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Evaluation of water volume and water quality over coffee quality using wet mill processing at two production areas of Guatemala

by

Sarah Patricia Santos Cooke

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MAGISTER SCIENTIAE IN INTEGRATED WATERSHED MANAGEMENT

SIGNERS:

Sergio Velásquez, M.Sc.
Major Advisor

Francisco Jiménez, Dr.Sc.
Advisory Committee Member

Gabriela Soto, M.Sc.
Advisory Committee Member

Cliserio González, M.Sc.
Advisory Committee Member

Glenn Galloway, Ph.D.
Dean, Graduate School

Sarah Patricia Santos Cooke
Candidate

DEDICATION

A mi esposo y familia, quienes han sido la fuente de inspiración y apoyo de mi vida.

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SUMMARY

Santos, S. 2010. Evaluation of water volume and water quality over coffee quality using wet mill processing at two production areas of Guatemala. Tesis Mag. Sc. CATIE. Turrialba, CR.119 p.

The main objective of this study was to assess the quantity and quality of water in different stages of wet processing and their effect on the quality of green coffee produced. This study was conducted in Guatemala in two coffee growing regions, Fraijanes and Huehuetenango; 4 wet mills were visited. In Fraijanes two coffee cooperatives were visited (Nuevo Sendero and Las Brisas) and in Huehuetenango two smallholders (El Retiro and El Jardin). The visited wet mills processing methods were described (coffee and water flow), also the quality of the wastewater and the effectiveness of the sanitation techniques were evaluated. Coffee samples were processed under each coffee wet milling condition using different volumes of water and processing methods. In addition, samples were collected in the existing facilities to monitor the on-going technology. For each sample collected in the study, the volume of clean water consumed was measured. A total of 36 green coffee samples were collected and evaluated for physical characteristics, sensory profile and the determination of the biochemical composition. The volume of clean water to process one quintal (100 pounds) to of green coffee fluctuated between 0.064 and 1.13 m^3 according to the different wet mill process. The volume of clean water consumed is related to the technology used but also to the management practices and the experience of the employee. There is no standard procedure in the coffee processing and water usage in the visited wet mills. Nuevo Sendero is the only wet mill that recirculates water for pulping and washing. Therefore, there is more consumption of clean water in Las Brisas, El Retiro and El Jardin. Through a statistical analysis, 3 coffee qualities (*good, regular and lower quality*) and two biochemical groups were determined from the 36 coffee samples. The water quantity consumed during the process wet milling process had no statistical effect on the sensory profile. The three groups of quality are related to the different alternatives of process, mainly duration and mode of fermentation (i.e. use of demucilager). The water quality parameters (pH, COD, BOD, etc) also had no statistical effect on the organoleptic and bicochemical characteristics. The different alternatives of washing (use of clean water, recirculated water, and two washes (which one was recirculated and other was clean water) had no statistical association with the organoleptic descriptors (positive attributes and off-flavors). However, the variable washing showed association with the biochemical variables and the locality (Fraijanes and Huehuetenango). The four wet mills had a wastewater sanitation treatment, although

none met the Regulation of discharge and reuse of wastewater and disposal of sludge of Guatemala. The water treatment facilities were efficient removing the total suspended solids, COD, BOD and decreasing pH. It is important to point out that at least the waste water is not being discharged without any prior treatment into the watersheds.

RESUMEN

Santos, S. 2010. Evaluación de la cantidad y calidad del agua utilizada en el beneficiado húmedo y su efecto sobre la calidad de café, en dos áreas productoras de Guatemala. Tesis Mag. Sc. Turrialba, CR. CATIE. 119p.

El objetivo principal del estudio fue evaluar la cantidad y calidad del agua utilizada en diferentes etapas del beneficiado húmedo y su efecto en la calidad del café oro producido. Además se evaluó la calidad de las aguas residuales y la eficacia del tratamiento de las mismas. El estudio se realizó en dos zonas productoras de Guatemala: Fraijanes y Huehuetenango, en cuatro beneficios húmedos, dos en Fraijanes (Nuevo Sendero y Las Brisas) pertenecientes a cooperativas y dos pequeños beneficios privados en Huehuetenango (El Retiro y El Jardín). Primeramente se describió el proceso de beneficiado húmedo en cada beneficio, luego muestras de café fueron procesadas en cada condición de beneficiado con diferentes volúmenes de agua y métodos de procesamiento. Para cada muestra recolectada se midió el volumen de agua utilizada. Un total de 36 muestras de café oro fueron recolectadas y se evaluaron sus características físicas, el perfil sensorial y la composición bioquímica. El volumen de agua para procesar un quintal (100 libras) de café oro fluctuó entre 0,064 y 1,13 m^3 de acuerdo con los diferentes procesos de beneficio húmedo. El volumen de agua consumido se relaciona con la tecnología utilizada, las prácticas de manejo y la experiencia del personal. No existe un procedimiento estándar en el procesamiento del café y en el uso del agua en los beneficios estudiados. Nuevo Sendero es el único beneficio húmedo que recircula el agua para despulpar y lavar, por lo que tiene un menor consumo de agua por unidad de producción de café, con relación a los otros beneficios. El análisis estadístico separó tres calidades de café (buena, regular y baja) y dos grupos por sus características bioquímicas. La cantidad de agua consumida durante el proceso de beneficiado por vía húmeda no tuvo efecto en el perfil sensorial. Los tres grupos de calidad están relacionados con las diferentes alternativas de proceso, principalmente la duración y el modo de fermentación (ej. el uso del desmucilaginador). Los parámetros de calidad del agua (pH, DQO, DBO, etc.) tampoco tuvieron ningún efecto estadístico sobre las características organolépticas y bioquímicas. Las diferentes alternativas de lavado (uso de agua limpia, agua reciclada, y dos lavados uno con agua recirculada y otro con agua limpia), no presentaron asociación estadística con los descriptores organolépticos (atributos positivos y malos sabores). Sin embargo, la variable de lavado mostró asociación con las variables bioquímicas y la localidad (Fraijanes y Huehuetenango). Los cuatro beneficios húmedos de café tratan las aguas

residuales, aunque ninguno cumple con el reglamento de vertido y reutilización de aguas residuales y eliminación de lodos de Guatemala. El tratamiento de aguas residuales fue eficiente al mejorar la calidad de las mismas, además que no se vierten a los cauces de los ríos, sin algún tratamiento previo.

INTRODUCTION

1.1 Background

Coffee is one of the most valuable of traded commodities and compromises about 1% of the overall value of the wor1d trade. In the year 2004/05, total world production was 6.9 million tons, valued at $ 11.2 billion. An estimated 100 million people are employed in the coffee industry, being involved in the cultivation, processing and marketing (Waller *et al*. 2007). Stanley (2009) predicts a production record for the 2009/2010 harvest of 134,356 million bags of 60 kg.

Coffee is crucial to the economies and politics of many developing countries; for many of the developing counties, exports of coffee account for more than 50 % of their foreign exchange earnings. Coffee is a traded commodity on major futures and commodity exchanges, most importantly in London and New York (ICO date unknown).

Guatemala is Central America's largest coffee producer, due partly to good extension an quality control provided by the producers association, ANACAFE. (Waller *et al*. 2007). Coffee has helped fuel the economy of Guatemala for over a hundred years and still remains one of the principal export products, accounting for 40% of all revenue generated by agricultural export (ANACAFE date unknown).

The traditional wet mill process was developed in the late XIX century, usually located in places with a high water supply flow, due to the large volumes of water needed for the coffee processing and generation of hydroelectric power for the operation. The traditional coffee wet mills use about 2000 to 3000 liters of water to process one quintal (45.36 kg) of dry parchment coffee (80 pounds of green coffee) and then the water is returned to the water body with byproducts such as coffee pulp and mucilage, contaminating water (ANACAFE 2005).

Now a day the aim is to reduce the volume of water used during the wet mill processing, therefore wet mills with adapted equipment and technology have been conceived to decrease by up to 90% the amount of water. New changes in technology are based on the reuse, use, handling and disposal of the byproducts, the optimization of water, reducing costs and the improvement of quality as a result from the processing (ANACAFE 2005).

1.2 Justification

Water is an essential element for life on the planet, but the increase in population growth and meeting human needs has led to pollution and conflicts over its use. There are several causes for the pollution of the water resource, but the most common being discharge of agro-industrial and domestic waste. This causes decrease in the water supply, deterioration of public health and the economy and damage to aquatic ecosystems and their components (Matuk *et al.* 1997).

In Guatemala the coffee production and quality have increased, it produces 60% more coffee than 30% years ago. The type of coffee has shifted away from primes to higher quality Hard Bean (HB) and Strictly Hard Bean (SHB). The country exported 3.75 million 60 kg bags in the year 2006/2007 and 83% of the exports are SHB (ANACAFE date unknown).

In Guatemala, due to the availability of the water resource there are over 5,000 coffee wet mills, allowing farmers to pulp coffee the same day to ensure quality (ANACAFE date unknown). About 70% - 75% of the wet mills are traditional and use between 2 m^3 to 3 m^3 of water to process one quintal of dry parchment coffee (46 kg bag). And 25% to 30% of the coffee wet mills are technified (avail of modern technology), which use the 0.2 m^3 to 0.15 m^3 water to process the same quintal of dry parchment coffee. These coffee wet mills can possibly avail of a wastewater treatment system (CCAD/USAID/DR-CAFTA 2009 in press).

Coffee wet processing cause's imbalances in the receiving ecosystem and its components, because the residual wastes are highly polluting by the acidity values, content of solids and chemical oxygen demand (COD). Wet mill effluents without treatment can be toxic to the ecosystem at concentrations above 300 ppm of COD (Matuk *et al* 1997). According to the NRDC (Natural Resources Defense Council), cited by Coffee (date unknown), for a period of 6 months in 1988, the wet coffee processing in Central America contaminated 110, 000 m^3 of water per day.

Wet processing of coffee can allow to obtain coffee quality such as the "Colombian washes" or other Centralamerican washes, but this process has been associated with the generation of organic pollution, affecting the water quality of water bodies. To produce one kilogram of coffee, by generating water for washing and pulping causes pollution equivalent to 5.6 people per day (Vásquez 1999).

The wet milling process of mature sound coffee cherries and the control of the equipment and conditions at each stage of the process, allows to produces good quality coffee. The washing stage of coffee in the wet milling process positively influences the production of high quality coffee and the absence of off-flavors in the cup (Puerta 1999).

The aim of this study was to analyze if the coffee quality could be affected by the quantity and quality of water used during the coffee wet milling process. To do so, 4 wet mills were visited in Guatemala in January 2010, at the peak of the harvest season; two of them were located in the department of Fraijanes and in department of Huehuetenango. The two coffee mills in Fraijanes are cooperatives and the coffee mills in Huehuetenango belong to smallholders. Also, the study established whether the oxidation ponds at the two sites studied are decontaminating and if the product of this process of treating the residual water is currently meeting the existing legislation of Guatemala.

1.3 Objectives

1.3.1 General

- Assess the quantity and quality of water in different stages of wet processing and their effect on the quality of coffee.

1.3.2 Specific objectives

- Objective 1. Describe the present wet processing methods in the two producing areas in Guatemala.
- Objective 2. Determine the volume and water quality used at different stages of wet processing and their relationship to the quality of coffee.
- Objective 3. Assess the quality of green coffee samples according to current and to alternative processing techniques.
- Objective 4. Analyze the quality of wastewater and the effectiveness of the sanitation techniques.

Hypotheses and research questions

Objective 1: Which is the water volume used in the wet mill during operation in the two producing regions of Guatemala?

¿Is there a difference between the amounts of water used in the different wet mills?

Objective 2 (Hypothesis):

- There are significant differences between coffee quality and the volume of water used in the different wet mills.

- There are significant differences between coffee quality and water quality in the coffee washing process stage.

Objective 3. Is there a difference between the current process methods and alternative processing techniques (different duration of fermentation, use of demucilager, washing methods, etc)?

Objective 4: What is the quality of wastewater at the outlet of the coffee wet mills?

What is the efficiency of treatment facility to sanitize the wastewater in the coffee wet mills?

REFERENCE FRAMEWORK

1.4 Coffee generalities

1.4.1 Origin of coffee

The origins of coffee crop can be traced to the Ethiopian highlands for *Coffea arabica* (arabica) and the forests of West and central Africa for *C. canephora* (robusta). Since the 14th century, records show that coffee has been used as a beverage in Yemen and later spread to other Middle Eastern countries. The crop was also taken to parts of Asia, Africa and South America, where it flourished in the absence of pest and diseases (Waller *et al*. 2007).

Coffee is grown presently in 60 tropical countries of the world and accounts for a significant part of the foreign exchange earnings of many. The coffee cultivation is predominantly done by smallholders. The crop is grown on over 11 million hectares worldwide. An estimated 25 million farmers depend on coffee for their livelihoods, even though smallholders often receive less than 5% of the retail value of a cup of coffee in Europe and North America. (Waller *et al*. 2007).

1.4.2 World Coffee Production

Coffee is one of the most valuable of traded commodities and comprises about 1% of the overall value of world trade. An estimated 100 million people are employed in the industry (growing, processing and marketing) and the crop is grown by approximately 25-30 million coffee farmers, the majority smallholders (Waller *et al*. 2007).

Coffee is crucial to the economies of many developing countries; for many of the world's developing countries, exports of coffee account for more than 50% of their foreign exchange earnings. Coffee is a traded commodity on major futures and commodity exchanges, most importantly in London and New York (ICO date unknown). Coffee production over the last 150 years has shown significant fluctuations, with the resulting imbalance of supply and demand causing important price variations (Waller *et al.* 2007).

Coffee production in Latin America is dominated by the world's two largest producers, Brazil and Colombia. Statistics in Latin America as a whole, therefore, are affected disproportionately by what is happening in Brazil. Since 1985, FAO statistics show that there has been a small decrease in the area of coffee planted but a small increase in production due to higher yields from improved varieties and technologies (Waller *et al.* 2007).

1.4.3 Coffee production in Guatemala

Guatemala is the largest coffee producer in Central America and 80% of the 62,500 farmers are smallholder's, accounting for 20% of annual production. Coffee is produced in many different areas in Guatemala, but mainly from the volcanic soils of San Marcos, Suchitepéquez, Quetzaltenango and Santa Rosa and from the limestone regions of Huehuetenango and Alta Verapaz (Waller *et al.* 2007). The coffee exportation in Guatemala for 2009/2010 harvest is 3,444,053 bags of 60 kg (Strictly Hard Bean (SHB) 72%; Semi Hard/Hard 12%; Prime/Extra Prime 9% and others 7%) (ANACAFE unknown date).

In Guatemala there are 270,000 hectares of coffee planted and it is grown in 20 of the country's 22 departments; 98% is shade grown and 98% is washed arabica. Crisscrossing mountain ranges alow coffee to be grown in most regions. The different geographic influences combined create more than 300 microclimates, which contribute to distinct cup profiles of each region's coffee (ANACAFE date unknown).

The finest coffe is cultivated between 1,300 and 2,000 metrs above sea level. The rainfalll in Guatemala's coffee regions is abundant and varied. Annual averages range from 88-5,000 mm, falling within a well defined rainy season. At least one abundant rain during the dry season induces the flowering that turns into coffee eight months later (ANACAFE date unknown.).

1.4.3.1 Coffee regions in Guatemala

Since the early 1990's, ANACAFE defined the country's coffee producing regions base don cup profile, climate, soil and altitude. As a result, eight distinct regions producing Strictly Hard Bean (SHB) have been identified. These coffee regions are: *Acatenango Valley*, *Antigua Coffee*, *Traditional Atitlán*, *Rainforest Cobán*, *Fraijanes Plateau*, *Highland Huehue*, *New Oriente*, *Volcanic San Marcos* (ANACAFE date unknown).

1.5 Coffee quality

1.5.1 Definition of quality

Quality has been defined by ISO 8402-1986 (cited by IIIy & Viani 1995), as "*the totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs*". Coffee quality refers to the intrinsic characteristics of the grain, namely the physical and organoleptic characteristics, which mainly affect the selling price of coffee. The coffee bean quality is influenced by the chemical composition of the coffee bean; which is determined by the genetic constitution of the species, being *C. arabica* or *C. canephora* and the variety used (Fischersworring & Robkamp 2001). The final quality of green coffee is the result of an interaction among different variables, such as varieties, soil, climate, husbandry, latitude, altitude, luminosity, harvesting, processing, etc. (Wintgens 2004).

The quality of the coffee is mainly determined by the quality potential of the cherries in the field. This potential can be revealed or ruined by the harvesting and/or processing technique but it cannot be created or boosted. Processing can however emphasize certain sensorial characteristics (De Smet 2009).

1.5.2 Physical characteristics of coffee beans

Among the physical characteristics are: size, appearance of green coffee, uniformity of size, humidity content (moisture), color of the green coffee and roasted beans, appearance and openness of the cleft of the grain (ANACAFE 2006; Fischersworring & Rosskamp 2001; CCI 1992). According to (IICA 2010), four physical parameters are assigned to a commercial batch (lot) (to determine the commercial value) of green coffee, which are humidity content, bulk density, granulometry and presence of defective beans. The defects can be imputed to field damage (genetic, environment, attacks by pests and diseases, crop management), field or process damaged beans, process damaged beans, process or storage damaged beans, and storage damaged beans.

Beans that present one of the following characteristics are considered defect beans: black, coffee berry borer (insect damage), amber bean, caracoli, stinkers, elephant bean, triangular bean, immature bean, etc. Larger amount of defective beans will increase the probability of off-flavors and lesser homogeneity in the cup, however low amounts of visible defects do not necessarily correlate with higher cup quality (Wintgens 2004).

1.5.3 Organoleptic quality

One of the most important criteria used for assessing coffee quality is based on sensory analysis and is referred to as cup quality (Franca *et al*. 2005; Feria-Morales 2002)

Cup tasting is the sensory or organoleptic analysis accepted internationally for the commercialization of coffee (Lingle 1999). Cup tasting, also known as cupping, is the method that has been and still is used as the ultimate procedure for the assessment of green coffee quality in the cup (Feria-Morales 2002).

The main goal in cup tasting is to evaluate the coffee in an objective and reproducible way and to describe the flavor profile by means of words (attributes) and values related to the intensity of each attribute. Trained tasters assess the coffee and judge it by its flavor, mouth feel and aftertaste and the basic attributes evaluated are: aroma, flavor, body and acidity (Wintgens 2004). Coffee quality is measured by its intensity and balance (Puerta 1999). The most used terms to describe the characteristics of coffee are:

- ✓ *Aroma*: the fragrance or odor perceived by the nose. There is a clear distinction between aroma and two different stages: aroma of the freshly ground coffee and the "in cup aroma" which is produced when water has been in contact with the ground coffee for 3 -4 minutes (Wintgens 2004).
- ✓ *Taste:* it is perceived by the tongue (Wintgens 2004).
- ✓ *Flavor:* it is the combination of aroma and taste. The flavor which contributes to the quality of coffee is described in terms of winey, spicy and fragrant. Off-flavors such as grassy, onion, musty, earthy. etc., reduce coffee quality. There are four basic flavors commonly used in sensory evaluation: acidity, sweetness, saltiness and bitterness. Sweetness and its interaction with acidity provide a broad spectrum of flavors for Arabica coffee but bitterness and saltiness are associated with Robusta and low-quality, dry-processed Arabica (Wintgens 2004). One of the major motivations for consumer preferences is flavor and it is the most important criterion for coffee quality evaluation (Cantergiani *et al*., 1999; Clarke, 1987 cited by Farah *et al*. 2006). Bitter

taste is a primary taste characterized by a solution of caffeine, quinine and certain alkaloids (Geel *et al*. 2005).

- ✓ *Body:* is a feeling of heaviness or richness on the tongue (Wintgens 2004).
- ✓ *Acidity:* it is a sharp and pleasing taste. It can range from sweet to fruity/citrus and is considered as a favorable attribute

1.5.4 Biochemical compounds

The biochemical composition of green coffees can be used to characterize quality (Davrieux 2004). The characteristic flavor and aroma of coffee result from a combination of hundreds of chemical compounds produced by the reactions that occur during roasting (Franca *et al*. 2005). The following biochemical compounds were used in this study:

- ✓ *Caffeine:* it is a benign chemical that is well tolerated by most people, it provides a "lift" by preventingthe normal action of substance called adenosine (Brault 2008). The average content of caffeine is 1.2% in Arabica and 2.2% in Robusta. Caffeine is a xanthine derivative that gives a bitter characteristic taste to coffee (Farah, DePaulis, Moreira, Trugo, & Martin, 2006 cited by Duarte *et al*. 2010).

- ✓ *Trigonelline:* The only minor contribution that trigonelline may make to the overall taste characteristics of the cup is due to its bitter taste, as it does not undergo complete degradation during toasting (Illy & Viani 1996). Trigonelline is a pyridine derivative known to contribute indirectly to the formation of desirable and undesirable aroma compounds during roasting (Macrae, 1985; Moreira, Trugo, & Maria, 2000 cited by Duarte *et al* 2010). Trigonelline content has also been correlated to good cup quality (Farah, Monteiro, Calado, Franca, & Trugo, 2006 cited by Duarte *et al.* 2010).

- ✓ *Proteins and amino acids:* amino acids are present in green coffee both free and bound to proteins. The free amino acids levels in the bean depend on the maturation. No correlations have been identified between composition and/or quantity of proteins and quality. The proteins consist of water-soluble (albumin) and water insoluble fraction, present in approximately equal amounts (Illy & Viani 1996).

- ✓ *Chlorogenic acids (CGA):* the coffee scientific community has agreed that the term chlorogenic acids be used to refer to the family of depesides (the esters formed by one or more aromatic acids with alcoholic hydroxyls of an alcohol-acid) of quinic acid with cinnamic, caffeic, ferulic, isoferulic and sinapic acids. The astringent taste that characterizes Robusta has been linked to its high CGA content and in particular to the feruloylquinic and dicaffeoylquinic acids. The content of CGA varies from 6 to 7% in Arabica beans and is about 10% in Robusta beans, it increases during maturation and decreases during germination (Illy & Viani 1996). Thermal degradation of chlorogenic acids will result on phenolic substances that will contribute to bitterness (Clifford, 1985 cited by Franca *et al.* 2005). Coffee beans are one of the richest dietary sources of CGA and for many consumers must be the major dietary source (Clifford 1999).

- ✓ *Lipids:* Arabica and Robusta coffees contain different levels of lipids, 0.2-0.3% present in a waxy layer surrounding and protecting the bean (Folstar et al. 1975 cited by Illy & Viani 1996).
- ✓ *Sucrose*: carbohydrates are present in green coffee both as insoluble and as soluble polysaccharides (which are polymers of mannose, galactose and glucose), with some arabinose (40-50%db), oligosaccharides (5-10% db), mainly sucrose, present in higher amounts in Arabica than Robusta and traces reducing sugars, higher in Robusta (Illy & Viani 1996). Sugars, particularly sucrose as the most abundant, will act as aroma precursors, originating several substances (furans, aldehydes, carboxylic acids, etc.) that will affect both flavor and aroma of the beverage (Farah *et al.* 2006).

1.5.5 Composition of the coffee berry

The coffee fruit looks like a cherry; therefore it is known by that name (Zuluaga 1989). In cross section of the coffee berry shows four anatomical fractions: the coffee bean proper or endosperm; the hull or endocarp; a layer of mucilage or mesocarp; and the pulp and esocarp. Each coffee bean is surrounded by a delicate spermoderm tissue known as the silver skin and is held in place by the membranous endocarp, also known as the parchment or coffee hull (Braham & Bressani 1979).

Only 6% of the weight of fresh fruit is used for the preparation of the drink, the remaining 94% is water and byproducts of the process that if not used become a source of environmental pollution (Zuluaga 1989). According to Braham and Bressani (1979), the material balance of coffee processing based on dry-weight, shows that pulp represents 28.7% of the weight of fruit, mucilage 4.9%, hulls 11.9% and 55.4% of coffee beans.

Coffee pulp is the first product obtained during processing. Representative values of the proximate chemical composition of fresh pulp, dehydrated pulp and pulp 2-3 days after being separated from the berry are given in table 1. The other byproduct of interest is mucilage; it is a colloidal liquid system and being a hydrogel it is a lyophillic. Chemically the mucilage contains water, pectins, sugars and organic acids (Table 2) Braham and Bressani (1979).

Table 1. Chemical composition (%) of coffee pulp.

	Fresh	Dehydrated	Naturally fermented and dehydrated
Moisture	76.7	12.6	7.9
Dry matter	23.3	87.4	92.1
Ether extract	0.48	2.5	2.6
Crude fiber	3.4	21.0	20.8
Crude protein	2.1	11.2	10.7
Ash	1.5	8.3	8.8
Nitrogen-free extract	15.8	44.4	49.2

Source: Braham & Bressani 1979

Table 2. Composition (%) of mucilage

Composition	%
Total pectin substances	35.8
Total sugars	45.8
Reducing sugars	30.0
Nonreducing sugars	20.0
Celluso + ash	17.0

Source: Braham & Bressani 1979

1.5.6 General principles of coffee processing

After harvesting, three different systems can be used for processing: dry-process; wet-processed and semi-dry process. Dry processing (used for almost all Robusta coffees) implies that the whole cherry is dried and later the dried pulp removed mechanically. During wet processing (used for most Arabicas and small percentage Robustas), the pulp is removed mechanically and the mucilage is removed before drying (later hulling of parchment coffee). In the semi-dry process, the mucilage is not removed after pulping and parchment with mucilage are dried together (later hulling of parchment) (Brando 2004). The final product is called green coffee (Molina 1999). In this research we will focus the wet processing, since the study was done in Guatemala were the wet mills are predominant.

1.5.6.1 Wet processing

The purpose is to remove the pulp and mucilage from the mature fruit. Over the last 25 years, the wet processing has started to evolve, first to accommodate the harvesting of cherries at different stages of maturity and then to control the damage caused to the environment. These changes caused the development and introduction of new technologies that decrease water consumption and contamination. For example, dry pulping, new types of mucilage removers, dry transport of coffee and pulp, etc. The combination of water saving and contamination control techniques is called Ecological wet milling. It has been proven that very substantial reductions in water consumption are possible without any quality loss (Brando 2004). This process must preserve intact the qualities of the grain to avoid damaging the quality and thus the assessment and pricing (Cleves & Echeverria 1998).

1.5.6.2 Harvesting, reception and sorting of the coffee

Harvesting is considered one of the most important stages in the coffee process and if only ripe cherries are harvest, it avoids problems in the following stages. Because coffee picking is not entirely accurate, undesirable types of fruit can also be harvest. These can be (ANACAFE 2005): a) immature (green): produce less weight and problems in the stages of coffee processing; b) Semi-mature: it causes problems in pulping, fermenting, washing and drying; d) over-ripe: it can stain the coffee beans and it causes uneven fermentation that can produce a defective grain; e) Vain: a coffee bean completely healthy and the other one is not (affects the yield and the coffee quality); f) Dry cherries (black cherries): are caused by fungal diseases or nutritional deficiency; g) Coffee berry borer: cherries attacked by *Hypothenemus hampei* (coffee berry borer) (it provokes low yields); h) Fruits collected from the ground: cherries that fall because of the rain and wind (it can alter the quality of the cup).

Preparing the drink with cherries which have different states of maturity causes undesirable tastes in the cup (Puerta 1999).

The *reception* of the cherries can be by weight or volume (boxes made in volumes of 100, 50, 25 pounds) and this is recorded in the respective card of the harvester. When having the weight / volume of the cherries the coffee goes into the reception tank, it can be a dry, semi dry or wet tank (ANACAFE 2005).

After the coffee reception, the coffee is sorted. The *classification (sorting)* of the cherries consists in separating different bodies of density with the use of water (ANACAFE 2005). Flotation is based on the principle that most good quality cherries and unripe cherries sink to the bottom while most off-quality cherries float. It generally occurs in a funnel-shaped tank filled with water. A pipe with a diameter of 4 to 6.5 mm, fitted in the middle of the tank and with its inlet towards the bottom of the tank, is connected to the pulper and operates as a siphon for the heavy cherries. An overflow eliminates the floaters. Soil and stones sink to the bottom beyond reach of the siphon inlet (De Smet 2009).

Floaters can be size-graded by a rotating sieve that divides them in cherries of average size (semi wet or dry processed) and small mummified cherries (dry processed). In case of regular selective picking, the majority of the floaters consist of ripe cherries that contain one defective (insect damaged or aborted) and one sound bean. Some operators remix these floaters with the sinkers followed by wet processing in order to recover the sound beans. In this case, flotation serves only to separate foreign matter and all off-quality beans have to be sorted out afterwards (De Smet 2009).

1.5.6.3 Pulping

The mature cherries are subjected to a mechanical stage which removes the pulp through a pulping machine that uses the lubricating quality of the mucilage (Cleves & Echeverria 1998a). Pulping can be done by disc, screen, drum and vertical pulpers (De Smet 2009). If this operation damages the coffee bean it will cause problems in the following phases, altering the beverage quality. It is recommended that the pulping is carried out the same day of picking, to prevent fermentation processes, heating, weight loss of the coffee and quality loss (Cleves & Echeverria 1998a). In conventional devices coffee cherries are pulped in a water flow but research has led to substantial reduction of water consumption in the pulping operation (Brando 2004).

After pulping, parchment coffee should be classified by size or density (or both) in order to separate the deformed, sick (defective), badly pulped coffee beans and pulp, but also to standardize the bean size. A high percentage of pulp in the fermentation tanks can damage the physical appearance of the coffee beans and it also causes uneven fermentation (ANACAFE 2005). A horizontal oscillating sieve or a rotating sieve is a simple and indispensable tool to separate cherries and pulp from parchment beans at the outlet of the pulper. The separated unpulped cherries, mainly of poor quality because smaller or harder than average, and the pulp can be returned to the pulper but a better solution is forwarding them to a repasser-pulper and processing the beans by the semi-wet method (De Smet 2009).

1.5.6.4 Mucilage removal

The stage that follows pulping is the mucilage removal. Mucilage is an insoluble colloidal material (hidrogel) and to remove it is necessary to solubilize it in order to eliminate by washing (Cleves 1998). The mucilage is removed to facilitate drying of parchment coffee, prevent deterioration of the coffee quality due to undesirable fermentation and also to prevent post-fermentative during sun drying or when stored on a heap (ANACAFE 2005).

Mucilage can be removed by fermentation (natural or accelerated by chemicals or enzymes) followed by washing or by strong friction in machines called mucilage removers (operate by rubbing parchment beans against the mobile and static parts of the machines). Natural fermentation is usually carried out in concrete tanks and natural fermentation may be dry (without water) or under water. Dry fermentation is faster, but more difficult to control and fermentation under water is often more homogenous (Brando 2004). Wet fermentation will improve the color and facilitates the later polishing of the beans (removal of the silver-skin). Both methods can be combined as to take advantage of both characteristics (De Smet 2009).

In both methods, the water conveying the coffee into the tanks must be completely drained; in the case of under-water fermentation the tank is then refilled with clean water (Brando 2004). Fermentation times can vary from 6 to 48 hours (Cleves 1998) or even 72 hours, depending on the temperature, the amount of mucilage and the concentration of peptic enzymes. Higher temperatures and thicker mucilage layers accelerate fermentation. Dry fermentation is faster because the peptic enzymes are not diluted and oxygenation is more intense. Coffee is held in fermentation tanks until the mucilage is completely digested and ready for washing. It is critical to stop fermentation at the right time because it avoids over-fermentation and the formation of stinkers (Brando 2004).

Mucilage removers are more efficient in terms of water consumption and can function as washers after fermentation (Brando 2004) and easier storage and treatment of a limited volume of waste water with highly concentrated mucilage (De Smet 2009). But there is still a debate over the actual impact on coffee quality caused by the elimination of natural fermentation (Brando 2004).

1.5.6.5 Washing and grading

The parchment coffee is washed to remove the remaining mucilage and loose materials during fermentation, to obtain a clean grain and not to cause problems during drying and storing and therefore undesirable flavors in the cup (ANACAFE 2005).

Washing coffee is one of the main sources of water consumption and contamination of wet processing (Brando 2004), even in case (part of) the water is recirculated and the polluting mucilage is possibly diluted in a high volume of water which renders its sanitation difficulties (De Smet 2009). Washing can be done manually in the tank itself and in channels, by centrifugal pumps or by specific machines (Brando 2004).

The washing may be combined with grading. The floating parchment beans and the floating pulp can easily be sorted out. The majority of the floating parchment beans contain defective beans though some are sound. They float because the parchment encloses a small air pocket (De Smet 2009). Grading contributes to obtain cleaner and better coffee quality. In Guatemala, the traditional wet mills use the concrete channels to classify the coffee beans, to obtain first class parchment beans, second class and "*natas*" (lighter and floating material) (ANACAFE 2005).

1.5.6.6 Drying

The wet mill process ends when it achieves to lower the coffee bean humidity to a commercial point level (10-12% green coffee beans). Drying can be done by sun drying (natural), taking advantage of the solar energy and air or using mechanically dryers (Guardiolas) (ANACAFE 2006). Sun drying is done on flat drying grounds (patios) with a slope to drain rainwater (Brando 2004). The duration of drying depends on the method used, the weather conditions, the relative humidity of the air, the thickness of the layer of cherries or parchment beans and the frequency of stirring (De Smet 2009).

1.5.6.7 Storage

Storage plays an important role in the conservation of the coffee beans. Coffee is to be stored in controlled environments so it does not deteriorate and causes defects in cup quality and undesirable defects like “old flavor” (ANACAFE 2006).

1.5.7 Ecological processing of coffee

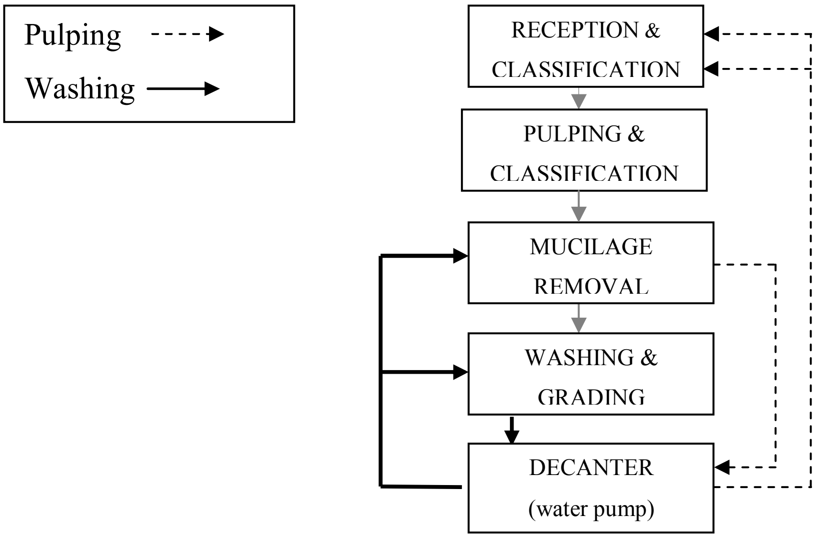
The traditional conception of wet mills hast to be changed. Today, an important objective is to minimize water consumption, to recycle the water that is used, to ensure the safe disposal of contaminated wastewater and solid byproducts while preserving coffee quality. Conventional wet-processing may consume from 20 to 100 ^{m3} of water per ton of green coffee, using less amount of water can only be achieved by recycling (Brando 2004).

Ecological wet milling should require less than 10 m^3, ideally less than 5 m^3 of water per ton green coffee. These principals should be taken into account when designing an ecological wet mill: all machines should operate with as little water possible or no water; the reception of cherries must be without water; all conveyance by gravity or by mechanical means, must be carried out without water; the contact of pulp and parchment with water must be minimized or avoided (so that soluble contaminants do not transfer to the water); and water that has to be used must be recycled as much as possible (Brando 2004).

Rodríguez (1998), comments that pulping without water, the mechanical transportation of pulp and the use of a demucilager (mechanical removal of mucilage) favors the final treatment of wastewater; reducing the contamination at least 50%. Assessments by ICAFE, (cited by Rodriguez 1998) report that pre-treatment (sieving and sedimentation) reduce the COD of the water by 30%.

1.5.7.1 Water recycling in the wet mills

According to ANACAFE (2005), water recirculation consists in returning the water from the stages of pulping and washing with a centrifugal pump (figure 1). Water recycling reduces environmental impact (it has been implemented over 35 years and has improved over time), it consists in collecting the wastewater in a tank and decanting the solids to reduce the organic load of the recycled water. Recirculation of water is a circuit system design to use little water volume in the stages of pulping and washing and grading using a pump installed in the decantation tank. By recycling, elements such as sugars, pectins and suspended solids are incorporated in the water.



Source: ANACAFE 2005

Figure 1. Diagram of recycling water in pulping and washing

Water recycling reduces water consumption and concentrates the organic loads. Recycled water can be injected into specific machines or mixed with incoming clean water. Several studies have shown that recycled water does not affect coffee quality even after several days of reuse, however, it seems that researchers and suppliers of equipment, agree that recycling of water should not exceed two days. After recycling, the wastewater must be treated or if not possible it must be retained in lagoons, seeped into the ground or used for irrigation (Brando 2004).

The recirculation of water in wet processing of coffee reduces the release of solids from the pulp up to 30% when the concentration of water is 11,000 mg/l and when it is 30,000 mg/l of COD the release of contaminants from the pulp can go down to more than 50%. The recirculation inhibits the generation of pollutants from the pulp, giving a richer pulp for later use (Vásquez 1996).

According to Vásquez (1993), recycled water from pulping that has been recirculated for 1 or 2 days, gives the coffee more acidity and aroma (all coffee samples were washed with clean water after pulping with recycled water). The variable body showed no differences between conventional practice and recirculation of water. This study was done with Caturra and Catuai.

Recirculated water for pulping ads to the parchment beans more natural sugars that produce a larger amount of bacteria that accelerate the fermentation process. When the fermentation is accelerated, the time of residence of the parchment beans is less, thus avoiding loss of volatile materials such as alcohols, essential oils and in some cases (depending on the temperature) increasing the coffee weight (6 a 8%) (Rodas 1987).

Following an investigation by Mencía *et al*. (1993), the recirculation of the washing water degrades the final quality of coffee which would result in significant percentage of damaged coffee (fermented).

1.6 Water consumption in wet processing

The volume of water used depends on the size of the siphon tank, the diameter of the siphon pipe, the machinery (i.e. drum or vertical pulper), the method for the removal of the mucilage (natural fermentation and washing, mechanically or both combined), the desired quality (i.e. graded or all-in parchment beans), the concept of the water recirculation (one or more closed circuits), the level of acceptable water pollution and hence the number of recirculation cycle, the efficiency of water sanitation and hence the volume of water available for recirculation and the prevailing mentality aiming at avoiding waste of water at all stages (De Smet 2009).

1.7 Byproducts from coffee processing

Coffee processing generates byproducts (erroneously called waste material) which, due to lack of technology, eventually end up polluting water and the local environment (Cleves 2004).

The byproducts generated during the wet mill process are *pulp*, which represents 39% of the weight of the fruit (Zuluaga 1989). Fresh pulp contains 78% water in weight (Chalarca 1987, cited by Zuluaga 1989). According to Zuluaga (1989), pulp can be used as animal feed, organic fertilizer, mushroom cultivation, and biogas.

Mucilage represents el 22% of the fresh fruit in weight (Zuluaga 1989) and 84. 2% of the weight of fresh mucilage is water (Nadal 1973, cited by Zuluaga 1989). Mucilage can be a source of pectin, animal feed, biogas (fuel), and organic fertilizer.

The *husk* has the potential to generate heat and can be used as fuel for the drying process (Rodríguez & Heinrich 1999).

1.8 Contamination caused by the coffee wet mills

Water in the wet mills acts as a principal agent and once it has been used it becomes wastewater with high organic substances (Morales 1989). The layers that wrap the coffee bean are composed of organic substances and once they start their decomposition process they become contaminant substances (Morales 1987).

Morales (1987) mentions that water is used and contaminated in the following activities: separate foreign matter by gravity in the siphon tank; transportation of the coffee cherries to the pulpers from the siphon tank; transportation of the parchment beans to the fermentation tanks, washing of parchment beans. Vasquez (1999), mentions that water is used for grading.

Cleves (1976) mentioned that the final wastewater ("*aguas mieles*") is produced by two types of water, the depulping and washing. The concentration of wastewater varies depending on the availability of water in the area (Arias & Nigiani 1987). Pollution by byproducts in wet processing of coffee is due to poor management of the water in the different operations and inadequate infrastructure (Zambrano & Zuluaga 1993).

In wet coffee processing, three pollutants are produced, *depulping water*, *washing water* and *pulp*. The *depulping water* contains a high amount of suspended solids, sugars, soluble matter and in general abundant organic matter, making it highly polluting. *Washing water* contains a large amount of coloidal gels of pectin and other products, which are less polluting substances (Morales 1987). *Pulp* can be cause pollution if discharged into water sources. The contamination from washing water is less than depulping water (Pahren and Saenz cited by Morales 1979).

Depulping water provides a pollution load of 160 g of COD per kilogram of coffee and the washing water 170 g COD (Vásquez 1996). Depending of the amount of organic waste discarded from the coffee wet mills and the content of the organic matter, it causes damage if dumped into water bodies. Depulping water and washing water causes a decreased in pH, impoverishment of dissolved oxygen, affecting aquatic life; also the turbidity by suspended solids hinders the passage of light, interfering with the photosynthetic activity (Arcilla-Otero 1979). A study done in the river basin, river Caldera, Panama by Canto (1984), comments that in the pulp and wastewater dumped into the river limited the use of water for drinking and agriculture; it also caused some health problems.

If the pulp is stored in open spaces, it allows the development and proliferation of flies due to the fermentation of sugars (Pahren & Saenz cited by Morales 1979), moisture, high temperatures and the food it provides to these insects. The decomposition of the pulp gives off an unpleasant odor and there are liquid discharges, resulting from the degradation of large amounts of accumulated solids (Morales 1979). The pulp produces a leachate with a high concentration of organic matter (Arias & Nigiani 1987).

If the depulping water has been recirculated a lot, it is highly polluting. Morales, A., cited by Echeverría & Cleves (1998b), obtained the following results (average): COD between 450 to 11,710 mg/l; suspended solids between 70 to 850 mg/l; total solids 2, 687 mg/l and a pH of 5.9. Another study by Rolz (cited by Echeverría y Cleves 1998b) found values of COD up to 28,020 mg/l. Dry pulping allows non hydraulic transportation of the pulp, which will reduce the generation of pollutants by more than 50% (Vásquez 1996). Pulping water has a higher BOD-COD than washing water, approximately 2.5 times higher, reaching values up to 30, 00 mg/l in intensely recirculated water (Echeverria & Cleves 1998b).

Mucilage has a pH in mature coffee from 5.6 to 5.75 (ANACAFE 2005), but in Antigua, Guatemala, Menchu states that the pH value reached 6 to 6.2 (Cleves 1998). Mucilage has a high organic load and to remove it from the bean water is used, which then must be treated (ANACAFE 2005). Water contact with the fruit lowers the pH to an average of 5.3 to 5.5. This acidification can be explained by the rapid dilution and diffusion of acidic and fermentable compounds that compose the pulp and mucilage (Mendoza *et al.* 1993). Table 3 is a summary on the generation and characteristics of wastewater.

Table 3. Description of the generation of wastewater and its characteristics

Operation	Use of water	Effluent characteristics
Reception and classification	Transportation agent and classification of mature cherries	Dirt from fruits and dissolved components from damaged cherries caused by transportation
Pulping and classification	Transportation agent and separation of the coffee pulp and classification of the pulped coffee (parchment beans).	Over 50% of the contamination load is generated in this process. Minimum discharge of 3 kg of COD per quintal (100 lb) of green coffee; depending of the process
Washing and grading	Removal of mucilage (natural fermentation, mechanical, chemical).	Contributes to approximately 3.4 kg of COD per quintal of green coffee in the form of suspended solids and dissolved matter in the water.
Transportation	Transportation of coffee to drying	Minimal pollution of water in this operation

Source: Rivas 2008 cited by CCAD/USAID/DR-CAFTA (2009 in press). Note: Some coffee wet mills in Central America do not use water in the reception and pulping stage of coffee, so the characteristics and volume of the effluent are different as described above (Centro Guatemalteco de Producción más Limpia 2007 cited by CCA/USAID/DR-CAFTA 2009 in press).

1.9 Characterization of residual water from coffee processing

Wastewater from coffee processing contains organic material by the characteristics of the coffee bean; pH tends to be low (which generates considerable COD) and presence of nitrogen. The organic material comes from pulping and washing, which together form the wastewater. Also, suspended solids are present in the wastewater. The constituents of these waters are a variety of biodegradable organic compounds, which have high levels of contaminants, considering the high concentrations of biochemical oxygen demand ($BDO_{5,20}$), chemical oxygen demand (COD), total suspended solids (TSS) and nitrogen (CCAD/USAID/DR-CAFTA 2009 in press). The following table 4 provides information from various sources about the characterization of depulping water and washing water.

Table 4. Characterization of residual water from coffee processing

Parameters	MORALES Costa Rica	WARD El Salvador	BRANDOM Africa	HORTON El Salvador	ROLZ El Salvador
			DEPULPING WATER (mg/l) and pH)		
Oxygen, biochemical or chemical demand	450 – 11 710 (COD)	2 360 (BDO)	7 750 (BDO)	3 280- 15 000 (BDO)	13 900 - 28 020 (COD)
pH	5.9	-	-	4.4	-
Suspended solids	70 - 850	848	-	625 – 1 055	-
Total solids	2 687	4 960	-	10 090 - 12 340	13 150 – 16 700
			WASHING WATER (mg/l and pH)		
Oxygen, biochemical or chemical demand	284 – 3 828 (COD)	1 725 (BDO)	6 040 (BDO)	295 – 3 600 (BDO)	2 900 – 10 500 (COD)
pH	5.6	-	-	4.5	-
Suspended solids	100 - 380	2 060	-	235 – 2 385	-
Total solids	532	4 260	-	885 - 3140	5 060 - 7 280

Source: Cleves & Echeverria 1998b.

The average values of the parameters $BOD_{5,\ 20}$, COD and TSS present in residual water from wet mills visited by CCAD/USAID/DR-CAFTA (2009 in press) in Guatemala and Costa Rica (Table 5).

Table 5. Parameters and average values of residual water from coffee wet mills

Parameters	Average values
Caudal	394 m^3 day
$BOD_{5,20}$ (input)	7 995 mg/ l
COD (input)	11 710 mg/ l
TSS (input)	3 285 mg/ l

Source: CCAD/USAID/DR-CAFTA 2009 in press.

Starting from the basic characterization of water discharges of coffee processing, with the high content of biodegradable organic load, both soluble and particulate, CCAD/USAID/DR-CAFTA (2009 in press) recommends the following parameters as a control:

- COD (chemical oxygen demand)
- $BOD_{5,20}$ (Biochemical oxygen demand at 5 days and 20ºC)
- Total suspended solids
- Total Kjendahl nitrogen
- pH

The CCAD/USAID/DR-CAFTA (2009 in press) takes into account the Kjeldahl nitrogen due to comments received from workshops held in this topic. The coffee process, causes the release of wastewater with organic nitrogen and ammonia (mainly by the composition of the fruit), nutrient which will contribute to eutrophication process. In this study the following parameters where used:

- *Biological oxygen demand ($BOD_{5,20}$):* it is an approximate measure of the amount of biochemically degradable organic matter present in a water sample. It is defined by the amount of oxygen required for the aerobic micro-organisms present in the sample to oxidise the organic matter to a stable inorganic form. BOD measurements are usually lower than COD measurements. Unpolluted waters typically have BOD values of 2 mg l^{-1} O_2 or less, whereas those receiving wastewaters may have values up to 10 mg l^{-1} O_2 or more, particularly near to the point of wastewater discharge (Chapman 1996). Samples of water are taken from the field and incubated in the laboratory at 20 ^{o}C for 5 days (unless specified otherwise), BOD values refer to this standard. Such values are useful in assessing stream pollution loads and for comparison purposes.

- *Chemical oxygen demand (COD):* it is a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant. The COD is widely used as a measure of the susceptibility to oxidation of the organic and inorganic materials present in water bodies and in the effluents from sewage and industrial plants. COD is a useful, rapidly measured, variable for many industrial wastes and has been in use for several decades. The concentrations of COD observed in surface waters range from 20 mg l-1 O2 or less in unpolluted waters to greater than 200 mg l^{-1} O2 in waters receiving effluents (Chapman 1996).

- *pH:* the pH of water is a negative log, base 10, of the hydrogen ion (H^+) activity in moles per liter: a pH of 7 is neutral, greater than 7 is alkaline and less than 7 represents acidic water. The pH is an indication of the balance of chemical equilibrium in water and affects the availability of certain chemicals or nutrients in water for uptake by plants. The pH of the water directly affects fish and other aquatic life, generally toxic limits are pH values less than 4.8 and grater higher than 9.2. Most freshwater fish seem to tolerate pH values from 6.5 to 8.4 and most algae cannot survive pH values higher than 8.5 (Brooks *et al.* 1991).

- *Temperature:* many physical, biological and chemical characteristics of surface water are dependent on temperature (Cech 2005). As water temperature increases, the rate of chemical reactions generally increases together with the evaporation and volatilization of substances from the water. Increased temperature also decreases the solubility of gases in water, such as O_2, CO_2, N_2, CH_4 and others. The metabolic rate of aquatic organisms is also related to temperature, and in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter (Chapman 1996).

- ✓ *Conductivity: it* is a measure of the ability of water to conduct an electric current. It is sensitive to variations in dissolved solids, mostly mineral salts. The degree to which these dissociate into ions, the amount of electrical charge on each ion, ion mobility and the temperature of the solution all have an influence on conductivity. Conductivity is expressed as microsiemens per centimetre (µS cm-1) (Chapman 1996).
- ✓ *Phosphorous:* is an essential nutrient for living organisms and exists in water bodies as both dissolved and particulate species. It is generally the limiting nutrient for algal growth and, therefore, controls the primary productivity of a water body (Chapman 1996). It originates from the weathering of igneous rocks, soil leaching, and organic matter. Problems of eutrophication often are associated with accelerated loading of phosphorus to waters that are naturally deficient in phosphorus (Brooks *et al*. 1991).
- ✓ *Nitrogen:* is essential for living organisms as an important constituent of proteins, including genetic material. Plants and micro-organisms convert inorganic nitrogen to organic forms. In the environment, inorganic nitrogen occurs in a range of oxidation states as nitrate (NO3 -) and nitrite (NO2 -), the ammonium ion (NH4 +) and molecular nitrogen (N2). It undergoes biological and non-biological transformations in the environment as part of the nitrogen cycle. The major non-biological processes involve phase transformations such as volatilization, sorption and sedimentation (Chapman 1996).
- ✓ *Total solids:* a well mixed sample is evaporated in a weighed dish and dried to constant weight in an oven at 103 to 105 ^oC. The increase in weight over that of the empty dish represents the total solids (APHA 1992).
- ✓ *Total dissolved solids:* a well mixed sample is filtered through a standard glass filter and the filtrate is evaporated to dryness in a weighed dish and dried to constant weight at 180 ^oC (APHA 1992) (Chapman 1996).

- ✓ *Total suspended solids:* a well mixed sample is filtered through a weighed standard glass-fiber filter and the residue retained on the filter is dried at a constant weight at 103 to 105 ^{o}C. The increase in weight of the filter represents the total suspended solids (APHA 1992).

1.10 Treatment Systems for residual water

The water once used in wet processing of coffee is called wastewater by its high content of organic substances and should be treated by physical-chemical methods and biological (Morales 1989). Each coffee mill, according to its location, weather conditions, processing method and types of coffee, require an adapted treatment (Cleves & Echeverria 1998c).

The assessment of the effectiveness of any wastewater treatment should be based on the difference in the quality of residual water entering the system of wastewater treatment and water quality discharged after treatment, given through measurement of physical-chemical parameters (CCAD/USAID/DR-CAFTA 2009 in press).

To calculate the efficiency (mass of pollutant removed) for each treatment system studied, using each of the control parameters considered, we use the following (CCAD/USAID/DR-CAFTA 2009 in press):

$$\text{Effectiveness} = \frac{(\text{Input data} - \text{Output data})}{\text{Input data}}$$

There is a consensus that a primary mechanical treatment, which consists of the mechanical removal of solids in suspension by filtration, centrifuging or by sedimentation, should be completed by a secondary chemical process (Cleves 2004).

Technological development has reduced the use of 120 to 150 liters per quintal of dry parchment coffee, through reengineering of the process and the establishment of wastewater treatment systems, which require the recirculation of water and, after that, the screening, neutralization, homogenization, flocculation, sedimentation, filtration and separation of clarified water and organic sludge, before being released into the respective oxidation pond. This technique allows the recovery of mucilage as sludge. The oxidation ponds are the last step of all the phases of the wastewater treatment system; in which there is a continuous decanting of the water and the "hydric standing time" is the entire time after the wet mill process is finished (ANACAFE 2005).

For the wastewater management of small coffee producers it is recommended the construction of "*estanques*" (or ponds) or "*acequias*" (hillside ditches) (can be both). This recommendation is based on the successful experience of using this system in the coffee area of the Pacific of Nicaragua and other Central American countries described in the document of PANIF (Programa Ambiental Nicaragua-Finlandia) 1998 entitled "Conceptual evaluation of technologies in wet mill coffee processing and the treatment of the wastewater ". The ponds ("*estanques*") don not represent a health threat, and have no effect on the soil and water bodies pollution; they are pits made in sandy soil without any coating on the walls and bottom of them (PANIF 1999).

Treatment of wastewater through physical structures such as oxidation ponds (and/or retention), hillside ditches with absorption wells and evacuation pipes to another place that will not cause harm to the water table, when the conditions of treatment mentioned above do not allow it. Hillside ditches with absorption wells are engineering solutions which are constructed based on a curve slope (depends on soil texture). In a clay texture the slope will be less than 1% and in sandy texture the slope is greater than 1%. The use of oxidation ponds is efficient in areas where there is high temperature, low relative humidity during harvest and an adequate soil infiltration rate (loam textures) (ANACAFE 1998, ANACAFE 2005).

The design of the ponds has to be carried out with high efficiency when there is recirculation of water during the process. It is necessary to measure the value on-site soil infiltration rate to have a baseline. Infiltration into the pond will be high at the beginning and then it will decline due to soil saturation. The water will have a horizontal movement in the areas of lower pressure areas. In addition, there is water loss by evaporation. It has been mentioned that the ponds are not efficient in some areas, due to high rainfall and soils of low infiltration capacity. The lagoons are efficient if they are associated with the use of decanters to minimize water recirculation at the beginning and end of harvest (ANACAFE 1998).

Also, the use of artificial wetlands, which have a self-recovery potential due to the presence of vegetation, soil and bacterial flora. The artificial wetlands are characterized for their simplicity with a low or minimal cost regarding the energy consumption, low waste production, low environmental impact and a good integration with the environment. The wetlands provide 3 basic functions for treating the wastewater or pre-treated wastewater: physically, they fix the contaminants in surface soil and organic matter; use and transform the elements through microorganisms and achieve treatment levels consistent with low energy consumption and maintenance. There are two systems of artificial wetlands developed for the treatment of wastewater. First, the free-flow system ("*sistema flujo libre*"), where the water level is above the ground surface, the vegetation is planted and emerges from the water surface. The water flow is mainly superficial. The treatment is produced during the circulation of the water through the stems and roots of the vegetation. Second, the subsurface flow system ("*sistema de flujo sub-superficial"*), where the water level is below the ground surface, the water flows through the bed of sand or gravel, and the roots penetrate to the bottom of the bed (ANACAFE 2005).

1.11 Water quality

A water quality standard refers to "*the physical, chemical or biological characteristics in reference to a particular use*". For example, water quality standards for irrigation are not necessarily acceptable for drinking water or certain changes in water quality due to watershed use can be acceptable for fisheries, irrigation and not for drinking (Brooks *et al*. 1991).

Each component of the hydrologic cycle (precipitation, surface water runoff, surface water and groundwater storage, evaporation) changes the quality of a water body. All humans generate waste trough the consumption of resources and the rapidly growing world population is contributing to the deterioration of the water quality. Water is considered to be polluted if it is unusable for a particular purpose (Cech 2005).

Each freshwater body has an individual pattern of physical and chemical characteristics which are determined largely by the climatic, geomorphological and geochemical conditions prevailing in the drainage basin and the underlying aquifer. The selection of variables for any water quality assessment programme depends upon the objectives of the programme (Chapman 1996).

MATERIALS AND METHODS

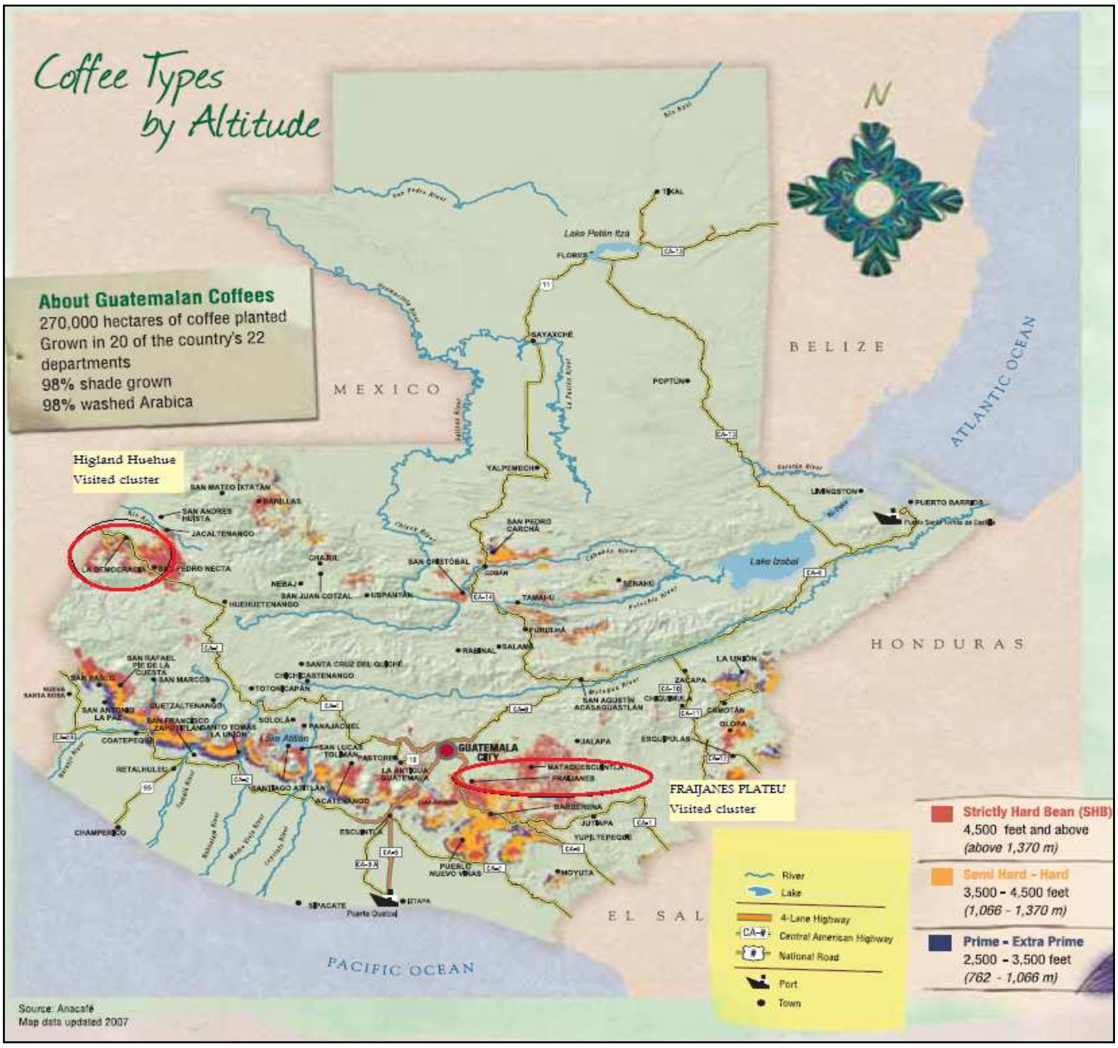
1.12 Location and general description of the area of study

This study was conducted in the departments of Santa Rosa, Jalapa and Huehuetenango, Guatemala which are traditional coffee regions. The figure 2 indicates the two clusters that were visited. Santa Rosa and Jalapa, are part of the Fraijanes Plateu region. According to ANACAFE (date unknown), this region has an average annual precipitation between 1500 y 3000 mm; an average temperature between 12 y 26 °C and a rank of relative humidity between 70 y 90%. The altitude varies between 1400 y 1800 meters. The harvest season in this zone is from December to February. The soil is volcanic with pumice.

Huehuetenago is known as the Highland Huehue region. It has an average rainfall between 1200 y 1400 mm, an average temperature between 20 y 24 °C and a relative humidity between 70 y 80%. The altitude varies between 1500 y 2000 msnm. The harvest season is from January to April. The soil is limestone. This areas remoteness requires that almost all of the coffee producers process their own coffee and also the region has a great number of rivers and streams, so the coffee mills can be located almost anywhere.

According to ANACAFE (date unknown a), the coffee production of 2008/2009 in the department of Santa Rosa was 1,227,821 qq (1qq =100 lb) green coffee (the department with the most production in Guatemala). The production in the department of Huehuetenango was 592,616 qq green coffee and Jalapa had a production of 191,096 qq green coffee.

In general, the cup profile of Guatemala according to (Wintgens 2004) is "*these Arabica coffees have a fine flavor-smoky and spicy with high acidity. The "SHB" coffees are among the best in the world-complete, full-bodied, acid and fragrant cup"*. According to ANACAFE (date unknown), the Guatemalan coffees reflect the combination of the different soils, climate patterns and high altitudes, create the regional differences. The cup profile of Fraijanes Plateu is described as "*Bright and persistent acidity. Aromatic with a defined body*" and the Highland Huehue is described as *"Fine, intense acidity with full body and pleasant wine notes."*



Adapted: ANACAFE, date unknown

Figure 2. Coffee quality distribution map in Guatemala showing the 2 regions where the study was conducted

1.13 Methodology by objective

1.13.1 Objective1. Describe the present wet processing methods in the two producing areas in Guatemala.

The two clusters (Fraijanes and Huehuetenango) were chosen by Nesspresso, since they purchase coffee from these areas and are also familiar with the wet mills. Previous to the visit of January (2010), on January of 2009 a field visit was done to five wet mills in the Fraijanes cluster with a Nestle representative, although only one wet mill was chosen for the study

(Nuevo Sendero). The other three wet mills for the study were chosen in December of 2009. Two field visits were done to Nuevo Sendero on December to observe how the wet mill functioned (coffee flow and water flow). The reason of visiting the wet mills in Fraijanes (Nuevo Sendero & Las Brisas) and Huehuetenango (El Retiro & El Jardin) was also to observe the wet coffee processing of cooperatives (Fraijanes) and smallholders (Huehuetenango).

During the field visit in all four wet mills, the description of the processing methods of the mills was done by direct observation and dialogue with the people in charge of the wet mills and workers. All wet mills were visited on January 2010; Nuevo Sendero was visited six times (12^{th} -16th and 28th); Las Brisas was visited three times (16^{th} & 18th and 28th); El Retiro was visited three times (21^{st} - 23^{rd}) and El Jardin was visited twice (25th – 26^{th}). The whole field work took three weeks.

1.13.2 Objective 2. Determine the volume and water quality used at different stages of wet processing and its relationship to the quality of coffee.

1.13.2.1 Measurement of water volume

The volume of water was calculated during every visit in the 4 wet mills. In Nuevo Sendero four measurements were made; twice in Las Brisas; twice in El Retiro and twice in El Jardín. To determine the consumption of water (clean water) and recirculation (depulping and washing water) in each coffee wet mill, the water flow was measured by determining the filling time a bucket of known volume (5 measurements were made to obtain the averages). If this was not possible because of the location (access) of the outlet tube, the volume of the recycled water tank was measured to calculate how much water was used during the coffee processing. An average volume for each process was obtained and this value was divided by the flow of coffee (volume of coffee cherries processed per unit of time), obtaining cubic meters of water used per ton of processed cherries.

1.13.2.2 Determination of daily income of cherries

For every field visit at the four wet mills, the information of the daily income of coffee cherries was provided by the wet mill after the pulping was finished each day (1 quintal=100 pounds = 45.36 kg). With this information the amount of water used to process one ton of coffee in the visited wet mills was determined.

1.13.2.3 Water quality in the coffee wet mills

For each field visit at the wet mills, several water samples were taken, the following table shows the details of the water sampling (Table 6). A total of 41 samples were taken. The water samples were collected and preserved according to the *Standard Methods for the Examination of Water and Wastewater* protocol (APHA 1992). The samples were stored and transported in an ice chest.

At the end of the day, the water samples were carefully stored so they could be taken to the laboratory the next day. The following water samples were taken in the four wet mills:

- Clean water to use as a reference
- Different stages of the coffee process (pulping, washing and grading).
- Evaporation ponds.

Table 6. Water sampling protocol in coffee wet mills.

Location	Operation	Facility	Water sample
Nuevo Sendero (Fraijanes)	Washing and grading	Recirculation tank	End first wash Middle of washing process End of washing process
(clean water comes from a well)	Pulping	Recirculation tank	End of washing=Beginning After 1 hour pulping After 3 hours pulping End of pulping
	Demucilager (2 samples coffee, fermented and freshly pulped)	End of pipe	End of processing
	Treatment of water	Evaporation pond	1 sample
Las Brisas (Fraijanes)	Washing and grading	Recirculation tank	End first wash End of washing
(clean water comes from spring)	Pulping	Recirculation tank	End of washing=Beginning After 1 hour pulping End of pulping
	Release of water into river	End of washing canal	When they considered water to be clean and released it into river.
	Treatment of water	Evaporation pond	1 sample
El Retiro (Huehuetenango)	Washing and grading	Recirculation tank	End first washing End of washing Alternative (2 washing instead 3)

(clean water comes from spring)	Pulping	Recirculation tank	End of washing=Beginning After 1 hour pulping End of pulping
	Treatment of water	Evaporation pond	2 samples
El Jardín (Huehuetenango)	Washing and grading	Recirculation tank	End first washing End of washing Alternative
(clean water comes from spring)	Pulping	Recirculation tank	End of washing=Beginning After 1 hour pulping End of pulping
	Treatment of water	Evaporation pond	1 sample

The following water parameters were examined *in situ* in the wet mills: pH, temperature and conductivity. The water samples were taken to the ANACAFE's laboratories (ANALAB), were they did the following analysis: pH, temperature, TS, TDS, TSS, COD, BOD, N total and P total.

1.13.2.4 Coffee quality (samples)

1.13.2.4.1 Control samples in wet mills

In each wet mill a control sample for coffee quality was prepared. First five subsamples were taken out of the coffee receiver; then the cherries were mixed together to make one composite sample. The sample was later weighed (10-12 kg sample of coffee cherries). After this the coffee was placed in a bucket with water and moved around with the hand. The floating cherries ("*floaters*") were removed and classified by size; this was done to imitate the use of the sieve in the wet mills in Fraijanes, Nuevo Sendero and Las Brisas. In these two wet mills they incorporate the big "floaters" and process them with the sinking cherries (good quality) and separate the small "*floaters*" to dry them and sell them for national consumption. The small "*floaters*" were weighed to calculate the % of floaters of the coffee samples. However, the smallholders in Huehuetenango removed all the floaters (big and small) with a basket and dry process them for national consumption.

After separating and removing the floaters from the control sample, the sinking cherries were pulped with a portable vertical hand pulper (PENAGOS). The control samples were fermented for 36 hours and later washed by hand with clean water and put to dry in the patios until the desired humidity was reached (12%). The workers of the wet mill handled these samples and they checked the humidity by biting a coffee bean or rubbing the parchment bean together.

After the samples were dry, they were put in plastic bags and ID with their corresponding code and then shipped to R&D Tours.

1.13.2.4.2 Diagnosis and alternatives of coffee samples in wet mills

In all the wet mills a diagnosis of the actual processing was done, the coffee samples were taken at the end of the day. These samples consisted of parchment beans collected at the outlet of the wet mill (~ 3.5 kg wet parchment). The samples were dried separately from the rest of the coffee pulped that day. The samples were dried on the patios and after they reached the desired humidity they were weighed (all coffee samples weighed 2 kg, dry parchment) and later stored in bags with their corresponding tag. All the samples were taken carefully by a worker from the wet mill. After the samples were dry they were shipped to R&D Tours.

The alternative treatments in the coffee mills consisted of trying different methods of coffee processing. The samples were fermented during different periods of time of fermentation (different to the normal number of hours). For example, a demucilager was used in Nuevo Sendero to wash the coffee after fermentation or wash directly after pulping. Meanwhile, in Huehuetenango two washes were used instead of three (recycling the second wash). The table 7 explains how each sample was taken and handled at each wet mill.

Table 7. Protocol for coffee samples.

Location	Treatment	Description	Coffee code	Sampling date
Nuevo Sendero	Control	Cherries at inlet mill. Removal of small floating cherries. Pulping by hand. 36 h dry fermentation in bucket.	FRW 01 (1 to 4)	12 to 15th January
	Diagnosis	Removal of small floaters, 12 h fermentation in tank, partly under recycled water from pulping (polluted). 1st and 2nd wash with recirculated water, 3rd with clean water. Outlet mill.	FRW 02 (1 to 4)	13/01/10
	Diagnosis	Removal of small floaters, 12 h fermentation in tank, partly under recycled water from pulping (polluted). 1st and 2nd wash with recirculated water, 3rd with clean water. Outlet mill.	FRW 03 (1 to 4)	14/01/10
	Alternative 1	Removal of small floaters, 12 h fermentation in tank, partly under recycled water from pulping (polluted). Washing by demucilager. No grading. Outlet demucilager.	FRW 04 (1 to 3)	14/01/10
	Alternative 2	Removal of small floaters. Pulping, mechanical demucilaging by demucilager. No grading. Outlet demucilager.	FRW 05 (1 to 3)	15/01/10
	Alternative 3	Removal of small floaters. Pulping, mechanical demucilaging, 12 h fermentation in bucket, washing, no grading. Outlet Demucilager	FRW 06 (1 to 2)	15/01/10
	Alternative 4	Removal of small floaters. Pulping, mechanical demucilaging, 36 h fermentation in bucket, washing, no grading. Outlet Demucilager.	FRW 07 (1 to 2)	15/01/10

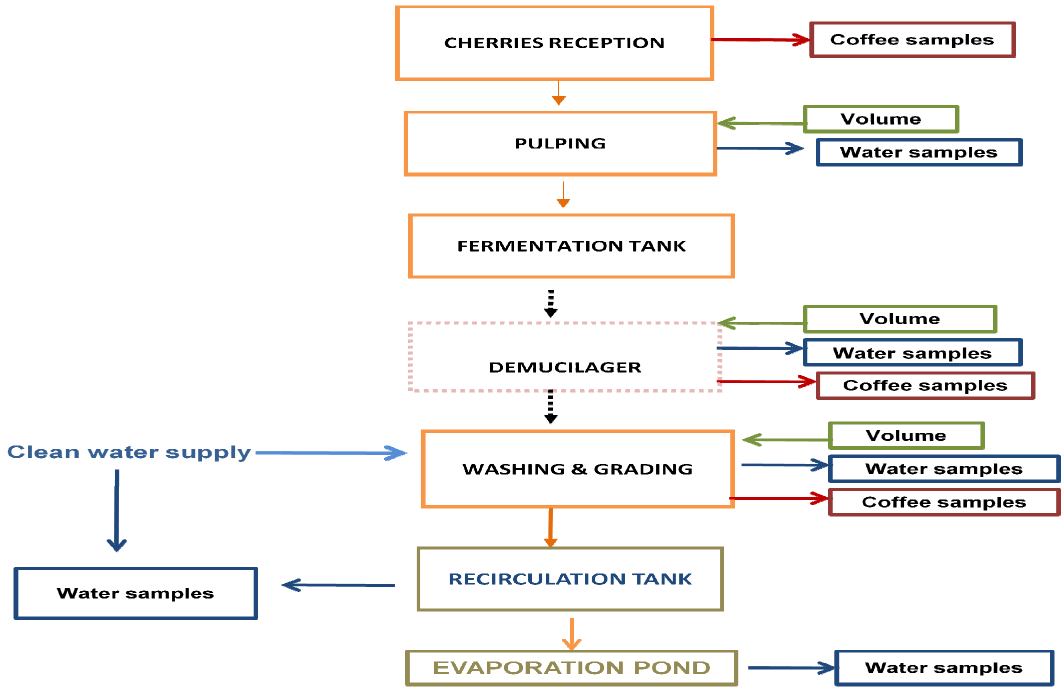
	Current production	Same as FRW 02. 2 days sun drying + mechanical drying. Samples from warehouse.	FRW 08 1 to 2)	Random
Las Brisas	Control	Cherries at inlet mill. Removal of small floating cherries. Pulping by hand. 36 h dry fermentation in bucket	FRW 10 (1 to 2)	16 & 18th January
	Diagnosis	Removal of small floaters. 24 h dry + 12 h wet fermentation in tank, washing and grading with clean water. Outlet mill	FRW 11 (1 to 2)	16/01/10
	Diagnosis	Removal of small floaters. 24 h dry + 12 h wet fermentation in tank, washing and grading with clean water. Outlet mill.	FRW 12 (1 to 2)	18//01/10
	Alternative 5	Cherries at inlet mill. Removal of small floating cherries. Pulping by hand pulper. 12 h dry fermentation.	FRW 09 (1 to 2)	16/01/10
	Current production	Same as FRW 11. Usual sun drying on floor. Samples from warehouse.	FRW 13 (1 to 2)	Random
El Retiro	Control	Cherries at inlet mill. Removal of small floating cherries. Pulping by hand. 36 h dry fermentation in bucket	HHW 02 (1 to 2)	21 & 23rd of January
	Diagnosis	Removal of floaters. 24 h dry + 12 wet h fermentation in tank. Washing and grading in clean water (3 washes). Outlet mill.	HHW 01 (1 to 2)	21/01/10
	Alternative 6	Removal of floaters. 24 h dry + 12 wet h fermentation in tank. Washing and grading in clean water (2 washes instead of 3; first wash clean water and the second wash was recycled). Outlet mill.	HHW 03 (1 to 2)	23/01/10
	Current production	Same as HHW 01. Usual sun drying on floor. Samples from warehouse.	HHW 04 (1 to 2)	Random
El Jardin	Control	Cherries at inlet mill. Removal of small floating cherries. Pulping by hand. 36 h dry fermentation in bucket	HHW 06 (1 to 2)	23 & 25 of January
	Diagnosis	Removal of floaters. 36 h dry fermentation in tank. Washing and grading in clean water (3 washes). Outlet mill.	HW 07 (1 to 2)	23/01/10
	Alternative 7	Removal of floaters. 36 h dry fermentation in tank. Washing and grading (the 1st wash was with recycled water from the last wash from the previous day; 2nd wash clean water. Outlet mill).	HHW 0 8 (1 to 2)	25/01/10
	Current production	Same as HHW 07. Usual sun drying on floor. Samples from warehouse.	HHW 05 (1 to 3)	Random

A total of 53 coffee samples were taken, but 11 samples were lost during transportation from Guatemala to the R&D Tours laboratories in France. The lost samples were (coffee code): FRW 01 1; FRW 01 3; FRW 03 1; FRW 03 2; FRW 05 3; FRW 07 2; FRW 08 1; FRW 08 2; FRW 09 1; FRW 11 2 and HHW 05 1.

1.13.2.4.3 Summary of coffee and water and sampling

The figure 3 shows the general coffee process flow of the visited wet mills and the location where the water volume measurements, water and coffee samples were taken. The visited wet mills had the inlet of clean water (clean water supply) in the washing and grading canals.

The graphic shows that that the water samples were taken during pulping, washing and grading, but actually during these processes the water sample was taken in the recirculation tank so the water sample would be homogenous and also because the accessibility to the tank.



Adapted: ANACAFE 2005

Figure 3. Location of water and coffee sampling

1.13.2.5 Analysis of the green coffee

1.13.2.5.1 Physical analysis

After the coffee samples arrived at the laboratory of Nestlé R&D Center Tours Laboratory, they were put in cloth bags and tagged with their corresponding ID (Pic. 1). The coffee samples were weighed before and after hulling. Also the percentage of humidity (moisture content), granulometry (bean size) and defects were measured.

To measure the percentage of humidity a subsample of a 100 g of green coffee was weighed and then put into the moisture analyzer (SINAR-AP 6060 Moisture Analyzer) (Pic. 2). After the percentage of humidity was measured the granulometry (bean size) of the coffee samples was determined. Different size sieves were used, No. 14 to 19 (Table 8) (Pic. 3). For each coffee sample, 3 subsamples 100 g green coffee were taken and sieved 3 times, if the coffee bean did not go through a sieve it was considered that sieve size. The coffee retained in each sieve was weighed on a digital balance (Mettler PE 600) and the percentage of each category was determined.

Table 8. Sieve diameters

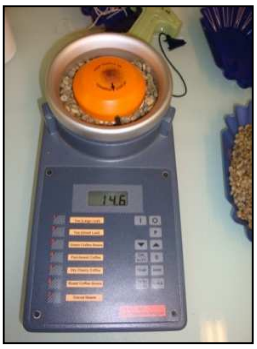
No. of Sieve[1]	**mm**
19	0.75
18	0.71
17	0.67
16	0.64
15	0.60
14	0.56

[1] n/64

Later, each coffee sample was sieved completely because the following tests in the laboratory only use coffee beans from No. sieve 16 and higher. The coffee beans under sieve No.16 were discarded.

To calculate the percentage of defects a subsample of 600 g of the coffee samples was taken. Defective beans were removed: beans damaged by coffee berry borer, elephant beans, elephant shell beans, elephant body beans, triangular beans, caracole beans, immature beans, black beans, brown beans, foxy beans and broken beans (Pic. 4). The defective beans were weighed and the percentage was calculated.

Pic. 1. Coffee samples



Pic. 2. % Humidity

Pic. 3. Sieves (granulometry)

Pic. 4. Defect beans

1.13.2.5.2 Organoleptic analysis (cupping)

The coffee samples were roasted at a determined temperature and duration according to the laboratory protocol (Pic. 5). Later the roasted coffee beans (Pic. 6) were grounded (Pic. 7) and the ground coffee was analyzed (AGTRON, model E-20 coffee roast analyzer) (Pic. 8). If the coffee samples did not have the desired value they would be roasted again until they did. Then the roasted coffee samples were ground and stored in the freezer. This procedure was done one day before each cupping session.




Pic. 5. Roasting machine Pic. 6 Roasted coffee beans Pic..7. Coffee grinder Pic. 8. Coffee roaster analyzer

The cupping was done according to R&D Tours protocol. For each cupping session, 4 professional panelists participated (Pic. 11). The cupping was completed in 5 sessions. For the organoleptic analysis a reference sample from Guatemala was cupped so the panelist had something to compare the samples to. The cupping samples were prepared from a specific weight of ground coffee (g) (Pic. 9) and hot water (ml); 4 cups were prepared for each coffee sample (Pic. 10). The attributes evaluated in the cup tasting test were: aroma, flavor, body, acidity, aromatic and off-flavors like: bitterness, green grassy, CWP (cereal, woody, paper), baggy, CMP (chemical medicinal), fermented and EMM (earthy, musty, moldy). Each coffee sample was given a quantitative and qualitative score. The evaluation scale was from 0 to 5, being 0 none and 5 the highest score.



Pic. 9. Preparation of coffee samples Pic. 10. Coffee samples Pic. 11. Cupping panel

1.13.2.5.3 Biochemical analysis

The analysis of the biochemical composition of the green coffee samples was done using Near-infrared spectroscopy (NIR) in R&D Tours (Thermo Antaris II). The green coffee left from cupping was used for this analysis. For each sample 3 scoops of green coffee were used. The biochemical compounds analyzed were: caffeine, trigonelline, total chlorogenic acids, sucrose, proteins, CTn 90, lipids, acidity and total acidity. It must be pointed out that CTn 90, aromatic and total acidity are not biochemical compounds but were analyzed using NIR. CTn 90 is a NIR predictive value of the roasting time to reach the color CTn90 and total acidity is a NIR predictive value of neutralization volume. Aromatic is NIR predictive value of the sensory score.

1.13.2.5.4 Statistical analysis

1.13.2.5.4.1. Organoleptic quality

The coffee quality was obtained by organoleptic analysis (cupping) of 36 samples of coffee and 12 variables were used to form the cup profile of each sample of coffee. These variables were used for the statistical analysis. The 12 variables were: aroma, flavor, acidity, aromatic, body (attributes) and bitter, grassy green, CWP, baggy, CMP, Ferm rank, EMM (off flavors).

To group the coffee samples according to the organoleptic variables (quality of coffee), a cluster analysis was performed. The variables used were the organoleptic variables and the criteria of classification were the coffee code of the samples. The distance used was Euclidean and the chaining method was Wards. Having identified the groups, a MANOVA test was done to assure whether the groups were really different. After identifying the organoleptic coffee groups an analysis of variance (ANOVA) was performed to determine whether there were differences between the groups, the test was multiple comparisons of Fisher Lsd. Also, a principal component analysis (PCA) was performed to classify the samples in different groups of coffee quality.

1.13.2.5.4.2. Physical quality

1.13.2.5.4.2.1 Effect of physical quality on the organoleptic quality

The bean size percentage (granulometry) of each coffee sample was used for the physical analysis. A generalized linear mixed model (GLMM) was performed to determine whether a relationship existed between the physical variables with the sensory variables. An ANOVA was also conducted between the physical quality (bean size) and the different groups of coffee quality.

1.13.2.5.4.2.2 Biochemical compounds

The biochemical compounds analyzed from the 36 coffee samples were obtained using the Near Infrared Spectroscopy (NIR). The 10 biochemical compounds were: caffeine, trigoneline, chlorogenic acids, sucrose, proteins, total acidity, and lipids. As mentioned before, CTn90, aromatic and acidity are not biochemical compounds, but NIR was used to obtain the values.

The variables used were the biochemical variables and the criterion of classification was the coffee code of the samples. The first step was to identify the number of groups of biochemical compounds by means of cluster analysis, the distance was Euclidean and the chaining Ward. Having identified the groups, a MANOVA test was done to assure whether the groups were really different. After identifying the biochemical groups an analysis of variance (ANOVA) was performed to determine whether there are differences between the groups, the test was multiple comparisons of Fisher Lsd. Conditions of normality and homosedasticity were tested. Also, a principal component analysis (PCA) was performed to classify the samples in different groups of coffee quality.

1.13.2.5.4.2.3 Relationship between organoleptic quality and biochemical compounds

A mantel matrix and simple correlation tests were performed between sensory and biochemical variables.

1.13.2.5.4.3. Effect of water volume used in the coffee wet mills on the organoleptic and biochemical variables of coffee

A Mantel test was performed to find association between the volume of water used to process one ton of coffee with the organoleptic variables (attributes and off-flavors) and biochemical components.

1.13.2.5.4.4. Effect of the water quality parameters on the organoleptic and biochemical variables of coffee

To find association between water quality and organoleptic and biochemical variables a Pearson correlation analysis was performed. The last sample was used for water quality during the wash.

1.13.3 Objective 3. Assess the quality of green coffee samples according to current and to alternative processing techniques

To meet this objective the green coffee samples were analyzed in R&D Tours laboratory as described in objective 2 (1.2.3.5 Analysis of green coffee). The current and alternative process techniques of the wet mills are explained in table 9. Diagnosis and alternatives of coffee samples in wet mills) and also the process and handling that each sample had. Since the use of water has not been mentioned during the process and handling of the coffee samples, the following table 9 shows a summary of the source of water that was used for pulping and washing for each coffee sample in each wet mill.

Table 9. Summary of the water source for pulping and washing.

Wet Mill	Coffee code	Treatment	Pulping water source[1]	Washing water source[2]
Nuevo Sendero	FRW 01 1 to 04	control	No	clean water
	FRW 02 1 to 04	diagnosis1	RW from washing	1&2 wash RW/3CW
	FRW 03 1 to 04	diagnosis2	RW from washing	1&2 wash RW/3CW
	FRW 04 1 to 03	alternative1	RW from washing	clean water
	FRW 05 1 to 04	alternative2	RW from washing	clean water
	FRW 06 1 to 02	alternative3	RW from washing	clean water
	FRW 07 1 to 02	alternative4	RW from washing	clean water
	FRW 08 1 to 02	current production	RW from washing	1&2 wash RW/3CW
Las Brisas	FRW 09 1 to 02	alternative5	No	clean water
	FRW 10 1 to 02	control	No	clean water

	FRW 11 1 to 02	diagnosis1	RW from washing	clean water
	FRW 12 1 to 02	diagnosis2	RW from washing	clean water
	FRW 13 1 to 02	current production	RW from washing	clean water
El Retiro	HHW 01 1 to 03	diagnose5	last wash RW	clean water
	HHW 02 1 to 02	control	No	clean water
	HHW 03 1 to 02	alternative6	last wash RW	2 wash RW
	HHW 04 1 to 02	current production	last wash RW	clean water
El Jardin	HHW 05 1 to 03	current production	clean water	clean water
	HHW 06 1 to 02	control	No	clean water
	HHW 07 1 to 02	diagnosis1	Last wash RW	clean water
	HHW 08 1 to 02	alternative7	last wash RW	2 wash RW

[1] no= pulping with vertical hand pulper (no use of water); *RW from washing*= recycled water from washing.

Note: *Last wash RW*= 3rd wash (last wash) was recycled for washing the coffee and later it was used for pulping.

[2] *2 wash RW*= only to washes were done and one of them was recirculated (no 3rd wash).

clean water= coffee sample washed in bucket with clean water

1&2 wash RW/3CW= recycled water of the whole washing process.

1.13.3.1.1 Statistical analysis

1.13.3.1.1.1 Effect of coffee wet processing on the organoleptic and biochemical variables

The variables of the coffee wet mill that were evaluated to see the effect on the organoleptic and biochemical variables were:

- **Equipment**: it refers to the coffee pulping machinery. A vertical pulper (does not use water) was used for processing the coffee samples (control). Horizontal pulpers were installed in the wet mills as the contrasting treatment.
- **Water for pulping (W for P)**: it refers to the source of water used for coffee pulping coffee. The water for pulping was classified in: *no water* (control samples); *RW from washing* (recycled water from washing) and *last wash* (when coffee was washed twice instead of 3 times and this water was recycled until the washing process was over).
- **Fermentation (Ferm.)**: it is the time (hours) that coffee was fermented and if the fermentation was performed by the dry or wet method. The fermentation was classified in: *12 h dry; 36 h dry; 12 h partly under polluted water; 12 h dry + 24 wet,* and *none* (no fermentation).
- **Demucilager**: it refers to the machinery used to remove the mucilage from the coffee bean. Only one wet mill had a demucilager, which was used twice, first to wash a coffee

samples *after fermentation* and second to wash the coffee samples *after pulping* (without fermentation).

- **Recycled water for washing (RW for washing)**: it is divided in *yes* and *no*; if the water was recycled (recirculation) for the washing process or not.
- **Washing**: it regards from where the water used for washing the parchment beans. The water was classified in *clean water* (only the control samples were washed with clean water); *recycled water* (1&2 wash RW/ 3CW) is water that was recirculated during the washing and grading processes; *2 wash RW* it means that two washes were done (one wash was recirculated and the other was done with clean water).

1.13.3.1.1.2 Association between the wet processing and the organoleptic and biochemical variables

Contingency and correspondence analyses were done to the wet mill process; organoleptic and biochemical variables. The variables that had significant associations were plotted using a biplot graph through a canonical correlation analysis.

1.13.4 Objective 4. Analysis the quality of wastewater and the effectiveness of the sanitation techniques

To analyze the quality of water that is released into the ecosystem, one sample of water was taken at the end of each day during the field visits. Because pulping is the last operation in the wet mill to use water, the water sample was taken at this point from the recirculation tank.

All water samples were collected and preserved according to the protocol of *Standard Methods for the Examination of Water and Wastewater* (APHA 1992). The samples were stored and transported in an ice chest.

Because only one wet mill had a wastewater treatment plant (Nuevo Sendero), it was possible to compare the wastewater at the outlet of the wet mill with the wastewater at the outlet of treatment plant (before going into the oxidation pond). Las Brisas was installing a new treatment facility; therefore they were only using the oxidation pond as a treatment method. The wet mills in Huehuetenango only had small oxidation ponds (called *"fosas"* by the smallholders) to treat their wastewater.

RESULTS AND DISCUSION

Percentage of floaters of the control samples in the 4 wet mills

The purpose of this test was to know the percentage of off-quality cherries. The majority of the floaters consisted of ripe cherries that contain one defective (insect damaged or aborted) and one sound bean (De Smet 2009). Nuevo Sendero and El Jardin have a higher percentage of floaters than the rest, although in Nuevo Sendero there is variability between samples. The following table 10 shows the percentage of floaters of the coffee samples taken.

Table 10. Percentage of floaters for coffee quality control samples

Wet mill and sampling day	Coffee code	Weight of floaters (cherries)	% of *floaters*
Nuevo Sendero (1 day)	FRW 01.1	0.7 kg / 12 kg total	5.83
Nuevo Sendero (2 day)	FRW 01.2	0.4 kg / 11 kg total	3.64
Nuevo Sendero (3 day)	FRW 01.3	0.2 kg / 10 kg total	2
Las Brisas(1 day)	FRW 010.1	0.2 kg / 10 kg total	2
Las Brisas (2 day)	FRW 010.2	0.3 kg / 10 kg total	3
El Retiro (1 day)	HHW 02.1	35.5 kg / 2038 kg total	1.74
El Retiro (2 day)	HHW 02.2	14.2 kg / 1905 kg total	0.74
El Jardin (1 day)	HHW 06.1	0.65 kg / 10 kg total	6.5
El Jardin (2 day)	HHW 06.2	0.45 kg / 10 kg total	4.5

1.14 Objective 1. Describe the present wet processing methods in the two producing areas in Guatemala

As mentioned before, 4 wet mills were visited in two harvesting areas in Guatemala. General information like number of members, cultivated area, altitude and coffee varieties was collected. The average of the daily income of cherries was measured and the volume of clean water. Also it was observed if the wet mills recirculated water for pulping and washing (Table 11). The present wet mill coffee processing methods of the 4 wet mills are described below.

Table 11. General characteristics of the visited wet mills

General characteristics	Nuevo Sendero	Las Brisas	El Retiro	El Jardín
Wet mill	Cooperative	Cooperative	Smallholder	Smallholder
Number of members	160 farmers	57 farmers	Owner	Owner
Cultivated area	300 ha	148 ha	11 ha	4.8 ha
Altitude (masl)	1200 – 1700	1400 – 1900	1700	1650

Coffee varieties	Catuai, Caturra, Bourbon and Pacas	Pache and Caturra	Pache and Caturra	Pache and Caturra
Average processed coffee (ton cherries)	35.66	7.8	1.78	0.972
Average clean water (m3)	23.9	7.2*	7.15	1.4*
Water recirculation for pulping	Yes	yes	yes	yes
Water recirculation for washing	Yes	no	no	no

*these values are not an average because it was only possible to measure the water volume for one day.

1.14.1 Cooperative Nuevo Sendero, Fraijanes

The wet mil Nuevo Sendero is located in Chapas, Nueva Santa Rosa in the department of Santa Rosa, Guatemala. This cooperative has 160 small coffee producers. The cultivated coffee area is 300 hectares, located at an altitude between 1200 – 1700 masl. The coffee varieties grown in Nuevo Sendero are Catuai, Caturra, Bourbon and Pacas. The harvest season is from December to March.

Coffee flow

The coffee started arriving in Nuevo Sendero from noon to late afternoon (Pic. 12). Some coffee producers have their farms as far as 4 hours away. Pulping started between 3 and 5 pm (it all depended on how much coffee they had to start working) and finished around 11:30 - 12:00 pm. The coffee producers weighed their coffee on the spot (Pic. 13); the workers then pour the coffee in the reception tank (Pic. 14). The coffee was transported by water to the siphon tank and then into to the 4 pulpers. The following figure 4 indicates the coffee process from the reception until drying.

Pic. 12. Producers taking coffee to wet mill

Pic. 13. Producer weighing coffee

Pic. 14. Reception tank

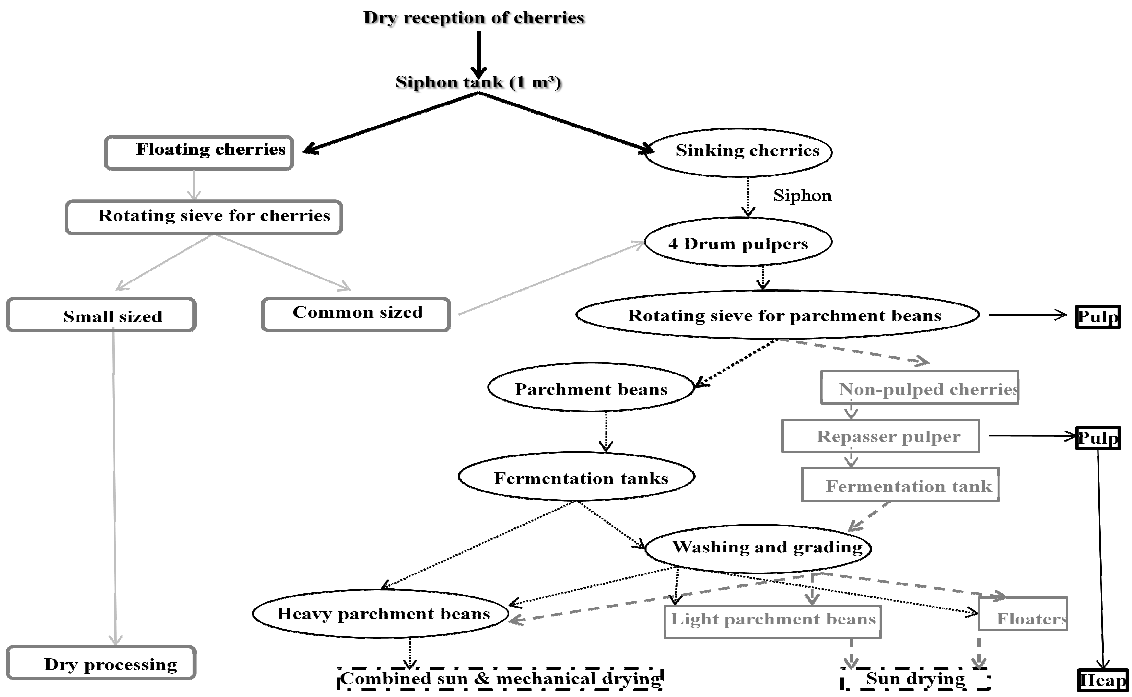


Figure 4. Diagram of coffee processing in the wet mill Nuevo Sendero

1.14.1.1.1 Pulping

Pulping is done with the recycled water from washing during the morning (figure 18); there is no consumption of clean water for this process. Water is used in the siphon to classify the cherries (heavy beans and floaters) and to transport the cherries to the pulpers, sieve and to the fermentation tanks. The pulp is transported to a faraway sieve that separates the pulp and water, the water is pumped back to the system to keep pulping. The pulp is left on a heap; it is used to do vermicompost or it is collected by small producers to make fertilizer for their coffee plantations. When pulping is finished the wastewater is sent to the decantation tank to be treated.

1.14.1.1.2 Washing and grading

The day started with washing and grading of the parchment beans that were pulped the previous day. The coffee was transported from the fermentation tanks after about 12 hours of fermentation (workers commented is it dry method but the next day it was observed that the parchment coffee was partly under polluted water because the tanks filled up slowly during fermentation with liquefied mucilage; the drain of the tanks could maybe be obstructed) (Pic. 15) to the washing and grading channels. The washing consisted of moving the coffee around with wooden paddles for approximately 20 minutes (Pic. 16). The transportation of coffee from the tanks to the channel is done with the help of a pump (water is pumped; the beans are transported by gravity), and the first tank started with clean water but later this water was recycled (in a small recirculation tank) for the transportation to the channels and the first wash in the channels. The transfer of the beans of other fermentation tanks to the washing channel and 1st wash was done with recirculated water from the 2nd and 3 washes of the previous tank (clean water was added when necessary).

Each fermentation tank was washed three times in the channels. After the first wash the recycled water is possibly partly used for the second wash (half of the first wash is disposed and clean water is injected) or it is directed to the big recirculation tank if thought it is to dirty to be used later in the day for pulping. The second wash started with clean water in the washing/grading channels or part of the recycled water of the first wash to which clean water was added; this water was recycled during washing in a small recirculation tank; at the end of the second wash the water was stored in the small recirculation tank and used for the first wash of the next cycle. The third wash (last wash of a washing cycle) is done with clean water (quick wash with little volume of water). At the end the beans are transported to drying area by a pump. The water from the third wash is stored in the small recirculation with water from the previous wash to start the first wash of the next cycle. This is done until all the fermentation tanks are washed and graded. The total volume of water used for washing is stored in the big recirculation tank for pulping in the afternoon (Pic. 17).



Pic. 15. Fermentation tank Pic. 16. Washing in channels Pic. 17. Large recirculation tank (water for pulping)

1.14.1.1.3 Water flow

In Nuevo Sendero the consumption of clean water is done during the washing and grading process. The pulping process uses the water from washing, so there is no consumption of clean water during this process (recirculation). The following diagram (Fig. 5) indicates how the water is used in each process.

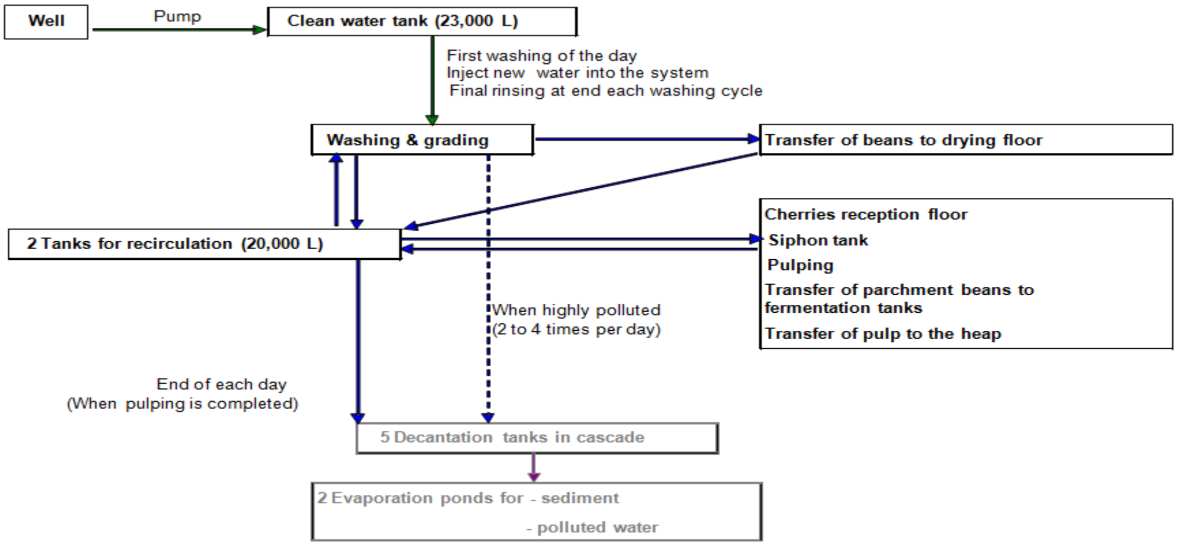


Figure 5. Water flow in wet mill Nuevo Sendero

1.14.2 Cooperative Las Brisas

The coffee wet mill Las Brisas, is located Mataquescuintla, Aldea Los Magueyes, in the department of Jalapa, Guatemala. This cooperative has 57 small coffee producers. The cultivated coffee area is 148 hectares and is located between 1400 – 1900 masl. The coffee varieties grown here are Pache (70%) and Caturra (30%). The harvest season is from December to March.

Coffee flow

The coffee flow is similar to Nuevo Sendero (Figure 4) with the exception that the cherries are pumped to the siphon and there is only one big pulper. The coffee beans are exclusively sun dried (Pic. 18). They do not process as much coffee as Nuevo Sendero.

Pulping

Pulping is done with the recycled water from washing during the morning; there is no consumption of clean water for this process (Pic. 19). Water is used in the siphon to classify the cherries (heavy beans and floaters) and to transport the cherries to the pulper, sieve and to the fermentation tanks. The pulp is transported to a heap by a screw conveyor by the recirculated water for pulping. The pulp is used for vermicompost or it is collected by small producers to make fertilizer for their coffee plantations. When pulping is finished the wastewater is send to the evaporation pond. New water treatment facilities were being installed during the visit.

Washing and grading

The day started with washing and grading of the parchment beans that were pulped the day before yesterday. The coffee was transported from the fermentation tanks (after about 24 hours dry fermentation + 12 hours wet fermentation) (fermentation methods can vary, they also do 36 hours dry fermentation) to the washing and grading channels. In Las Brisas they do not recycle the water for washing, each time they wash the coffee they use clean water. The washing consisted in moving the coffee around with wooden paddles in the channels.

In Las Brisas they had clean water flowing during the washing process. The washing water from the beginning (which looked dirty) was sent to a tank that overflowed into the evaporation pond. But during the end of washing the workers would send the water into a river (when they taught it was not too polluted or looked to dirty).



Pic. 18. Drying area Pic. 19. .Recirculation tank Pic. 20. Water tank with clean water

Water flow

The water used in Las Brisas comes from a spring; this water is stored in a 14 000 liter tank (Pic. 20). This water goes to a smaller tank by gravity; it is not only used for coffee processing but also for the villager's consumption. The consumption of clean water is done during the washing and grading process. The pulping process uses the water from washing, so there is no consumption of clean water during this process (recirculation). The figure 6 indicates how the water is used in each process.

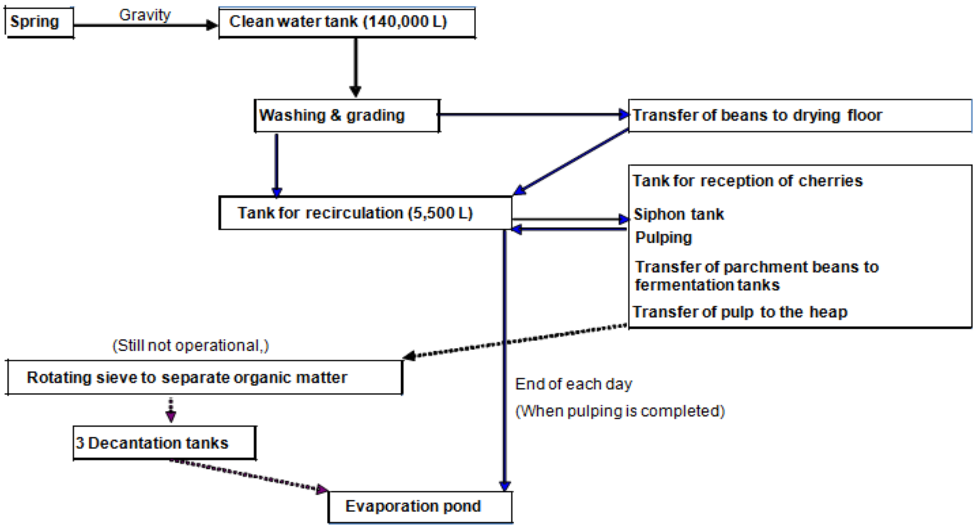


Figure 6. Water flow of Cooperative Las Brisas.

1.14.3 Farm El Retiro

The farm El Retiro is located in the village of Vista Hermosa, La Democracia, in the department of Huehuetenango, Guatemala. The farm is owned by a smallholder who is part of the "ADESH" association. The cultivated coffee area is 11 hectares and is located at 1700 masl. The coffee varieties grown on the farm are Pache and Caturra. The harvest season is from January to April.

1.14.3.1.1 Coffee flow

The visited farm does not manage large volumes of coffee. During the visit there were only three people who managed the wet mill, the owner and a worker. If they process more coffee than the capacity of the fermentation tank (only one) they would put the pulped coffee in big plastic containers. The pulp is also transported manually with a wheelbarrow; it is used as a fertilizer in the farm. The following figure (Fig. 7) shows the coffee flow of the wet mill.

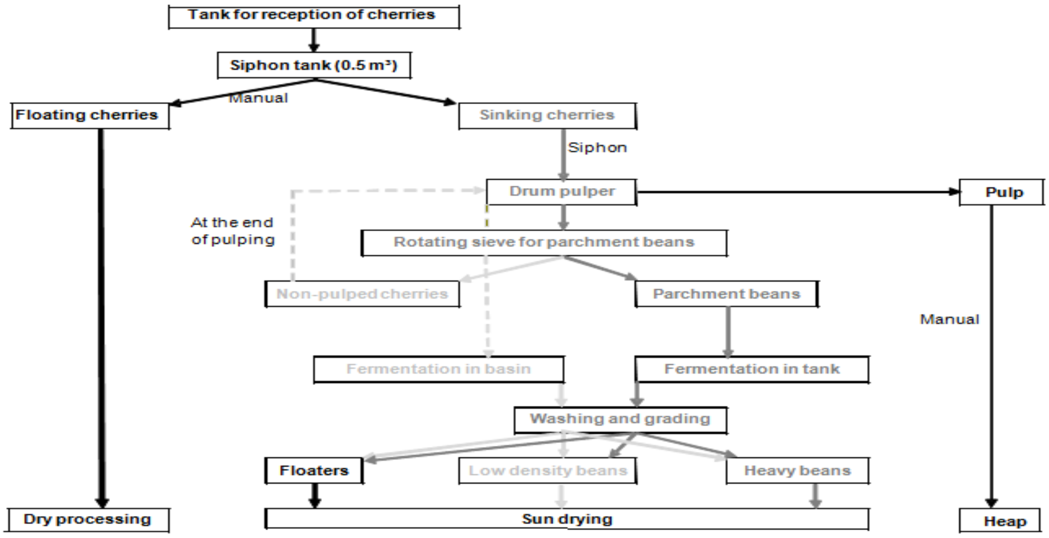


Figure 7. Coffee flow in the Farm El Retiro

1.14.3.1.2 Pulping

Pulping is done with the recycled water from the last wash from the morning; there is no consumption of clean water for this process. Water is used in the siphon to classify the cherries (heavy beans and floaters) and to transport the cherries to the pulper, sieve and to the fermentation tanks. When pulping is finished the wastewater is send to a small evaporation pond; there are two, the first one overflows into the second one.

1.14.3.1.3 Washing and grading

The day started with washing and grading of the parchment beans that were pulped the day before yesterday. In Farm El Retiro (Pic. 21), they washed the coffee 3 times (sometimes twice) and they do not recycle the water for washing, each time they wash they use clean water. During the visit, the first and second wash was done in the fermentation tanks (after 24 hours dry fermentation + 12 hours wet fermentation) (fermentation can vary, can be 36 hour dry); they remove the floaters with a basket in the tank (Pic. 22). The water from the second wash is used to transport the coffee from the tanks to the washing channels. The third wash and grading (Pic. 23) is done in the channel. The washing consisted in moving the coffee around with wooden paddles. The water from the first and second wash is send to a tank that overflowed into the evaporation pond. The water for pulping is also send into the evaporation pond.

Pic. 21. Smallholders wet mill

Pic. 22. Removing floaters with basket

Pic. 23. Coffee washing and grading

1.14.3.1.4 Water flow

The water used in Las Brisas comes from a spring and it is stored in a tank. This water goes to the wet mill by gravity. The consumption of clean water is done during the washing and grading process. The pulping process uses the water from washing, so there is no consumption of clean water during this process (recirculation). The figure 8 indicates how the water is used in each process.

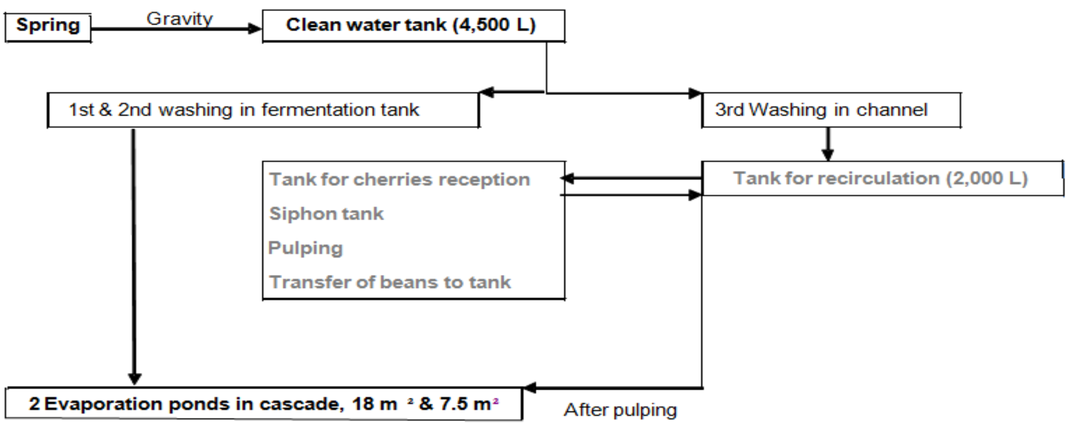


Figure 8. Water flow in coffee processing in the wet mill of the Farm Retiro

1.14.4 Farm El Jardín

The farm El Jardin is located in the village Vista Hermosa, La Democracia, in the department of Huehuetenango, Guatemala. The farm is owned by a smallholder who is part of the "ADESH" association. The cultivated coffee area is 4.8 hectares and is located at altitude is 1650 masl. The coffee varieties grown on the farm are Pache and Caturra. The harvest season is from January to April.

1.14.4.1.1 *Coffee flow*

The visited farm does not manage large volumes of coffee. During the visit only two workers were managing the wet mill (Pic. 24). The floaters are removed manually in the small tank with a basket and are put to dry on the patio (Pic. 25). The pulp is transported manually with a wheelbarrow; and used as a fertilizer in the farm. The figure 9 shows El Jardin's coffee flow.

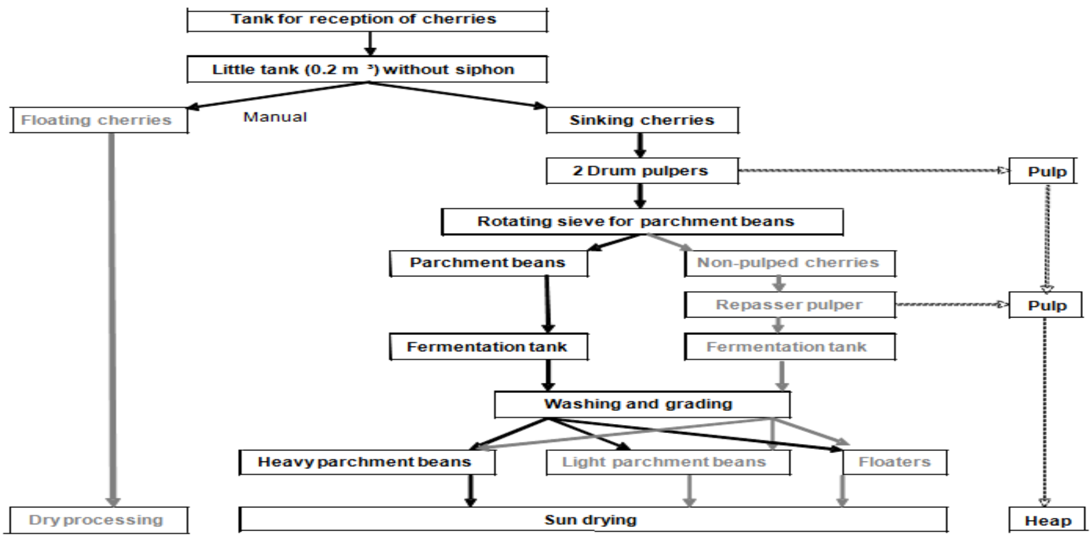


Figure 9. Coffee flow in the Farm El Jardin

1.14.4.1.2 *Pulping*

During the visit pulping was done with the recycled water from the second and third wash or just the third wash from the morning; there is no consumption of clean water for this process. Water is used in the small tank to classify the cherries (heavy beans and floaters) and to transport the cherries to the two pulpers, sieve and to the fermentation tanks. When pulping is finished the wastewater is send to a small evaporation pond.

1.14.4.1.3 *Washing and grading*

The day started with washing and grading of the parchment beans that were pulped the day before yesterday. In El Jardin they washed the coffee 2 to 3 times. During the visit, the first wash was done in the fermentation tank (about 36 hours of dry fermentation) with water used in the pulping process from the previous day or with water from the last wash; this recycled water is stored in the recirculation tank. After the first wash they use the recycled water to transport the parchment coffee to the channels. The second and third wash was done in the channels with clean water. The washing consisted in moving the coffee around with wooden paddles. The water from the first wash is send to the evaporation pond.

1.14.4.1.4 Water flow

The water used in El Jardin comes from a spring and it is stored in a tank. The water comes by gravity into the farm. The consumption of clean water is done during the washing and grading process. The pulping process uses the water from pulping or washing, so there is no consumption of clean water during this process (recirculation) (Pic. 26.). The figure 10 indicates how the water is used in each process.

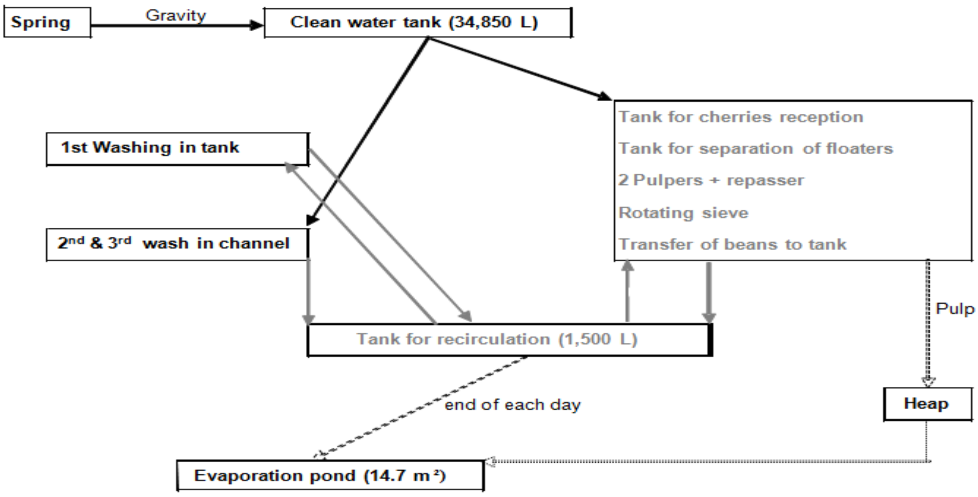


Figure 10. Water flow in coffee processing in the wet mill of the Farm El Jardín

Pic. 24. Wet mill

Pic. 25. “Floaters” sun drying

Pic. 26. Recirculation tank

Discussion

The coffee process (coffee flow) in the four wet mills is similar, although the Fraijanes wet mills process a lot more coffee volume than the Huehuetenango’s wet mills. All of them process their coffee in the same way: reception tanks, siphon tank (except El Jardin), sieving (except the 2 Smallholders), pulping by horizontal drum pulper, removal of mucilage by natural fermentation and washing and grading in channels. There is not a standard procedure in the coffee processing and water usage in the visited wet mills. Each day they adapt it to the work load, depending on the volume of coffee to be processed, availability of clean water, level of pollution of recycled water (Nuevo Sendero) and availability of the drying area. The cooperatives, Nuevo Sendero and Las Brisas have more workers than the smallholders El Retiro and El Jardin (2-3 workers in wet mill).

The two wet mills from Fraijanes (Nuevo Sendero and Las Brisas), incorporate part of the floaters (big cherries) back into the coffee process but the smallholders do not; off-quality cherries are graded out. In the wet mills the parchment bean is washed when the mucilage has completely liquefied (they test it by rubbing some beans by hand), however in Nuevo Sendero this did not sometimes occur because of the lack of fermentation tanks and because in the afternoon they pulp. The duration of fermentation is flexible in the wet mills (if they think fermentation is not done they would ferment for longer periods; wash coffee before time if they thought it was done; combine dry and wet method, etc).

The four wet mills separated the heavy parchment beans, low density beans and floaters and would refer at it as “first quality”, “second quality” and “*bolita*”. The first quality would be for exportation purposes and the sun dried cherries (“*bolita*”) would be sold for national consumption.

All wet mills recycle water; however, Nuevo Sendero is the only wet mill that recirculates water for pulping and washing. Las Brisas used to recycle water for washing, but had some quality problems and received advice not to so. Therefore, there is more consumption of clean water in these three wet mills.

The other three wet mills only recirculate water for pulping. In Huehuetenango, the smallholders commented that they fear that contact of parchment beans with polluted water during washing would have negative impact on the coffee quality. One of them also commented that in that area only 6 wet mills out of 70 have recirculation facilities (tank, pump and pipes). If this is true, it means that the wastewater is released into the ecosystem without any prior treatment. They also commented that the surrounding population has complained about this problem.

As mentioned before, all the visited wet mills recirculate water for pulping. Nuevo Sendero and Las Brisas use all the washing water from the morning for pulping but El Retiro and El Jardin only use the last washing water for pulping. The recycled water for pulping in all wet mills was used to transport the cherries from the reception tank, to the siphon tank, for pulping, to the fermentation tanks and also to transfer the pulp to the heap; only Nuevo Sendero and Las Brisas would transport pulp with water, Las Brisas had a conveyance screw and El Retiro and El Jardin, would do it manually.

1.15 Objective 2. Determine the volume and water quality used at different stages of the wet mill processing and its relationship to the quality of coffee

1.15.1 Measurement of water volume, daily income of cherries and water quality of the coffee wet mills.

1.15.1.1 Cooperative Nuevo Sendero

1.15.1.1.1 Water volume and daily income of cherries

Each day the coffee and water volume were measured to calculate how much water was needed to process one ton of green coffee (m^3/ton) (Table 12). During the visits to Nuevo Sendero, the average amount of coffee cherries processed was 35.5 tons. The range of clean water for washing was between 11 – 33.5 cubic meters. The average consumption of water was 0.67 cubic meters for one ton of coffee cherries and 3.99 m^3/ ton of green coffee.

Table 12. Coffee and water volume used during the coffee processing in the cooperative Nuevo Sendero

Working date	Coffee volume (ton cherries)	Clean water volume for washing (m^3)	Clean water/cherries (m^3/ton)	Clean water/green coffee* (m^3/ton)	Water/green coffee (m^3/qq)**
12/01/2010	28.8	11	0.38	2.29	0.104
13/01/2010	41.0	20	0.49	2.93	0.133
14/01/2010	34.4	31.1	0.90	5.42	0.246
15/01/2010	37.6	33.5	0.89	5.35	0.243
Average	**35.5**	**23.9**	**0.67**	**3.99**	**0.1815**

Recirculated water for washing (m^3)	Washing (m^3/ton cherries)	Washing (m^3/ton green coffee)
27.50	0.95	5.7
50.0	1.22	7.32
77.75	2.26	13.56
83.75	2.23	13.38
59.75	**1.67**	**9.90**

*Cherries/green coffee: 6/1 ; ** 1 qq (quintal) = 100 pounds= 45.36 kg

Working date	Coffee volume (ton cherries)	Recirculated water for pulping (m^3)	Pulping (m^3/ton cherries)	Pulping (m^3/ton green coffee)
12/01/2010	40.99	149. 10	3.64	21.89
13/01/2010	34.43	160.44	4.66	27.95
14/01/2010	37.56	121.55	3.24	19.42
15/01/2010	29.67	145.86	4.91	29.49
Average	**35.66**	**144.24**	**4.11**	**24.67**

The third day of work (14/01/10) the workers had some technical problems during the washing, making them use more water, however, during the fourth day the water consumption was almost the same. The water consumption in Nuevo Sendero depends entirely of the workers; they decide when to pump clean water into the system and when to dispose of it.

1.15.1.1.2 Water quality for washing and pulping

Washing and grading

The values of the water parameters for washing are showed first because coffee processing starts with the washing process (the coffee pulped the previous day is washed in the morning). The water samples of the first day of sampling indicate that the pH decreases from 6.84 (initial quality) to 4.1 during the first wash and remains approximately the same, pH 4.2, for the second and last wash. The water parameters of the first wash (T.S; T.D.S; T.S.S; C.O.D; .B.O.D; N total; P total) are higher during the first wash also (Table 13). The sample of the first wash of the first fermentation tank was taken in the small recirculation tank at the end of the first wash. The first wash was disposed of when they finished. For this sample approximately 750 kg equivalent dry parchment was washed. The second water sample was taken after washing approximately 3750 kg equivalent dry parchment. Clean water was injected during the process when needed. The third sample was taken at the end of the entire washing process.

Table 13. Water quality from the first day of sampling of washing and grading in the coffee wet mill Nuevo Sendero, (13/01/10)

Water quality parameters	Initial water quality	Water quality of 1st sample	Water quality of 2nd sample	Water quality end of washing
pH	6.84	4.1	4.2	4.2
Temp C^0	20.1	18.6	18.4	18.3
T.S (mg/l)	-	12 800	10 000	10 400
T.D.S (mg/l)	-	5 400	3 600	3 800
T.S.S (mg/l)	3.75	7 400	6 400	6 600
C.O.D (mg/l)	0.25	18 705	12 485	12 995
B.O.D (mg/l)	17	21 505	12 168	13 953
N total (ppm)	<6	350	259	273
P total (ppm)	0.4	29.90	22	22.50

The first water sample was taken at the end of first wash of the first fermentation tank; when it was finish it was disposed of. For this sample approximately 1500 kg equivalent dry parchment was washed. The second sample was taken after washing approximately 3750 kg equivalent dry parchment and the third sample taken at the end of the washing process. The water samples of the second day of sampling indicate that the pH decreases from 6.84 to 4.05 during the first water sample and remains approximately the same, for the second and last water sample. The water parameters of the first wash (T.S; T.D.S; P total) are higher during the first wash also. However, the S.T.S parameter is lower in the first wash than the second and last (Table 14). The B.O.D and C.O.D are higher during the second wash than the first and last wash. Maybe one of the reasons the values are higher during the second wash is because there were technical problems with the recirculation that day, causing the first wash to get mixed up with the second wash.

Table 14. Water quality from the second day of sampling of washing and grading in the coffee wet mill Nuevo Sendero, (14/01/10)

Water quality parameters	Initial water quality	Water quality of 1st sample	Water quality of 2nd sample	Water quality of 3rd sample
pH	6.84	4.05	4.08	4.26
Temp C^0	20.1	18.6	24	24.1
Conductivity (mV)	-	156.2	158.9	159
T.S (mg/l)	-	15 000	14 800	14 800
T.D.S (mg/l)	3.75	5 400	4 200	3 600
T.S.S (mg/l)	0.25	9 600	10 600	11 200
C.O.D (mg/l)	17	22 710	24 240	22 578
B.O.D (mg/l)	<6	20 997	26 058	23 124
N total (ppm)	0.4	427	343	455
P total (ppm)	0.17	19.50	38.50	41.50

For the third day of sampling the first sample was taken at the end of the first wash but the water was not immediately dispose of. For this sample approximately 1500 kg equivalent dry parchment was washed. The workers said the water was not too contaminated, so they only disposed half of it and put clean water for the next wash. The second sample was taken after washing approximately 4500 kg equivalent dry parchment. This was the last sample of the day; the other tanks were no washed because the rest of the coffee was not ready (did not reach desired fermentation point). The water samples of the third day of sampling indicate that the pH decreases from 6.84 to 4.07 during the first wash and remains approximately the same, for the second and last wash. The water parameters of the second wash are higher than the first wash (T.S; T.D.S; C.O.D; B.O.D; P total), perhaps because the second wash had water from the first wash (first wash was not disposed of). However, the N total was higher for the first wash (Table 15).

Table 15. Water quality from the third day of sampling of washing and grading in the coffee wet mill Nuevo Sendero, (15/01/10)

Water quality parameters	**Initial water quality**	**Water quality of the 1st sample**	**Water quality of the 2nd sample**
pH	6.84	4.13	4.07
Temp C^0	20.1	23.4	25.4
Conductivity (mV)	-	154.8	160.2
T.S (mg/l)	-	11 200	13 800
T.D.S (mg/l)	3.75	4 400	5 000
T.S.S (mg/l)	0.25	6 800	8 800
C.O.D (mg/l)	17	12 510	19 264
B.O.D (mg/l)	<6	12 187	18 297
N total (ppm)	0.4	357	420
P total (ppm)	0.17	33.08	35.14

Pulping

During the pulping process the water pH decreases from 4.2 to 4.02 at the end of pulping. At the end of pulping the water parameters have increased (T.S; T.D.S; C.O.D; N total; P total), being C.O.D the parameter that has increased more, however B.O.D was lower at the end of pulping than the first and second wash (table 16).

Table 16. Water quality of the first day of pulping in Nuevo Sendero (13/01/10)

Water quality parameters	**Initial water quality***	**After one hour of pulping (4:50 pm)**	**After 3 hours of pulping (7:50 pm)**	**End of pulping (11:30 pm)**
pH	4.2	4.1	4.2	4.02
Temp C^0	18.3	18.8	21.1	20.4
Conductivity (mV)	-	-	-	150.1
T.S (mg/l)	10 400	12 600	18 200	24 800
T.D.S (mg/l)	3 800	4 200	7 000	10 800
T.S.S (mg/l)	6 600	8 400	11 200	14 000
C.O.D (mg/l)	12 995	19 505	28 524	37 670
B.O.D (mg/l)	13 953	21 937	33 511	12 226
N total (ppm)	273	336	301	511
P total (ppm)	22.50	30	42.50	39.50

* This initial water for pulping is the same water from the end of washing.

The second day of sampling the water pH decreases from 4.26 to 3.06 during the second wash and goes up to 4.02 at the end of pulping. At the end of pulping all the water parameters have increased considerably (table 17).

Table 17. Water quality of the second day of pulping in Nuevo Sendero (14/01/10)

Water quality parameters	**Initial water quality***	**After one hour of pulping (5:43 pm)**	**After 3 hours of pulping (8:43 pm)**	**End of pulping (11: 48 pm)**
pH	4.26	3.9	3.6	4.02
Temp C^0	24.1	16.7	17.2	25.2
Conductivity (mV)	159	-	-	162.8
T.S (mg/l)	14 800	21 400	28 200	35 200
T.D.S (mg/l)	3 600	7 200	11 000	14 000
T.S.S (mg/l)	11 200	14 200	17 200	21 200
C.O.D (mg/l)	22 578	25 648	44 030	45 213
B.O.D (mg/l)	23 124	30 768	51 723	54 240
N total (ppm)	455	476	469	595
P total (ppm)	41.50	49.22	61.26	63.80

* This initial water is the water from the end of washing.

For the third day of pulping, the pH of the water decreases from 4.07 to 3.6 at the end of pulping, but for the first and second wash pH is between 4.2 and 4.4. At the end of pulping all the water parameters have increased considerably (table 18).

Table 18. Water quality of the third day of pulping in the cooperative, Nuevo Sendero (15/01/10)

Water quality parameters	Initial water quality*	After one hour of pulping (4:40 pm)	After 3 hours of pulping (7:40 pm)	End of pulping (11: 57 pm)
pH	4.07	4.26	4.4	3.6
Temp C^0	25.4	25.5	17.1	17.2
Conductivity (mV)	160.2	149.3	-	-
T.S (mg/l)	13 800	12 000	24 800	31 200
T.D.S (mg/l)	5 000	4 000	6 600	11 800
T.S.S (mg/l)	8 800	8 000	18 200	19 400
C.O.D (mg/l)	19 264	10 020	28 200	43 729
B.O.D (mg/l)	18 297	11 773	35 010	53 557
N total (ppm)	420	476	315.00	609
P total (ppm)	35.14	49.46	28.90	23.80

* This initial water is the same water from the end of washing.

1.15.1.2 Cooperative Las Brisas

1.15.1.2.1 Water volume and daily income of cherries

During the visit the average amount of processed coffee was 7.8 tons. It was only possible to measure water volume for one day. The consumption of clean water consumption was 7.2 cubic meters, so the volume of water used to process one ton of cherries was 1.26 m^3/ton and 7.56 m^3/ton green coffee. The water consumption of clean water is only done for washing and grading of coffee (Table 19).

Table 19. Water and coffee volume used in Cooperative Las Brisas

Working date	Coffee (ton cherries)	Clean water (m^3)	Water/cherries (m^3/ton)	Water/ green coffee (m^3/ton)*	Water/green coffee (m^3/qq)**	Water recirculation Washing (m3/ton)	Water recirculation Pulping (m3/ton)
16/01/10	5.707	7.2	1.26	7.56	0.342	-	0.2397
18/01/10	9.892	-	-	-	-	-	-
Average	**7.8**	**7.2**	**1.26**	**7.56**	**0.342**	**-**	**0.2397**

*Cherries/green coffee: 6/1; ** 1 qq (quintal) = 100 pounds= 45.36 kg

1.15.1.2.2 Water quality for washing and pulping

Washing and grading

The initial water quality in Las Brisas has a pH of 7; for the first and second was it decreases to 4.23 and 4.31, although for the last wash it increases to 5.75. The other parameters are also higher for the second wash. The first and second sample was taken in the tank were the washing water is stored for pulping, this water overflows into the oxidation pond. Because for the third wash just a small quantity of water was send to the tank and the rest was directed to the river, the sample was taken in the channel before it was directed into the river. The parameters of the third wash are lower than the first two washes (Table 20).

Table 20. Water quality after the first day of sampling Cooperative Las Brisas (16/01/10)

Water quality parameters	**Initial water quality**	**Water quality after first wash**	**Water quality after second wash**	**Water quality after third wash***
pH	7	4.23	4.31	5.75
Temp C^0	23	18.9	20.5	21.3
Conductivity (mV)	-5.6	146.8	143.5	63.2
T.S (mg/l)	400	2 200	3 400	1 000
T.D.S (mg/l)	400	1 600	1 800	800
T.S.S (mg/l)	0	600	1 600	200
C.O.D (mg/l)	674	2 755	3 840	1 335
B.O.D (mg/l)	<50	274	3 552	1 000
N total (ppm)	175	91	182	126
P total (ppm)	10.26	5.45	19.50	9.30

*For these samples approximately 1141 kg equivalent dry parchment was washed.

For the second day of sampling the 3 water samples were taken in the tank. The pH for the 3 samples remains within a range from 4.2 to 4.6. The first wash has higher values than the second and third wash (Table 21). One of the reasons that the third wash has lower values than the first two washes is that the recirculation tank where the water is stored (used later for pulping) fills up with the clean water from washing and it also overflows.

Table 21. Water quality after the second day of sampling in Cooperative Las Brisas (18/01/10)

Water quality parameters	**Initial water quality**	**Water quality after first wash**	**Water quality after second wash**	**Water quality after third wash***
pH	7	4.2	4.2	4.6
Temp C^0	23	-	-	-
Conductivity (mV)	-5.6	-	-	-
T.S (mg/l)	400	-	-	-
T.D.S (mg/l)	400	-	-	-
T.S.S (mg/l)	0	4 000	4 400	1 400
C.O.D (mg/l)	674	13 385	9 175	3 275
B.O.D (mg/l)	<50	15 052	8 473	2 771
N total (ppm)	175	315	294	119
P total (ppm)	10.26	17.59	18.14	8.98

* For these water samples approximately 1978 kg equivalent dry parchment was washed.

Pulping

The water quality samples show that pH and T.D.S. remain the same for the pulping process. However, T.S; T.S.S is higher for the first hour of pulping and C.O.D; B.O.D; N total and P total are higher at the end of pulping (table 22).

Table 22. Water quality of the first day of pulping in the cooperative Las Brisas (16/01/10)

Water quality parameters	Initial water quality	After one hour of pulping (5:55 pm)[1]	End of pulping (8:45 pm)
pH	5.75	4.2	4.2
Temp C^0	21.3	23	22.2
Conductivity(mV)	63.2	-	-
T.S (mg/l)	1 000	22 200	20 600
T.D.S (mg/l)	800	9 400	9 400
T.S.S (mg/l)	200	12 800	11 200
C.O.D (mg/l)	1 335	22 005	33 048
B.O.D (mg/l)	1 000	24 200	30 562
N total (ppm)	126	511	637
P total (ppm)	9.30	41.56	62.25

1. There is no sample after 3 hours because pulping did not take that long, because they did not receive too much coffee. Note: 5,707 kg cherries were pulped during this day.

The water quality parameters of the end of pulping are higher than at the first hour of working, except for N total (Table 23).

Table 23. Water quality of the second day of pulping in the cooperative Las Brisas (18/01/10)

Water quality parameters	Initial water quality	Water quality after one hour of pulping (5:55 pm)	Water quality at the end of pulping (8:45 pm)
pH	4.6	3.9	3.9
Temp C^0	-	20.1	20.3
Conductivity (mV)	-	-	-
T.S (mg/l)	-	-	-
T.D.S (mg/l)	-	-	-
T.S.S (mg/l)	1 400	7 400	9 200
C.O.D (mg/l)	3 275	27 162	34 749
B.O.D (mg/l)	2 771	33 271	42 556
N total (ppm)	119	525.00	497
P total (ppm)	8.98	8.98	63.75

1. There is no sample after 3 hours because pulping did not take that long; they did not receive too much coffee. Note: 9,892 kg cherries were pulped during this day.

1.15.1.3 Farm El Retiro

1.15.1.3.1 Water volume and daily income of cherries

In Huehuetenango, the wet mills (smallholder's farms) did not process a lot of coffee during the visit. The average processed coffee in this wet mill was 1.78 ton cherries and the use of clean water was 7.15 m^3. The first day of the visit in Farm El Retiro, the smallholder used 8.3 m^3 to wash 305 kg equivalent dry parchment, doing 3 washes. However the second day only 2 washes were done, using 6 m^3 to wash 408 kg equivalent dry parchment; saving 2.3 m^3 water (Table 24). An average of 24.89 m^3 clean water was used to wash one ton green coffee.

Table 24. Water and coffee volume in the Farm El Retiro

Sampling date	Coffee (ton cherries)	Clean water (m3)	Clean water/cherries (m^3/ton)	Clean water/green coffee (m^3/ton)*	Clean water/green coffee (m^3/qq)**	Water recirculation	
						Washing (m3/ton)	Pulping (m3/ton)
21/01/10	1.527	8.3	5.44	32.64	1.48	-	7.566
23/01/10	2.038	6	2.94	17.14	0.78	-	-
Average	**1.78**	**7.15**	**4.19**	**24.89**	**1.13**	**-**	**7.566**

*Cherries/green coffee: 6/1 ; ** 1 qq (quintal) = 100 pounds= 45.36 kg

1.15.1.3.2 Water quality of washing and pulping

Washing and grading

The first wash was with clean water inside the fermentation tank. After they are finished it is disposed to the evaporation pond. The second wash was also done in the fermentation tank with clean water (floaters were removed), after washing this was used to transport the parchment beans into the washing channels. The third wash and grading was done with clean water in the channel. The initial pH is 6.06 and after the first wash it drops to 4.12 but it then goes up to 4.2 for the second and third wash. The other water parameters are lower for the third wash than the first two. One of the reasons the third wash has lower parameters is that the mucilage has almost been completely removed in this stage (table 25).

Table 25. Water quality after the first day of sampling in Farm El Retiro (21/01/10)

Water quality parameters	**Initial water quality**	**Water quality after first wash[1]**	**Water quality after second wash[2]**	**Water quality after third wash[3]**
pH	6.06	4.12	4.2	4.2
Temp. C^0	17.9	17.3	18.4	18.3
Conductivity (mV)	45.9	153.4	-	-
T.S (mg/l)	-	-	-	-
T.D.S (mg/l)	-	-	-	-
T.S.S (mg/l)	0	7 200	1 200	400
C.O.D (mg/l)	1116	15 305	2 511	1 569
B.O.D (mg/l)	<50	8 332	1 750	1 050
N total (ppm)	140	364	105	84
P total (ppm)	0.86	19.50	4.61	5.48

Note: For this sample approximately 200 kg equivalent dry parchment was washed.

There is no information of the first wash because this water was discarded of before the visit to the wet mill. The second wash was done with clean water in the fermentation tank and was used to transport the parchment coffee to the washing and grading channels. This washing water was recirculated to finish the washing and grading in the channel. There was no third wash. The initial pH was 6.06 and dropped to 4.35. If the parameters of the second wash are compared to the parameters of the second wash of the previous day (table 25), there are not many differences, although C.O.D is a little higher (table 26).

Table 26. Water quality after the second day of sampling (23/01/10)

Water quality parameters	**Initial water quality**	**Water quality after second wash[2]**
pH	6.06	4.35
Temp C^0	17.9	19.2
Conductivity (mV)	45.9	140.9
T.S (mg/l)	-	-
T.D.S (mg/l)	-	-
T.S.S (mg/l)	0	1 400
C.O.D (mg/l)	1116	3 153
B.O.D (mg/l)	<50	1 413
N total (ppm)	140	112
P total (ppm)	0.86	8.80

Note: For this sample approximately 182 kg equivalent dry parchment was washed.

Pulping

The initial pH is 4.2 and drops to 3.9 after the first hour of pulping but at the end of washing it goes up to 4.1. The water parameters are higher at the end of washing than the initial water (table 27).

Table 27. Water quality after the first day of sampling in Farm El Retiro (21/01/10)

Water quality parameters	**Initial water quality***	**After one hour of pulping (6:00 pm)**	**Water quality at the end of pulping (8:30 pm)**
pH	4.2	3.9	4.1
Temp. ^{o}C	18.3	-	-
Conductivity (mV)	-	-	-
T.S (mg/l)	10 400	-	-
T.D.S (mg/l)	3 800	-	-
T.S.S (mg/l)	6 600	5 400	10 800
C.O.D (mg/l)	12 995	15 390	32 145
B.O.D (mg/l)	13 953	14 226	28 122
N total (ppm)	273	273	280
P total (ppm)	22.50	15.70	55

* This initial water for pulping is the water from the third wash. There is no sample after 3 hours because pulping did not take that long; they did not receive too much coffee.

The water parameters during the second day of sampling are not higher at the end of pulping; there are variations between the values. The pH did decrease from 4.35 from to the initial water quality to 3.7 after the first hour and the end of pulping (table 28).

Table 28. Water quality after the second day of sampling (23/01/10)

Water quality parameters	**Initial water quality***	**Water quality after one hour of pulping (6:20 pm)[1]**	**Water quality at the end of pulping (8:55 pm)**
pH	4.35	3.7	3.7
Temp C^{0}	19.2	-	-
Conductivity (mV)	140.9	-	-
T.S (mg/l)	-	-	-
T.D.S (mg/l)	-	-	-
T.S.S (mg/l)	5 400	4 400	4 400
C.O.D (mg/l)	15 390	12 964	14 030
B.O.D (mg/l)	14 226	15 876	13 585
N total (ppm)	273	217	175
P total (ppm)	15.70	25.85	22.90

* This initial water for pulping is the water from the third wash. There is no sample after 3 hours because pulping did not take that long; they did not receive too much coffee.

1.15.1.4 Farm El Jardin

1.15.1.4.1 Water volume and daily income of cherries

In Farm El Jardin, the smallholder did not process a lot of coffee during the visit. The average processed coffee in this wet mill was 0.972 ton cherries. The first day of the visit the smallholder used the water from pulping from the previous day to do the first wash (1.494 m^3) and clean water for the second and third wash (it was not possible to measure the water during these two washes). However, for the second day only 2 washes were done to wash and classify 1.045 ton cherries. For the first wash the water of the last wash from the previous day was used (this water was recirculated during the first wash). Clean water was used for the second wash (1.4 m^3) to wash 209 kg equivalent dry parchment (table 29).

Table 29. Water and coffee volume from Farm El Jardin

Sampling date	Coffee (ton cherries)	Clean water (m3)	Water/ cherries (m3/ton)	Water/green coffee (m3/ton)*	Water/green coffee (m3/qq)**	Water recirculation	
						Washing (m3/ton)	Pulping (m3/ton)
23/01/10	0.907	-	-	-	-	-	-
25/01/10	1.045	1.4	1.34	8.04	0.064	21.18	4.5
Average	**0.972**	**1.4**	**1.34**	**8.04**	**0.064**	**21.18**	**4.5**

*Cherries/green coffee: 6/1 ; ** 1 qq (quintal) = 100 pounds= 45.36 kg

1.15.1.4.2 Water quality of washing and pulping

Washing and grading

They used the water from the previous day (end pulping) to transport the coffee to the washing channels. The first wash was with clean water in the channels. After they are finished it is disposed to the evaporation pond. The second wash and grading was also done in the channels with clean water. The third wash and grading was done with clean water in the channel. The initial pH is of clean water is 6.9 and after the first wash it dropped to 4.19 but it went up to 4.46 for the second and third wash. The other water parameters are lower for the third wash than the first two (table 30).

Table 30. Water quality after the first day of sampling in Farm El Jardin (23/01/10)

Water quality parameters	Initial water quality	Water quality after first wash	Water quality after second wash	Water quality after third wash[1]
pH	6.9	4.19	4.46	4.5
Temp C^0	16.2	19.1	20	20.4
Conductivity (mV)	-3.3	149.7	134.2	147.1
T.S (mg/l)	-	-	-	-
T.D.S (mg/l)	-	-	-	-
T.S.S (mg/l)	0	3 000	800	400
C.O.D (mg/l)	547	8 865	2 598	1 350
B.O.D (mg/l)	< 20	< 221.5	774	550.00
N total (ppm)	49	328	91	70
P total (ppm)	0.81	28.60	4.40	3.64

1. The third wash was done clean water; this water is later used for pulping. Note: For this sample approximately 200 kg equivalent dry parchment was washed.

The parchment coffee was transported to the washing and grading channels with the last washing water from the previous day in clean water was pumped into the system. This first wash was recirculated in the channels and was disposed of at the end. The second wash was done with clean water and the water was also recirculated to finish the washing and grading in the channel. There was no third wash. The pH after the first wash was 4.27 for the third wash went up to 4.49. The parameters of the second wash decreased compared to the first wash (table 31).

Table 31. Water quality after the second day of sampling in Farm El Jardin (25/01/10)

Water quality parameters	Initial water quality	Water quality after first wash	Water quality after second wash
pH	6.9	4.27	4.49
Temp C^0	16.2	16.1	16.8
Conductivity (mV)	-3.3	143.3	137.8
T.S (mg/l)	-	-	-
T.D.S (mg/l)	-	-	-
T.S.S (mg/l)	0	3 600	1 000
C.O.D (mg/l)	547	6 465	1 878
B.O.D (mg/l)	< 20	4 683	1 300
N total (ppm)	49	252	98
P total (ppm)	0.81	6.55	4.60

Note: For this sample approximately 182 kg equivalent dry parchment was washed.

Pulping

The water from the last wash was used for pulping. The initial pH is 4.5 and drops to 3.9 after the first hour of pulping but at the end of washing it goes up to 4.1. The water parameters are higher at the end of washing than the initial water (table 32).

Table 32. Water quality after the first day of sampling in Farm El Jardin (23/01/10)

Water quality parameters	Initial water quality*	Water quality after one hour of pulping (5:30 pm)[1]	Water quality at the end of pulping (7:00 pm)
pH	4.5	3.9	4.1
Temp C^0	20.4		
Conductividad (mV)	147.1	-	-
T.S (mg/l)	-	-	-
T.D.S (mg/l)	-	-	-
T.S.S (mg/l)	400	2 600	2 400
C.O.D (mg/l)	1 350	5 123	8 400
B.O.D (mg/l)	550.00	4 864	7 350
N total (ppm)	70	147	42
P total (ppm)	3.64	10.15	13.55

* This initial water for pulping is the water from the third wash. 1. There is no sample after 3 hours because pulping did not take that long, they did not receive too much coffee.

The water parameters during the second day of sampling are higher at the end of pulping; T.S.S is the only parameter that is higher during the first hour of pulping. The pH decreased from 4.49 to 3.7 at the end of pulping (table 33).

Table 33. Water quality after the second day of sampling in Farm El Jardin (25/01/10)

Water quality parameters	Initial water quality*	After one hour of pulping (6:00 pm)[1]	Water quality at the end of pulping (8:30 pm)
pH	4.49	3.7	3.7
Temp C^0	16.8	-	-
Conductivity (mV)	137.8	-	-
T.S (mg/l)	-	-	-
T.D.S (mg/l)	-	-	-
T.S.S (mg/l)	1 000	2 600	2 400
C.O.D (mg/l)	1 878	5 123	8 400
B.O.D (mg/l)	1 300	4 864	7 350
N total (ppm)	98	147	42
P total (ppm)	4.60	10.15	13.55

* This initial water for pulping is the water from the third wash. 1. There is no sample after 3 hours because pulping did not take that long; they did not receive too much coffee.

Discussion

El Jardin is the wet mill that consumed less water to process one ton of coffee (0.064 cubic meters per quintal green coffee) but it must be pointed out that this value is not an average, it is only one value of one day of measurement; and only two washes were done instead of 3. Nuevo Sendero used an average 0.1815 cubic meters per quintal green coffee because it recirculates the pulping and washing water. Las Brisas used in an average of 0.342 cubic meters of water per quintal green coffee (value not an average, only one measurement);

followed by El Retiro that used an average of 1.13 cubic meters per quintal of green coffee; this average is done with one value of 3 washes which is 1.48 m^3 water per quintal green coffee and the other value of two washes which is 0.78 m^3 water per quintal green coffee. By doing 2 washes instead of 3, El Retiro saved 2.3 m^3 of clean water. The wet mills Las Brisas, El Retiro and El Jardin only recycle water for pulping, not for washing.

CICAFE cited by Echeverria & Cleves (1998c), performed a study in which they determined carefully the amount of water consumed in a traditional wet mill (no recirculation) and as a result obtained that 2.2 cubic meters are needed to process one quintal of green coffee. In other wet mills they obtained higher volumes. Brandom (cited by Echeverria & Cleves 1998c) mentions water volumes from 2.3 to 3.5 cubic meters per quintal green coffee.

In El Salvador, Ward (cited by Cleves 1998c), says that the amount of water necessary to process 1 quintal of green coffee varies from 0.4 to 1 m^3 green coffee with recirculation. Cleves (1998), mentioned that during a visit to two wet mills in El Salvador with intensive water recirculation, was informed that the water consumption was 0.4 m^3/ qq of green coffee in one wet mill and 0.2 m^3/qq of green coffee in the other. Brando (2004) mentions that the ecological wet milling should require less than 10 m^3, ideally less than 5 m^3 of water per ton green coffee (0.45 m^3 and 0.23 m^3 per quintal); Nuevo Sendero, Las Brisas and El Jardin use less water than what Brando mentions but El Retiro uses more than 0.45 m^3 to process on quintal of green coffee.

In Guatemala 70% - 75% of the wet mills are traditional, using 2 m^3 to 3 m^3 of water to process one quintal of dry parchment coffee (80 pounds green coffee) and 25% to 30% have technology to use less water, use byproducts, recirculate water, etc ("*tipo tecnificado*"), which use of 0.15 m^3 to 0.2 m^3 to process the same quintal of parchment coffee. This type of wet mill may have or not a system of wastewater treatment (CCAD/USAID/DR-CAFTA 2009 in press). The semi-technified wet mill is generally located near a water source because the process is the same as a traditional wet mill but with a gradual conversion (mainly in the water recirculation, achieving a 50% decrease of water consumption). The technified wet mill does not have to be located necessarily near a water source because its technology development has created systems that have allowed decreasing the water consumption up to 90% in comparison with the traditional wet mills.

In Nuevo Sendero the minimum value of water to process one quintal of green coffee was 0.104 m^3 and the highest 0.243 $m^{3;}$ in Las Brisas 0.342 m^3; El Retiro 0.78-1.48 m^3 and in El Jardin 0.064 $m^{3.}$ It was estimated that during the visit approximately 10% of water was lost during the coffee processing in Nuevo Sendero (transportation pulp and parchment coffee to drying area). When the water volumes used to process one quintal green coffee from Nuevo Sendero, Las Brisas and El Jardin are compared to the values from Cleves (1998) and Ward it can be observed that these three wet mills fall into these ranges of water consumption (wet mills that recircualte water). El Retiro also recirculates water as the other wet mills do but it has the highest value of water consumption to process one quintal coffee; it must be pointed out that this smallholder paid an extremely amount of attention to detail to the his coffee processing, especially the washing stage. Farm El Retiro is above the average from Ward and Cleves, but as it was mentioned above, the smallholder is more interested in the coffee quality than the water consumption and also maybe he did not receive too much volume of cherries and used the same amount of water as usual. Bello et al. (1993), mentions that it must be considered that the amounts of cherries that come into the wet mills daily are highly variable. These fluctuations are rather progressive. During the harvest season the daily amounts collected of cherries increase to a maximum on peak harvest, and then decrease. On the other hand, the consumption of water has little variation. This relationship directly affects the daily water/cherry processing. In this circumstance it is important the influence of the workers in the water consumption, since a higher liquid flow, the operation is faster and less labor.

The *depulping water* contains a high amount of sediment solids, sugars, soluble matter and in general abundant organic matter, making it highly polluting. *Washing water* contains a large amount of coloidal gels of pectin and other products, which are less polluting substances (Morales 1987). If the depulping water has been recirculated a lot, it is highly polluting. Morales, A., cited by Echeverría and Cleves (1998), obtained the following results (average): COD between 450 to 11,710 mg/l; suspension solids between 70 to 850 mg/l; total solids 2, 687 mg/l and a pH of 5.9. Another study by Rolz (cited by Echeverría & Cleves 1998) found values of COD up to 28, 020 mg/l.

If the water quality parameters of the four wet mills are compared, it can be observed that Nuevo Sendero has the highest values of water parameters for depulping water and washing water. For the washing process, Nuevo Sendero has a pH from 4.05 to 4.26 and for pulping from 3.6 to 4.4 and if compared to table 4 (Characterization of residual water from coffee processing) the pH are similar, however the information on this table are not values of recirculated water nor combined (washing water with depulping water). The parameters of the washing water for Nuevo Sendero are much higher than does of table 4 and the parameters and average values of residual water from coffee wet mills (table 5). But it must be pointed out that in Nuevo Sendero the washing water is recirculated during the entire washing of the parchment coffee and sometimes clean water is injected during the process.

During pulping in Nuevo Sendero, the COD values go from 10,020 mg/l (value after one hour of pulping) to 45,213 mg/l (value and the end of pulping), however, it should be noted, that pulping in Nuevo Sendero is operated with the washing water from the morning. This COD values, when compared to the parameters and average values of residual water from coffee wet mills (table 5), Rolz (table 4) and Morales cited by Cleves are higher. The values of total solids go from 12, 600 mg/l (after one hour of pulping) to 35,200 mg/l (end of pulping), much higher than 2, 687 cited by Morales; however if compared to table 4 there are values cited by Rolz up to 16, 700 mg/l. The values of suspended solids go from 4,000 mg/l (after one hour of pulping) to 21, 200 mg/l (end of pulping), also higher than what is cited. The values of BOD go from 11,773 mg/l (after one hour of pulping) to 54,240 mg/l (end of pulping), these values are much higher than the values that Horton has in table 4 (15, 000 mg/l). The values for washing are also higher than table 4.

The washing water for Las Brisas, El Retiro and El Jardin has a COD values from 1,335 mg/l (minimum) to 8, 865 mg/l. These wet mills do not recirculate water for washing. The COD values from washing when compared to table 4 can be noticed that the results from this study are between the values cited by the different authors. However, in Las Brisas the maximum value of COD reaches 13, 385 mg/l and in El Retiro 15, 305 mg/l.

1.15.2 Organoleptic quality

As mentioned in the methodology, the organoleptic variables were grouped by cluster analysis (fig. 11). Three groups of coffee quality were identified, according to the cluster analysis, being statistically different (MANOVA; $F = 14.64$, $p < 0.0001$). The coffee samples were from different wet mills, Nuevo Sendero contributed with more coffee samples for the analysis, followed by Finca El Retiro, El Jardín and Las Brisas.

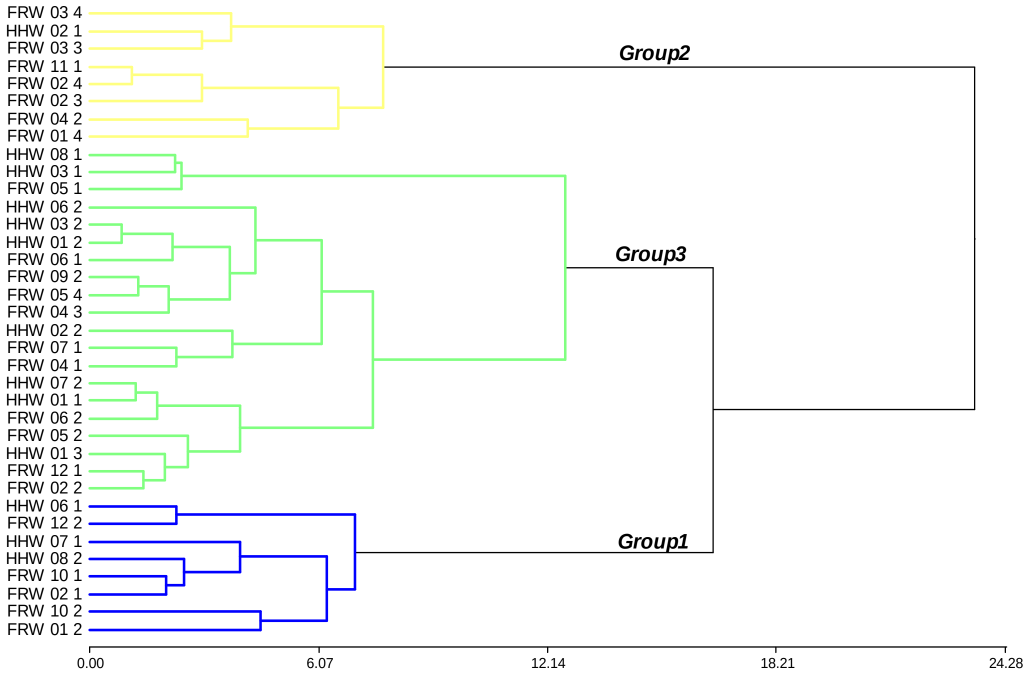


Figure 11. Cluster of the 36 samples of coffee quality through the organoleptic variables.

The cluster shows three distinct groups. In group 1 samples from Farm El Jardin, Las Brisas and Nuevo Sendero with similar proportion were grouped. Group 2, was composed of samples from El Retiro, Las Brisas and Nuevo Sendero, this last one with the highest proportion. Group 3 was composed of samples from all the wet mills but the highest proportions come from the wet mills El Retiro and Nuevo Sendero (Table 34).

Table 34. Number and proportion of coffee samples of different coffee wet mills belonging to different groups of quality coffee.

Name	**Group1**		**Group 2**		**Group 3**		**Total**
	#	**Proportion**	**#**	**Proportion**	**#**	**Proportion**	
El Jardin	3	0.375	0	0	3	0.15	6
El Retiro	0	0	1	0.125	6	0.3	7
Las Brisas	3	0.375	1	0.125	2	0.1	6
Nuevo Sendero	2	0.25	6	0.75	9	0.45	17
Total	**8**	**1**	**8**	**1**	**20**	**1**	**36**

The ANOVA showed significant differences between the organoleptic variables of the 3 groups (table 35). The variables that separated the 3 groups were aroma, flavor, acidity, bitter, body, aromatic, green grassy, CWP, baggy, ferm. rank and EMM, except for green grassy and baggy. Aroma was higher in group 3 and 1 than in group 2. For flavor the highest group was 3, followed by group 1 and 2. Acidity in group 3 and 2 were higher than 1. For the characteristic bitter group 1 and 2 were higher than 3. The variable body was higher for group 1 and 3 than group 2. In aromatic, el group 3 was higher than group 1, followed by group 2. For CWP, group 1 was higher than group 2 and 3. For the undesirable characteristic CMP, group 2 was higher than group 1 y 3. The ferm.rank was higher for group 2 than group 1 and 3. The EMM feature was higher for group 1 than group 2 y 3.

Table 35. Analysis of variance of organoleptic variables. Means and errors of the coffee organoleptic variables. Also the values of distribution F and probability (n=36, α = ≤ 0.05) are presented. Different letters indicate significant differences to a critical value of α.

Organoleptic	**Group 1**	**Group 2**	**Group 3**	**F**	***p***
Aroma	2.98±0.12 a	2.24±0.12 b	3.17±0.07 a	23.34	**< 0.0001**
Flavor	2.99±0.10 b	2.43±0.10 c	3.24±0.06 a	24.28	**< 0.0001**
Acidity	3.14±0.07 b	3.46±0.07 a	3.58±0.04 a	14.87	**< 0.0001**
Body	3.19±0.08 a	2.84±0.08 b	3.09±0.05 a	4.73	**0.0156**
Aromatic	1.21±0.09 b	0.81±0.09 c	1.44±0.05 a	18.72	**< 0.0001**
Bitter	1.93±0.09 a	1.70±0.09 a	1.48±0.06 b	9.77	**0.0005**
Green grassy	0.11±0.05 a	0.05±0.05 a	0.15±0.03 a	1.25	0.2988
CWP	0.46±0.07 a	0.04±0.07 b	0.11±0.04 b	12.38	**0.0001**
Baggy	0.00±0.01 a	0.00±0.01 a	0.02±0.01 a	1.29	0.2877
CMP	0.03±0.03 b	0.13±0.03 a	0.00±0.02 b	5.94	**0.0063**
Ferm. rank	0.00±0.13 b	1.85±0.13 a	0.14±0.08 b	73.07	**< 0.0001**
EMM	0.21±0.03 a	0.03±0.03 b	0.01±0.02 b	12.6	**0.0001**

CWP= cereal, woody, paper; CMP= chemical, medical; Ferm.rank = fermented; EMM= earthy, musty, moldy; aroma= refers to the fragrance of the coffee; aromatic= refers to the flavor.

The PCA shows association between the organoleptic variables and the identified groups (fig. 12). The CP1 separates group 3 and 1 from group 2 with an explained variability of 38.7% and the CP2 separates group 3 and 1 with an explained variability of 22.9%. Group 2 separates from group 3 and 1 in the CP3 with a variability of 10%.

As mentioned, the main goal in cup tasting is to evaluate the coffee in an objective and reproducible way and to describe the flavor profile by means of words (attributes) and values related to the intensity of each attribute. Coffee is judge it by its flavor, mouth feel and aftertaste and the basic attributes evaluated are: aroma, flavor, body and acidity (Wintgens 2004). Because of this, the coffee quality groups were classified the following way:

Group 3 is more associated with the desirable organoleptic variables (acidity, body, aromatic, flavor and aroma) because of this it was appointed as the group of "*good quality*". Group 1 also shows greater association with the desirable attributes but it is also associated with the off-flavor CMP, therefore it is named *"regular quality*". Since group 2 is more associated to off-flavors like ferm.rank, CMP and EMM it was named *"lower quality"*.

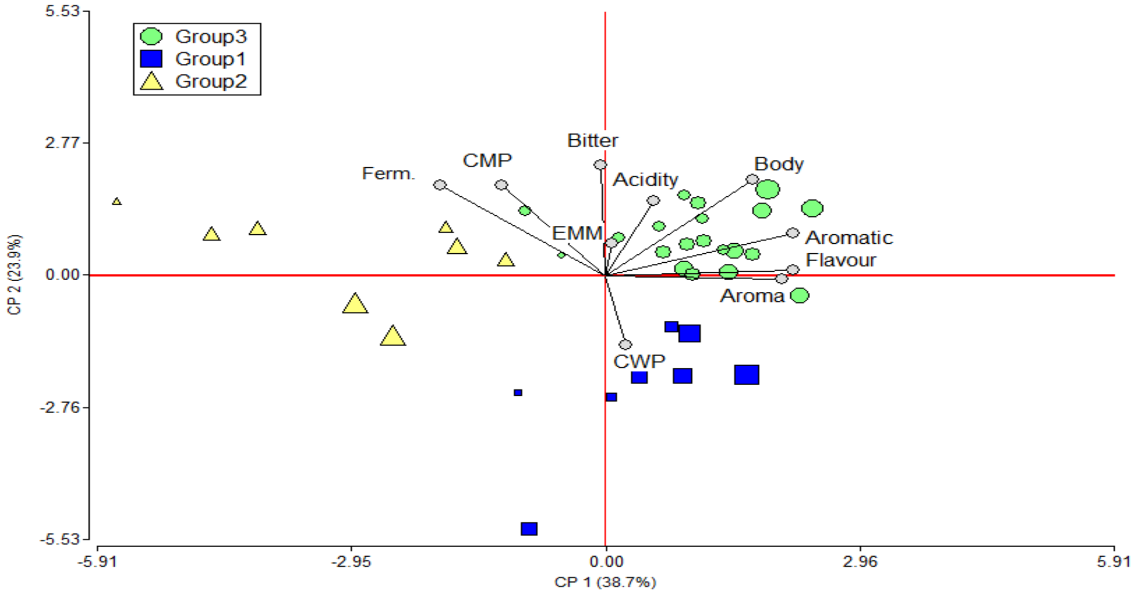


Figure 12. Biplot of the relationship between organoleptic variables and their association with the different qualities of coffee

As shown in table 34, the wet mill with the most samples is the cooperative Nuevo Sendero, followed by Farm El Retiro, El Jardin and Las Brisas. The wet mill with the most samples of *good quality* was Nuevo Sendero, followed by El Retiro, El Jardin and Las Brisas. The wet mill with more samples of *regular quality* was both El Jardin and Las Brisas, followed by Nuevo Sendero and El Retiro. For the *lower quality*, the wet mill with the most samples was Nuevo Sendero, followed by El Retiro and Las Brisas which had the same amount of samples, while El Jardin did not have any samples of lower quality.

1.15.3 Physical quality

1.15.3.1 Effect of the physical quality of coffee on the organoleptic quality

No linear relationship was found between the bean size and acidity (Table 36). However, the bean size 18 presents a quadratic relationship (figure 13). This shows that there is a threshold where the acidity begins to decrease as the proportion of bean size increases; the maximum proportion beans is 30% from this the acidity decreases.

Table 36. Correlation of the variables of physical quality and organoleptic quality, adjusted with general linear mixed models (n=36, α ≤ 0.05).

Bean size	**Organoleptic variable**	
	Acidity	
	r	***P***
B size 19	0.812	0.4425
B .size 18	0.035	0.6708
B .size 18^2	-0.651	**0.0038**
B .size.17	0.812	0.9106
B size 16	0.812	0.682

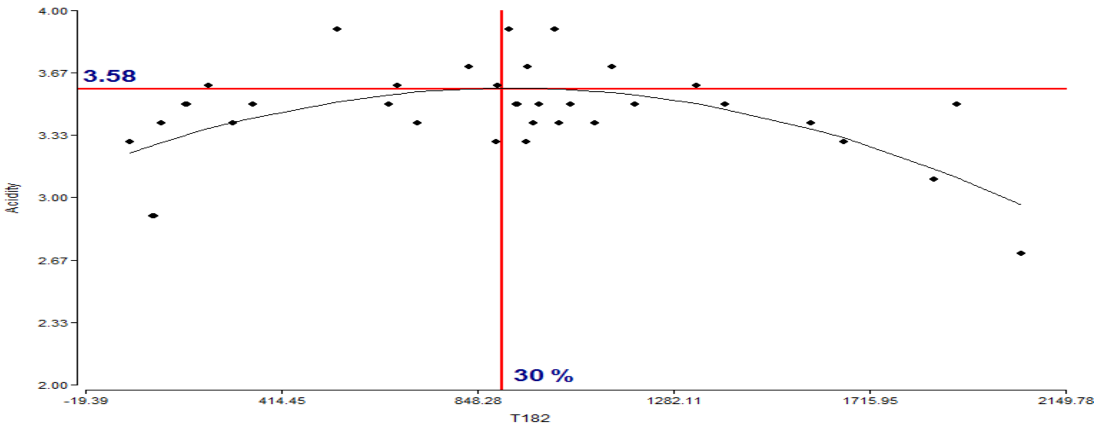


Figure 13. Correlation between bean size and the acidity. The graph shows the quadratic relationship between the two variables and indicates the threshold of change in the acidity according to the proportion of grains in the sample

An ANVOVA was also performed between the physical quality (bean size) and the three types of coffee quality (*good quality, regular quality and lower quality*) (table 37). No relation was found between the different bean sizes and the coffee quality.

A study (thesis) by Banegas 2009, found that there is no effect of the bean size of the coffee varieties Lempira and Paca on the coffee quality, however, the bean size from the sieve size T20-T18 of the variety Typica had a negative effect on the attributes fragrance (p=0.02; r = - 0.43), body (p= 0.04; r = - 0.40) and acidity (p= 0.03, r = - 0.42).

Table 37. Analysis of variance (ANOVA). Means and errors of the coffee bean size and the coffee quality groups. The values of the distribution of F and probability are presented (n=36, $\alpha \leq 0.05$)

Bean size	Coffee quality			F	*p*
	Good quality	Regular quality	Lower quality		
B size 19	5.7 ± 1.30 a	10.47 ± 2.06 a	7.63 ±2.06 a	1.93	0.1608
B size 18	25.99 ± 2.14 a	28.03 ± 3.38 a	33.89 ± 3.38 a	1.95	0.1582
B size 17	33.29 ± 1.18 ab	28.96 ± 1.86 b	34.74 ±1.86 a	2.75	0.0789
B size 16	17.68 ± 1.48 a	17.64 ± 2.34 a	12.66 ± 2.34 a	1.78	0.1838

Bean size plays an important role for roasting because the more uniform the bean size, the better the heat is transferred and consequently the roast is better. Consumers associate bean size to quality; however larger beans do not necessarily taste better than smaller. Larger amount of imperfections (defective beans) will increase the probability of off-flavors and lesser homogeneity in the cup; however low amounts of visible defects do not necessarily correlate with higher cup quality (Wintgens 2004).

1.15.4 Biochemical compounds

The cluster analysis classified the biochemical components in two groups (Figure 14), being statically different MANOVA (F=7.54 y p <0.0001).

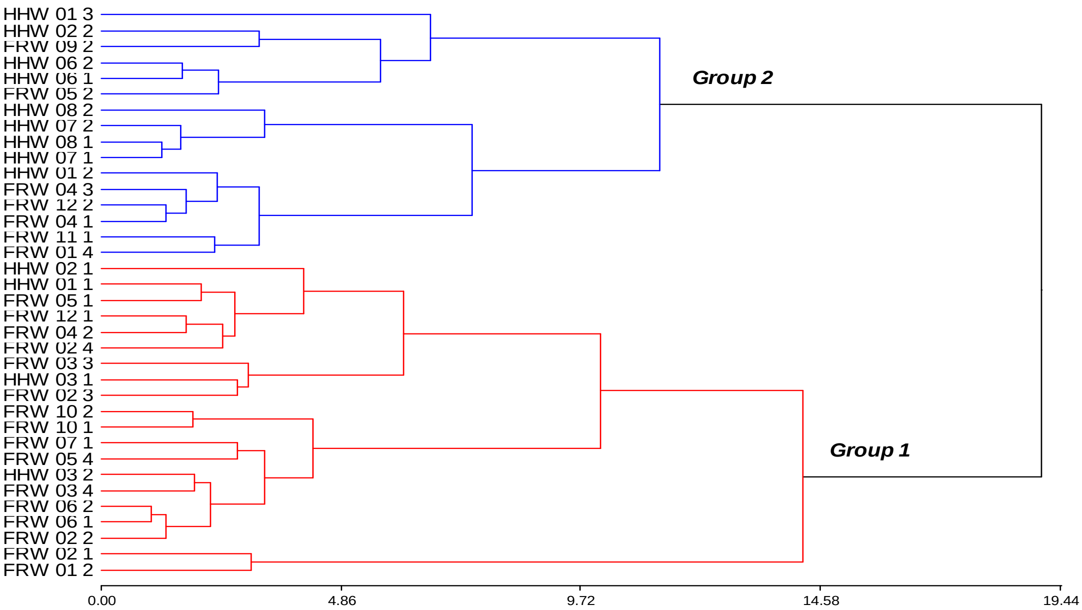


Figure 14. Cluster of 36 coffee samples base on the variables from the biochemical analysis

The ANOVA indicated significant differences between the groups from the cluster according to their biochemical characteristics. Trigonelline, chlorogenic acids, proteins, total acidity and CTn90 obtained higher values in group 1 than in group 2. However, for the variables caffeine, sucrose, lipids, aromatic and acidity had higher values in group 2 than in group 1. Lipids and sucrose showed no significant differences (Table 38). The cluster shows a clear association between coffee samples and the region where they come from, however, there are samples that come from different regions; Nuevo Sendero and Las Brisas belong to the Fraijanes region and El Retiro and El Jardin to the Huehuetenango region. Group 1 is composed in its majority from coffee samples of Nuevo Sendero (65%), followed by El Retiro (20%), Las Brisas (15%) and none from El Jardin. Group 2 is composed in its majority from samples from El Jardin (37.5%), followed by Nuevo Sendero (25%), El Retiro (18.75%) and Las Brisas (18.75%).

These clusters could be due to factors in the region of origin and the variety of coffee, fruit ripening, altitude, climate and soil conditions, wet mill management, among others. Feria-Morales (2002) mentions that the coffee variety does not automatically produce the same cup profile. For example the variety “Typica” will not produce the same cup quality in the mountains of Jamaica or in the mountains of Guatemala; all coffee varieties will have an ideal set of conditions at which one can obtain the best cup quality.

The final quality of green coffee is the result of an interaction among different variables, such as coffee varieties, soil, climate, husbandry, latitude, altitude, luminosity, harvesting, and processing (Wintgens 2004). The quality of the coffee is mainly determined by the quality potential of the cherries in the field. This potential can be revealed or ruined by the harvesting and/or processing technique but it cannot be created or boosted. Processing can however emphasize certain sensorial characteristics (De Smet 2009).

Since most of the coffee samples grouped (figure 38) match the locality of origin, a MANOVA using Hotelling, showed that there is difference between biochemical characteristics and the 2 locations (Fraijanes and Huehuetenango) ($F=7.04$, $p \leq 0.001$).

Table 38. Means and errors of the biochemical variables of coffee for both biochemical compound groups. Also the values of distribution F and probability ($n=36$, $\alpha = \leq 0.05$) are presented. Different letters indicate significant differences to a critical value of α.

Biochemical variables	**Group 1**	**Group 2**	**F**	***P***
Caffeine	1.34±0.01 b	1.40±0.02 a	9.67	**0.0038**
Trigonelline	0.99±0.01 a	0.94±0.01 b	10.47	**0.0027**

Chlorogenic acids	7.84±0.05 a	7.61±0.06 b	8.67	**0.0058**
Sucrose	8.42±0.05 a	8.45±0.06 a	0.22	0.6392
Proteins	12.12±0.09 a	11.82±0.10 b	4.67	**0.0379**
Total acidity	2.09±0.02 a	1.90±0.02 b	47.58	**<0.0001**
CTn 90	293.23±1.69 a	285.45±1.89 b	9.37	**0.0043**
Lipids	11.24±0.13 a	11.47±0.14 a	1.46	0.2346
Aromatic*	2.04±0.06 b	2.41±0.06 a	19.66	**0.0001**
Acidity	3.23±0.04 b	3.41±0.04 a	9.95	**0.0034**

*Note: aromatic is not a biochemical compound it is a NIR predictive value of the sensory score.

CTn90 = NIR predictive value of the roasting time to reach the color. CTn: 90; Total acidity = NIR predictive value of the neutralization volume.

The PCA (figure 15) shows association between the biochemical compounds and the two groups identified. CP1 separates group 1 and 2 with 39.1% explained variability. CP1 right quadrant shows that group 1 is more associated with variables trigonelline and chlorogenic acids but also to the variables CTn 90, protein, sucrose and total acidity. CP2 has 24.7% explained variability and it separates the variables lipids, total acidity and proteins that are located in the lower quadrant from the rest of the variables in the upper quadrant.

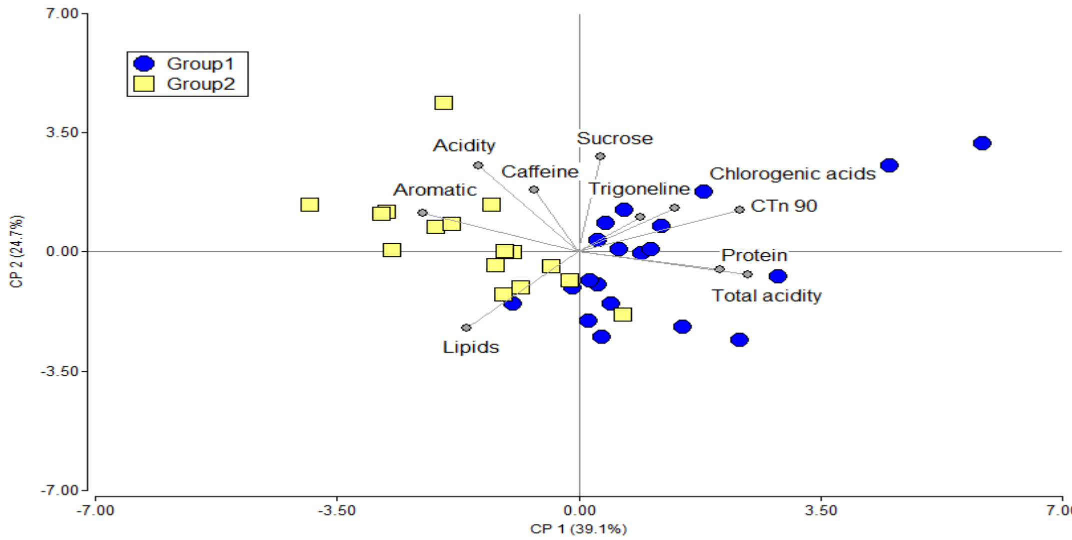


Figure 15. Biplot of the relationship between biochemical variables and their association with the groups from the cluster

Caffeine gives a bitter characteristic taste to coffee (Farah, DePaulis, Moreira, Trugo, Martin 2006 cited by Duarte *et al.* 2010). The only minor contribution that trigonelline may make to the overall taste characteristics of the cup is due to its bitter taste, as it does not undergo complete degradation during toasting (Illy & Viani 1996), but also it is known to contribute indirectly to the formation of desirable and undesirable aroma compounds during roasting (Macrae, 1985; Moreira, Trugo, & Maria, 2000 cited by Duarte *et al.* 2010) and it has also been correlated to good cup quality (Farah, Monteiro, Calado, Franca, & Trugo, 2006 cited by Duarte *et al*. 2010). No correlations have been identified between composition and/or quantity of proteins and quality (Illy & Viani 1996). Thermal degradation of chlorogenic acids will result on phenolic substances that will contribute to bitterness (Clifford, 1985 cited by Franca *et al*. 2005). Sucrose will act as aroma precursors, originating several substances (furans, aldehydes, carboxylic acids, etc.) that will affect both flavor and aroma of the beverage (Farah *et al*. 2006).

1.15.5 Relationship of organoleptic quality and biochemical compounds

The Mantel correlation analysis showed no association between the matrixes which included the organoleptic and the biochemical variables (*attributes*; r = 0.06, p = 0.2430, *off-flavors*; r = 0.16, p = 0.1870). However, the Pearson correlation (table 39) shows association between the bean size 17 and acidity and a negative relationship with chlorogenic acids. The bean size 19 and 18 show a negative association with the biochemical variable sucrose but the bean size 16 shows a positive association. The bean size 18 shows a negative association with CTn90, while the bean size 16 shows a positive association. The organoleptic variable acidity shows a negative association with the biochemical variables protein and total acidity. There is also association between the variables CTn90 and aromatic (sensorial variables from NIR) with the organoleptic variable total acidity.

Table 39. Pearson correlations between the coffee organoleptic and biochemical variables

r/p	Physical variables					Organoleptic variables				
	Bsize 19	Bsize 18	Bsize 17	Bsize 16	Defects (%)	Aroma	Flavor	Acidity	Body	Aromatic
Bsize 19	1	-	-	-	-	-	-	-	-	-
Bsize 18	-	1	-	-	-	-	-	-	-	-
Bsize 17	-	-	1	-	-	-	-	-	-	-
Bsize 16	-	-	-	1	-	-	-	-	-	-
Defects (%)	-	-	-	-	1	-	-	-	-	-
Aroma	-0.04	-0.14	0.01	0.12	0.32	1	-	-	-	-
Flavor	-0.12	-0.22	0.01	0.22	0.22	-	1		-	-
Acidity	-0.28	0.03	**0.41***	-0.1	-0.02	-	-	1	-	-
Body	0.04	-0.01	-0.01	0.06	0.22	-	-	-	1	-
Aromatic	0.02	-0.05	-0.02	0.03	0.21	-	-	-	-	1
Caffeine	0.09	-0.08	-0.24	0.1	0.32	0.15	0.17	-0.05	-0.06	0.07

Trigonelline	0.2	0.09	-0.3	-0.1	-0.29	-0.25	-0.19	-0.2	-0.27	-0.21
Chlorogenic acids	0.17	-0.02	**-0.35***	0.18	0.22	-0.06	-0.06	-0.31	0.19	0.1
Sucrose	**-0.49****	**-0.66*******	0.16	**0.68*******	0.07	0.22	0.12	-0.07	0.06	0.12
Proteins	-0.1	-0.18	0.01	0.13	0.07	-0.05	-0.15	**-0.38***	0.04	-0.2
Total acidity	0.17	0.01	-0.28	-0.01	0.01	-0.17	-0.14	**-0.49****	0.14	-0.08
CTn 90	-0.17	**-0.36***	-0.17	**0.33***	0.1	0.01	0.02	**-0.42****	0.03	-0.01
Lipids	0.13	0.3	0.19	-0.31	-0.29	-0.13	-0.04	0.31	-0.09	-0.02
Aromatic	-0.08	0.11	0.15	-0.07	-0.13	0.1	0.16	**0.44****	-0.06	0.13
Acidity	-0.13	-0.28	-0.09	0.32	0.05	0.14	0.08	0.15	-0.08	0.03

***p≤0.05; **p≤0.01; ***p≤0.001; ****p≤0.0001; *****p≤0.00001**

A thesis done by Lara (2005), found a negative association between sucrose and T16-20 (bean sizes from 16 to 20).

1.15.6 Effect of water volume used in the wet mill on the organoleptic and biochemical variables

The Mantel correlation matrix analysis showed no correlation between the volume of water used to process one ton of coffee and the quality of coffee and biochemical variables (Table 40). This result suggests that coffee quality is not affected by the amount of water used in the wet milling process. Given the importance of this aspect there should be studied in greater detail and scope in future investigations.

Table 40. Mantel correlation matrix of the volume of water and the organoleptic and biochemical variables ($\alpha \leq 0.05$)

Variables	r	*p*
Organoleptic variables (attributes)	-0.11	0.8030
Organoleptic variables (“off flavors”)	-0.16	0.9720
Biochemical variables	0.09	0.1150

p≤ 0.05 indicates correlation between the analyzed variables

1.15.7 Effect of water quality parameters on the organoleptic and biochemical variables of coffee

The Spearman correlation analysis found association between water quality parameters (pH, BOD, COD, etc) and organoleptic (table 41) and biochemical variables (table 42). However, when scatter plots were performed, it was observed that the correlation found was not a real relationship of the variable.

Table 41. Spearman correlation coefficient between water quality variables and organoleptic variables

Organoleptic variables	Water quality parameters													
	pH		ST		STD		STS		DQO		DBO		P total	
	R	*p*	R	*P*	r	*P*	R	*P*	r	*p*	r	*p*	r	*P*
Aroma	0.29	0.27	-	-	-	-	-	-	-	-	-	-	-	-
Flavor	0.43	0.11	-	-	0.45	0.09	-	-	-	-	0.45	0.09	0.45	0.09
Acidity	0.01	0.98	0.45	0.09	0.41	0.13	0.45	0.09	0.45	0.09	0.41	0.13	0.41	0.13
Bitter	-0.01	0.96	-0.08	0.76	-0.03	0.92	-0.08	0.76	-0.08	0.76	-0.03	0.92	-0.03	0.92
Body	0.49	0.07	0.32	0.23	0.25	0.35	0.32	0.23	0.32	0.23	0.25	0.35	0.25	0.35
Aromatic	0.43	0.11	0.35	0.19	0.25	0.36	0.35	0.19	0.35	0.19	0.25	0.36	0.25	0.36
Green grassy	0.44	0.1	0.3	0.26	0.19	0.48	0.3	0.26	0.3	0.26	0.19	0.48	0.19	0.48
CWP	0.31	0.25	-0.01	0.97	-0.01	0.97	-0.01	0.97	-0.01	0.97	-0.01	0.97	-0.01	0.97
CMP	0.02	0.95	0.23	0.39	0.39	0.14	0.23	0.39	0.23	0.39	0.39	0.14	0.39	0.14
Ferm. Rank	-	-	0.03	0.9	0.11	0.68	0.03	0.9	0.03	0.9	0.11	0.68	0.11	0.68
EMM	0.21	0.43	0.08	0.77	0.12	0.66	0.08	0.77	0.08	0.77	0.12	0.66	0.12	0.66

p≤ 0.05 indicates correlation between the analyzed variables

Table 42. Spearman correlation coefficient between water quality variables and biochemical variables

Biochemical Variables	Water quality parameters															
	pH		ST		STD		STS		DQO		DBO		N total		P total	
	R	*p*	r	*p*	R	*p*	r	*P*	R	*p*	r	*p*	r	*p*	r	*p*
Caffeine	0.48	0.07	-0.11	0.69	-0.18	0.49	-0.11	0.69	-0.11	0.69	-0.18	0.49	-0.18	0.49	-0.18	0.49
Trigonelline	0.31	0.24	-0.28	0.3	-0.25	0.34	-0.28	0.3	-0.28	0.3	-0.25	0.34	-0.25	0.34	-0.25	0.34
Chlorogenic acids	0.58	-	-0.06	0.82	0.06	0.82	-0.06	0.82	-0.06	0.82	0.06	0.82	0.06	0.82	0.06	0.82
Sucrose	0.32	0.23	0.64	-	0.61	0.61	0.64	-	0.64	-	0.61	-	0.61	-	0.61	-
Proteins	-0.18	0.49	0.27	0.31	0.32	0.23	0.27	0.31	0.27	0.31	0.32	0.23	0.32	0.23	0.32	0.23
Total acidity	0.14	0.61	0.01	0.96	0.11	0.68	0.01	0.96	0.01	0.96	0.11	0.68	0.11	0.68	0.11	0.68
CTn 90	0	0.99	0.4	0.14	0.57	-	0.4	0.14	0.4	0.14	0.57	-	0.57	-	0.57	-
Lipids	-0.07	0.8	-0.21	0.44	-0.31	0.25	-0.21	0.44	-0.21	0.44	-0.31	0.25	-0.31	0.25	-0.31	0.25
Aromatic	-0.04	0.87	0.11	0.68	0.04	0.87	0.11	0.68	0.11	0.68	0.04	0.87	0.04	0.87	0.04	0.87
Acidity	0.47	0.08	-0.06	0.83	-0.11	0.67	-0.06	0.83	-0.06	0.83	-0.11	0.67	-0.11	0.67	-0.11	0.67

p≤ 0.05 indicates correlation between the analyzed variables

1.16 Objective 3. Asses the quality of green coffee samples according to current and to alternative processing techniques.

1.16.1 Association between the wet mill coffee processing variables and the organoleptic variables

The contingency table analysis showed a positive association between coffee quality groups with the demucilager and fermentation. The other variables in the wet mill process showed no significant association with the quality groups (table 43).

Table 43. Association of the wet mill coffee process variables and the organoleptic variables through contingency table analysis ($\alpha \leq 0.05$)

Wet mil variables	***Description of the wet mill Variables***	***R***	***Chi Cuadrado MV-G2***	***p***
Equipment	Drum pulper; Vertical hand pulper	0.23	3.49	0.1745
Water for pulping (W for P)	last wash RW; no water, RW from washing	0.27	9.28	0.0544
Demucilager	yes; no	0.28	7.54	**0.0231**
Fermentation	12h dry; 12h dry partly under polluted water; 24h dry + 12h wet; 36h dry; None	0.39	16.69	**0.0335**
RW for washing	no; yes	0.19	2.44	0.2957
Washing	Clean water; 1&2washRW/3CW; 2 washRW	0.29	8.63	0.0712

Equip=equipment; W for P= water for washing; Demu=Demucilager; Ferm=fermentation time; RW for washing= use of recycled water for washing; Wash= source of water for washing.

Correspondence analyses show that axis 1 has an inertia of 0.26 and Axis 2 has an inertia of 0.18. Axis 1 separates the *regular quality* and *lower quality* from *good quality* of coffee. While axis 2 separates the *regular quality* from *good* and *lower* quality. It can be observed (figure 16) that the duration of fermentation is associated with different types of coffee quality. *Good quality* is associated with fermentation of 24 hour dry + 12 hour wet. The samples of no fermentation (None) (samples obtained from the demucilager after being pulped) also show association with this type of coffee quality as well as dry fermentation of 12 hours after the demucilager. *Regular quality* is associated to 36 hour dry fermentation, while the *lower quality* is associated to 12 hour fermentation partially under polluted water.

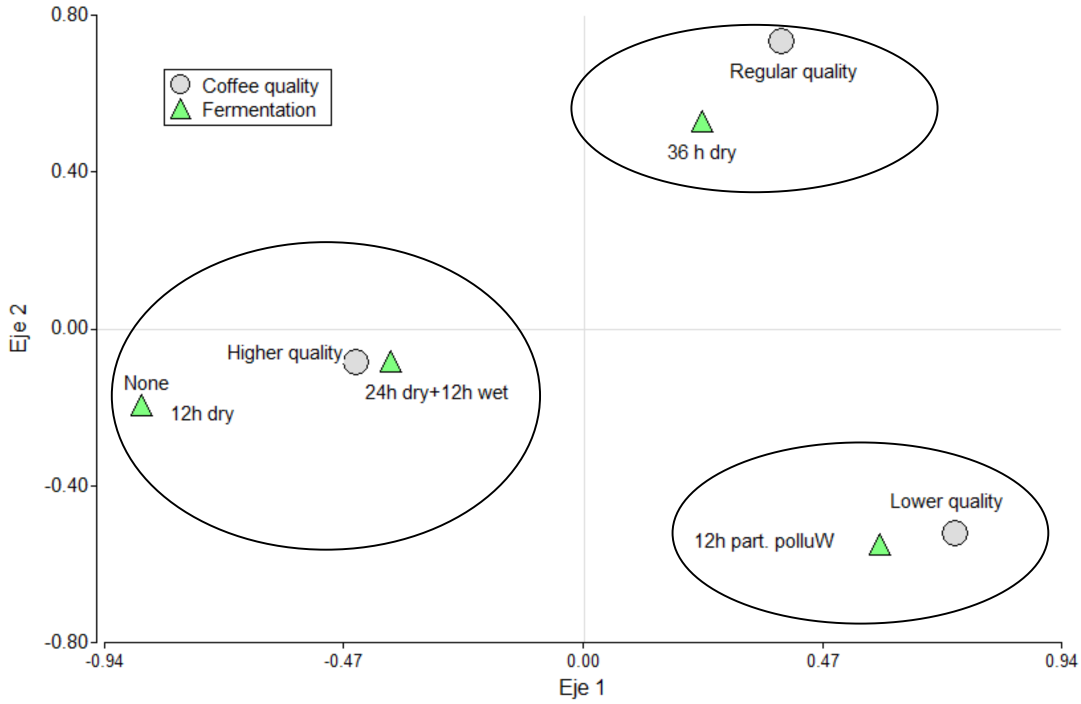


Figure 16. Association between the wet mill process and organoleptic variables trough a multiple correspondence graph

Two types of coffee quality were obtained with the coffee samples that were processed by the demucilager and different fermentation hours, *good* and *lower quality*, which axis 1 separates with an inertia of 0.50. Axis 2 has an inertia of 0.33. The *good quality coffee* is associated to the coffee samples that were fermented after using the demucilager, which were fermented for 12 and 36 hour dry. The coffee samples that were not fermented (None) after pulping and were processed by the demucilager also show association with this quality. The *lower quality* is associated to the samples that were fermented for 12 hour under polluted water and then processed by the Demucilager (figure 17).

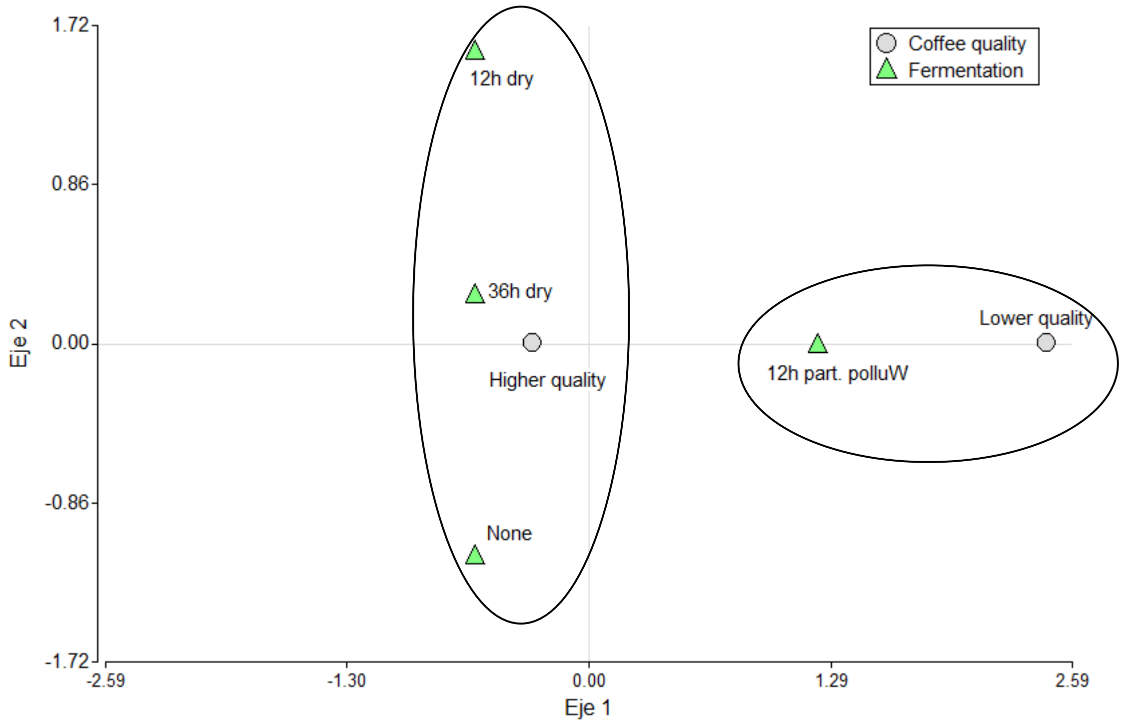


Figure 17. Association between types of coffee quality, fermentation and use of demucilager, through a correspondence graph

Although, the analysis of contingency did not show relation between the washing water and the quality of coffee, according to Vásquez (1993), recycled water from pulping that has been recirculated for 1 or 2 days, gives the coffee more acidity and aroma (all coffee samples from this study were washed with clean water after pulping with recycled water). The variable body showed no differences between conventional practice and recirculation of water. This study was done with Caturra and Catuai. However, Mencía *et al.* (1993) observed that the recirculation of the washing water degrades the final quality of coffee which would result in significant percentage of damaged coffee (fermented). A study done by Jackels *et al*. (date unknown), concluded that under controlled conditions, there is a weak positive correlation between ph of washing water and coffee quality.

1.16.2 Association between the coffee wet mill process and biochemical variables

The variable *wash* from the wet mill coffee process showed association with the biochemical variables. The other wet coffee processing variables were not significant (table 44).

Table 44. Associations of wet mil coffee process variables and biochemical variables through analysis of contingency tables (α≤0.05)

Wet mil variables	*Description of the wet mill Variables*	*r*	*Chi Cuadrado MV-G2*	*p*
Equipment	Drum pulper; Vertical hand pulper	0.09	0.60	0.4396
Water for pulping (W for P)	last wash RW; no water, RW from washing	0.24	4.37	0.1126
Demucilager	yes; no	0.09	0.61	0.4344
Fermentation	12h dry; 12h partly under polluted water; 24h dry + 12h wet; 36h dry; None	0.23	3.87	0.4232
RW for washing	no; yes	0.22	3.56	0.0591
Washing	Clean water; 1&2wash RW/3CW; 2 wash RW	0.28	8.03	**0.0181**

W for P= source of water for pulping; RW for washing= use of recycled water for washing; Washing= source of water for washing.

Correspondence analyses show that axis 1, with a 0.42 inertia separates group1 from group 2. The Group 1 shows association to the recycled water (1&2washRW/3CW) and the recirculation of the second wash (2washRW), while Group 2 shows association with clean water (figure 18).

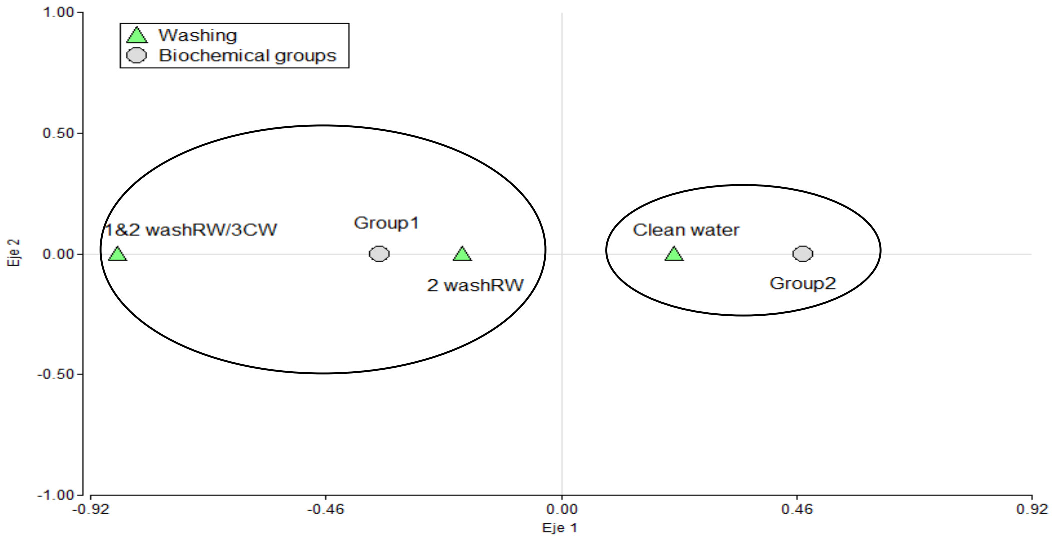


Figure 18. Association between biochemical groups and the variable wash, through a correspondence graph

When exploring the association between the method of washing and the wet mills, significance is found (chi2=17.91, p=0.0065, r=0.54). This shows what was observed during the field phase; the water method of wash in Nuevo Sendero is associated to the use of recycled water (1&2washRW/3CW), Las Brisas and el Retiro to the use of clean water for the washing process and El Jardin and El Retiro to the use of 2 washes (2washRW) (figure 19). Also, the consumption of water in the coffee process is related to the wet mill technology (i.e. water reciculation for pulping and washing) in each visited wet mill but also the management practices and the experience of the employees. Smith 1985, cited by Duarte *et al*. 2010, indicates that the post-harvest processing has pronounced effects on the chemical composition of coffee seeds, especially in water-soluble components like sugars, caffeine, trigonelline and chlorogenic acids.

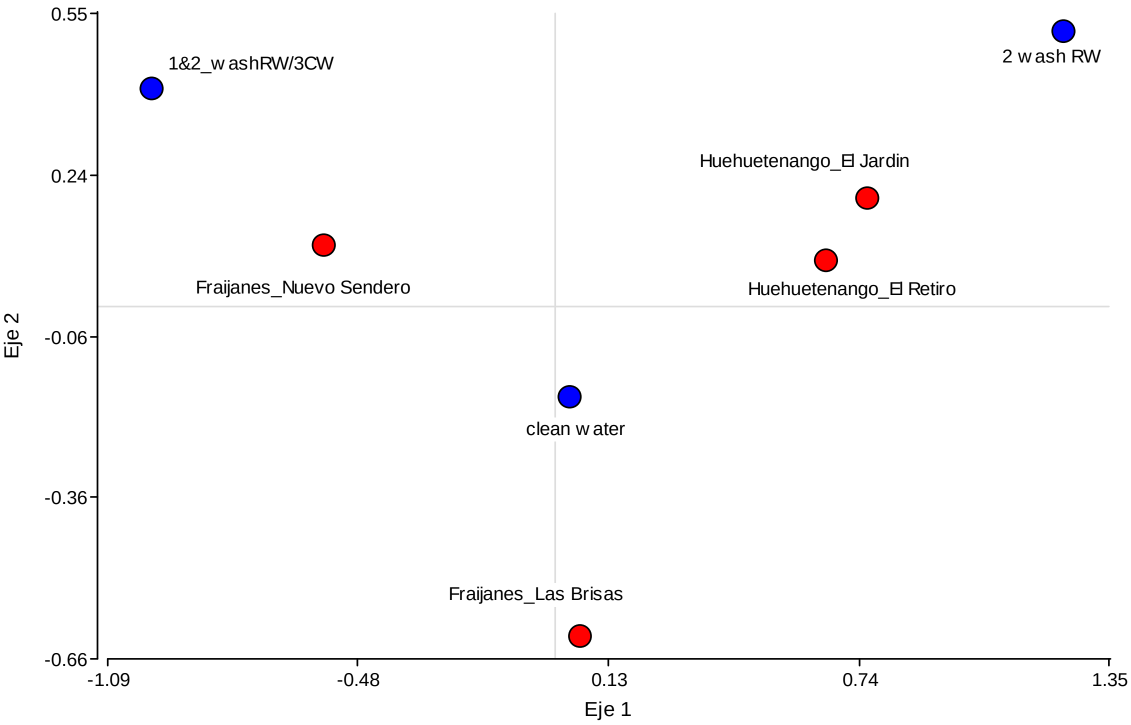


Figure 19. Association between biochemical the different wet mills and the variable wash, through a correspondence graph

The analysis of contingency tables for the organoleptic variables showed that the variable washing (clean water, 2washRW and 1&2 wash RW/3CW) had no association with the organoleptic variables (attributes and off-flavors) (table 45).

Table 45. Association of the wet mill process variable wash and the organoleptic variables through the analysis of contingency tables ($\alpha \leq 0.05$)

Organoleptic variables	**r**	**Chi Cuadrado MV-G2**	***p***
Aroma	0.23	4.36	0.1128
Flavor	0.19	2.78	0.2494
Acidity	0.04	0.14	0.9311
Body	0.22	4.08	0.1300
Aromatic	0.20	3.90	0.1422
Bitter	0.19	2.54	0.2803
CWP	0.11	1.14	0.5645
CMP	0.29	4.54	0.1035
Ferm.rank	0.23	4.36	0.1128
EMM	0.16	2.79	0.2477

Note: Green grassy and Baggy were not included in the analysis because they were not significant in ANAVA.

The analysis of contingency between the variable wash and the biochemical variables show association with the biochemical variables trigonelline, proteins and aromatic (table 46).

Table 46. Association of the wet mil process variable wash and the biochemical variables through the analysis of contingency tables ($\alpha \leq 0.05$)

Biochemical variables	***r***	***Chi Cuadrado MV-G2***	***p***
Caffeine	0.18	2.47	0.2915
Trigonelline	0.29	7.79	**0.0204**
Chlorogenic acids	0.20	4.13	0.1270
Proteins	0.23	6.04	**0.0487**
Total acidity	0.07	0.39	0.8218
CTn90	0.29	4.54	0.1035
Aromatic*	0.25	5.80	**0.0551**
Acidity	0.20	4.35	0.1136

Note: Sucrose y Lipids were not included in the analysis because they were not significant in ANAVA. *Aromatic is not a biochemical compound it is a NIR predictive value of the sensory score.

Axis 1 with an inertia of 0.23 separates the variable clean water from the recirculated water (1&2washRW/3CW) for washing. Axis 2 has an inertia of 0.24 and separates the biochemical variables trigonelline-, aromatic- and proteins+ of the lower quadrant from the variables proteins-, aromatic+ and trigonelline+ from the upper quadrant. The variable clean water is associated to aromatic+, proteins- and trigonelline- but also to trigonelline+, proteins+ and aromatic-; clean water shares all the biochemical variables. However, the variable of recycled water (1&2washRW/3CW) is only associated to the variables trigonelline+, proteins+ and aromatic- (figure 20).

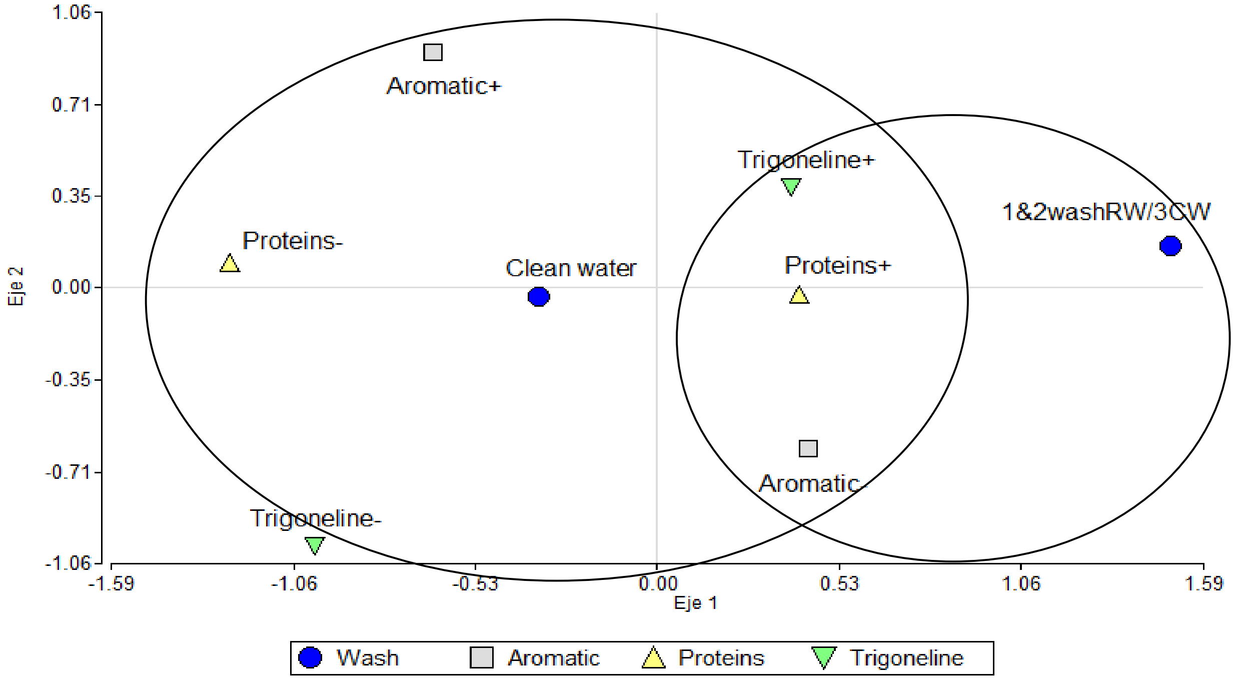


Figure 20. Association of the biochemical variables with the variable wash, product of a corresponded graph ($\alpha \leq 0.05$). The use of the signal (-) and (+) for the biochemical variables indicates higher or lower value of these variables.

Regarding cup quality, washed coffees are known to present better quality, less body, higher acidity and more aroma than the unwashed coffees (Mazzafera & Padilha-Purcino, 2004, cited by Duarte *et. al*. 2010).The post-harvest processing has pronounced effects on the chemical composition of coffee seeds, especially in water-soluble components like sugars, caffeine, trigonelline and chlorogenic acids (Smith 1985, cited by Duarte *et al*. 2010). Duarte *et al*. 2010, concluded that the wet method produced an increase in chlorogenic acids and trigonelline contents and a small loss in sucrose contents comparing to semi-dry method, however, since the soaking period in the wet method is largely variable, more dramatic changes may be observed in these coffee components when seeds are soaked for longer periods of time.

1.17 Objective 4. Analyze the quality of wastewater and the effectiveness of the sanitation techniques.

Among visited wet mills, only Nuevo Sendero had a wastewater treatment facility. Las Brisas was in the process of installing a new wastewater treatment plant (presently they have a anaerobic pond to treat their wastewater). The two wet mills in Huehuetenango, El Retiro and Las Brisas do not have wastewater treatment facilities; they dispose their wastewater into ponds. None of the wet mills discharge their wastewater into water bodies. The effectiveness of the wastewater treatment was done using the last sample of water taken at the end of pulping for each visit.

The wastewater treatment in Nuevo Sendero is the following steps: screening, neutralization (lime $CaCO_3$), flocculation, sedimentation, filtration and separation of clarified water and organic sludge (both with their drains to the oxidation ponds). Although the mill has a wastewater facility it was observed it was not used properly during the visit (do not leave the wastewater in the flocculation/decantation tanks as long as they should; it is suppose to be 2 days). The water sample was taken at the end of the wastewater facility (befo re entering the oxidation pond). The next table 47 presents the initial water quality and the samples of the end of pulping before going into the wastewater treatment facility.

Table 47. Water quality of water being released into evaporation pond (Las Nuevo Sendero)

Water quality parameters	Initial water quality*	End of pulping second day	End of pulping third day	Sample taken at the end of pipe
pH	6.84	4.02	3.6	4.38
Temp C^0	20.1	25.2	17.2	21.5
Conductivity (mV)	-	162.8	-	140.2
T.S (mg/l)	-	35 200	31 200	-
T.D.S (mg/l)	3.75	14 000	11 800	299
T.S.S (mg/l)	0.25	21 200	19 400	-
C.O.D (mg/l)	17	45 213	43 729	40 850
B.O.D (mg/l)	<6	54 240	53 557	21 500
N total (ppm)	0.4	595	609	-
P total (ppm)	0.17	63.80	23.80	111. 21

To calculate the effectiveness (mass of pollutant removed) for each treatment system studied, using each of the control parameters considered, we use the following (CCAD/USAID/DR-CAFTA 2009 in press):

$$\text{Effectiveness} = \frac{(\text{Input data} - \text{Output data})}{\text{Input data}}$$

Table 48. Effectiveness of wastewater treatment in cooperative Nuevo Sendero

Water quality parameters	Efficiency % End of pulping second day	Efficiency % End of pulping third day
T.D.S (mg/l)	97.9	97.5
C.O.D (mg/l)	9.65	6.58
B.O.D (mg/l)	60.36	59.85

As the previous table 48 demonstrates there is a high efficiency of removal of total dissolved solids (average 97.5%), however if the efficiency of the sample of wastewater of the end of the working day is evaluated one can observe that the efficiency is negative. But if the other two days are compared the efficiency of the removal of COD is from 6.58 and 9.65 and BOD is more than 50%. But as mentioned this sample is before the wastewater is discharge into the oxidation pond so it still has another treatment.

As it has been mentioned, Las Brisas was in the process of installing a new wastewater treatment plant. So the only treatment of their wastewater was the oxidation pond. Table 49 shows the parameters of the wastewater at the end of the working day and table 50 the effectiveness of the pond. It can be observed that the effectiveness of removal of pollutants for all the parameters is above 50%.

However a sample of water (third wash, table 19) was taken before being released into the river and if compared to the Regulation of discharge and reuse of wastewater and disposal of sluge of Guatemala (Annexes table 54 *Reglamento de descargas y reuso de aguas residuales y la disposición de lodo*) it can be observed that P total is lower than the maximum permissible limit but N total is not, but if compared with the present permissible limits both parameters would be acceptable.

The parameter T.S.S and pH are also under the maximum permissible limit. But B.O.D does not comply with the wastewater regulations, it is a 1000 mg/l and the maximum permissible limit is 200 mg/l (article 19 of the Regulation of discharge and reuse of wastewater and disposal of sluge of Guatemala). If the T.D.S is compared with the drinking water standard COGUANOR NGO 001:99 29 (table 55 *Norma COGUANOR NGO 29 001:99. Agua potable*) it does comply with the maximum permissible limit (is the value of the concentration of any water quality characteristic, above which the water is not suitable for human consumption).

Table 49. Water quality of water being released into evaporation pond in Las Brisas

Water quality parameters	Initial water quality	End of pulping first day	End of pulping second day	Evaporation pond
pH	7	4.2	3.9	3.97
Temp C^0	23	22.2	20.3	21.8
Conductivity (mV)	-5.6	-	-	166.8
T.S (mg/l)	400	20 600	-	7 800
T.S.D (mg/l)	400	9 400	-	4 600
T.S.S (mg/l)	0	11 200	9 200	3 200
C.O.D (mg/l)	674	33 048	34 749	11 185
B.O.D (mg/l)	<50	30 562	42 556	13 975
N total (ppm)	175	637	497	189
P total (ppm)	10.26	62.25	63.75	13.14

Table 50. Effectiveness of wastewater treatment in cooperative Las Brisas

Water quality parameters	Effectiveness % (first day)	Effectiveness% (second day)
T.S (mg/l)	62.14	-
T.S.D (mg/l)	51.06	-
T.S.S (mg/l)	71.42	65.22
C.O.D (mg/l)	66.16	67.81
B.O.D (mg/l)	54.27	67.16
N total (ppm)	70.33	61.97
P total (ppm)	78.89	79.39

In Farm el Retiro they had two ponds (when the first pond would fill up the water would flow into the next one; they were in cascade). As mentioned before, the washing process is done with clean water and only the last wash is stored for pulping, the other washes were send to the pond. When pulping is done this water is also send to the oxidation pond. These ponds are the only treatment the wastewater receives. There are two columns with values of the water samples of the wastewater (Table 51), the values that are used to calculate the effectiveness of the pond are from pond number two. Table 52 shows the effectiveness of the pond.

Table 51. Water quality of water being released into evaporation pond in El Retiro

Water quality parameters	Initial water quality	End of pulping (8:30 pm)	End of pulping (8:55 pm)	Evaporation pond 1	Evaporation pond 2
pH	6.06	4.1	3.7	3.72	3.67
Temp C^0	17.9	-	-	19.00	18.10
Conductivity (mV)	45.9	-	-	175.60	178.70
T.S (mg/l)	-	-	-	-	-
T.D.S (mg/l)	-	-	-	-	-
T.S.S (mg/l)	0	10 800	4 400	2 600	1 600

C.O.D (mg/l)	1116	32 145	14 030	6 910	5 428
B.O.D (mg/l)	<50	28 122	13 585	7 935	5 149
N total (ppm)	140	280	175	182	133
P total (ppm)	0.86	55	22.90	15	10.95

Table 52. Effectiveness of wastewater treatment in Farm El Retiro

Water quality parameters	Effectiveness% first day	Effectiveness% (second day)
T.S.S (mg/l)	85.19	63.64
C.O.D (mg/l)	83.11	61.31
B.O.D (mg/l)	71.78	62.10
N total (ppm)	52.50	24.00
P total (ppm)	80.09	52.18

In Farm El Jardin they have one big "*fosa*" (pond) for the wastewater. It was not possible to take a sample of the pond because when it was going to be taken all the water had infiltrated. Maybe this could have occurred because they were not using before the visit. Table 53 shows the values of the parameters of the water quality before being released into the pond.

Table 53. Water quality of water being released into pond in Farm El Jardin

Water quality parameters	Initial water quality	End of pulping first day	End of pulping second day
pH	6.9	4.1	4.4
Temp C^0	16.2	-	-
Conductivity (mV)	-3.3	-	-
T.S (mg/l)	-	-	-
T.D.S (mg/l)	-	-	-
T.S.S (mg/l)	0	10 800	1 000
C.O.D (mg/l)	547	32 145	1 878
B.O.D (mg/l)	< 20	28 122	1 300
N total (ppm)	49	280	98.00
P total (ppm)	0.81	55	22.90

Discussion

During the visit none of the wet mills would discharge their wastewater into water superficial water bodies, except in Las Brisas (they would discharge the end of the last washing water into the river). None of the wet mills discharged pulp into superficial water bodies; it was all used as fertilizer (compost).

However if wet mills discharge the pulp and wastewater into superficial water bodies there is a risk of damaging the resource, these elements can affect the water drastically, it causes a reduction in pH, impoverishment of dissolved oxygen, affecting aquatic life; also the turbidity by suspended solids hinders the passage of light, interfering with the photosynthetic activity

(Arcilla-Otero 1979; ANACAFE 1998). A study done in the river Caldera river basin, Panama by Canto (1984), comments that in the pulp and wastewater dumped into the river limited the use of water for drinking and agriculture; it also caused some health problems.

Although shade-grown coffee in its production phase is friendly to the environment by the use of trees of various species as shadow which has contributed to the conservation of ecosystems, yet at the stage of coffee processing there are negative effects as the dumping of wastewater and pulp into water bodies; soil contamination by organic acids that acidify and cause burning to the plants; effect on the communities in terms of agriculture, fishing and recreation; competition of water in population centers; esthetic deterioration of the environment by the appearance of contaminated water and accumulations of pulp, air pollution caused by the decomposition of the pulp (Blanco *et al*. 1999 cited by Gonzales 2000).

CONCLUSIONS

- The water consumption in all the wet mills depends on the employee's criteria and experience. There is no standard procedure in the coffee processing and water usage in the visited wet mills. Each day the workers and smallholders have to adapt to the work load, depending on the volume of coffee to be processed, availability of clean water, level of pollution of recycled water and availability of the drying area.

- The visited wet mills Nuevo Sendero, Las Brisas, El Retiro and El Jardin recirculate water in the coffee process consume less water than the traditional wet mills that do not recirculate water.

- All wet mills recycle water; however, Nuevo Sendero is the only wet mill that recirculates water for pulping and washing. Therefore, there is more consumption of clean water in Las Brisas, El Retiro and El Jardin.

- The water quality parameters (pH, COD, BOD, TSS, etc) for depulping and washing are higher in Nuevo Sendero than Las Brisas, El Retiro and El Jardin but it could be because they recirculate the washing water and depulping water. The other wet mills only recirculated the depulping water. Las Brisas, El Retiro and El Jardin fear that the contact of parchment beans with recycled water (polluted) during washing would have negative impact on the coffee quality.

- The statistical analysis showed three types of organoleptic coffee quality: *good*, *regular and lower quality*; which were classified depending on their organoleptic characteristics. The physical quality (bean size) showed no relationship with the three types of organoleptic coffee quality.

- The coffee biochemical variables were separated in two groups: Group 1 (trigonelline, chlorogenic acid, CTn 90, protein, total acidity, sucrose) and Group 2 (acidity, caffeine, aromatic and lipids).

- The water quality parameters (pH, COD, BOD, TSS, etc) showed no statistical relationship with the organoleptic and biochemical variables.

- The water volume shows no statistical relationship with the coffee quality attributes (aroma, flavor, body, acidity and aromatic) and the off-flavors and the biochemical variables. This result suggests that coffee quality is not affected by the amount of water used in the wet milling process. Given the importance of this aspect, this should be studied in greater detail and scope in future investigations.

- The organoleptic variables showed that the variable washing (use of clean water, recirculated water (1&2washRW/3CW) and two washes, which one was recirculated (2washRW)) had no association with the organoleptic variables (attributes and off-flavors). However, the variable washing showed association with the biochemical variables and the locality (Fraijanes and Huehuetenango); the coffee quality may be determined by factors such as variety, climate, altitude and coffee processing.

- There is association between the organoleptic variables and the demucilager and fermentation variables. The fermentation of 24 hours dry + 12 hours wet and the samples of no fermentation (None) (samples obtained from the demucilager after being pulped) show association with desirable organoleptic variables and produced the higher coffee quality. Meanwhile, the 36 hours dry fermentation produced regular quality coffee and 12 hours dry produced the less quality coffee and 12 hour dry fermentation partly under polluted water was associated to lower quality.

- Two types of coffee quality: high and low were obtained with the coffee samples that were processed by the demucilager and different fermentation periods. The *good quality coffee* is associated to the coffee samples that were fermented after using the demucilager, which were fermented for 12 and 36 hour dry. The coffee samples that were not fermented (None) after pulping and were processed by the demucilager also show association with this quality. The *lower quality* is associated to the samples that were fermented for 12 hour under polluted water and then processed by the demucilager.

- It is difficult to try to find a relationship between the coffee quality and the recirculation of water because there are many variables that could affect it and that could not be controlled during the sampling process. Some of these variables are different coffee varieties, harvesting (ripeness of cherries), management and processing methods of the wet mills (pulping, fermentation time, washing, drying, etc).

- Among visited wet mills, only Nuevo Sendero had a wastewater treatment facility although it was not well managed. Las Brisas was in the process of installing a new wastewater treatment facility (presently they have oxidation pond to treat their wastewater), it was the only wet mill that discharged the last water from the last wash into a river. The two wet mills in Huehuetenango, El Retiro and Las Brisas do not have wastewater treatment facilities; they dispose their wastewater into ponds (*"fosas*").
- The oxidation ponds ("fosas") are essential in wet mill coffee processing since the pollutant load from the residual water has levels above the Guatemalan regulation of discharge and reuse of wastewater and disposal of sluge. Actually, the water treatment is efficient to remove total suspended solids, COD, BOD, decrease pH in all the mills studied. It is important to point out that at least the waste water is not being discharged without any prior treatment into the watersheds and directly into to the rivers (except for Las Brisas, who discharge some of the washing water). However, the effect of the infiltration of polluted water over the ground water has not being yet evaluated.

RECOMMENDATIONS

- This study must be replicated under a controlled environment and with an statistical design in order to be able to evaluate the effect and associations of the different variables/treatments over the quality of the coffee
- A manual (or protocol) must be implemented for the overall management of the wet mills under different workload scenarios because leaving the decisions in the hand of workers could cause a high variability in the processed coffee.
- In order to decrease the water consumption and the contamination loads, the visited wet mills should: pulp without water (vertical pulper), transport pulp without contact with water and have a better management of water recirculation. Also, owners and workers of the mills should be trained and advised about the new and improved machinery that is on the market that uses less or no water for coffee processing.
- Future investigations should test the system of implementing two washes (using the water from pulping or washing from the previous day and recirculate it during the first wash and

than using clean water for the second wash) instead of three in the in the washing stage because the preliminary results obtained show a high efficiency in the smallholders farm El Jardin.

- The cooperative members and smallholders must be trained to be sensitized about the effects and impacts that the water usage and the wastewater sanitation has on the ecosystem, water bodies and surrounding communities.
- Although the cooperative Nuevo Sendero does primary treatment to its wastewater, this process should be adopted in all wet mills to reduce the negative impacts of polluted wastewater.
- The effects of the polluted water being infiltrated by the sanitation ponds over the groundwater quality should be evaluated.

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ANNEXES

Table 54. Regulation of discharge and reuse of wastewater and disposal of sluge of Guatemala (ACUERDO GUBERNATIVO NÚMERO 236-2006)

			Fecha máxima de cumplimiento			
			Dos de mayo de dos mil once	Dos de mayo de dos mil quince	Dos de mayo de dos mil veinte	Dos de mayo de dos mil veinticuatro
			Etapa			
Parámetros	**Dimensionales**	**Valores iniciales**	**Uno**	**Dos**	**Tres**	**Cuatro**
Temperatura	Grados Celsius	TCR +/- 7	TCR +/- 7	TCR +/- 7	TCR +/- 7	TCR +/- 7
Grasas y aceites	Miligramos por litro	1500	100	50	25	10
Materia flotante	Ausencia/presencia	Presente	Ausente	Ausente	Ausente	Ausente
Sólidos suspendidos	Miligramos por litro	3500	600	400	150	100
Nitrógeno total	Miligramos por litro	1400	100	50	25	20
Fósforo total	Miligramos por litro	700	75	30	15	10
Potencial de hidrógeno	Unidades de potencial de hidrógreno	6 a 9	6 a 9	6 a 9	6 a 9	6 a 9
Coliformes fecales	Número más probable en cien mililitros	$< 1x10^8$	$< 1x10^6$	$< 1x10^5$	$< 1x10^4$	$< 1x10^4$
Arsénico	Miligramos por litro	1	0.5	0.1	0.1	0.1
Cadmio	Miligramos por litro	1	0.4	0.1	0.1	0.1
Cianuro total	Miligramos por litro	6	3	1	1	1
Cobre	Miligramos por litro	4	4	3	3	3
Cromo hexavalente	Miligramos por litro	1	0.5	0.1	0.1	0.1
Mercurio	Miligramos por litro	0.1	0.1	0.02	0.02	0.01
Níquel	Miligramos por litro	6	4	2	2	2
Plomo	Miligramos por litro	4	1	0.4	0.4	0.4
Zinc	Miligramos por litro	10	10	10	10	10
Color	Unidades platino cobalto	1500	1300	1000	750	500

TCR = temperatura del cuerpo receptor, en grados Celsius.

Note: The texts in yellow are the present permissible values, however in this study we are comparing with the 2011 maximum permissible values.

Maximum permissible limit: the value assigned to a parameter, which must not be exceeded at the corresponding stages for wastewater and water for reuse and sludge

Article 19. COMPLIANCE TARGET. The goal of compliance, at the end stages of progressive reduction model of loads, is set to three thousand kilograms per day of biochemical oxygen demand with a quality parameter associated with equal or less than two hundred milligrams per liter of biochemical oxygen demand. The existing generating entities to achieve and maintain these values will have achieved the goal set in this paper and the model of progressive reduction of charges of Article 17 of this Regulation.

Table 55. Norm COGUANOR NGO 29 001:99. Drinking water.

Tabla 2. Substancias químicas con sus correspondientes límites máximos aceptables y límites máximos permisibles

Características	Límite máximo aceptable	Límite máximo permisible
Cloro residual libre (1) (2)	0.5 mg/L	1.0 mg/L
Cloruro (Cl^-)	100.000 mg/L	250.000 mg/L
Conductividad	---	< de 1 500 µS/cm
Dureza Total ($CaCO_3$)	100.000 mg/L	500.000 mg/L
Potencial de hidrógeno (3)	7.0-7.5	6.5-8.5
Sólidos totales disueltos	500.0 mg/L	1 000.0 mg/L
Sulfato ($S0_4^{--}$)	100.000 mg/L	250.000 mg/L
Temperatura	15.0°C-25.0°C	34.0°C
Aluminio (Al)	0.050 mg/L	0.100 mg/L
Calcio (Ca)	75.000 mg/L	150.000 mg/L
Cinc (Zn)	3.000 mg/L	70.000 mg/L
Cobre (Cu)	0.050 mg/L	1.500 mg/L
Magnesio (Mg)	50.000 mg/L	100.000 mg/L

(1) El límite máximo aceptable, seguro y deseable de cloro residual libre, en los puntos más alejados del sistema de distribución es de 0.5 mg/L, después de por lo menos 30 minutos de contacto, a un pH menor de 8.0, con el propósito de reducir en un 99% la concentración de *Escherichia coli* y ciertos virus.

(2) En aquellas ocasiones en que amenacen o prevalezcan brotes de enfermedades de origen hídrico, el residual de cloro puede mantenerse en un límite máximo permisible de 2.0 mg/L, haciendo caso omiso de los olores y sabores en el agua de consumo. Deben de tomarse medidas similares en los casos de interrupción o bajas en la eficiencia de los tratamientos para potabilizar el agua.

(3) En unidades de pH.

Maximum acceptable limit (MAL): is the value of the concentration of any water feature, above which water passes to be rejected by consumers, from a sensory point of view but not involving harm to the health of consumers

Maximum permissible limit (MPL:) is the value of the concentration of any water quality characteristic, above which the water is not suitable for human consumption.