Czech University of Life Sciences Prague

Technical Faculty

Department of Technological Equipment of Buildings

Diploma Thesis

Evaluation and trends in coffee roasting

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Contents

LIST OF FIGURES

LIST OF TABLES

I. ACKNOWLEDGEMENTS

First of all, I want to thank God for giving me strength, will and energy to achive this work during this time, at Czech University of Life Sciences in Prague.

This work is dedicated to my family, friends, and to my best friend Ada, who have unstintingly supported my studies from the very beginning. I sincerely thank my diploma thesis supervisor Ing. Mrs. Ludmila ŠKARKOVÁ. CSc., for her consultations and proposals during proceeding with my thesis. Also I would like to thank all of the staff of Technical Faculty, especially Prof.Dr.Ing Mr. František KUMHÁLA, Mrs. Marie MALOUNOVA, for their support.

II. DECLARATION

I hereby declare that I have worked on this diploma thesis independently. All information sources are quoted in References.

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III. ABSTRACT

Nowadays, green coffee beans are the second largest legal commodity traded on the global market, second only to oil. This diploma thesis presents the evaluation of the three main degrees of coffee roasting , mostly used Europe. Two different coffee varieties were taken for roasting, Colombia medium – hard beans and Nicaragua strictly hard beans. A Probat sample roaster was used to roast the coffees to light, medium and dark roasting degree and a time – temperature profile data logger was evaluated. Image analysis of *L*a*b** color space parameters of coffee revealed that color may be reliable criteria for acrylamide formation. Mean RGB values were measured and evaluated regarding the quality of the roasting degree. Analysis of the volatiles profile was performed by gas chromatography–mass spectrometry (GC – MS). Sensory evaluation was performed as a final assessment of coffee flavor and quality. The results indicated that the medium roast, mostly preferred by Europeans, revealed the best cup and that time – temperature profilers are necessary for every roasting degree.

Keywords:

coffee, harvest/post-harvest operations, coffee processing, coffee roasting, roasting degree.

ABSTRAKT

V současnosti jsou zelená zrna kávovníku, hned po ropě, druhou největší komoditou obchodovanou na světových trzích.Tato diplomová práce přináší hodnocení tří základních stupňů pražení kávy, využívaných převážně v Evropě. Dva druhy kávy byly vybrány k pražení, Colombia medium - tvrdá zrna a Nicaragua - tvrdá zrna. Za použití pražírny vzorků Probat byla zrna upražena do světlého, středního a tmavého stupně, ze záznamníku byly poté vyhodnoceny profilové údaje o čase a teplotě. Obrazová analýza L*a*b barevných parametrů kávy odhalila, že právě barva může být spolehlivým kritériem pro tvorbu akrylamidu. Byly naměřeny a zhodnoceny průměrné hodnoty RGB vzhledem ke kvalitě stupně pražení, poté byla provedena analýza těkavých látek prostřednictvím plynové chromatografie a hmotové spektrometrie (GC - MS). Nakonec proběhlo sensorické hodnocení jako finální posouzení chutě a kvality kávy. Výsledky ukazují, že Evropany upřednostňovaný střední stupeň pražení zajišťuje nejlepší kávu a že každý stupeň pražení vyžaduje svůj profil času a teploty.

Klíčová slova:

káva, sklizňové/posklizňové úpravy, zpracování kávy, stupeň pražení.

1. INTRODUCTION

Coffee is the second most valuable legal traded commodity on the face of the earth, only after oil. It's just this little seed, which has this enormous – political, social and economic impact on human beings (Pedergrast, 2010). More money is spent for trading coffee than any other commodity in the world, except for oil. Coffee is a beverage that shares its birthplace with our earliest human's ancestors, it came from Ethiopia and the first cultivation was made by Arabians, in their harbor, Mocha, in the nearby of mountains of Yemen.

Coffee is produced in 70 countries, which are often heavily dependent on coffee for their export earnings. More than 100 million people in the coffee growing areas worldwide directly or indirectly derive their income from it (ECF, 2008).

From harvesting to the cup, coffee includes a big range of operations and processes, such as hand and mechanical picking, preparation and post-harvest operations of cherries, dry and wet processes, pulping, fermentation, mucilage removal, washing, cleaning, hulling, grading, sorting, storage, transporting, roasting, etc. It makes coffee one of the first commodities for using technological equipments.

Green coffee beans have no taste and no flavor, the desired flavor of coffee is produced during roasting. Roasting and its main three stages are the objectives of my diploma research, resulting into an evaluation of pros and cons of each stage and concluding to determine the most favourable roasting degree. Coffee roasting is a very important unitary operation to develop the specific organoleptic properties (flavors, aromas and color) which underlie the quality of coffee and guarantee a good beverage. Even though, this process is highly complex, since the quantity of heat transferred to the bean is crucial. During coffee roasting, moisture loss and chemical reactions (oxidation, reduction, hydrolysis, polymerization, decarboxylation and many other chemical changes), as well as major changes (to color, volume, mass, form, bean crack, density and volatile components) occur, and CO2 is generated. At the end of this all these chemical and physical changes, the beans must be cooled rapidly to halt the reactions (using water or air as a cooling agent) and prevent excessive roast which will alter product quality (Sivetz and Desrosier, 1979;

Raemy, 1981; Raemy and Lambelet, 1982; Nagaraju, 1997; Singh, 1997; Illy and Viani, 1998; Schwartzberg, 2000).

Roasting is a crucial stage in the coffee processing, that is aimed to change markedly the chemical, physical, structural and sensorial properties of the green beans by heat induced reactions. In this way roasting process makes coffee beans suitable for brewing. The green beans are, in fact, characterised by only a weak and greenly aroma and a hard texture, whose make them non-acceptable for consumption (Wiley, 2002).

The quality of coffee, in my work, is evaluated according to criteria such as roasting degree, bean color, cupping, an main volatile compounds. Such criterias are also mention before in previous studies in Banks (1999), Franca (2005), Selmar (2006), and Agresti (2008).

This diploma work is divided in four parts, starting with a background overview about the main processes of coffee and its current state, then materials and methods used for experiments, the third part consist of the conducted results and their discussions with other author, and the last part is conclusions of the work done.

2. LITERATURE REVIEW

2.1 Botany and botanical description of coffee

Coffee (Fig.1) is a woody, perennial evergreen dicotyledon belonging to the botanical family *Rubiaceae*, genus *Coffea,* which contains some 500 genera and over 6000 species. It is grown between the tropics of Cancer and Capricorn. This family comprises many genera including *Gardenia, lxora, Cinchona* (quinine) and *Rubia.* The latter includes *Rubia tinctoria* (the Turkey Red), from which the name of the family Rubiaceae was derived. Coffee is an evergreen shrub or evergreen tree height of 5-10 m of the family. Coffee tree has a greenish-gray bark. Branches are long, flexible, spreading. Leaves entire, single cut, slightly wavy, opposite, 5-20 cm long and 1,5-2 cm wide, on short petioles. The genus *Coffea* covers approximately 70 species. Out of 70 species, only two have the most economical importance and are widely cultivated: the *Coffea Arabica* (Fig.2) Linnaeus and *Coffea canephora*Pierre(var. *robusta*) (Fig.3). The primary branches are opposed and horizontally drooping, and the leaves grow in pairs on short stalks. They are about 15 cm in Coffea arabica and longer in Coffea canephora, oval, and fairly dark green in color Two other species which are grown on a much smaller scale are *Coffea liberica* (Liberica coffee) and *Coffea dewevrei* (Excelsa coffee).

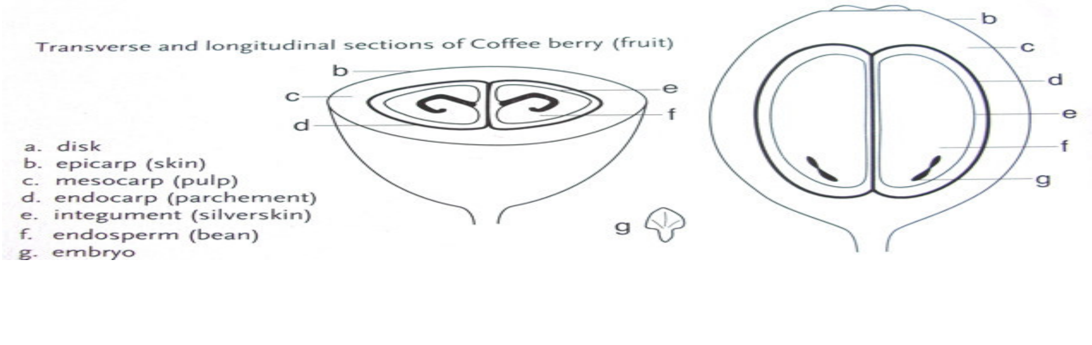
Fig. 1 Coffee Flower

Fig. 2 Arabica coffee

Fig. 3 Robusta coffee

An altitude of 600–1200 m is ideal for coffee, but it can also be grown at up to 1800 m. It can also be grown in sea level. But as in the case of tea, the higher the altitude, the better the quality. But the limiting factor is that coffee cannot withstand frost. Type of coffee tree and its fruit depending on variety, climate, soil, agricultural. The plant does not tolerate strong tropical heat and the weakest frosts. Coffee trees grow best in loose soil in a warm climate with stable temperatures and require from 1500 mm up to 3000 mm of precipitation per year. Seeds are light-gray, oval, plano-convex, the flat side has a deep furrow. They are solid, covered with a thin "silver" or "parchment" shell, which when processed is erased, its remnants are held only in the groovem (Ramalakshmi., Raghavan, 2003). The coffee plant takes approximately 3 years to develop from seed germination to first flowering and fruit production (Wintgens, 2004). A green coffee bean germinates six to eight weeks after planting. The first leaves appear between two and four months, the first crop is produced after 3 years. The coffee tree lives for 50 years (up to 80 yrs, if maintained properly). There are also positive effects of coffee plantations in terms of biodiversity protection, carbon capture and oxygen generation. It is estimated that coffee plants give an equivalent of about 35% of the positive effects of carbon dioxide capture of the same area of woodlands (Anacafe, 2001). It flowers twice yearly (eight to ten times in very wet seasons). Each tree produces about 30.000 white flowers with a jasmine-like scent. After 24-36 hours they set and the fruit begin to form. The cherries often called as coffee berry (Fig.4) are the fruit of the coffee tree. Yellow at first, they turn orange and finally ripen to a bright cherry red, 6 to 8 months after flowering (Boe, 2001**).** A normal cherry contains two seeds, or beans, that grow nestled against each other. When one of these beans doesn't develop properly, the remaining bean takes over the extra space and becomes more rounded. These anomalies are known as "peaberries". Because of their unique appearance and flavour(according to their aficionados), they are sold separately. The beans are basic elements for producing roast and ground coffee, soluble coffee powders, and coffee liquor. From an adult plant can receive up to 500 g of green beans per year.

Fig. 4 Transverse and longitudinal sections of Coffee cherry



2.1.1 Arabica vs Robusta

Coffee Arabica accounts for between 60% and 70% of world production. At most, 10% out of 70% is actually of "specialty" quality. Arabica coffee is milder, more aromatic and contains less caffeine than Robusta coffee. It has low enzymatic variability. Measurements made with a large number of seeds of *Coffea arabica* indicate that the seeds are 10 to 18 mm long and 6.5 to 9.5 mm wide (Dedecca, 1957**)**. Arabica coffee is grown throughout Latin America, in Central and East Africa, in India and to some extent in Indonesia. *Coffea canephora* accounts 30% to 40% of world production. With a tree population of abour 3.5 billion adult cultivated plants, *Coffea canephora* is second on the list of world-wide distribution. *Coffea robusta* is noted for its resistance to disease. Robusta coffee is grown in West and Central Africa, throughout South-East Asia and to some extent in Brazil, where it is known as Conillon.

Tab. 1 Differences between Coffee Arabica and Coffee Robusta

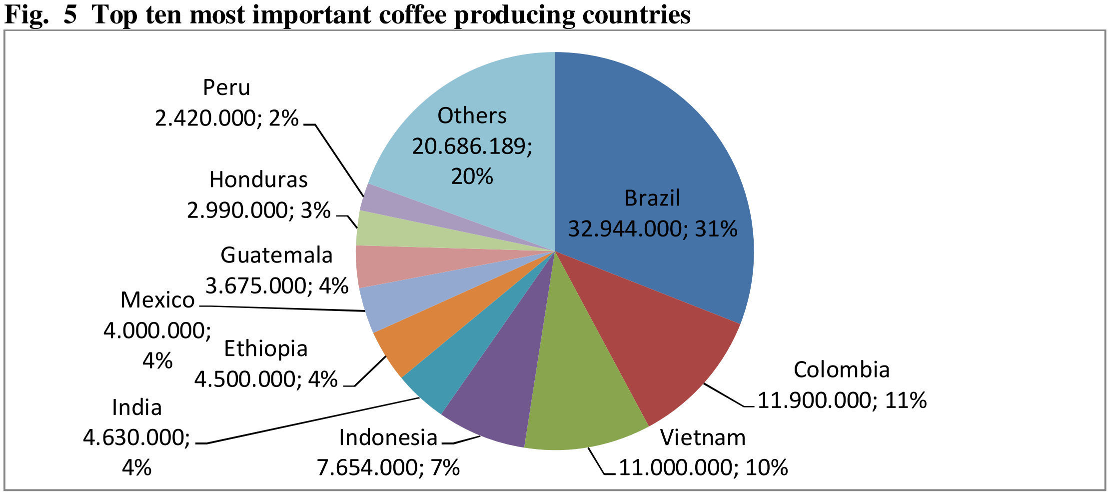
The differences between Arabica and Robusta		
	Arabica	**Robusta**
Height	6-8 m	10 m
Genes	44chromosomes	22 chromosomes
Yeild(kg beans/ha)	1500-3000	2300-4000
Soil requirements	Fertile soil	Poorer soil
Temperature requirements	Moderate	More heat tolerant, more sensitive to cold
Optimum temperature(yearly average)	15-24° C	24-30° C
Optimal rainfall	1500-2000 mm	2000-3000 mm
Optimum altitude for growth	1000-2000 m	0-700 m
Coffee berry disease	Susceptible	Resistant
Typical brew characteristics	Acid, fuller flavour	Bitter, weaker flavour
Caffeine content of beans	0.8-1.4%	1.7-4.0%

Source: Adapted from International Coffee Organization, www.ico.org

2.2 Economy of coffee

Coffee is the world's second most important export product for the developing countries after crude oil. In 2005, exporting countries earned an estimated USD 9,2 billion for exports totalling 86,2 million bags (5,2 million tonnes). Production - World coffee production by the top ten producing countries (Fig.5) is projected to grow by 0.5 percent annually from 1998–2000 to 2010-2012, compared to 1.9 percent of the previous decade. Global output is expected to reach 7.0 million tonnes (117 million bags) by 2010-2012 compared to 6.7 million tonnes (111 million bags) in 1998–2000. In Colombia, based on the age profile of the coffee areas, output is projected to grow at an annual rate of 0.7 percent to 2010-2012 to reach 747 000 tonnes (13 million bags), compared to 699 000 tonnes (12 million bags) in 1998– 2000. Some plantings took place during the 1990s in response to the surge in demand for Colombian Milds, which fetch premium prices over other Arabicas (FAO, 2003).

Fig. 5 Top ten most important coffee producing countries

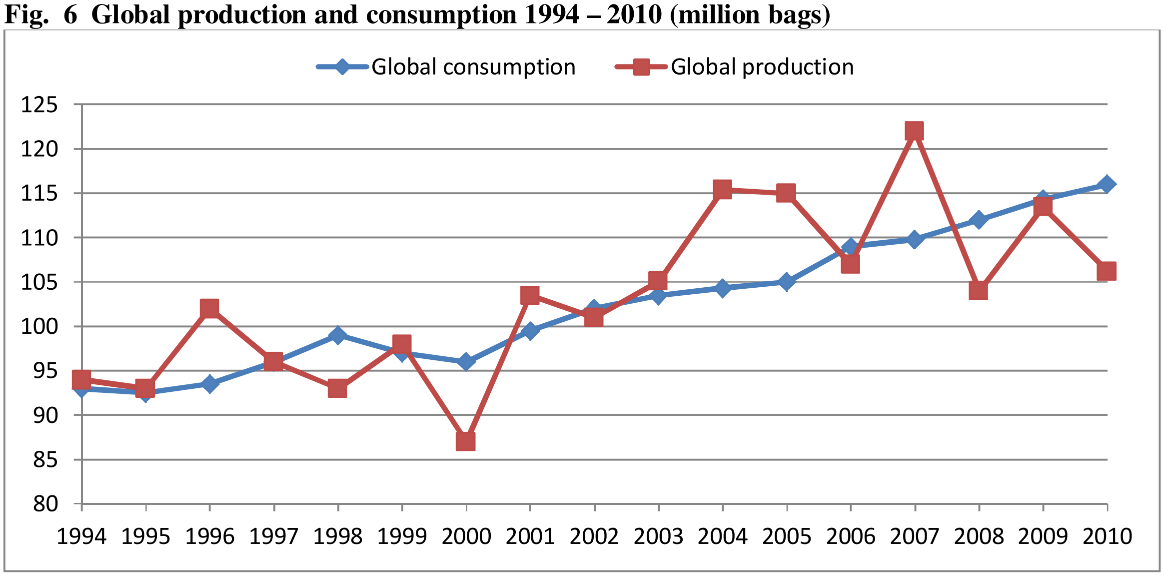


(volume in bags 60kg and in percentage share of total production)

(Source : International Coffee Organization, (08/2006)).

Consumption - World consumption of coffee (Fig.6) is projected to increase by 0.4 percent annually from 6.7 million tonnes (111 million bags) in 1998– 2000 to 6.9 million tonnes (117 million bags) in 2010-2012. Coffee consumption in developing countries is projected to grow from 1.7 million tonnes (29 million bags) in 1998–2000 to 1.9 million tonnes (32 million bags) in 2010-2012, at an annual rate of 1.3 percent, while their share in the world market is expected to increase from 26 percent in the base period to 28 percent in 2010-2012. Coffee consumption in developed countries is projected to grow by 0.1 percent annually to 5.0 million tonnes (83 million bags) by 2010-2012. In Europe, demand for coffee is projected to increase by 0.4 percent per year to 3.1 million tonnes (51 million bags) by 2010-2012. The European Community is projected to account for 2.2 million tonnes (36 million bags), or 68 percent of total consumption in Europe (FAO, 2003).

Fig. 6 Global production and consumption 1994 – 2010 (million bags)



(Source : International Coffee Organization, (08/2010)).

2.3 Social impacts and psychological effects of coffee

The real social impact of coffee is the sense of humanity, human connection around the coffee, and coffee experience. Coffee is one of the great romantic beverages of our time, it's filled all over with such unique history and it's the beverage of truth. The coffee drink has had a curious evolution. It began, not as a drink, but as a food ration. Its first use as a drink was as a kind of wine. Civilization knew it first as a medicine (Ukers, 1935). Wherever coffee has been introduced, it has brought revolution or change; coffee which has given so much pleasure to Europe will bring enormous pain to Africa, where it comes from and the colonies, where it's going. The irresistible bean is about to catch fire across the ocean, and it will transform the economies, ecologies and politics of all of the americans (Angelico, 2005).

Coffee is one of the world's largest traded commodities, produced in more than 70 developing countries, and consumed mainly in developed countries with over US$70 billion of retail sales each year. At least 14 countries depend on coffee for 10% or more of their export earnings. Coffee is an important income generator for more than 125 million people in 52 tropical developing countries. About 25 million people, mostly small-holders, cultivate this perennial crop on 11.8 million hectares of arable land, to produce 6.6 million tonnes of consumable coffee annually (ICO, 2003). After oil, coffee is the second largest internationally traded commodity. Between 1962 and 1989, coffee was subject to an international commodity agreement, the International Coffee Agreement (ICA). This agreement has led to a sustainable coffee growing and/or production, which within itself it has a large social benefit. This social benefit is a less precarious standard of living for local producers. This includes stable employment, improved conditions of health for workers and support for local community development. Community projects include basic health care, education and housing improvements (Wintgens, 2004). When it is about social life of coffee, it is about Fair-Trade. Fair-Trade is an international system for assuring that farmers get paid a fair price for their work.

Coffee was the first Fairtrade labelled product, launched in 1989 and is still the best known Fairtrade labelled product among consumers in Europe, North America and Japan. Sales of roasted Fairtrade coffee in 2004 were 24,323 tonnes, corresponding to about 0.42% of demand. The largest markets for Fairtrade coffee in 2004 were the US, followed by the UK, the Netherlands and Germany. Sales worldwide were up 26% from the previous year and there has been significant growth since 1999. About 12% of all Fairtrade coffee sales in 2004 were also organically certified (Consumers International(CI), 2006).

Research results seem to be inconclusive when trying to associate its intake with beneficial or detrimental effects on health (Shlonsky, 2003). There is a big question between benefits and risks regarding coffee consumption and its most common chemical component caffeine. Caffeine is the most widely taken psychoactive drug on earth, and coffee is its foremost delivery system (Pendergrast, 2010). Because of its presence in popular drinks, caffeine is doubtlessly the most widely consumed of all behaviorally active drugs (Serafin, 1996; Fredholm, 1999).

Caffeine – $C_8H_{10}N_4O_2$ is one of the alkaloids: organic (carbon-containing) compounds built around rings of nitrogen atoms. It has no smell or colour, but accounts for 10% of the bitter taste of roasted coffee (Chambers, 2009). Coffee is one of the most common beverages consumed by millions of people all over the world and results in stimulant effects on central nervous and cardiovascular systems (Berger, 2003).

Some benefits : Coffee can be described as a "useful painkiller". Coffee consumption can apparently help prevent Parkinson's disease in heavy coffee drinkers(3-4 cups/day), Alzheimer's disease, cardioprotective, antioxidant due to anticancer compound methylpytidinium, liver cancer, colon cancer, type 2 diabetes, gallstones and gout(Shearer, 2007). Caffeine's bronchodilatatory action may help to relieve mild asthma. It may help soothe some migraines by acting on the cerebral circulation, because caffeine is a component of some drugs used to relieve migraine. It is a mild diuretic. It is a mild laxative. It increases the secretion of hormones by pancreas, stimulates the formation of acid in the stomach and prevents the formation of kidney stones. Coffee boosts athletic performance (perhaps through stimulation of more adrenaline) by increasing muscular recovery and physical performance(Weinberg., Bealer., 2001). In the nervous system, caffeine can improve concentration and reflexes, increase ability to perform some repetitive tasks without tiring, improve coordination while performing more complex tasks, such as driving(Daly., Fredholm., 2004).

Some drawbacks: These drawbacks are usually known as "Caffeine dependency". Coffee can cause several negative health impacts regarding cardiovascular system, gastrointestinal system, muscular/skeletal, reproductive and respiratory systems. First negative signals of coffee consumption are anxiety and sleep changes, during its half-life, which varies from 2 to 6 hours after intake (Nehlig, 1999; Ogita, 2003; Farah, 2006a; Toci, 2006).

Caffeine causes the blood vessels to dilate. Boiled (but not filtered) coffee has been shown to increase blood cholesterol. Excessive intake can cause shaking, irritability and anxiety. The toxic effects of caffeine are reached at the level of more than 0.5 grams (five cups of coffee daily). Above this there is an increased risk of palpitation of the heart, and eventually convulsions, coma, and pulmonary oedema. According to the *Harvard Medical School* , the fatal level is at about 10 grams of caffeine in the blood(75-100 cups of coffee a day). Other problems regarding the intaking of caffeine are grown-up effects in childrens, iron deficiency anemia and last but not least cholesterol. (Malliani., Pagani., Lombardi., Cerutti., 1991).

2.4 Harvest Operations of Green Coffee

2.4.1 Harvesting

Harvesting is a crucial step in the production of a good-quality coffee(Paquin, 2009). Even though the awareness of quality is very important throughout the whole agricultural process, the degree of maturation of coffee fruit and the care to avoid undesirable fungus contamination and growth during harvesting, drying and storage of the seeds are critical points (Taniwaki, 2003).

On the other hand estimation of harvest operations is of interest to all the participants in coffee production. In an industrial plantation, of a cooperative or of coffee-growers associations, this can be used to determine more accurately the logistical necessities for transport and post-harvest treatment for instants and overhead needs. On a national scale, early coffee harvest assessments allow the responsibles to fix and negotiate the prices of green coffee (Jacquet, 1996).

There are usually 2-main harvests periods: the largest harvest comes in October through December, and the smallest one comes in April and May. But it can very a lot, in different countries. For instance in Nicaragua, harvesting can start from December through to March, and in Colombia, the main one from September to January, and within the main harvest, there is also a new season around February – March.

(Source: www.grumpymule.co.uk/coffee-tour/coffee-from-seed-to-cup/coffeeharvests-and-seasons)

Each year coffee is harvested during the dry season when the coffee cherries are bright red, glossy, and firm. According to Brando (1999), harvesting of coffee fruits is done in three different ways:

1. by hand-picking/selective harvesting – ripe cherries are individually picked by hand, usually only used for arabica
2. by manual stripping – all cherries, including unripe and overripe cherries, are stripped from the tree simultaneously
3. mechanical harvesting – all cherries are collected using a specially designed harvesting machine (Brando, 1999)

The ideal situation is to harvest all fresh, ripe cherries with the least possible damage to the tree, irrespective of the processing system to be used. With the high progress of harvesting technology nowadays, 100 % cherry harvesting may be only achieved by *selective hand-picking*, which mostly corresponds to the most expensive option available. All the flavor potential exist at the moment of picking, each step after that provides the opportunity, to maintain that flavor or imperil in some ways or other. When only ripen cherries are picked, then the amount of quality coffee is higher, too. From a quality perspective, it is better to avoid the use of immature cherries, and from an OTA perspective, the removal of overripe cherries, in certain situations, may be regarded as a useful OTA-prevention measure. On the other hand if a mixed product is picked, the amounts of quality coffee are smaller, but harvesting costs fall.

In hand-picking, only ripe fruits are picked one by one, by visual means using color as criterion and when, on gently squeezing the fruit, the bean inside pops out easily. Mostly, used in Central American arabica plantations. Ripe cherries are either red or yellow depending on the coffee variety. Unripe cherries are several shades of green, whereas over-ripe cherries go from grayish-red or yellow to full black. It is a long and delicate task, repeated from 7 up to 10 times a year as more fruit ripens. A worker can selectively harvest from 50 to 120 kg of fresh cherry per working day. According to Rothos, trees must be harvested rapidly since the period that elapses between the beginning of the ripening process and the onset of the state of overripenness is at most 10-14 days (Rothfos, 1980).

If, for any reason, it is not possible to pick coffee as it ripens, the over- and underripe fruits should be scrupulously sorted out before using them for pulping. They may be dried separately as cherry beans. It is advisable to wash and dry the bags that are used for collecting the harvested fruits frequently(Ramalakshmi, 2003).

Manual stripping, aslo known as “milking”, consists of removing everything from the branches by hand such as: flowers, leaves and ripe, overripe and immature fruit. It is in use in Brazil and Africa, it produces a high yield but poor quality. All cherries, in different maturation stages are picked and dropped either directly to the ground, that has been previously cleared, or onto plastic sheets or cloths spread under trees. A worker can strip harvest between 120 and 250 kg of cherries per working day (Wintgens, 2004).

2.4.2 Mechanical Harvesting

Nowadays, there are two alternative technologies for mechanical coffee harvesting: large mechanical harvesters on wheels and light hand-held harvesters.

Large harvesters on wheels

Introduced and made for the first time in Brazil in 1970, then in the U.S.A and Australia. Lighter, tractor-driven versions are more recent. Basically all large harvesters work on the same principle: one or two vertical or forward-leaning shaking heads that travel along the coffee row causing the cherries to drop. The shaking head is composed of a center shaft and spoke-like rods made of synthetic materials (e.g. fiberglass, nylon, graphite, etc.) (Wintgens, 2004).

In self-propelled machines the usual arrangement is two shaking heads, one on each side of the coffee row, dropping coffee onto a “fish-plate” collection system which unloads the cherries into a conveyance system that lifts them to a pneumatic separator to discharge leaves and other light impurities and to load the clean cherries into bags or boxes.

Three basic parameters are used to evaluate the performance of the large coffee harvesters: selectivity, crop removal and recovery.

Light hand-held harvesters

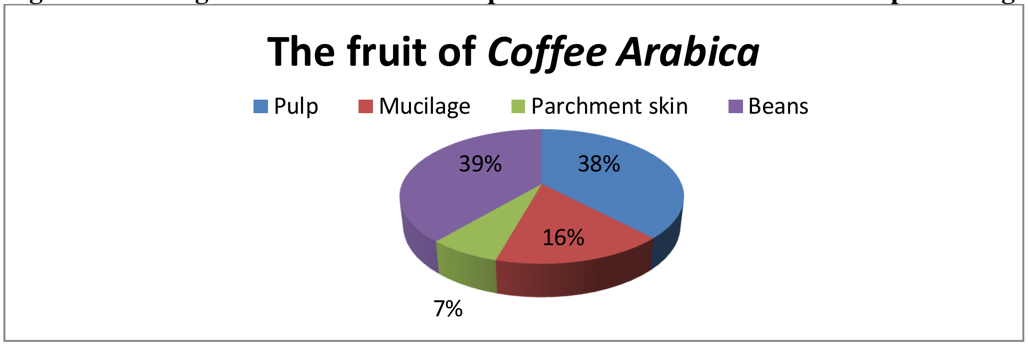
Hand-held harvesters were tested in Brazil in 1994 and commercially sold from 1995. Widely used in Brazil, mainly in areas where the slope and tree spacing do not allow he use of the larger machines on wheels. The hand-held harvesting tool is composed of two sets of rods driven by a pneumatic piston. As the tips of these hand-like sets of rods move, they transmit vibrations to the branches of the tree and cause the ripe cherries to fall on the previously covered ground. This small shaking head is assembled at the end of a pole that is available in several lengths in order to harvest trees of different heights. This individual shaking head is light and manually operated so it can be directed to the branches or parts of branches where maturation is more uniform. Their advantages are that, they may be used in all conditions, i.e on all types of slopes as well as in flat areas, with coffee trees of all heights and any spacing between trees and they cause less damage to the trees than harvesters on wheels (Brando, 1999).

2.4 Post-Harvest Operations of Green Coffee

At the moment that coffee fruits are ripen, and after that harvested as cherries, they unsuitable for consumption, storage and transport. The pulp containing water and sugar, the moist parchment skon and beans – all this would rapidly ferment, moulder and rot if transported or stored. In order to achive the state that is necessary for the further preparation of coffee until it has reached its final state for consumption, the entire coating of the actual seed of coffee fruit must be removed, and the beans dried and cleaned (Rothfos, 1980).

In order to obtain marketable coffee it is thus necessary to remove the fruit skin, pulp, mucilage, parchment, and if possible the silver skin, as well as the major amount of water inside the beans . The water content of the whole ripe fresh cherry is about 65%. Coffee processing aims to lower the water content of fresh cherries to a level which allows the preservation of beans (about 11-12 %), removing all the covering which surround the beans and preparing the beans according to market requirements (Brando, 1999).

Fig. 7 Percentages of the main fruit components of Coffee Arabica before processing



There are three known ways, that are used for processing :

1. Dry process – gives natural coffees, and the coffee obtained by this process is called *cherry coffee*. It implies that the whole cherry is dried together with pulp, parchment and bean. The whole hull (dried pulp and parchment) is then removed mechanically to obtain green coffee. The dry process is used for more than 80% of Brazilian, Ethiopian and Yemen Arabicas, and for almost all Robusta coffees in the world.
2. Wet process – gives washed coffees, and the coffee is called *parchment coffee*. This process tends to generate a higher-quality beverage. It implies that the pulp is removed mechanically. The mucilage is also removed before drying. Hulling of dry parchment coffee leads to green coffee. The wet process is used for all Arabicas other than those mentioned above and only for a small percentage of Robustas. Frequently, wet processing is used in places where coffee is harvested by picking, such as Colombia, Asia and Central America.
3. Semi-dry process – or pulped natural process, created in Brazil. Here, the mucilage is not removed after pulping, and parchment and mucilage are dried together. Green coffee is obtained by hulling dry parchment with dried mucilage adhering to it. The semi-dry process is used in Brazil and Burundi.

Cherries must undergo either dry, semi-dry or wet processing as soon as possible after harvesting, as this helps reduce the opportunity for mould growth and the risk of OTA contamination.The major difference between dry and wet processing is that in the wet processing all material that involves the seeds is removed before drying (Paquin, 2009).

Green coffee, obtained by any of the three processes, is submitted to three successive types of sorting according to size, density and color. Mechanically, manually and/or electronically sorting can eliminate defective beans. process may be followed by an additional sorting with UV excitation to separate defects which may be produced during both dry and wet processing and which are very difficult to separate from healthy beans, except for the fact that they show special fluorescence (Flament, 2002; Bee, 2005). Blending of different coffee types or bulking of equal qualities may be required for export or roasting.

2.5.1 Dry Processing

According to Trugo (2003), the objective of dry process is to lower the moisture content of cherry coffee (also parchment coffee) to about 12% so as to avoid any bacterial and mould growth, and ochratoxin A production – as a main factor influencing coffee quality, as well to preserve the beans safely in storage.

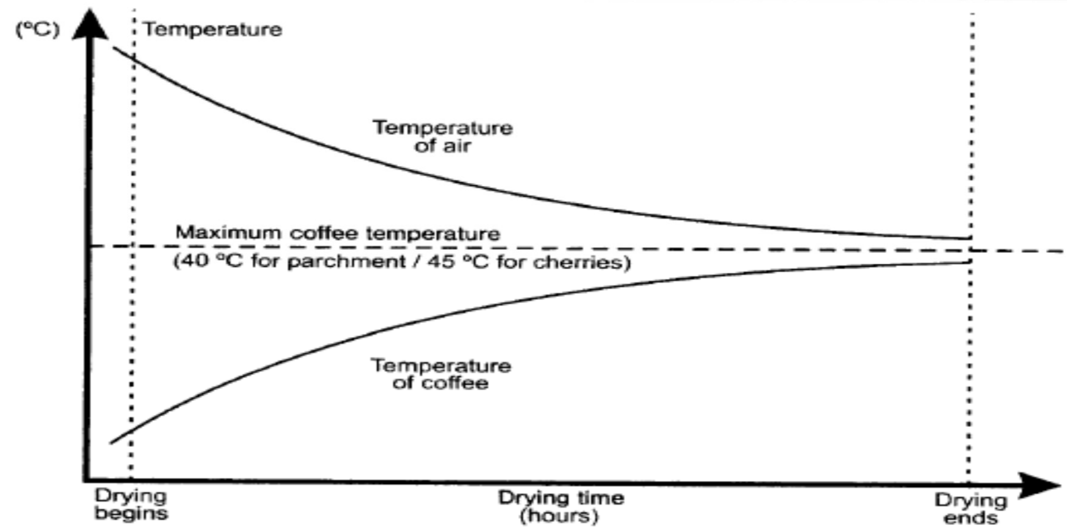
Wet parchment coffee has a moisture content of approximately 60%, and fresh cherry coffee is obviously higher. The optimum moisture content of coffee beans must be dried to, is 12.5%, the maximum level recommended by the International Coffee Organization. Moisture contents above 12 % increase the risks of quality and weight loss in storage. In areas with a high humidity content, coffee is usually dried to 10 or 11 % to increase storage time, before coffee catches moisture from the air. But in other areas drying may stop at 13 or 14% to account for moisture losses in hulling. Moisture levels under 10 or 11 % increase the breakage of beans at hulling, in particular with Robustas that are more brittle. Drying is complete when the moisture content of the dried cherries is around 12%. At this stage the outer shell is dark brown and brittle. The bean rattles inside the husk. Dried beans are bagged and stored for several weeks.

Hulling of dried cherries is not usually practiced after drying. During this time the green beans inside the dried shell continue to lose some of their moisture content and spread out evenly by osmosis. The ratio of dry cherry to green beans is usually 2:1 (Sivetz., Desrosier, 1979).

Drying on the bare ground is not advisable as cherries become stained by dust and earth and often acquire an earthy smell and taste. Drying in the sun takes 3 to 5 weeks depending on the thickness of the layers of cherries, temperature, and amount of daily sunshine. During the dry process the cherries have to be turned over at regular intervals to ensure even drying to prevent fermentation of the lower layers when the temperature drops or ultimately rains occur. The coffee must be covered or placed under shelter during night timings.It is necessary to emphasize that proper drying contributes to the healthy color and quality of the bean. Under-dried parchment turns 'moldy' and is 'bleached' during storage and subsequent curing operations (Chakraverty., Mujumdar., Raghavan., Ramaswamy, 2003).In this process, coffee is dried by increasing the temperature of the bean to evaporate water. Three main steps of the dry processing are : cleaning, drying and hulling. The coffee beans in this process can be either dried by sun, also known as sun-drying, or dried mechanically, a.k.a mechanical drying.

In sun drying beans are heated by direct exposure to the sun and by radiation from a heated surface (in the case of drying grounds). Convection and wind move the saturated air away. In mechanical drying beans are heated by the passage of hot air which also carries the moisture away (Rothfos, 1980). Temperatures must be monitored during natural and artificial drying. Coffee temperatures should not exceed 40°C for parchment and 45°C for cherries. It is often thought that overheating can only occur in mechanical dryers. Reality points to the opposite. Maximum tolerated temperatures may well be exceeded in sun drying if the beans are not revolved frequently. In sun drying, temperature is controlled by revolving the coffee frequently. Parchment should be covered before it becomes too hot. In machine drying, the temperature is controlled by fuel feeding, air flows, etc. An efficient drying system must ensure a good temperature control, homogeneous air distribution, and frequent revolving of coffee. In the Fig.8 , it shows how air and coffee temperature behave in a dryer (Brando, 1999).

Fig. 8 Relations between coffee and air temperature in a dryer



(Source : Coffee - Growing, Processing, Sustainable Production. Wintgens, 2004)

In most types of dryers the coffee will not heat beyond 30°C while the moisture is high even though the air temperature may reach 90°C. If any damage to the color or liquoring quality of the coffee is to be avoided the coffee beans with a moisture content of about 20% will tolerate temperature of only 40°C over several days, of 50°C for some (10 at most) hours, and of 60°C for less than one hour. It is widely accepted that the color and quality of Robusta coffees benefit from a high air temperature at the initial stages of drying. Air temperature must be lowered as drying progresses. Control of the air temperature is critical towards the end of the drying process because the coffee starts to gain temperature rapidly. In order to preserve quality, temperatures for parchment coffee should not go above 40"C, whereas for cherry coffee they should not exceed 45 "C. In Fig.8, it is assumed that coffee enters the drier "fully wet" (recently picked cherries or parchment that has just been washed) and leaves the dryer with a moisture content of 12 %.

The damage caused by overheating depends on coffee moisture content, the temperature and the time coffee is exposed to overheating (Clarke., Macrae., 1985). The speed of drying cannot be increased above the speed at which moisture migrates from the center to the periphery of the bean. The speed at which water migrates in response to the temperature gradient artificially created is limited. This is a physical characteristic of the coffee beans and it cannot be changed. Attempts to accelerate drying beyond accepted limits will always leave moisture in the center of the bean.

This moisture can be removed later on, and it will have a negative effect on the characteristics and the quality of the coffee (Wintgens, 2004).

2.5.1a Sun drying

Sun drying is also referred as natural drying. Most of the world's coffee is dried in sun, although the present tendency is to dry more and more in mechanical dryers because of rising labor costs, unfavorable weather, and the goal of obtaining uniformly dried beans. Freshly pulped and washed coffee usually contains 52% to 54% moisture. After draining of excess water, beans are spread on the drying terrace. The thickness of the layer is usually 5–10 cm and coffee is raked at frequent intervals during daytime (Rothfos, 1980; Ramalkshmi., Raghavan., 2003; Wintgens, 2004).

To prevent uneven drying and cracking of the parchment during intense heat or sunshine, the coffee beans should be covered or dried in shade; in the case of cherry coffee, the fruits are heaped for 1 or 2 days to allow softening and then dried in open yards. Fruits are dried up to a moisture level of 12%; drying may take about 1 week for washed coffee and about 3 weeks for natural coffee (Sutherland., Varnam, 1994).

The cherries are sun-dried in flat layers on suitable ground. For a quantity of 40 kg of fresh cherries normally a maximum layer of 5 to 6 cm is needed, and in terms of square metres one reckons one twentieth of the number of trees. Thus for every 1000 trees a minimum area of 50 square metres is needed for drying, because during the time that is necessary for the cherries to become dry there will be continuous influx of newly harvested crops. For large plantations covering more than 100.000 trees much space might be needed as a drying ground. According to the calculation mentioned, 100.000 trees already require an area of 5000 square metres, and 200.000 trees require 10.000 square metres or 100 x 100 metres (Rothfos, 1980).

Three methods of natural/sun drying process can be :

1. Drying grounds – patios, flat surfaces built with a small slope (0.5-1 %) to drain rainwater. Screens with holes smaller than the coffee beans are placed at the low points to drain rainwater. Drying grounds are usually made of concrete, tiles or asphalt. Compacted soil patios, still found in some areas, should not be used if coffee quality is a concern. Wet coffee is spread in thin layers and revolved 8-10 times per day with a flat rake. During the initial stages of drying coffee should not be covered at night or when it rains. Regarding climatic conditions, sun drying in patios takes from 7 to 15 days for parchment and from 12 to 21 days for cherries.
2. Drying racks – wire or plastic mesh trays assembled on table legs. Mostly used to dry parchment coffee. Depending on climatic conditions, parchment takes 5-10 days to dry on raised racks.

2.5.1b Mechanical drying

Mechanical dryers are referred as artificial dryers. Generally, machine drying consists of passing hot air through a bed of coffee. Some mechanical dryers are: a) static dryers - are the most primitive type of dryers. Easy and cheap to build anywhere, they only require a tray made of a perforated metal plate, a fan (optional) and a source of heat. Colombia, which relies heavily on static dryers, has developed several types of two-tray static dryers that enable alternate air flows with a view to improving homogenity. b) column/tower batch dryer - consists of a round, rectangular or square tower, several meters high. Inside this, there is a smaller perforated structure of similar shape which receives the hot air and distributes it through the coffee layer. The space between the two structures is completely filled with coffee which moves downwards slowly. After passing through the layer of coffee beans, the moisture-saturated air leaves the drier either through its open top or through perforations in the walls of the outside tower. c) rotary dryers – are horizontal rotating drums whose cylindrical walls are made of a perforated metal sheet. Heated air is blown into the hollow shaft of the drum from one or both ends. The shaft may be perforated and have different shapes or attachments like radial perforated pipes to distribute warm air evenly along the drum and to force it to pass through the tumbling coffee. Moist air leaves the drum through perforations in the outer walls (Rothfos, 1980; Wintgens, 2004).

Tab. 2 Ripeness, moisture and duration of the artificially drying process

cherries	moisture in percent	Drying hours at 40 °C
unripe,green	66 - 70	80
almost ripe, yellow	60 - 67	84
red-ripe	60 - 66	90
overripe	50 - 62	63
slightly dried, dark grey to brownish	25 - 50	30
dried, dark grey to brownish	12.5 - 25	5

(Source: Coffee Production. Rothfos, 1980)

2.5.2 Semi-dry processing (Pulped Natural)

For the first time was initiated in 1990s as an mid-process between the traditional dry and wet methods. The objective of the semi-dry process is to go one step beyond the dry process and to mechanically separate unripe cherries from ripe cherries in order to treat the ripe ones separately to obtain a better cup quality.

2.5.3 Wet processing

Wet process was originated due to climatic reasons only. The entire process of wet preparation is carried out in the presence of water. The objective of wet processing is to remove pulp and mucilage from ripe coffee cherries in an environmentally friendly way. In order to process only fresh ripe cherries, it is necessary to harvest only such cherries or to separate the undesirable products before pulp and mucilage are removed. The description of the wet process will be divided into cleaning and separation, pulping and mucilage removal (Rothfos, 1980).

2.5.4 Pulping

Preparation of coffee by the wet method requires pulping equipment and an adequate supply of clean water. Fruits should be pulped on the harvest day to prevent fermentation before pulping. Pulping is carried out in two steps. In the first step the fruit is squeezed between the roughened surface of a rotating cylinder or a disk and a stationary part that is smooth. The distance between the two surfaces is carefully adjusted so that the space narrows as the fruit is carried through the breast. The breast is often held by springs that permit tension. The passage produces a squeezing action that detaches skin and flesh from the fruit. The rotating drum has small projections that assist the dragging of the pulp. In the second step, the seeds are separated from the pulp. In the market three types of pulpers, viz., disk, drum, and vertical, are available. The disk type is not 100% efficient because of variation in size of berries and the fixed gap between the moving and stationary parts of the pulper. The important drum type pulper is capable of rejecting the unpulpable fruits and has facility for green cherry separation (Rothfos, 1980; Ramalkshmi., Raghavan., 2003; Wintgens, 2004).

2.6 Coffee Processing - Hulling, Polishing, Grading and Sorting and Storage

2.6.1 Hulling

Hulling is a general term used to describe the separation of parchment hulls and silver skin from parchment coffee and husk from dried cherry coffee. Polishing is an additional action to remove any silver skin that may still cling to the bean after hulling. Hulling is performed by rubbing the beans against the metal parts of the machines or tearing the husk as the coffee is pushed against a sharp edge of a blade, of screen hole or both. The hulling machines, often handling both the dry processed and the washed coffee, separate the beans from their parchment shells by throwing them against a resistance or by cracking the shells through pressure. Green coffee beans undergo further processing, such as polishing, grading, and sorting.

2.6.2 Polishing

Polishing involves removal of the silver skin except that retained in the center cut of the beans. The purpose is purely cosmetic, to improve the appearance of the bean. Polishing may not be required for wet processed coffee. Polishers resemble these of smout friction hullers but use phosphor bronze bars, which are softer than steel and do not harm the beans. Polishing is carried out by friction as the beans rub against each other and against the machine.

2.6.3 Grading

Coffee is graded by size to enable improved density and color separation, to allow more uniform roasting and, most importantly, to meet client requirements. A flat bed grader and a drum grader separate the beans according to size, and pneumatic separators, often called catadors, grade the beans by density. Green (hulled) coffee is separated by size by sifting the mixed beans in flat screens that vibrate or in round screens that rotate. Flat beans are separated by screens with round holes. Peaberries are separated by screens with slotted holes.

2.6.4 Sorting

Sorting is usually the final stage in the preparation of coffee for export. It is required to remove any defective bean remaining after processing. Sorting may be carried out physically by blasting air upward through the beans; the process of air lifting removes the defective beans. Hand sorting is a traditional process and is highly labor-intensive, but the cost can be justified by the high quality of coffee hand sorted by expert sorters.

2.6.5 Color sorting

Color sorting is to remove defective coffee beans that have an undesirable color. Coffee beans are color sorted by comparing the wavelengths associated with their color with wavelengths that correspond to acceptable colors. Off-color beans are rejected by a compressed-air ejection system. The typical defects that may be removed by color sorters are black, dark, pale, white, unripe, waxy and fermented beans. Beans that are chipped, insect-damaged or broken may be removed if their color differs from that of sound beans. Fresh stinker beans may be removed by UV sorters. Ultraviolet sorting machines, which operate on the same mechanical principles as bichromatic machines, identify defective beans by exposing them to ultraviolet light. Color sorters gain capacity and accuracy when they process beans that have been previously graded by size and density. Electronic color sorting machines of the monochromatic type use the reflection of white light to identify beans whose surface brightness differs from that of the rest. Monochromatic machines are mainly used for sorting of Robusta. Bichromatic sorters measure two wavelengths which makes the machine sensitive to more subtle color differences. They are able to separate pale green, unripe, waxy, yellowish and brownish beans as well as the beans separated by monochromatic sorters (white, pale, dark or black). Bichromatic machines are used more often for Arabica coffees.

2.6.6 Storage, as the main stage in coffee production

Being one of the most important stages in the processing of any agricultural commodity, storage plays a crucial role in coffee processing, especially in post-harvest operations. Its goal is to achieve and maintain coffee’s commercial value as long as possible by preserving the integrity of the bean with all its characteristics. On the other hand, being one of the most important commodity in the world, coffee should have very well managed and developed storage strategies to preserve its value. Losses caused by inadequate storage could seriously impact many sectors of the world economy, and also many national economies depend on coffee for a considerable part of their GNP. The main factors of storage influencing color, appearance in green coffee, and by this indirectly affecting flavor and aroma of roasted coffee, are moisture content, time period in warehouse and temperature of storage. *Storage moisture* – a bean of 12% m.c. is generally considered to be safe for storage for Arabica and 13% for Robusta. Beans with a moisture content lower than 9% (10% - in most of the cases) may be irreversibly damaged in color, as well as in their cup taste and consistency, which means that it is not worth reducing the moisture content to such a low level when drying. A relative humidity(RH) of 75% corresponds to a moisture content in the bean of 15-16%. According to the Henderson balance, this is the critical level for fungi formation (Wintgens, 2004).

As a result, the RH level should be kept below 60% because one of the most obvious effects of a high RH level, in combination with temperature variations, is the condensation of water which, in turn, contributes to the proliferation of fungi and insects. Arabica coffee pick up moisture more rapidly than Robusta. This was shown in an experiment at 80% RH where after only two months of storage the m.c. of arabica and robusta beans was 14.5% and 12%, respectively (Narasimhan, 1972).

Under such conditions, green arabica beans may have a storage life of only six months whereas green robusta beans can maintain their quality for much longer. For example, the coffee cup and product quality of robusta beans was unaffected by eight months storage in jute bags at an average 11.5% m.c. (Bucheli, 1998). *Storage temperature* – is the second mos important element which affects coffee bean quality. Studies have been shown that even coffee with a m.c 11% will lose their quality after 6 months under a temperature of 35°C. But, on the other hand, coffee with m.c more than 15% will maintain its quality at temperatures as low as 10°C (Stirling, 1980). The effects of temperature should be kept in mind for coffee storage in producing countries where average dayhight temperatures can easily range between 28°C and 30°C (Bucheli, 1998). A general recommendation is to keep the storage temperature below 20°C and RH 50-70%, in order to preserve the quality of coffee (Muriithi, 1977).

Coffee is stored in bags, they are usually made from jute and conform to the standards of the International Coffee Organization (ICO) which specifies that a standard bag should contain 60kg of beans. Typically, bagged coffee is palletised in storage. Normally each pallet holds 20 to 25 bags in 4-5 layers, arranged in alternate directions. The coffee bags must be kept at least 15 cm off the floor and not close to the roof, and at least 20 cm away from the walls (Mabbett 1990).

2.7 Roasting

The first step in the preparation of any consumable product from green coffee is roasting (Fig.9). Green coffee possesses very little or no aroma. The characteristic aroma is developed only through roasting. The Standard Industrial Classification (SIC) code for coffee roasting is 2095. The aroma of green coffee is very different (grassy smell) from that of the roasted beans we know. It is only after roasting that coffee gains its characteristic aroma and flavor (Boe, 2001).

In chemical terms, roasting is simply heating at elevated temperatures in the presence of oxygen. In physical ones, roasting means applying dry heat to the raw beans. This heat should be applied for the Millard and other chemical reactions to occur during the process.

Color, flavor and aroma - the very essence of coffee - are produced by chemical and physical reactions that take place during the roasting process. During roasting, the temperature of the beans increases significantly and a series of physical and chemical changes take place. The roasting conditions will influence these changes considerably and, as a consequence, the results on quality and on the cup. Coffee roasting is a chemical process by which aromatics, acids, and other flavor components are either created, balanced, or altered in a way that should augment the flavor, acidity, aftertaste and body of the coffee as desired by the roaster (Sinnott, 2010).The process involves the use of fuel or electricity, which indirectly is fuel, to produce heat. The coffee roasting process consists essentially of cleaning, roasting, cooling, grinding, and packaging operations.

Fig. 9 Roasting of coffee

Bags of green coffee beans are hand- or machine-opened, dumped into a hopper, and screened to remove debris. The green beans are then weighed and transferred by belt or pneumatic conveyor to storage hoppers. From the storage hoppers, the green beans are conveyed to the roaster. The most common roasters available for domestic use and in coffee industries include different types of drum roasters (the beans are in contact with fire or hot surfaces) and fluidized/spouted bed roasters (the beans are in contact with hot air/gases), currently the most preferred by industries because they grant colour homogeneity and fastness in the process through the control of air/gas temperature and speed inside the roaster, allowing variation of heat input and management of bean temperature over time.

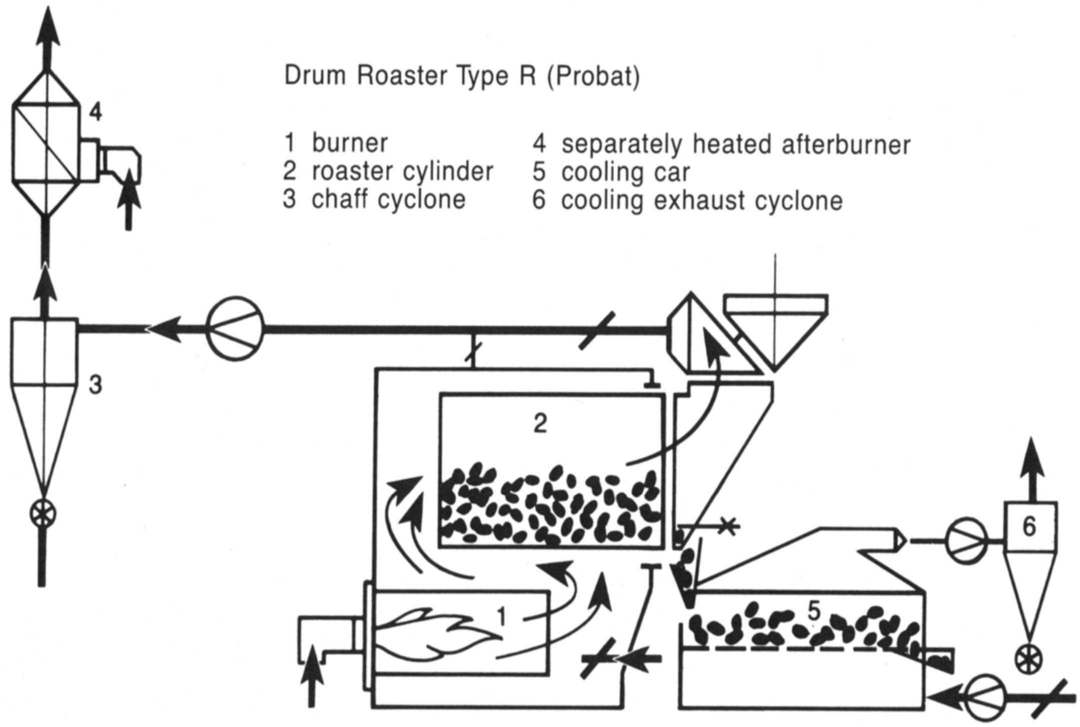
The roasters operate in either batch or continuous modes and can be indirect- or direct-fired. Indirect-fired roasters are roasters in which the burner flame does not contact the coffee beans, although the combustion gases from the burner do contact the beans. Direct-fired roasters contact the beans with the burner flame and the combustion gases. There can be also tangential and centrifugal roasters, used mostly by big roasting factories. The conventional roasting equipment consists of a metal container in which green coffee is heated while it is continuously rotated. Heat may be supplied by conduction from hot metal surfaces or convection from hot air or more generally a mixture of both methods of heat transfer together. Earlier roasters made use of various types of frying pans and hand rotated cylinders. It is necessary that during the roasting process heat be applied quickly and uniformly and the beans be continuously stirred (Segall, 2001; Wilson, 2006).

Drum roasters (Fig.10) have a horizontal rotating drum with either a solid or perforated wall in which hor air from furnace is passed through tumbling green bean. Coffee beans are compartmentalized within the cylinder and separated from the cooling section by a central disk. In drum roasting, a perforated cylinder holds the beans, which get heated from below by radiant heat. The cylinder constantly rotates to evenly distribute heat across the beans. In addition, a steady stream of hot air blows through the cylinder’s center, creating a heating environment much like a convection oven, encouraging a consistent, uniform roast. The majority of commercial operations use a drum method to roast their coffee (Segall, 2001).

Fig. 10 Drum roaster

The Probat R type (Fig.11) is the most common commercial drum-type roasters nowadays. The working process is described in the picture below.

Fig. 11 Drum Roaster Type R

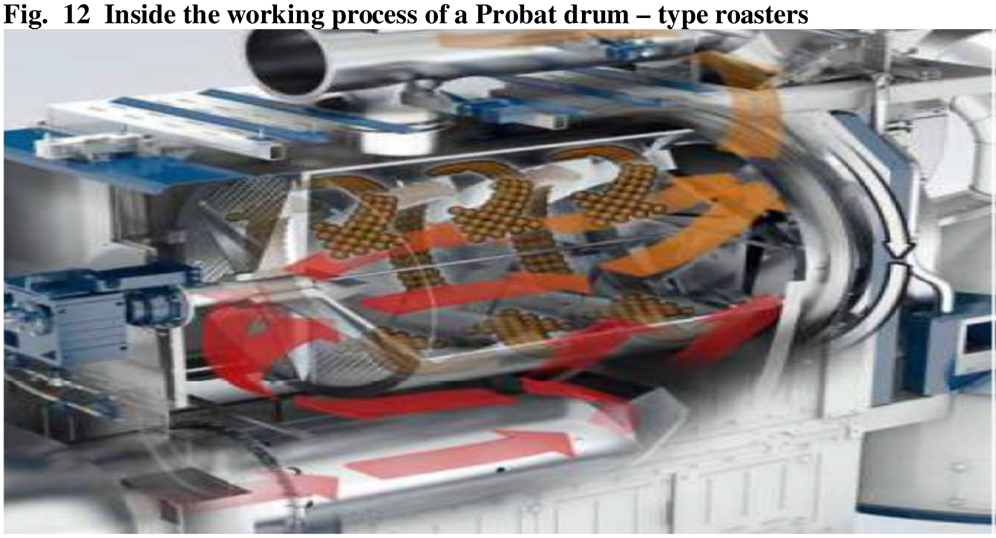


(Source: Courtesy of Probat-Werke GmbH, www.probatburns.com)

Probat R roasters are often called “batch-type” roasters in which a rotating horizontal bowl is used for intimate contact of hot gases and beans. Hot air blast assisted by centrifugal force carries the seeds to the periphery; they then fall back to the center. Air plays a key role in coffee roasting.

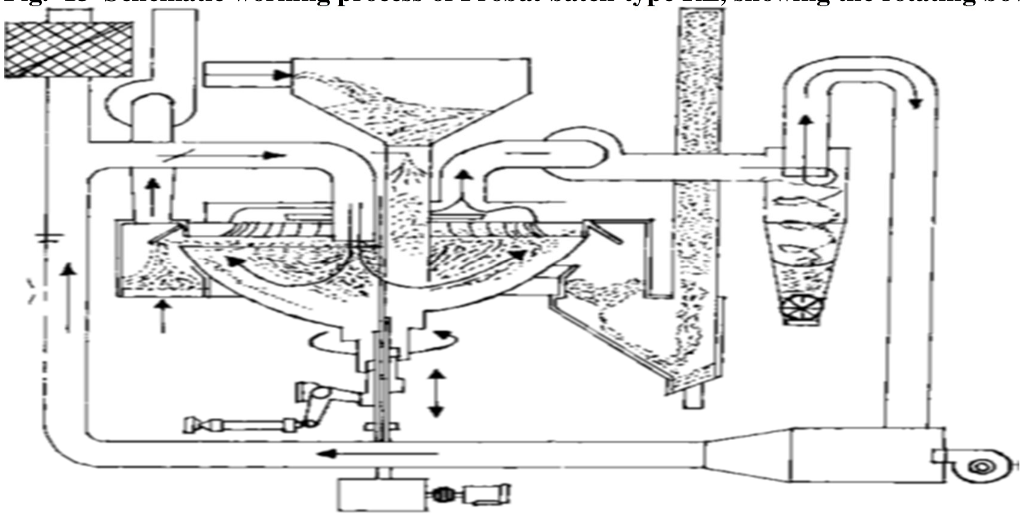
The heat type in Probat roasters (Fig.12) is conductive,radiant and convection,which are the most important and used one. During the entire roasting process, the roasting exhaust gas is directed back to the burner and reheated to roasting temperature. This helps to reduce both energy consumption and the level of emissions. Long roast time. Drum roasters usually take between fifteen and twenty minutes to roast. This is good in general, but it can be stressful trying to hit the cooling cycle button at just that magic moment. Their advantages are : a)Perfect yield; b)Developed, complex flavor. Many in the coffee industry believe drum roasters offer great complexity of flavors. Whether this is due to longer roast times or type of heat compared to fluid-air roasting is the subject of intense debate. It calls for more taste tests; c)No noise. Most drum roasters are extremely quiet, allowing the roast master to listen for the subtle distinction of the first and second cracks (**Sinnot, 2010**).These tradional method of roasting gives particularly high aroma development.

Fig. 12 Inside the working process of a Probat drum – type roasters



(Source: Probat Roasting Solutions, www.probat.com)

Fig. 13 Schematic working process of Probat batch-type RZ, showing the rotating bowl



(Source: Courtesy of Probat-Werke GmbH, www.probatburns.com)

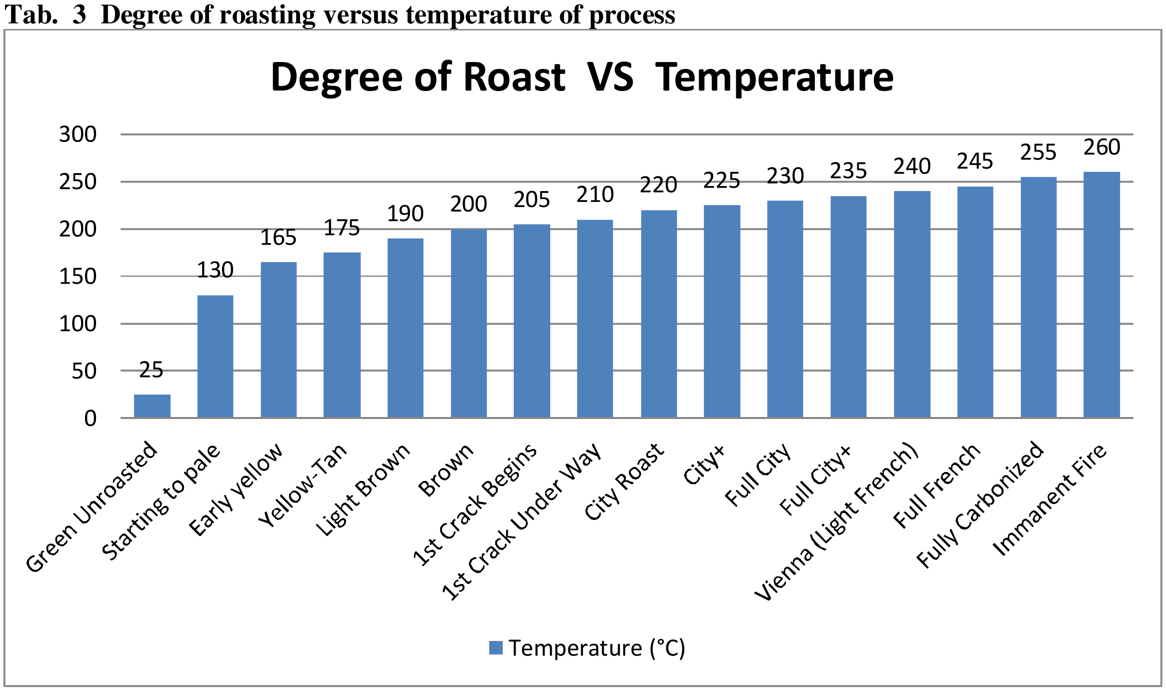
Generally, the beans are spun in the cylinder to heat them evently, meanwhile the roast master monitors their progress by the two most important parameters: time and temperature, and on the other hand he uses the 3S rule – *sight, sound, and smell*. All of these important visual and auditory feedback is achieved by means of a small, trough-like probe called a “tryer”. The tryer permits roasters to pull samples of beans from the drum at any point during roasting (Knox., Huffaker., 1997).

Degree of Roasting – is used to describe the internal bean temperature (BT) during roasting process, in relation with environmental temperature (ET). From Cinnamon (light) to the French roast (dark), roasters call it roast profile to distinguish the different varieties of flavor. The best method of judging the bean’s color is by eye, and the technical method consist of Agtron scale (based on the AGTRON/SCCA Roast Classification Color Disc System). This scale is commoly used to determine the roasting degree and bean color in aging. It varies from 25-40 Agtron number, the Spanish roast almost 30% dioxide carbon to the 70-95 Agtron number, the very light one. Roasting degree can vary quite a kot between the two so-called “cracks”.

Technical process of roasting – The temperatures used to roast the beans will depend on the type of roaster, but maximum temperatures commonly used in drum roasters vary between 210 and 230°C. In the initial phase of the roasting process, evaporation of free and bound water occurs. When the bean temperature reaches 130 °C, caramelization of sucrose and browning take place, and the beans start to swell. The chemical changes in the initial phase of the process are relatively small compared with those at the end of the process. In temperatures higher than 160 °C, a series of exothermic and endothermic reactions take place and the colour of the beans changes to light brown; their volume increases considerably and the aroma formation starts. The chemical reactions responsible for generation of typical aroma and flavour of roasted coffee are triggered when the beans temperature reach about 190 °C. Maillard and Strecker reactions, in which carbohydrates, proteins and other classes of compounds participate, take place, with simultaneous degradation and production of low and high molecular weight compounds such as melanoidins (Clarke., Macrae., 1987). During this process, changes in the colour of the beans from light brown to almost black are observed (Farah, 2004). These reactions are interrupted at the desired point based on the colour of the bean or programmed time. The beans are rapidly cooled by cool air or water. Air is currently preferred because water increases humidity and chances of microorganism growth. After roasting, the beans are ground and marketed as ground roast coffee or used for instant coffee production.

All roasting degrees and their associated temperatures, in a nutshell :

Tab. 3 Degree of roasting versus temperature of process



(Source: www.sweetmarias.com, 02/2012)

3. AIM

The aim of this diploma work is to evaluate the three main roasting degree, which are light, medium and dark roast by the time-temperature profile data loggers, to obtain a better understanding of the process of roasting. To assess the best roasting stage, evaluation of coffee color, chemical compounds and water activity are taken into account in this work.

4. MATERIALS AND METHODS

Both types of coffees provided for my experiments are taken and roasted from *Balirny Coffee Factory*, Praha 7, Holesovice. The coffee beans taken for my research are from two different countries Colombia and Nicaragua. Both of them Arabica coffees, Colombia is grown in less than 800m above sea level, and is considered as medium hard bean coffee and Nicaragua in more than 1400m above sea level, considered as a strictky hard bean coffee. Both varieties of these coffees were roasted in three main different stages, which are light, medium, and dark (Full City). There are taken 8 samples and they are named in this way :

Samples:

Green bean	Colombia	4GC
Light	Colombia	1C
Medium	Colombia	2C
Dark	Colombia	3C
Green bean	Nicaragua	4GN
Light	Nicaragua	1N
Medium	Nicaragua	2N
Dark	Nicaragua	3N

a) *Coffee roaster.* Single Barrel Probat Sample Roaster (Fig.14) – was the laboratory equipment used to roast Colombia and Nicaragua coffee. This roaster is using electrical energy to supply heat in the drum, for roasting the coffee.

Fig. 14 Probat Sample Roaster

All coffee samples were weighted prior to roasting. According the roast master, the samples should be 300 gr of green beans for each stage of roasting. Every step of roasting was recorded and written down the bean and environmental temperatures and times for light, medium and dark to provide the time-temperature profile logs, as an evaluating parameter of the process. The time-temperature profile logs, were then calculated by a computer software program called TYPICA (Version 1.3.11, 21-3-2011) by Neal Evan Wilson, from *Wilson's Coffee and Tea Company, Inc.*. The file typica.w contains both C++ source and the documentation for that code. Typica is common data logger tool in the craft of coffee roasting. Convertion of heat supply: 1 BTU = 1055 W = 1055 J

b) *Image analysis of L*a*b* parameters and mean RGB values.* Made in the The Institute of Chemical Technology, Prague (ICT). Every sample was checked and controlled by Prof. Frantisek Pudil. Three grams from each of eight samples of ground green and roasted coffee were brewed and taken pictures. The green beans of Colombia and Nicaragua, were roasted for 5, 10, 12, 14, and 16 min and in every stage L*a*b* mean values were calculated in all these times. Colour measurements (CIE L*a*b* colour space) were performed using a Minolta CM-3600d model spectrophotometer. The L*a*b* values were calculated from the visible spectral data as defined by the *Commission Internationale de l'Eclairage* (CIE) in 1976. L* is the luminance or lightness component, which ranges from 0 to 100 (black to white), and parameters a* (from green to red) and b* (from blue to yellow) are the two chromatic components, which range from - 20 to 20.

For evaluation of RGB color, Hue Typical, Hue Variation and Mean Saturation values was used a Canon EOS 60D, ISO 100 - manual photocamera operated with 50 mm Φ 25.5 objective. The aim of image processing and extraction was to enable on-line control of the roasting process based quality parameters (color and surface) and to determine the degree of coffee roasting. Before, each experiment, the system was calibrated, using a color palette which was photographed under exactly the same conditions as the beans (Hernandez Perez, 2002). The video camera always had fixed apperture and focus. Bean quality was determined in terms of brightness, which is measured using the grey level of bean pixels after a threshold value had been fixed :

Grey level = (RED+GREEN+BLUE) / 3.

For determination of the results, a computer program was used: *NIS – Elements AR* (Nikon CFI60 Infinity Optical System). It features fully automated acquisition and device control through full 6D (X, Y, Z, Lambda (Wavelength), Time, Multipoint) image acquisition and analysis.

c) *Sensory analysis of the coffees.* All the eight coffee samples were evaluated by a group of 20 people, 8 of them sensory experts from The Institute of Chemical Technology, Prague and 12 of them students for Czech University of Life Sciences, Prague. This evaluation is an organoleptic determination of human response to any kind of food, in particular to the coffee. Every coffee, must be cupped and evaluated by a stuff of experts. In my case, some mistakes are taken into account, depending in a lot of factors influencing the persons. The coffee samples were all brewed and ready to be tasted in the cups. A paper of the 5 main factors, given be standard sensory evaluation of *Specialty Coffee Association of America* (SCAA), is given to each person to fill it. This paper contains *: 1) Flagrance and Aroma, 2) Body, 3) Acidity, 4) Flavor* and *5) Aftertaste*.

All these 5 factors, were evaluated from 1-awful to 10-perfect. Scoring was divided in this way: 1 to 10 (10=perfect/ 9=excellent/ 8=very good/ 7=good/ 6=average/ 5=mediocre/ 4=not good/ 3=pretty bad/ 2=bad/ 1=awful).

d) *GC – MS analysis.* Performed in the laboratories of the Institute of Chemical Technology, Prague. Under the supervision of Prof. Frantisek Pudil.

Apparatus - GC–MS analysis was performed with an HP 5890 series II gas chromatograph equipped with a HP 5890 GC split/splitless injector and interfaced, by a GC transfer line, to a VG Trio-2000 quadrupole mass spectrometer (VG BIOTECH, Altrincham, UK). The GC chromatographic column consisted of a Supelcowax fused silica capillary column (30m length, 0.25mm i.d. with 0.25µm film thickness, Supelco). The carrier gas was helium. The flow was 2 mL/min, and the same temperature program as reported under Headspace-GC/O was used. Mass spectra were generated in the electron impact mode (MS/EI) at 70 eV.

Solid phase microextraction – Coffee powders (1 g) were placed into 7ml clear vials (Supelco), the vials were sealed with hole caps and PTFE-faced silicone septa (Supelco), equilibrated for 2 h in a thermostatic bath at 60°C and subjected to HS-SPME. HS extraction were carried out for 5 min. Thermal desorption (5 min desorption time) was performed directly into the GC injection port maintained at 250°C.

e) *Water Activity (Aw).* This experiment was made possible by the Department of Microbiology and Food Hygiene, in Prague. Under the supervision of RNDr. Vladimir Erban, CSc. Method of measurement was the device Aw sprint (Novasina), in the temperature of 25°C.

Data elaboration. During the whole period of experiments, the computer program STATISTICA Version 7.0, Copyright, StatSoft, Inc. 1984 – 2004, was used for statistical measurements of image analysis and GC – MS analysis. This product is licensed to Mr. Frantisek Pudil.

Additional Experiment: *Atomic Absorption Spectrometry* (AAS)

Determination of Cd, Cr, Cu, Mn, Ni, Pb and Zn in the samples of coffee

The content of the elements was determined in digested samples of coffee by atomic absorption spectrometry (AAS). Frozen samples were dried by the lyophilisation using the LYOVAC GT 2 (LEYBOLD-HERAEUS, GmbH, Germany) and microwave digested in an acid solution using MWS-3+ (Berghof Products + Instruments, Germany). The dried samples were weighted into the Teflon digestion vessel DAP-60S (minimum 400 mg). Then 2 ml of nitric acid 65%, p.a. ISO (Merck) and 3ml H2O2 30%, TraceSelect (Fluka) were added. The mixture was shaken carefully and vessel was after 12 hour waiting closed and heated in the microwave oven. The decomposition proceeded for 1 h in the temperature range 100-190°C.

The digests obtained were transferred into the 50ml silica beaker and evaporated to wet residue, then diluted with 1.5 % nitric acid prepared from HNO3 65%, p.a. ISO (Merck) and deionised water (Barnstead). The digests were transferred to probes and adjusted with 1.5% HNO3 to 16 ml.

The concentrations of cadmium, chromium, nickel and lead in the digests were measured by electrothermal (ETAAS) technique using Varian AA 280Z (Varian, Australia) with graphite tube atomizer GTA 120 and PSD 120 programmable sample dispenser. The concentrations of copper, manganese and zinc were measured in the same digests by flame AAS technique using Varian AA 110 (Varian, Australia). Standard solution ASTASOL (Analytika, CR) of lead was used in the preparation of a calibration curve for the measurement.

The quality of analytical data was assessed by simultaneous analysis of reference material IPE 180 (Oil Palm leaf) (8 % of all the samples). Analytical data obtained for the elements in this RM were found in the confidence interval given by the producer of the RM for these elements. The background of the trace element laboratory was monitored by analysis of 8.3 % blanks prepared under the same conditions, but without samples, and experimental data were corrected by mean concentration of the elements in blanks, and compared with detection limit (mean ± 3SD of blanks).

Mercury contents in the samples of coffee were determined using one-purpose analyser AMA-254 (Altec, ČR).

5. RESULTS AND DISCUSSIONS

Results made from all experiments of are shown in associated figures. They show differences between heat supply, bean temperature and environmental temperature (Fig.15,16,17,18,19,20), color space parameters *L*a*b** (Fig.21,22,23), mean RGB values (Fig.24,25,26,27), cupping profiles (Fig.28,29,30,31,32,33,34), GC – MS main volatile compounds (Fig.35,36) and water activity (Fig.37) of green and roasted beans. Main purpose of the results is the comparison of three roasting degrees – light, medium, and dark.

a) Results made from the Probat Sample Roaster are shown in fig.15,16,17,18,19 and 20. During personal communications by e-mail with Mr. William Boot, from *Boot Coffee Consulting Company, Inc*., and Mr. Neal Wilson, from *Wilson's Coffee and Tea*, the following results were discussed. In these figures roasted coffee is described as presenting a light, medium and dark degree of roast, depending on its color. Each stage of roasting is shown and measured separately and therefore environmental temperature (ET) and bean temperature (BT) are measured, so to have a better understand of what is happening during roasting process. ET is red line, because is always bigger than BT, blue line. These time-temperature profile logs of roasting are compared between Colombia and Nicaragua coffee types, there are differences between light, medium and dark roast, especially during the time of the first crack (FC) and as well during the ending time, and ending temperature. After loading the beans into the drum, the bean probe will display a drop in temperature, which will bottom out at the turning point (TP). In all the three stages (light, medium and dark), hard beans – like Nicaragua were roasted with high initial heat, as shown in Fig. 16,18,20, where the heat was 100% BTU. Up to the beginning of the first crack, the heat inside the beans is endothermic – meaning that the beans are absorbing the supplied heat. After the start of the forst crack the heat inside the beans becomes exothermic and they start generating heat. At this point, we should reduce energy supply, in order to have the control of the roasting process, as shown in Fig. 15,17,19 by 25 %, 40%, 50% BTU for light, medium and dark Colombia, respectively, and in Fig. 16,18,20 by 40%, 60%, 70% BTU for Nicaragua. Because roasting too fast, and maintaining high heat supply from beginning to the end of process, produces sour, astringent and malty roasting taints. Waiting approximately 2 or 3 minutes and controlling the roast with slow energy supply, then we increased the heat preparing for the end of the roast – endothermic heat; the beans are again absorbing heat. From this point starts again the increase of energy where the bean temperature is rising again up to the second crack (SC) or the end. During roasting process, was seen by the trier that coffee beans were expanding dramatically, especially during dark roast, and their volume was increased with more than 75%. As it was recommended by Mr. Boot, to obtain a linear roasting curve, the internal bean temperature should increase proportionally with the roasting time. The roasted coffee composition will vary with processing conditions, being characterized by the degree of roast, which is reflected on the external color of the beans (varying from light to dark brown), the developed flavor, the amount of dry matter loss that occurs and specific changes in chemical composition (Clarke, 1987). Weight loss values per roasting degree for Colombia coffee were 14.55%, 16.3%, and 18.23%, corresponding to light, medium and dark roasts, respectively. And for Nicaragua, weight loss were 12.7%, 16.44%, and 18.04%. It is important to mention that roasting temperature and degree presented a significant effect on weight loss behavior.As shown in all figures from Fig. 15 to Fig. 20, the turning point , had almost the same time in light and medium roast, but different in dark roast which resulted in a strong body and a bitter aftertaste cup. In below-mentioned figures roasting process is summarized as follows (as a three stage cycle) : the drying stage – moisture content of Colombia coffee is reduced to about 2% and for Nicaragua coffee 3%. The moisture content of the green beans is partially free or is present as bound moisture and is contained in the carbohydrate molecules. In drying stage (0-4 minutes of roasting), weight loss is mostly attributed to removal of water, crude coffee volatiles, intensive release of organic compounds, CO_2, water resultant from pyrolysis and other roasting reactions such as Maillard reactions. This behavior has been reported by previous studies on coffee roasting (Sivetz., Desrosier., 1979; Dutra, 2001; Oliviera, 2005). On the other hand, Dutra (2001) mentioned that the increase in the surface area was caused by three phenomena occurring during the roasting process: water vaporization, the release of carbon dioxide CO_2, and the release of volatile components from beans. During drying phase, free moisture plays an important role in the heat transfer during roasting. As fast as beans are energized with heat, the moisture of the bean conduct this heat throughout the bean. When the bean temperature reaches 100°C, the free moisture starts evaporating. Coffee beans only begin to swell when their internal temperature reaches more than 100°C, thus confirming the hypothesis put forward by

Guyot (1993) which attributes this expansion to the pressure of water steam. In the second phase, starting from FC to the SC, coffee beans develop their aromas and flavors, which can produce a very complex cupping profile. Studies made by Eichner., Schwartzberg., (2006), showed that more than 650 new aroma compounds were produced during medium roasting of any type of coffee, as also it will be discussed in sensory evaluation that medium roast of Colombia and Nicaragua are the best roasting profiles with the best aroma, flavor & fragrance and the best acidity. Based on their work, the range where most roasting reactions occurred, was between 170°C – 225°C of bean temperature, making again the medium roast profile, the desired one. At the end of the second stage, which corresponds with the ending of second crack (in medium and dark roast), all free moisture has been evaporated. The time length of this stage depends on the roasting degree, which usually varies a lot from Colombia to Nicaragua, or any other coffee type. On the other hand, in dark roast Colombia and Nicaragua, there is also a third stage which can been seen when ET is equal to BT, meaning that carbonization takes place and the bound moisture is destroyed. Fig. 19, temperature 229°C and Fig. 20, temperature 222°C. Different studies showed that during the this degree of roasting which in our case corresponds to the dark roast, caffeine content was decreased only in this degree. Probably, there were two competing mechanisms for caffeine removal during roasting, water vapor drag and sublimation (Franca, 2009).

Fig. 15 Colombia light roast – 1C

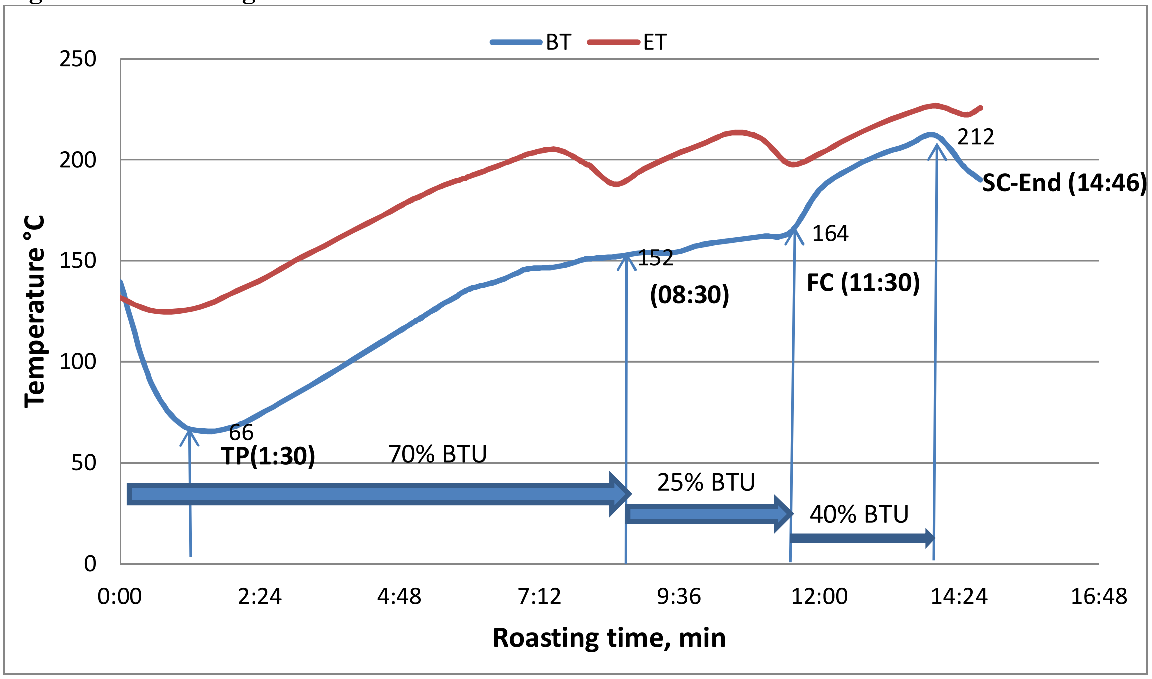


Fig. 16 Nicaragua light roast – 1N

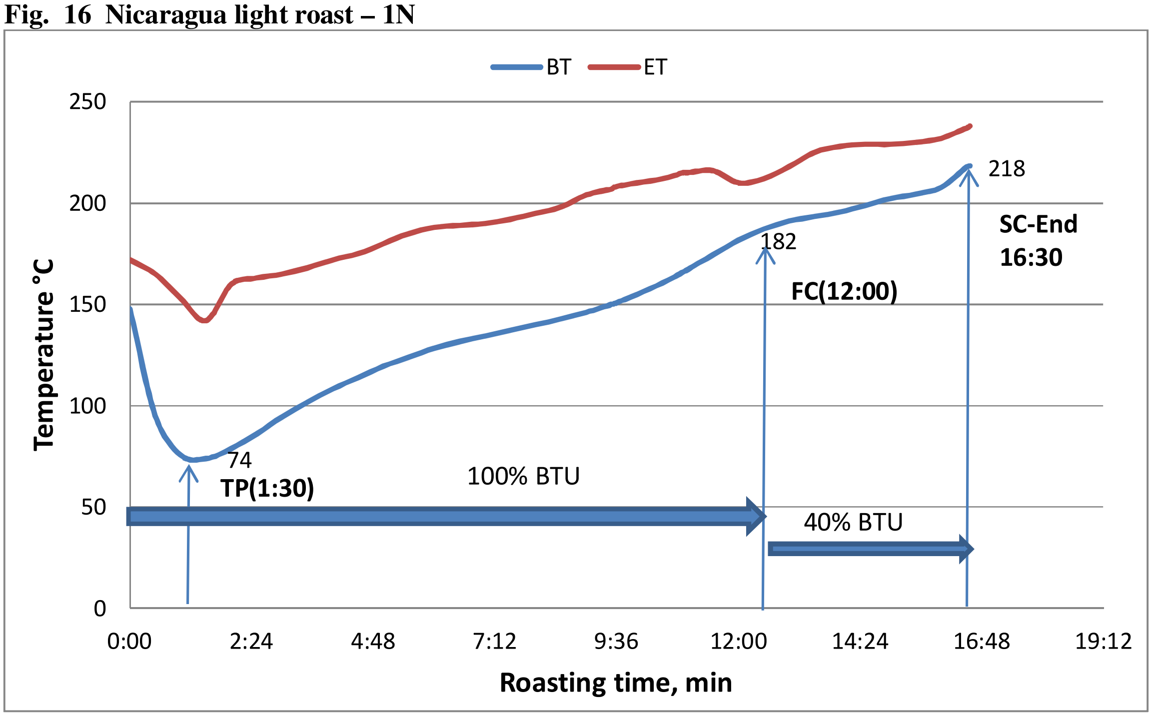


Fig. 17 Colombia medium roast – 2C

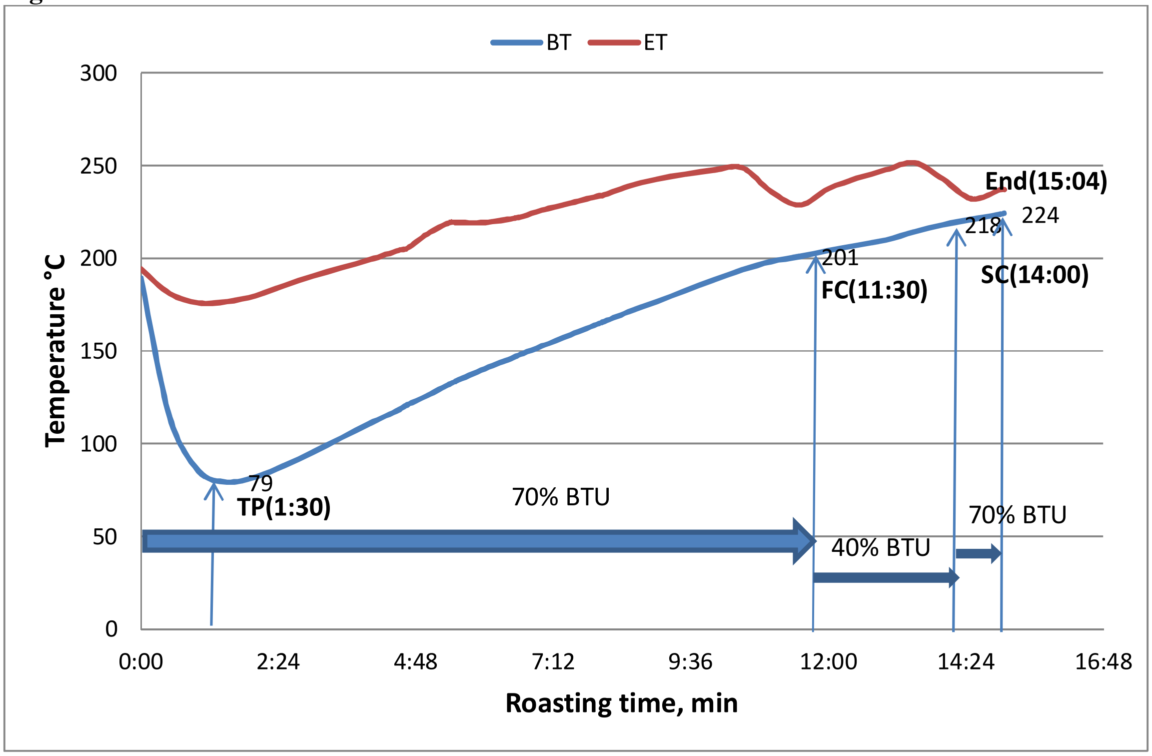


Fig. 18 Nicaragua medium roast – 2N

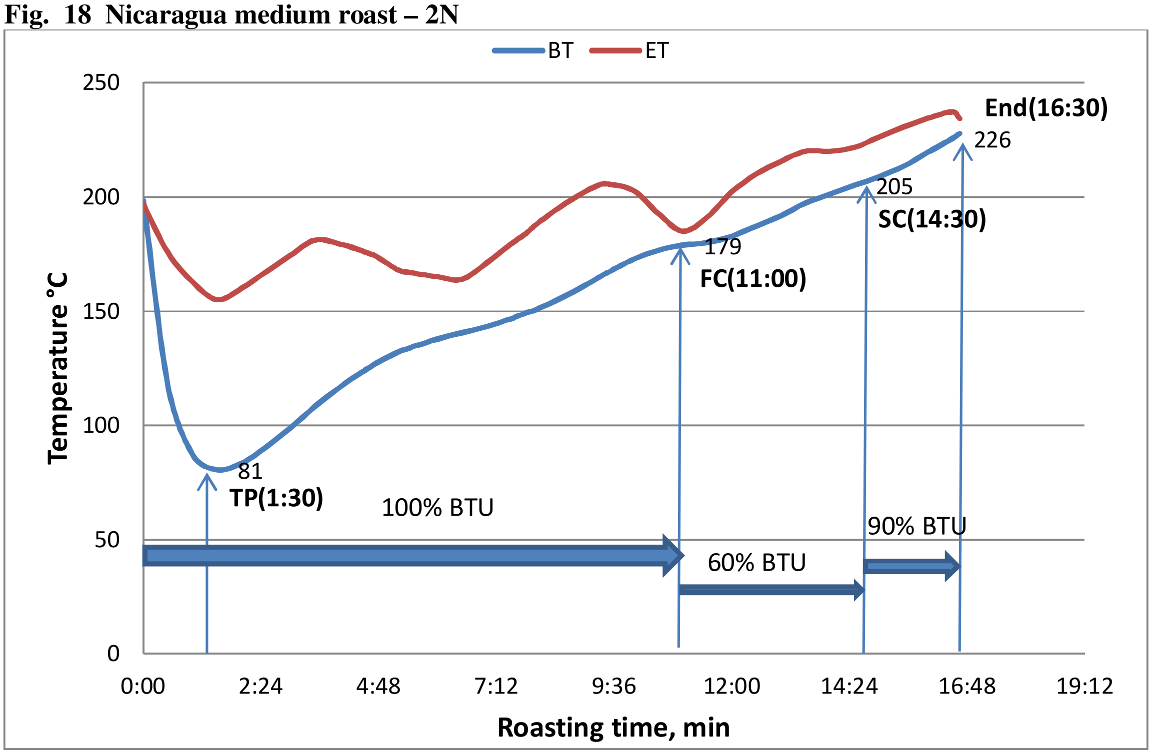


Fig. 19 Colombia dark roast – 3C

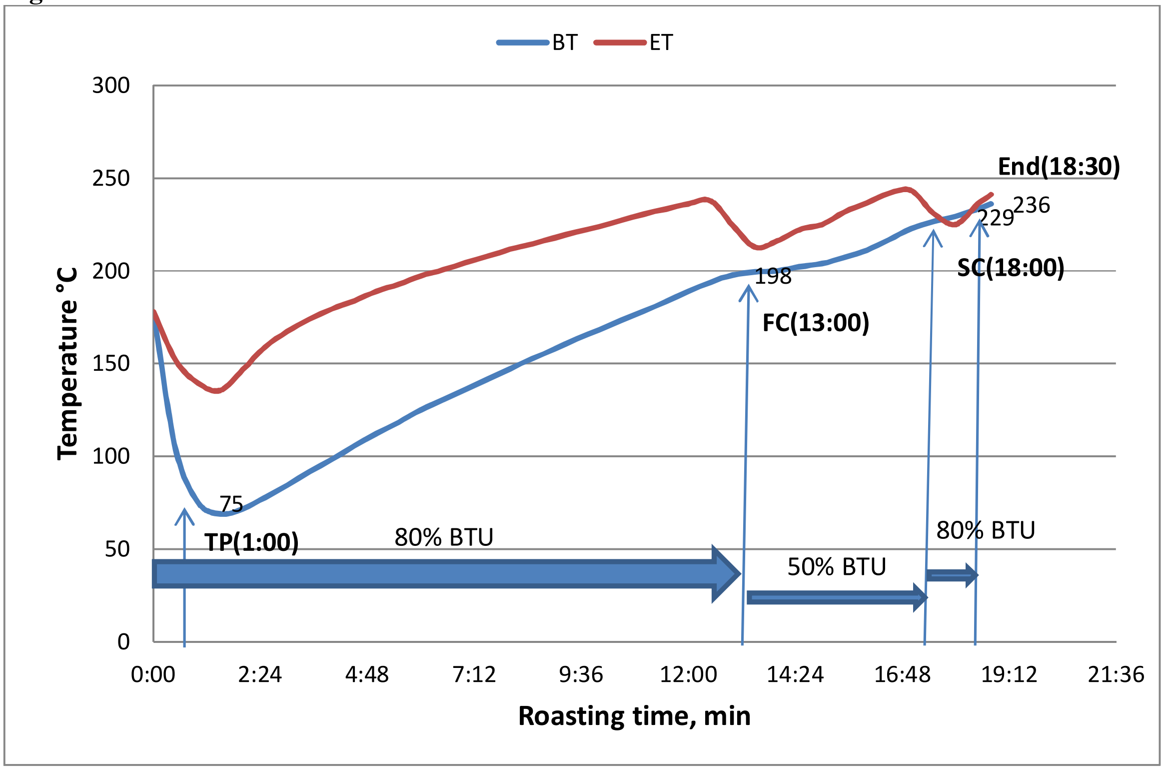
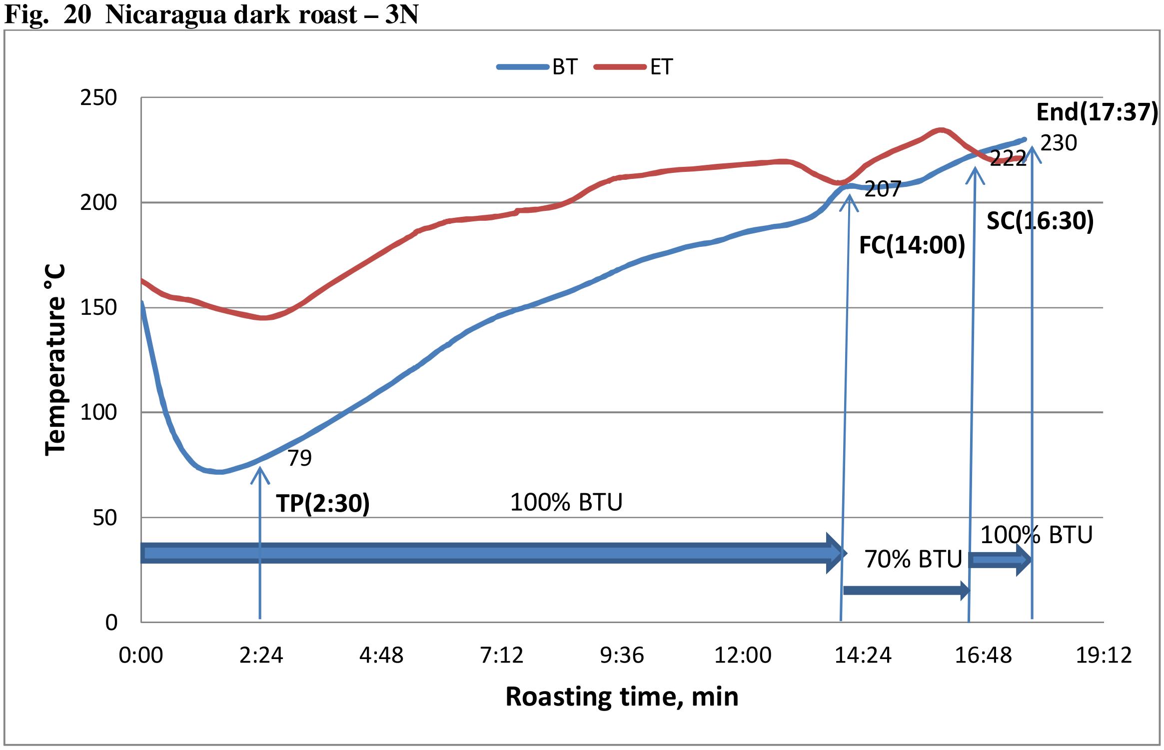


Fig. 20 Nicaragua dark roast – 3N



b) Image analysis of both coffee types and how these analysis affect coffee roasting are shown in figures from Fig. 21 up to the Fig. 22. Variables such as time and the three stages of roasting degree are taken into account.

In the Fig. 21, 22 and 23, the reason of these results is to have a better understanding between the stage of roasting, time of roasting and acrylamide formation. Acrylamide was found to occur during the browning process by Maillard reaction of reducing sugars with asparagine at temperatures above 120°C (Friedman, 2003). The means of both Colombia and Nicaragua light, medium and dark roast were taken to evaluate the colour space parameters L*a*b*. From Fig. 21 and Fig. 23, L* and b* decreased exponentially with time, while from Fig. 22, a* increased rapidly during medium and dark roast, reaching its maximum at minute 10', and then decreasing exponentially , but for light roast it was continuously increasing with the time passing. As we see from the Fig. 22 and Fig. 22a, changes in acrylamide levels and a* have almost the same trends during ligh, medium and dark roast. Results from other studies (Gokmen, 2005), showed that acrylamide and the redness parameter a*, had a similarity between them, this was conducted during the three stages of roasting for both types of coffee, Colombia and Nicaragua. This similarity (Fig. 22 and Fig. 22a) revealed that color may be a reliable indicator of acrylamide in thermally processed foods. Also, regarding Taeymans, 2004, the darker colored coffee may contain lower amounts of acrylamide than the light colored coffee.

Fig. 21 Mean L* values of both Colombia and Nicaragua

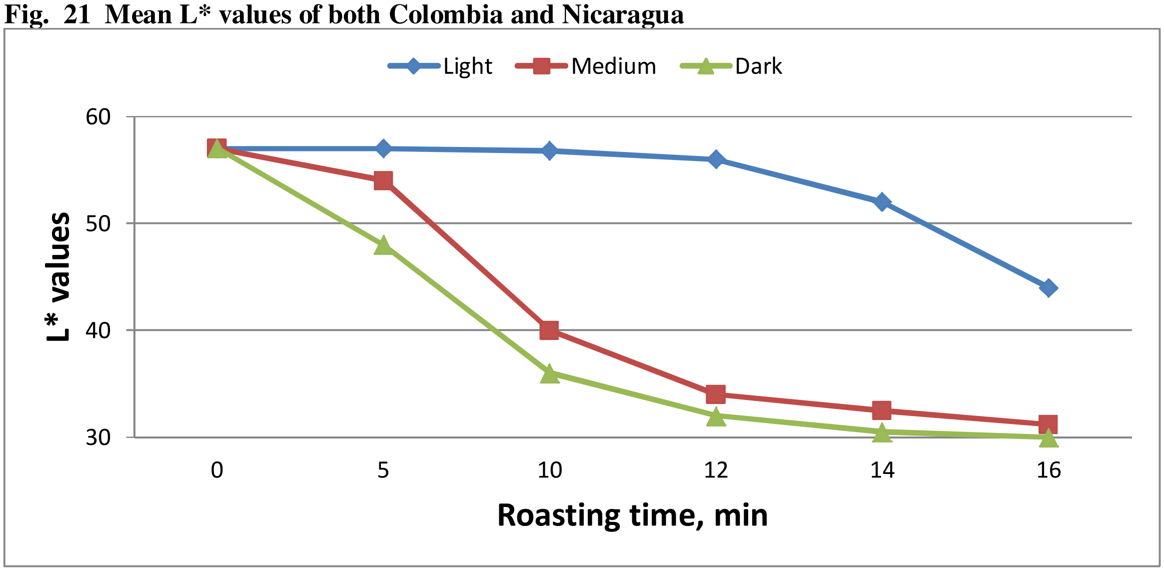


Fig. 22 Mean a* values of both Colombia and Nicaragua

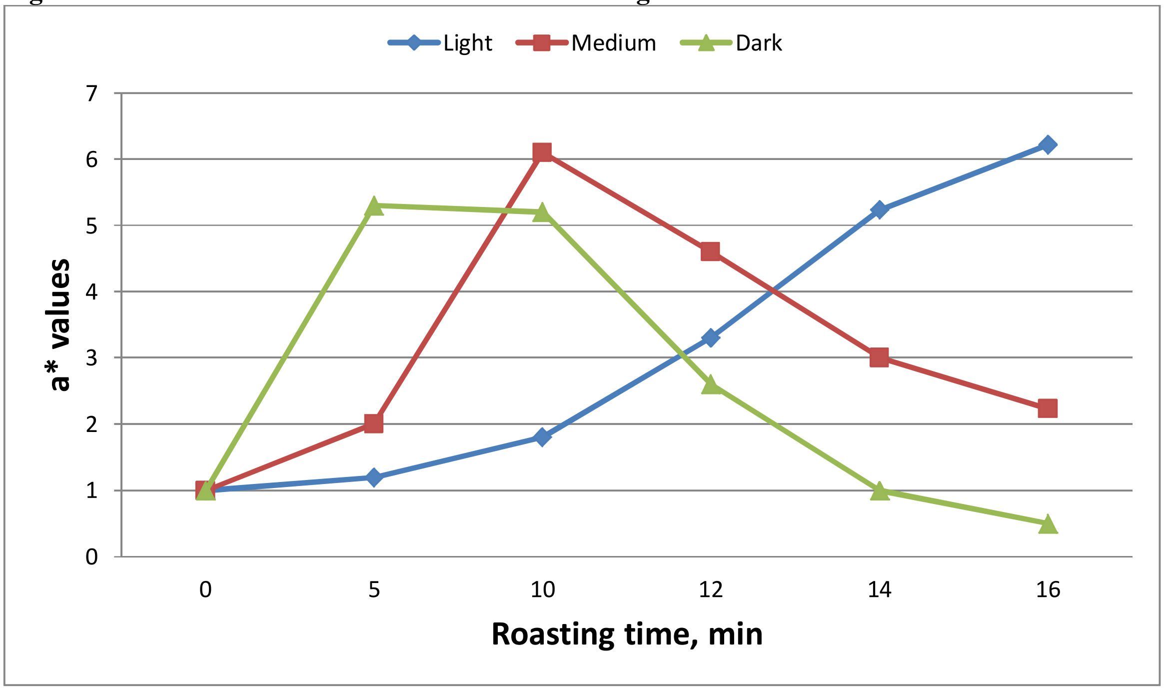
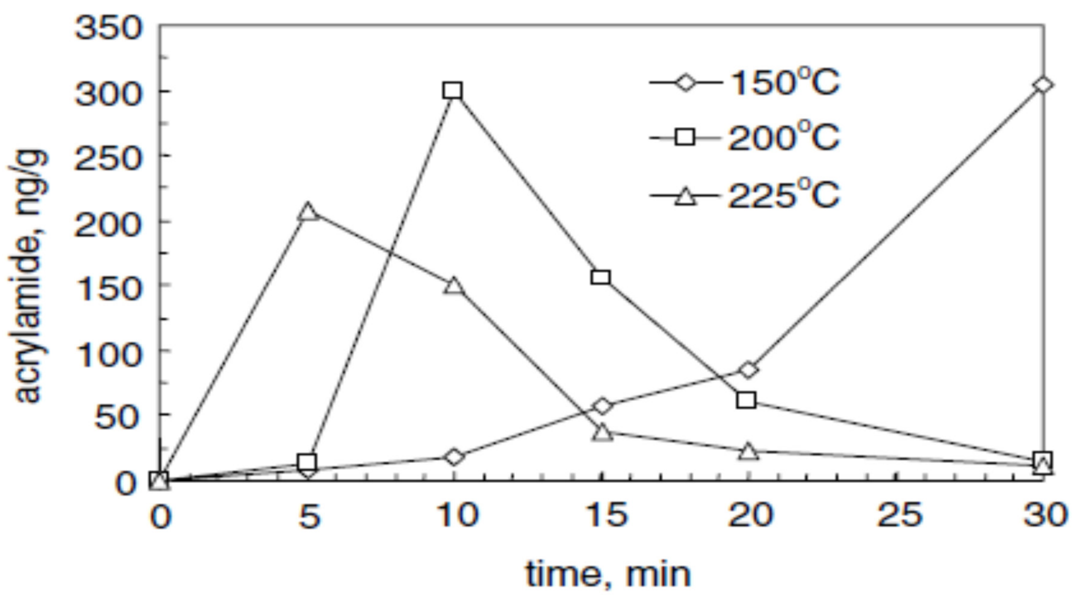
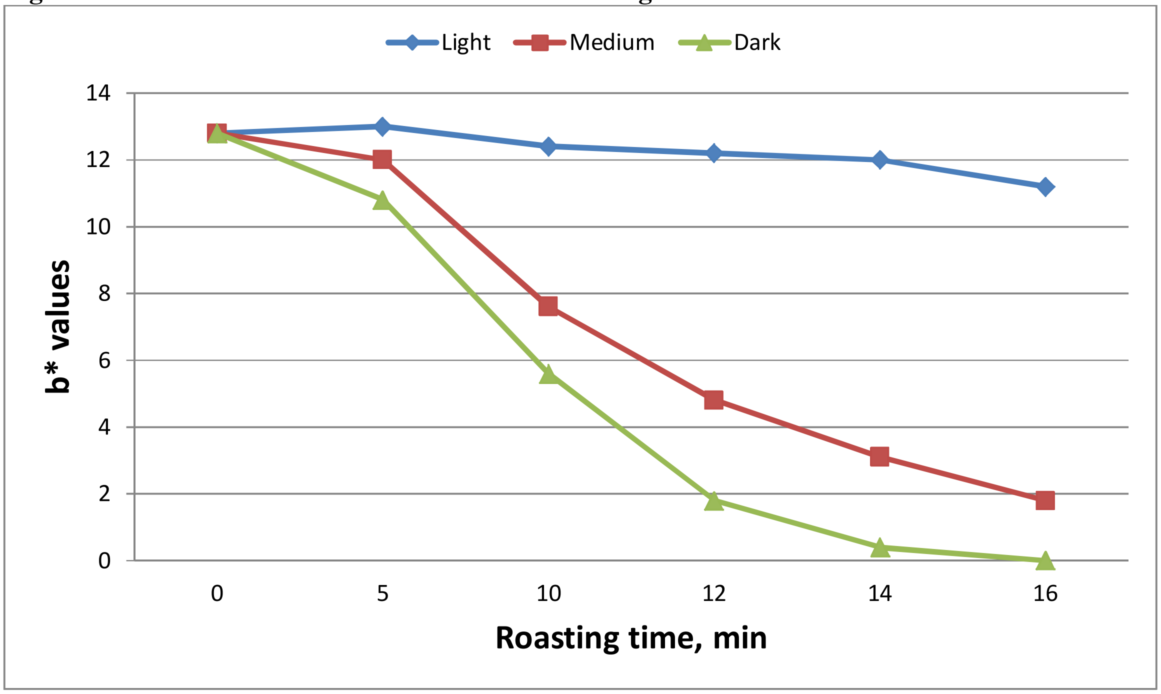


Fig. 22a Acrylamide levels during heating at 150, 200, and 225°C



(Source: Gokmen.; Senyuva, 2005)

Fig. 23 Mean b* values of both Colombia and Nicaragua



From the computer program NIS Elements AR we were able to measure and find the main factors for describing the RGB values of coffees in light, medium and dark roasting as shown in the figure 24, 25, 26, and 27. As shown in figures, Nicaragua coffee seems to have a better and strong correlation for meanRed, meanGreen and meanBlue, which is typical for strictly high grown (SGH) coffees and hard coffee seeds. Image analysis of RGB values, its aim is to determine the bean quality in terms of brightness, which is measured by using the grey level of bean pixels after a threshold value that had been fixed previously. Grey value for Colombia coffee in light, medium and dark roast was 44,3, 35.6, and 36.6, respectively. And for Nicaragua coffee was 49.4, 42.4, and 36.6. Different research showed that the best grey value for most coffee factories is approximately 36, meaning that in this study only dark roasted coffee (3C and 3N) were considered as a high quality bean, after roasting.

Fig. 24 Mean Red of Colombia and Nicaragua, separately

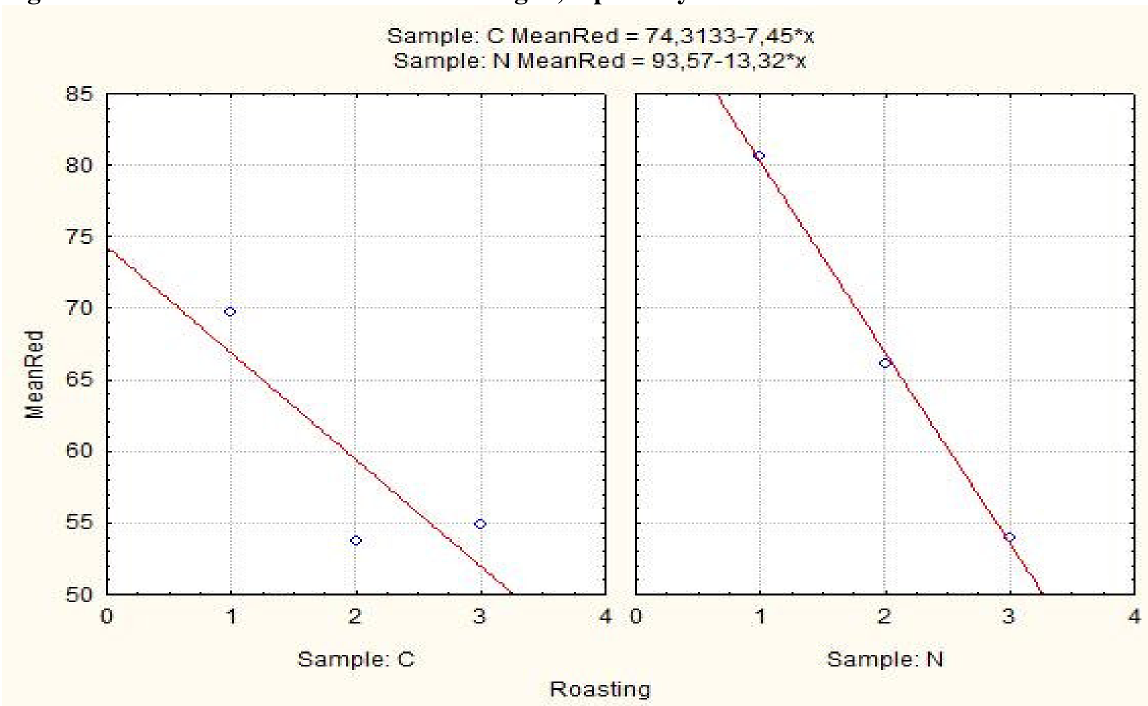


Fig. 25 Mean Green of Colombia and Nicaragua, separately

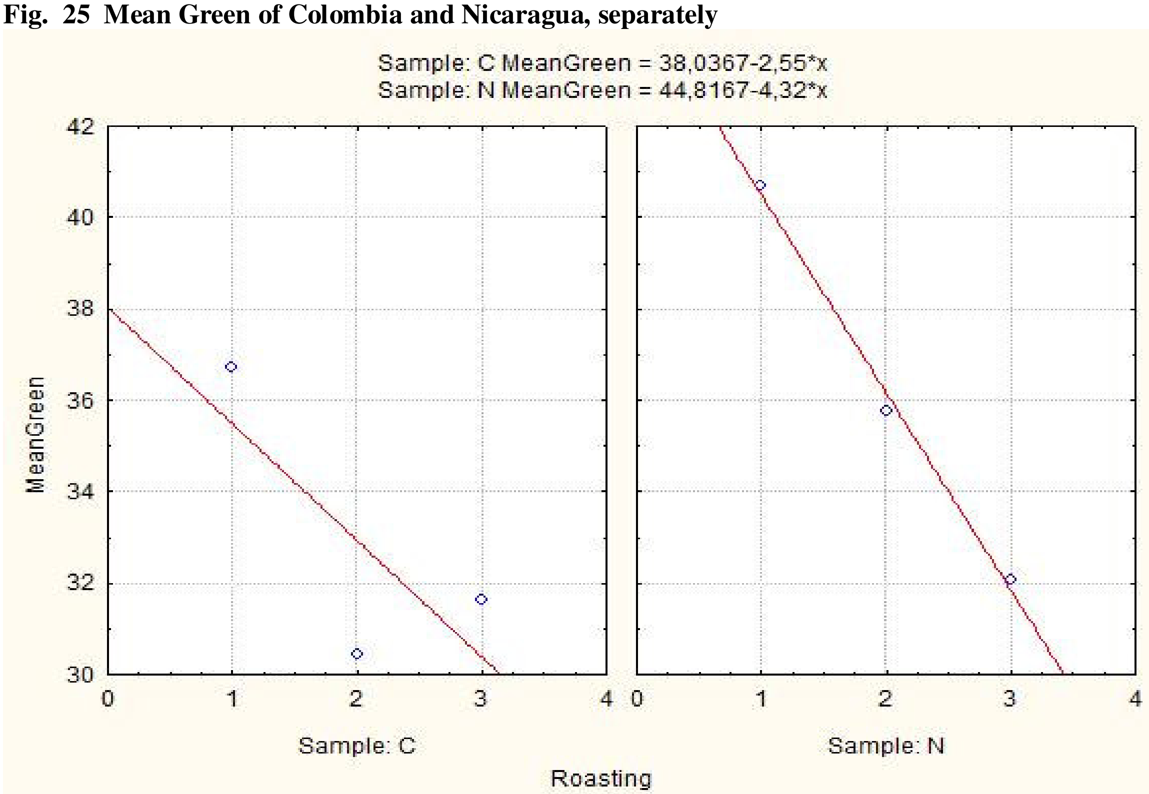


Fig. 26 Mean Blue of Colombia and Nicaragua, separately

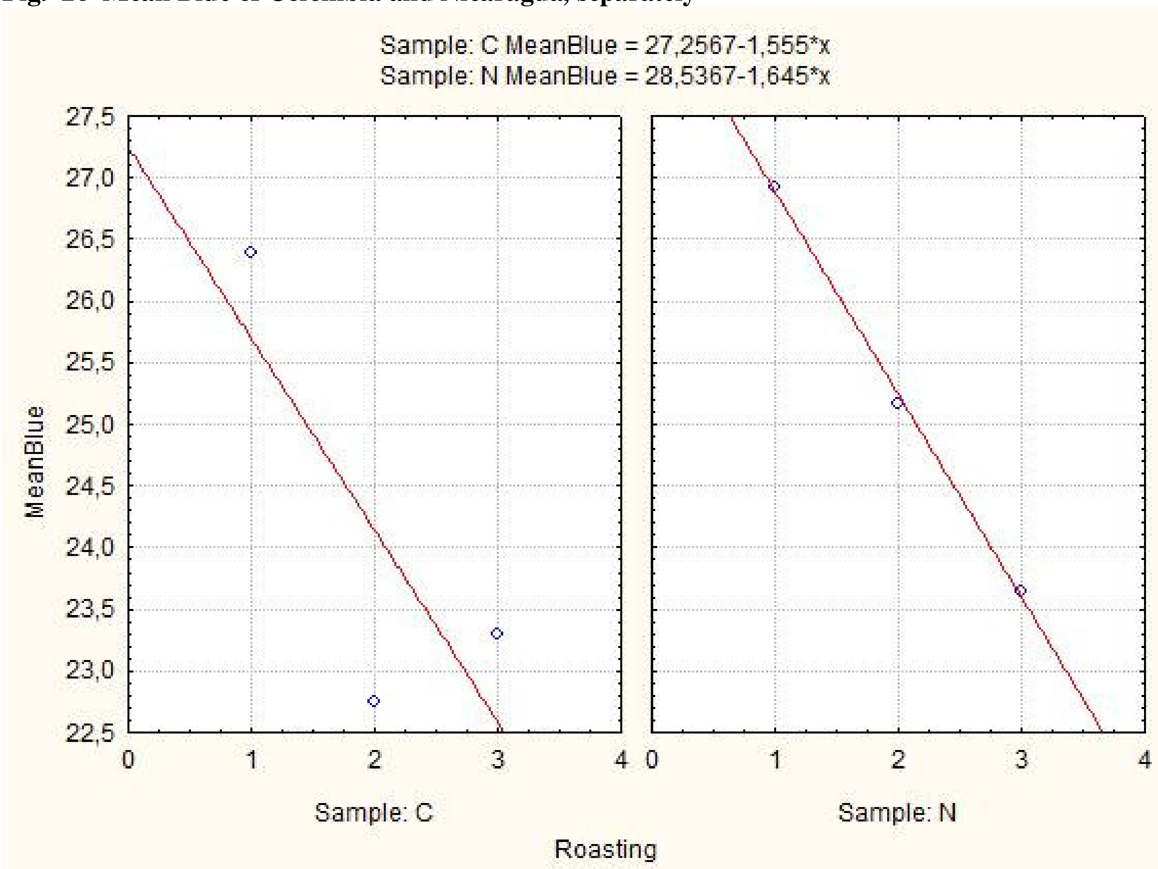
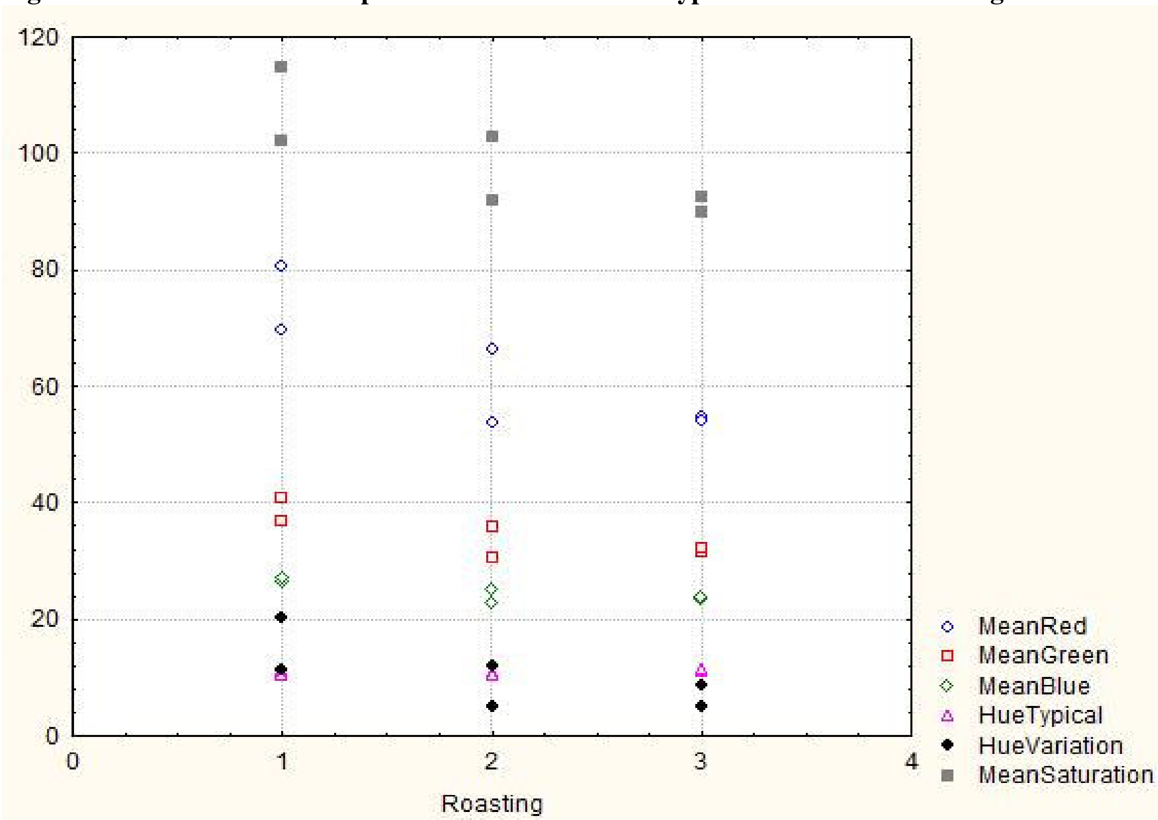


Fig. 27 All the six color main parameters of both coffee types Colombia and Nicaragua



c) The most important criterion of coffee should be cup quality (Feria-Morales, 2002). Sensory evaluation is determined by histograms and spider graphs, in this way to better understand the changes between Colombia and Nicaragua coffee varieties. Both Colombia and Nicaragua coffee are considered by the SCAA as “Gourmet” or “Speciality” coffee, meaning that sensory evaluation and cupping it is “a must” for the final examination of these coffees. Thier results in cupping are quite different as shown in the figures 28, 29, 30, 31, and 32. From these results, is clear that medium roast for both varieties of coffees was the best roasting degree, scoring the highest point in Colombia medium roast and as well in Nicaragua medium roast. In the Fig. 28, regarding flagrance and aroma, the medium roast, referred as Roasting No.2 , Colombia scored an average of 8.3 making this cupping profile a very good coffee. On the other hand Nicaragua scored an average of 8.75, which makes it a very good to excellent coffee. In Fig. 29, body for Colombia was 4.05, 6.15, 8.35 for light, medium and dark roast, showing quite a lesser body than Nicaragua with 4.55, 6.9, and 8.5. Only in the dark roast we have a very good body. In the Fig. 30, acidity is ranging from 7.15 to 8.2 in Nicaragua, which makes this coffee a very good coffee for acidity, typical for strictly high grown coffees (SCAA). Regarding flavor (Fig. 31) both coffees showed an excellent cupping profile in medium roast, 2C – 8.6 and 2N – 9.05.

Fig. 28 Flagrance and Aroma

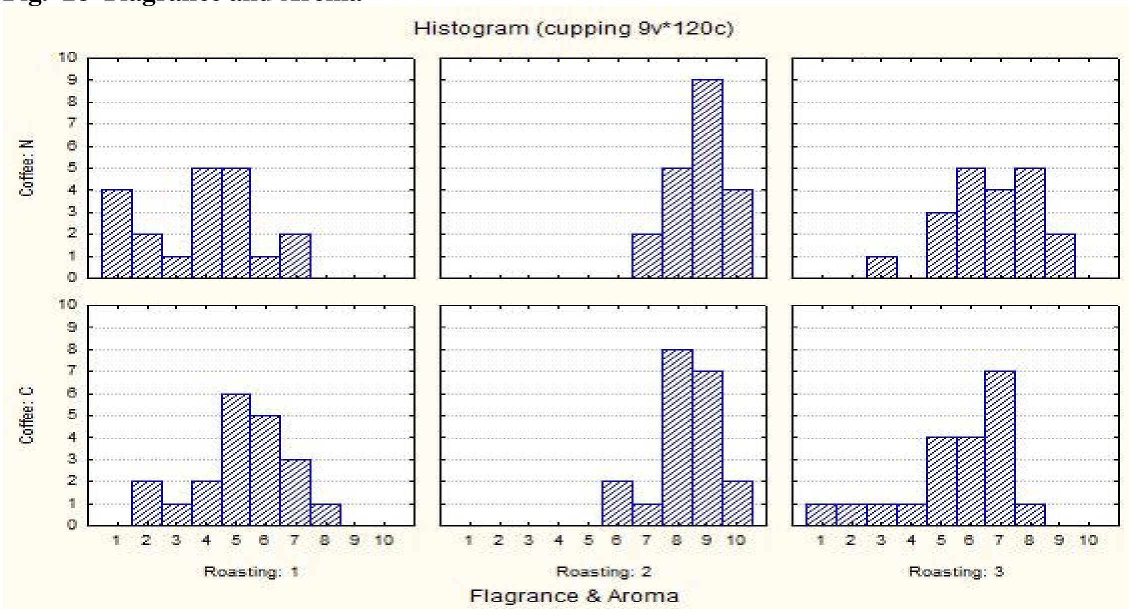


Fig. 29 Body

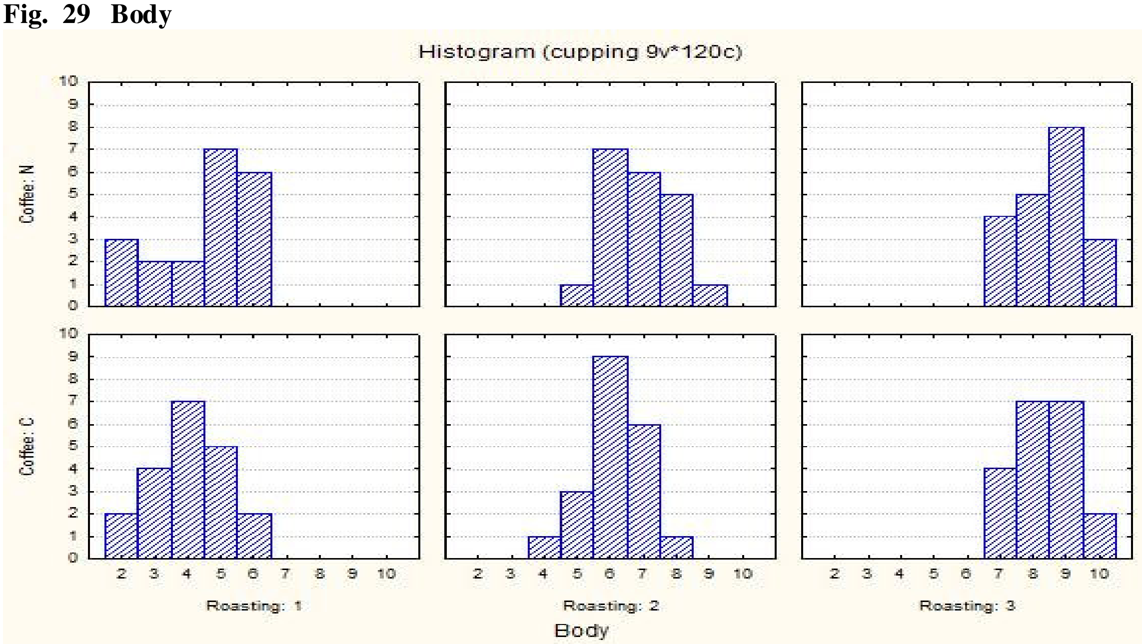


Fig. 30 Acidity

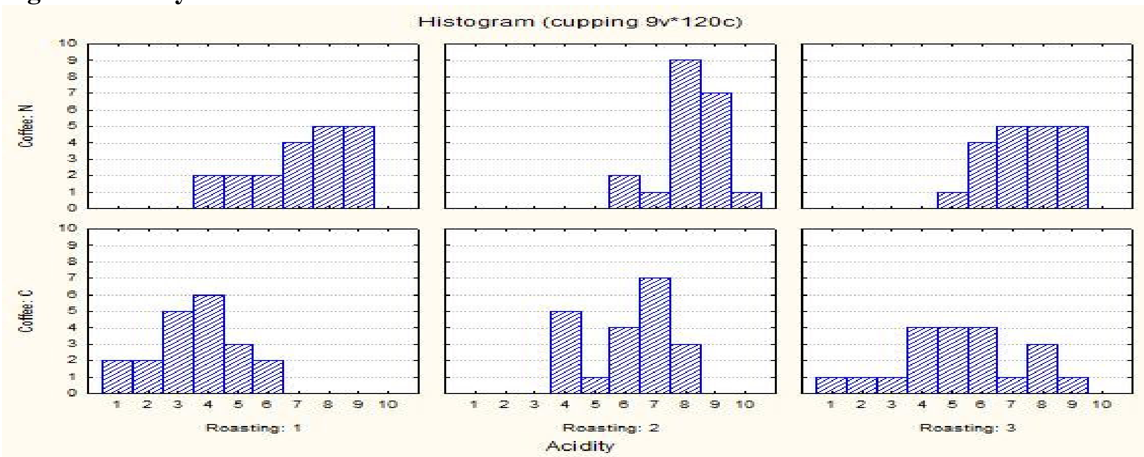


Fig. 31 Flavor

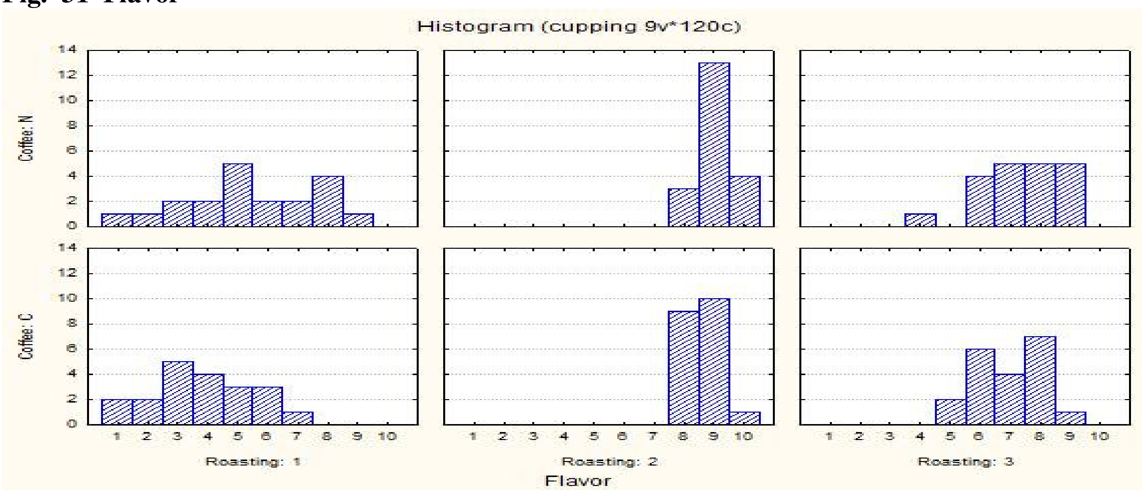


Fig. 32 Aftertaste

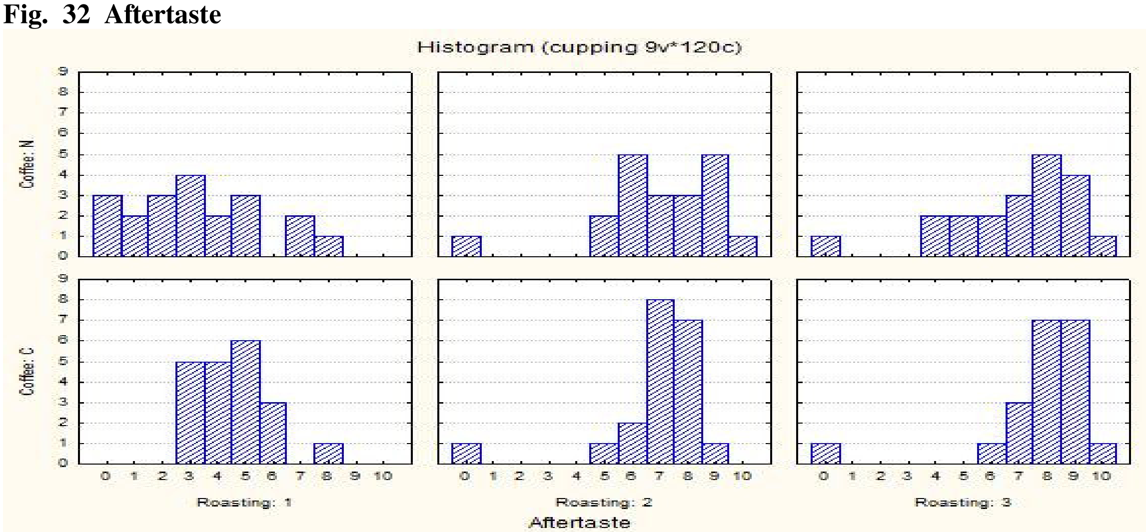


Fig. 33 Spider map – Cupping of both coffee types

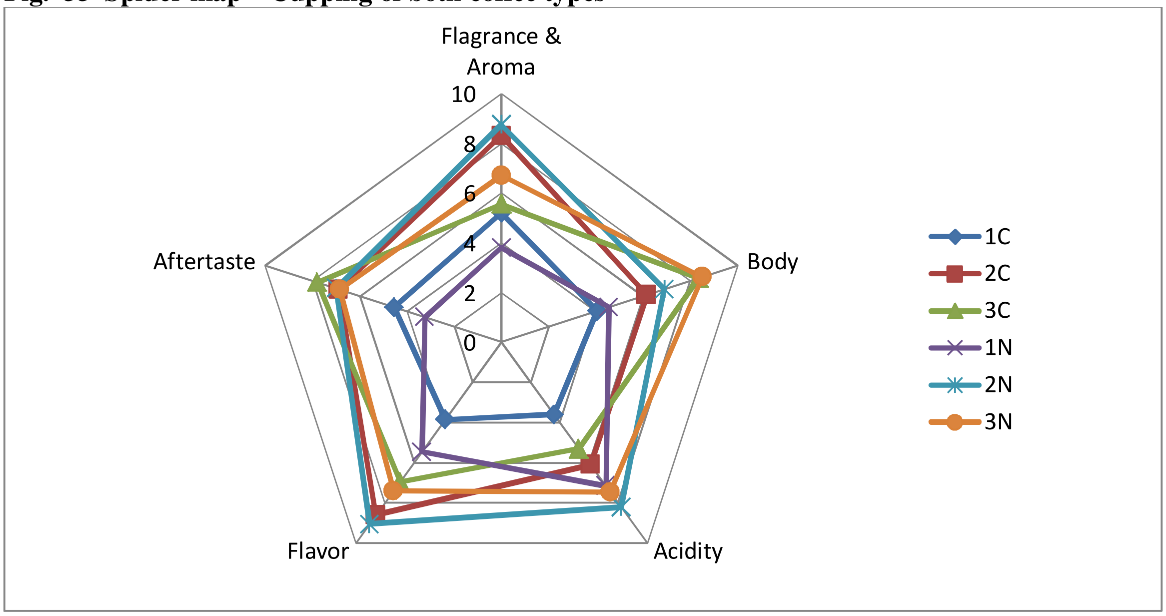
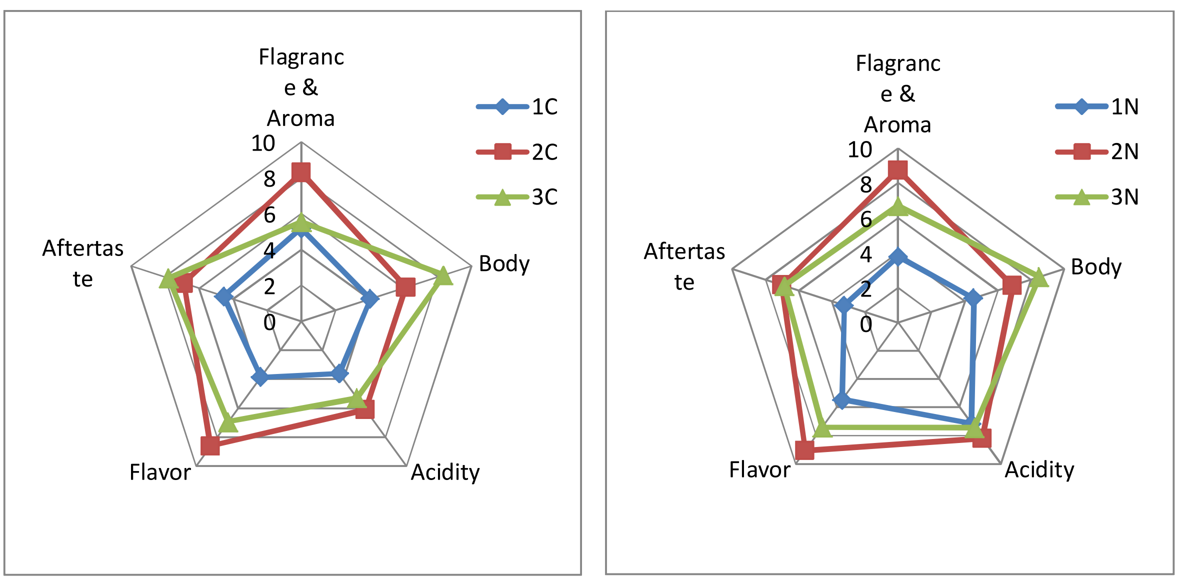


Fig. 34 Spider map – Cupping of Colombia coffee and Nicaragua coffee



d) GC – MS analysis are shown in the Fig. 35, and Fig. 36. Typical chromatograms obtained from green and roasted coffee of Colombia and Nicaragua, using different SPME fibers are presented in the following figures. It was possible to extract and detect a great number of volatile compounds. Many different research made by Grosch (2001) and Rocha (2003) regarding characterization of flavor-related substances in coffee, with over 850 substances being identified in the volatile fraction of roasted coffee. A total of 68 peaks were detected in Nicaragua and 74 peaks for Colombia. Among the detected peaks, 45 were tentatively identified, including benzemic and phnenolic compounds, alkenes, esters, alcohols, and ketones. A wide variety of compounds were detected in roasted coffee, with the number of substances increasing with both roasting degree and temperature. These include furans, ketones, pyrazines, pyridines, and pyrroles that have been previously reported in the literature (Grosch, 2001; Rocha, 2003). These compounds are found in roasted coffee headspace profile since they all could be products of Maillard, Strecker's degradation and other types of reactions that occur during roasting of coffee. The amount of pyridines depends on the degree of roast, and such compounds have been reported to be characteristic of darker roasts (Dart, 1985). Caffeine is known to be present in all coffee samples, regardless of roasting, but according Dutra (2001), it presents lower concetrations in dark roast. According to Arctander (1969), 3-methylpropanal has a sweet and fruity flavor and is considered one of the key odorant compounds of roasted Colombia and Nicaragua ground coffee. Vernin (1985) described 2-methylfuran as having a burnt material aroma with a sweet odor very similar to that of coffee. The flavor of furfural is similar to that of bread and caramel at certain concentrations, still possessing a bitter taste character. The flavor of furfuryl formate is associated to malt, fruits and cereal aromas, while 5-methyl-2-furancarboxyaldehyde has a spicy, candy and slightly caramel odor. 4-Ethylguaiacol has a smoky and burnt material flavor and 3-methylthiophene is responsible for a slightly sweet off-flavor similar to tinned meat, with sulfuric odor like baked onions (Flament, 2002). The flavor of 2-ethyl-3,6-dimethylpyrazine was described as burnt material and earthy by Grosch (2001) and as fermented stuff. The phenol derivatives are formed by degradation of free phenolic acids during the roasting process (Dart, 1985). Methoxyphenols, for example, 4-ethylguaiacol, 4-vinylguaiacol and vanillin are among the 22 main compounds responsible for the flavor of roasted coffee (Grosch, 2001).

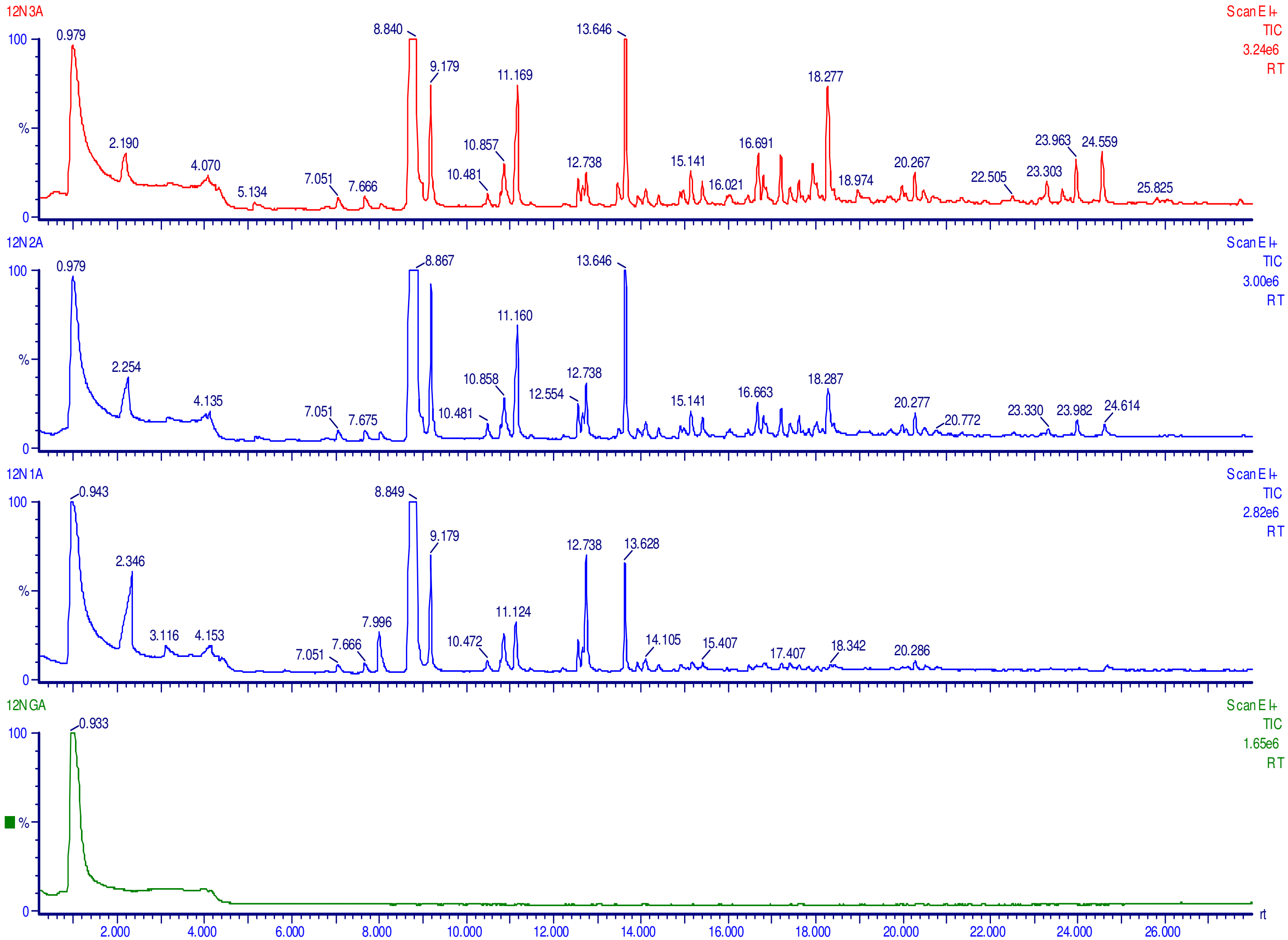


Fig. 35 GC – MS analysis of volatile compounds of Nicaragua coffee

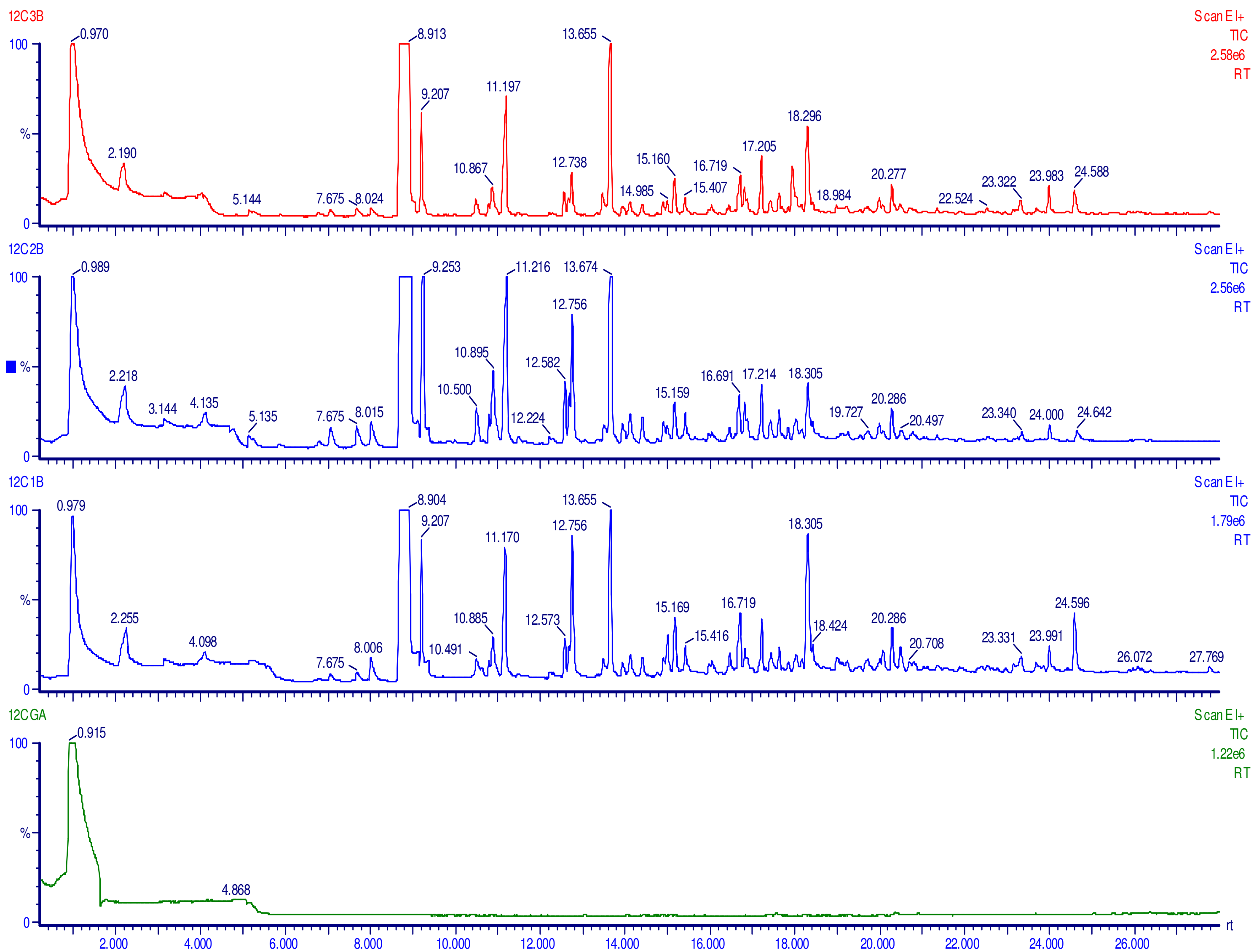
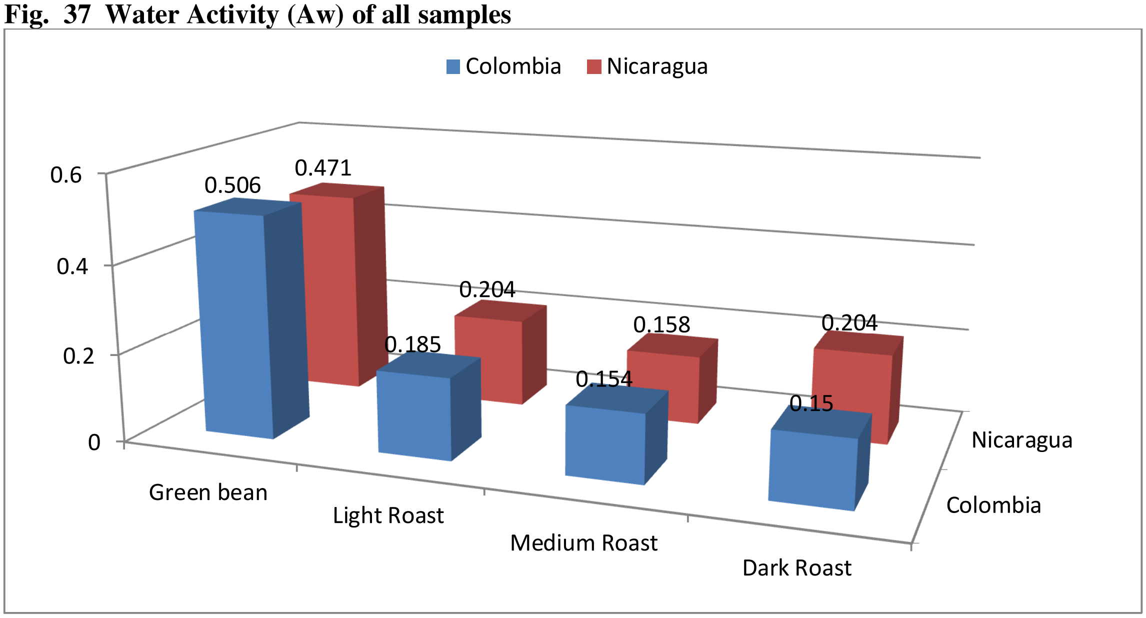


Fig. 36 GC – MS analysis of volatile compounds of Colombia coffee

d) The results of water activity are shown in the Fig. 37. Water activity has a significant importance because of OTA (ochratoxin A) producing fungi. The level of available water is the most important factor to be considered. At high water activity (aw > 0.95) OTA-producing fungi will not likely grow, as fast-growing hydrophilic fungi and yeasts grow first. At lower water activity (aw <0.80) the OTA-producing fungi can be present but not produce the toxin, and at aw below 0.78-0.76 they cannot grow. Aw of green bean are on limit between low and intermediate moisture foods Aw=0,600, with Aw=0.506 for Colombia and Aw=0.471 for Nicaragua greem beans. The limits under which microbial growth is impossible. Nicaragua dark roast (Aw=0.204) has a little higher Aw which is done by wetting of not a proper packaging, maybe. Therefore the green and roasted beans are microbiologically safe

Fig. 37 Water Activity (Aw) of all samples



6. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results in this diploma work, it was evaluated and concluded that time – temperature profile logs have a significant importance in roasting industry. Each roasting degree had a distinct profile, making them different during roasting process. In this work, it was attempted to obtain an almost linear roasting curve, with the internal bean temperature increasing proportionally with the roasting time. Therefore bean temperatures and bean temperature histories affect how much of a given coffee aroma or flavor forms and survives. Different bean temperature versus time histories will produce different reaction product balances even when those different histories provide equal roast color values. As it was showed by the results, that for a given coffee the same balance of aroma and flavor can be provided, roast after roast, by maintaining the same bean temperature (BT profile) versus time history. According results, medium roast, preferred mostly by Europeans, was the best roasting degree resulting in a flavor – rich and high aromatic cup. Roast times should not be faster than 8 minutes and not slower than 13 minutes. Image analysis showed a relationship between color generation represented by the redness component a* and acrylamide formation. Sensory evaluation proved how big the impact of roasting degree can be on the flavor of the coffee. Unfortunately, the cupping session cannot be 100% accurate because the cuppers could not sense at all if the differences in flavor were the result of the coffee or of the sample roasting protocol. In results obtained by GC – MS analysis, demonstrated that caffeine was present in all roast degrees, but interestingly it was in low levels at dark roast. Volatile compounds changed roughly during roasting, presenting a direct impact on coffee flavor and aroma, providing a more reliable measure of the roasting degree.

It should be emphasized that moisture content of coffee during roasting is a key parameter and should be taken into account for any research studies in roasting industry. Due to time limited and lack of proper instruments it was impossible to make this experiments.

Recommendations

1. Regular time – temperature profile logs should be evaluated in every roasting process, it gives a better understanding of the process to the roast master. If it is possible, I recommend to install a gas pressure gauge, that displays every adjustment in gas flow to the burners.
2. Medium hard beans should be roasted with moderate initial heat and moderate heat in the final stage, and strictly hard beans with high initial heat and moderate heat in the final stage of the roast process.
3. I highly recommend "Cupping". Tasting what you have created. Tasting at least two cups per roasted batch. Regular cupping protocols will prevent roasting process defects and by this will maximize customer satisfaction.

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IV. APPENDIX

A) LIST OF TABLES

B) LIST OF FIGURES

Tab. 1 Global Coffee Production and Consumption (in million bags)

Period	Global consumption, million bags	Global production, million bags
1994	93	94
1995	92.5	93
1996	93.5	102
1997	96	96
1998	99	93
1999	97	98
2000	96	87
2001	99.5	103.5
2002	102	101
2003	103.5	105.1
2004	104.3	115.4
2005	105	115
2006	109	107
2007	109.8	122
2008	112	104
2009	114.3	113.5
2010	116	106.2
Total	**1742.4**	**1755.7**

(Source : International Coffee Organization, (08/2010). www.ico.org)

Tab. 2 Roasting process degrees and temperature – depending transformations

Degree of Roast	Temperature (°C)
Green Unroasted	25
Starting to pale	130
Early yellow	165
Yellow-Tan	175
Light Brown	190
Brown	200
1st Crack Begins	205
1st Crack Under Way	210
City Roast	220
City+	225
Full City	230
Full City+	235
Vienna (Light French)	240
Full French	245
Fully Carbonized	255
Immanent Fire	260

(Source : www.sweetmarias.com, 10/2011)

Tab. 3 Colombia light roast
Weight loss – 14,55%

Colombia - light roast 1C

Time, min:sec	BT (°C)	ET (°C)
0:00	139	132
0:30	92	126
1:00	70	125
1:30	**66(TP)**	128
2:00	68	135
2:30	76	142
3:00	84	150
3:30	92	157
4:00	101	165
4:30	110	172
5:00	119	180
5:08	121	182
5:30	128	187
5:46	132	189
6:00	136	192
6:30	140	197
6:49	144	201
7:00	146	203
7:30	147	205
8:00	151	198
8:03	151	197
8:30	**152**	188
9:00	154	196
9:30	154	202
10:00	158	208
10:30	160	213
11:00	162	211
11:30	**164(FC)**	198
12:00	185	203
12:30	195	211
13:00	202	217
13:30	207	223
14:46	**212(SC)**	227

Tab. 4 Colombia medium roast
Weight loss – 16,44%

Colombia - medium roast 2C

Time, min:sec	BT (°C)	ET (°C)
0:00	189	194
0:30	114	181
1:00	86	176
1:30	**79(TP)**	177
2:00	82	180
2:30	88	186
3:00	96	191
3:30	103	195
4:00	111	199
4:30	118	204
4:39	121	206
5:00	126	213
5:23	132	219
5:30	134	219
6:00	141	219
6:30	147	222
6:40	149	223
7:00	153	226
7:30	159	230
8:00	165	234
8:03	166	234
8:30	171	239
9:00	177	243
9:30	183	246
10:00	188	248
10:30	194	249
11:00	198	236
11:30	**201(FC)**	229
12:00	204	238
12:30	207	243
13:00	210	248
13:30	214	252
14:00	**218(SC)**	243
14:30	221	232
15:00	224	237
15:04	**224(End)**	237

Tab. 5 Colombia dark roast Weight loss – 18,23%

Colombia – dark roast 3C

Time, min:sec	**BT (°C)**	**ET (°C)**
0:00	177	178
0:30	103	152
1:00	**75(TP)**	139
1:30	69	136
2:00	72	147
2:30	78	159
3:00	84	167
3:30	92	174
4:00	98	179
4:30	106	184
5:00	112	189
5:30	118	193
6:00	125	197
6:30	131	201
7:00	136	204
7:30	142	208
8:00	147	212
8:30	153	214
9:00	158	218
9:30	163	221
10:00	168	224
10:30	173	227
11:00	178	231
11:30	183	233
12:00	189	236
12:30	194	238
13:00	**198(FC)**	224
13:30	199	213
14:00	200	216
14:30	202	222
15:00	204	225
15:30	207	232
16:00	211	237
16:30	217	242
17:00	223	243
17:30	227	231
18:00	**229(SC)**	225
18:30	**236(End)**	236

Tab. 7 Nicaragua light roast Weight loss – 12,7%

Nicaragua - light roast 1N

Time, min:sec	**BT (°C)**	**ET (°C)**
0:00	148	172
0:30	95	165
1:00	76	153
1:30	**74(TP)**	142
2:00	79	160
2:30	86	163
3:00	94	165
3:30	102	168
4:00	108	172
4:30	114	175
5:00	119	180
5:30	124	185
6:00	128	188
6:30	132	189
7:00	134	190
7:30	137	192
8:00	140	195
8:30	143	198
9:00	146	204
9:30	150	207
9:34	151	208
10:00	155	210
10:30	161	212
10:55	166	215
11:00	167	215
11:30	174	216
12:00	**182(FC)**	210
12:30	187	212
13:00	191	218
13:30	193	225
14:00	196	228
14:30	199	229
15:00	202	229
15:30	204	230
16:00	208	232
16:30	**218(SC)**	237

Tab. 8 Nicaragua medium roast   Weight loss – 16,44%

Nicaragua – medium roast 2N

Time, min:sec	**BT (°C)**	**ET (°C)**
0:00	198	197
0:30	117	176
1:00	87	163
1:30	**81(TP)**	155
2:00	83	160
2:30	91	167
3:00	99	174
3:30	108	181
4:00	117	179
4:30	124	176
4:45	127	174
5:00	130	171
5:13	132	168
5:30	134	167
6:00	138	165
6:30	141	164
7:00	143	171
7:30	147	179
7:46	149	183
8:00	151	188
8:30	156	196
9:00	161	202
9:21	166	206
9:30	167	206
10:00	173	203
10:30	177	193
11:00	**179(FC)**	185
11:30	180	191
12:00	183	202
12:30	187	210
13:00	192	216
13:30	197	220
14:00	201	220
14:30	**205(SC)**	222
15:00	209	226
15:30	213	231
16:00	219	234
16:30	**226(End)**	237

Tab. 9 Nicaragua dark roast   Weight loss – 18,06%

Nicaragua - dark roast 3N

Time, min:sec	**BT (°C)**	**ET (°C)**
0:00	152	163
0:30	99	156
1:00	77	153
1:30	72	149
2:00	74	147
2:30	**79(TP)**	145
3:00	85	149
3:30	92	157
4:00	99	164
4:30	106	172
5:00	114	179
5:27	121	185
5:30	122	186
6:00	131	190
6:07	132	191
6:30	138	192
7:00	144	193
7:29	149	195
7:30	149	196
8:00	153	197
8:30	157	200
9:00	162	207
9:18	166	210
9:30	168	212
10:00	173	213
10:30	176	215
11:00	179	216
11:30	182	217
12:00	186	218
12:30	188	219
13:00	190	219
13:30	195	213
14:00	**207(FC)**	209
14:30	207	218
15:00	208	224
15:30	210	229
16:00	216	234
16:30	**222(SC)**	226
17:00	226	220
17:30	229	221
17:37	**230(End)**	221

Tab. 10 Mean *L*a*b** color space parameters of both, Colombia and Nicaragua coffee

Time, min	L* (luminosity)			a* parameter			b* parameter		
	Light	Medium	Dark	Light	Medium	Dark	Light	Medium	Dark
0	57	57	57	1	1	1	12.8	12.8	12.8
5	57	54	48	1.2	2	5.3	13	12	10.8
10	56.8	40	36	1.8	6.1	5.2	12.4	7.6	5.6
12	56	34	32	3.3	4.6	2.6	12.2	4.8	1.8
14	52	32.5	30.5	5.24	3	1	12	3.1	0.4
16	44	31.2	30	6.22	2.23	0.5	11.2	1.8	0

Tab. 11 Mean RGB values, Mean Grey Level, Hue Typical, Hue Variation and Mean Saturation of Colombia coffee

Roasting degree	Mean Red	Mean Green	Mean Blue	Mean Grey Level	Hue Typical	Hue Variation	Mean Saturation
1C	69.73	36.73	26.4	44.3	10.81	20.18	101.98
2C	53.68	30.45	22.75	35.6	10.52	11.8	91.78
3C	54.83	31.63	23.29	36.6	10.88	8.49	92.53

Tab. 12 Mean RGB values, Mean Grey Level, Hue Typical, Hue Variation and Mean Saturation of Nicaragua coffee

Roastin g degree	Mean Red	Mean Green	Mean Blue	Mean Grey Level	Hue Typical	Hue Variation	Mean Saturation
1N	80.63	40.7	26.93	49.4	10.41	11.29	114.68
2N	66.17	35.77	25.17	42.4	10.39	5.15	102.81
3N	53.99	32.06	23.64	36.6	11.41	5	89.81

Tab. 13 Cupping mean values of Flagrance&Aroma, Body, Acidity, Flavor and Aftertaste

Description	**Colombia coffee**			**Nicaragua coffee**		
	1C	**2C**	**3C**	**1N**	**2N**	**3N**
Flagrance & Aroma	5.2	8.3	5.55	3.8	8.75	6.7
Body	4.05	6.15	8.35	4.55	6.9	8.5
Acidity	3.6	6.1	5.3	7.15	8.2	7.45
Flavor	3.85	8.6	6.95	5.45	9.05	7.4
Aftertaste	4.55	6.9	7.8	3.25	7	6.85

Tab. 14 Water activity (Aw) values calculated

Roasting degree	**Colombia**	**Nicaragua**
Green bean	0.506	0.471
Light Roast	0.185	0.204
Medium Roast	0.154	0.158
Dark Roast	0.15	0.204

Tab. 15 Determination of Cd, Cr, Cu, Mn, Ni, Pb and Zn in the samples of coffee

Origin		Hg	Pb	Cd	Cr	Ni	Zn	Mn	Cu
Colombia	mean	0.0019	0.2350	0,002	0.6696	0.8307	4.900	28.022	15.862
	standard deviation	0.0006	0.0737		0.0719	0.1159	0.661	1.459	1.057
Nicaragua	mean	0.0016	0.0552	0.0054	0.2953	0.2343	5.946	12.951	15.407
	standard deviation	0.0002	0.0122	0.0032	0.0305	0.0212	0.805	0.870	0.699

Fig. 1 Complete green coffee processing
(Source: *Coffee*: Growing, Processing Sustainable Production. Wintgens, 2004)

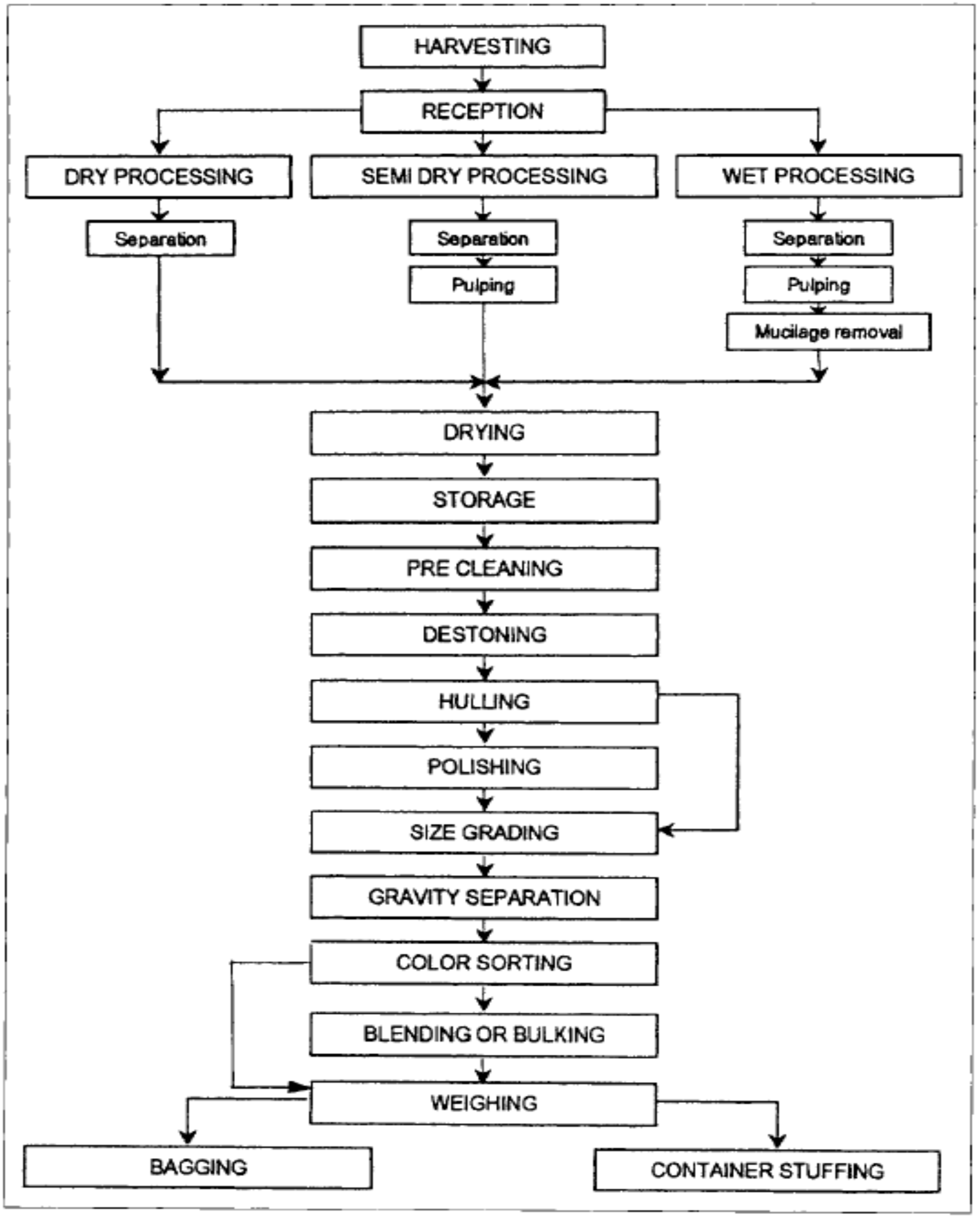


Fig. 2 Tractor – driven coffee harvesters , mainly used in Brazil and Colombia

(Source: *Coffee*: Growing, Processing Sustainable Production. Wintgens, 2004)

Fig. 3 Oxbo 9200 Coffee Harvester

(Source: http://www.oxbocorp.com/Products/Coffee.aspx, 10/2011)

Fig. 4 All eight samples, before image analysis

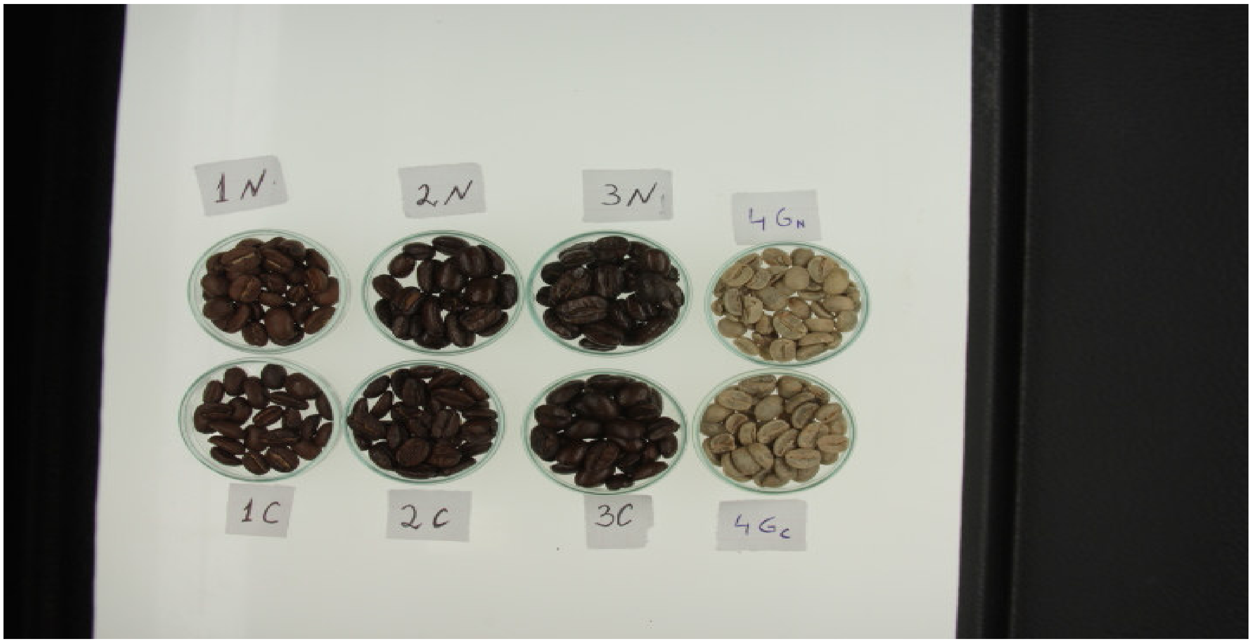


Fig. 5 Brewed coffees in image analysis.(1st row – 4GN, 3N, 2N, 1N; 2nd row – 4GC, 3C, 2C,1C)

Fig. 6 Samples brewed and taken pictures. Ready for *L*a*b** color space measurements.

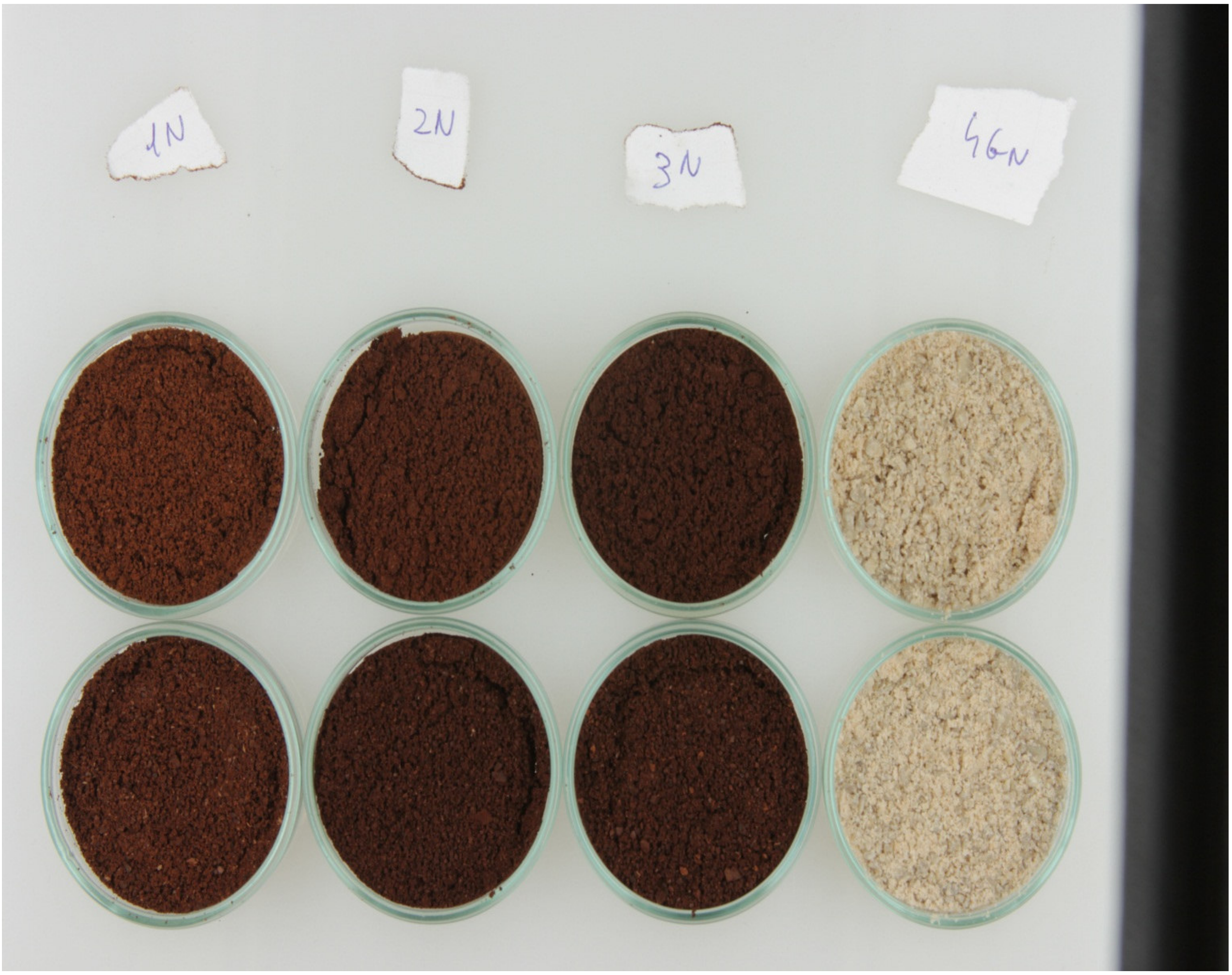
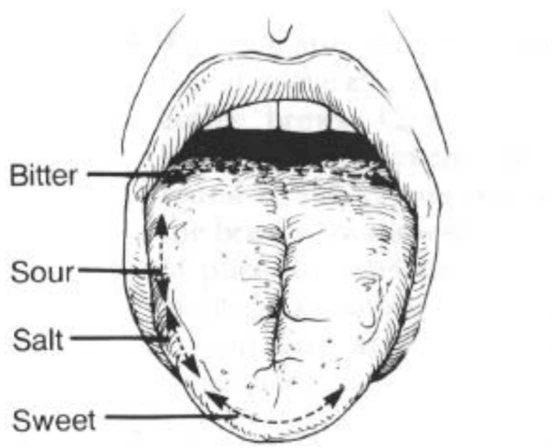


Fig. 7 Sensory evaluation of roasted coffee samples (1)

Fig. 8 Sensory evaluation of roasted coffee samples (2)

A Coffee Taster's Glossary



Acidity

High acid (or acidy) coffees have a sharp, pleasing, piquante quality that points up their flavor and gives them snap, verve, liveliness in the cup. Acidity may be high, medium, light, low, or lacking altogether in coffees, in which case the coffee tastes flat and dull. Acidity is characteristic of high-grown coffees.

Aroma

Refers to the odor of the prepared coffee beverage. It may be lacking, faint, delicate, moderate, strong, or fragrant (also called aromatic), and distinctive as to character.

Body

The tactile impression of weight and texture in the mouth. Coffees may be watery, *thin*, slight, light, medium, full, heavy, thick or even sirupy in body, as well as buttery, oily, rich, smooth, chewy, etc., in texture. Easiest to detect in full-strength coffee.

Flavor

(a) The total impression of aroma, acitidy, and body; if the impression is strong, fine, and pleasant, the coffee is described as flavory or flavorful or ranked on a scale from poor, fair, good, to fine-flavored.
(b) Specific taste flavors may suggest, spices, chocolate, nuts, or something less complimentary - straw, grass, earth, rubber etc.