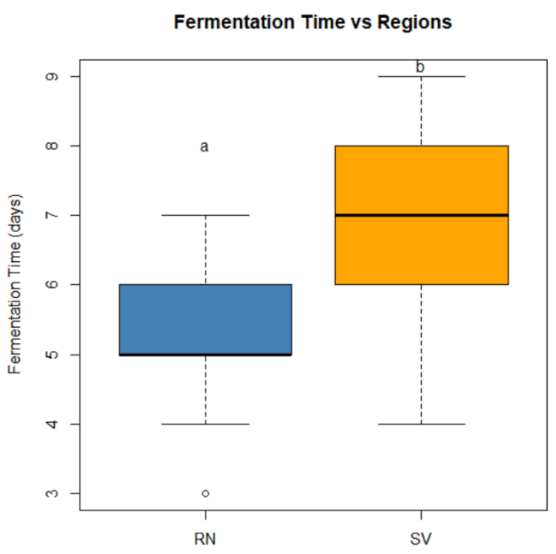

Figure 4.20: Boxplots showing distribution of fermentation time in % present in the cocoa beans of each region (Rionegro (RN) in blue, San Vicente (SV) in orange.). Letters represent statistical differences (P<0.05) between the locations (i.e. RNHigh vs RNMid vs RNLow vs SVHigh vs SVMid vs SVLow using a two- way ANOVA.

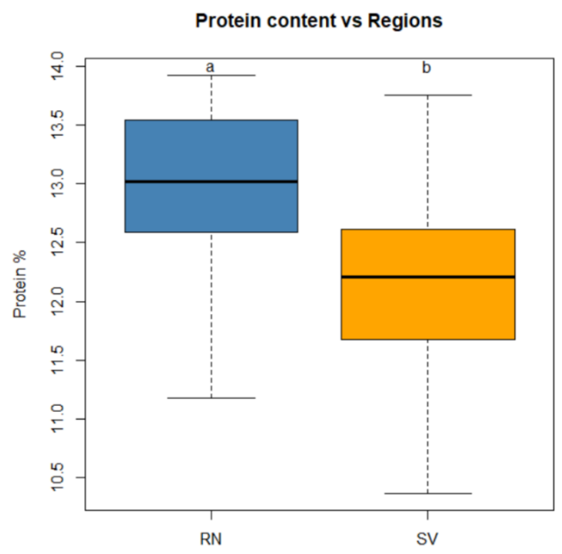

Figure 4.21: Boxplots showing distribution of the protein content in % present in the cocoa beans of each region (Rionegro (RN) in blue, San Vicente (SV) in orange.). Letters represent statistical differences (P<0.05) between the locations (i.e. RNHigh vs RNMid vs RNLow vs SVHigh vs SVMid vs SVLow using a two- way ANOVA.

Soil effect

The effect of the soil on the protein content was partly explained by the **pH**-H_2O and by the regions (R^2_{cond} =0.35 and R^2_{marg}= 0.15) (Table A.2 in annex). From the 35% variance accounted for the protein % was explained by the effect of the soil, 20% was linked to the random effect. As a result, the effect of pH H_2O is very small.

4.4.3 Fat content

All beans had a similar fat content with averages between 52 and 57% and almost no variation between the different locations.

Nonetheless, it was negatively predicted (R^2= 0.42) by the mean annual **precipitation** (*P<0.01*). and the **carbon** percentage (*P<0.001*). It was furthermore positively predicted by the **exch. Al** (*P<0.001*).and **exch. Na** (*P<0.01*). The time and scope of this thesis did not allow to study the possible causal correlations between those parameters.

4.4.4 Moisture content

The beans in San Vicente had a significant higher moisture content (*P<0.01*). Consequently, the mixed effects model showed an influence of the random effect. The only significant fixed effect was the **bio-available phosphorus** (*P<0.01)* but with a low corresponding R^2 (R^2_{cond}=0.246 and R^2_{marg}= 0.150).

The moisture content in the beans was highest in San Vicente (p<0.01). The moisture content should be between 8 and 6.5%: dry beans with a moisture content exceeding the 8% are very vulnerable for bacterial infection resulting in mould growth, which will affect the flavour of the chocolate while a bean with a moisture below the 6.5% will easily disintegrate during transportation which results in a much lower protection of the bean (Wood, 2008; CAOBISCO/ECA/FCC, 2015).In figure 4.22 can be seen that only one farm produced beans between the recommended values whereas the farms of San Vicente had higher values than the recommended range. The drying time in figure 4.23 shows a shorter drying time for Rionegro. This is counter intuitive. The data about the drying time was obtained during the survey and was not the actual drying time for those specific beans. Furthermore, the drying time depended mostly on the weather and not all beans were dried at the same period, nor under the same conditions. So, the drying time does not have a direct influence on the moisture content. Based on the moisture content, the beans of San Vicente

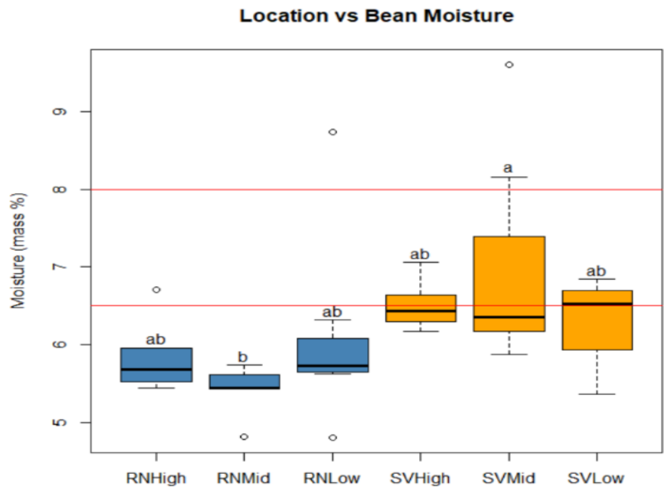

Figure 4.22: Boxplots showing distribution of bean moisture (in %) present in the cocoa beans of each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl). Letters represent statistical differences (P<0.05) between the locations (i.e. RNHigh vs RNMid vs RNLow vs SVHigh vs SVMid vs SVLow using a two- way ANOVA.
The upper red line indicates the maximum limit of 8% moisture
The bottom red line indicates the lower limit of 6.5%

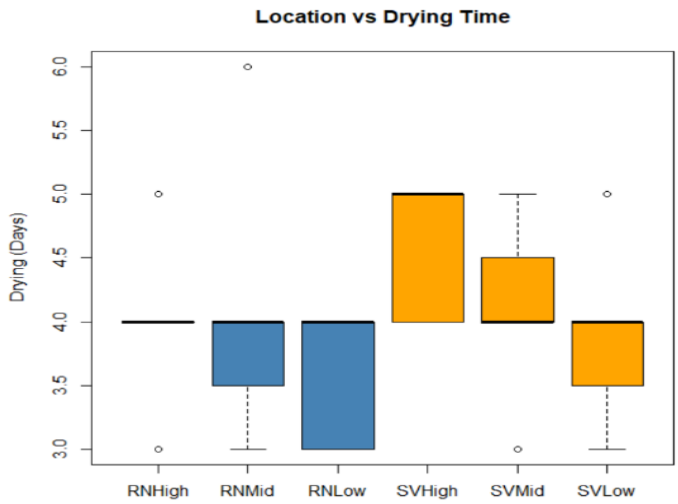

Figure 4.23: Boxplots showing distribution of the drying time (days) of cocoa beans in each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl). Letters represent statistical differences (P<0.05) between the locations using a two- way ANOVA. If no letters are present, it means no significant differences were found

4.4.5 Bean mass

The only significant effect of altitude on cocoa bean quality parameters was on bean mass (table A.3 in annex). Disregarding regions, high altitudes showed a positive effect (*P<0.01*) on average bean mass compared to low altitudes. According to Norma Tecnica Colombiana (NTC) 1252 and the International Standard Organisation (ISO) average mass of one bean should be at least 1.0 g (with a range between

1.0 – 1.2 g per bean). The bean mass for the premium category is at least 1.2grams. The average mass of all the beans at each location in this study was 1.4 grams. Thus, the investigated farms of San Vicente and Rionegro produce excellent physical bean quality (i.e. bean mass is from 1.14 to 2.15 g).

Disregarding the regions, the soil parameters such as **% C** (*P<0.001*), **Na** (-) (*P<0.01*) and **P** (*P<0.05*) and on management level the **pruning frequency** (*P<0.01*) and the **fermentation time** (*P<0.001*) appears to be significant predictors of the bean weight (see table A.2 in annex).

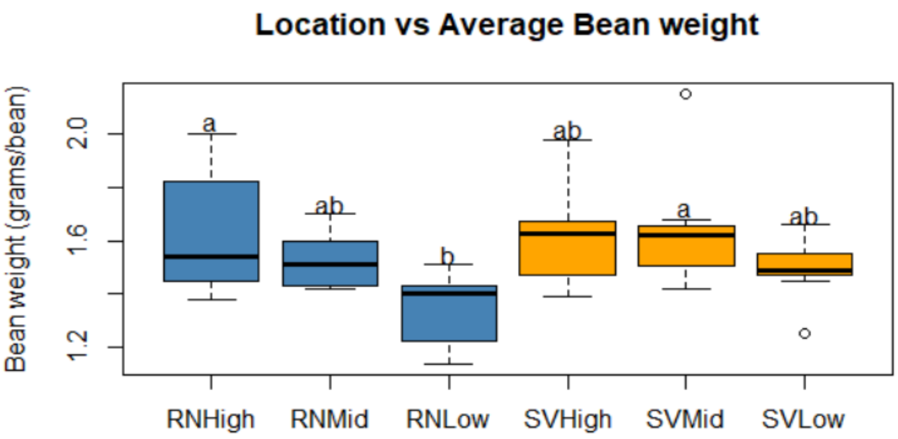

Figure 4.24: Boxplots showing distribution of the average bean mass present in the cocoa beans of each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl). Letters represent statistical differences (P<0.05) between the locations (i.e. RNHigh vs RNMid vs RNLow vs SVHigh vs SVMid vs SVLow using a two- way ANOVA.

Varieties

The Trinitario hybrids tend to be less productive and had smaller beans compared to the other main varieties present in the high altitudes (ICS 1 – 39 – 60, FSV 41, EET 8) which do all have a high average bean weight higher than 1.7 grams. CCN 51 has a medium one (1.4 – 1.6 grams) (Villamil *et al.*, 2013).

Climate

As studied by Daymond and Hadley (2008) a (weak) negative relationship was found between temperature and bean size. Since the higher altitudes have lower temperatures, the pod matures slower, and the beans will have more time to assimilate nutrients and to develop their internal structure, which leads to heavier beans and may contribute to a better aroma.

Management effect

As was found by the LME, the number of **prunings** per year would have a positive impact on the bean mass. The purpose of the pruning is to obtain an equilibrium between the vegetative and the productive parts of the tree. The better pruning is applied, the more the tree will be able to concentrate its nutrients and sugars into the fruits. Govindaraj K & Jancirani P (2017) found that an adequate pruning contributed to an optimal development of the fruit in terms of physical and aromatic quality.

No causal links were found for the **fermentation time**.

Soil effect

Carbon (C) is the main element present in all organic elements. **Phosphorus** (P) promotes the development of roots, is important in the formation of fruits and seeds, is vital in the process of photosynthesis and in the transport, storage and transfer of energy, accelerates the ripening of the fruits

No causal links were found for those parameters and were out of scope of this thesis but we could speculate that a higher uptake of those two elements can only be beneficial for the weight of the beans.

4.4.6 Fermentation Index (FI)

The Fermentation Index was significantly higher in San Vicente de Chucurí ($P<0.01$). A fermentation index with values higher or equal to 1 would suggest good fermented beans. The fermentation index was positively predicted by the **fermentation time (**$P<0.001$**)** and the **age of the cocoa trees (**$P<0.05$**)** (table A.2 in annex).

Management effect

From figures 4.25 – 4.26 can be observed that the higher the **fermentation time**, the higher the fermentation index. So, based on the fermentation index, the beans in San Vicente are better fermented and of better quality than those of Rionegro.

The fermentation index in Rionegro was below 1 and thus unfermented while their fermentation time comply with the recommended values. Here can be stated that a better fermentation (i.e. FI=1) take place with a fermentation time of 7 days and not 6 days as the literature reports.

From those results, the fermentation index could be an indicator of the fermentation time and thus predict the amount of free amino acids that on their turn would give an estimation of the (flavour) quality of the bean (see section 5.4.2 Protein Content) (León-Roque *et al.*, 2016).

No causal links were found with the age of the trees.

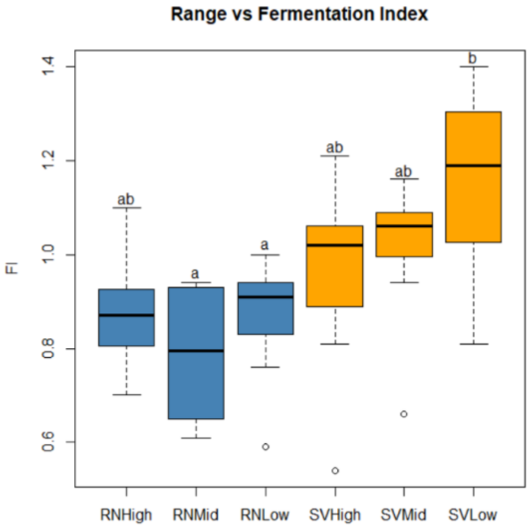

Figure 4.25: Boxplots showing distribution of the fermentation index of cocoa beans of each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl). Letters represent statistical differences (P<0.05) between the locations using a two- way ANOVA.

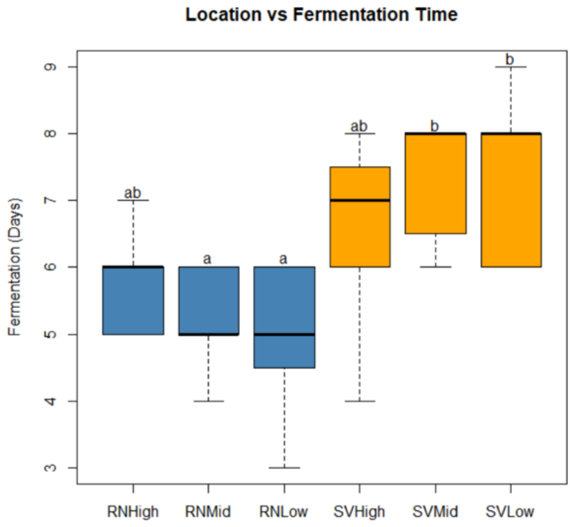

Figure 4.26: Boxplots showing distribution of the fermentation time applicated of each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl). Letters represent statistical differences (P<0.05) between the locations using a two-way ANOVA.

4.4.7 Cut test score

A significant higher cut test score was found for Rionegro (figure 4.27). Since the cut test score should give an indication on the fermentation quality of the bean, it should result in a similar outcome as the fermentation index. But as it is a subjective measurement, it can subsequently give a great bias towards reality, especially if it is done by an untrained person. The cut test score in this case even indicates opposite values to the fermentation index and so is unsuitable for further use.

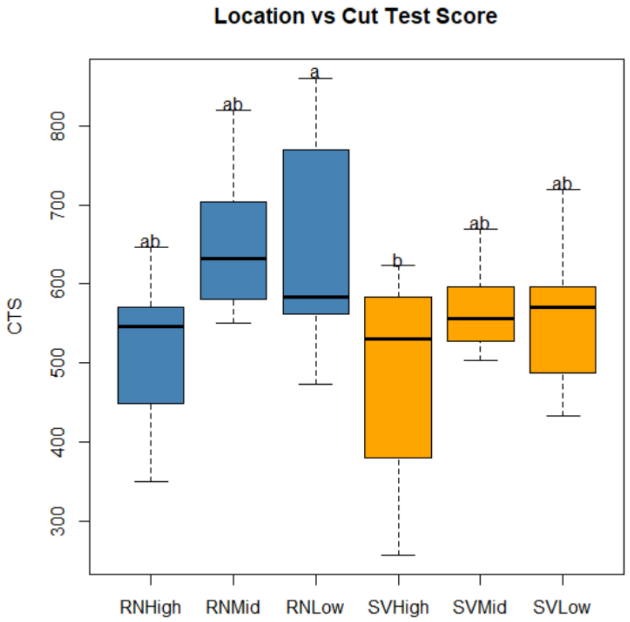

Figure 4.27: Boxplots showing distribution of cut test scores of cocoa beans of each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 m asl), Mid (600-900 m asl) and Low (<600 m asl). Letters represent statistical differences (P<0.05) between the locations using a two- way ANOVA.

4.4.8 Cadmium

The problem of cadmium was also present in Santander. Figure 4.28 shows significant higher cadmium levels in San Vicente de Chucuri ($p<0.001$) compared to Rionegro. As reported in the literature review, the European Union will set new maximum limits for this heavy metal as of January 1, 2019.

Although there is no specification of the maximum concentration of cadmium in dried cocoa beans, the European Commission will adopt maximum limits of 0.8 mg kg^{-1} cadmium for chocolate with >50 % total dry cocoa solid (European Commission, 2014). However, the Codex Committee on Contaminant in Food (CCCF) has proposed a maximum limit of 1.3 mg kg^{-1} cadmium for cocoa powder (100% total cocoa solids on a dry matter basis).

Assuming the maximum limit of 1.3 mg kg^{-1} for the cadmium content of the cocoa beans, only 1 farm in Rionegro exceeded the maximum limit. While all farms, except one, exceeded this maximum limit in San Vicente de Chucurí (see figure 4.28). Also, significantly higher cadmium levels were found in the cocoa beans of San Vicente de Chucurí, using a two-way ANOVA (region – altitude). The outliers demonstrate that there is a high variability of cadmium content on very short distances.

So, what is so different in San Vicente that causes such different amounts of cadmium in the beans compared to Rionegro?

Figure 4.30 indicates that the presence of cadmium occurred in the soils of both regions without any significant differences between the locations. San Vicente had an average of 3.3 mg kg^{-1} and Rionegro 2.3 mg kg^{-1} (with outliers) or a difference of 1.0 mg kg^{-1}. In other words, both regions do contain cadmium in their soils. This indicates that the soil parent material was not the main reason for the differences in cadmium content of the beans between San Vicente and Rionegro.

Looking now at figure 4.31, which portrays the bio-available cadmium content in the soil, San Vicente showed a higher average than Rionegro ($P<0.05$), where the difference between both regions decreased to a cadmium content of 0.05 mg/kg compared to the total cadmium. Again, no significant differences were found between the locations. Although, SVMid and SVHigh do have an increasing trend in the available cadmium while in the total cadmium, no trend is noticed. Further, the variability in San Vicente is much larger than in Rionegro, which is also reflected in the bean cadmium content.

Using mixed effect models with regions as random effect, a positive correlation was obtained between the cadmium content in the cocoa beans and the **available cadmium** ($P< 0.01$) in the soil, the **precipitation** ($P< 0.01$), the exchangeable **calcium** ($P< 0.001$) and exchangeable **potassium** ($P< 0.05$) with a conditional $R^2 = 0.80$ and the marginal $R^2= 0.23$. This means only 23 % of the variance is explained by this model and the other 57% is included in the random effect which are the regions.

Soil effect

A positive correlation was found on the soil **available cadmium** and the amount cadmium absorbed by the cocoa trees. The increasing trend in the available cadmium content in San Vicente is now supported by cadmium present in the beans, having a significantly difference between the locations and a high significant difference between the regions ($P<0.001$) (figure 4.32).

Different authors (Smolders, 2001; Chavez *et al.*, 2015; Gramlich *et al.*, 2017, 2018) found a relationship between the availability of cadmium for the plants and the soil pH, clay content, soil organic matter, P, the age of the trees, phosphate containing fertilizers,.

The ranges of the soil pH, ECEC and total cadmium, were all similar for the different locations (see table A.1.1 in annex). The only significant different soil parameters found by the two-way ANOVA were the carbon, nitrogen and phosphorus content (see table A.3 in annex).

The carbon and nitrogen percentage were higher in San Vicente and in high altitudes (table A.3 in annex). The organic matter should lower the Cd availability (Kirkham, 2006). The trend of the soil carbon % and nitrogen % confirms this statement, yet with a much larger scale in San Vicente. No logical links were found in relation to phosphorus. Further, no link was found with the use of fertilizers, here the low altitudinal farms fertilized even less (figure 4.7). Neither the varieties should be the cause since similar cultivars were found in both regions.

So far in the hypothesis, the reason why San Vicente differs that much in terms of cadmium availability, is the organic matter (C% and N%). This only applies for the altitudinal ranges in San Vicente. Thus, according to the dataset, no significant cause was found to explain the difference in cadmium availability between the different regions.

The soil texture was not analyzed but may also be an explanation for the difference in exchangeable cadmium in the soil between the two regions (Sharma and Sachdeva, 2015; Gramlich *et al.*, 2017). In chapter 3, materials and methods, was found that the soils in Rionegro were Arenosols while the high altitudes of San Vicente consisted mostly of Leptosols and the mid and low altitude where Cambisols (table 3.1). Gramlich *et al.* (2017), has found that the clay content had a positive influence on the available amount of cadmium in the soil.

No links were found on the relation of the other parameters (precipitation, exchangeable calcium and exchangeable potassium) with the amount of cadmium present in the beans.

Possible Solutions

Because of the (natural) presence of cadmium, which varied a lot depending on the location, and the upcoming maximum limits enforced by the European Union, the high-quality beans of San Vicente will become unexportable. Therefore, solutions have to be found.

As can be seen in this case, the problem is not really the presence of cadmium in the soil, but rather the available cadmium and its uptake by the cocoa beans. So, measures should be taken to prevent the cadmium to be available. On the farm level different general practices should be getting attention:

- The uptake of the available cadmium is often correlated with the pH of the soil (Smolders, 2001; Kirkham, 2006; Gramlich *et al.*, 2018). Since the soils are acid (with average pH values around 5.1 and 5.9), the soil should be carefully analyzed and if necessary the pH should be increased to above 5.5 through liming in order to prevent the cadmium to become available and resulting in a lower uptake by the plants;
- P fertilizers are also an important source of cadmium, so deficient nutrients should be identified and an adequate fertilizer should be used (Chavez *et al.*, 2015);
- Once the cultivation is contaminated, the pruned and harvested material should not be recycled in the cultivation.
- An alternative is phytoremedation, by interplanting hyperaccumulator plants as *Thalspi caerulescens* which can accumulate high amounts of heavy metals in their tissues (Kukier *et al.*, 2004; Sharma and Sachdeva, 2015). This plant grows only in temperate regions. Research for hyperaccumulator plants in the tropical regions should be promoted.

On a market level mixing the high-quality cadmium-infected-beans with good quality cadmium-free-beans would be an option but still risky in case of controls since a 100 % homogenous mix only exist in the theory. In addition, the fact of mixing the “poor” quality cadmium beans with high quality cadmium free beans, will upgrade the value of the poor-quality beans, but at the same time, the real high-quality beans will be degraded and the demand for that cocoa will decrease with the time. In this case, San Vicente could mix their beans with the beans of Rionegro.

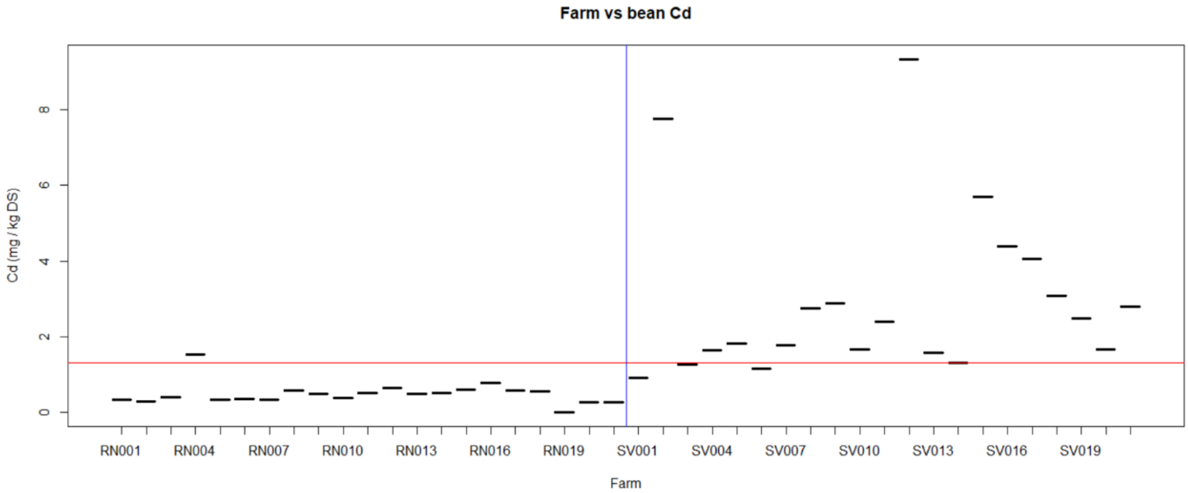

Figure 4.28: Distribution of cadmium (mg kg^{-1} dry matter) present in the cocoa beans of each farm in Rionegro (left) and San Vicente (right) for the three altitudinal ranges: respectively 1-7: High (>900 masl), 8-14: Mid (600-900 masl) and 15-21: Low (<600 masl). Red horizontal line = maximum limit of cadmium present in cocoa powder (100% total cocoa solids, proposed by CCCF). Vertical line: separation between Rionegro (left) and San Vicente (Right)

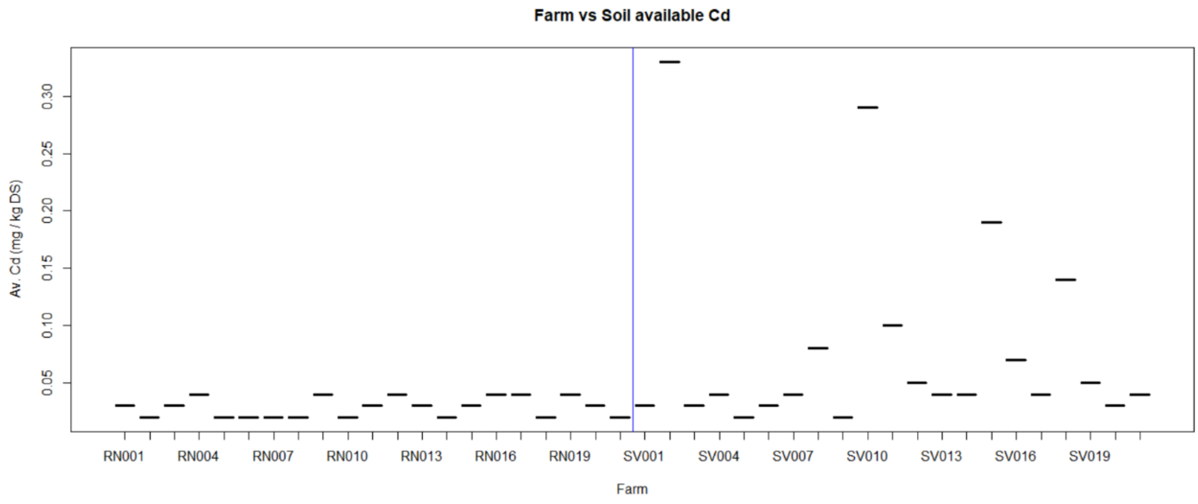

Figure 4.29: Distribution of the available cadmium (mg kg^{-1} dry matter) in the soils of each farm in Rionegro (left) and San Vicente (right) for the three altitudinal ranges: respectively 1-7: High (>900 masl), 8-14: Mid (600-900 masl) and 15-21: Low (<600 masl). Vertical line: separation between Rionegro (left) and San Vicente (Right)

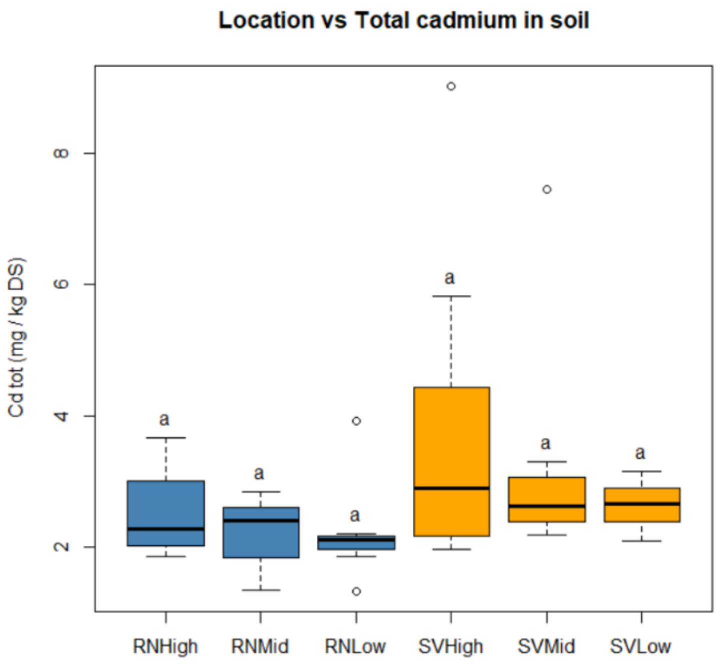

Figure 4.30: Boxplots showing distribution of the total cadmium content present in the soil of each region (first three: Rionegro, Last three: San Vicente) for the three altitudinal ranges: respectively High (>900 masl), Mid (600-900 masl) and Low (<600 masl). The letters a, b , c, … respesent the statistical differences (p<0.05) between the locations (i.e. RNHigh vs RNMid vs RNLow vs SVHigh vs SVMid vs SVLow using a two way ANOVA..

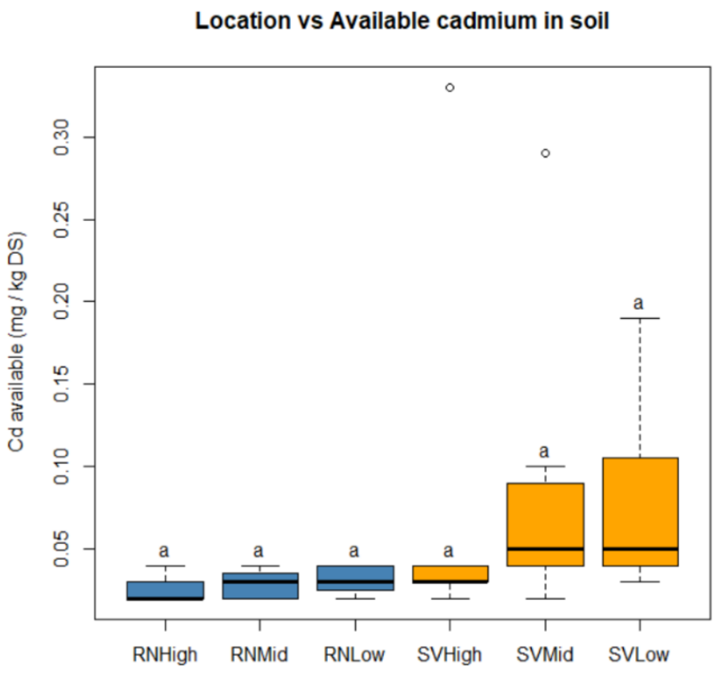

Figure 4.31: Boxplots showing distribution of the bio-available cadmium present in the soil of each region (Blue: Rionegro; Orange: San Vicente) for the three altitudinal ranges: respectively High (>900 masl), Mid (600-900 masl) and Low (<600 masl). The letters a, b, c, … represent the statistical differences (p<0.05) between the locations (i.e. RNHigh vs RNMid vs RNLow vs SVHigh vs SVMid vs SVLow using a two way ANOVA

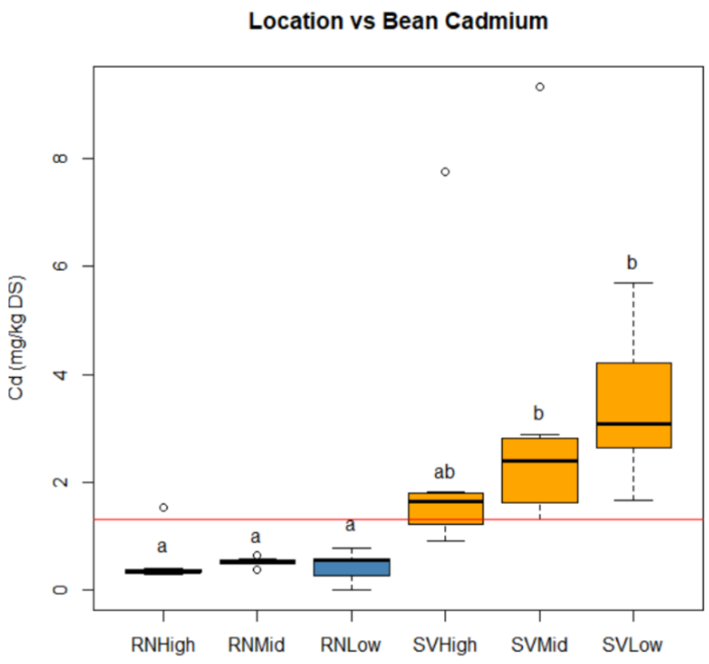

Figure 4.32: Boxplots showing distribution of the cadmium content present in the cocoa beans of each region (Blue: Rionegro, Orange: San Vicente) for the three altitudinal ranges: respectively High (>900 masl), Mid (600-900 masl) and Low (<600 masl).
The letters a, b , c, … respesent the statistical differences (p<0.05) between the locations (i.e. RNHigh vs RNMid vs RNLow vs SVHigh vs SVMid vs SVLow using a two way ANOVA..

5. Conclusion

In general terms, one can assess that the beans in both regions are of good quality based on the analysed quality aspects. San Vicente met all recommended values while Rionegro fell below the optimal values in terms of fermentation index and moisture content.

While the literature recommends a fermentation time of 6 days, the fermentation index shows that in these regions and with these varieties, the optimal fermentation time is 7 days. In San Vicente the fermentation time was slightly higher at around 7-8 days, representing a higher fermentation index, which resulted in less proteins in the dried beans. This could indicate a higher amount of flavour precursors in the beans of San Vicente. Here we found that two more days of fermentation gave 1% less proteins in the dried cocoa beans.

The moisture content was not decreased by a longer drying time – in fact, the results were counter intuitive: a higher drying time showed a higher moisture content. Here it could be concluded that the weather conditions will have a much bigger influence on the final moisture content than the number of days.

The effect of the altitude was only present on the bean mass. Higher altitudes showed significantly heavier and bigger beans than lower altitudinal ranges. This is paradoxical as low altitudes were expected to be most suitable in terms of climatic conditions. Due to the relative higher presence of pests and diseases in warm and humid weather, the cultivation of cocoa is less profitable in low altitudes, and farmers invest more in other practices such as livestock: cocoa cultivation serves as their second source of income. As a result, the low altitudinal farms are characterized by old hybrids and monilia resistant cultivars as CCN51. The former produces considerably smaller beans, while the flavour quality of the latter is not fully appreciated.

Contrary to the fermentation index, the cut test is a subjective assessment for the evaluation of well fermented beans. In this thesis, the cut test score gave opposing values compared to the fermentation index and demonstrate the importance of trained people for such quality tests.

While the quality of cocoa beans in San Vicente de Chucuri seems optimal to meet the global demand, the cadmium content in the beans make them unexportable to Europe, the biggest consumer of chocolate. Although cadmium was present in the soils of Rionegro and San Vicente the levels of available cadmium in the soil and their accumulation in beans differed. While the soils of Rionegro contained almost no available cadmium and therefore almost no cadmium accumulated in the beans, much cadmium available was present in the soils of San Vicente and the accumulation in the cocoa beans largely exceeded the maximum limits set by the European Commission. No causal links were found to explain the difference in the availability and uptake of the cadmium in both regions, but the soil texture may have a major influence.

The presence of cadmium is thus the biggest obstacle preventing the global demand to be met. Since the available cadmium is the main factor that affects the accumulation of this heavy metal in the beans, further research should focus on limiting the availability and absorption of cadmium in cocoa trees and on how to implement it in situ. Practices such as conventional soil remediation (e.g. liming) and adapted farm management (e.g. fertilizers) are not applicable everywhere. A promising future solution seems to be phytoremediation, but there is still a lot of research to be done on this subject.

Furthermore, a lot of soil predictors were found to influence bean quality, but due to the time and scope of this thesis and the lack of research of soil effect on bean quality, few causal links could be established.

In depth research of this subject is strongly recommended to fill the big gap in the literature and to better understand the importance of the soil for the quality of the beans.

Finally, a lot of research has been done in the literature on the strong correlation between the management practices on the farms and the quality attributes of the cocoa beans. However, the results of this thesis were not able to definitively assert what the best positive management practices for cocoa agriculture are. Several reasons can be suggested for the discrepancy. First, the survey's main focus was on the qualitative aspects of the farming practices of the farms: no measurements were taken or analysed, and the only data source on this topic was based on the answers from the farmers. Secondly, in most cases, little variation was seen on the outcome of the different practices that can explain the little correlation with the different quality aspects of the beans.

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Annex: Tables

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Table A.1.1: Average Chemical Soil Properties in Investigated Cocoa Locations in, Santander, Colombia. (With SV= San Vicente de chucurí, RN: Rionegro, the two Regions and High: 900-1200 masl, Mid: 600-900 masl Low: 300 – 600 masl the three altitudinal ranges.). Letters represent statistical differences (P<0.05) between the locations using a two- way ANOVA.

LOCATION	pH-H_2O	pH-KCl	% N	% C	$\frac{C}{N}$	Exch Al $(\frac{cmol}{kg})$	Exch Ca $(\frac{cmol}{kg})$	Exch K $(\frac{cmol}{kg})$	Exch Mg $(\frac{cmol}{kg})$	Exch Na $(\frac{cmol}{kg})$	Avail. P $(\frac{mg}{kg})$	ECEC $(\frac{cmol}{kg})$	Sum of cations	$\frac{K*Na}{Mg*Ca}$
RNHigh	5.06	3.84	0.11^{ab}	1.25^{ab}	11.49^{b}	0.08	1.62	0.08	0.93^{a}	0.01	0.36^{a}	2.73	2.65	0.11
RNMid	5.40	4.01	0.11^{ab}	0.91^{a}	8.36^{a}	0.03	2.68	0.08	1.11^{ab}	0.02	0.44^{a}	3.91	3.88	0.03
RNLow	5.91	4.32	0.09^{b}	0.74^{a}	8.09^{a}	0.01	4.25	0.11	1.34^{ab}	0.03	1.07^{a}	5.74	5.73	0.03
SVHigh	5.40	4.19	0.21^{c}	1.95^{b}	9.37^{a}	0.07	4.73	0.10	0.42^{a}	0.02	1.30^{a}	5.34	5.27	0.04
SVMid	5.42	4.49	0.18^{ac}	1.39^{ab}	7.69^{a}	0.05	6.16	0.09	0.47^{a}	0.03	3.77^{b}	6.80	6.75	0.06
SVLow	5.29	3.83	0.11^{ab}	1.01^{a}	8.89^{a}	0.01	3.28	0.10	2.66^{b}	0.03	0.47^{a}	6.09	6.08	0.02

Table A.1.2: Average Bean Quality Properties in Investigated Cocoa Locations in, Santander, Colombia. (With SV= San Vicente de chucurí, RN: Rionegro, the two Regions and High: 900-1200 masl, Mid: 600-900 masl, Low: 300 – 600 masl the three altitudinal ranges).). Letters represent statistical differences (P<0.05) between the locations using a two- way ANOVA.

LOCATION	Bean Weight (gram/bean)	Cut Test Score	% Moisture	pH	% Acidity	% Protein	FI	% Fat	Cd (mg/kg)
RNHigh	1.64^{a}	511.43^{ab}	5.83^{ab}	5.24^{a}	1.01	12.31^{abc}	0.88^{ab}	55.58^{a}	0.50^{a}
RNMid	1.53^{ab}	652.78^{ab}	5.42^{b}	5.46^{a}	0.79	13.17^{ac}	0.79^{a}	56.13^{a}	0.51^{a}
RNLow	1.34^{b}	654.29^{a}	6.11^{ab}	5.35^{a}	0.77	13.34^{c}	0.86^{a}	54.53^{a}	0.43^{a}
SVHigh	1.61^{ab}	476.67^{b}	6.51^{ab}	5.42^{a}	0.84	12.80^{abc}	0.95^{ab}	53.73^{a}	2.33^{ab}
SVMid	1.64^{a}	568.10^{ab}	7.00^{b}	5.39^{a}	0.80	11.67^{b}	1.01^{ab}	57.40^{a}	3.13^{b}
SVLow	1.49^{ab}	555.71^{ab}	6.29^{ab}	5.46^{a}	0.84	12.14^{ab}	1.15^{b}	52.05^{a}	3.45^{b}

Table A.2: Outcome Linear Mixed Effect Models done for the abiotic, soil and management effects. The significant predictors for each bean parameter have following significant levels: P> 0.05 (ns: non significant), P< 0.05 (*), P<0.01 (**), P<0.001 (***).

Bean Parameter	***R^2 (cond–marg)***	***Explanatory***	***Significant predictors***
Bean Weight	0.19 – 0.18	Abiotics	Altitude**
	0.39 – 0.39	Soil	C***, Na (-)**, P*
	0.37- 0.37	Management	Prun**, Fung (-) .^{ns} , Ferm***
Moisture	/	Abiotics	/
	0.246 – 0.150	Soil	P**
	/	Management	/
pH	/	Abiotics	/
	0.253 – 0.253	Soil	phH2O*, Al .^{ns} , K*(-), Mg*, P .^{ns}
	/	Management	/
Acidity	/	Abiotics	/
	/	Soil	/
	/	Management	/
Protein	/	Abiotics	/
	0.346 – 0.154	Soil	pH H2O*
	0.194	Management	Ferm** (-)
Fat	/	Abiotics	/
	0.42	Soil	Prec**(-), C***(-), Al***, Na**
	/	Management	/
Cadmium		Abiotics	
	0.802 – 0.228	Soil	Prec**, Cd av**, Ca***, K*
		Management	/
FI		Abiotics	/
		Soil	/
	0.3416	Management	AgeTrees*, Ferm ***

Table A.3: Outcome 2 way ANOVA with regions (San Vicente and Rionegro) as factors on soil and bean parameters. With following significance levels: $P < 0.05$ (*), $P<0.01$ (**), $P < 0.001$ (***).

SOIL	RANGE	REGION	ALTITUDE
PH H2O	4.47 – 7.22	/	/
PH KCL	3.46 – 6.73	/	/
%C	0.43 – 3.67	SV > RN**	H > L**
%N	0.05 – 0.35	SV > RN***	H > L*
C/N	6.44-12.62	RN > SV *	H>L***
EXCH AL (CMOL /KG)	0.0 – 0.37	/	H > L*
EXCH CA (CMOL /KG)	0.28– 18.73	/	/
EXCH K (CMOL /KG)	0.04 – 0.24	/	/
EXCH MG (CMOL /KG)	0.1 - 5.86	/	L > H*
EXCH NA (CMOL/KG)	0.00 – 0.07	/	/
PHOSPH (MG/KG)	0.04 – 8.31	SV > RN**	M*
ECEC (CMOL/KG)	0.56 - 19	/	/
K+NA/MG+CA	0 – 0.27	/	/
TOTAL CADMIUM (MG/KG)	1.32-9.03	SV > RN*	/
PLANT AV CD	0.02 – 0.33	SV>RN *	/
SOIL QUALITY INDEX	0.12-0.71	SV>RN *	/

BEANS	RANGE	REGION	ALTITUDE
PH	4.74 – 6.47	/	/
ACIDITY %	0.07 – 0.27	/	/
PROTEIN %	10.37 – 13.92	RN > SV**	/
FAT %	38.11 – 76.67	/	/
MOISTURE MASS %	4.81 – 9.6	SV > RN**	/
BEAN WEIGHT	1.14 – 2.15	/	H > L**
FI	0.6-1.4	SV > RN**	/
CUT TEST SCORE	256.67 - 860	RN > SV*	L&M > H*
CADMIUM MG/KG	0 – 9.34	SV>RN***	/
BEAN QUALITY INDEX	0.84 - 1	RN > SV ***	L&M > H**

Tables A.4 Characterisics of main cultivars (introduced and regional) in Santander, Colombia

Regional varieties

Name: FSV 41: **F**edecacao, **S**an **V**icente de Chucurí,
Origin: Santander, Colombia
Breed: Hybrid Trinitario

General			
	Yield (kg/ha/year)	1.474	
	Pod Index	13	
	Bean Index	2.1	
	Compatibility	SC	
	% Intercompatibility	81	
	Monilia	S	
Beans			
	Weight (Humid) (g)	234.4 ± 17.87	
	Beans / Pod	39.2 ± 2.69	
	Length (mm)	29.9 ± 0.32	
	Width (mm)	10.9 ± 0.18	
	% Shell	11.2 ± 0.29	
Chemical Characteristics			
	% Fat	59.4 ± 0.49	
	% Fiber	4.5 ± 0.44	
	% Protein	10.9 ± 0.22	
Sensory profile	Light brown flavor, spicy flavor, ripe fruits in the process of fermentation a little sweet soft and pleasant.		

Introduced varieties

Name: EET 8: **E**stación **E**xperimental **T**ropical
Origin: El Limón, Costa Rica
Breed : Hybrid Trinitario

General			
	Yield (kg/ha/year)	1.235	
	Pod Index	13	
	Bean Index	2.2	
	Compatibility	SI	
	% Intercompatibility	81	
	Monilia	S	
Beans			
	Weight (Humid) (g)	239.2 ± 9.24	
	Beans / Pod	37.4 ± 1.28	
	Length (mm)	29.1 ± 0.25	
	Width (mm)	11.8 ± 0.19	
	% Shell	9.7 ± 0.14	
Chemical Characteristics			
	% Fat	57.6 ± 0.38	
	% Fiber	4.6 ± 0.11	
	% Protein	11.9 ± 0.37	
Sensory profile	Acid aroma and cocoa notes. Brown color. Low sustained acid flavor with medium flavor to cocoa and medium bitter. Low nutty taste and greasy feeling are perceived.		

Name: CCN 51: **C**olección **C**astro **N**aranjal
Origin: Ecuador
Breed: ICS 95 x IMC 67

General			
	Yield (kg/ha/year)	1.441	
	Pod Index	15	
	Bean Index	1.6	
	Compatibility	SC	
	% Intercompatibility	68	
	Monilia	MR	
Beans			
	Weight (Humid) (g)	224.9 ± 13.44	
	Beans / Pod	48.3 ± 2.20	
	Length (mm)	25.7 ± 0.26	
	Width (mm)	9.1 ± 0.19	
	% Shell	11.8 ± 0.49	
Chemical Characteristics			
	% Fat	59.6 ± 0.45	
	% Fiber	3.1 ± 0.37	
	% Protein	11.6 ± 0.41	
Sensory profile	Liquor with a mild aroma of cocoa and acid. medium coffee color. Taste with ripe fruits. In the half time chocolate notes emerge. Medium acidity, sustained. Low walnut notes were found		

Name: ICS 60: **I**mperial **C**ollege **S**elections
Origin: Trinidad
Breed: Hybrid Trinitario x Criollo

General			
	Yield (kg/ha/year)	1.076	
	Pod Index	13	
	Bean Index	2.3	
	Compatibility	SI	
	% Intercompatibility	75	
	Monilia	S	
Beans			
	Weight (Humid) (g)	216.5 ± 15.72	
	Beans / Pod	37.9 ± 2.80	
	Length (mm)	28.6 ± 0.33	
	Width (mm)	12.6 ± 0.16	
	% Shell	11.5 ± 0.84	
Chemical Characteristics			
	% Fat	57.6 ± 0.39	
	% Fiber	4.4 ± 0.14	
	% Protein	11.7 ± 0.11	
Sensory profile	Cocoa with medium cocoa flavor with citrus fruit notes, medium sustained acidity and bitter end. Low nut flavor that is perceived before the end of tasting.		

Name: ICS 95: **I**mperial **C**ollege **S**elections
Origin: Trinidad
Breed: Hybrid Trinitario x Criollo

General			
	Yield (kg/ha/year)	902	
	Pod Index	20	
	Bean Index	1.4	
	Compatibility	SC	
	% Intercompatibility	95	
	Monilia	R	
Beans			
	Weight (Humid) (g)	128.9 ± 6.87	
	Beans / Pod	37.1 ± 1.35	
	Length (mm)	25.3 ± 0.32	
	Width (mm)	10.0 ± 0.12	
	% Shell	12.2 ± 0.83	
Chemical Characteristics			
	% Fat	58.1 ± 0.32	
	% Fiber	5.2 ± 0.10	
	% Protein	11.9 ± 0.10	
Sensory profile	Trinitarian liquor with intense citrus notes at the beginning of the tasting, which soften at the end, herbal flavor and malt that are perceived half the time on a nice cocoa background. It is an excellent reference of fruity and cocoa.		

UNIVERSITEIT GENT

FEDERACION NACIONAL DE CACAOTEROS
FEDECACAO

PROYECTO EQUIPO CACAO

SOSTENIENDO LA PRODUCCIÓN DE CACAO DE ALTA CALIDAD DE PEQUEÑOS AGRICULTORES COLOMBIANOS

Cuestionario de agricultores para la encuesta Socio-Económica, 2017

Información de la encuesta

SV: San Vicente

Nombre del encuestador:	
Fecha de la encuesta:	
Hora de inicio:	
Hora de terminación:	
Departamento:	
Municipio:	
Vereda:	
Teléfono del agricultor:	
Coordenadas:	N: E:
Código de la finca	
Altitud	

RN: Rionego

	1.7 Características del Hogar			
	Miembros del Hogar	Edad	Nivel Educacional	Ocupación
	Esposo/Esposa			
1ro				
2do				
	Niños			
1ro	Hijos			
2do				
3ro				
1ro	Hijas			
2do				
3ro				
	Dependientes:			
	Sobrinos			
1ro				
2do				
	Sobrinas			
1ro				
2do				
	Madre			
	Padre			
	Otros (detallar)…			
		01=Ninguno 02=Educación básica primaria (hasta 5to) 03=Educación básica secundaria (hasta 9no) 04=Educación media (bachillerato, hasta 11no) 05=Educación Técnica o Tecnológica 06=Educación superior (universitaria) 07=No formal		01= Artesanos 02= Trabajadores 03= Compradores de cacao 04= Pequeños comerciantes 05= Hogar 06= Profesor 07= Estudiante 08= Agricultor 09= Otro (detallar)…

1.0 CARACTERÍSTICAS DEMOGRÁFICAS

1.1 Nombre del Agricultor principal: ………………………………..............	
1.2 Edad del Agricultor: ………...........	
1.3 Género?	01=Hombre 02=Mujer
1.4 Nivel Educacional: ………………..	01=Ninguno 02=Educación básica primaria (hasta 5to) 03=Educación básica secundaria (hasta 9no) 04=Educación media (bachillerato, hasta 11no) 05=Educación Técnica o Tecnológica 06=Educación superior (universitaria) 07=No formal
1.5 Estado Civil: …………………….....	01=Soltero/Soltera 02=Casado/Casada 03=Divorciado/Divorciada 04=Viudo/Viuda 05=Otro…
1.6 ¿Cuántos años ha estado usted dedicado al cultivo del cacao? (experiencia del agricultor) …..	01. [1 – 5 años] 02. [6 – 10 años] 03. [11 – 15 años] 04. [16 – 20 años] 05. [21 – 25 años] 06. [26 – 30 años] 07. [31 – 35 años] 08. [36 – 40 años] 09. [41 – 45 años] 10. [46 – 50 años] 11. [Sobre 50 años]

2.0 CARACTERÍSTICAS DE LA FINCA

2.1 ¿Cuántas fincas de cacao tiene?...

2.2 Completar la siguiente tabla:

Finca	Grande/ Pequeña *	Acuerdo de tenencia de la tierra#	Topografía de la tierra**	Tamaño de la finca (ha)	Hectareas en Cacao (ha)	Año que adquirio la finca	Edad promedio de los principales árboles de cacao
1.							
2.							
3.							

*01= Grande, 02 = Pequeña +1= Híbrido, 2= Clones

\+ Variedad de Cacao plantada+:
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
…………………………………………………………………………………………………….

01=Propietario 02=Sociedad 03=Rentado/leased 04=Otro (detallar)…

**01= Valle 02 = Plano 03 = Montaña suave 04 = Moderado 05 = Escarpado

2.3 ¿Cuál es el rendimiento de la producción (kg) de la finca principal de cacao en los últimos tres años por ha?

2014	2015	2016	2017 (hasta ahora)

2.4¿Qué piensa usted de la fertilidad del suelo de su finca de cacao?

01 = El suelo es fértil y apoya el crecimiento de los árboles de cacao.

02 = El suelo no es fértil y no apoya el crecimiento de los árboles de cacao.

03 = Otro (detallar)………………………………………………..

3.0 PRÁCTICAS DE GESTIÓN DE LA FINCA (para fincas principales de cacao)

3.1 ¿Qué tipo de sistema de cultivo tienen?

☐ Monocultivo ☐ Cultivo mixto

3.2 En caso de cultivo mixto, nombrar todos los tipos de cultivos plantados…………………
……………………………………………………………………………………………………

3.3 Además, en caso de cultivo mixto, ¿Están los tipos de cultivo intercalados?

01=Sí 02=No

3.4 ¿Cuál es la distancia entre las filas de árboles de cacao en esta finca?

=> # árboles/ha

3.5 ¿Cuál es la distancia entre surcos de árboles de cacao en esta finca?

3.6 ¿Qué especie es utilizada como árbol de sombrio transitorio (múltiples respuestas permitidas)

☐ Plátano (*Platanus spp.)*
☐ Matarraton (*Gliricidia sepium*)
☐ Higuerilla (*Ricinus communis)*
☐ Guandul (*Cajanus cajan)*
☐ Otro (detallar)…

3.7 ¿Qué especie es utilizada como árbol de sombrio permanente (múltiples respuestas permitidas)

☐ Cedro (*Cedrela spp.)*
☐ Moncoro (*Cordia gerascanthus)*
☐ Nauno (*Pitchecellobium guachapele*)
☐ Anaco (*Erythrina sp.)*
☐ Abarco *(Cariniana pyriformis)*
☐ Otro (detallar)…

3.8 ¿Cuál es la distancia entre los árboles de sombra en esta finca?

=> # árboles/ha

3.9 ¿Qué afirmación sobre la copa de los árboles de cacao es más precisa? => %

- ☐ La copa de los árboles de cacao no está cerrado en absoluto (no hay ramas entrelazadas, la luz del sol puede llegar al suelo) (0 – 33 %)
- ☐ Hay espacios en la copa de los árboles de cacao (No todas las ramas están entrelazadas o existen espacios en un dosel cerrado, la luz del sol puede alcanzar el suelo en algunos lugares) (33 – 66%)
- ☐ La copa de los árboles de cacao está cerrado (las ramas están entrelazadas, la luz solar no puede llegar al suelo) (66 – 100%)

3.10 Mencione la(s) principal(es) enfermedad(es) que atacan a los árboles de cacao (se permiten múltiples respuestas)

- ☐ Escoba de Bruja (Witches Broom)
- ☐ Antracnosis del cacao (*Colletotrichum gloeosporioides)*
- ☐ Monilia
- ☐ Enfermedad de la mazorca negra (= Black Pod Disease, *Phytophthora palmivora*)
- ☐ *Rosellinia pepo*
- ☐ Mal del Machete *(Ceratocystis fimbriata)*
- ☐ Otro (detallar)…

3.11 Mencione la(s) principal(es) plaga(s) que atacan a los árboles de cacao (se permiten múltiples respuestas)

☐ Cápsidos (Chinche Monalonio)	☐ Polillas
☐ Trips del cacao (*Thriphidae)*	☐ Gorgojos grises (*Myllocerus)*
☐ Perforador de la Mazorca (Carmenta)	☐ Hormigas (Atta)
☐ Pasador del Tronco (Xileborus)	☐ Chinche negro (Mecistorhinus)
☐ Cochinillas	☐ Otros …………………………..

3.12 Mantenimiento agrícola de la finca (en los últimos 12 meses)

	Modo de control	No. de veces	Cuando (meses; etapa del árbol)	Quien realiza el trabajo+	Tipo de producto químico	Fuente del producto químico	Dosis utilizada [cm³/L]
Control de la hierba	01=deshierbe 02=herbicidas						
Fumigación de chinche/monalonium y otras plagas	01=máquina de fumigación 02= Otro…						
Fumigación de *Phytophthora* y otras enfermedades	01=máquina de fumigación 02= Otro…						
Aplicación de fertilizantes	01=Foliar 02=Edafica (Suelo)						
Poda	01=Tijera mano 02=Tijera aérea 03= Segueta 04= Motosierra 05= Otro ……..						
Eliminación del plantas parasitas/injerta							

+ 01 = Agricultor 02 = Familia 03 = Trabajador ocasional
04 = Trabajador a tiempo completo 05 = Otro (especificar) ....

3.13 Gestión del agua (en los últimos 12 meses)

	Porque?	Fuente del agua	Método de canalización de agua	Método de recolección de agua	Sistema de riego
RIEGA 01= Si 02= No	01= No suficiente agua 02= suficiente agua se drena 03= Otro?	01 = Arroyo 02 Agua subterránea 03 = Naciniento 04 = Agua de lluvia 05 Otros?	01= bombeado 02= Natural 03= Canal creado por el hombre 04= Otros?	01= Tanques de agua 02= estanque 03= Pozo 04= Otros	01= Surco 02= Aspersor 03= Inundación 04= Goteo 05= Otra?

	Cantidad [L / ha] por vez	No de veces	Momento (cuándo? Meses, etapa del árbol)	Posee concesión de aguas?
RIEGA				01 Si 02 No

¿Qué piensa usted de la calidad del agua de su finca?

01 La calidad del agua que se recibe es buena y apoya el crecimiento de los árboles de cacao.

02 La calidad del agua que se recibe es pobre y afecta el crecimiento de los árboles de cacao.

03 Otro (detallar)………………………………………………………..

¿Alguna vez ha tenido un análisis de agua

01 Si

02 No

¿Cree que un análisis del agua es necesario?

01 Si

02 No

4.0 PRÁCTICAS POST-COSECHA (principal temporada de cacao) dentro de los últimos 12 meses

	Cada cuanto cosecha	Cantidad en kg cosechada seco	Quien realiza el trabajo+	Cantidad de granos en una mazorca en promedio	Que tipo de herramienta utiliza para cosechar?
4.1 Cosecha de mazorcas de cacao					01=Tijera mano
Abril – Junio					02= Machete
Octubre - Enero					03= Orquilla
Otros meses					04= Otro ……..

	Número de días después de cosechadas	Lugar de almacenamiento	Quien realiza el trabajo+
4.2 Almacenamiento de las mazorcas de cacao		01= Lotes 02=Hogar 03=Otro (detallar)...	

	Método de fermentación	Número de días de fermentación	Número de volteos de los granos en fermentación	Cantidad de kilogramos de grano seco usados por fermentación	Quien realiza el trabajo+	Capacidad (Kg granos secod
4.3 Fermentación	01= Barriles 02=Canasto 03=Cajones 04=Bandeja 05= Costales 06=Otro...					

- Ha hecho una selección de los granos para la fermentación?
- Mezcla granos de mazorcas en días diferentes de recolección?
- Cual es la distancia encima del suelo de los recipientes fermentadores?
- La fermentación se realiza en un lugar cubierto y cerrado o cielo abierto?

	Método de secado	Número de días por secado	Numero de volteos durante el secado	Cantidad de granos secos (kg) por vez	Quien realiza el trabajo+	Capacidad (Kg granos secos)
4.4 Secado	01= Costales 02= Piso de concreto 03= Artificial 04= Elba 05= Marquesina 06=Otro....					

+ 01 = Agricultor 02 = Familia 03 = Trabajador ocasional
04 = Trabajador a tiempo completo 05 = Otro (especificar) ....

5.0 FORMACIÓN DE AGRICULTORES Y CAPITAL SOCIAL

5.1 En los últimos 12 meses, ¿ha recibido usted algún tipo de formación? 01=Sí 02=No

5.2 En caso de ser Sí, ¿puede decirnos la fuente?

- ☐ Cooperativas
- ☐ ONGs
- ☐ Ministerio de Agricultura y Desarrollo Rural
- ☐ Empresas comercializadoras
- ☐ Otros agricultores
- ☐ Fedecacao
- ☐ Otros (detallar)….

5.3 ¿Qué tipo de capacitación recibió?

- ☐ Sensibilización del trabajo infantil
- ☐ Salud y seguridad
- ☐ Plantación y expansión agrícola
- ☐ Diversificación de cultivos
- ☐ Deforestación y medio ambiente
- ☐ Mantenimiento de la finca
- ☐ Aplicación de fertilizantes / pesticidas
- ☐ Buenas Practicas Agricolas (BPA)
- ☐ Manejo Integrado del Cultivo del Cacao
- ☐ Otro..

5.4 ¿Tiene alguna certificación la finca? 01=Si 02=No

5.5 En caso afirmativo, mencione la certificación obtenida y la entidad adjudicadora ……………………………..……………………………………………………………………

5.6 ¿Tiene crédito / facilidades de crédito? 01=Si 02=No

5.7 ¿Cuál es la fuente del préstamo / crédito? (múltiples respuestas permitidas)

- ☐ Banco privado
- ☐ Banca publica
- ☐ Cooperativa de ahorro y credito
- ☐ Individuo privado
- ☐ Otro (detallar)…

5.8 ¿Pertenece a alguna organización social? (buscar las redes/contactos sociales)

- ☐ Junta de acción comunal
- ☐ Pertenezco a un grupo cooperativo
- ☐ Pertenezco a una iglesia
- ☐ Ninguna de los anteriores

6.0 INGRESOS DE LA FINCA (en el último año)

6.1 Completar la siguiente tabla:

Fuente (última temporada de cacao)	**Venta?** **01= Si** **02= No**	**Cantidad (kg)**	**Precio por Unidad** **(COP/kg)**	**Monto total de los ingresos (COP)**	**Comentarios**
Ingresos por venta de cacao					
Finca de cultivos alimentarios: (fincas separadas)					
Maíz					
Yuca					
Plátano					
Cítricos					
Aguacate					
Otros (detallar)…					
Ganado:					
Aves de corral					
Vacuno					
Cerdos					
Caprinos					
Otros (detallar)…					
No agrícola:					
Activos (por ejemplo, automóvil, arriendos, etc.)					
Ahorros					
Donaciones de Gobierno, Iglesia, ONG, etc.					
Remesas					
Otros (detallar)…					

7.0 GASTOS DE LA FAMILIA (en el último año)

7.1 Completar la siguiente tabla:

Fuente (última temporada de cacao)	**Gastos?** **01= Si 02= No**	**Cantidad total de egresos (COP)**	**Comentarios (es decir, componentes de los costos, etc.)**
Gastos en el cultivo de cacao			
Finca de cultivos alimentarios: (fincas separadas)			
Maíz			
Yuca			
Plátano			
Cítricos			
Aguacate			
Otro (detallar)…			
Ganado:			
Aves de corral			
Ganado vacuno			
Cerdos			
Cabras			
Otros (detallar)…			
No agrícola:			
Comida			
Ropa de vestuario			
Renta			
Litigios o pleitos			
Gastos médicos			
Servicios funerarios			
Educación			
Iglesia			
Otros (detallar)…			

8.0 Características de las muestras de suelo

8.1 Número de muestra del suelo: …………………..

	Profundidad (cm)	*Color*	*Textura*	*Mojado/seco Contenido de humedad*	*Comentarios*
O			*x*		
A					
(E)					
B					
C					
Bedrock					

8.2 Descripción del entorno natural en general (plano, terraza, delta, cima de la meseta xxx, bosque,
...)………………………………………………………………………………………………
………………………………………………………………………………………………

8.5 Pendiente ………% Altitud 1: ……….. Altitud 2: ………..

8.6 Direccíon de la pendiente (N, NE, E, SE, S, SO, O, NO)

8.7 Bulk Density ……………grams

8.8 Drainage / Aeration/ Permeability

- Drenaje: muy pobre pobre moderado bueno muy bueno
- Aereacíon: muy pobre pobre moderado bueno muy bueno
- Permeabilidad: muy pobre pobre moderado bueno muy bueno

8.9 Vegetación circundante:

8.10 ¿Alguna vez ha tenido un análisis de suelo? 01 Si 02 No
8.11 ¿Cree que un análisis del suelo es necesario? 01 Si 02 No

Comentarios:

9.0 Muestra de granos de cacao

Fecha de la muestra: **………….**

Numero de muestra 1: **………….**
Peso de la muestra 1: **………….**

Numero de muestra 2: **……………..**
Peso de la muestra 2: **……………..**

Comentarios: