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Review of the Quality Potential of Cocoa in Southern Vietnam

Aeren Pauwels

Promotor: Prof. dr. ir. Koen Dewettinck
Co-promotor: Prof. dr. ir. Kathy Messens
Tutor: Ing. Helena Everaert

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Aeren Pauwels Gent, August, 2016

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III. List of abbreviations

ANOVA	Analysis of Variance
CATIE	Tropical Agronomical Centre for Investigation and Education
CPB	Cocoa Pod Borer
DANIDA	Danish International Development Agency
EUR	Euro (€)
FAO	Food and Agriculture Organisation of the United Nations
FI	Fermentation Index
GC-MS	Gas Chromatography-Mass Spectrometry
GPA	Generalised Procrustes Analysis
ICCO	International Cocoa Organisation
ICGD	International Cocoa Germplasm Database
ICGT	International Cocoa Genebank in Trinidad
MARD	Ministry of Agriculture and Rural Development
MC	Moisture Content
NPK	Nitrogen-Phosphorus-Potassium
PCA	Principal Component Analysis
SNP	Single Nucleotide Polymorphisms
SPME-HS	Solid phase micro extraction in
SSR	Simple Sequence Repeats
SUCCESS	Sustainable Cocoa Enterprise Solutions for Smallholders
VND	Vietnam Dong
VSD	Vascular Streak Die-back

IV. Abstract

Since a few years, Vietnam's cocoa sector has been static or in decline. To understand this trend and gain insight into possible solutions, this research aimed to provide an overview of the quality potential of cocoa in southern Vietnam. First, an analysis of the current state of the cocoa value chain in Vietnam was made, including suggestions towards increasing farmer income, consolidating cocoa acreage, and raising cocoa quality.
Secondly, quality characteristics of currently unapproved cocoa clones were assessed and the challenge of cocoa acidity in Vietnam was addressed. Two alternative drying methods were tested to reduce the acidity. An expert panel and consumer panel further performed a sensorial analysis to evaluate the efficacy of the drying methods.
Vertical integration appeared to be the most viable option to stabilise cocoa production and improve the cocoa quality. At farm level, farmers should focus on intercropping, pruning and timely fertilization. Quality characteristics of clones vary widely between regions, which demonstrates the need for an overview of each clone based on yield, disease resistance and flavour potential. In terms of acidity reduction, standard drying procedures can be maintained as alternative drying methods did not reduce the final acidity in chocolate. Finally, the alternative drying had no influence on other flavour notes, and the consumer panel did not rate them differently for likeability.
Keywords: Cocoa, Vietnam, chocolate, quality, acidity reduction, cocoa value chain

Nederlands:

De cacaosector in Vietnam krimpt al enkele jaren en om deze trend te begrijpen en mogelijke oplossingen te beschrijven is een analyse uitgevoerd van de huidige cacao-keten in zuid Vietnam. Het doel van dit onderzoek is om te voorzien in een overzicht van kwaliteitspotentieel van cacao in zuid Vietnam. Deze analyse leidde tot suggesties voor het verhogen van het inkomen van boeren, de bestendiging van het cacao-areaal en de toename van cacao-kwaliteit.
Kwaliteitsparameters van niet goedgekeurde cacao-klonen werden bepaald. De uitdaging van de zuurheid van Vietnamese bonen werd ook bestudeerd. Twee alternatieve droogmethodes voor cacao werden uitgetest om de zuurheid te reduceren. Een panel van experten en consumenten evalueerde de effectiviteit van de gepoogde zuurvermindering.
De meest rendabele optie om cacao opbrengsten en kwaliteit te verhogen lijkt verdere verticale integratie. Op het niveau van de boer moet er aandacht gaan naar mengteelten, snoeien en tijdige bemesting van cacao. Kwaliteitsparameters van klonen bleken sterk te variëren tussen regio's. Het nut van regionale lijsten voor deze parameters, ziekteresistentie en aroma-potentieel werd aangetoond. Met betrekking tot vermindering van zuurheid waren de geteste methodes niet effectief. De standaardprocedures voor drogen kunnen dus gehandhaafd worden. Bovendien hadden de droogmethodes geen invloed op smaakdescriptoren en werden ze niet onderscheiden door het consumentenpanel.

***Trefwoorden**: Cacao, Vietnam, Chocolade, kwaliteit, zuurvermindering, cacao-keten*

1 Introduction

Chocolate as a modern confectionary product is appreciated around the world for its flavour and its use in myriad food products. Its origin lies in mid-seventeenth-century Europe, over one hundred years after its principal ingredient, cocoa beans, were brought back from the Americas to Spain by the conquistador Cortéz.
The center of the genetic diversity lies in the Amazon basin in South America. Here the Olmecs began cultivating the cocoa tree as a domestic crop where after it spread further North to the Mexican and Guatemalan Aztec empire (Badrie, Bekele et al. 2015). Over time cocoa evolved from a pungent ritual drink in the tropical forests of the Americas, into a sweet watery beverage in Renaissance Europe, to finally become the ubiquitous bar with the familiar gloss and snap now called chocolate.

1.1 *Theobroma cacao* L.

The cocoa tree was first scientifically described and named *Theobroma cacao* L., by Swedish botanist Carl Linnaeus in the eighteenth century. It is a diploid tree with 20 chromosomes in somatic cells (2n=20), growing in the tropics at temperatures between 18-30 °C with annual rainfall of at least 1500 mm (ICCO, 2015b). The harvested crop is the fruit of the tree, also known as the pod, which contains the sought after cocoa seeds (or beans) in a sugary pulp.

Cocoa trees will start flowering after two to five years, forming harvestable pods when pollinated. The cocoa flowers are bisexual and grow in clusters on old leaf scars on the tree trunk and main branches in structures called flower cushions. This inflorescence from woody parts, rather than new shoots is termed ‘cauliflorus’, derived from *caulis* (trunk or stem) with the suffix *flower* (Chavez et. al 2010). Each flower possesses five (male) stamen, each with two anthers, and a central (female) stigma divided into five carpels. A graphical overview is provided below in Figure 1. Both self- and cross-pollination occurs and is done by midges. However, in areas without natural pollinators, pollination can be carried out manually. Once the flower has grown into a pod, each of the pod’s five carpels contains between five and twelve seeds embedded in mucilaginous pulp. Each fruit thus on average contains between twenty to sixty seeds. The seeds are composed of two cotyledons and an embryo, and are surrounded by a seed coat. (Badrie et al., 2015; Hebbar et al. 2012).

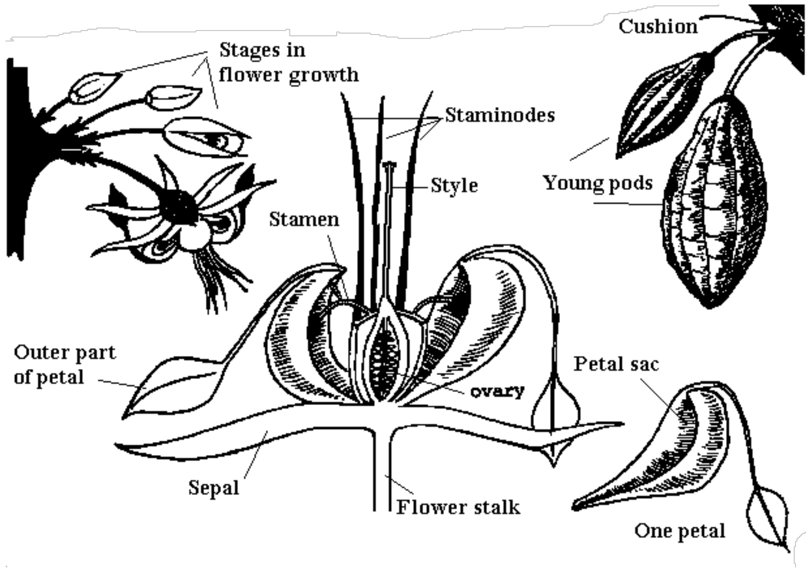


Figure 1: Cocoa inflorescence and fruit development (CocoaProject, downloaded on 21/03/2016)

1.1.1 Cocoa varieties

Cocoa has always been cultivated in different environments, leading to different varieties each with their own advantages and disadvantages. Globally, the three main cocoa varieties are *Criollo, Forastero* and *Trinitario*. They differ in their phenotypical characteristics, with further subdivisions based on morphology and geography (Badrie et al., 2015). *Criollo* and *Forastero* are the most distinct with *Trinitario* being a hybrid of the former two.
Criollo has a low yield and a high sensitivity to pests and disease. However, its flavour is widely appreciated, earning higher market prices. The fruits are usually pointed with a thin exocarp, which can either be smooth or warty. The exocarp colour ripe fruits varies from yellow to red and the carpel ridges may protrude from the fruit. Cotyledons vary from white to light purple. Two cultivars within the *Criollo* type are the *Cundeamor* and *Angoleta* which are both bottlenecked in shape. The distinghuishing trait between these two is the bluish-white pod colour of *Angoleta* before ripenin. (Thi et al., 2015)
Forastero yields are higher and disease resistance is better. In short, this variety is more easily cultivated and globally has become the most widespread cocoa variety, earning it the name 'bulk cocoa'. Three traditional cultivars within *Forastero* have been described, i.e. the *Amelonado, Calabacillo* and *Nacional*. For all three, cotyledons are normally purple. *Amelonado* cultivars are ovoid in shape, with slight tips and may or may not be bottle-necked. The grooves can either be deep or light, and the surface texture either smooth or warty. Ripe fruits are seldomly red, but instead vary from green to yellow hues. The same traits are apparent in the *Calabacillo* cultivar, although here a tip is usually lacking. Finally, within the *Forastero* group the *Nacional* cultivar is usually bottlenecked and tipped, with a smooth or warty and lightly grooved surface of the fruits, which are yellow when ripe (unpublished manuscript by Viet Ha, 2016).
Trinitario is a hybrid with mixed characteristics of the former two varieties; higher resistance to pests and diseases, in combination with a fine flavour. Due to its much broader genetic base than the *Criollo* type, *Trinitario* also exhibits a far wider range of morphological traits. The fruits can either be rounded (*Amelonado* and *Calabacillo* types) or pointed, similar to a *Criollo*. The exocarp of ripe fruits is usually thicker than a *Criollo*, yellow in colour, although

this may vary, and not grooved. The mesocarp is also woodier than a *Criollo*'s. *Trinitario* beans are often flat, with deep purple cotyledons. (Thi et al., 2015, Badrie et al.)

1.1.2 Cultivar identification

Over the years, mislabeling in germplasm collections and intercropping on plantations has led to uncertainty about the identity of many trees. Additionally, to achieve optimal growth and production it is useful to know which cultivars have been planted. For this reason, different methods have been devised to identify cocoa cultivars.

Currently, pod and bean morphology are still the most important identifiers in cocoa classification. However, recently studies have been conducted attempting to link bean quality parameters to genetics and back to the traditional subdivision in *Forastero*, *Trinitario* and *Criollo* varieties (Fang et al., 2014). These studies on cocoa genetics will allow for a deeper understanding of traits such as productivity, pest and disease resistance and climatological suitability. Eventually, this knowledge can be applied in modern breeding techniques to efficiently improve cocoa quality.

To conduct this research, germplasm collections are necessary because cocoa seeds are only viable for a short time after harvest. Furthermore sexual reproduction between parent trees leads to unpredictable traits in offspring and is therefore undesirable. Scientific collections of cocoa trees in the tropics are thus the living libraries of genetic diversity. The two most important international collections are the International Cocoa Genebank in Trinidad (ICGT) and the Tropical Agronomical Centre for Investigation and Education (CATIE) in Costa Rica.

For DNA fingerprinting of cocoa currently 15 SSR primers have been identified, which are recognized as the international standard (Saunders et al., 2004). These primers are also the basis for the most comprehensive worldwide genetic database of cocoa clones, namely the International Cocoa Germplasm Database (ICGD) of the Univeristy of Reading, UK. The latest development in research is looking into Single Nucleotide Polymorphisms (SNP's) which seem promising.

1.1.3 Cocoa pests and diseases

Pests, fungal diseases and viral diseases are of major economic importance in cocoa cultivation, leading to yield losses of up to 40 % (Guest, 2015). Certain pests and diseases occur worldwide, either as distant relatives of the same taxonomic family (such as mirids/capsids), or as newly introduced pests and diseases through international trade. Other pests and diseases occur only in certain countries or regions but may be very destructive nonetheless.

In the Asia-pacific region, the most harmful pests are a moth called the cocoa pod borer (CPB) (*Conopomorpha* spp.) and mirids of the genus *Helopeltis* spp. *Helopeltis* spp. will prick into the exocarp of the fruits with their sucking mouth parts, causing damage, consuming sugars and leading to drying of the fruits if present in high numbers (personal correspondence with Dr. Phuoc). Fungal diseases such as Vascular-streak dieback (VSD) (caused by the fungi *Oncobasidium theobromae* and *Ceratobasidium theobromae*) are equally destructive. Each of these pests and diseases leads to yield losses easily exceeding 80 % if not combatted (Keane et al., 1992).

In the Americas the fungal diseases witches broom disease (caused by *Moniliophthora perniciosa)* and frosty pod rot (caused by *Moniliophthora roreri*) are the most destructive. For example, in the 1990s Brazil suffered complete crop failures due to witches broom and currently the entire American continent suffers from the rise of frosty pod rot (ICCO, 2015). An example of a worldwide disease is necrosis (e.g. black pod disease (BPD), stem cankers, and blight) which is mostly caused by the fungus *Phytopthora* spp., and particularly *Phytophtora palmivora.* Yields can also be severely affected by *Colletotrichum* spp. infestations, causing leaf spots and pod rot.

To reduce pest- and disease-induced yield losses a three-tiered pest management system works best. Firstly, phytosanitary pruning and regular and complete harvesting is done in parallel with other sanitation measures to reduce pests. Secondly, ensuring healthy trees by providing adequate nutrients for plant development is of key importance. The third and final component of effective pest management is the targeted use of pesticides or biological pest control. These three components are discussed in more detail below.

Phytosanitary practices depend on the pest or disease: for example sleeving of young pods can be an effective protective measure against CPB. To control *P. palmivora* infestations, removing diseased pods is an efficient method, aside from improved drainage and general humidity control in the vicinity of the pods. Humidity control can be achieved through selective pruning of the shade cover, which allows sufficient irradiation around the pods. Choice of variety also plays and important role. For example, *Cundeamor* and *Calabacillo* are less susceptible to *P. palmivora* infestation than *Amelonado*. This may be due to their smooth and more waxy pod which leads to dryer pod surfaces and a reduced susceptibility to *P. palmivora* infestations (Nyadanu et al., 2011).

The second component of pest management is ensuring tree health. This is principally achieved by planting varieties which are more resistant to the pests and diseases prevalent in that region. This idea has been the driver behind the development of resistant cultivars with high yields. Planting these cultivars provides a cost effective way of reducing pesticide use and avoiding their potentially harmful effects on people and the environment. Also, ensuring good soil structure and nutritient availability is key. Cocoa requires soils rich in potassium, nitrogen and trace elements with a pH ranging from (5)6.5 - 7.5 (ICCO, 2015b). Ideal organic matter content is over 3.5% with a carbon-to-nitrogen ratio C/N greater than 9 (Hebbar, 2012). Taking the above elements into account promotes tree health and will thus reduce pest and disease stress.

Finally, pesticides and biological pest control will be discussed specific to Vietnam below in section 1.5.6 Diseases and pests in Vietnam

1.2 Cocoa as a global commodity

In 2013 world production of dry cocoa beans amounted to 4.372 million metric tons according to the most reliable estimate (ICCO, 2016). Overall about 73 % of world production is situated in West-Africa with top producers being Ivory Coast (1.7m tons) and Ghana (897,000 tons). The remaining 27 % of global production is divided between the Americas (around 16,5 %) and Asia (around 10,5 %). In America, Brazil (228,000 tons) and Ecuador (234,000 tons) are the largest producers (Cocoa barometer, 2015; ICCO, 2016). In

Asia, Indonesia was the top producer (375,000 tons) followed by Papua New Guinea (36,000 tons) (summarised below in Figure 2).

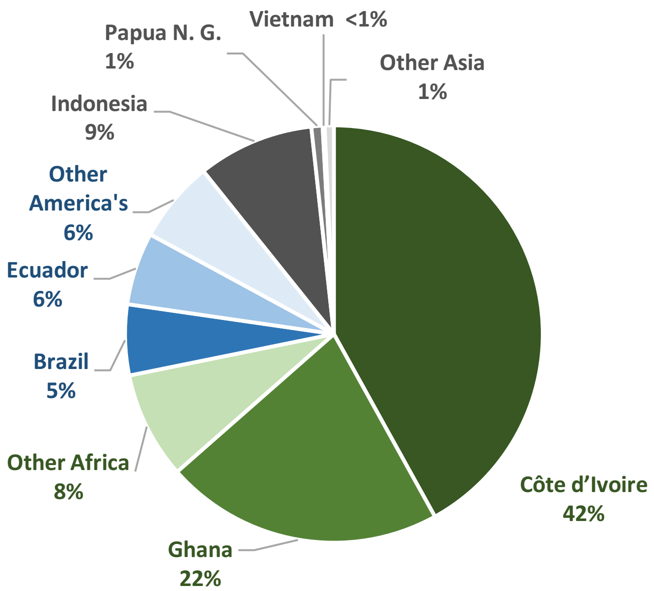


Figure 2: Pie chart of the distribution of global cocoa production in 2013. Africa shown in red hues, the Americas in blue and Asia in green hues. Vietnam is shown to underline its nascent role in the global cocoa market at roughly 6600 tons (adapted from FAOSTAT, 2015)

In recent years the cocoa industry has been evolving. Traditionally the value chain for dry fermented beans led from traders with warehouses in cocoa producing countries to the processing countries where beans were sold to grinders. Grinders produced cocoa mass and cocoa butter (with cocoa powder as a byproduct) and sold these on to chocolate manufacturers. Nowadays however, grinding facilities are increasingly delocalised to cocoa producing countries. The impetus to establish grinding facilities in cocoa producing countries is that for grinders the local capacity to grade and sort beans has become essential. As a result, the share of origin grindings in total cocoa grindings has risen substantially (up from a few percent a decade ago to 45 % in recent years)(ICCO, 2014).

A guaranteed supply of cocoa beans to the grinders and of cocoa derivatives to chocolate manufacturers is paramount to the industry. To promote this reliable flow of beans, cocoa beans are traded in so called 'futures trading contracts'. A set amount of cocoa beans is to be sold to the buyer at an agreed upon date in the future at a predetermined price, as stated in the initial contract. The prices in these contracts form the basis of global cocoa commodity prices. It is safe to say that currently commodity prices stand high, propped up by predictions of a supply deficit (ICCO, 2014). Since 2005 prices have risen from around 1500 USD/ton to 2200 USD/ton in 2012. In November 2015, the prices published by the International Cocoa Organisation (ICCO) of cocoa-beans-futures-trading were 3430 USD/ton. However, these prices are volatile, and subject to strong speculation on both production rises and grindings data.

Today, grinders have become the cornerstones of the cocoa value chain as local traders have lost influence. Additionally, the global grinding segment has now consolidated around three transnational companies: Cargill, ADM and Barry Callebaut. In 2012 43% of the world's cocoa was traded through these three companies (Cocoa barometer, 2015). As such the dominant actors in the cocoa value chain operate in an oligopolistic market. This position has been achieved thanks to their financial and technological resources, allowing them to capitalise on the economies of scale that vertical integration of the value chain offers. (Fold, 2002)

However, this development has been detrimental for other actors in two ways. Firstly, it has weakened traditional name-brand chocolate manufacturers' market power. Only part of their own beans are now ground in-house and their focus has shifted mainly to production of chocolate and its marketing. Secondly, farmers and local cooperatives have become price takers. Middlemen sell the dry fermented beans on to the grinders, who have internalised bean purchase and local grinding through subsidiaries. Overall this means the number of transactions between players prior to shipping has decreased, mainly to the benefit of the grindings companies because of their intra-firm transactions and integration (Fold, 2002).

Local governments did not counter the increasing dominance of the three grindings giants because of the short term advantages offered by local grinding: foreign investments in processing plants, a transfer of technology, creation of labour in industrialised zones, an increase in added value and in foreign currency reserves which in turn contributes to an increased national trade surplus.

1.3 Cocoa quality

1.3.1 Quality perception in the value chain

Cocoa quality is a complex phenomenon which can be considered from different perspectives. Its physicochemical, microbiological and sensory indices are assessed differently by farmers, consumers, nutritionists, and manfacturers. These views can sometimes be conflicting, as not all properties are desireable for all actors in the value chain.

Farmers are paid by fermenters for the bulk weight of the pods they deliver. Pods are visually inspected for ripeness (colour), and pest or disease damage. Hence, maximised production with minimal damage and impurities are desireable for farmers.

In an increasingly consumer driven pull-market, consumer acceptance is key to the survival of a food business. Place associations, brand name, and recently the awareness trend for environmental and social aspects are all important in consumer perception of 'quality' (Cidell et al., 2006). Ultimately however, consumer acceptance of foods is most notably linked to its sensory quality (Viaene et al., 1999; Araujo et al., 2014). Consumers buy and eat chocolate mainly for hedonic reasons.

From the nutritionist's perspective it is desirable for cocoa to contain high amounts of antioxidants. However, the nutritional perspective's impact on the cocoa market is still in its infancy. Only in 2013 was the first health claim on cocoa flavonols approved by the EU, and the first products with this claim are expected on the market in the course of 2016 (Food Navigator, 2016). Flavonoids, and more specifically, flavan-3-ols and their oligo- and polymeric derivatives such as procyanidins, have a variety of beneficial functions including antioxidant protection and regulation of vascular health (Bruna et al., 2012).

On the Western consumer market the trend of increased health awareness cannot be ignored, and cocoa quality will eventually also be judged by its flavonoid content. However, this conflicts with the observation that lower polyphenol content is associated with richer cocoa flavour as will be described below.

For manufacturers, homogeneity and consistency of physical characteristics are desireable, besides also generally cheaper raw materials. Thus the ability of the cocoa beans to fulfill specific technological requirements during processing is key. One parameter which stands out here is the bean fat content and yield, which usually ranges from 53–60 % (Afoakwa et al., 2013b). Additionally, consumer acceptance is essential for a manufacturer. Firstly, this means manufacturers also take sensorial bean quality into account when assessing overall bean quality[1]. Secondly as the market for premium chocolate grows there is a producer tendency towards targeting innovations such as single origin and single estate chocolates on specific groups of consumers (Fold, 2002).

Finallly, a legal foundation which harmonises farmer, consumer, nutritionist and manufacturer views on quality hardly exists. Regional or national regulatory bodies or cocoa organisations may have their own quality standards for their members but in the end, cocoa processors set specifications. Existing quality factors as described by CODEX STAN 141-1983 limit themselves to stating cocoa mass may not contain more than 5 % m/m cocoa shell and germ on fat free dry matter. Also, cocoa butter content must be between 47-60 %.

1.3.2 Sensorial cocoa bean quality

As described above, consumer acceptance is mainly driven by sensorial appreciation, which in turn drives manufacturers to pursue high sensorial bean quality.
This sensorial cocoa bean quality is impacted by the different stages of production. During primary production climate, soil type, and agronomic practices are of importance. Next, fermentation, drying, storage and handling and finally roasting and conching, all play an important role in cocoa bean flavour.

Generally speaking, unroasted and dried cocoa beans need to meet a set of basic requirements, including a moisture content lower than 7.5%, absence of clusters and of foreign material. Next, unroasted beans can be graded into different classes. This is done according to bean count per 100 grams of beans (i.e. bean size is usually expected to exceed 1 gram (CRU, 2009)), percentages of mouldy or slaty beans, insect damaged beans, germinated beans or flat beans. These are determined with the so called cut test for which fermented beans are cut open lengthwise and the inside of the cotyledons is inspected.

To asses flavour potential prior to roasting two main indicators are used related to cotyledon

[1] For manufacturers, correlating technological and sensory evaluations of cocoa products is useful because it allows to predict consumer acceptance without the need of sensory evaluations of every delivered batch of cocoa beans before processing to liquor. However it is still advised to perform a sensory analysis on every liquor batch to make informed downstream processing decisions (Reed, 2010). A common cocoa liquor flavour wheel for sensory evaluations, as used among other at Cargill is shown in Appendix 1.

colour[2].: the fermentation index and a colour-based bean cut test (Shamsuddin at al., 1986). In the bean cut test the percentage of brown and light purple compared to deep purple beans is counted. The fermentation index is the ratio of wavelength absorbance at 460 nm and 530 nm. Both these indicators are heavily influenced by the amounts of polyphenols and anthocyanins left after fermentation (Jinap et al. 2003).
During fermentation polyphenol oxidation and anthocyanin hydrolysis takes place, followed by enzymatic browning during sun drying[3]. This reduction goes hand in hand with protein and sugar hydrolysis which are the actual chocolate flavour precursors. As such, the transition from deeper purple to more brown cotyledons, and analytically the increase in wavelength absorbtion at 460 nm compared to 560 nm light indicates proper fermentation.

Aside from the bean cut test and fermentation index a more sophisticated set of criteria can also be used to predict flavour potential including reducing sugars, free amino acid content, polyphenol content and phenolics content (such as catechin and epicatechin), and bean pH.
In dry fermented beans before roasting polyphenol content usually varies from 2-6% depending on geographical origin and variety (e.g. *Forastero* tends to have higher polyphenol contents than *Criollo*) (Bruna et al., 2011). The lower polyphenol content increases cocoa flavour formation during roasting because aroma precursors no longer bind to the polyphenols, in part explaining the higher market value of *Criollo* cocoa, often termed 'fine flavour cocoa' as opposed to the 'bulk cocoa' *Forastero* types (Tran et al., 2015).
Optimal post fermentation pH is in the range of 5-6. Below this fewer flavour precursors will have been produced during fermentation, and the final product will be overly acidic (Saltini et al., 2013).

Overall though, many more parameters may be assessed depending on the perspective on sensorial bean quality taken. Total fat, total acidity, organic acids (e.g. acetic or lactic acid), caffeine, theobromine, heavy metals and content of macro- and micronutrients (such as calcium, potassium, iron or magnesium) may all be measured (Araujo et al., 2014, Afoakwa et al., 2013).

1.3.3 Developments in cocoa quality

As previously stated in the section 1.1.2 on cocoa cultivar identifcation, up to now most breeding research with molecular markers has focused on identification of yield and disease resistant markers in cultivars. However recently interest has risen in markers for genotype-specific flavours and sensorial properties as well.
If flavour attributes of fine flavour cocoa can be linked to specific genotypes, and furthermore, the relevant molecular markers can be identified, cocoa breeding programmes could more easily intensify focus on sensorial bean quality too (Kadow, 2013). As such, desireable fine flavour properties could be maintained or promoted in new cultivars. This could benefit all actors in the value chain: e.g. financial incentives could be given to farmers by traders in order to shift farmers' focus to also include bean quality, and eventually

[2] It has been shown that bean colour in itself can be used as a proxy for the fermentation index, and is therefore also an appropriate indicator to assess bean quality (Ilangantileke et al., 1991).

[3] The fermentation process itself will be discussed in more detail in the following section 1.4

consumers may have access to a wider range of products, ranging from average to high-end chocolate at fair prices.

1.4 Chocolate production

At first sight chocolate appears to be a relatively simple product with a limited list of ingredients and processes involved in its manufacturing. However, each of the processing steps of cocoa contributes to the development of final flavour and therefore needs to be properly understood and controlled.

The first step in chocolate production[4] is harvesting the cocoa pods. After facultative pod storage, the pods are opened and the cocoa beans with sweet white pulp are piled up for fermentation. This can be done for instance in wooden or plastic boxes, or on the ground. The pulp is covered, often with banana leaves or jute bags and left to ferment between three to six days, turning and aerating the beans at fixed intervals. For research purposes, the fermentation can be monitored through temperature and pH measurements, with a pH rise of the pulp from around 3.9 to 4.5 or more and temperatures up to 50 °C.
Over the course of the fermentation a series of microorganisms dominates one after the other. These are mainly naturally occurring yeasts, and then lactic acid bacteria followed by acetic acid bacteria. Yeasts are responsible for the reduction in citric acid content, degradation of pectin and metabolisation of reducing sugars into ethanol. In a second phase initiated by aeration, lactic acid bacteria further degrade reducing sugars. Depending on the conditions they will utilize a homo- or heterofermentative metabolism for this, producing either only lactate or lactate, acetate and ethanol respectively. In a third and final stage, acetic acid bacteria will flourish, producing more acetate as more oxygen is brought into the pulp through aeration. The produced acetic acid and ethanol will infiltrate into the bean cotyledon as the temperature rises up to 50 °C killing the bean germ. Thus in essence the microorganisms metabolise the pulp's sugars to produce short chain acids such as lactic and acetic acid and other volatiles. Additionally, cell lysis caused by the bean's death releases proteases, increasing free amino acid and peptide content concurrent with flavour precursor formation through a series of biochemical reactions. Among these for example polyphenol content drops as phenolics bind to sugars and amino acids or are degraded. Combined, all these mechanisms produce the flavour precursors essential in the development of the final chocolate flavour. However, if the fermentation is continued beyond this point, aerobic spore-forming bacteria and eventually fungi will start to grown on the pulp, which is detrimental to quality, producing off-flavours and should therefore be avoided (Schwan et al. 2004). (Afoakwa 2013; Afoakwa 2013b; CRU, 2009; de Brito et al., 2001; Nielsen, 2007; Schwan et al., 2004; Sukha, 2008)

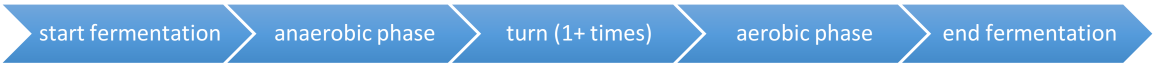


Figure 3: basic fermentation process with succession of an anaerobic and aerobic phase with consecutive production of ethanol, lactic acid and acetic acid

[4] See "Appendix 2: Bean to Bar Chocolate Production Flow Chart (Adaptation from Beckett, 2011)"

After fermentation, the beans are dried, artificially or naturally, to a moisture content of about 7 % on mats or on the floor. Below this moisture content, enzymes are no longer active.
During drying, part of the acetic acid in the fermented beans may evaporate. Different drying schemes can be employed in an attempt to maximally reduce acidity. One such possible method is to partially dry the beans before storing them in an airtight container for a time before final drying. The idea behind storage is to allow acetic acid in the bean to diffuse again from the centre of the bean to the surface after initial drying. When drying is started again, overall more of the acetic acid may volatilise than would be the case under a single drying period (correspondence with dr. Phuoc, March 2016). This method of reducing acidity will be investigated as part of this thesis.

Once dry, debris caked onto the beans is cleaned off. The bean cotyledons are then roasted at 120-160 °C for 20-40 minutes, further contributing to flavour development (Ramli et al. 2006). Here the peptides, amino acids and reducing sugars react in non-enzymatic browning reactions such as the Maillard reaction and its side reaction, the Strecker degradation, to produce mainly pyrazines, furanes, and aldehydes responsible for a 'chocolate' aroma (Kadow et al., 2013). After roasting beans are crushed and broken into cocoa nibs in a process called winnowing, and are then ground in order to release the cocoa fat from the cotyledon's cells. The fat may either be left in the cocoa mass, or removed, producing cocoa butter and a cocoa cake which forms the basis for cocoa powder.

Other ingredients (usually sugar and milk powder - if producing milk chocolate) are mixed with the cocoa mass. The mixture is then refined using roll-mill refiners to produce a narrow particle size distribution for optimal flow properties of the chocolate. To avoid a gritty mouthfeel, particle size of the non-fat fraction of chocolate needs to be lower than 30 μm. Finally, conching is performed for optimal flavour development. During this process, the previously produced flavour compounds are distributed over the fat and non-fat phases while certain (undesirable) volatiles are lost. Agglomerates are broken up and moisture evaporates. During conching, the liquid fat phase coats the non-fat particles, which allows for the transition from the so called 'dry' to the 'pasty' phase. Depending on the desired final product viscosity varying amounts of emulsifier and cocoa butter are added, producing the 'liquid phase'. The liquid chocolate is then tempered to produce β^{V} polymorph fat crystals, essential for optimal snap and gloss of the chocolate, while also being less susceptible to fat bloom caused by the β^{IV} to β^{VI} polymorph transformation. (Beckett, 2011; Saltini et al., 2013; Schwan et al., 2004)

1.5 Cocoa cultivation in Vietnam

1.5.1 A brief overview

The cocoa tree is not native to Vietnam but was introduced under the French colonial administration. However, at the time the sector failed to take root because it was outpriced by cashew, pepper and coffee (Ooi, 2004; personal correspondence with Marou, 2016). In the 1980s a second attempt was made by the Vietnamese government but given that processing and export facilities were lacking again the sector failed to establish itself.

Eventually during the mid-nineties slump in global cocoa production the Vietnamese sector revived. Lessons were drawn from Vietnam's earlier attempts at cocoa cultivation and thanks to its favourable climate it remained an appealing place in which to develop a cocoa sector. Thus in 1993 the World Cocoa Foundation (WCF) and Mars Inc. showed interest in Vietnam and together with NGOs and the Vietnamese government introduced cocoa in the Mekong River Delta, the Southeast regions, Central Highlands and South Central Coast.
In the decade proceeding 1993 nurseries were set up, different cocoa varieties were tested and agronomy practices were disseminated in selected communities. Important international donor organisations in the sector's development were the Danish international development agency (DANIDA) and the Swiss association for international cooperation (Helvetas)(Nguyen, 2014).

Between 1997 and 2005 the national Vietnamese government's Cocoa Development Committee worked further on the development of the industry. Currently, the cocoa industry developments are planned and guided by Vietnam's Cocoa Coordinating Board, together with the Ministry of Agriculture and Rural Development (MARD). This is done according to the approved programs from the Cocoa Development Committee. The current program ran into 2015. MARD and the other government agencies are mainly involved in facilitating sector expansion through research on clones, issuing standards, setting out broader policies, engaging in extension work, dissemination of findings and capacity building.

A notable project in the sector's development was the public-private partnership 'Sustainable Cocoa Enterprise Solutions for Smallholders (SUCCESS) program', co-funded by USDA, USAID and Mars Inc. It ran from 2003 to 2010 with a total budget in excess of $(US) 5,5 million (ACDI, 2016). It provided technical training for farmers, led to an increase in cocoa acreage and helped to set up a purchasing network for fermenters, ensuring farmers could sell their pods (Nguyen, 2014; Pham et al., 2008). In total over 20.000 farmers in the Southeast and Mekong Delta received some form of training and over 120 fermentation centres were set up in Ben Tre up to 2009. In 2006 the project expanded its initial target regions to include the Highlands as well where up to 900.000 seedlings were distributed and a pilot project was started integrating a cocoa agroforestry system into the periphery of a protected natural park. (ACDI, 2016).

These combined efforts have led to a 200-fold increase in production volume of cocoa in Vietnam in the last decade (from 35 tons in 2005 to 6600 tons in 2015). Production areas per province in 2014 are shown in descending order below in Figure 4.
However it should be noted that production is well below the initial target for 2015 of 26.000 tons, set by MARD in the early 2000s (Nguyen, 2014). Additionally, production area has been in decline since its peak of around 20.000 hectare (ha) in 2012, when competing crops such as pomelo became more profitable (Nieberg, 2016). The total production area is now around 11.700 ha and is concentrated in the Mekong Delta, Southeast and the Central Highlands (see map in Appendix 3).
Currently there is little literature and there are few other internet sources providing more detailed information on the stalling cocoa production. In order to assess the causes of this decline more information should be made available in the public domain.

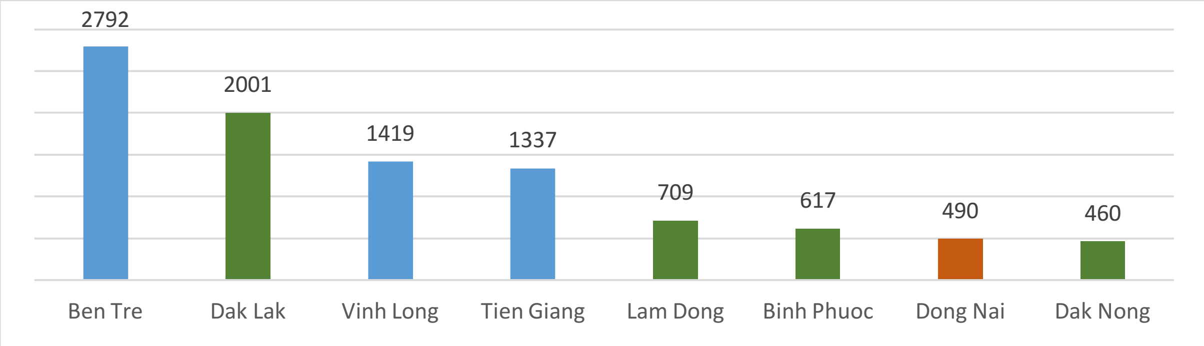


Figure 4: Production areas in hectares, per province in 2014 in descending order. Blue hues indicate the Mekong Delta, greens the Central Highlands and orange the Southeast. (adapted from Nguyen, 2014)

1.5.2 The cocoa value chain

Vietnam's agricultural sector employs 48% of the national workforce (CIA, 2016). It is characterised by a high number of smallholder farmers working on family-owned plots. This form of organisation is the same for the cocoa sector as Vietnamese smallholder farmers provide the bulk of produced cocoa (Pham et al., 2009). Following primary production, cocoa beans are sold on through a series of middlemen to grinders and manufacturers who export cocoa and eventually produce chocolate (Nguyen, 2014). The smallholder farmers usually own and cultivate cocoa on fields smaller than one hectare (Pham et al. 2009). They will either ferment harvested beans themselves or will sell pods or wet beans on to collectors or fermenters who perform the fermentation for them. Fermenters generally buy larger quantities of beans from a number of nearby farms and subsequently ferment and dry the beans. They then sell them on to grinders and manufacturers such as Mars Inc., Puratos Grand-Place or smaller local processors. (Nguyen, 2014; Pham et al., 2009)

In published literature describing the cocoa value chain, knowledge gaps exist. Detailed information on the ratio of farmers fermenting themselves versus those fermenting at fermentation units is not available in the public domain. Furthermore, it appears few attempts have been made in Vietnam to investigate the dynamics concerning the decision to perform fermentation on the farm or not. Equally so, the subsequent impact this has on farmer income and the quality of the produced cocoa is mostly described in generalised terms in the optimistically skewed final reports of development projects, such as Helvetas' PPP-project to strengthen cocoa production (Helvetas, 2016).

1.5.3 Challenges in the cocoa value chain

Despite apparent knowledge gaps in the understanding of the value chain, a number of issues have been identified. Most importantly the sector's failure to meet government targets for production needs to be understood. So far two interlinked impediments have been identified: inconsistent quality and low productivity (Nguyen, 2014). A third challenge constitutes countering the recent acreage decline as described in section 1.5.1.

The first two challenges of inconsistent quality and low productivity have been associated with farmers' inadequate practices. Given the small average farm size, efficient dissemination of best practices for cocoa has proven difficult. As such, large numbers of farmers work small areas without the necessary understanding of agronomic principles or the fermentation process to achieve high yields of high quality cocoa, and this despite many multi-stakeholder attempts to rationalise the sector. (Nguyen, 2014, Pham et al., 2009)

A third challenge is posed by the decline of cocoa acreage over the past four years, due to the replacement of cocoa by more profitable crops such as pomelo (Nieberg, 2016).
A 2008 study on fluctuating coffee prices in Dak Lak province found that in the coffee sector farmers with less land generally have fewer opportunities to enhance liquidity in the short term when commodity prices fall. As such they were found to be more likely to adjust to price changes by shifting land use to new crops (Ha et al., 2008).
Drawing a parallel with cocoa farming, small, low-input farmers (who produce the majority of cocoa in Vietnam) may be especially sensitive to price fluctuations of cocoa and competing crops and will thus readily cut trees to be replaced with more profitable crops. The study of the coffee sector suggested to provide the farmers with opportunities to diversify income instead. This may be applicable in the cocoa sector as well, including alternative intercropping methods.

As a final side note, Nguyen (2014) describes the high number of middlemen in the value chain as a barrier to increased farmer income. The paper points to a piece of legislation reinforcing this form of organisation.
According to a series of stipulations in Circular No. 08/2013/TT-BCT issued on 22 April 2013, a locally licensed firm – such as a raw bean collector or a fermentation cooperative – is required to function as an intermediary between foreign owned companies and the bean producers. It essentially prohibits foreign-invested enterprises to organise networks of goods purchase for export and as a result of this stipulation, companies like Cargill, ED&F Man, ADM or Puratos Grand-Place would in theory not be allowed to buy beans directly from farmers but instead would need to set up a locally licensed firm to do this on their behalf.
The rationale behind this government policy is most likely to protect local traders from the market dominance of these foreign owned companies. However, the extent to which foreign-invested enterprises are influenced by these stipulations remains unclear.

In order to address the prevalent challenges in the value chain and develop more targeted measures, corroboration of previous findings and deepening of insight in the value chain is necessary. More effective measures could lead to increasing farmer resilience to price fluctuations and could contribute to consistency in output. Specific research questions which will be addressed in this paper towards this objective are:

- How is the value chain structured?
- How are value and value addition distributed?
- Under which circumstances is quality currently highest?
- Are high numbers of middlemen reducing farmer income?
- Does intercropping increase farmer resilience to price fluctuations and make them less likely to chop cocoa trees

1.5.4 Cocoa cultivars in Vietnam

Currently, nine clone cultivars are recognised by MARD meeting as ‘1A Vietnamese standards’ in quality criteria, and are therefore promoted over other hybrids. To be eligible for approval by the national government, a clone must produce high yields in diverse settings and be versatile over the cocoa growing regions. Until recently TD9 and TD11 cultivars were not approved despite being widely used by farmers and having regional government approval (e.g. in Ben Tre for TD11). When the last application round took place, TD9 had grown too slowly to have produced enough pods, however in 2015 it received MARD approval. TD11 has favourable growth and yield properties but until recently was only grown in the Mekong Delta. As yield data for TD11 in the Highlands in 2016 is also taken up in the application, it is hoped in 2017 TD11 will also receive MARD approval (personal correspondence with Dr. Phuoc, 2016).

The now recognised cultivars are TD1[5], TD2, TD3, TD5, TD6, TD8, TD9, TD10 and TD14, all originated from Malaysia.

Most TD cultivars are *Trinitario* and *Forastero* hybrids, although for TD8 and TD11 it is generally accepted these are ‘pure’ *Forastero* cultivars (Phuc, 2013). Some uncertainty still exists about the lineage of certain other clones, such as TD2. Genetic and anatomical research needs to be conducted to provide decisive answers. A generally accepted list of clones with their origins is provided in *Table 1.*

Table 1: Overview *of the commonly used, commercial clones in Vietnam. All are MARD approved except TD11 (Phuc, 2013; Everaert, 2016; ICDG, 2015)*

Thủ Đức	Clone	Derivation	Lineage
TD1	BAL209	Borneo albacca plantation	*Trinitario* x (Upper Amazon) *Forastero*
TD2	BAL224	Borneo albacca plantation	*Forastero* x *Forastero* (?)
TD3	BR25	Balung river	*Trinitario* x *Forastero*
TD5	KKM22	Klon koko mardi	*Trinitario* x (Upper Amazon) *Forastero*
TD6	PBC123	Prang besar clone	*Trinitario* x (Upper Amazon) *Forastero*
TD8	PBC157	Prang besar clone	*Forastero*
TD9	PBC159	Prang besar clone	*Trinitario* x (Upper Amazon) *Forastero*
TD10	PBC230	Prang besar clone	*Trinitario* x (Upper Amazon) *Forastero*
TD11	PBC236	Prang besar clone	*Forastero* x *Forastero*
TD14	QH441	Quoin hill	PA 173 x SCA 9 (*Forastero*)

1.5.5 Cocoa cultivation in Vietnam

Cocoa is cultivated in Vietnam according to different practices. It can be monocropped or intercropped with coconut, cashew or other shade trees and is either intensively farmed, or farmed with minimal external inputs. Commercial cocoa clones from established germplasm collections account for the majority (more than 80 %) of the total cultivated area, alongside unidentified trees and hybrids of selected parent trees. The cocoa trees are never sown; instead seedlings from commercial nurseries or research centers are planted.

Among the four regions where cocoa is cultivated, the Mekong Delta climate is highly favorable. The annual average temperature is 26-27 °C and annual rainfall ranges from 1250 – 1500 mm, with a lot of additional water available from the Mekong river basin (Pham, 2008). Plantation size is small, usually between 0,3 to 0,5 ha. Cocoa is mostly intercropped

[5] TD stands for Thủ Đức District in Ho Chi Mihn City, where the National Cocoa Seed Centre is located

with coconut or cashew, and is planted on raised dikes to avoid the tap root system being flooded by the canals or tides. Spatial distribution of cocoa trees and other fruit trees has been optimised to increase yields. Also, the prevailing low winds speeds are favorable to cocoa cultivation. (Pham, 2008)
An issue in the Mekong Delta is the ease with which farmers chop down their trees to replace them with other crops which are more profitable on short term. In 2014, Ben Tre farmers cut down 15 % of their acreage to be replaced with longans and other fruits when cocoa prices declined sharply that year (Nguyen, 2014).

In the Central Highlands there is more rainfall (1600-2000 mm per year, 80-90% from May to October) and a lower average annual temperature (22 - 23 °C) (Pham, 2008). The average farm size is larger than in the Mekong Delta (2-4 ha). Farming is also done by smallholders; about one third uses intensive methods and another third uses very low external inputs (Pham et al. 2008). This leads to large variability in the average productivity, ranging from 0.4 to 2.5 tons per ha and an average yield of 0.8 tons of dry beans per ha. Besides low productivity, consistent quality of the produce is also an issue. Harvesting unripe pods for reasons of convenience, to prevent theft or because of the presence of rats, is not uncommon.

As mentioned in the general section on cocoa quality, agronomical practices and soil type have an impact on cocoa quality. Specific to Vietnam, most likely as a result of soil type, cocoa beans are more acidic than most other cocoa cultivated in the world. The beans appear to easily take up volatile organic acids produced in the pulp during fermentation, which reduces their quality (Afoakwa et al., 2013; Nguyen, 2014). Several mitigation strategies are possible, usually involving pulp preconditioning, i.e. modifying pulp properties prior to microbial fermentation. Three possible preconditioning methods are pod storage after harvest prior to fermentation, partial mechanical juicing of the pulp and spreading out of the beans during fermentation. These methods mainly influence moisture content and sugar concentration of the pulp, which influences the microbial fermentation and thus acid production (Afoakwa et al., 2013b). The extent to which these are commonly performed in the different regions has yet to be determined.

1.5.6 Diseases and pests in Vietnam

Like elsewhere in the world, also Vietnam is confronted with a host of pests and diseases reducing yields.
In the Central Highlands, the main pest is *Helopeltis antonii,* a capsid bug. Plant damage is induced by the sucking mouth parts, causing leaf damage and bud or shoot necrosis when capsids are present in large numbers. Capsids reduce overall plant resilience, so that the cocoa tree becomes more sensitive to other infestations as well. Mealy bugs (*Pseudococcidae*), soft mirids (*Brevicoryne brassacicae*), stem borers (*Xyleborus morstatti*), *Adoretus* spp. and *Zeuzera coffeae* are pests of secondary importance. In the rainy season, under high humidity conditions, the fungi *P. palmivora* and *Fusarium* spp. cause VSD and black pods, thus also reducing yields with an average of 30 %. (Pham et al., 2008)
The cocoa pod borer is still absent in Vietnam, contrary to Indonesia and the Philippines, where it is by far the most destructive pest (correspondence with dr. Phuoc).

In terms of the three-tiered pest management approach as described in section 1.1.3 'Cocoa pests and diseases', progress can likely still be made.
Firstly , it should be determined which phytosanitary measures need to be promoted further and implemented. Currently preventative pesticide and fungicide application on plots under an intensive production system is thought to be widespread. However, MARD actively already promotes integrated pest management, including pruning, mulching and introduction of biological pest control such as *Lasius niger* ants to combat capsids in the Mekong Delta, but it is not known how effective this promotion has been.
Canopy management of the shade trees can also be applied to allow sufficient heat and airflow around the cocoa trees to reduce humidity and avoid BPD caused by *Phytophtora* spp. (Phong, 2011).
Secondly extra attention may be paid to ensuring tree health. Approved varieties should be chosen depending on suitability to an area, encompassing climate, soil, pest and disease stress. TD3 and TD5 clones are currently the most widely used. However, TD5 is susceptible to *P. palmivora*, and therefore less suited to wetter regions in the Central Highlands. TD1 and TD14 are also more susceptible to *Phytophtora* spp. and are likely to be removed from the MARD approved list of cocoa clones in the future (Pham et al., 2008).
The final component of pest management is spraying. Spraying practices should be surveyed to determine which substances are being used, how they are being applied and under which circumstances.

1.6 Research goals

This research aims at providing an overview of the quality potential of cocoa in southern Vietnam. Vietnam's cocoa sector has been static or in decline for a few years now. If Vietnam takes part in the growing market for premium chocolate the declining trend might be countered.
To determine whether this is an option, firstly an analysis is required of the current state of the cocoa value chain in Vietnam and a promising model for the market is described. This should include an analysis of the distribution of value and of favourable market conditions for high quality cocoa. It should also include suggestions towards increasing farmer income and consolidating cocoa acreage.
Secondly, bottlenecks in current farming practices need to be charted and a list of suggestions to resolve them offered. In parallel the qualities of new cocoa clones need to be assessed. In the longer run, diverse data on different clones will allow farmers and processors to select clones not only for yield and disease resistance but also for flavour and aroma potential.
The challenge of cocoa acidity in Vietnam also remains. Fermentation processes have been largely harmonised across Vietnam. Looking into alternative drying methods aimed at reducing acidity may offer perspectives on further acidity reduction. These results should then further be tested using expert and consumer panels, not only on acidity but other flavour notes as well, which may have been influenced by alternative drying processes.

2 Methodology

2.1 Agronomic and postharvest survey and market information in Vietnam

A preliminary comment with regards to this survey is required. The survey sample size includes only 14 respondents. This number is too low for a thorough analysis of the value chain and agronomic practices. Instead the survey can be seen more as an observation of the current practices of a small subset of the population of cocoa farmers and fermenters. This entails that results will be interpreted more intuitively, where averages and standard deviations merely have a qualitative value and the significance level of the result is disregarded.
This form of market observation can be seen as a first step towards evaluating current practices in cocoa farming and production in Vietnam. Results will therefore mainly be interpreted through visual representations of graphs rather than analytically.

A second comment pertains to the sampled farmers. This subset of the population of farmers was not taken randomly. Surveys were collected from from farmers supplying specialised processing companies: the first was the fermentation unit of Puratos Grand-Place, the second a cocoa trader and processor with strong ties with Nong Lam University. This second trader was once a Cargill cocoa training centre and among the first three cocoa buying centres in Vietnam to receive UTZ certification in 2011 (Thanh Dat Cocoa Company). As such, it can be expected that the sampled farmers display a higher degree of skill and knowledge about cocoa farming than the average cocoa farmer as described in the introduction of this paper.

The survey consisted of 5 sections. In the first section on demographics, farmers were asked about their experience growing cocoa and education level. In section two on farm characteristics, farm size was asked and farmers listed their preferred clones and traits of each clone. In section 3, farm management practices were surveyed: intercropping and pruning practices, fertiliser use, pesticide use and yield data was gathered. In the final section on post-harvest practices, farmers were asked about harvesting frequencies, storage, fermentation and drying practices, before final questions pertaining to training and social capital.
The complete survey can be found in Appendix 4.

Additional interviews were conducted with a number of people involved in the sector. Three main sources of information in this respect were Dr. Phuoc Pham of Nong Lam University, who has been involved in the cocoa sector since the early 2000's. Additionally Mr. Raphael Rouzeau, the sourcing director of Puratos Grand-Place Vietnam, and Alexandre Parizel, sourcing director of Marou Chocolate, Vietnam provided their insights.

2.1.1 Estimate of number of cocoa trees

Farmers were asked what the total number of cocoa trees and other crop trees on their farm was. An estimate was also made based on the spacing of trees in rows and columns, using an estimation formula:

$$N° \; cocoa \; trees = \frac{area \; (m^2)}{row \; spacing \; (m) * column \; spacing \; (m)} - N° \; fruit \; trees$$

N° is the estimate for the number of cocoa trees, area the total farm area in m^2, row and column spacing the distance between trees planted in a grid, and N° fruit trees the reported number of fruit bearing trees other than cocoa (e.g. mango, durian). This formula resulted in a slight overestimation compared to the reported tree numbers by farmers reporting both spacing and number of cocoa trees.
Therefore, for farms with a reported number of trees, the reported number was used. For farms where no number of trees was reported, the estimated number is used, corrected with the average overestimation of trees from farms reporting spacing and tree numbers.

Example of the corrected estimate of number of cocoa trees:
Tree estimate based on spacing formula for respondent 3 in Ba Ria: 889 cocoa trees
Average overestimation of formula: 107 cocoa trees
Corrected estimate for respondent 3 in Ba Ria: 889 – 107 = 782 cocoa trees

2.2 Cocoa genotypes

This research aims to contribute to the characterisation of physico-chemical properties of unapproved Vietnamese cocoa clones. Cocoa pods were harvested in Tân Phú District, Đồng Nai Province in Southeast Vietnam in late March 2016. The planted area in Tân Phú, Dong Nai, encompasses about 3 ha, with 48 varieties currently being tested. The area is separated into three repetitions of the 48 clones. Eight clones were selected based on on-site availability, genetic filiation (Everaert et al., 2016) and pod morphology. Ripe pods of each clone were harvested using the farm's map of varieties, tree labels and common pod morphology. Pods were put together in woven polypropylene bag and labelled ntil fermentation.

The harvested varieties are TD3, TD9, TD13, TD28, TD54, SIAL339, PA70 and M3. No official clone names or derivations are known for the last 5 clones, except for PA70 (Parinari 70, imported to Vietnam from Puerto Rico, originally described in Peru (ICGD, 2015)).

2.3 Commercial estate samples

In order to observe the impact of region on physico-chemical characteristics a second and third subset of fermented dry beans was collected from Puratos Grand-Place (TD5 and TD9) in Bến Tre Province, and from Thanh Dat Cocoa Company (TD3 and TD9) in Bà Ria-Vũng Tàu Province (see coding in Table 2: Cocoa clone coding for repetitions from commercial estates). Results will be compared to those of the same cocoa clones from Đồng Nai. (The fermentation and drying procedures were the same for the single clones from Đồng Nai province, as described in section 2.5)

Table 2: Cocoa clone coding for repetitions from commercial estates

Code	Clone	Origin
TD3b	TD3	Thanh Dat Cocoa Company
TD5a	TD5	Thanh Dat Cocoa Company
TD5b	TD5	Puratos Grand-Place
TD9b	TD9	Puratos Grand-Place

2.4 Mixed variety primary processing

Besides a description of clone characteristics, this research aims to asses the potential of an alternative drying method to reduce cocoa bean acidity. For this, a second set of cocoa beans were taken from Tân Phú District in Đồng Nai Province in March 2016. They were harvested, fermented and dried between March 9th and 28th, 2016 . These 7 samples each contain a mixture of *Trinitario* varieties from the farm. They were fermented and dried as summarised in Table 3. During the drying procedure, drying was stopped by putting beans in closed plastic bags for one to three days, after which beans were dried further to optimal moisture content.

Table 3: Fermentation and drying procedure for 7 samples of mixed Trinitario beans, codified as T for Trinitario and the batch serial number

Sample	Fermentation time (h)	Turning procedure (t_1(h), t_2(h))	Drying procedure (first drying time(d), storage time (d), second drying time (d))
T1	120	t_1(24)	3,1,3
T2	120	t_1(24), t_2(96)	3,1,3
T3	120	t_1(24)	2,3,3
T4	120	t_1(24), t_2(96)	8
T5	120	t_1(24), t_2(96)	*2,3,3*
T6	120	t_1(24)	8

2.5 Single variety post-harvest processing

A standardised protocol for fermenting and drying from small cocoa bean samples based on Sukha et al. (2008) was followed in Đồng Nai (Figure 5). However, given limitations in harvested pod numbers, the amounts of each variety for fermentation was different. Ripe healthy pods were bagged in 40 x 60 cm green nylon bags with 4 mm mesh size. The beans were juiced with a primitive pressing apparatus using a car jack until the 30 cm layer of beans had been compressed about 2 cm, and until it stopped dripping. The bags were buried about 15 cm deep in a mass of *Trinitario* beans in wooden fermentation boxes (60 (H) x 50(W) x 60(D) cm) with slits at the bottom for drainage. The beans were covered with fresh banana leaves and jute bags and left to ferment for 110 hours. Beans were turned after 24 hours and again after 95 hours, before starting drying at 110 hours. However, due to low temperatures (less than 45 °C after 48 hours), "box 2" was turned a second time at 65 hours and not turned at 95 hours.

Figure 5: turning frequency employed for the two fermentation batches. Box 2 was turned earlier as the temperature had not reached 45 °C after 48 hours

2.6 Mixed variety bean to bar processing

The mixed variety beans from Đồng Nai were further processed into chocolate. The recoded names can be found in Table 4. Final chocolate acidity will be measured and finally a consumer panel will evaluate the chocolates as described in section 2.12.
A dark 70 % chocolate was chosen because cocoa flavours would be less muddled by sugar's sweetness than for a 35% - 50% dark chocolate. A 70% dark chocolate is also a product which fits into the expanding niche of dark origin chocolates, in which Vietnam should aim to obtain market share.

First, roasting conditions were selected from a low (118 °C, 35 min), medium (125 °C, 34 min) and high-roast (135 °C, 30 min) test. This test was done on a 1:1:1 mixture of samples T1, T3 and T6 on plates in an oven (V-Zug, Switzerland). Roasted beans were tasted by four university staff members with experience in cocoa tasting. Optimal roasting conditions were chosen at 125 °C for 34 minutes.
Samples T2, T4 and T5 were separately roasted (125 °C, 34 min) on plates in an oven (V-Zug, Switzerland). After roasting, the beans were winnowed and the obtained cocoa nibs were ground to a coarse powder in a Moulinex coffee grinder. Cocoa mass was produced in a validated melanger with a particle size of 40 μm (70 min, ECGC-12SLTA CocoaT Melanger, USA). Molten cocoa mass (45 - 55 °C) was mixed with pre-broken sucrose in proportion to yield 27 m% fat on the mixture (45 °C, 20 min (VEMA BM30/20 variomatic planetary mixer)) and then refined using a three-roll refiner to reduce particle size to less than 20 μm (Exakt 80S three-roll refiner, "2-1" setting, 35 °C). Additional cocoa mass was added to the refined mixture to yield a mixture of 30/70 sugar/cocoa, and placed in the conching machine (Bühler Elk'olino conche). A small amount of soy lecithin was added (ca. 0,4 m%) at the start of the liquid conching phase. Total conching time was 390 min, divided as follows:

- First 120 min: dry conching, 1200 rpm, temperature up to 60 °C, mixing mode
- Next 240 min: dry conching, 1200 rpm, temperature constant at 80 °C, shearing mode
- Next 15 min: liquid conching, 2400 rpm, temperature to 45 °C, shearing mode
- Final 15 min: liquid conching, 2400 rpm, temperature constant at 45 °C, mixing mode

Samples were incubated at 32 °C for melting and tempering. Finally, chocolate samples were moulded using polycarbonate moulds and stored at 18 – 20 °C and 70 % relative humidity.

Table 4: Recoding of bean sample to chocolate sample

Bean sample coding	Chocolate coding
T2	C2
T4	C4
T5	C5

2.7 Proximate analysis

To determine the standard set of physico-chemical specifications required to characterise foodstuffs, proximate analysis forms the basis. For cocoa this is especially relevant as fat, protein and carbohydrates largely determine the final chocolate quality.

The unroasted cocoa beans were tested in duplicate for moisture and ash analysis, and in triplicate for protein and total fat analysis. All analyses were done on peeled beans, ground to a gritty powder using a coffee grinder (Moulinex AR1105, France).
Dry bean moisture content was determined on 5 g of powder mixed with sand and dried in a hot air oven at 101-103 °C until constant weight (AOAC method 935.29, AOAC (1995)).
Ash content was determined in a muffle furnace on 10 g of powder at 550 °C.
For protein, the Kjeldahl method was performed on 0,5 g of powder to obtain the crude protein content. A conversion factor of 6,25 was used (protein = nitrogen × 6,25).
For fat content, the peeled beans were first ground to a smooth paste by pestle and mortar. The Weibull method was then performed on 10 g of sample.

2.8 pH and non-volatile titratable acidity

Central to the research design is an analysis and comparison of acidity of the tested drying methods. These analyses were performed on peeled ground unroasted beans, on cocoa mass, and finally on the chocolates.
pH values were determined using the following standard method (Gourieva, 1979): 10 g of ground beans/cocoa mass/ chocolate were mixed with 90 mL of hot distilled water and stirred for 30 s with a magnetic stirrer and filtered using a Whatman N°40 filter paper and cooled to 20-25 °C. 25 mL filtrate was transferred into a beaker and the pH was measured using a pH meter (Schott instruments, Germany), calibrated with buffers at pH 4.01 and 6.98. Acidity was determined by titration to an end point pH of 8,1 with 0,01 M NaOH solution. Values were reported as moles of NaOH per 100 g sample. The analysis was conducted in duplicate and the mean values were reported.

2.9 Fermentation: Fermentation Index and Bean Cut Test

In order to determine whether cocoa beans are well fermented, a fermentation index (FI) is used. The FI value uses a cut-off value above 1 to distinguish well dried, fermented beans (Gourieva & Tserevitinov 1979). Beans with values below this are generally not considered well fermented.
50 mL of methanol–hydrochloric acid (97:3 v/v) was added to 0,5 g of bean powder and the mixture was stored at 8 °C for 30min. The mixture filtered through a Whatman N°1 filter paper and diluted with methanol–hydrochloric acid (97:3 v/v) to 50 mL. The filtrate absorbance was measured at 460 nm and 530 nm using a spectrophotometer (Varian, USA). The fermentation index (FI) of the samples was obtained by calculating the ratio of the absorbance at 460 nm and 530 nm (FI = A460/A530).

The bean cut test was done on a total of 100 beans per batch, 50 at a time. Beans were cut lengthwise using a guillotine visually examed under ambient lighting. Numbers of fully brown, pale purple, deep purple and flat beans were counted, and averages per batch were calculated. Percentages of brown beans over 70 % are indicative of good fermentation (Jinap et al. 2003, Kongor et al, 2013).

2.10 PSD

Particle size distribution (PSD) was measured with the 2000 S Mastersizer (Malvern instruments Ltd, Worchestershire, UK) following the method as described by De Pelsmaeker (2016).
The PSD relates the volume particles take up with the particle diameter by approximating non-sperical particles as spheres.
D [3,2], the Sauter mean diameter is defined as the diameter of a sphere which has the same volume to surface area ratio as the particle. D [4,3] is the volume based mean particle diameter. Finally, D [v, x] represents the volumetric diameter for which the x^{th} percentile of particles is smaller than the given size.

For sample preparation 0,50 g of chocolate was weighed and 10 mL of isopropanol (Chem-Lab NV, Belgium) was added. The samples were then melted in an oven at 40°C for 30 minutes. Samples were removed from the oven just before analysis and shaken vigorously to disperse the chocolate in the solvent.
With a plastic pipette small amounts of sample were introduced into the Mastersizer pump system up to an obscuration between 10 and 30%. Beam length was set at 2,4 mm and the analysis model was polydispersed. 5 measurements were performed for each chocolate subsample. Analysis per chocolate was performed in triplicate.

2.11 Sensory evaluation of cocoa liquor

A Generalised Procrustes Analysis (GPA) of a conventional profiling setup on 5 cocoa flavour descriptors was performed on sensory results by a trained panel at Puratos Belcolade in Erebodegem, Belgium. GPA is a variance-based form of factor analysis which takes into account differences in scaling between experts in given ratings. It performs scalings, rotations and translations of the expert ratings to obtain a consensual configuration for the descriptors over all experts. Two factors are retained containing the maximal variance between the descriptors. This reveals co[6]rrelations between the descriptors.
Principal Component Analysis is then performed, reducing the 5 descriptors to the two factors factors from GPA. Coordinates for the cocoa liquors are obtained. Graphically a correlation biplot can then be constructed with consensus coordinates for each of the flavour descriptors, superimposed with coordinates for each of cocoa liquors. This allows judging of the proximity between cocoa liquors and descriptors. The analysis was performed with XLstat (Addinsoft, France).
Cocoa liquor of samples T2, T4 and T5 was tested for the descriptors cocoa, acidity, fruitiness, astringency and earthiness. For profiling experts were asked to rate the descriptors on a 6 point semantic scale ranging from 0 (less) to 5 (more). [7]

[7] Scores as follows: 0 = none present, 1 = just a trace and may not be found if tasted again, 2= present in the sample, 3 = clearly characterizing the sample, 4= dominant, 5 = extremely dominant

2.12 Sensory evaluation of chocolate

The objective of consumer testing on the three produced chocolates was to test the following central research question:

- R1: "Do consumers differentiate between chocolates with different drying methods?"

Additional research questions to this end were:

- R2: "Is there a difference in likeability and ranking between chocolates?"
- R3: "Is there a difference in rating of flavour notes between chocolates?"
- R4: "Are certain flavour notes correlated with higher acceptability?"

The following hypotheses were proposed within this framework:

- H1: Self-reported consumers preferring dark chocolate will rate all '70 % cocoa chocolates' higher for likeability than self-reported consumers preferring milk or white chocolate
- H2: Consumer-reported acidity ranking will correspond with analytical acidity results
- H3: Likeability score over all consumers will be higher for the chocolate with higher pH

Quantitative descriptive data was collected at the UGent sensory evaluation laboratory through chocolate tasting sessions held on August 3-4, 2016. A non-random sample of 91 respondents was obtained, including faculty staff and people reached through social media, who each tried three chocolates (C2, C4 and C5).
Consumers were asked about their preference and consumption frequency of dark chocolate. A 9 point semantic scale between 'extremely tasty' and 'extremely not tasty' was provided for likeability. 7 point scales for flavour notes were provided ranging from 'very' to 'not at all'. Four flavour notes were selected, namely sweet, acidic, bitter and fruity, based on suggestions by the Puratos chocolate company for Vietnamese chocolate. Finally panellists were asked to rank the three chocolates from most to least preferred.
Segmentation of consumers was done according to a self-reported preference for dark or for milk and white chocolate. The complete survey can be found in Appendix 6.

2.13 Statistical Analyses

Inter- and intra-clone variability for physico-chemical properties was assessed. Changes in acidity through processing, and between drying methods were also analysed. Finally, the results of sensory evaluations of cocoa liquor and chocolate needed to be analysed and compared to physic-chemical results.
For proximate analysis results a two-sample t-test was used for pairwise comparison of intra-clonal results between two regions. Inter-clonal testing was done with a one-way ANOVA (SPSS 22, Chicago, USA). Equal variances testing was done with the Modified Levene

Test. Under equal variances, post-hoc tests were performed with Tukey tests, otherwise the Games-Howell test was used.
For chocolate survey-, and cocoa liquor results one-way ANOVA tests were performed when comparing factors. Correlations between flavours and likeability were established with bivariate correlations using the Pearson correlation coefficient.
All tests were done at a significance level of 0.05.

3 Results

3.1 Agronomic and post harvest survey results

3.1.1 Socio-demographic and general information

This survey is an attempt to provide a first look at the current state of cocoa farming and post-harvest processing in Vietnam.
14 farmers were interviewed, of which 3 women and 11 men. Each survey lasted approximately 45 minutes (35 to 70 minutes). All respondents were married and worked together on the cocoa farm. In all cases they co-owned the land with their partners. Respondent's formal level of education and age distribution is shown below in Figure 6.

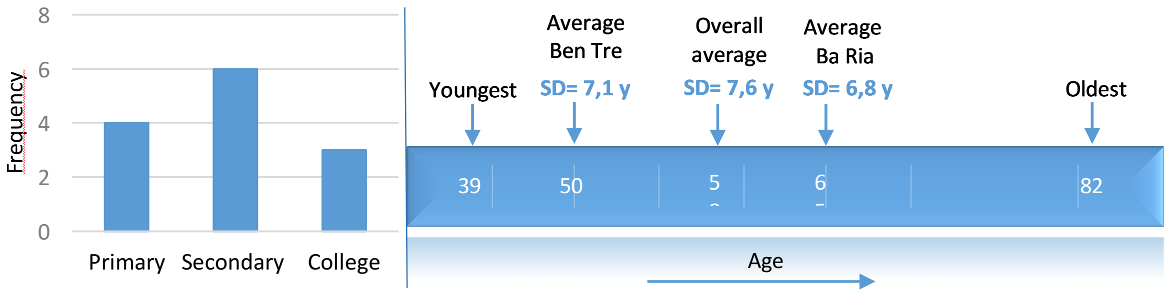


Figure 6: LEFT: Formal education levels of respondents (n= 13). RIGHT: A timeline displaying ages of farmer sample (n= 14)

Survey results for Ba Ria and Ben Tre concerning farm size and experience are presented below in Figure 7. Farmers in both areas had similar experience with cocoa, most farmers having started cocoa cultivation between 10 and 15 years ago.
The average farm size in Ba Ria was 1,1 ha (ranging from 2000 to 20.000 m^2). In Ben Tre, the average farm size was slightly higher, at 1,2 ha (ranging from 7000 to 18.100 m^2). If farmers had multiple adjacent plots the sum of respective areas is shown.

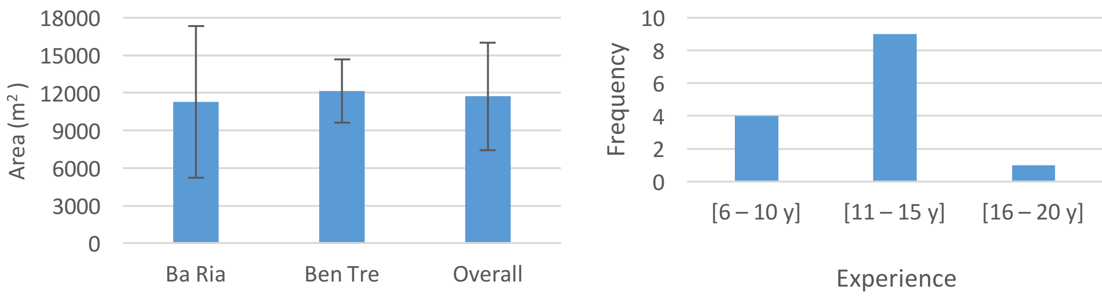
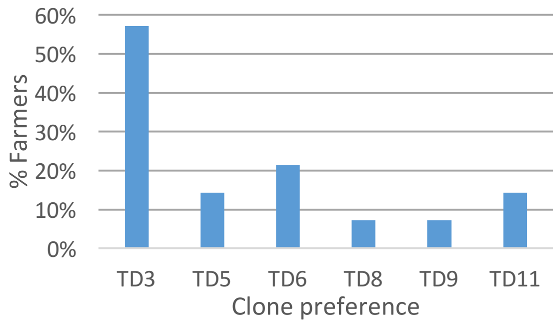


Figure 7: LEFT: Average farm size in Ba Ria and Ben Tre with standard deviations (n= 14). RIGHT: Frequency depiction of years of experience with cocoa(n= 14)

3.1.2 Clone preference

Farmers appeared to have a relatively consistent preference for certain clones. The most planted varieties roughly correspond to the most preferred varieties, namely TD3, TD5 and TD6. An overview of preferred pods and gathered brief comments regarding clone properties is given below in Figure 8. All farmers mentioned only yield and disease resistance as reasons for their preferences.



TD3: many pods per tree but small pods
TD5: high pod yield, but low bean/pod ratio, susceptible to *Phytophtora.*
TD6: satisfactory yield
TD8: high bean/pod ratio
TD9: high bean/pod ratio
TD10: large pods but susceptible to *Phytophtora*

Figure 8: LEFT: Percentage of farmers with a preference for the mentioned clone. (For reference: one response corresponds to the bar height of TD8 and TD9.) (Farmers sometimes listed 2 or more clones, so totals exceed 100%.)(n= 14). RIGHT: farmer's comments regarding clone properties

When asked about clone preference however, it must be added that on the spot, many farmers were unsure as to the identity of a certain pod. They usually have a basic idea of the main clone on their farm and can distinguish morphologically different pods but have trouble identifying pods with a similar appearance. (e.g. TD3 and TD6 are both red when ripe and are likely to be mixed up, but they will not be confused for a TD8 pod which is green and rough (see Figure 9).
Thus, farmer's accounts alone are insufficient to assess the suitability of a clone.

Figure 9: From left to right ripe pods of TD3, TD5, TD6, TD8, TD10. Farmers often confuse TD3 and TD6 which are both greenish-red to red when ripe (photographs provided by NLU)

3.1.3 Agronomic practices

3.1.3.1 Intercropping

In Ba Ria, 5 out of 7 farmers intercropped cocoa, while 6 out of 7 did so in Ben Tre. An overview of crops is given below in Figure 10.
Of the 11 farmers who intercropped, 6 had only one other crop and 5 had two or more crops. In all cases there were also a few coconut or mango trees mainly for family consumption.
From the right figure it can be deduced that profitability of fruit trees is higher than that of cocoa: in both provinces farmers reported a share of income from fruit trees which is higher than the share of fruit trees on total number of trees.

No shade trees were left on mature plots solely for the purpose of shade. If shade trees were present, their primary purpose was as a fruit tree.

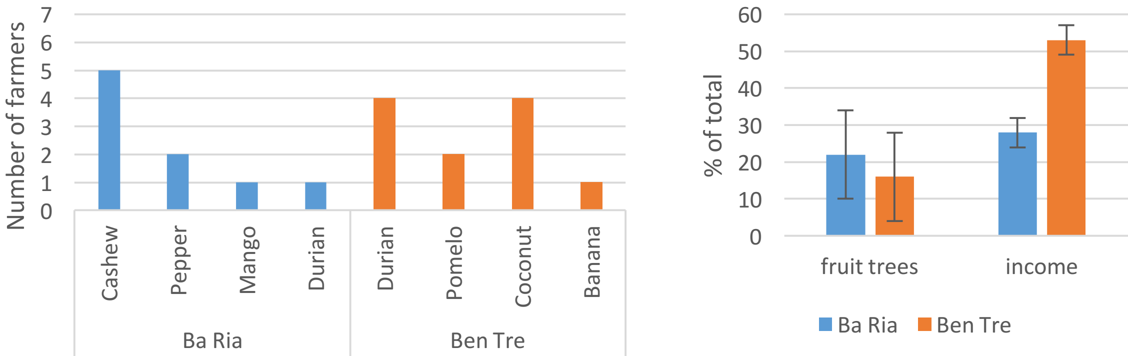


Figure 10: LEFT: Crops planted in intercropping systems with cocoa in Ba Ria (n= 7) and Ben Tre (n= 7). 5 out 7 farmers in Ba Ria intercropped cocoa, and 6 out of 7 in Ben Tre did so. RIGHT: percentage of fruit trees on total number of trees on the farm (n= 7), and percentage of income derived from non-cocoa crops on the farm (n= 9)

3.1.3.2 Fertiliser use

The use of Nitrogen-Phosphorus-Potassium (NPK) fertiliser was widespread. All farmers (n= 14) used NPK fertiliser although composition and additional micronutrient content varied. Application frequencies varied a lot, ranging from only twice a year to monthly. In Ba Ria fertiliser was applied 3,5 times per year on average (± 1,2) and 5,6 times per year in Ben Tre (± 2,8).

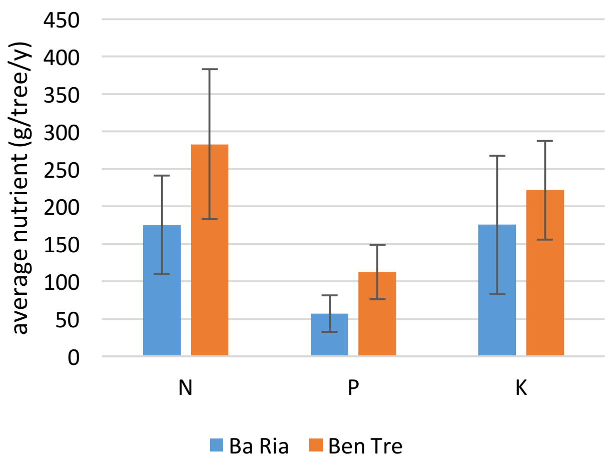
Elemental nitrogen (N), phosphorus (P) and potassium (K) use in grams per tree per year (g/t/y) were calculated based on reported NPK use and estimated or reported number of trees. Results are shown below in Figure 11.

The most common fertiliser used in Ba Ria was 'Chuyen Dung Cho Cacao', an NPK 13-8-21 fertiliser with additional sulphur, magnesium and calcium. Two farmers mentioned using it after a neighbour said he was pleased with the results. Another common fertiliser was an NPK 16-16-08. Other farmers bought fertiliser depending on which brand was cheapest at that moment, and stated not to look at fertiliser composition when making a purchase. In Ben Tre, the most coming fertiliser was an NPK 12-11-18. Overall most farmers (n= 9) apply fertiliser by casting pellets among their trees (broadcasting), while the rest (n= 5) apply fertiliser only around the tree trunk (ring application).

Two farmers also gave compost to the cocoa trees. One farmer had heard about composting on the radio. The other had taken part in a Helvetas project in the commune in 2011.

Compost was made from empty cocoa pods, cow manure and a *Trichoderma* starter culture and left to compost for several months in a specially built shed. It was apparent by observation that top soil on these farms contained more organic matter.

In the Mekong Delta manure and other organic matter is commonly thrown into the ditches and left to rot. During the next growing season the decomposed material is shovelled out again and used as fertiliser for cocoa trees. Its nutritional quality is thought to be high. However, no estimate could be made about the amounts used or its composition.



Common fertilisers (NPK):

- Ba Ria
  - 13-8-21 (n= 4)
  - 16-16-08 (n= 2)
- Ben Tre
  - 12-11-18 (n= 3)

Application method (both provinces)

- Broadcasting (n= 9)
- Ring (n= 5)

Application frequency (per year)

- Ba Ria (n= 7)
  - Av. 3,5 times, SD: 1,2
- Ben Tre (n= 7)
  - Av. 5,6 times, SD: 2,8

Figure 11: LEFT: Elemental N-P-K nutrient use per tree per year for each region with standard deviations. (Ba Ria, Ben Tre: each n= 7). RIGHT: overview of fertiliser use, expressed as standard NPK units

Self-reported yield data of dry beans (for Ba Ria) and cocoa pods (Ben Tre) was plotted against estimated nutrient use per tree per year (Figure 12). Correlation coefficients between yield and each nutrient were highest for N (R^2= 0,48 in Ba Ria), and all were lower than 0,50. However, only based on visual interpretation, for N and P overall yields do seem to coincide with higher nutrient use. This trend is less apparent for K. Thus it could be tentatively put that farmers with higher N and P use obtained higher yields.

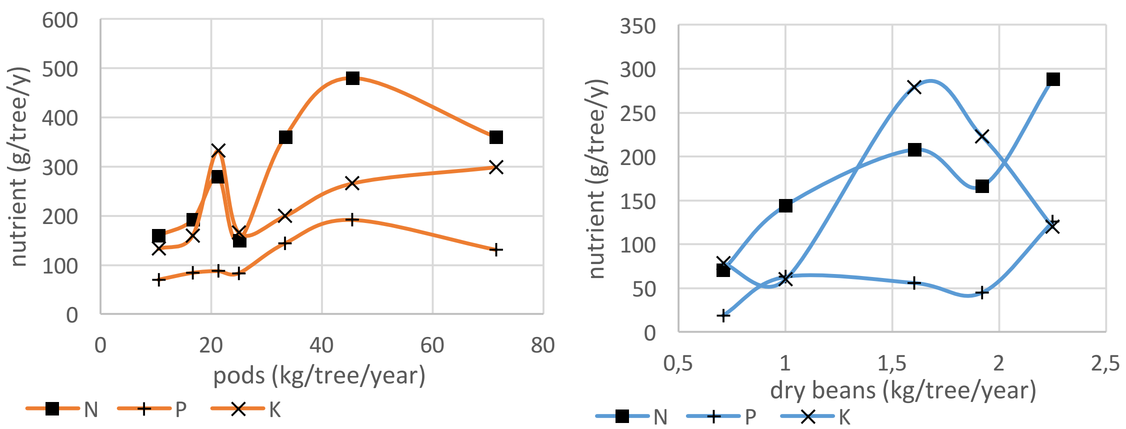


Figure 12: Pod yield (Ben Tre, orange) or dry bean yield (Ba Ria, blue) in relation to elemental nitrogen, phosphorus and potassium fertilisation

3.1.3.3 Pesticide use

12 out of the 14 farmers used pesticides and fungicides. Most farmers used two or more substances, which they bought at their local agent and claimed to use as instructed on the packaging. Some farmers preferred not to discuss which pesticides they use. In other cases they only remembered a local brand name and did not show the packaging during the survey. In these cases the active substance could not be verified. An overview on pesticide use is given in Table 5. When asked when pesticides and fungicides are applied, most farmers mentioned multiple situations, such as at outbreak, on small pods, or at the start of the rainy season rather than only one reason for spraying (Table 5).

Table 5: Overview of common pests and diseases mentioned by farmers, substances used and application times. Most farmers mentioned all listed application times

	Prevalence (on total n= 14)	Substance used	Application
Pest	-Capsids (n= 10) -Mealy Bugs (n= 3) -Zeuzera sp. (n= 3)(Ben Tre only)	-(α)-Cypermethrin (n= 4) -Chlorpyrifos (n= 2)	-At outbreak -On small pods at the start of rains -Rainy season
Disease	-Black pod disease (n= 14) -Canker (n= 5)	-Cuprous oxide (n= 2) -Metalaxyl (n= 1)	-On small pods at the start of rains -Rainy season

3.1.3.4 Pruning

Canopies with breaks are the most common (n= 11 of 14). To maintain open canopies the majority of farmers prune leaves which do not get sunlight. Reducing tree height to below 3 metres was also commonly done, as was cutting of long shoots. One farmer hired a specialised cocoa pruning team to prune his trees twice a year, stating a lack of time to do this himself. All other farmers pruned at regular intervals, ranging from every time they harvest to every few months or only during the rainy season; no consistent pattern emerged between farmers.

3.1.3.5 Harvesting, storage, fermentation and drying

Half of the farmers harvest weekly. Others more regularly, or only every 10 to 14 days. During the wet season, beans are harvested more often than during the dry season (from December to May). As an anecdote, one farmer went around his small plot daily to pick ripe pods because he had 'too much time'.

All farmers were familiar with pod storage. During the dry season pods are stored on average 3 to 4 days until enough pods have been harvested for a fermentation. During the wet season storage times were shorter, usually less than 3 days.
In case pods are sold on to fermenters, the farmers do not store pods themselves. Instead they are usually picked up the day they are harvested.
After pod opening, empty pods are most often used for animal feed (8 out of 11), mulching (6 out of 11) or compost (2 out of 11).

Fermentation was always carried out in wooden boxes, except for one case where the farmer ferments about 10 kg of beans at a time in woven baskets covered with banana leaves. Box sizes vary, ranging from (0,6 ; 0,6 ; 0,6) to (0,45 ; 1,5; 0,45) (L; W; H) in metres, with raw bean capacities up to 300 kg of wet beans. Farmers know little about drainage holes or plank spacing. Jute bags are more commonly used than banana leaves to cover the beans because they are reusable and not all farmers have banana trees. Jute bags are also used at the Puratos fermentation unit (Figure 13).

Figure 13: Puratos Grand-Place fermentation boxes with jute bags (LEFT) and drying tables of woven mats in the drying hall (RIGHT). During fermentation, box contents are mechanically poured into a mixing device to turn the beans three times during fermentation (Confectionery News, 09/03/2016, Twitter)

Among farmers who mentioned turning beans during fermentation, 6 out of 7 turned twice, usually at 48h and 72 or 96h. 1 farmer only turned once. Fermentation times are shorter in the dry season, usually 4 to 5 days, and up to 7 days in the wet season.
Drying is rarely carried out on woven mats raised on platforms off the ground (2 out of 10). Instead beans are dried on tarps on the floor in open air (8 out of 10), where beans are taken inside should it rain. Drying times are usually 4 to 5 days in the dry season but vary strongly in the wet season.

3.1.3.6 Training

In Ba Ria farmers could not remember when they had last received training. Most talked of roughly a decade ago. None of these farmers had any certification.
In Ben Tre all interviewed farmers had received a training from Puratos Grand-Place in February, 2016 on the topics of soil nutrients and pruning practices. In terms of certification most are engaged in Puratos Grand-Place's CocoaTrace certification program[8] which trains farmers in responsible agronomic practices and pays a price premium to involved farmers.

Puratos' February 2016 training on fertilisation proposed in total four products to be applied four times per year (Table 6). Farmers were trained in how to apply the products, at which times and in which concentrations.

Table 6: Overview of the fertilisation scheme as promoted during Puratos Grand-Place's last training in February, 2016

Small crop season (February)		Budding Season (April or May)		Young pods (July)		Final pod maturation (October or November)	
Name	Amount	Name	Amount	Name	Amount	N ame	Amount
YaraMila Winner	200 g/tree	YaraMila Winner	200 g/tree	YaraMila Winner	350 g/tree	YaraMila Winner	350 g/tree
YaraLiva Nitrabor	50 g/tree					YaraLiva Nitrabor	50 g/tree
YaraVita Hydrophos	2 L/ha	YaraVita Bud Builder	1-2 kg/ha	YaraLiva Nitrabor	50 g/tree	YaraVita Hydrophos	2 L/ha

[8] http://www.belcolade.com/nl/product-range/cacao-trace/182

Elemental N-P-K requirements derived from the proposed fertilisation plan per year are shown below (Table 7). Data was derived from the fertiliser composition (Table 8) as published on the manufacturer's website (Yara, 2016). In the discussion this data will be compared to on-farm data and general recommendations for cocoa farming.

Table 7: Elemental nutrient allowance as per Puratos Grand-Place's recommendations, per growth period and the year total

Elemental component	February (g/tree)	April or May (g/tree)	July (g/tree)	October or November (g/tree)	Year Total (g/t/y)
N	37,5	31,7	60,2	60,2	189,6
P	14,3	8,4	13,7	16,7	53,1
K	34,2	33,2	58,1	59,1	184,6

Table 8: Yara Fertiliser NPK composition (www.yara.co.uk)

Product Name	Composition (N-P-K)	Micro-nutrients
YaraMila Winner	15-9-20	S, Mg
YaraLiva Nitrabor	15,4-0-0	Ca
YaraVita Hydrophos	0-29,7-5	B
YaraVita Bud Builder	6,9-5-0	Zn, Mg, B

3.2 Cocoa bean quality parameters

Quality parameters for single clone beans and mixed variety beans from Dong Nai, as well as single clone beans from Vung Tau and Ben Tre are provided below. Results will be discussed within the framework of this research in section 3.

3.2.1 Single-clone pod data

A photographic overview of the pods of the 8 fermented clones is given in Appendix 5. Harvest data of the eight fermented clones are summarised in Table 9.

Table 9: Overview of harvest data for 8 fermented clones from Tân Phú. Beans per pod is an average of 5 pods per clone with the standard deviation SD (σ) derived from the variance $\sigma^2 = \sum_{i=1}^{N} \frac{(x_i-\mu)^2}{N}$, N the pod number, x_i the number of beans in this pod, μ the average value over all pods of this clone. All other data is a weighted average of all pods collected from the three repetitions. Standard deviations are derived from the weighted sample variance according to the formula $\sigma^2 = \sum_{i=1}^{N} \frac{(x_i-\mu)^2}{\sum_{i=1}^{N} w_i}$ with standard deviation σ, N the repetition, $_x i$ the average of this repetition, μ the average value over all three repetitions, wi the number of pods in each repetition

Name	Beans per pod (n°)	Pod weight (kg)	Pulp/ pod ratio (kg/kg)
TD3	37,2 ± 1,04	0,27 ± 0,030	0,26 ± 0,004
TD9	42,8 ± 5,84	0,57 ± 0,133	0,34 ± 0,069
TD13	34,6 ± 2,32	0,30 ± 0,114	0,30 ± 0,024
TD28	38,0 ± 6,4	0,64 ± 0,062	0,25 ± 0,020
TD54	41,6 ± 3,12	0,39 ± 0,040	0,30 ± 0,039
SIAL339	38,8 ± 3,44	0,42 ± 0,029	0,25 ± 0,037
PA70	23,2 ± 5,92	0,32 ± 0,081	0,25 ± 0,022
M3	32,4 ± 3,28	0,64 ± 0,127	0,23 ± 0,068

Notes: Values are mean ± SD

The fermentation of the eight clones was followed up by taking temperature readings in 4 points of each fermentation box twice a day. The evolution for each box in each measuring point is shown below in Figure 14.

Temperatures exceeding 45 °C after 48h indicate a proper fermentation process. In box 1 this was reached at the top and centre of the box after 40h. In box 2 these temperatures had not been reached after 48h, and so beans were already turned a second time at 65h, introducing additional oxygen. This resulted in a rapid temperature increase at the top of the box to over 47 °C.

The lower temperatures generally witnessed deeper in the boxes in the corners are most likely due to heat losses through the panels. By turning, beans are evenly distributed and additional oxygen incorporated, initiating the aerobic phase and allowing temperatures to rise and even out, as can be seen during the last 2 temperature readings in both boxes.

Clones TD2, TD4, TD9, TD13, TD28 and SIAL339 were fermented in box 1. TD54, PA70 and M3 were fermented in box 2.

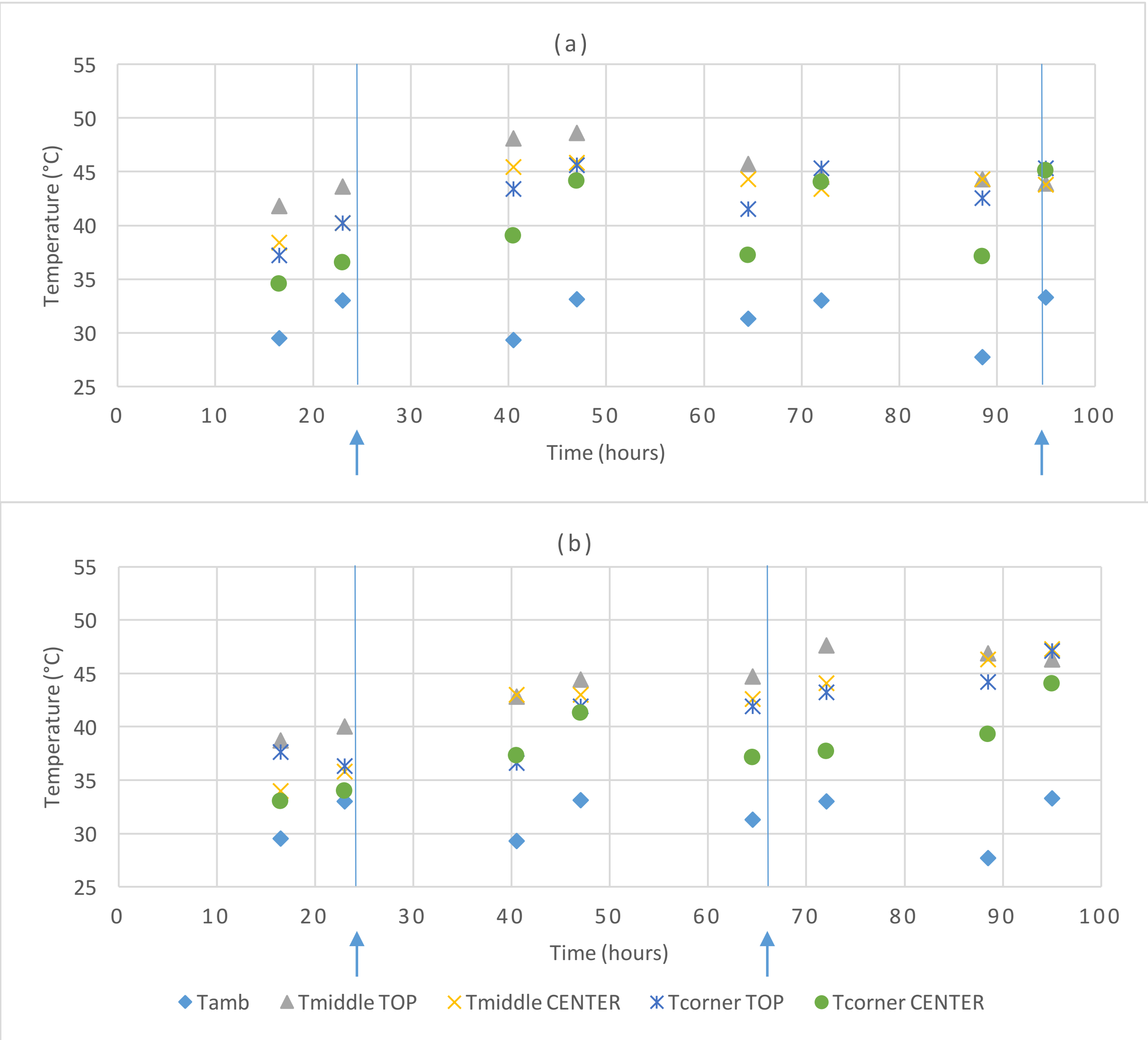


Figure 14: Follow-up of the fermentation process temperature. (a) represents box 1, which was turned at 24h and 95h, indicated by the arrows and full line. (b) represents box 2, which was turned at 24h and 65h , indicated by the arrows and full line. Tamb is the ambient temperature, TmiddleTOP is the temperature taken in the middle of the box viewed from above, at 5 cm depth from the top. TmiddleCENTER is the temperature taken in

the middle of the box viewed from above, at 25 cm depth from the top. TcornerTOP was taken in a freestanding corner of the box viewed from above, at 5 cm depth from the top, TcornerCENTER was taken in a freestanding corner of the box viewed from above, at 25 cm depth from the top. Clones TD2, TD4, TD9, TD13, TD28 and SIAL339 were fermented in box 1. TD54, PA70 and M3 were fermented in box 2

3.2.2 Mixed variety bean parameters

An overview of averages of physical quality parameters of the mixed variety fermentation and drying is given in Table 10. Bean cut test data is given in Table 11.

Table 10: Results of analysis (n=2) for moisture content on wet base (W.B. m %), pH and titratable acidity ($mol\ H^{+}/100\ g\ sample$),and fermentation index (Abs_{460nm}/Abs_{530nm}). The first series T1 – 7 are from the Dong Nai research farm. The second series T5b and T5c are repetitions of the T5 procedure from a neighbouring farm

Method	Moisture	pH	Titratable Acidity	Fermentation Index
T1	7,48 ± 0,535	4,96 ± 0,007	5,42E-03 ± 3,77E-04	0,99 ± 0,0140
T2	7,18 ± 0,021	5,27 ± 0,014	4,89E-03 ± 3,69E-05	0,95 ± 0,0147
T3	5,90 ± 0,435	5,04 ± 0,007	5,97E-03 ± 1,34E-04	0,91 ± 0,0070
T4	5,78 ± 0,153	4,81 ± 0	7,63E-03 ± 1,71E-04	0,98 ± 0,0052
T5	5,44 ± 0,396	5,13 ± 0	4,69E-03 ± 9,05E-05	0,95± 0,0157
T6	4,99 ± 0,191	5,05 ± 0,014	5,48E-03 ± 9,15E-05	0,90 ± 0,0200
T7	5,12 ± 0,163	5,04 ± 0,014	5,16E-03 ± 1,63E-04	0,90 ± 0,0189
T5b	/	5,41 ± 0,021	4,36E-03 ± 4,70E-05	1,33 ± 0,0680
T5c	/	5,19 ± 0,014	4,73E-03 ± 8,48E-05	1,41 ± 0,0060

Notes: Values are mean ± SD

Table 11: Bean cut test data of the fermented and dried Vietnamese Trinitario bean mixes

Method	% Deep purple	% Light purple	% Brown	% Flat
T2	10,00±2,82	5 ± 1,42	85 ± 1,42	0
T4	12,00±2,82	5 ± 1,42	84 ± 0	0,5 ± 1,42
T5	10,00±2,82	5 ± 2,82	81 ± 1,42	0,5 ± 1,42

Notes: Values are mean ± SD. No significant differences in brown bean counts between methods at p=0,05

It must be noted that the fermentation index for samples T1 to T7 are between 0,90 and 1, which is considered low for a good fermentation. Jinap et al. (2003) obtained a FI of 1,58 (± 0,01) for fully fermented Malaysian beans (Vietnamese Trinitario clones originate from Malaysia). Thus the Vietnamese beans appear under-fermented.
Considering the bean cut test, for Malaysian beans Jinap reported a percentage of brown beans of 84.2 (± 3.30), in line with experimental data. Thus the bean cut test results show enough brown beans to consider the batches properly fermented.
Furthermore a professional test panel for cocoa mass at Belcolade did not raise any comments about under-fermented flavour. Finally, the final pH is within the range of 4,75 –

5,19 defined by Afoakwa et al. (2008) as well fermented cocoa and the normal temperature readings during fermentation also point in the direction of a good fermentation.

3.2.3 Single-clone bean parameters

An overview of the physico-chemical properties of the single clones from the research farm and commercial estates is given in **Fout! Verwijzingsbron niet gevonden.**. It must be noted again that the fermentation index for all Dong Nai samples is too low to be considered properly fermented, despite the standard fermentation process having been followed. The fermentation index for beans from the commercial estates is higher than 1 (min. 1,11) so these beans can be considered properly fermented, and the results thus likely more representative for the clones in question.

Between the regions Dong Nai and Vung Tau and Ben Tre, intra-clone variation was significant. For TD3, protein (t_{crit}=4,30 p=0,05, t=5,18), fat (t_{crit}=4,30 p=0,05, t=44) and ash content (t_{crit}=4,30 p=0,05, t=4,90) was significantly different between the Dong Nai and the Ba Ria sample.
For TD5 there were no significant differences between the Ben Tre and the Ba Ria sample for protein, fat or ash.
For TD9 protein (t_{crit}=4,30 p=0,05, t= 5,75) and fat content (t_{crit}=4,30 p=0,05, t=100,31) was significantly different between the Dong Nai and the Ben Tre sample. Ash content was not significantly different.
Overall it can be said that intra-clone physico-chemical variation is significant between regions (despite equal fermentation and drying methods).

Inter-clone variation at the Dong Nai plantation also showed significant differences between certain clones for the tested parameters fat and protein.
At the 5% significance level, protein content differed between TD3/TD9, TD3/PA70, TD9/TD28, TD9/TD54, TD28/PA70, TD54/SIAL339, and TD54/PA70.
At the 5% significance level fat content differed between TD9/TD13, TD13/TD54, TD13/M3, TD28/TD54, TD13/PA70.

Table 12: Results of proximate analysis for moisture content (n=3) on wet base (W.B. m %), crude protein (n=3), fat (n=3), ash content (n=2) on dry base (D.B. m %)), pH and titratable acidity ($mol\ H^{+}/100\ g\ sample$) (n=2),and fermentation index (Abs_{460nm}/Abs_{530nm}) (n=2). (The first series TD3 – M3 are from the Dong Nai research farm. The second series TD3b – TD9b are from commercial estates.)

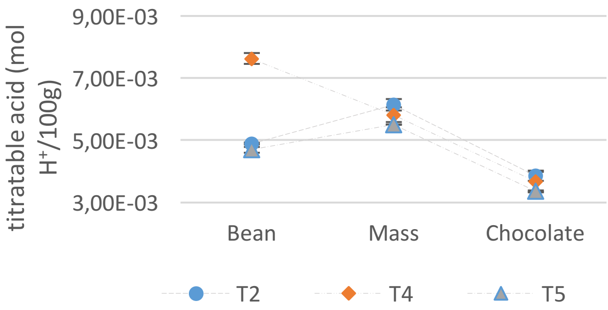
Clone	Moisture	Crude Protein	Fat	Ash	pH	Titratable Acidity	Fermentation Index
TD3	6,07 ± 0,035	15,53[a,g,h] ± 0,224	54,56[c] ± 0,628	3,57[e] ± 0,037	5,095 ± 0,007	7,01E-03 ± 4,82E-05	0,95 ± 0,0297
TD9	5,22 ± 0,031	14,62[b,g,i,j] ± 0,126	58,17[d,n] ± 0,350	2,90 ± 0,049	5,275 ± 0,007	4,20E-03 ± 2,46E-04	0,78 ± 0,0244
TD13	5,10 ± 0,165	15,24 ± 0,422	53,03[n,p,r] ± 1,834	3,55 ± 0,115	5,145 ± 0,021	4,94E-03 ± 4,25E-06	0,89 ± 0,0229
TD28	6,43 ± 0,232	15,57[i,k] ± 0,706	54,55[p,q] ± 1,983	3,49 ± 0,131	4,905 ± 0,021	6,88E-03 ± 2,98E-04	0,98 ± 0,0002
TD54	4,62 ± 0,072	15,66[j,l,m] ± 0,553	58,62[o,p,q] ± 0,914	2,85 ± 0,044	5,205 ± 0,007	4,75E-03 ± 2,20E-05	0,98 ± 0,0073
SIAL339	5,41 ± 0,203	14,72[k,l] ± 0,603	56,35 ± 2,140	3,22 ± 0,122	5,325 ± 0,021	4,92E-03 ± 1,76E-04	0,88 ± 0,0078
PA70	4,39 ± 0,084	14,92 ± 0,280	57,72[p] ± 1,136	2,73 ± 0,071	5,08 ± 0,01	5,90E-03 ± 1,68E-04	0,81 ± 0,3075
M3	5,06 ± 0,014	14,41[h,k,m] ± 0,064	58,38[r] ± 0,515	2,81 ± 0,011	5,04 ± 0,01	5,78E-03 ± 1,17E-04	0,74 ± 0,0015
TD3b	6,69 ± 0,004	14,43[a] ± 0,149	51,61[c] ± 0,085	3,31[e] ± 0,028	5,18 ± 0,01	5,73E-03 ± 2,51E-05	1,33 ± 0,0160
TD5a	5,40 ± 0,086	15,37 ± 0,321	56,86 ± 0,937	3,02 ± 0,048	4,86 ± 0,01	2,04E-02 ± 1,55E-04	1,14 ± 0,0072
TD5b	6,84 ± 0,061	14,92 ± 0,295	57,53 ± 0,552	2,73 ± 0,030	5,245 ± 0,021	5,70E-03 ± 5,47E-05	1,11 ± 0,0092
T9b	8,18 ± 0,072	13,98[b] ± 0,196	53,02[d] ± 0,469	3,01 ± 0,028	5,045 ± 0,007	8,01E-03 ± 6,37E-05	1,23 ± 0,0013

Notes: independent two-sample t-tests were used to test for significant differences within single clone repetitions (n=2, p=0,05, tcrit=4,30): a (t=5,18); b (t= 5,75), c (t= 44,00), d (t=100,31), e (t= 4,90). One way ANOVA was used to test for significant differences between Dong Nai clones for protein and fat content (n=3, p=0,05): g,h,I,j,k,l,m,n,o,p,q,r
Values are mean ± SD

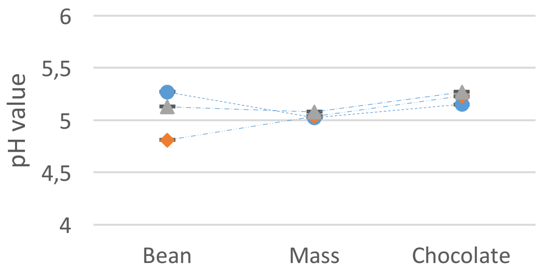
3.3 Acidity of cocoa beans, mass and chocolate

Bean samples T2 and T5 saw an increase in titratable acid after roasting and grinding to cocoa mass, with a corresponding reduction in pH value (Figure 15, Table 13 and Table 14). Further processing from cocoa mass to chocolate by conching led to a pronounced decrease in titratable acid and corresponding increase in pH value. For T4, titratable acid saw a reduction over all processing steps with corresponding increases in pH.

At dry unroasted bean level, T4 beans were the most acidic, with a pH of 4,81. After all processing steps to chocolate however, T2 chocolate had both the lowest pH and highest titratable acid value, and was significantly more acidic than T4 and T5 (based on pH). Overall, acidity parameters largely converge for the three bean samples in the final chocolate.



Overall decrease in titratable acid of 21 % (T2), 28 % (T5), and 51 % (T4) through roasting, conching and dilution with 30 % sugar on total weight



Increase in pH value over all processing steps for T4. Initial pH decrease for T2 and T5 from bean to mass, subsequent increase to final value between 5,13 and 5,27

Figure 15: Graphic representation of effect of processing from raw cocoa bean to chocolate on titratable acid and pH from bean samples T2, T4, T5

Table 13: Titratable acid values for bean samples T2, T4, T5 over main processing steps (shown graphically in Figure 15). Independent two-sample t-tests were used to test for significant differences between T2/T5 and T4/T5 in mass and chocolate (n=2, p=0,05, t_{crit}=4,30): a (t=4,88)

	Raw beans	Mass	Chocolate
T2	4,89E-03 ± 3,69E-05	6,14E-03[a] ± 1,83E-04	3,85E-03 ± 1,68E-04
T4	7,63E-03 ± 1,71E-04	5,82E-03 ± 2,32E-04	3,66E-03 ± 3,12E-04
T5	4,69E-03 ± 9,05E-05	5,51E-03[a] ± 4,34E-06	3,36E-03 ± 2,74E-05

Notes: Values are mean ± SD

Table 14: pH values for bean samples T2, T4, T5 over main processing steps

	Raw beans	Mass	Chocolate
T2	5,27 ± 0,014	5,03 ± 0,01	5,15 ± 0,01
T4	4,81 ± 0,01	5,04 ± 0,014	5,23 ± 0,01
T5	5,13 ± 0,01	5,08 ± 0,01	5,27 ± 0,014

Notes: Values are mean ± SD

3.4 PSD

The D [4,3] was significantly different between all three samples (Table 15). The same holds for the D [3,2]. Overall, C2 particles were largest, followed by C4 and C5. However despite the differences, the general volume distribution does show a similar distribution with a main peak around 10 µm and a secondary peak around 100 µm (Figure 16).

Table 15: Particle diameters for chocolates C2, C4, C5. D [4,3] is the mean volume diameter, D [3,2] the Sauter Diameter. D [v, 0.1], the 0.1 percentile for the volume distribution

Diameters (µm)	C2	C4	C5
D [4,3]	13,863 ± 5,528[a]	14,081 ± 2,140[a]	13,847 ± 1,648[a]
D [3,2]	2,700 ± 0,235[b]	2,666 ± 0,128[b]	2,824 ± 0,121[b]
D [v, 0.1]	1,419 ± 0,166	1,351 ± 0,064	1,414 ± 0,093
D [v, 0.5]	8,543 ± 0,720	8,562 ± 0,358	8,573 ± 0,270
D [v, 0.9]	30,781 ± 17,079	31,155 ± 4,280	28,587 ± 2,062

Notes: Values are mean ± SD. Significant differences between clones tested at p=0,01: a,b

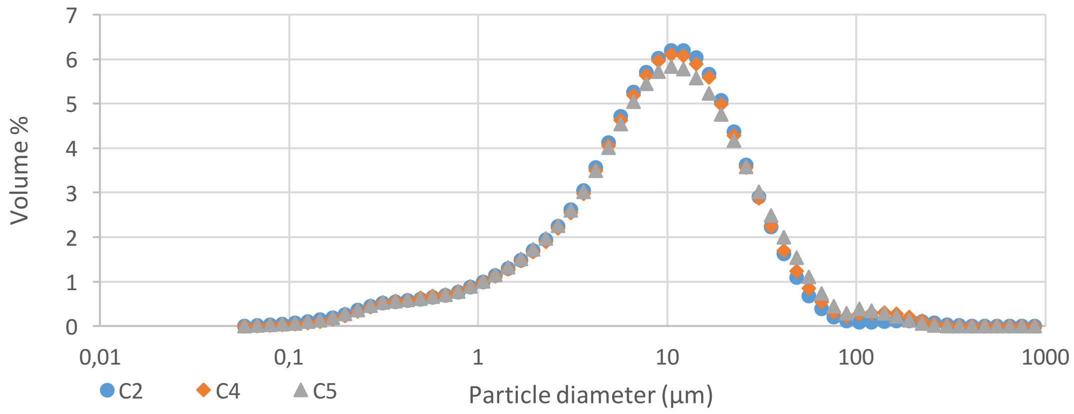


Figure 16: Particle size distribution for chocolates C2, C4, C5

D [4,3] emphasizes the detection of larger particles. As a result, the D [4,3] for C2 and C5 is closer together than their respective D [3,2]'s. This is due to C5's higher share of detected large particles, which pushes up the D [4,3] value.

The presence of larger particles is due to grinding with the ECGC-12SLTA CocoaT Melanger. It did not refine all particles to the apparatus specification of 40 µm. The small amount of cocoa mass which stuck to the walls was ground down less. During subsequent roll mill refining, not all cocoa mass was refined due to the 27 m% fat limit for the roll refined mixture. As such, about half of the particles in the cocoa mass were not reduced to the 10 µm setting of the roll refiner. These larger particles would be very noticeable for the human tongue.
As such, the suitability of the CocoaT Melanger for lab-purposes can be questioned.

3.5 Expert panel sensory test on cocoa liquor

Six trained panellists at Puratos Belcolade, Erebodegem Belgium compared cocoa masses produced from bean mixes T2, T4 and T5.
The least consensus by experts in scoring over the five descriptors was for liquor T5 (Figure 17), which had the highest residuals after transformations (Res_{T5}=3,157, Res_{T4}=2,002, Res_{T2}=

1,997). Most of these residuals are from two of the six experts which diverged from the consensus (they account for 60 % of total residuals), and can be considered outliers.[9]

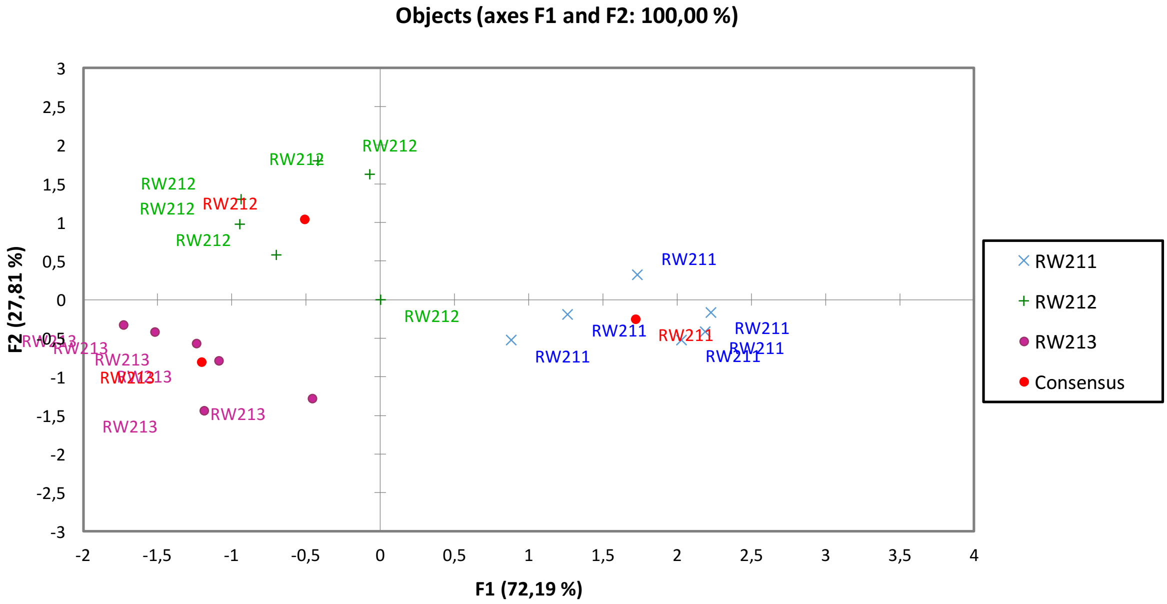


Figure 17: PCA-derived scatter plot for cocoa liquors. Notice the outlier for T5/RW212 in the origin. Legend: RW211=T4, RW212=T5, RW213=T2

During GPA the five flavour descriptors were reduced to two factors. The two retained factors account for all of the variance after transformations, with 72,19% taken up by factor 1 and 27,81 by factor 2 (Table 16). Factor 1 is strongly correlated with the flavour descriptors cocoa (R= 0,846), fruitiness (R= 0,859) and earthiness (R= 0,859). Factor 2 is very strongly related with acidity (R= -0,997) and astringency (R= -1,000) (Table 17).

Table 16: Procentual and cumulative variability ascribed to the factors F1 and F2, derived from the eigenvalues

	F1	F2
Eigenvalue	1,557	0,600
Variability (%)	*72,19*	*27,81*
Cumulative %	*72,19*	100

Table 17: Correlations between descriptors and factors in the GPA consensus configuration

Descriptor	F1	F2
Cocoa	0,846	-0,533
Acidity	-0,0722	-0,997
Astringent	0,0142	-0,*100*
Fruity	0,859	0,512
Earthy	0,8589	0,512

The PCA biplot reveals a number of things. Firstly, the angles between the descriptors are analysed. The cosine of the angle between Earthy/Fruity and Acidity/Astringent is close to 1: these pairs of descriptors show a linear relation. The cosine between Cocoa and the

[9] Scaling factors in the transformation were limited ranging from 0,788 to 1,287, or at most a 21,2% shrinking and 28,7% stretch of scores for two of the experts. This indicates experts generally gave equal ranges of scores.

Acidity/Astringent and Earthy/Fruity pairs is close to 0: these descriptors show almost no relation. Finally, the cosine of the angle between the Acidity/Astringent and Earthy/Fruity pairs approaches -1. These descriptors are essentially inversely related.

Next, the relative position of the consensus coordinates for the liquors is compared to the descriptors. The intersection of a perpendicular from a liquor to a descriptor line approximates the value of the liquor for this descriptor. Based on this, a ranking can be made up for each of the descriptors.
T4 has the highest cocoa flavour, followed by T2 and T5. For Earthy/Fruity, T4 ranks the highest, followed by T5 and T2. Finally, for Acidity/Astringent T2 ranks highest, followed by T4 and T5.
Overall, T4 is characterised by strong cocoa flavour, T2 by high acidity and astringency and T5 does not score high on any of the flavour descriptors, although this is partly due to the low consensus on descriptors for this liquor.

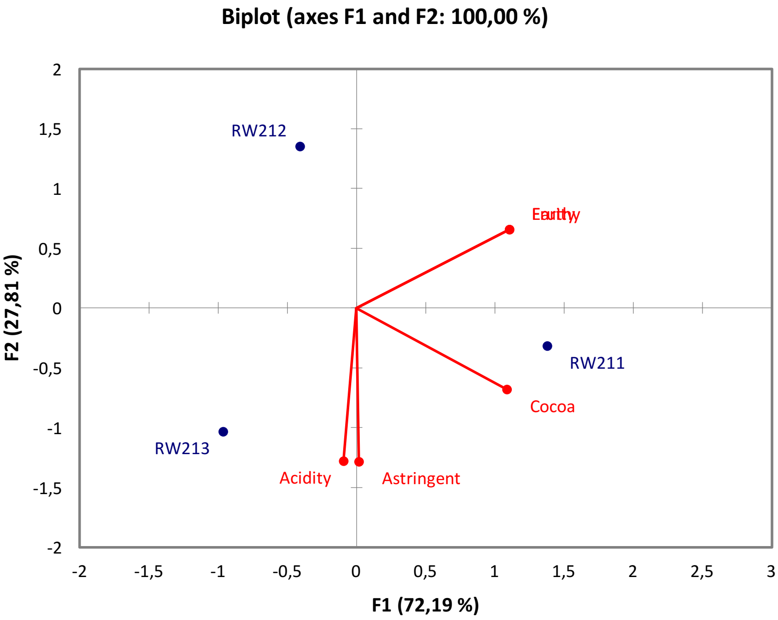


Figure 18: Biplot of cocoa descriptors derived from GPA-correlations superimposed with cocoa liquor coordinates after PCA. Earthy and Fruity have the same coordinates, and overlap
Legend: RW211=T4, RW212=T5, RW213=T2

3.6 Sensory evaluation of chocolate

A taste test survey was carried out to assess the influence of the drying methods on the sensorial perception of consumers. Out of 91 respondents, 56 % was female and the average age was 34.

Consumption patterns for dark chocolates were surveyed: among panellists, 85 % consumed chocolate at least once a week or more. 20 % almost never ate dark chocolate. 20 % of the respondents eat dark origin chocolate at least once a weak. 60 % almost never eats dark origin chocolates. Finally, 60 % of respondents indicated that higher cocoa contents are an important characteristic of chocolate.

3.6.1 Segmenting “Dark Users” and “Light Users”

Panellists were asked which kind of chocolate they generally prefer. The “Dark User” group consisted of 49 respondents. The “Light User” group consisted of 42 respondents.
“Dark users” were found to give significantly better likeability scores to the three chocolates under review than “Light users”. The segmentation of the sample of panellists into these two groups is therefore warranted (Table 18).

Table 18: Panellist overall likeability score for the 3 tasted chocolates (significance[a] on p= 0,001)

	Average score	Corresponding qualifiers
Dark Users	3,84 ± 1,54[a]	Tasty(3)/Rather tasty (4)
Light Users	4,59 ± 1,78[a]	Rather tasty (4)/ Neutral(5)

Notes: Values are mean ± SD

3.6.2 Likeability scores of 3 chocolates

Over all the 91 respondents and within both segments, no significant differences were found in likeability between the three chocolates (Table 19). (Concurrently the ranking of chocolates from most to least preferred did not yield significant results among all respondents nor in the two user segments separately: the modes of the rank of each chocolate was 2, and this for all user segments.)

Table 19: Panelist likeability of each chocolate for both segmentes. Significant differences between users[a] (p=0,025)

	C2 Average score (St. Dev.)	C4 Average score (St. Dev.)	C5 Average score (St. Dev.)	Corresponding qualifiers
Dark Users	4,02 (±1,51)	3,61 (±1,38)	3,90[a] (±1,71)	Tasty(3)/Rather tasty (4)
Light Users	4,62 (±1,71)	4,24 (±1,85)	4,90[a] (±1,82)	Rather tasty (4)/ Neutral(5)

Notes: Values are mean ± SD

3.6.3 Correlation of flavour notes and overall likeability

Panellists were asked to rate each chocolate for the four flavour notes ‘acidic’, ‘bitter’, ‘fruity’ and ‘sweet’ on a 7 point semantic scale ranging from ‘extremely’ to ‘not at all’.[10]
For “Dark Users” there was a weak inverse correlation between ’acidity’ and ‘likeability’ (R= -0,271, p=0,001) and a weak positive correlation between ‘sweetness’ and ‘likeability’ (R= 0,195, p= 0,018).
For “Light Users” there was a medium positive correlation between reported ‘sweetness’ and ’likeability’ (R= 0,604, p=0,001) and between ‘fruitiness’ and ‘likeability’ (R= 0,342, p= 0,001) (Table 20).
Implications will be discussed within the framework of the research in 4.4.

[10] For the sake of completeness flavour/flavour correlations were also established. The following correlations greater than r=0,30 were observed, Fruitiness/Sweetness correlation of R=0,38 (p=0,001) for “Dark Users”, Fruitiness/Sweetness correlation of R=0,50 (p=0,001), Bitterness/Acidity correlation R= 0,325 (p= 0,001) for “Light Users”.

Table 20: Pearson product-moment correlation coefficients for significant correlations of flavour and likeability for both user groups over all three chocolates. (Dark n= 147, Light n= 126).

		Likeability correlation coefficient r (significance level)
Dark Users	Acidity	-0,271 (p= 0,001)
	Sweetness	0,195 (p= 0,018)
Light Users	Sweetness	0,604 (p= 0,001)
	Fruitiness	0,342 (p= 0,001)

3.6.4 Flavour notes in chocolate

Average scores for each flavour note were compared between the 3 tested chocolates. A value of 1 correspond with “not al all”, a value of 7 with “extremely”.
For “Dark Users” chocolate C2 was rated as significantly more acidic than chocolate C5 (mean score of C2 was 4,54 (SD: ±1,008) versus C5 of 4,00 (SD ±1,225) (p= 0,007). This corresponds to a rating of ‘Neutral/Rather acidic’ for C2 and ‘Neutral’ for C5. No other significant differences for acidity or other flavour notes were observed between the 3 chocolates.
For “Light Users” no significant differences were observed between the three chocolates for any of the 4 flavour notes.
Additionally, no significant differences were observed between groups in panellist rating of flavour notes. As such, obtained flavour profiles largely overlap between the two user groups and between the three chocolates (Figure 19).

Figure 19: Flavour profiles over three chocolates (C2, C4, C5) for sweetness, fruitiness, bitterness and acidity. LEFT: “Light Users”, RIGHT: “Dark Users”. Value 1, representing the centre of the figure corresponds with ‘Not at all’. A value of 7, representing the outermost diamond, corresponds with ‘Extremely’

4 Discussion

4.1 Survey on farming and post-harvest practices

4.1.1 Cultivation practices

Interviewed farmers in both the Ba Ria and Ben Tre regions deliver beans to professionalised processing companies. As such, in comparing survey results with scientific literature and publications in the public domain, it is apparent that the reported practices of most of the interviewed farmers are not representative of average farming practices in Vietnam. Instead, farmers are already more skilled and knowledgeable.

In literature, the average farm size in the Mekong Delta is mentioned at 0,3 – 0,5 ha. Average farm size for the interviewed farmers stood at 1 – 1,3 ha in Ben Tre and 1,1 – 1,4 ha in Ba Ria. Average yield of dry beans per tree per year is commonly put at 0,7 kg. For interviewed farmers in Ba Ria it was 1,49 (±0,51) kg (interviews with dr. Phuoc, Mr Rouzeau, Mr Parizel, and the director of Thanh Dat Cocoa).
The main intercropped trees in the Mekong Delta proper (Ben Tre) were durian, pomelo and coconut. In Bà Rịa-Vũng Tàu Province (considered the Southeast), cashew and pepper were the most common crops. Which crops are grown depends strongly on the profitability of the crops at a given time (see 4.2.5).

Based on survey results, farmer preference is highest for the varieties TD3, TD5, TD6 and TD11. Fermenters and purchasers have a preference for TD8 and TD9 because these have favourable pulp/pod ratio's (oral communication with Puratos Grand-Place purchasor). For Puratos Grand-Place, preferred clones are TD6 and TD10 for their combined yield, disease resistance and expected favourable aroma qualities. TD11 is also expected to have desirable aroma properties and needs to be examined in more detail (oral communication with Mr Rouzeau). TD11 will likely be officially approved by MARD for cultivation in all regions in 2017 (correspondence with Dr. Phuoc).

4.1.1.1 Fertiliser use

All surveyed farmers used fertilisers, usually more than 4 times per year, although farmers were unclear when precisely this was done. Comparing the current fertiliser use with Puratos Grand-Place's recommendations, and for reference, FAO[11] recommendations for cocoa in West-Africa, it is apparent that the respondents already use sufficient amounts of fertiliser (Table 21).

Table 21: Elemental NPK use[1] and NPK recommendations[2] (incl. FA0, 2016)

Origin	Elemental N-P-K (g/tree/y)
Ba Ria[1]	175 - 57 - 176
Ben Tre[1]	282 - 113 - 222
Puratos Grand-Place[2]	189 - 53 - 184
FAO West Africa[2]	60 - 33 - 75

[11] Food and Agriculture Organisation of the United Nations

However, when making this comparison it must be noted that two of the products listed by Puratos in its training program are for foliar application, which is generally accepted to increase uptake effectiveness. Furthermore, these fertilisers were also rich in other nutrients such as calcium, sulphur, magnesium and boron. Surveyed farmers did not consider these nutrients when purchasing fertilisers.
With regard to the adoption rate of the proposed products during the training by Puratos, one of the surveyed farmers who had received the foliar fertilisers stated he did not intend to purchase them once they ran out because it was expensive and he was not convinced about the benefits.

In conclusion, with regards to fertiliser use –based on accounts of surveyed farmers – it seems they stand to benefit from timing fertiliser application more, and buying fertilisers which also contain sufficient micronutrients. Applying more NPK fertilisers does not appear to be necessary. Finally, trained farmers need to be followed up to establish adoption rates and limiting factors to successful adoption.
Given the observed beneficial effects on soil quality, a cost-benefit analysis of composting empty cocoa pods versus using them as animal feed should also be performed.

4.1.1.2 Integrated pest management

Sampled farmers have made tentative steps towards responsible pesticide use and integrated pest management.
In terms of phytosanitary measures, firstly, knowledge about pruning seems to be present and most canopies had enough breaks to allow sufficient airflow and sunlight among the leaves and pods. However, a lack of time made some farmers postpone pruning for too long. Secondly, 6 farmers use cocoa pods for mulching and 8 farmers use empty pods as goat feed. Empty pods are thus cleared away instead of being left to rot (on only one farm a large pile of decomposing empty pods was found.) Biological pest control is largely absent however. Only one farmer mentioned noticing the beneficial effects of ants but did not actively promote their presence. The impact of MARD’s promotion of biological pest control is not yet apparent in the field.
Tree health as such is not a main item of concern. On two fronts progress can still be made; firstly, in the short term farmers can further optimise fertiliser use to ensure vigorous tree growth, as explained above. Secondly, in the long term new or rejuvenated farms should more carefully select cocoa varieties suited to the local climate and prevalent pests and diseases. In this respect, among currently approved clones TD3, TD6 and TD10 seem promising, combining disease resistance, favourable growth and aroma. TD2, TD5 and TD8 however are overly sensitive to diseases despite their favourable growth. More research needs to be done on TD11 to verify its potential.

As a final component of pest management, spraying should become a measure of last resort. In this respect it was positive to observe that farmers generally only spray when the pest or disease appears, or at the start of the rainy season when they know pods are especially susceptible to damage. Ideally though, spraying should only be done when the extent of crop damage exceeds the cost of controlling the pest or disease (economic threshold). Farmers currently do not take this approach. Additionally, current pesticides are broad-spectrum pesticides, killing a whole range of insects, arachnids and mites. Beneficial insects such as ants are also killed when applied.

To conclude, further efforts should be made to educate farmers on timely pruning and optimal fertilisers. Spraying can also be further optimised: spraying should only be done when the pest or disease exceeds the economic threshold, and more specific pesticides need to be used for each of the pests and diseases.

4.1.1.3 Storage, fermentation and drying

Reported storage, fermentation and drying procedures were largely consistent among respondents. It would be expected that these farmers produce beans with an acceptable fermentation index and low numbers of defects.
For all surveyed farmers in Ben Tre and 3 (out of 7) farmers in Ba Ria, farmers reported that less than half of their income comes from selling their own fermented beans. Sampled farmers often sold most of their pods or wet beans to larger fermenters and processors.
The ceding of fermentation by farmers to another actor in the cocoa value chain is part of a larger trend observed in the sector; namely a further integration of all postharvest steps by a single actor. An attempt at understanding the mechanisms behind this trend will be made in the section below.

4.2 Discussion of the Cocoa Value Chain

In literature, knowledge gaps exist about the organisation of the cocoa value chain. Specific research questions pertaining to these gaps were identified earlier in section 1.5.3 and will be discussed one by one below.

Overall, an attempt will be made within the scope of the current research to describe the different ways in which the cocoa value chain is currently organised and how these forms of organisation influence cocoa quality and farmer income. These preliminary findings may form a basis for further research aimed at developing more effective strategies to ensure high yield, high quality cocoa in Vietnam.

4.2.1 Structure of the cocoa value chain

Three currently coexisting forms of organisation (‘models’ below) for the cocoa value chain are shown in Figure 20. These models are based on interviews with Mr Rouzeau, Mr Parizel, and Dr Phuoc, coupled with personal observations in the field and results of the survey conducted with 14 farmers in Ben Tre and Ba Ria. The most obvious difference between the models is the position of the fermentation process in the chain.

In the first model, farmers ferment their own beans before selling them on to traders. According to Dr. Phuoc, Mr Rouzeau and Mr Parizel, this model is generally characterised by low quality cocoa due to the lack of expertise in postharvest processing by the farmers. Fermentation is usually carried out in small batches in an improvised manner, without homogeneity of production and with generally high numbers of slaty or mouldy beans. Just under half of all cocoa farmers are said to work like this.

In the second model, smallholder farmers may sell cocoa pods to fermenters who can either be farmers themselves, or have cocoa fermentation as their sole occupation. Fermentation is usually carried out according to specifications provided by the cocoa bean traders and processors. Larger fermenters have often received trainings on postharvest processing through government or NGO initiatives (as was the case for Thanh Dat Cocoa Company). As a result, these beans often have low amounts of defects and are fermented well enough to potentially qualify as 'quality cocoa'. According to Mr Rouzeau, this segment also encompasses just under half of all cocoa farmers.

The third model is a result of the strong push for vertical integration that the cocoa sector has witnessed worldwide over the past decade. The trend can also be observed in Vietnam and is exemplified by Puratos Grand-Place's purchasing system based on wet beans. In this third model ripe fruits are harvested by farmers and wet beans are extracted. Fermentation is not performed by farmers but instead small groups of farmers coordinate transporting the wet beans to the Puratos Grand-Place's fermentation unit in Ben Tre. From there all further processes are carried out intra-firm up to shipping dried beans, nibs or cocoa mass and chocolate production. According to Mr Parizel, this most recently developed model was developed precisely to address the issues of low yields and low quality cocoa among smallholder farmers.

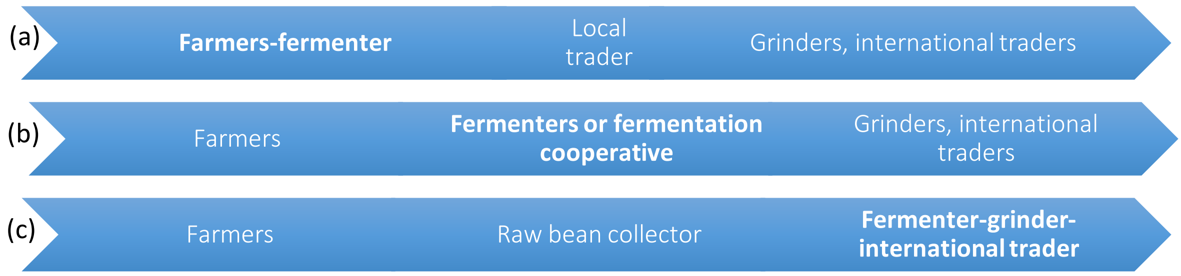


Figure 20: Three models for the cocoa value chain in Vietnam. **(a)** Smallholder farmers ferment their own beans. Bean quality is usually low. (b) Farmers sell raw beans to fermenters. Bean quality can be good. In (a) and **(b)** beans are then sold on to international grinders and traders. **(c)** Raw beans are purchased by one firm integrating fermentation, grinding and international trade. Cocoa bean quality is high.

4.2.2 How are value and value addition distributed?

In this section an attempt is made to verify whether pricing of the raw materials and intermediaries by Puratos Grand-Place (model 3) currently forms a financial incentive for farmers to go along with the push for vertical integration and whether in fact they stand to benefit from it. At the same time a comparison will be made with value addition in the two other models.

In May 2016, average prices[12] in Ba Ria for pods were 6000 VND/kg and 66.000 VND/kg for dry beans. In Ben Tre averages prices were 5350 VND/kg for pods from Châu Thành district

12 The official currency exchange rate at this time was 24.700 VND for 1 EUR.

and 5600 VND/kg in Chợ Lách district. Wet bean prices[13] were 27.000 VND/kg and 27.500 VND/kg respectively. For dry beans prices were 69.000 VND/kg in both districts.

A breakdown of financial gains in each processing step is given below for Puratos Grand-Place's pricing strategy in Ben Tre (

Table 22). Potential percentage income gains are calculated for selling wet beans instead of pods, dry beans instead of pods and wet beans instead of dry beans. Weight ratios of the cocoa intermediaries were calculated for TD9[14] corresponding to the current conditions at the time of research (first weeks of the wet season) and for the cocoa prices mentioned above.

The financial gains as shown in

Table 22 assume there is no opportunity cost for time spent engaged in performing the additional processing steps. In other words, it is assumed that the farmer does not forego income from alternative activities if he takes on more cocoa processing steps on the farm. An in depth cost-benefit analysis of all activities on the farm would be required otherwise, which is outside the scope of this research.

Table 22: Overview of choices farmers face in terms of which intermediary cocoa product to sell. Potential income gains by performing more processing steps themselves are given (weight ratios shown as used at Puratos Grand-Place's fermentation unit in Ben Tre).

	Wet bean versus Pod	Dry bean versus Pod	Wet Bean versus Dry Bean
Price ratio	4,72	11,76	2,49
Weight ratio	0,27	0,11	0,4
Potential income gain (%)	27 %	27 %	0 %

Notes: Potential income gain calculated as (($Price\ Ratio * Weight\ Ratio$)-1) * 100 %

Table 22 demonstrates that Puratos Grand-Place's current pricing strategy forms a financial incentive for farmers to sell wet beans to its fermentation unit: a 27% potential gain in income can be achieved by farmers if they extract pulp themselves (2nd column). If they further process these wet beans into cocoa, this yields 0% additional income gain (4th column). As such, the total process from pod to dry bean (3rd column) also only entails potential income gains of 27 % compared to selling pods.
In short, income is lowest for selling pods but is equal for selling wet beans or dry beans; no additional income can be derived from fermenting and drying beans by the farmer compared to simply selling their wet beans.

By not performing cocoa fermentation and cocoa drying on the farm farmers save on labour which can instead be devoted to other tasks, such as for example farm maintenance and tree health. Puratos Grand-Place's pricing strategy thus aims to give farmers more time to

13 The price difference for wet beans between both districts was due to the greater distance and transportation cost from the farm to the fermentation unit (53 km from Chợ Lách versus less than 10 km from Châu Thành).

14 The weight ratios were 9,25 kg of pods and 2,5 kg of wet beans for 1 kg of dry beans.

devote to their farming activities in an attempt to increase yields, and additionally ensure optimal quality of fermented cocoa by internalising this process.

4.2.3 Under which circumstances is quality currently highest?

Puratos Grand-Place internalised cocoa fermentation and drying in order to ensure cocoa quality in reliably high volumes.
As described in section 1.5.3, large numbers of farmers work small areas without the necessary understanding of agronomic principles or of the fermentation process to achieve high yields of high quality cocoa. Although a small proportion of farmers and fermenters may in fact produce cocoa of adequate quality, the supply is both too low and unpredictable (as described by Mr Rouzeau and Mr Parizel).

As such, internalising cocoa fermentation seems to be the best way to ensure high quality cocoa. The precise factors driving this trend for vertical integration will again be discussed based on the example of Puratos Grand-Place's fermentation unit in Ben Tre. As mentioned, the two main factors to consider are a need for a reliable flow of large volumes of cocoa and consistently high quality cocoa.

First, in order to increase cocoa volumes, Puratos Grand-Place has chosen to concentrate on increasing farm productivity. Resources have been allocated to train farmers on sound agronomic principles to increase average yield and reduce pest and disease damage to pods. Field trials have achieved an increased yield from 700 grams to over 3 kg of dry beans per tree per year within three years of optimising fertilizer and pesticide use and pruning. It is expected that this increase in productivity will contribute to an increased profitability of cocoa for farmers. A further reward is built into the system under a program called 'Cocoa plus': farmers who attend productivity related training are given a cash bonus depending on their yield increase. The combined advantages of increased profitability will hopefully make farmers less likely to cut down cocoa trees when prices of competing crops are high.

Secondly, the impetus behind fermenting themselves is to adequately control all postharvest processing steps to assure high quality cocoa. Two further elements are at play here.
For one, buying beans directly from 'model 1' farmers requires extensive training of large numbers of farmers independently working on small plots. This is due to the fact that fermentation generally yields low quality cocoa as mentioned previously in 'model 1'. Previous efforts in Vietnam have all largely failed to improve agronomic and postharvest practices by farmers.
Also, it was mentioned before that 'model 2' was capable of producing high quality cocoa. However, according to Mr Rouzeau and Mr Parizel, despite the improved knowledge and skills, foul play and tampering with cocoa beans is said to be commonplace when buying dried beans from fermenters and traders. Certain traders will outprice Puratos Grand-Place for high quality dry beans or will purchase beans with a high number of defects from 'model 1' farmers, or ask farmers to reduce fermentation times to just three days in order to increase the bean weight. The traders will then mix high quality beans with low quality beans in order to meet the most basic quality criteria certain grinders use. (Mr Rouzeau

mentioned Mars Inc.[15] as one of the buyers of these lower quality bean mixes). Overall, traders optimise their short term profits, and undercut Puratos Grand-Place's efforts at securing a reliable source of high quality beans.
Thus, to ensure its grinding facilities of a reliable supply of high quality beans, setting up its own fermentation unit was essential.

4.2.4 Are high numbers of middlemen reducing farmer income?

Nguyen (2014) claimed that the number of middlemen in the cocoa value chain could not be reduced due to government regulations. Furthermore, he claimed that this regulation negatively impacted smallholder farmer income. However, the models described in section 4.2.1 do not seem to corroborate this finding.

In Ba Ria, interviewed local traders were also smallholder farmers themselves who organised informal networks to deliver pods or dried beans to the local Thanh Dat Cocoa Company by motorbike, a few kilometres away. However most farmers simply transported pods or beans to the processing plant themselves.
Also, in the case of Puratos Grand-Place in Ben Tre, farmers mainly transport wet beans to Puratos Grand-Place themselves. Some farmers deliver pods to a nearby farmer who opens the pods and then transports the wet beans to Puratos Grand-Place for fermentation. The main driver behind this form of organisation is the large distance to the fermentation unit, causing joint transportation of wet beans to reduce costs.
As such, interviewed farmers in Ba Ria and Ben Tre confirmed that there seems to be little room to reduce the number of middlemen in the first place.

Moreover, findings in this research did not corroborate the claim made by Nguyen (2014) that foreign-invested enterprises are effectively prohibited to organise networks for goods purchase for export themselves. Mr Rouzeau was unaware of this circular, and Puratos Grand-Place organizes part of its purchasing network itself. Mr Rouzeau supported the observation that when intermediaries are used it is because this facilitates sourcing: in Ben Tre farms are located far away from each other and transport is costly. Purchasing wet beans through intermediaries saves on transporting pod weight and saves labour for Puratos Grand-Place.

In conclusion, firstly middlemen do not seem to appear to adversely impact smallholder farmer income. Secondly, the stipulations in Circular No. 08/2013/TT-BCT do not impact the foreign-invested enterprise in this survey.

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[15] The strategy behind Mars Inc.'s buying of low quality beans at market prices is not clear to Mr Rouzeau. He surmises it is perhaps meant to keep the cocoa sector from contracting further in the Mekong Delta, in order to secure a future opportunity to easily enter the sector again. This seems plausible given the large investments Mars has already made into the sector. However, according to Mr Rouzeau this undercuts the general interest of promoting high quality cocoa which he considers the only viable option for Vietnamese cocoa.

4.2.5 Does intercropping increase farmer resilience to price fluctuations and make them less likely to chop cocoa trees?

Chopping of cocoa trees is evidently an issue in all cocoa growing regions of Vietnam. Survey results indicated that farmers who intercrop cocoa with fruit trees derive disproportionately more income from non-cocoa trees than from cocoa trees. However, the decisions leading to cocoa chopping are more complex than a simple comparison of cocoa prices and competing crop prices. The following anecdotal evidence illustrates that a more thorough investigation is required to understand what drives the decision to chop cocoa trees:

- None of the surveyed farmers expressed explicit intentions to chop their cocoa trees
- One respondent in Ba Ria said he already invested too much in his cocoa plantation to chop the trees but that he would plant pepper trees if he had a new empty plot
- Two respondents in Ben Tre had recently chopped most of their durian trees because they were old. They now rely more on cocoa for their income. They do not intend to plant new fruit trees
- One respondent in Ben Tre said his durian trees are more heavily affected by salt water intrusion than his cocoa trees

In the short term, however, research can also be conducted into optimising existing intercropping systems to allow cocoa trees to reach their full potential. In this respect Mr Rouzeau described the case of cocoa/pomelo intercropping, where ineffective pruning practices are one of the factors reducing cocoa yields.
Farmers in Ben Tre often allow the pomelo tree canopies to spread and open. This greatly reduces light availability to cocoa trees and subsequently reduces the yields. Furthermore, this method of pomelo pruning has not been shown to increase pomelo yields either. Dissemination of future research findings to farmers can increase both cocoa and pomelo yields and contribute to increased farmer resilience to price fluctuations.

4.3 Single clone characteristics

4.3.1 Single clone data

At farm level, data for each clone for 'beans per pod', 'butterfat content', 'pod size', 'bean weight', 'shell content', disease resistance and 'pods per tree per year' allows growers to select clones based on productivity. A case will be made to provide a range for each parameter for each separate growing region.

Little physico-chemical data is available on clones other than the currently approved TD[16] and CT clones. The experimental data provided in section 3.2 for unapproved clones is a first step in filling this void.
To determine the need for ranges for parameters per region, experimental and published data is compared below for butterfat content of approved clones.[17]

[16] TD1, TD2, TD3, TD5, TD6, TD8, TD9, TD10 and TD14

[17] Beans per pod compared with published data (TD3= 40 beans per pod, TD9= 49 beans per pod): TD3 contained fewer beans per pod (-3, p= 0,05). For TD9 no difference was observed (Nguyen,2014).

For butterfat content significant differences were observed for each clone and each region compared to published butterfat data (Table 23) (Cao Nguyen,2014).
The observed intra-clone butterfat variability for different regions is up to 5% (Table 23). Inter-clone variability for the collected Dong Nai clones was also up to 5% (Table 23).

Table 23: Butterfat content for 3 collected clones versus a published reference

Butterfat	TD3 (% DM)		TD5 (% DM)		TD9 (% DM)	
	Dong Nai	Vung Tau	Vung Tau	Ben Tre	Dong Nai	Ben Tre
Test results	54,56	51,61[a]	56,86	58,37[b]	58,17[c]	53,02[d]
Ref.(Nguyen,2014)	54[a]		57[b]		60[c,d]	

Notes: one-sample t-tests were used to test for significant differences within single clone repetitions (n=3, p=0,05, t_{crit}=2,92): a (t=52,3); b (t= 15,81), c (t= 8,77), d (t=255)

Clearly, the impact of region (soil, climate, season) on butterfat content can be just as large as the variation found between cocoa clones grown on the same farm under equal conditions. In this light it would be useful to develop a range of butterfat contents per clone encompassing different regions and climates.
The current requirement for national approval of a clone in Vietnam that the clone provides high yields in all regions is clearly not the most efficient (1A Vietnamese standards, Dr. Phuoc). Each region should have its own officially approved clones based on data specific to this region, regardless of results in other regions.

An E-nose and GC-MS analysis was not performed on the single clones to determine clone-specific aroma profiles. Due to a lack of ripe cocoa pods at the time of harvest, multiple clones were fermented in a single, sufficiently large batch. This entails that the bean pulp, and produced compounds in each clone's pulp, were mixed with each other. However in terms or aroma, according to Kadow et al. (2013) only the chocolate aroma derives from endogenous seed components such as its proteins and carbohydrates during the Maillard reaction. On the other hand, other aromas related to fine flavour have mainly been linked to the fruit pulp as products of the fermentation and degradation of antioxidants. As such, in the current study, fruity, floral, astringent, green, or other aromas originating from the fruit pulp would probably not have been sufficiently ascribed to a single clone.

4.4 Acidity reduction: Chocolate survey and processing from bean to bar

Acidity reduction in Vietnamese chocolate is considered important to increase consumer acceptance of the product. An alternative drying method was devised, aimed at reducing acidity. To determine the effectiveness of the alternative drying methods, physico-chemical parameters will be compared to consumer responses from the chocolate tasting survey and expert panel results on the cocoa mass.

Chocolates C2, C4 and C5 were identically processed and produced except for the drying method. Beans came from the same farm and were all harvested in March 2016. As such, the bean batches can be considered equal. Fermentation was carried out in separate batches, but fermentation indices are essentially equal, thus also this step can be considered equal. Roasting, grinding, refining and conching were also equal for all chocolates.
With regards to grinding, PSD showed slight differences in particle size between the three chocolates. However, all chocolates showed a similar size distribution, with a peak around 10 µm and a secondary peak around 100 µm. In cocoa seed cotyledons most fat and polyphenol storage vacuoles are found in cells ranging in size from about 20 – 30 µm (Elwers, 2010). The reported D [4,3] of around 14 µm is well below this figure. As such, for

all three chocolates it can be expected that acids, polyphenols, fats and other flavour compounds will have all been fully released from their cell matrices. In this respect, no acidity or flavour difference is expected between the cocoa beans due to differences in particle size.

Survey results indicated that overall likeability between the chocolates was the same. As such, the alternative drying methods did not increase or decrease the likeability of chocolates C2 and C5 compared to the standard drying procedure employed for C4.
Dark users did however rate C2 as more acidic than C5. Overall though, this increased perceived acidity did not negatively influence the likeability of chocolate C2, despite the weak negative correlation which was observed for dark users between acidity and likeability. The expert tasting of liquor also rated T2 as more acidic than T4, which in turn was more acidic than T5.
Thus overall, acidity levels reported in the both surveys are in line with lab results, yielding an acidity ranking of C2 > C4 > C5 (Table 24): the standard drying method C4 has a final acidity in between the two alternative methods C2 and C5.

Table 24: Comparison of acidity measurements and chocolate ratings for titratable acid and dark consumer ranking. Cocoa mass expert ranking is for cocoa mass, not for chocolate. Significant differences in acidity on (p = 0,05): a(p= 0,007), b(p=0,01).

	pH	Titratable acid (mol H^+ / 100g)	Dark consumer ranking (semantic acidity scale 4=neutral, 5= rather acidic)
C2	5,15[b]	3,85E-03 ± 1,68E-04	4,536[a] ± 0,97
C4	5,23	3,66E-03 ± 3,12E-04	4,328 ± 1,01
C5	5,27[b]	3,36E-03± 2,74E-05	4,000[a] ± 1,25

Additionally, the intensity of bitter or acid flavour notes was found to be less important to dark chocolate users than to milk or white chocolate consumers: dark users appear more tolerant towards stronger flavour notes, which only weakly influence the overall likeability of a chocolate.
Previous research does not support this finding however. Both Torres-Moreno (2012) and Afoakwa (2010) in Spain and Ghana respectively, reported a correlation coefficient R^2 of 0,789 between flavour acceptability of dark chocolates and overall dark chocolate acceptability (panel size n= 95). As such, it would be expected that acid and bitter flavours more heavily influence likeability of dark chocolate users than the correlation coefficients observed in this survey indicate (R^2= 0,073). A possible explanation could be that in the final chocolate, differences in acidity are observable but too low to drive likeability scores. Additionally, flavour preferences in Belgium can be different to those in Ghana and Spain.

The 6 experts in the cocoa mass survey reported slight differences in acidity between samples, with a mode of 2 for the acidity rating of all samples, corresponding with "present in the sample". This is in line with analytical results where pH varied only between 5,03 and 5,08 for the three masses and there was no significant difference in titratable acidity either.
More interestingly however, the GPA and PCA showed differences between flavour descriptors where the consumer panel did not. These differences were not confirmed by an ANOVA analysis on the cocoa mass ratings however. The ANOVA for cocoa mass rating by experts also failed to find significant differences between the samples.

The fact that GPA/PCA did discern differences is due to the more powerful GPA method used to distinguish flavour descriptors.
Thus it appears the alternative drying only slightly affected flavour descriptors. These differences were too small for a consumer panel to notice and the difference is only revealed in the expert rating using the more powerful GPA method.[18] The GPA/PCA and ANOVA analysis should be repeated with a larger expert panel to verify this finding.

In conclusion, the effectiveness of the alternative drying method for acidity reduction can be questioned given the outcomes of the surveys and analytical results presented above.
In the dry beans the alternative drying methods T2 and T5 yielded less acidic beans than the traditional drying method used for T4, in line with expectations about the experimental setup. However, during grinding large amounts of acid evaporated from T4, reducing general acidity, whereas the grinding increased the acidity of T2 and T5. The increase in acidity alternative methods T2 and T5 is likely due to the release of more acids by reducing particle sizes during grinding. The reduction in the traditional method T4 is more difficult to explain; perhaps the large excess of free acids which had not evaporated during drying were easily released during grinding, bringing the levels of acidity closer to those of the alternative methods T2 and T5.
Finally, after conching and sugar addition all chocolates largely converged at a lower acidity level. Hence, overall a large reduction in acidity of the traditional method T4 took place through grinding and conching, eliminating the benefits of the alternative drying methods T2 and T5.

[18] It must also be added that faculty staff at the UGent Cacaolab all had personal favourites and did in fact make clear distinctions between chocolates. This prompts the idea for additional research into the effects of drying techniques on flavour notes and aroma.

5 General conclusions

The aim of this research was to provide an overview of the quality potential of cocoa in southern Vietnam.
High quality cocoa products are the niche Vietnam should aim to occupy. The current trend of vertical integration appears to be the most viable option to achieve this. To processors it ensures a reliable supply of high volumes of high quality cocoa and has the potential of improving farmer income due to an improved farm productivity and higher quality production, as farmers selling wet beans instead of dry beans have more time to manage their farms.
Additional training on pruning times, efficient fertiliser use and integrated pest management could further increase farmer income. Farmers need to learn that intercropping fruit trees with cocoa increases resilience to price fluctuations of both fruits and cocoa, and that combining fruit trees and well managed cocoa plots offers higher income security. To this end, intercropping systems require further research and optimisation.

This research confirmed the need for quality parameters of cocoa clones to be developed per region. Intra-clone variability for fat content between regions is as big as inter-clone variability within the same farm. Further research in the area is required for new clones growing in Vietnam. TD3, TD5 clones are currently most widespread but have the disadvantage of low overall yield for TD3, and of disease susceptibility of TD5.
TD6, TD10 and TD11 are increasingly tested in commercial settings for their favourable yield and aroma potential, although TD10 remains susceptible to disease too. In this light, TD crosses such as TD28 or TD54 need to be tested for disease resistance and aroma potential.

In term of the alternative drying methods aimed at acidity reduction, the methods resulted in lower acidity of the dry bean but not in the final chocolate. As such, the standard uninterrupted drying procedure for fermented beans can be maintained. Additionally, the alternative drying had no influence on the perception other flavour notes by consumers. Also, the consumer panel did not rate them differently for likeability.
Finally, for Belgian consumers of dark origin chocolate the acidity of Vietnamese beans did not negatively affect likeability. Thus in the light of consumer acceptance of origin chocolate, one may even ask whether a further reduction in acidity of Vietnamese beans is desirable in the first place.

6 Suggestions for future research

Firstly, the survey revealed the need for improved intercropping systems. Research opportunities in this field are optimisation of cocoa/pomelo intercropping systems in Ben Tre, and also the viability of the conversion from rubber to cocoa plantations on state-owned land in the Southeast. A trial project on cocoa/rubber is already running between Puratos Grand-Place and state-owned companies.

Secondly, as discussed in section 4.3.1, variability in pulp/pod ratio's is high between seasons and regions. As such, it would be advisable to determine ranges for pulp/pod ratio's for each clone farmed in Vietnam. Equally so, a similar range for other parameters should be created for each clone over different regions and seasons in Vietnam as illustrated below in Table 25.

Table 25: Example of table with the essential cocoa quality parameters for each clone, per region

Clone	Climate Zone/Region/Province per season (e.g. Dong Nai, Dry Season)					
	Beans/Pod	Pod Weight	Bean Weight	Shell content (%)	Pods/ tree/year	Disease resistance score
TD3	-	-	-	-	-	
TD5	-	-	-	-	-	
…	-	-	-	-	-	

The combined data can then be used alongside other parameters e.g. butterfat content to adequately assess and compare the benefits of clones in each region.
The data is also useful in price setting for pods, pulp or dry beans in commercial companies, and is essential in economic analyses to understand the value chain (demonstrated in 4.2.2). Once the ranges for butterfat content and pod/pulp ratios have been established for each clone these could eventually be linked to the clone's genetic filiation: is there a correlation between genetic clustering and butterfat content, pod/pulp ratio's or certain flavour profiles?

Thirdly, aroma profiles for Vietnamese clones should be obtained. E-nose fingerprinting and GC-MS analysis of unroasted or roasted cocoa beans can be performed to characterise and distinguish cocoa clone aromas. This data is of interest to cocoa processors looking for specific flavours. However, care should be taken to ferment each clone separately to avoid mixing pulp of different clones, which would also mix pulp-derived aromas such as fruitiness. In parallel, odour activity values of volatiles in cocoa should be quantified to determine which volatiles actually contribute to cocoa aroma. This could be specialised further to determine the contribution of key compounds to the total aroma perception of certain desirable flavour notes.

Finally in terms of flavour notes and consumer acceptability, the negative correlation of acidity and likeability should be verified for different consumer groups. For dark chocolate consumers in this research, the correlation was weak. However, likeability scores of the tested chocolates were too close together to distinguish between chocolates. The analysis can be redone on chocolates with more pronounced differences in taste profile. An ideal acidity with highest likeability can then be determined for a specific consumer segment.

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V. Appendices (electronic only)

Appendix 1: Cocoa liquor flavour wheel: Impacts of different processing steps on flavour of the cocoa

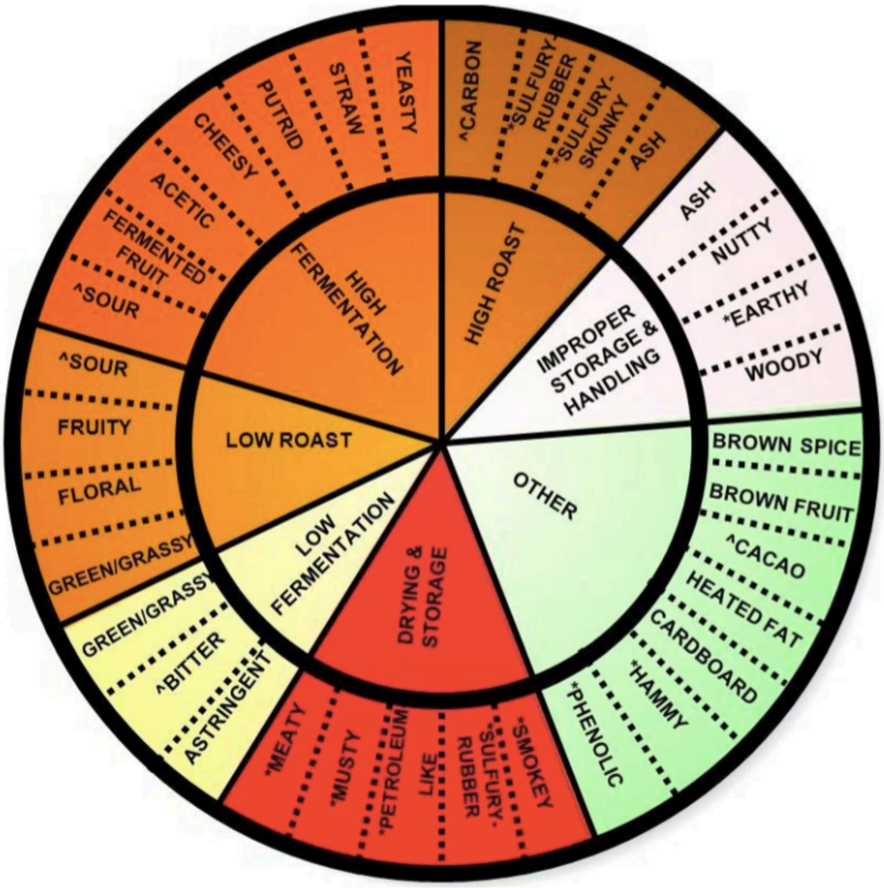

Fig. 1: Cocoa flavour wheel

Appendix 2: Bean to Bar Chocolate Production Flow Chart (Adaptation from Beckett, 2011)

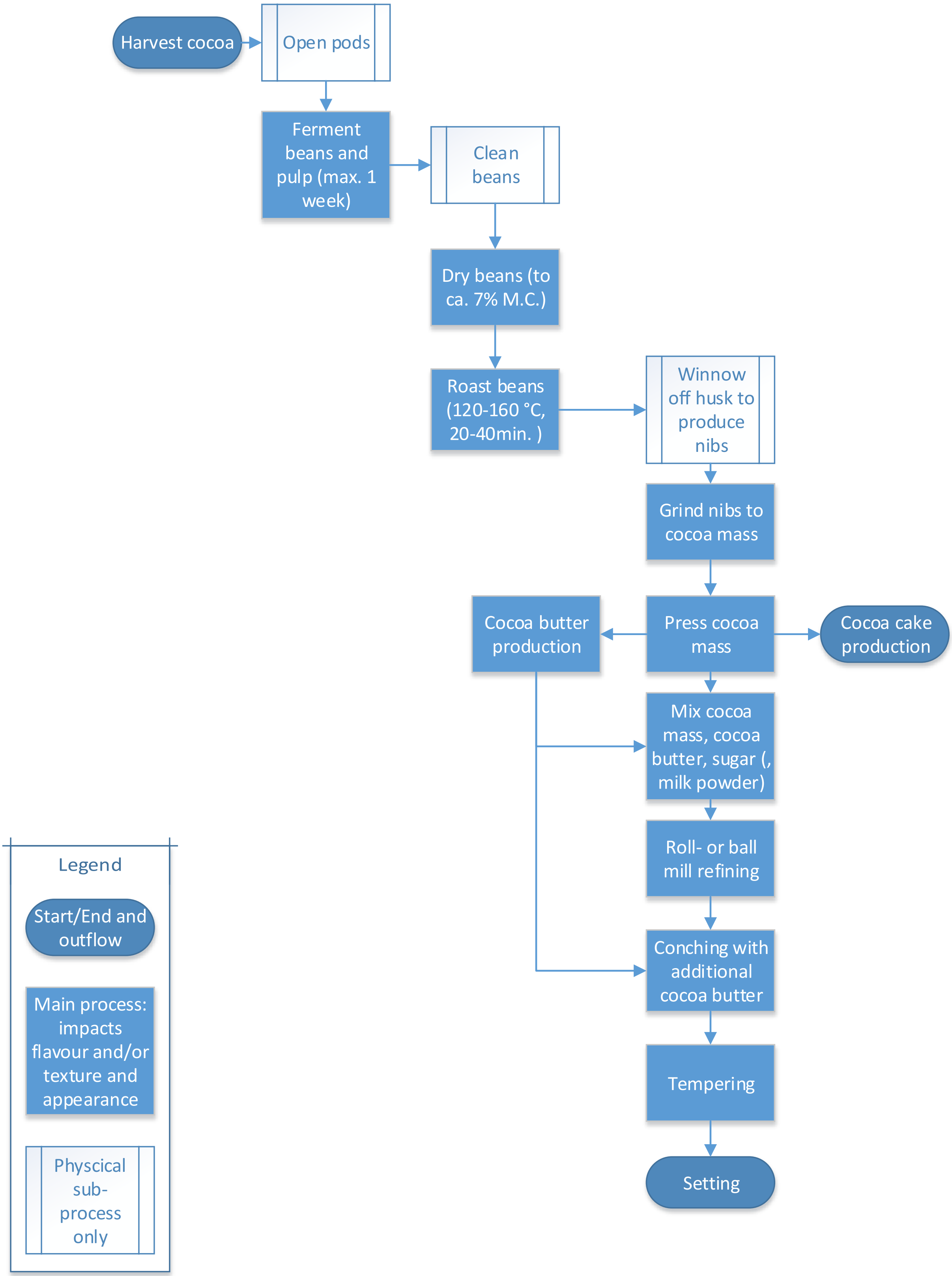

Fig. 2: Overview of the production process of dark or milk chocolate

Appendix 3: Map of Vietnam *(Wikipedia, 2015)*

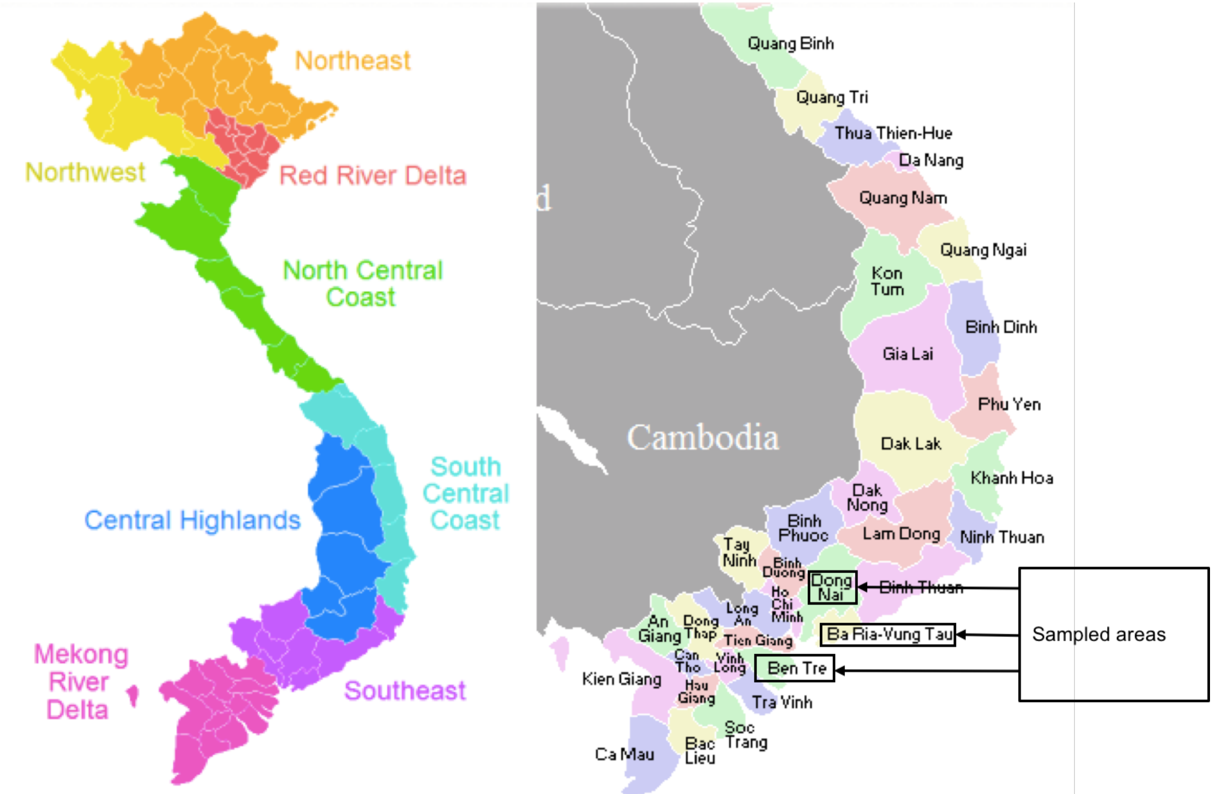

Fig. 3: Map of Vietnam with regions (left) and provinces (right). Highlighted provinces were sampled and results used in this research.

Appendix 4: Complete Farm and Post-Harvest Survey

COCOA PROJECT

EVALUATION AND CHARACTERISATION OF DIFFERENT VIETNAMESE COCOA CLONES/VARIETIES

Farmer Questionnaire, 2016

Survey information

Name of interviewer:	
Date of interview:	
Starting time:	
Ending time:	
Survey region:	
District:	
Village:	
Farmer's Tel:	

Codes for region

01. LK : EaKar-Daklak province (Highland)

02. PD: Phongdien-Cantho province (Mekong Delta)

03. BT: Chauthanh-Bentre province (Mekong Delta)

04. DN: Trangbom-Dongnai province (Southeast)

1.0 DEMOGRAPHIC CHARACTERISTICS

1.1 Name of Farmer: ………………………………….......... **1.2** Age of Farmer: ………......... **1.3** Gender? .... **1.4** Educational Status: ……… **1.5** Marital Status: ………….. **1.7** Experience of farmer (years engaged in cocoa cultivation):	01=male 02=female 01=None 02=Up to primary school 03=JSS/Middle school 04=Secondary School 05=Tertiary level 06=Non-formal 01=Single 02=Married 03=Divorced 04=Widow/widower 05=others (state)………… 01. [1 – 5 yrs] 02. [6 – 10 yrs] 03. [11 – 15 yrs] 04. [16 – 20 yrs] 05. [21 – 25 yrs] 06. [26 – 30 yrs] 07. [31 – 35 yrs] 08. [36 – 40 yrs] 09. [41 – 45 yrs] 10. [46 – 50 yrs] 11. [Above 50 yrs]

2.0 FARM CHARACTERISTICS

2.1 How many cocoa farms do you have? ………………………………….

2.2 Fill in the following Table.

Farm	Major/ Minor*	Land tenure arrangement#	Location (village)	Topography of the land**	Farm Size (acres)	Age of farm (yrs)	Planted cocoa variety/clone and farm ratio
1.							
2.							
3.							

*01= Major, 02 = Minor

01=Owner 02=Family 03=Rented/leased

04=other (specify)........................

**01= flat 02= system of dikes and ditches (flat) 03= on a slope 04= on a hill

+ Name clones, ratio and, 1 = *Forastero*, 2 = *Trinitario*, 3 = *Criollo*, 4 = Mixed

2.34 Which produced clone has the best results? …………………………

2.4 Do you like another clone too for another reason?

Which clone: ……………….

01= year round pods

02= natural canopy architecture

03= disease resistance

04= other

2.4 What is the yield of production (kg) from the major cocoa farm in the last three years?

2013	2014	2015

2.5 What do you think about the fertility of the soil on your major cocoa farm?

01 = soil is fertile and supports growth of the cocoa trees

02 = soil is not fertile and does not support growth of cocoa trees

03 = other (specify drainage, organic matter)..

2.6 What fraction of your plot income comes from selling cocoa?

3.0 FARM MANAGEMENT PRACTICES (on major cocoa farm)

3.1 What type of farming (cropping) system?

☐ Mono cropping ☐ Mixed cropping

3.2a If mixed cropping, list all the crops planted……………………………………….

………………………………………………………………………………………

3.2b How many other trees (not cocoa) are in your plot? ………………..

3.3 Also, if mixed cropping, are the crops intercropped? 01=Yes 02=No

3.4a How far apart are the cocoa trees in rows on this farm?

3.4b How far apart are the cocoa trees in columns on this farm?

OR

3.5a How many cocoa trees do you have on your plot?

3.5b What is the area of your plot?

3.6 What plant is used as shade tree (multiple answers allowed)

☐ Plantain

☐ Banana

☐ Others (state)……………………………..

3.7 How many shade trees do you have on your farm?.......

3.8 What statement about the canopy of the cocoa trees is most accurate?

☐ The canopy of the cocoa trees is not closed at all (No interlocking branches; sunlight can reach the ground)

☐ There are breaks in the canopy of the cocoa trees (Not all branches are interlocking or gaps exist in an otherwise closed canopy; sunlight can reach the ground in some places)

☐ The canopy of the cocoa trees is closed (Interlocking branches; sunlight cannot reach the ground)

3.9 Mention the major disease(s) that attack the cocoa trees (multiple answers allowed)

☐ Stem Cankers ☐ Black pod disease ☐ Others (state)…

3.10 Mention the major pest(s) that attack the cocoa trees (multiple answers allowed)

☐ Capsids/Helopeltis ☐ Mealy bugs

☐ Cocoa thrips ☐ Gray weevils ☐ Others (state)…………..

	Mode of control / eradication (circle applied mode)	N° of times and season*	Chemical		
			Type	Source	Quantity
Weed control	01 = weeding 02 = weedicides				
Spraying of Capsids, mealy bugs and other pests	01=Spray machine 02= Other (e.g biological control?)				
Spraying other diseases	01=Spray machine 02= Other.........				
Fertilizer application	01= Broadcasting method 02= Ring application 3= Subsurface application				
Pruning	01=Use of cutlass 02=Other………….				

* 1 = systematically, every ……………………….. 2 = at outbreak of pest or disease, 3= start of rainy season, 4= other

	Mode of pruning(circle applied mode)	N° of times and season*
Production Pruning	01= leaves which do not get sunlight 02= leader pruning: new growth of leaves 03= leaves at the end of shoots far from pods	
Architecture pruning		

* 1 = systematically, every ……………………….. 02 = when too dark, 03= other

4.0 POST HARVEST PRACTICES (major cocoa season) within the last 12 months

4.1 Harvesting of cocoa pods	N° of times*	Quantity harvested

*Otherwise provide frequency: 01=weekly, 02= every ten days, 03=every two weeks, 04=other

4.2 Pod storage	N° of days	Place of storage
		01=farm 02=home 03=other..........

4.3 Fermentation	Method	N° of days	N° of turning	N° of pods used
	01=box 02=other...			

*If box please provide dimensions and number and size of drainage holes

4.4 Drying	Method	N° of days	Turning	Quantity of dried beans (kg)
	01=mats 02=floor 03=artificial 04=other....			

4.5 Price of (per kg):

Raw cocoa fruits:………..

Raw beans: ………..

Dried fermented beans: ………..

4.6 Use of cocoa shells

Are the remaining cocoa shells used as a fertilizer for mulching?

01. = Yes

02. = No

03. = Animal feed

043.= Other ………………..

5.0 FARMERS TRAINING AND SOCIAL CAPITAL

5.1 In the last 12 months, have you received any form of training? 01. =Yes 02. = No

5.2 If yes, tell us the source………..

- ☐ Cooperatives
- ☐ NGOs
- ☐ Ministry of Food and Agriculture
- ☐ Licensed buying company (LBC)
- ☐ Other farmers
- ☐ Other (state)…..

5.3 What kind of training did you receive?

- ☐ Health and safety
- ☐ Applying fertilizers/pesticides
- ☐ Planting and farm expansion
- ☐ Crop diversification
- ☐ Deforestation and environment
- ☐ Farm maintenance
- ☐ Other...

5.4 Have you received any kind of certification? (01=Yes , 02= No) If yes, when? …………

5.5 If yes, mention the certification and the awarding organization…………………………..
……………………………………………………………………………………………….

Appendix 5: Photographic overview of ripe pods of the 9 fermented clones

Name	*In-variety morphological variability*	*Side-view*	*Cross-section*
TD2			
TD9			

TD13

TD28

TD54

SIAL339

PA70

M3

Appendix 6: Consumer chocolate tasting survey

RESP

				1

Welcome to our survey about Vietnamese origin chocolate!

We would like to thank you for your time and effort to participate in this experiment conducted by the Sensolab at the UGent. This survey will take up about 10 minutes. Please do **not eat** the chocolates immediately, follow the instructions carefully.

Aeren Pauwels
Helena Everaert

Do you have an allergy or discomforts for dark chocolate products?

- ◯ No
- ◯ Yes

Do you eat chocolate?

- ◯ Yes
- ◯ No

How often do you eat chocolate (all kinds)? (Chocolate as a food product, so not processed in other products)?

- ◯ Daily
- ◯ Multiple times a week
- ◯ Once a week
- ◯ Once a month
- ◯ Almost never

Which kind of chocolate do you prefer?

- ◯ Dark chocolate
- ◯ Milk chocolate
- ◯ White chocolate

How often do you eat **dark** chocolate?

- ◯ Daily
- ◯ Multiple times a week
- ◯ Once a week
- ◯ Once a month
- ◯ Almost never

How often do you eat dark **origin** chocolate? (*"Origin"* means the chocolate is made from cocoa beans from one specific region)

- ◯ Daily
- ◯ Multiple times a week
- ◯ Once a week
- ◯ Once a month
- ◯ Almost never

How is your knowledge about the taste and the flavor profile of dark (origin) chocolate?

- ◯ Low: consumer, slight interest in chocolate
- ◯ Average: wide interest in taste profiles of chocolates, chocolate as a hobby, make your own chocolates
- ◯ High: Professional, involved in chocolate taste developments, attending at least two times a month a chocolate tasting, chocolate is a passion

RESP	PRODUCT
1	546

Please drink a little bit of water and eat a piece of the cracker to clean the mouth.

Take a **first bite** of chocolate **546.**

How do you like the taste of chocolate 546?

Extremely tasty	Very tasty	Tasty	Rather tasty	Neutral	Rather not tasty	Not tasty	Not at all tast	Extremely not tasty
○	○	○	○	○	○	○	○	○

Take a **second** of chocolate **546.** (You may take more bites if necessary. But **do not finish all of this chocolate** yet)

How would you rate chocolate 546 for acidity?

Very acidic	Acidic	Rather acidic	Neutral	Rather not acidic	Not acidic	Not at all acidic
○	○	○	○	○	○	○

How would you rate chocolate 546 for sweetness?

Very sweet	Sweet	Rather sweet	Neutral	Rather not sweet	Not sweet	Not at all sweet
○	○	○	○	○	○	○

How would you rate chocolate 546 for fruitiness?

Very fruity	Fruity	Rather fruity	Neutral	Rather not fruity	Not fruity	Not at all fruity
○	○	○	○	○	○	○

How would you rate chocolate 546 for bitterness?

Very bitter	Bitter	Rather bitter	Neutral	Rather not bitter	Not bitter	Not at all bitter
○	○	○	○	○	○	○

RESP	PRODUCT
1	156

Please drink a little bit of water and eat a piece of the cracker to clean the mouth.

Take a **first bite** of chocolate **156.**

How do you like the taste of chocolate 156?

Extremely tasty	Very tasty	Tasty	Rather tasty	Neutral	Rather not tasty	Not tasty	Not at all tast	Extremely not tasty
○	○	○	○	○	○	○	○	○

Take a **second** of chocolate **156.** (You may take more bites if necessary. But **do not finish all of this chocolate** yet)

How would you rate chocolate 156 for acidity?

Very acidic	Acidic	Rather acidic	Neutral	Rather not acidic	Not acidic	Not at all acidic
○	○	○	○	○	○	○

How would you rate chocolate 156 for sweetness?

Very sweet	Sweet	Rather sweet	Neutral	Rather not sweet	Not sweet	Not at all sweet
○	○	○	○	○	○	○

How would you rate chocolate 156 for fruitiness?

Very fruity	Fruity	Rather fruity	Neutral	Rather not fruity	Not fruity	Not at all fruity
○	○	○	○	○	○	○

How would you rate chocolate 156 for bitterness?

Very bitter	Bitter	Rather bitter	Neutral	Rather not bitter	Not bitter	Not at all bitter
○	○	○	○	○	○	○

RESP	PRODUCT
1	739

Please drink a little bit of water and eat a piece of the cracker to clean the mouth.

Take a **first bite** of chocolate **739.**

How do you like the taste of chocolate 739?

Extremely tasty	Very tasty	Tasty	Rather tasty	Neutral	Rather not tasty	Not tasty	Not at all tast	Extremely not tasty
○	○	○	○	○	○	○	○	○

Take a **second** of chocolate **739.** (You may take more bites if necessary. But **do not finish all of this chocolate** yet)

How would you rate chocolate 739 for acidity?

Very acidic	Acidic	Rather acidic	Neutral	Rather not acidic	Not acidic	Not at all acidic
○	○	○	○	○	○	○

How would you rate chocolate 739 for sweetness?

Very sweet	Sweet	Rather sweet	Neutral	Rather not sweet	Not sweet	Not at all sweet
○	○	○	○	○	○	○

How would you rate chocolate 739 for fruitiness?

Very fruity	Fruity	Rather fruity	Neutral	Rather not fruity	Not fruity	Not at all fruity
○	○	○	○	○	○	○

How would you rate chocolate 739 for bitterness?

Very bitter	Bitter	Rather bitter	Neutral	Rather not bitter	Not bitter	Not at all bitter
○	○	○	○	○	○	○

RESP

				1

What is your gender?

- ◯ M
- ◯ F
- ◯ X

What is your age?

Where did you participate to this experiment?

- ◯ In the SensoLab
- ◯ In a classroom
- ◯ At home

Thank you for your cooperation and time! (if you have any chocolate left, you can keep it)