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ECOLOGICAL PROCESSING OF COFFEE AT THE FARM LEVEL.

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INTRODUCTION

This work is based essentially on the research carried out in the last fourteen years at CENICAFE, The National Research of the Colombian Coffee Growers Federation - FEDECAFE, period in which the *Post-harvest Program* of CENICAFE was created. Thanks to the support of the FEDERATION and to the contribution of the Colombian Universities, mainly from the programs of Agricultural Engineering, through the works of six professors' sabbatical year and of thirty-four students' theses the Post-harvest Program, in a relatively short period has been able to propose substantial modifications to all of the stages of the traditional coffee processing system that has been practiced in Colombia and in the countries that use the coffee wet processing method. Nevertheless, the good quality of the coffee is preserved, the conservation of the environment is favored and the whole business becomes more profitable.

Because of the sound theoretical foundation of the research program and because the continuity of their resulting executions, typical of a long term scientific programming, not solely the techniques of ecological and profitable character of the process are introduced. Simultaneously, the processing recommendations are valid to obtain a high quality product, to eliminate unessential stages, the simplification of most of the procedures and the significant decrement of the qualitative and quantitative losses that occur using the traditional methods of processing of the coffee. The new technological methods additionally coincide with the smallest necessary manpower and the physical space. Typically the new technology occupy one fourth to one fifth of the traditional area. And the transformation of the by-products pulp and mucilage, that used to cause the traditional contamination, are recommended to mix and treat them in an elementary and

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efficient way, into products of trade value, represented by organic manure and animal protein.

The technology that was introduced commercially only in 1996 is already being used in hundreds of satisfied farmers, in Colombia and overseas. FEDECAFE plans to participate directly in the introduction of 17,000 new processing mills, in a four-year program in Colombia. The *Post-Harvest Program* of CENICAFE, in reason of this development, received the distinction of excellence in research, given by the *COLOMBIAN INSTITUTE OF SCIENCES 'COLCIENCIAS'*, December 1996 and also received the First Prize of *"PLANETA AZUL"* instituted by the *BANCO DE OCCIDENTE* of Colombia in March 1997. In occasion of an International Course on Ecological Processing of Coffee, hold at CENICAFE in October 1996, the technology was presented to the international community, to 26 participating countries.

I. GENERALITIES.

The *pulp and the mucilage* of the coffee are not toxic or poisonous elements. On the contrary, they are organic products that properly managed can represent a high added value for the coffee grower. In particular, like it will be shown in this work, in their simple or mixed form, they have immediate use to produce organic compost and animal protein of good quality.

The contamination that the pulp and the mucilage produce is due to a portion of their organic matter that is dissolved or remain in suspension within the waters, produced in the different stages of the process and in the transportation of the coffee or their sub-products. The *dissolved organic materials can withdraw or consume the oxygen of the water*, very quickly in a natural process of oxidation. The pulp and the mucilage contained in a kilogram of coffee cherry can retire the whole oxygen to 7.4 cubic meters of clear water, propitiating their quick deterioration.

The pulp, separated from the grain in absence of water, represents 72% of the possible contamination. The mucilage that remains on the grain represents 28%. If the parchment coffee is left in tanks with flowing water currents for cooling purposes, as is done in many processing mills, additional contamination is generated as the grain loses dry matter by diffusion. The potential contamination that the management of pulp can cause is very high, due to its high organic content and because when it is transported hydraulically it can lose half of its content. The yield of fresh annual pulp in Colombia is of the order of 2.5 million tons and that of the mucilage of 1.3 millions.

It is a commonplace practice in the countries that produce coffee, processed by the wet method, to use water in practically all the stages of the process. Water is used in the transportation of cherries from the field to the mills, using of coffee ducts; in the reception hoppers for the coffee cherries; during the transportation of the cherries to the siphons tanks (hydraulic classifiers of coffee cherries by difference of density); in the transportation of the coffee cherries to the pulpers; in the transportation of the pulp to the their deposit, or to the streams and rivers. Also water is used in the transport of the coffee with mucilage to the fermenting tanks; in the washing of the fermented mucilage; in the different stages of classification of the coffee cherries or during the transportation of the wet parchment grains to the dryers.

The *washing of the coffee*, is the only process in which *water is needed indispensably*. In the work of CENICAFE (131) it has been proven that it is possible to wash off the fermented mucilage with less than 5 liters of water for kilogram of dry parchment coffee. (See Section 3.6.). It has also been shown recently (72) that is possible to demucilage the coffee mechanically, to wash and clean it with water consumption of 0.6 L/kg of dry parchment coffee (See Section 3.8.). The mentioned values of consumption of water are very distant from the values used in many of the existent coffee mills, where it is used around 40 L/kg. Therefore, the potential of reduction of water and to decrease the contamination caused in the wet process of the coffee is very large.

It has been proven (See Section 3.12) that the traditionally polluting products, the pulp and the mucilage can be handled adequately, in the same moment that the coffee process takes place, to control more than 90% of the potential contamination. The technology has being denominated BECOLSUB (*Ecological Processing and Handling of*

By-products). The main element of the module, the optimized mechanical demucilager is denominated DESLIM (*Demucilager - Cleaner*) and it is described thoroughly in Section 3.8.4.

Ecological processing of the coffee, wet way, is the collection of operations that are carried out to transform the coffee cherry into dry parchment coffee, preserving its quality, fulfilling the marketing standards, avoiding unnecessary losses of coffee, eliminating needless processes, taking advantage of the by-products, to represent the biggest economic entry for the coffee grower and yielding the minimum alteration to the strictly necessary water for the process.

They exist in principle two procedures, mutually complementary, to practice ecological coffee processing techniques. The first one consists on *rationalizing the conventional process*, eliminating the stages not strictly necessary as the hydraulic transport and the fermentation of the mucilage. Avoiding the use of water in the pulping process, the excessive classification or separation of the grains and minimizing, as an overall practice, the consumption of water. The second method consists on *eliminating the organic matter contained in the contaminated water by means of the biological actions of microorganisms in bioreactors*.

If the mechanical demucilager is used, and in particular the last version, the DESLIM device (72), it is easy to handle simultaneously, in continuous flow, 1) the highly concentrated mucilage mixed with residuals coming from the grains (complete and half-covered grains with dry pulp) and of crushed low-grade coffee that didn't resist the mechanical efforts and 2) the pulp. These elements mix evenly in a screw conveyor (See Section

3.11.) that is also the transporting mechanism, to generate a new substrate type that is consumed by the red worm. This way, it is possible to *control, by physical methods only, approximately 92% of the potential contamination*. The coffee that leaves the demucilager washed and clean can go directly to the dryer. If the raw material it is not of very good quality, it can be advisable to use a method to complement the classification and washing processes as is done by the hydrocyclone (See Section

3.9.).

The inclusion or use of a mechanical demucilager, without the optimal attributes, doesn't assure that the contamination decreases. On the contrary, if a demucilager is not used optimized in its construction and operation, and the fluxes of water are superior to 1.0 liter by kilogram of dry parchment coffee, or the pulp and the released residuals are not handled properly; the contamination that is caused is higher that the one that would be obtained without the introduction of the mechanical demucilager. This is the case because of the introduction of new contaminating elements originated in the operation of the demucilager, in comparison with the conventional fermentation method, practiced with rational washing and an appropriate method for handling the pulp.

The second procedure of ecological processing, as is considered by CENICAFE, consists on eliminating the organic matter of the contaminated waters by bioreactors (133). The method can be used to treat the waters used for washing the coffee, (131) after the conventional fermentation of the mucilage. This procedure allows reducing 90% of the contamination of these waters, and by the appropriate handling of the pulp, it allows a global control of 97% of the potential contamination.

It is possible to use the bioreactors system, to complement the BECOLSUB technology, in big properties and in central mills, to decontaminate the remainder 10% of contaminated waters presented in the liquids that were not possible to control, by physical methods.

When no physical or biological procedures are implemented and the coffee by-products are dumped into the water, the *use of the oxygen of the water by the organic residuals in the process of the coffee, cause the following problems*:

- Death of the animals and of the plants for oxygen deficiency and for the high acidity of the water.
- Proliferation of undesirable microorganisms.
- Non potable and inadequacy for the domestic use.
- Inadequacy of the waters for the industrial use, including for the processing of the coffee in other coffee mills.
- Proliferation of bad odors, attraction of flies and other insects and deterioration of the landscape.

The conventional process of the coffee might use 40 liters of water per kilogram of dry parchment coffee (DPC), (12.5% in pulping; 37.5% in the washing and transport of the beans and 50% in the transport of the pulp). This figure implies that 46 million cubic meters of water would be needed each year to process 16.7 million sacks of green coffee (60 kg) in Colombia. This volume is equivalent to the human consumption of a city of 840,000 inhabitants in one year, assuming that each person uses 150 liters of water per day.

Also, it is essential to have adequate quantity of water stored to avoid full losses during the processing, in case of a failure of the natural direct supply during the processing days.

The volume of the storage tanks is designed depending on the availability of water in the region. The recommended minimum amount of stored water is the equivalent to the consumption of 2 days of maximum processing. The volume of the necessary tanks for storage of the water needed for the Colombian coffee production would be of 1.84 million cubic meters, what represents a cost of approximately US $70.5 millions, to be financed by the farmers.

II. QUALITY OF COFFEE

2.1. GENERAL CONSIDERATIONS [2].

For some products like coffee, the *sensorial characteristics* are more important than their nutritious value. The quality of the coffee (89), (95), (98) comprehends the appearance, the color and the smell of the parchment, of the green and of the toasted coffee, as well as the organoleptic qualities of the drink that comprehend the aroma, the acidity, the bitterness, the body and the flavor.

More than four hundred organic and inorganic compounds contribute to the distinctive flavor of the coffee; the aroma is constituted by more than seven hundred substances, mainly aldehydes, cetanes, esters and hydrocarbons of low molecular weight (57). Many of these compounds are present in a very small quantity and can not be considered alone as the primary component of the coffee. In fact, many of the natural components of the coffee, when they are separated from it and they are concentrated, they present flavors and scents very different to coffee. Other components are unstable and evaporate forming compounds, that present different flavors and scents (30), (32), (58).

The *quality of the Colombian coffee* has been appreciated and worldwide recognized by the consumer countries at world level as one of the *best within the Arabic coffees*. This quality is determined genetically and influenced by many factors, such as the cultivation conditions, the climate, the soil, the phytosanitary attentions, the agronomic practices, the quality of the harvest, the type and control during the processes, the roasting and the preparation of the drink (10), (11), (17), (35), (43), 44), 48), (64), (65), (85), (89), (91), (92), (93), (94), (95), (98), (114), (128), (129).

They exist likewise pronounced differences in the qualities and choices between the coffee consuming countries. For example, the French and Italians prefer a drink with bitterness and high body, while the Germans like a cup with high acidity and aroma and moderate body.

2.1.1. The quality of the varieties of coffee cultivated in Colombia.

At the present time there are in Colombia near of a million hectares planted with coffee (29),(48), of which 40% are modern fields planted with *the Colombia variety*, an hybrid, *resistant to the leaf rust* (69). The rest corresponds to the cultivation of Típica, Caturra and Borbón traditional plantations (2).

The quality of the beverage of the Colombia variety was one of the most important aspects in its development and improvements and it were assessed through the investigation by national and international sensory panels (23),(69), 70), 80).

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[2] Prepared by Puerta, G. I. Química Industrial, CENICAFE.

In CENICAFE, during the 1995 crop, the quality of the prepared beverage from experimental plots of different varieties of coffee, were evaluated. The main varieties of the *Coffea Arabic* L. species cultivated in Colombia: Typical, Caturra, Borbón and Colombia of red and yellow fruit were determined. The sensorial qualities of the intensity of the aroma of the ground coffee were evaluated. Also the aroma, acidity, bitterness, body and global impression of samples of wet processed coffee, in a controlled way, under normalized conditions of toasting and milling, were investigated (93). There were carried out 1,100 descriptive, quantitative and comparative sensorial tests, describing each property of the beverage within a scale from 1 to 9, where 9 corresponded to the best cup and 1 to the worst and of total rejection (24), (37), (90). It was demonstrated that the quality of the varieties of coffee of the species Coffea Arabic cultivated in Colombia are very homogeneous and they present general characteristics of softness in body and bitterness and a marked aroma and acidity, as it is shown in Table 1.

Likewise, it was verified by Colombian and international (members of the *International Coffee Association of America*) tasters that the *variety Colombia* stands out for its high acidity and marked bitterness, as long as the variety Borbón presents characteristics balanced in all the attributes. The Typical variety produces very soft and neat cups and the Caturra variety is characterized by its acidity and aroma.

*Table 1. Qualification of the sensorial characteristics of the varieties of coffee Coffea Arabic L. cultivated in Colombia **

Sensorial Characteristic	*Variety*				
	Borbón	*Caturra*	*Colombia Yellow*	*Colombia Red*	*Típica*
Aroma of the toasted and milled coffee	7.22	7.38	7.24	7.32	6.98
Aroma of the drink	7.19	7.42	7.21	7.33	7.19
Acidity	7.35	7.53	7.45	7.57	6.96
Bitterness	7.25	6.93	6.93	6.74	6.68
Body	7.26	7.32	7.18	7.39	7
Global impression	7.25	7.31	7.27	7.4	6.97

* *Results of 1,100 analysis for each sensorial characteristic.*

It is worth to note that in the tests carried out with multiple comparisons, to identify the five varieties, only in 28% of the cases the panelists selected the correct variety. All the varieties were mistaken from the other ones for all the seven tasters, at least once, and it was not easy at all, to select the correct variety for all of them, under the same conditions of the samples (93).

2.1.2. The wet processing of coffee and their influence in the quality.

2.1.2.1. The harvesting

The biggest defects caused by an *inadequate harvesting* are the aromas and acrid flavors produced by the presence of black grains; the ferments by harvesting overmature grains, and the flavor and the astringency by the presence of green and immature grains.

2.1.2.2. The removal of the mucilage

During the natural fermentation, bacteria, yeasts and enzymes act to transform the peptic compounds and sugar constituents of the mucilage, into alcohols and carboxylic, acetic, lactic, propionic and butyric acids, which are then removed in the washing process. *The process of fermentation is of the most critical steps during the wet processing, in what refers to the conservation of the quality of the coffee*, and therefore it should be controlled carefully the time of the process. It is indispensable *avoiding overfermentations*, that originate aroma and flavors to vinegar, mature pineapple, onion, rancid and nauseous. In the same way, before drying the beans, it is necessary that the coffee is free of mucilage, otherwise the parchment will discolor, the drying would be hindered and the cup could acquire flavors to dirty or sour. The mixture of coffee of different days of being harvested in tanks for their later process also originates defects of ferment in the aromas and flavors of the coffee.

In overfermentation trials of mixtures of cherries it was found that *after 20 h of fermentation it were perceived flavors to vinegar pineapple in the drink; at 40 hours, 37.5% of the samples were classified as fermented and stinker; and after 64 hours, more than 75% of the cups gave nauseous flavor* (88).

2.2. EFFECT OF THE MECHANICAL DEMUCILAGE IN THE PHYSICAL AND ORGANOLEPTIC QUALITY OF THE COFFEE. (77)

2.2.1. Elimination of the mucilage.

In processing of coffee by the wet method, as it is used in Colombia and the mild coffee producing countries, the mucilage is eliminated by washing the natural residuals of the fermentation process. When this operation is carried out under good control, coffees are obtained with high cup quality. However, in many cases there is little control, especially when the production is low and coffees of 2 or 3 days of being harvested are mixed in one tank, giving origin to ferment and in more critical case *"stinker"* type of coffees. In both cases important economic losses are produced, since the buyers refuse these materials.

The *fermented mucilage* is retired from the coffee beans by washing them in the same tank (in the case of small producers) or using devices like *open channels or the semi-submerged channels* (25), (63), (127). When the coffee is washed in the fermentation tank the specific water consumption can be decreased down to 4.2 L/kg of dry parchment coffee (131). When the coffee is washed and classified in the open channel the consumption of water, without recirculation, is of the order of 39.0 L/kg (25),(127). In the case of the semi-submerged channel the specific consumption is of the order of 6.1 L/kg (63). Recirculation of the water in any continuous washing system is of difficult achievement, since after some time of practicing the procedure the coffee kernels will be washed with non-clean waters.

The mechanical demucilaging process carried out with the appropriate equipment, allows the quick removal of the mucilage with many advantages (See details in sections 3.8.6. y 3.12.) compared with the natural fermentation process. Some of the advantages are: significant reduction in the consumption of water, reduction of the contamination (96), larger yields of dry coffee due to the elimination of the losses of dry matter by respiration of the grain (124),(125) and the recovery of good coffee kernels that were covered (totally or partially) with dried pulp (111), and better use of the dryers because this equipment can start operation the same day of the harvest. Finally, significant reduction of the civil structures and human labor are required for the operations.

The *contamination* generated by the washing of the coffee, in terms of grams of chemical demand of oxygen (CDO)/kg of coffee cherry, in the case of the natural fermentation is of 30. This represents 26.3% of the potential contamination generated by the wet processing method of coffee (131). By means of the appropriate use of the demucilaging machines this value decreases to 10%, or less (96).

2.2.2. Physical quality of the demucilaged coffee.

The *physical quality* of the demucilaged coffee depends on the equipment used, the control of the process and the quality of the coffee cherry (content of immature grain, dry cherries, strange materials, etc.). Additionally, the physical quality is also affected by the previous and later treatment to the process: elimination of the lights and strange materials from the coffee cherries, separation of coffees with complete or partial covered with dried pulp from the pulped coffee. Elimination of floats, coffee grain complete or partial covered with dried pulp and strange materials separated from the demucilaged coffee.

When the coffee comes from the main harvest season the percentage of immature grain grains is generally less than 3% (132). In the case of grains coming from coffee plantations with low incidence of phytosanitarian problems, low content grains with partial of complete cover with dried pulp, the demucilaged product obtained is normally of high physical quality and will fit well within the *purchase norms (47)* established by the National Coffee Federation of Coffee Growers of Colombia.

The norm establishes that the parchment dried coffee (PDC) should contain *less than 0.5% of strange materials, less than 3.0% of coffee with dried pulp, and less than of 2.0% of bitten and hulled grains*.

The results of the *physical quality* of wet (53% of moisture content) parchment coffee are presented in
Figure *1*. The results were obtained from 29 evaluations with an upward flow demucilager (washer and cleaner) developed at CENICAFE (See section 3.8.4.). The light materials were retired using a semi-submerged channel (with recirculation of water). The analysis

of the quality of the wet parchment coffee obtained after pulping (d) and after demucilaging (D) shows that only one factor (1.8% strange materials content), was superior to the limits established by the quality norm of the FEDERATION (0.5%). However, using some of the hydraulic devices employed in the processing (recycling the water) the strange materials can be decreased to values of less than 0.5%.

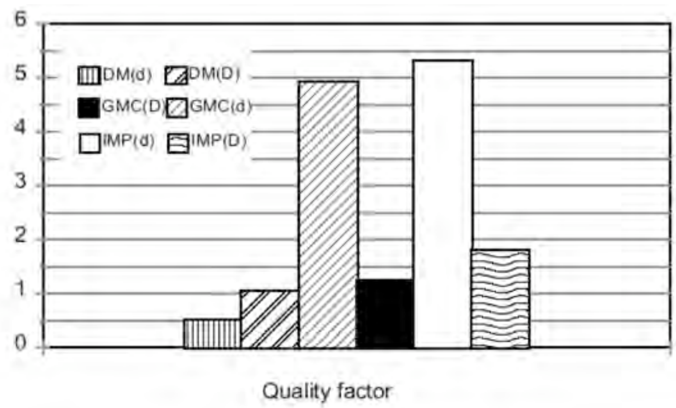

Figure 1. Effect of the mechanical demucilaging in the physical quality of coffee: mechanical damage (DM), coffee grain with partial or complete coverage with dried pulp (GMC) and strange materials (IMP), after pulping (d) and after demucilaging (D).

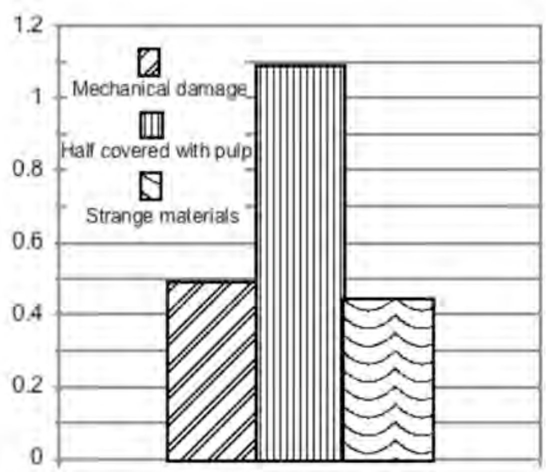

Figure 2. Physical Quality of the coffee obtained by mechanical demucilaged without previous float elimination and without sifting the pulped coffee. Only part of the coffee grains completed covered with dried pulp and strange materials were removed, by means of a hydrocyclone, after the demucilaging process.

The average values of the physical quality of wet parchment coffee, (from 20 batches), obtained without previous elimination of the floats before pulping and without using the sieve for the pulped coffee is presented in Figure 2. Part of the strange materials and the grains complete covered with dried pulp, present after the demucilaging process, were retired using a hydraulic classifier and cleaner, the hydrocyclone (See section

3.9.). Mechanical damage values (0.49%), coffee grain complete covered with dried pulp, half face covered (1.09%) and strange materials (0.45%) indicate that the quality of the coffee obtained with this process satisfies the norm requirements established by the Colombian Coffee FEDERATION for commercialization of the parchment coffee.

2.2.3. Organoleptic quality of the demucilaged coffee.

It is of generalized acceptance that mechanical, chemical and biochemical forms exist to retire the mucilage efficiently in much shorter times that those used by the conventional method of subjecting the pulped coffee to the fermentation of the mucilage in fermenting tanks, for 12 and 24 hours and washing it afterwards, using clean water.

Samples of coffee with the mucilage mechanically removed and samples obtained from fermentation tanks were stored ALMACAFE (Colombian coffee storage warehouses), in Chinchiná, Caldas and in Letras, Caldas (73). The quality of the drink was evaluated by the sensory panel of the Quality Control Unit (U.C.C.) of FEDECAFE (Colombian Coffee Federation), in Bogotá, and by the firm John D´Elena, of New York. The results presented in the *Table 2* allow concluding that the *cup quality of the coffee* demucilaged mechanically is equal or superior to the one obtained by means of the natural fermentation.

Sanz (111) compared the quality of the beverage between fresh coffee samples obtained from natural fermentation from those using mechanical demucilaging. The results shown in the Table 3 indicate that with the mechanical demucilaging obtained better drink qualities.

The evaluations of the cup quality were continued in the period 1995-1996, with coffee obtained from the process of mechanical removal of the mucilage, in different processing plants, and the natural process.

Table 2. Quality comparisons of the coffee cup obtained with the mucilage removed mechanically and by the natural process.

Treatment	*Evaluator*	*Acidity-Aroma-Body*	*Global Impression*
DESMULAC –	U.C.C.	A-M	
0 months	J.D´ELENA	M-B M-B M-B	Excellent
REFERENCE	U.C.C.	M-B	
	J.D´ELENA	M-B M-B M-B	Excellent
DESMULAC –L	U.C.C.	M-B	
3 months	J.D´ELENA	A A A	Good
TESTIGO –L	U.C.C.	B	
3 months	J.D´ELENA	A A M	Good
DESMULAC –C	U.C.C.	B	
3 months	J.D´ELENA	B A A	Good
TESTIGO –C	U.C.C.	B	
3 months	J.D´ELENA	A-M M M	Good
DESMULAC –L	U.C.C.	B	
6 months	J.D´ELENA	A A	Good
TESTIGO –L	U.C.C.	B	
6 months	J.D´ELENA	A A	Good

Symbology: A = High; M = Medium; B = Low
L= Letras; C= Chinchiná;
U.C.C.= Quality Control Unit

Table 3. Comparative Evaluation of the quality in cup of the coffee obtained with natural fermentation and mechanical demucilaging.

Attribute	*Natural Fermentation*	*Mechanical Demucilaged*
Aroma intensity	7.1	7.0
Aroma of the beverage	6.7	6.8
Acidity	6.1	5.2
Bitterness	5.0	5.2
Body	6.4	6.8
OVERALL	6.4	6.9

The work was done with the collaboration of the sensory panels of CENICAFE, the Freeze-dried Coffee Factory from Chinchiná, Caldas and ALMACAFÉ in Bogotá.

From the analysis of seventy-seven (77) comparisons of the quality of the drink, it was concluded that:

According to the panel of CENICAFE, during the period of main crop (August 1995 - December 1995), the *quality of the coffee obtained with technology DESLIM* (See Section 3.8.4.) was *superior* to the one obtained with the traditional method of processing with fermentation. Starting from January 1996, until June of 1996, time of very scarce crop, the quality of the drink was, in general, not good, for both methods. With few exceptions the drinks obtained a qualification of 6. The panel of the Freeze-dried Coffee Factory reported normal drinks and similar acidity levels, for both samples. ALMACAFE reported similar aroma, acidity, body and a notorious tendency to astringency and herbal flavors in the evaluated samples. In accordance with the sensory panel of CENICAFE, the quality of the drink could be affected notably by the presence of some level of overmature grains that can originate drinks with flavor to vinegar, immature grains that give astringent flavor to the drink, and the presence of grains attacked by the coffee borer (Hypotenemus hampei) that generate strange flavors to the quality of the drink.

In an overall summary, comparing all possible pairs of attributes of the cup quality, processed by the two methods, from 127 results, 56 were favorable to the mechanical procedure, 40 times there were no differences and 31 times were superior for the conventional method. *The absolute ratio between the favorable and unfavorable results (1.81) states that 81% more favorable results were obtained for the system of removing the mucilage mechanically*.

Simultaneously to the realization of these experimental quality tests, the national and *international literature* relevant to the topic was reviewed (77). In conclusion, all the revised authors that presented experimental results coincide with the results obtained in CENICAFE, and we can affirmed categorically that the fermentation *doesn't influence the quality of the coffee*, with relation to the mechanical procedure for demucilaging. Also, it can be stated that the practice of fermentation present high risks of ruining the quality for delays, if it is not stopped, starting after the first 20 hours of fermentation. On another side, there is unanimity in attributing a weight loss of around *1.5% of the dry matter* of the grain during the normal process of the fermentation due to respiration of the living tissues.

2.3. EFFECT OF THE MECHANICAL COOLING IN THE QUALITY OF THE STORED COFFEE TO BULK. (102), (120) 3

Few efforts have been conducted to find *alternatives to the conventional storage system for dried parchment coffee in sacs, placed inside covered structures*, for medium periods (about six months) or long periods (for more than one year). However, it is well known that the coffee stored in the conventional sacks, and mainly in warm places, loses its quality and their price quickly. After one year of having it stored, practically in any place in

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3 Prepared by Roa G., Trejos R., and Cruz, M. Ingeniería Agrícola, CENICAFE.

Colombia, the coffee might be considered old and its value be an only a small fraction of the value of the fresh coffee, depending of the demand.

The mechanical cooling of grains disposed in bulk has proven to be a successful method to conserve the quality of the seeds and of the grains that present physical resistance and interstitial uniformity to allow the air pass through them, in bins of several tenths of meters high.

To find the best conditions of the air for mechanical cooling, to best conserve the quality of the coffee stored for long terms, 10 metallic silos of square section of 0.5 x 0.5 m with a height of 2.8 m (effective height of 2.35 m) , were designed and built (Figura 3). Their capacity was between 220 and 250 kg of dry parchment coffee. The section and height of these pilot bins were chosen so that they were geometrically similar to the 30 silos, of 6 m of diameter and 30 meters of height, of the storage bin complex of ALMACAFE, in Bello, Antioquia. This way the experimental results obtained in the laboratory could be better applied to the industrial silos. Nine bin walls were isolated with 5 cm of fiberglass, to minimize the effects of the variations of the environmental external conditions. The following variables were measured to study the history of the changes of the products: coloration of the beans, the moisture content, the population of the undesirable microorganisms and the cup test.

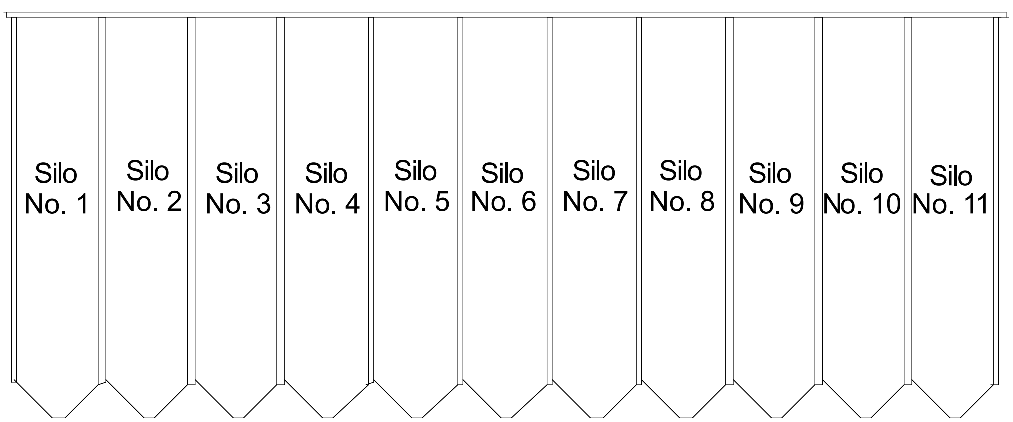

Figura 3 Metallic bins for studies, at laboratory level of the storage of coffee, with mechanically forced cooled air.

The conditions of the cooling air were controlled by equipment designed at CENICAFE that could give air at 15 m^3/h at a pressure of 5 cm of water column. Caturra variety of the Substation of Naranjal, Caldas of CENICAFE was used. The grains were processed by the traditional wet method. Drying was done using the traditional bin-dryers provided with air reverse direction. The apparent bulk density of the coffee measured in each silo varied between 388 and 435 kg/m^3.

The temperature of the cooling air was varied between 11 and 20 °C. The relative humidities between 68 and 80%. The used flows varied between 20 and 30 m^3/h. These values gave a specific airflow of storage of $1m^3/(min \times ton)$. The cooling time varied between 10 and 17 hours. The following pairs of temperatures (°) and relative humidities

(%) of the air were chosen for each bin: 15°C and 70%, 15°C and 70%, 18°C and 68%, 20°C and 70%, 15°C and 80%, 18°C and 68%, 11°C and 80%, 15°C and 70%, and 12°C and 80%. These values were chosen by considering the previous knowledge of the possible better conditions for storage of coffee, and by the known the relationships of equilibrium moisture content of the coffee (See section 4.7.1.1.).

It was stored the same quantity of coffee additionally in an identical silo, but no aeration was performed on it. Representative samples of coffee of each silo were also stored in fiber sacks of 3 kg of capacity. The sacs were stored in the traditional form, subjected to the environmental conditions of the place of the study (laboratories of CENICAFE, Chinchiná.)

It was found experimentally that *in order to cool the masses of coffee completely they were necessary between 220 and 590 m^3 of air for each m^3 (cubic meter) of coffee*. Each bin was considered cooled when the difference between the exit and inlet temperatures of air was of 2 °C or less. The temperatures of the coffee masses were measured at different heights of the bins. The moisture content was determined at 8 different points, located at different heights of the bin, separated 30 cm vertically, one point from the each other. The coloration of the beans and the percentage of discolored grain was determined monthly from samples taken from the inferior, the middle and the superior layers. Color models of general acceptance for FEDECAFE were applied to quantify the information. The cup tests were determined from the inferior, middle and superior layers, every month until the third month, and later on, until the first year, every two months. The sensory panels of the Quality Control Unit, Bogotá, CENICAFE, Chinchiná, and the Freeze-Dried Coffee Factory of Chinchiná, were used.

After one year of storage, the coffee that was aerated mechanically maintained the grain moisture content between 10 and 12%. The lowest values in moisture corresponded to the lower temperatures of the air, because they induced the transfer of moisture from the surface of the grain toward the air, due to larger differences of water vapor pressures between the grain surface and the air.

The samples that were left as control in fiber sacs, became humidified to an average value of 12.9%, almost one point above the maximum recommended value (10 to 12%). This value corresponds very approximately to the value of the equilibrium content (13.2%) for the average ambient conditions.

The coffee that was stored with controlled conditions maintained their quality, *Figure 4*, according to the overall qualification of the beverage up to 10 months of storage. The coffee was classified in three categories: poor cup (2-3), regular cup (4-6) and acceptable cup (7-9). For some combinations of temperature and relative humidity, the good beverage qualification stayed up to after a (1) year. The combination of the moisture of the grain between the 10 and 12% and a temperature in the range of 10 to 15 °C, permit the good storage and the conservation of the quality.

According to these experiences it was concluded that:

- The storage in bulk under conditions of *controlled aeration showed advantages with respect to the percentage of discolored grain, cup test, moisture content and population of microorganisms with relation to the coffee stored in bags, or to the coffee stored in the bin without aeration*. The prevailing environmental conditions of the experiments in Chinchiná were 20.6 °C of temperature and 76% of relative humidity.

- For a *1-year storage* design, to assure the minimum loss of quality, two combinations of temperature and relative moisture are *recommended, 15°C - 70% and 18°C - 80%.* The *specific airflow* for storage should be equal or higher than *1m^3/(min x ton)*.
- To store dry parchment coffee, in bulk, for a maximum period of 10 months, for a minimum loss of quality, using mechanically cooled air, the following pair combinations of temperature and relative humidity are recommended: 15°C - 70%, 18°C - 68%, 20°C - 70%, 15°C - 80% y 11°C - 80%.

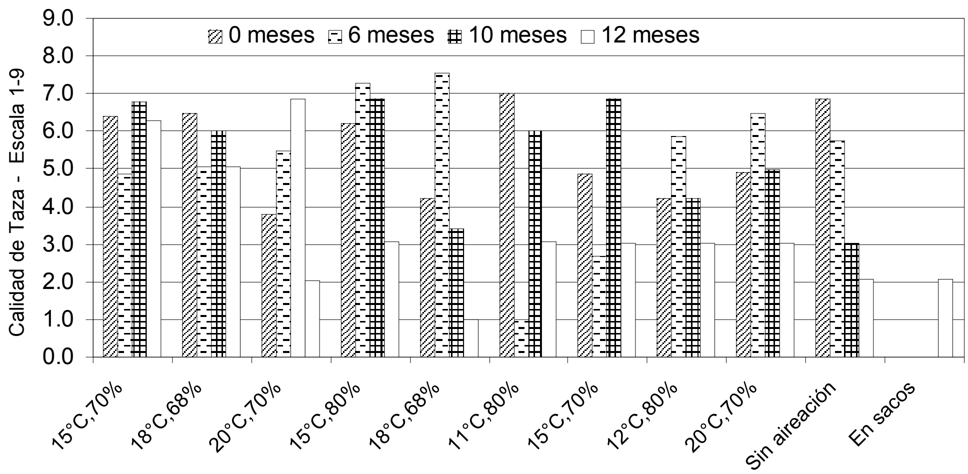

Figure 4. Quality of the beverage of coffee, according to the conditions of the air cooled mechanically, air without cooling and coffee stored in bags in conventional way, according to the time of storage.

- The coffee stored in fiber bags, under the normal conditions of storage became humidified above the maximum recommended value for storage (12%). They also became discolored, above the values accepted commercially. The populations of the microorganisms exceeded the acceptable values and as consequence the quality of the cup was poor, starting after 3 months of storage, in some cases.
- The *main criteria for the operation of the aeration system* for the mechanical cooling of the grains is the *difference of vapor pressures* at the surface of the grains (that depends on the temperature and the humidity of the grain) and the vapor pressure of the air. If the grains present temperatures of 5 or more degrees centigrade above the ambient temperature, it is possible to practice the aeration with air with relative humidity of saturation (100%), without the coffee adsorb humidity. This phenomenon is due to that the vapor pressure at the surface of the grain is still larger than the vapor pressure of the saturated air.
- There exits the possibility that the coffee becomes lightly overdried during the cooling period, process that takes place in only a few hours. This inconvenience has a

feasible solution by practicing aeration afterwards, using air with high humidities, such as those that occur at night or at the first hours of the mornings. This method was tested successfully in the plant of coffee bins of ALMACAFE, Bello, Antioquia (Figure 5), with of 340 tons of dry parchment coffee stored in the bin . In genera, during the last 6 years, following the recommendations of CENICAFE, of practicing cooling aeration procedures, including the night hours, it has been possible *decrease 4 centigrade degrees commercially, on the average, to the masses of coffee stored in the whole battery of silos, with immense advantages*, in comparison with the conventional system of storage in bags.

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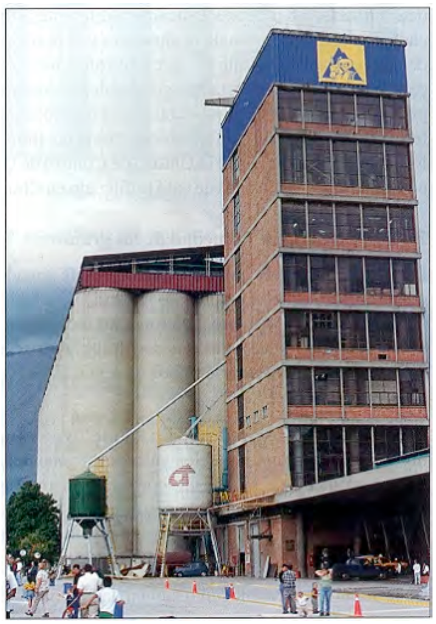

Figure 5. Battery of 60 silos of 30 m of height and 6 m of diameter, of ALMACAFE, Bello, Antioquia, where parchment coffee is stored with nocturnal forced aeration

- The results obtained in this work are highly satisfactory, and they coincide with similar achievements obtained for other grains, legumes and seeds, capable to be stored in bulk. In particular, for coffee, preliminary work was done by FEDECAFE, before the construction of the silos of Bello. Other investigators indicated the feasibility of the operation (115) and (116).

2.4. EFFECT OF THE DRYING AND THE STORAGE ON THE QUALITY OF THE SEED OF COFFEE (V. COLOMBIA).4

- The Colombian Federation of Coffee Growers – FEDECAFE, cultivates and processes the whole production of the seeds of the Colombia variety, a hybrid resistant to the leaf rust. It stores the seeds at the appropriate conditions (See section

[4] Prepared by Alvarez G. J. and Roa G. Ingeniería Agrícola. CENICAFÉ.

- 2.4.) and delivery them to its extension body with the necessary vitality. In this form the farmers can obtain robust and sound coffee plants.

This was not the system for processing the coffee seeds in Colombia. It started in 1983, when the leaf rust made its presence in Colombia, when immediately FEDECAFE started to produce, process, storage and distribute commercially the seeds. Before, all the coffee seeds were produced directly by the coffee growers with individual special care.

CENICAFE, through the section of *Agricultural Engineering, developed the necessary technology to process commercially the seed* (42).

The concepts of conventional processing of the coffee were modified to pulp, classify, wash, transport, dry and store the seed. (See sections 3.7. and 2.5. to for the appropriate technology to wash, transport and demucilage the seed of the coffee, either using semi-submerged pumps with a hydraulic system of transportation and the recirculation of the water).

In the present section the most relevant results of the work done (50) to maintain the quality of the seed during the drying and the storage processes are presented. It is of importance to mention that the results of this investigation had an immediate application. Indeed, as soon as the final report was presented, with the very clear conclusions, on the best methods for the drying and storage systems, it was decided immediately to adopt the recommendations. *The drying was performed in trays and fixed beds, with reversal of the air direction each 6 hours, with maximum temperature of 40°C, and storing the seed of coffee at 11% of content of moisture, and 11-14°C.*

This way it has been possible to *conserve the seed, with the necessary vigor for more than one year* of having being harvested, processed and stored.

2.5. EFFECT OF THE MECHANICAL DEMUCILAGING IN THE QUALITY OF THE COFFEE SEED. [5]

The damage to the seed of the coffee means the loss of its germinate function and it frequently occurs during the transformation of the cherries to dry parchment coffee. In this process rigorous interactions of the live cells of the kernels with the different elements of the mechanisms and to the different type of stress caused by the environmental conditions that the seed has to support during the processes of pulping, demucilaging, washing, transporting, drying and storing.

The appropriate mechanical design of the systems to avoid the harmful influence of the percussion originated by the pumps and the collisions of the grains inside the hydraulic ducts (113), are presented in the section 3.7.

The mechanical interactions can originate crushed, bitten, cut or hulled grains that might affect the viability of the seed or in some cases induce a double root or double germination of the embryo.

Some mechanical damages caused to the embryo, such as, fracture and collapse, are noticed only after having germinated the grain, and are manifested in abnormalities, as

[5] Prepared by Alvarez G. J. Agricultural Engineering, CENICAFE.

separated seeds, healed tissues, restriction of growth of the plant, unequal position of the cotyledons, primary roots and divided hypocotyls and atrophied roots (112).

Work done at CENECIAFE (112) evaluated the losses of quality of the seed of coffee during the processing. The seeds that suffered mechanical damage in their kernels reduced their germinating capacity significantly. The seeds that were cut by action of the cylinder surface in the pulper reduced their germinating capacity from 89.6% to 50.5% and the seeds that were bitten diminished their germinating capacity from 89.6% down to 40.4%.

Given the big advantages presented by the mechanical demucilaging system and the great convenience of processing continuously and quickly the coffee seeds from the centers of production of seeds of FEDECAFE, several tests were made at CENICAFE, to investigate about the possible damage of this equipment to the seed.

The BECOLSUB Modules 600, 1000 and 3000 (See section 3.12) were used in CENICAFE, Chinchiná, with the following operation parameters: angular velocity of a traditional horizontal pulper = 160 rpm; speed of the demucilager = 860 rpm; specific consumption of water = 0.8 L/kg of dry parchment coffee (DPC).

Table 4. Viability of the seed obtained by the use of different BECOLSUB models.

Treatments	*BECOLSUB-600 germination, %*	*BECOLSUB-1000 germination, %*	*BECOLSUB-3000 germination, %*	*Mean germination,%.*
Pulped	96.7	99.4	98.8	98.3
Demucilaged	99.1	98.9	98.8	98.9

A sample of 1 kg was taken after pulped and 1 kg after demucilaged. Only grains with sound parchment were selected.

The hulling of the parchment coffee was done manually, with two repetitions. The seeds were disinfected by submerging them 30 minutes in a solution of 2.5 g of Difolatán and 0.6 g of Benlate in one liter of water. They were planted on wet paper and were left for 35 days in the darkness, at ambient room conditions. After this period the count of the germinated seeds was established. The determinations of viability were expressed as germination percentage.

To determine the damage for double root and for forked root, the seeds that presented one or other defect were counted at the same moment of the readings for germination.

In Table 4 the obtained averages values of the different tests are shown for the viability of the seed of coffee. For the model BECOLSUB 600, 19 tests were carried out. For the Model BECOLSUB 1000, 7 tests and for the model BECOLSUB 3000, 5 tests. In total 2,100 readings were made.

It is observed that the viability of the seed was very high under the selected treatments: for pulping (98.3%) and for demucilaging (98.9%). It indicates that the *seed can be processed by the BECOLSUB equipment in its three different sizes, with viability losses of the order of 1.7 and 1.1% (*Figure 6*).*

In Table 5 it is observed, from the same previous samples, that the damage to the seed as a result of the depulping and demucilaging, measured by the appearance of double roots, for the three BECOLSUB models was minimal, less than 1%, for each case.

Figure 6. Normal germination of the seeds of coffee mechanically demucilaged.

Table 5. Percentage of damage measured by double root caused by the different BECOLSUB models in pulping and mechanical demucilaging of coffee seeds.

Treatments	*BECOLSUB 600 %*	*BECOLSUB 1000 %*	*BECOLSUB 3000 %*	*Mean %*
Pulped	1.0	0.57	0.6	0.72
Demucilaged	0.8	0.85	0.2	0.62

Table 6. Percentage of damage of forked root caused by different models BECOLSUB in pulped and demucilaged of seeds of coffee.

Treatments	*BECOLSUB 600* %	*BECOLSUB-1000* %	*BECOLSUB-3000* %	*Mean* %
Pulped	0.21	0.14	0.4	0.25
Demucilaged	0.63	1.43	1.2	1.08

It is common to find forked root when the seed is subjected to mechanical stresses but also for the abuse of the chemicals in the preparation of the bed of seeds. The mechanical damage was evaluated (forked root) caused to the seed by the process in the BECOLSUB three different modules.

Table 6 presents the incidence of damage by forked roots. In the three types of modules BECOLSUB the damage is of 0.25%, on the average. By the action of the demucilage process the damage, for each one of the BECOLSUB processes is of the order of 1.08%, which is a very low damage contribution that the BECOLSUB technology cause to the seed.

It is concluded, therefore, that the seed of coffee can be processed using the technology DESLIM-BECOLSUB in anyone of the three different existent modules without decrement of its viability.

These results are indicative of the very delicate mechanical process that the demucilagers perform to retire the mucilage of the coffee, especially taking into consideration that the embryo of the coffee is external and susceptible to mechanical damage. It is also of general acceptance that the first quality attribute that the coffee loses is its vigor and its viability. Indeed, the coffee grain might loose its viability and still maintain excellent qualities of its beverage.

The mechanical effect of demucilaging is due mainly by the cutting shear forces that take place by the relative movement of the fluids and the grains and not simply for friction, and or, for collisions between grains (See section

3.8.2.).

The positive results of this investigation has been verified in the commercial production of seeds with mechanical demucilage of coffee for more than four years, in the Substation of CENICAFE, in Rosario, Antioquia.

III. ECOLOGICAL PROCESSING OF COFFEE.

The ecological processing as it is defined and promoted by CENICAFE consists of several elements or components that are the presentation objective of this section. In order that the ecological concept can be successfully applied, all of their elements should be projected, installed and operated according to strict technical specifications. It is *easy to lose the whole ecological concept if only one of the components fails*.

Considering that the ecological, wet method of processing coffee can be a continuous process (with the only exception of the drying), each of the unitary transforming stages and the transportation systems for the coffee, in its different states and their by-products, must match their appropriate capacities of transformation and transporting.

3.1. HANDLING OF THE CHERRY COFFEE.

The coffee should be *harvested with the biggest care*. In particular it is recommended to harvest *only the mature grains*, without the peduncle, in opportune form, executing all the necessary passes and avoiding breaking the branches. Recently, FEDECAFE has recommended to increase the number of passes in the recollection of the coffee to avoid the unnecessary permanency of mature berries in the tree that might serve as food to the coffee borer of the coffee.

The daily harvest should be planned in such a form that as soon it ends, *the transformation process should start as quick as possible*. The coffee in cherry is a perishable fruit that deteriorates quickly. The most appropriate and economic method to stop this deterioration process is by removing the pulp, the mucilage of the pulped grain and lowering the moisture content of the wet parchment, by drying it.

Proceeding in this form, the following *advantages* are obtained:

- It is obtained the maximum quantity of the weight of the coffee. The one that corresponds to its physiologic maturity.
- Not immature or overmature grains are collected, that harm the quality of the beverage and do not allow the correct operations of pulping and demucilaging.
- It is obtained the minimum losses of coffee, by falling to the floor.
- The best control for the coffee borer is achieved.
- It is avoided delays in handling the wet grain that propitiate the great majority of the defects of quality of the coffee, both in its physical appearance and in the cup quality.

3.1.1. Transport of the coffee cherry of the field to the processing mill.

The transport of the cherries to the processing plant can be carried out in different forms: in the shoulder of the pickers; in the loin of animals; in cars of different capacities; in hydraulic coffee ducts; by air cables of gravity or activated by motors. Three works were done in this line at CENICAFE, as follow: the *characteristics of the hydraulic coffee ducts* *were studied* (85) to understand the system and to minimize the amount of water needed and its contamination effects. The design, construction evaluation and recommendations for transportation of cherry coffee sacs by cable of gravity (83) and cable moved by a motor (86) were completed.

3.1.2. Transport of coffee cherry for gravity, inside the processing plant.

The transport for gravity is an ecological system, and in many opportunities it is the simplest and most economic.

The transport of the coffee by gravity demands some technical requirements related with the physical properties of the coffee in different states and of the surfaces the coffee will become in contact

*Table 7 *. Slide angles, in degrees, for the coffee in different states, with different surfaces*

	State of the coffee bean				
Surface	*Cherry*	*Pulped*	*Washed*	*Dried Parchment*	*Green*
Wood brushed with perpendicular fiber to the flow	33.0	30.1	50.4	21.3	24.2
Wood brushed with parallel fiber to the flow	32.2	33.8	47.2	24.2	26.6
Rough wood with perpendicular fiber to the flow	36.5	38.0	51.3	50.2	29.7
Rough wood with parallel fiber to the flow	37.2	38.0	50.2	52.4	25.2
6" PVC pipe	26.1	15.1	31.0	19.8	18.8
Metal	31.8	16.7	33.8	29.2	21.8
Alfagrés (ceramic)	37.2	17.2	42.6	45.6	31.8
Concrete	28.8	35.8	49.2	57.2	45.0
Majolica	31.8	19.8	41.3	44.1	29.7

* *For practical effects, the obtained data of the* Table 7 *should multiply for an empiric factor that varies between 1.20 and 1.50 depending on the critical of the application.*

with. To *guarantee that the transport really occurs by gravity*, without physical restrictions, the *angles of natural slide* were studied (75) for the coffee in different states, on different surfaces, commonly used in the construction of coffee processing plants. In Table 7 the results of the research is presented.

Not always it is easy to promote the transportation of cherry coffee by gravity. Good, big and old structures already built exist that the owner wants to continue using, or it might be desirable, by any reason, to use the excellent characteristics of the water for classifying and transporting the coffee. Also it might be impracticable to modify the complete system to be able to use the gravity as a way of transport, for the number and the complexity of the civil works, or for the damage that might be caused to the equipment. An ecological alternative for these cases will also be presented in the next section.

3.1.3. Dry hopper for the receipt of the coffee cherry.

For the best control in the overall operation of the process and to be able to correctly calculate the yield (relation between the raw material and the finished product) (See chapter

V.), it is of the biggest importance to weigh the products. For this, it is important to individualize all the measurements, before beginning and after finishing the transformation, according to the lots, from where the coffee proceeds.

The *dry hoppers*, Figure 7, can be built in wood, or in wood recovered by aluminum sheets, or of other materials. The angle formed between their walls and the horizontal plane (the floor) should be between 45 to 50°, that is, a slope equal or larger than100%. This slope should also be maintained especially in the ducts that discharge the cherries to the pulpers. The coffee transported in bags, Figure 7, or in bulk,

Figure 45. The discharge duct of the hopper can be constructed in a 10 cm (6") tube or in a square form, 20 cm of side. The duct should have a gate or guillotine to control the flow of the grain.

Figure 7. Dry hopper for the coffee cherries

It is highly desirable that the *hopper that receives the cherry coffee and feeds the pulpers work completely without water* so that the pulping stage can operate in the same way. The simplest form for the small coffee grower it is to use the dry hopper, where the cherries are deposited without water, taking care of not introducing hard objects with the coffee.

For properties with low productions, of less than 4 tons of dry parchment coffee a year, the reception of the coffee can be made in the hopper of the pulper. Enlarging its walls with pieces of flat wood normally increases the capacity of this hopper.

The capacity of the hoppers, as a general rule, is calculated approximately for the 70% of the day of maximum production. They are built in form of an inverted pyramid trunk, coupled to the duct (or parallelepiped) that delivers the coffee to the pulpers, located underneath the hopper.

For large facilities where mechanical equipment should be used, the screw conveyor (See section

3.11.), or transportation bands, are recommended. This way the pulp is maintained in absence of water and able to retain the maximum quantity of mucilage for optimal contamination control.

A second, less perfect option, but a solution for the cases of very difficult application of the mechanical ways of transport, is the use of *hydraulic handling systems, with recirculation*, using closed tube circuits and a submergible pump. This way, the cherries can be transported to the hopper with water, that might be used also to separate the heavy and light objects and grains excessively infested with the coffee borer.

In these cases it is indispensable the recirculation of the water in the daily operation and the appropriate design of the tanks, transport ducts and of the hydraulic system, in general. The quantity of the necessary total water should not surpass ½ cubic meter. If big quantities of coffee cherry are managed, the specific consumption of water can be negligible. The water used in one day can not be reused the following day.

It is indispensable, in this second case, to retire the water that drains in the same hopper of the cherry coffee. This can be accomplished by means of a perforated floor built above their bottom and arranging two hoppers in series, as it is pictured in Figure 46, item number [6]. This way the water consumption is minimized drastically and the cherries present only a small amount of water at the surface.

For the correct operation of these hoppers it is necessary that before circulating the water, the hoppers should be filled with the cherries. This way the water encounters the smallest free space to move, its kinetic energy decreases and it is forced to travel by gravity through the spaces between the grains and to the bottom of the hopper, where it is separated by the perforated floor. This way it is obtained the very good separation and the addition of to second stage with double bottom, in series, supplements the retirement of practically all the present water in the coffee. There is only a remainder of water adhered to the surface of the pulp that still will permit the pulp to control well the contamination.

It is necessary to make an appropriate maintenance and periodic cleaning up of the hoppers to avoid that the perforated floor plows or get obstructed.

3.2. PULPING OF THE COFFEE.

Between the pulp and the parchment, in mature coffee grains, the mucilage, a jellied liquid with viscosity and appropriate moisture, is present. Because of this component the pulping process is greatly facilitated, helping the separation of the kernels from the pulp, without addition water.

The supply of water to the process of pulped was considered necessary in the conventional systems of processing, to obtain coffee of good quality, with acceptable capacities from the machines. The *non-use of the water* was practiced by some small coffee grower in Colombia, but this technique was considered characteristic of the lack of the minimum necessary technical requirements for the appropriate processing of the coffee.

Studies carried out at CENICAFE (3), demonstrated the possibility to pulp the coffee without water*, (*

Figure 8), using pulpers of horizontal shaft and a vertical one

Table 8. Quality and capacity of pulped of the coffee without water

	Type of pulper						
	Comitecafé No. 3		*Cordillera No. 3*		*Fimar No. 4*		*ICON TEC (55) Norm*
	Water utilization						
Variables	No water	Wa-ter	no water	Wa-ter	no water	Wa-ter	
Hulled grain, %	0.39	0.37	0.29	0.29	0.26	0.27	0.5
Bitten grain, %	0.14	0.25	0.26	0.26	0.29	0.30	0.5
Unpulped grain, %	2.79	1.84	3.18	1.57	2.58	1.73	1.0
Pulp in the grain, %	2.26	1.88	1.44	1.10	2.05	2.15	2.0
Pulping capacity, kg/h	388	348	781	743	893	915	

Figure 8. Pulpers of horizontal shaft that operate without water

(PENAGOS 255C model), without affecting the capacity of the process and the quality of the product. Results are presented in Table 8, for four variables: pulp in the grain, grain without pulping, hulled grain and bitten grain.

To liberate the grains from their external cover (pericarp or pulp) it is necessary to break the pulp fibers by action of tension (longitudinal and traverse) and shear forces.

The stresses they generate when compressing the cherries in the space conformed by a fixed plate (breastplate) and a surface mounted on the revolving cylinder that approximates to a rasp-like surface, or the projecting teeth in case of a disk pulper.

The channels of the breastplate propitiate the separation of the grains from the pulp. They present a slanted form to allow the transport of the grains to the exit holes and simultaneously withdrawal the pulp from the flow of the grains. The pulps are separated by the dragging effect of the sharp projections of the cylinder or the teeth of the disks, and for the action of the centrifugal force given by the rotating cylinder.

The process of pulping of the mature cherry is shown in a typical curve of applied force vs. deformation, (

Figure 9). In this case the rupture of the pulp begins when the applied load reaches 60 Newton (N) and the resulting deformation is about 2.5 mm (point A). The rupture process of the pulp continues. The seeds begin to be expelled and it starts a new compression process of the seeds, until it is reached a new high load value of 80 N and the corresponding deformation of 4-mm (point B). *The compression process can cause large deformations in the seeds*, especially to those of big sizes, perhaps superior to those that they can support, producing structural damages which are reflected at the end of the processing process as flat, veined, and discolored grains.

The immature cherries are material more rigid offer greater resistance to the pulping process, and consequently they do not allow the normal pulping

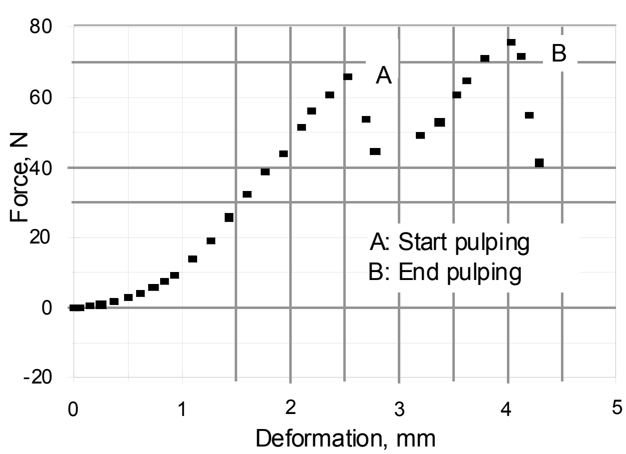

Figure 9. Behavior of a mature cherry of coffee subjected to compression among parallel plates.

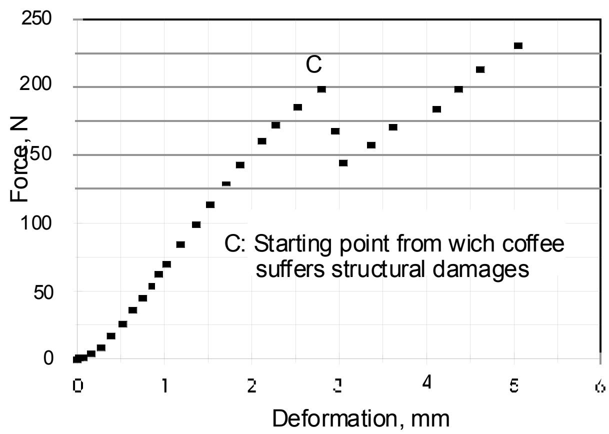

Figure 10. Behavior of an immature coffee grain subjected to compression among parallel plates.

process, and support loads superior to 200 N, like it is shown in Figure 10. The pulper damages a high percentage of these materials. The immature and overdried grains also contribute to increase notoriously the power required to drive the pulpers.

A contribution of importance for the practice of the ecological processing, made by the Coffee Extension Committee of Antioquia and the private industry is the development of a disk pulper that works without water. If this equipment is used, it allows the presence of some hard objects, mainly stones that crush inside the machine causing small damages to the disks This is not the case of the pulpers of traditional horizontal shafts that are very sensitive to damages by the presence of any hard object.

3.3. DECREASE OF THE LOSSES IN THE CONVENTIONAL PULPING PROCESS.

In a recent study contracted by the Coffee Extension Committee of Caldas (33) that included 5,112 visits to coffee properties during the main crop of 1995, it was concluded that *large losses, 3.7% as average, of the production of the department where attributable to the bad state or operation of the pulpers*. In some municipalities the *losses on pulping where of 9.0%, 6.7%, 6.5%, 6.1%, and 5.7%*.

These losses happen mainly by the overpressures that the grains receive in the pulper during their course through the channels of the breastplates (See Section 3.2.). This narrowness can be due to a wrong design, bad current condition, bad calibration, bad operation of the pulpers, or by the presence of grains too big, as well as grains that do not get aligned appropriately, by some reason.

CENICAFE, pursuing studies of optimization of the DESLIM equipment (See Section 3.8.) prepared a solution to avoid this type of losses with excellent results. It was found that the *overpressures can simply be avoided increasing the height, or depth, of the channels of the breastplates in 1 millimeter* (actually the pulper was left in a "non-calibrated form ", according to the traditional standards). As a result the grains flowed more freely, with less obstacles, diminishing or eliminating the overpressures and therefore, the mechanical damage. *The damage to de grain was shown to be zero (0)*, in several experimental trials and commercial operations. Also as a result of this alteration a proportion of grains were not pulped (about 10%, as a maximum), but this was not a problem at all, according to the experimental results, because the demucilager easily pulped these portion on grains.

3.4. CLASSIFICATION OF THE COFFEE BY SIEVES.

To obtain dry parchment coffee, FEDERATION type, the highest grade for commercialization of the Colombia coffee, the processing system of Figure 13 and Figure 14, is acceptable for small farmers. The figures show the arrangement of de dry hopper, the pulper that works without water, the plane sieves or screens and the fermenting tank (118) and (6). The sieves should be located in the receipt of the pulped coffee to retire the pulp, strange elements and the grains that were not pulped, from the good grains. The separated low grade coffee can be processed by another pulper, calibrated in different form, or by special type of machines, or by demucilagers, to separate the good grains. The sieves some times are used before the pulping process, or after the drying of the parchment coffee.

The plane sieves are conventionally used by small productions and the cylindrical sieves of bars (

Figure 24) are used for grater productions. For the last ones and to avoid that the grains are trapped among the bars, a roller continually cleans them. The roller is activated with the same sieve. This procedure avoids

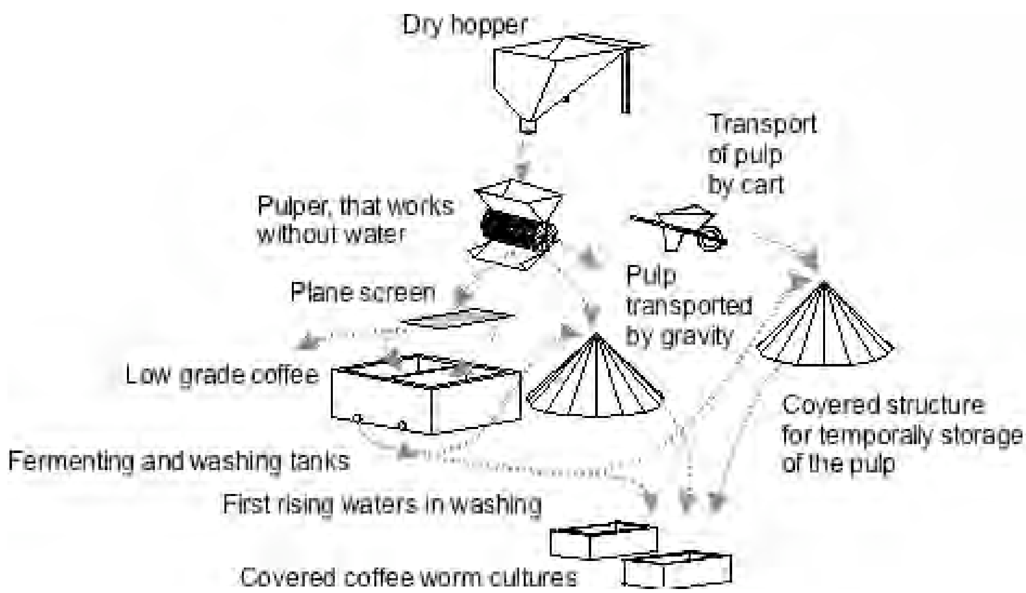

Figure 11. General outline of the ecological processing using screens and tanks of fermentation.

the use of water that commonly is used for this purpose. The worn culture (See chapter VI.) using regular pulp, or pulp mixed with the first two rinses of the washing of the fermented mucilage, complements the process.

Torres (118) concluded in their work that a plane sieve placed after the pulper, was enough as unique classification system to obtain FEDERATION type of coffee*. In particular with the single plane screen, it was possible to retire 43.3% of the low-grade coffee as it is shown in the*

Table 9 and in the Figure 12. This classification work is normally supplemented during the washing, in the same tanks of fermentation, (Figure 14), retiring the floating materials manually by means of simple devices as a mesh or strainer.

Table 9. Retired percentage of low grade coffee of coffee in the plane screen after the pulper

Test Number	Lower Grade Initial %	Lower Grade Final %	Lower Grade Removed %
1	13.1	5.8	55.7
2	15.3	9.9	35.2
3	17.7	10.7	39.7
4	11.9	6.6	44.4
5	12.3	6.8	44.8
6	11.0	6.5	40.8
7	14.6	7.6	48.1
8	10.7	5.67	46.9
9	14.7	10.3	29.9
10	10.8	5.7	47.2
Mean	13.2	7.6	43.3

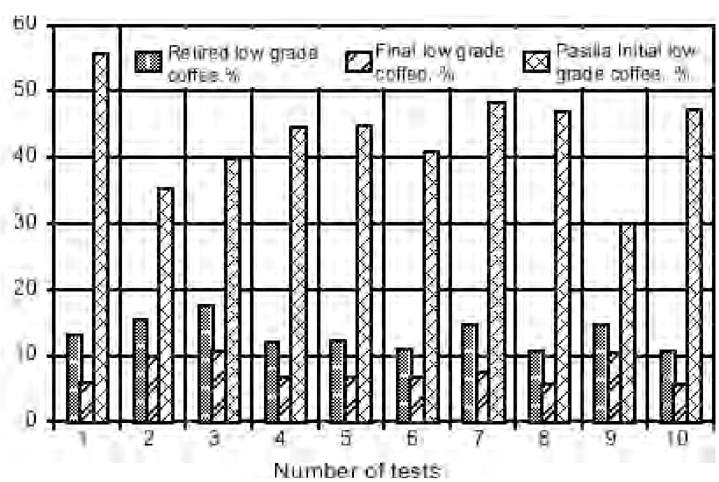

Figure 12. Performance of a plane sieve to classify pulped low-grade parchment coffee.

Good quality was obtained using the plane sieve as a unique classification device in small processing plants (6), Figure 14. Two types of tanks of fermentation, were used, the traditional tank and a new tank, the tub tank, (130), (131). The tub tank presents the innovation of the modification of the corners at the bottom, by means of fillings of concrete, to form curved surfaces to facilitate the handling of the shovels and to decrease in the consumption of the water.

The BECOLSUB models (See details in section 3.12.) are built with an optional cylindrical screen, (

Figure 24) and (Figure 41) that classify the coffee after pulped. The screens separate the grains of better quality from grains from the inferior type, from the pulp and from strange materials to the coffee, by the physical principle of differences in sizes. *They are especially useful when the quality of the coffee cherry is poor*. The use of the sieves can help to a better presentation of the coffee parchment, but the yields (See chapter

V.) of the coffee decreases. There is *an economical question to resolve, before taking the decision of using or not using the sieve*. Fortunately, the models that include the screen can be operated bypassing it.

The recommendation of CENICAFE of not using water in the classification of coffee, and in particular to not use open channels of or semi-submerged channels (63), (118), promote, in principle, the use of efficient classifying sieves that work without water, mainly when the raw matter is of bad quality.

The screen is optional in the BECOLSUB module because it has been demonstrated that without it, and having raw materials of good quality, it is possible to obtain FEDERATION type. The explanation of this fact is based in that *the DESLIM equipment*, (See Section 3.8.) *is itself a classifier element*. Because of the mechanical cutting stresses, the machine is able to polish good grains, retiring from them the adhered dried pulp, or to destroy the faulty grains that do not

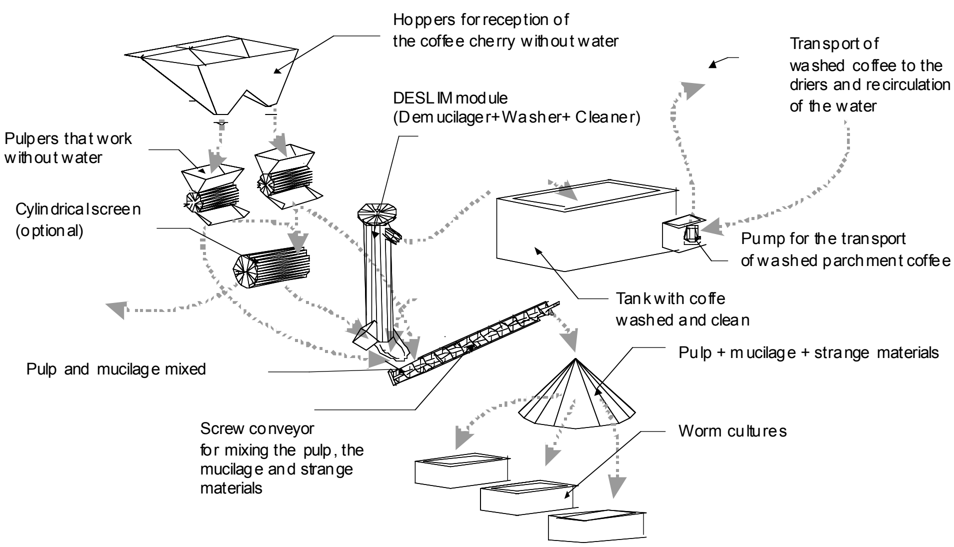

Figure 13. General Outline of the BECOLSUB system for processing coffee.

present good physical structure, and to expel those that present very small dimensions.

On the other hand, the *plane and the cylindrical screens have been used in CENICAFE with great efficiency, to separate the grains kernels after drying, in the intermittent, concurrent flows tower dryers (CENICAFE – IFC) in the Ecological Processing Central of Anserma, Anserma (See section 3.16.), Caldas, and in the processing plant of CENICAFE.* The resulting final quality of the coffee is improved notably. This process is a very good classification option, without using water. It is particularly useful to separate the grains infested with the coffee borer, the immature grains, and in general low grade coffee that loses its fragile parchment during the combined action of the demucilaging, hydraulic handling and in the drying.

3.5. FERMENTATION OF THE MUCILAGE.

The mucilage of the coffee contains 15% of solids in the form of a water insoluble colloidal hydrogel, without cellular structure. The present solids in it contain 80% of peptic acids and 20% of sugars.

During the fermentation of the mucilage, multiple biochemical reactions occur, and as their result, after 10, 18 or 24 hours, allow the mucilage to be dissolved in water. The process of conventional fermentation is one of the most critical processes during the wet processing, for the possible effect on the quality of the coffee. Therefore, the time of the process should be controlled carefully avoiding overfermentations, which originate vinegar, mature pineapple, onion, rancid and nauseous, aromas and flavors.

The elimination of the fermentation stage is widely desirable for multiple reasons, including the coffee quality, space savings and reduction if infrastructure and man power. Also unneeded biochemical reactions of respiration and diffusion of the solids from the grain to the water are eliminated that cause losses of the order of 1.5% of dried matter.

In general, there exists a deficient control of quality for the processing process at the farms, that makes very frequent to conclude the fermentation process of the mucilage before or after the recommended point, that in turn, depends on several factors that are not easy to control. This form it is very common to obtain bad washed coffees, that prevents the good drying or induce fermented coffees. The two possibilities originate serious defects to the coffee quality.

3.6. WASHING OF THE COFFEE WITH FERMENTED MUCILAGE.

It is common practice to use the fermentation tanks for simultaneously wash and classify the coffee, Figure 14 and Figure 15. It has also been demonstrated that it is possible to rationalize the washing process in the tank, to minimize the consumption of water (131) by using the *procedure of four rinses*. The technique, Figure 14, consists on applying to the coffee with the fermented mucilage, the necessary water to cover the grains completely and to stir the mass vigorously. The water of the first rinsing is evacuated and ideally taken to irrigate the worm cultures. This water is replaced with clean water, and the process is repeated the three more times. The water of the first rinse contains 66% of the organic matter of the hydrolyzed mucilage. The water of the two first rinses contains the 90%. If these waters are appropriately handled and the pulp is managed appropriately, without water, the potential contamination can be controlled in approximately 85%. The total *specific water consumption demanded by this process is of 4.5 L/kg of dry parchment coffee*. If the tank is small, the removal of the coffee can be made with a shovel.

It is also feasible to practice the washing with *the four-rinse method in large coffee mills*, Figure 15. A submergible hydraulic pump for the transport of the coffee from one tank to an another should be used.

The proper use of this type of pumps will be discussed en the next section.

.

Figure 14. Washing of the coffee by manual agitation in the tub tank. The plane screen classifies the pulped coffee.

The practice of washing the fermented mucilage using the traditional *open channels* (25), (63), (127) has been traditional in Colombia, mainly for small coffee growers, but also used for medium and big ones. It was considered as a tradition that the coffee has to be washed and classified by this method, to be able to commercialize it. In effect, this procedure permit an *excellent distribution of the coffee in the channel, distributed in a perfect gradient of coffee densities*, from where all type of separations can be made, including coffee with zero defects. But the cost of using this technique is very high: high water consumption, the contaminated waters go directly to the streams and rivers, high demanding labor, large losses of good grain, large area needed in the mill. Finally, it was demonstrated (118) that *this separation process to obtain perfect coffee is not necessary*, because the FEDERATION norm allows the coffee to present maximum of 5% of lower-grade coffee, without penalizing its price. This can be obtained with the new technology presented in this work.

3.7. WASHING AND TRANSPORT OF COFFEE WITH A SUBMERGIBLE BOMB.

The submergible bombs, are used for the washing and transport of the coffee, with concentrated mucilage coming from their fermentation tanks, in the conventional processing plant of medium and large producers.

These bombs are in general *centrifugal bombs* conformed by a group of rotational vanes inside a shell casing that give centrifugal energy to a fluid or to a suspension. The result is the transport of the fluid or suspension from one place to another, through a closed pipe.

The washing in *semi-submerged channels* (25), (63) is carried out simultaneously with the classification of the coffee with fermented mucilage, in open channels of rectangular section, 0.20 cm of wide, lengths between 2 and 3 m, with grooves at the bottom of the channel, separated 0.5m from each other approximately. The coffee is transported through the channel by means of a submergible bomb. The coffee of good quality, due to its higher density, goes through the grooves. The approximate capacity of washing and classifying is of 7,000 kg of PDC for hour and the consumption of water, without recirculation, of 6.4 L/kg PDC. The complete recirculation of the water is not advisable, because being a washing system, the recycled water every time acquires larger amount of mucilage and other undesirable materials concentrations, that do not permit to wash the coffee appropriately. The efficiency of the washing, without recirculation of the water, is superior to 90%.

Figure 15. Washing of the coffee using four rinses method, by use of a pump and a transporting system.

The transportation system using the submerged bomb can be used with the DESLIM equipment to transport the washed coffee to the dryers. Although this device uses water, it elevates the mixture to a water-grain separator (7), Figure 16.The water is recuperated and used again when returned to the bomb uptake. By this form the water consumption decreases significantly.

A good engineering design is necessary for the appropriate operation of a washing system and the transport of parchment coffee, using a pump and a hydraulic circuit with recirculation of water. The power of the selected bomb should be enough to overcome the resistance of the gravity, the friction offered by the vertical and horizontal pipe walls, and of the connecting accessories that are restrictions to the flow of the water and coffee mixture.

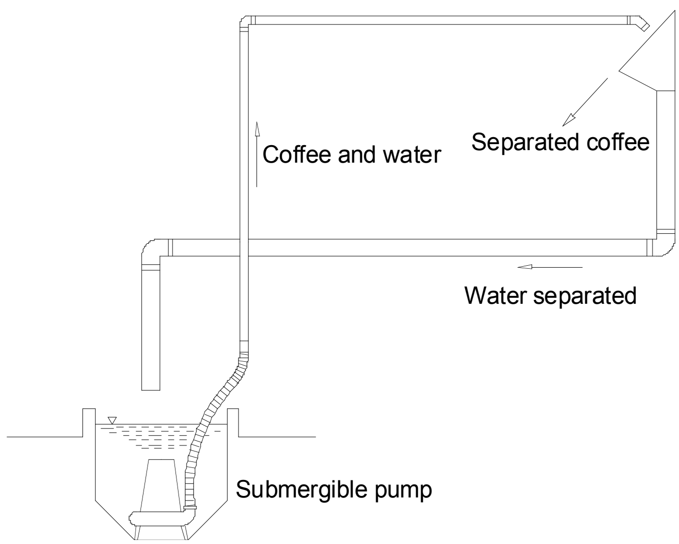

Figure 16. Outline of a washing and transport system for washing coffee, using the for rinses method.

When transporting this mixture with a submergible bomb, *the pressure losses are increased considerably in comparison with the handling of water solely*. In CENICAFE a study was executed to determine, the losses of pressure in this system, when the concentration of coffee was varied in the water, The effect of this variable in the increment of the mechanical damage of the product (112) and (113) was also studied.

It was found that for the hydraulic transport of coffee in vertical pipes of 76.2 mm of diameter (3") with speeds of flow of the mixture between 1.0 and 1.7, m/s, *the pressure drop* can be predicted with a good approximation by the *Equation 1*:

$$(h_f)_v = 0.417738\,V^{0.1976}\,C^{0.6964}$$

Equation 1 Losses of pressure in a vertical pipe of water with coffee, in function of the speed and of the concentration.

Where:
$(h_f)_v$ = losses of pressure for the mixture, m.c.a. /100m.
V = mean speed of the mixture, m/s.
C = Concentration of coffee, apparent volume of café/volume of water.

For the hydraulic transport of the mixture water - coffee for horizontal pipes of 76.2 mm (3") of diameter with speeds between 1.5 and 2.5 m/s, the *pressure losses* can be predicted with good precision by Equation 2.

$$(h_f)_h = h_f - 0.1244 + 1.60497C$$

Equation 2. Losses of pressure in a horizontal pipe of water with coffee, in function of the speed and of the concentration

Where:

(hf) h = losses of pressure for the mixture, m c.a. /100m.
hf = losses of pressure with single water, m c.a./100m.
C = concentration of coffee, apparent volume of coffee / volume of water.

It was also found that the *losses of pressure that occur in elbows and tees* in PVC pipe of 76.2 mm (3") of diameter, expressed in equivalent distance of direct pipe can be considered similar to the equivalent distance of these same accessories when water is transported.

Additionally it was developed the *characteristic curve of the submergible bomb* used in the tests. Model: Marks HWH 10-21-3. Power = 0.746 kW (1 HP).

For this purpose different concentrations were used in volume (volume of water/apparent volume of coffee). In the

Figure *17* the results can be observed.

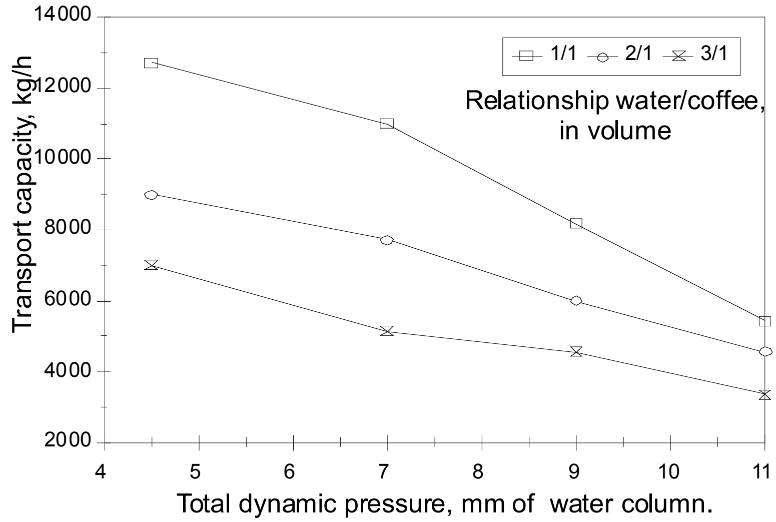

Figure 17. Characteristic curve of a submergible pump. Mark = IHM; model = HWH 10-21-3; Power = 1 HP, transporting washed coffee with water.

3.8. MECHANICAL DEMUCILAGING, WASHING AND CLEANING OF THE COFFEE. EQUIPMENT DESLIM [6].

The mucilage covers the parchment, with thickness that varies from 0.4 mm (in the plane face of the grain) up to 2.0 mm (in the convex part). It Represents 22%, in weight, of the pulped coffee and 13% of the weight of the cherry. The mucilage contains water, peptic substances, reducer sugars and non-reducer sugars, cellulose and ashes.

3.8.1. Elimination of the mucilage.

In most of the countries producing mild denominated coffees the mucilage is eliminated by means of the natural fermentation and the later washing. When this task is carried out with good control and the drying is executed under appropriate conditions it is obtained coffees with clean parchment and of high cup quality.

However, in many cases there is *little control in the property*, especially when the production is low and the pulped coffee of several days are mixed in the same tank. These conditions usually give origin to coffees of bad quality with ferment flavor that causes important economic losses, because the buyers reject the coffee.

The mechanical demucilaging allows to obviate these problems The demucilaged parchment coffee washes itself directly in the demucilager type DESLIM (See Section 3.8.), a demucilager-washer equipment in which the washing section is included in the superior part, with grain and water flows in counter-current.

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[6] Prepared by Oliveros, T. C.E. and Sanz, U. J.R. Ingeniería Agrícola, CENICAFE.

There can be one or a combination of several conditions that determine that the washing in the demucilager itself might not be enough to leave the coffee washed to satisfaction. They are: raw matter of bad quality and absence of screen classifier in the BECOLSUB module (See section 3.12), bad calibration of the equipment, desire of the coffee grower to have an excellent presentation of his grain.

One of the best options to supplement the washing in these circumstances is to use the hydrocyclone (See section

3.9.), or using the pump during the transport of the coffee to the dryers, as a wash complement (See section 3.7.), or finally a manual rinsing.

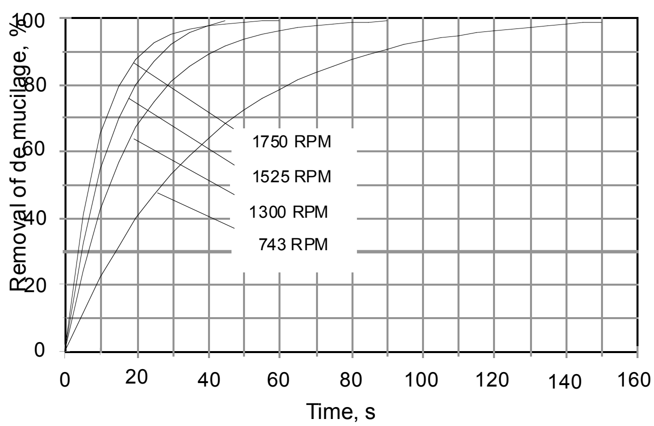
3.8.2. Principles of mechanical demucilaging of the coffee.

When a mass of pulped coffee becomes agitated it is possible to remove a large percentage of mucilage in only a few seconds Figure 18. The fluids mucilage + the added water, and the particles originated from the pulp present in the pulped coffee, residuals of grains (immature, attacked by the coffee borer, etc.) and other strange materials, give origin to a highly viscous suspension of pseudoplastic nature (74). That is, its viscosity decreases markedly when the rate of deformation is increased.

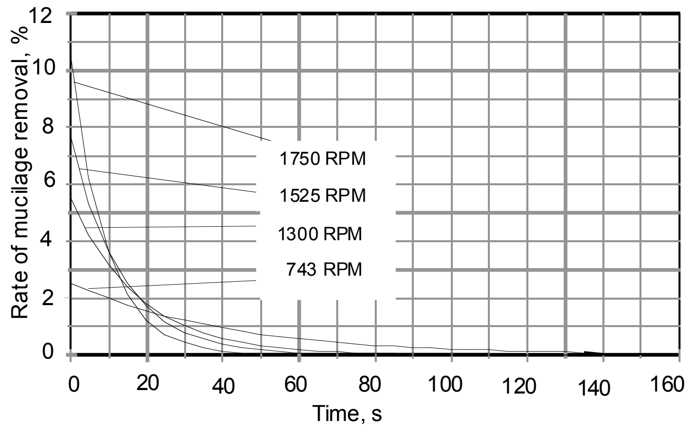
When the rotational speed is increased the deformation rate of the suspension *mucilage-coffee* is increased, the cutting stresses that act in the vicinity of the grains increase and the frequency of the collisions among grains is also increased (bigger energy exchange). This explains why the *rate of mucilage removal is increased*.

However, when the rotational speed is very high (more than 1,500 rpm in the CENICAFE III rotor) the grains spread around and become aligned with the main

Figure 18. High mucilage detachment in the first instants of the process. Two different stages are shown, the demucilaging (inferior part) and the washing with flows of water and of grain in counter-current (superior part).



(a)



(b)

Figure 19. Effect of the rotational speed in the detachment of the mucilage (a) and the rate of mucilage removal (b).

direction of the flow (tangential) with reduction in the collision frequency between grains. This phenomenon causes an apparent stability in the viscosity of the suspension and under these conditions the demucilaging rate decreases.

Under high-speed conditions of rotation, uncertainties in the pattern of flow could occur (appearance of vortexes) that also influence in the demucilaging rate.

The demucilaging process is affected mainly by the diameter of the rotor, the rotational speed, the rotor type and the viscosity of the suspension (this one depends also of the rotational speed, the mass of water used and by the quality of the coffee that enters to the demucilager). In general terms, *the best performance was obtained with the COLMECANO type rotor* Figure 20.

Figure 20. Robust rotor COLMECANO type, composed by gears agitators, fused in aluminum, used traditionally in pulpers, COLMECANO type.

3.8.4. The Technology DESLIM.

The technology DESLIM (Demucilager, Washer, Cleaner) was developed in CENICAFE by incorporating the concept of upward washing used in earlier models (CENICAFE-C-I prototype) and the COLMECANO rotor, giving origin to an upward vertical grain flow demucilager. A short screw conveyor was incorporated in the inferior part (See section

3.8.5.)

With the equipment DESLIM the consumption of water was of less than 1.0 l/kg of PDC and highly concentrated honeys were obtained, viable to be mixed with the pulp.

Two important parameters were determined for the appropriate scaling of the technology DESLIM: the *applied mean cutting rate* (AMCR) by the rotor and the power requirement.

In the selection of the demucilager rotors the concept of Applied Mean Cut Rate was applied as a parameter to evaluate and to compare equipment in applications of agitation (as in the demucilaging of coffee). The AMCR for the of the DESLIM equipment (built with the COLMECANO agitator), Figure 20, external diameter of 13.5 cm, internal diameter of 9.0 cm and 8 vanes of trapezoidal section of 1.3 cm of thickness) was obtained. In

Figure 21 the effect of the rotational speed is shown in the AMCR in the range from 500 to 1.300 r.p.m.

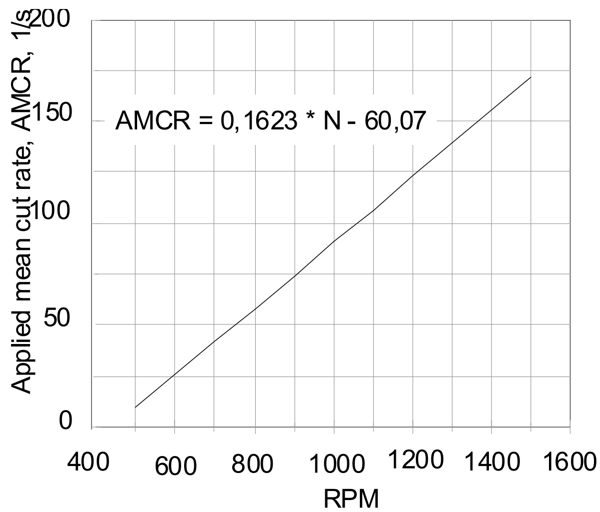


Figure 21. Applied mean cutting rate (AMCR), for a COLMECANO rotor, with agitators of 13.5 cm of external diameter and 9.0 cm of internal diameter.

The *power required* to activate a rotor of a demucilager depends on the length (or number of agitators), the diameter, the rotational speed, the viscosity of the suspension coffee-mucilage and the rotor type. Additionally in the case of the equipment DESLIM the power is affected sensibly by the longitude of the ring space configured between the shield, or perforated cylinder, and the external diameter of the agitator. The ratio between the diameter of the rotor and the diameter of the cylinder was set in 0.61.

In the Figure 22 the curve of power is presented for the rotor of the DESLIM 3000 demucilager. The rotor consists of 25 COLMECANO type agitators of 13.5 cm of external diameter and 9.0 cm of internal diameter. The shell casing has a diameter of 22.0 cm. The free space between the shield and the external diameter of the rotor (annulus) is 4.25 cm.

In general, a *non-linear relationship is observed between the power consumption and the rotational speed* (RPM). For rotational speeds lower than 1,100 r.p.m. the power to maintain the tangential flow (Pt) it is notoriously superior to the power to impel the coffee through the annulus (Pv). At higher speeds of rotation (>1,100 r.p.m.) Pv is superior to Pt. The power to install in a DESLIM 3000 equipment, to work at a specific speed, can be calculated by adding the losses due to the viscous dissipation (thermal dissipation, 13%) and the losses in the transmission of power (10%) to the power value given by Figure 22.

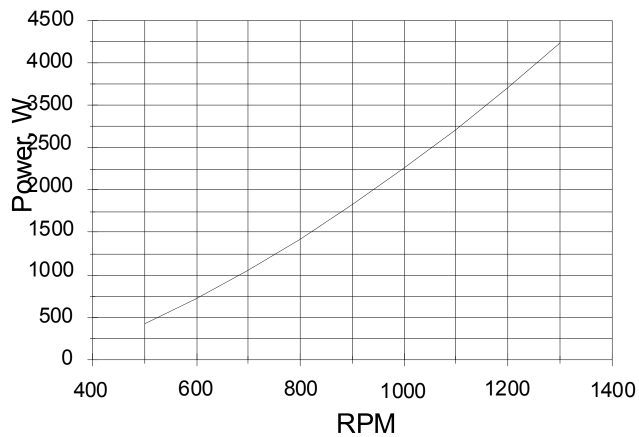


Figure 22. Effect of the rotational speed in the power consumption for a DESLIM 3000 equipment, operated with 1,500 kg of pulped coffee/hour.

The casing, the size and the form of the openings, affect notoriously the operation of the DESLIM equipment. Through the perforations, it is expelled the mucilage and the main part of other materials as pulp residual, fractions of grains, etc., due to the effect of the centrifugal force. Because of the tangential pattern of the flow in a demucilager, the particles, including the grains, are aligned in this direction. To better clean the coffee it is convenient to place the openings also in the same tangential direction. The size of the openings should only allow exiting of the strange materials and should not permit small grains of coffee to incrust in it. This is achieved with oblong perforations of 20-mm length and 3.2 mm wide.

3.8.5. Composition of the equipment DESLIM.

After the numerous evaluations at laboratory level and in commercial processing plants made by CENICAFE, the following essential constituent parts of the DESLIM equipment are recommended:

3.8.5.1. Casing.

The casing is the fixed part of the machine. The form, the size, the form of the oval perforations (3.2 x 20 mm) and to the disposition of these (horizontally aligned), are designed to separate the removed mucilage and the residual materials (pulp and parchment mainly) of the grains of coffee, Figure 23

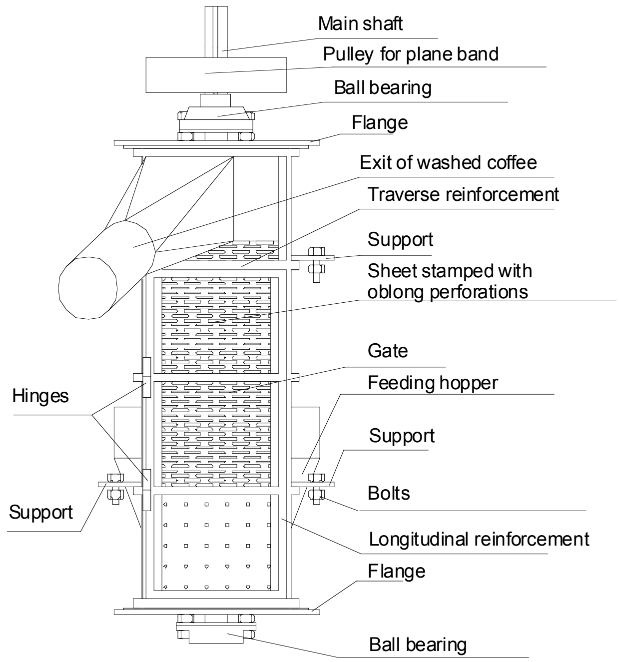


Figure 23. General sketch, and main components of the DESLIM equipment for coffee.

The casing of the DESLIM mechanical demucilagers is of variable length according to their capacity. To resist the stresses that are generated inside the demucilagers, the stamped sheet cylinder should be reinforced by a structure of rings in square bars of steel. It should have, in the front part, an access door with a sufficiently strong closing mechanism to avoid opening during the demucilaging process.

In the intermediate and in the superior parts, inlets of water are added for the demucilaging and the washing processes, respectively. For a good performance and good demucilaging quality the consumption of water values, are presented in Table 10

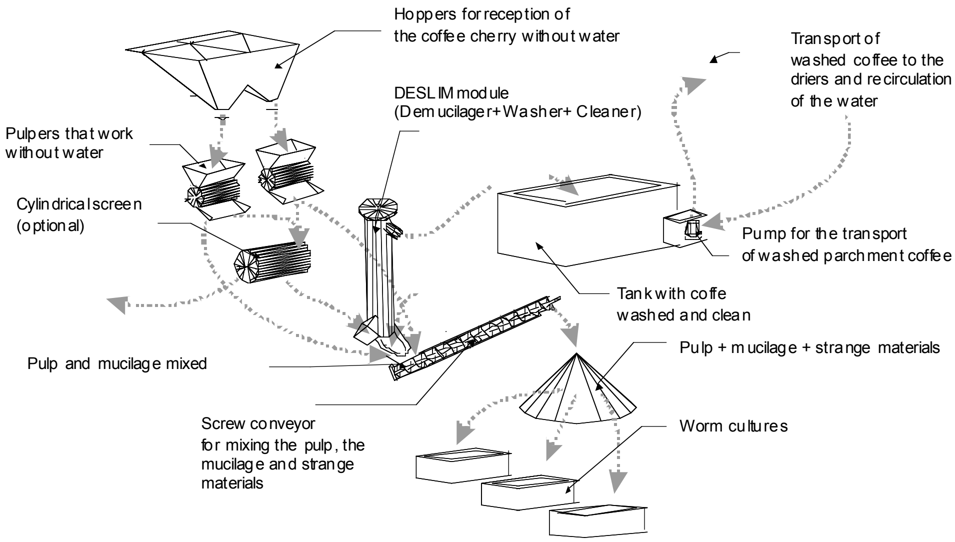


Figure 24. Outline of the coffee processing plant using the BECOLSUB module.

Table 10. Main Characteristics of the three DESLIM models for coffee.

Characteristic	*Capacity kg cc./h*		
	600	1000	3000
Rotor length, m	0.53	0.70	1.00
Power, kW	0.89 (1.2 HP)	1.34 (1.8 HP)	4.92 (6.6 HP)
Demucilaging water, L/min	1.0	1.75	3.75
Washing water, L/min	1.0	1.75	3.75

3.8.5.2. Rotor

The rotational part, Figure 20 and Figure 25, is the mechanical device that *causes the cutting stresses to the mass of coffee*, necessary for the separation of the mucilage attached to the grains. It is formed by three elements assembled in one shaft: the feeder and control of the flow, the agitators and the cleaners. The shaft is of circular section at the ends and of squared section at the intermediate part.

To avoid obstructions to the casing several cylindrical cleaners are attached to the bar.

The power is transmitted by means of a pulley. The rotor operates at 870 rpm. A feeding hopper provides the pulped coffee continually to the mechanical demucilager. By means of a discharge duct the demucilaged coffee is conducted outside the casing by centrifugal force.

The mucilage and the materials that come out through the perforations of the casing mix with the pulp, by the action of the screw conveyor of the BECOLSUB module. (See section 3.12)

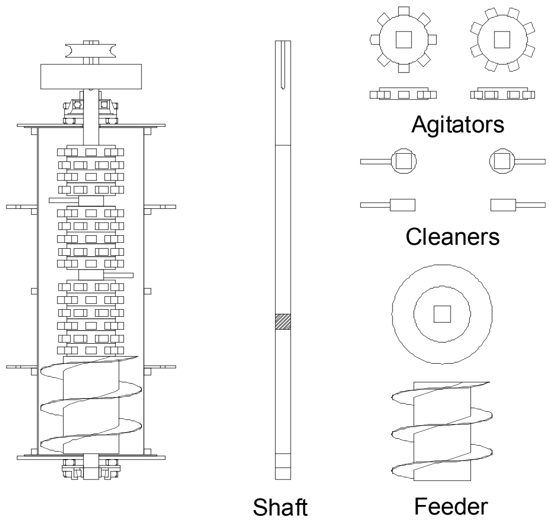


Figure 25. Constituent elements of the demucilager, washer, cleaner DESLIM, for coffee.

Figure 26. DESLIM 1000; constituent part of a BECOLSUB module built by the national industry.

3.8.6. Particular characteristics and performance of the demucilagers DESLIM 600, DESLIM 1000 and DESLIM 3000.

The equipment DESLIM 600, with capacity for 600 cc/h kg, consists of a rotor with 10 agitators, COLMECANO type, external diameter of 13.5 cm, internal diameter and 9.0 cm, separated (center-center) 28 mm. A screw conveyor of 20.5 cm of internal diameter, 10.2 cm in pitch and 20.0 cm of length, located in the inferior part of the equipment, forces the coffee upwards (Figure 18). The water required in the process is given in the intermediate part of the demucilaging chamber (1 l/min) and in the superior part of the equipment (1 l/min).

In the model DESLIM 1000 a similar rotor is used but with 15 agitators COLMECANO type. The used water (3.5 l/min) is applied at two locations: at half of the height of the camera and at the discharge (1.75 l/min in each one). The rotor spins at 870 r.p.m. and a motor of 2.4 HP activates it. In the modules BECOLSUB 1000 a motor of 3.0 HP is necessary to drive the pulper, the demucilager and the screw conveyor.

In the equipment DESLIM 3000 a rotor is used with 25 similar agitators, rotating 870 r.p.m. The shield is also of the same diameter (0.222 m). When pulped coffee is feed at a rate of 2,400 kg cherry coffee/h), without previous screening a motor of 4.8 HP is needed. When the feeding rate is of 3,000 cherry coffee/h it is required of a motor of 6.6 HP. The water, 7.5 l/min, in the case of 3,000 kg of cherry/h, is applied.

In Figure 27 the average values of the quality of the coffee parchment obtained with a DESLIM 600 unit is presented, compared with results of conventional processing, with fermentation. To the cherry coffee used in the evaluations the immature and dry grain

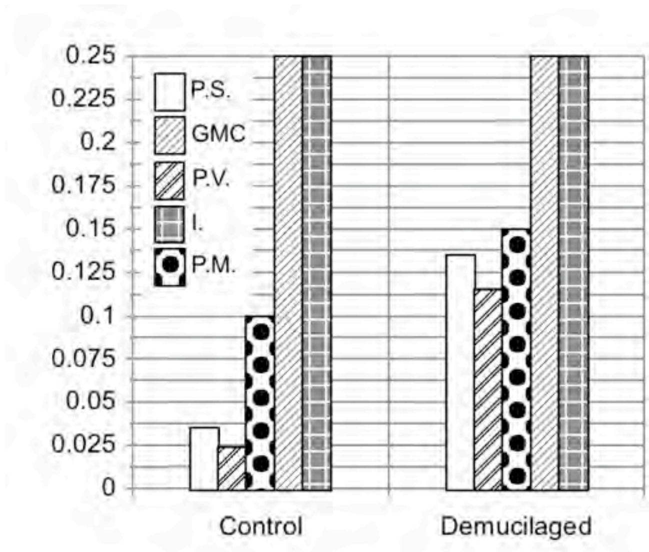


Figure 27. Physical quality of the obtained coffee (P.S = dried parchment; GMC = coffee grain half covered with dry pulp bean; P.V. = immature parchment; I = strange materials; P.M. = monster parchment, with the equipment DESLIM 600.

was retired. The unpulped grains and part of the pulp were retired to the coffee with mucilage, using a screen. The coffee obtained by the two methods is of high physical quality. The intrinsic mechanical damage, due only to the equipment, is very low (<0.2%). The specific consumption of water was low (0.96 l/kg of dried coffee) and the ratio of installed power to the capacity of the system was of 3.68 W/(kg of coffee pulped coffee/h). Similar results were obtained with the DESLM 1000 and DESLIM 3000 modules.

To the coffee processed in the DESLIM equipment it is necessary to retire the floats before taking it to the dryer. In the case of small properties this operation can be carried out by adding clean water to the coffee until covering it with a layer of 10 cm. The floats can be retired using a perforated recipient. In large properties a pump is used to transport the coffee to the dryers. The floats are retired in the by overflowing them from the pump tank. The remaining strange materials might be removed by means of a device like the hydrocyclone (See section 3.9).

In the previous operations in which water is used as a classifier device, contamination is generated in the levels shown in Figure 28. *The values of chemical demand of oxygen* (CDO) per liter of used water, for the first rinsing, although intrinsically high, are very inferior to those observed in the resulting syrups of the processing with natural fermentation. Unfortunately this flows traditionally are thrown to the streams or to the rivers with contamination levels superior to 30,000 mg of CDO/liter.

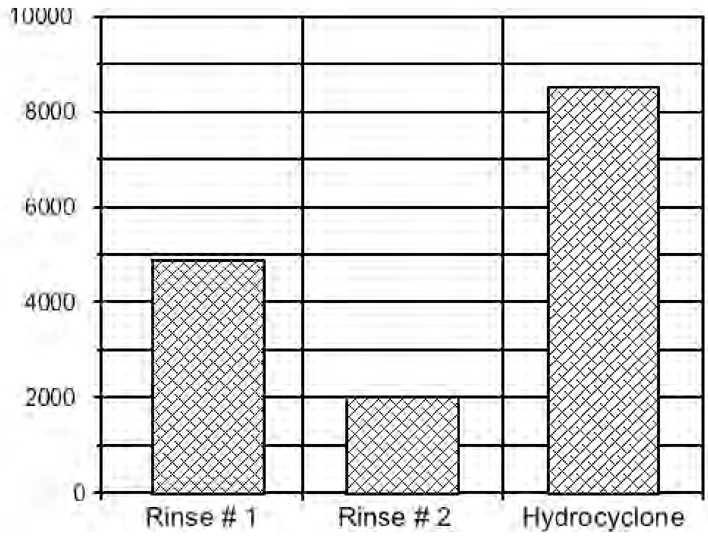


Figure 28. Contamination generated by rinsing a demucilaged grain for the elimination of the floats and strange materials.

The values of CDO/liter for the second rinsing (sometimes necessary for the bad quality of the coffee) are notoriously inferior to those of the first rinsing. In Figure 28 the values of CDO/liter are presented for the case of the processing of 3,000 kg of coffee cherry of bad quality (high content of grains infested with the coffee borer, dry cherries and grain complete covered with dried pulp). The BECOLSUB technology and the hydrocyclone, used with recirculation of the waters, were used for the processing. In this case, the concentrated particles, removed by the hydrocyclone, increased the organic load of the used waters (0.12 l/kg of dry coffee).

Finally, with the technology BECOLSUB, developed in CENICAFE, it is possible to obtain the following *advantages* with relation to the conventional process of the natural fermentation:

- Important reduction in the specific consumption of waters (<1.0 l/kg of PDC).
- Notorious improvement in the yield, conversion cherry/dried, for the recovery of mature cherries and half-ripe that because the size and failures in the calibration of the pulpers are not pulp, and from cherries with normal kernels, but with the pulp adhered to the parchment due phytosanitarial problems. In evaluations of the DESLIM equipment it has been observed conversions cherry to dry in the range 3.8 to 4.5 while with the natural fermentation the conversions were superior at 4.4.
- Control of more than 50% of the liquid contamination generated by the resulting syrups of the process by the retention of more than 50% of fluids when mixing them with the pulp, using a screw conveyor (BECOLSUB process). If the pulping and the transport of the mixed pulp to the transformation places are carried out without water more than 90% of the contamination can be controlled physically, with respect to the values that are caused traditionally by the wet process.

- Important reduction in the size and in the cost of the buildings required for the wet processing of the coffee.
- Simplification of the wet processing method for coffee. When the cherry is of good quality (less than 5% of immature and dry cherries) it is possible to obtain washed parchment coffee with less than 2.0% of coffee grain complete or half covered with dried pulp and less than 0.5% of strange materials. When the cherry is not of good quality, situation that is presented usually in times outside of the main crop, the coffee can be washed, after demucilaged, using devices like the hydrocyclone with recirculation of water, or after drying, by classifying with sieves with oblong openings of 4.5 mm.

3.9. WASHING AND CLASSIFING THE COFFEE BY THE HYDROCYCLONE. [7]

In the wet processing of the coffee the open channel and the semi-submerged channel have been used traditionally, to wash the coffee and to retire the vain grains and the strange materials, to obtain coffees of high physical quality (46).

However, important limitations, as the high consumption of water (more than 15 liters of water per kg of dry parchment coffee) and high percentages (up to 19%) of good coffee mixed with the low-grade coffee (63), 118). In consequence, the ecological handling of the contaminated waters is extremely difficult, the time of the operations is too long and economic losses caused to the coffee grower are big.

The hydrocyclone, HC,

Figure *29* and

Figure 30 is a device that allows to retire the strange materials of the coffee with high effectiveness and efficiency. The particles are fed under pressure using a submergible bomb. The suspension rotates around the longitudinal axis of the HC forming a descending external whirl that drags the denser grains (good coffee) toward the walls, until evacuating them from the inferior part, or apex. The particles of smaller density (immature grains, infested with the coffee borer and some good grains) and those of flat form (pulp remains), are dragged toward an upward interior whirl, and are discharged from the superior part, or localizer.

The geometric variables of a hydrocyclone,

Figure *29* they are:

[7] Prepared by Aristizabal, G. J. Agricultural Engineering, CENICAFE.

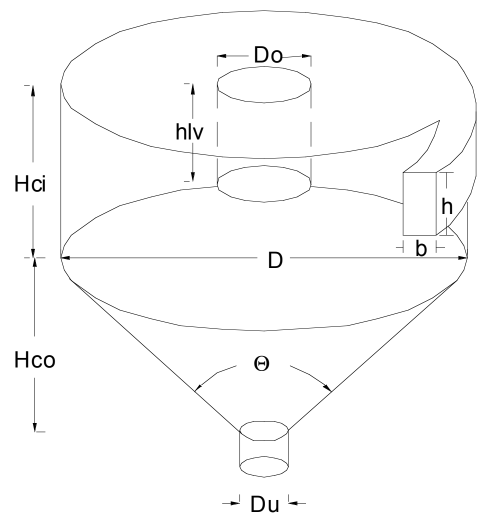


Figure 29. Design variables of a hydrocyclone.

Main diameter*: D;* Entrance section: *bxh;* Diameter of the apex: *Du;* Diameter of the localizer: *Do;* Height of the localizer: *hlv;* Height of the cylindrical section: *Hci;* Height of the conical section: *Hco;* Angle of the cone: θ

The operating variables that have more influence on the operation of the HC are: the flow and the concentration of the suspension water-coffee.

The capacity of the HC depends mainly on the variable D and Hci, the characteristics of the installed pump and the rate of coffee fed to the pumping tank (12), (15), (59), (110).

It was designed (12) and evaluated the performance of an HC in the washing and in the classification of coffee coming from the tanks of fermentation. The dimensions of the equipment are presented in

Table *11* and

Figure *29*.

3.9.1. Design of a hydrocyclone.

To design a hydrocyclone the flow of coffee to process should be known, expressed in (kg/min), the flow of suspension water - coffee that can transport the bomb and the distance between the tank of pumping and the entrance to the hydrocyclone. With these parameters the dimensions of the equipment can be defined. In Table 12 the dimensions of hydrocyclones are presented for different transport capacities and total dynamic height of pumping (Δ H). Additionally, the minimum values of the required power of the pump are given in each case.

Table 11. Dimensions of the experimental hydrocyclone of CENICAFE for classification of the coffee.

D cm	D cm	Du cm	Do cm	Hlv cm	Hci cm	Hco cm	θ °
35.0	5.17	3.83	6.30	12.0	21.0	21.0	81.0

Table 12. Dimensions of the hydrocyclone for different conditions of pumping

Capacity Kg/h	*Flow L/min*	*H m*	*Power kW*	*D cm*	*Di Cm*	*Du Cm*	*Do cm*	*hlv cm*	*Hci cm*	*Hco cm*	*θ °*
1,500	100	5.0	0.37(1/2HP)	35.0	5.46	3.34	5.46	14.0	24.0	26.0	62.7
2,200	380	2.5	0.56(3/4HP)	64.0	8.89	1.90	5.45	25.0	29.0	33.0	81.0
3,000	200	5.5	0.74(1.0HP)	55.0	8.89	4.37	8.89	22.0	33.0	30.0	80.0

3.9.2. Construction of the hydrocyclone.

The hydrocyclone is constituted in its superior part by a cylinder, of diameter D, and in its inferior part by an angle cone, θ. The localizer penetrates a distance *hlv* into the body of the cylinder, equivalent to 40% of the value of the main diameter. It is recommended to build the entrance to the hydrocyclone in form of rectangular section (*bxh*), that wraps the body of the cylinder, with its larger side parallel to the axis of the hydrocyclone. The height of the cylinder (*Hci*) should be 2 to 3 times the height of the entrance section (calculated based on *Di*, diameter of the equivalent area with section *bxh*). The height of the cone (*Hco*) is chosen equal to the height *Hci*, or the corresponding value to a cone angle θ *between* 60 and 90°. In the final part of the cone, corresponding to the diameter of the apex (*Du*), it is recommended to couple a cylinder of the same diameter and 10 cm high. It should be avoided that the superior discharge presents a siphon effect. In the event of requiring a conduction below the inferior discharge, an overflow tube should be implemented to the exit of the HC (12) (See Figure 12).

Figure 30. Hydrocyclone in operation, classifying parchment coffee.

3.10.3. Installation and operation of the hydrocyclone.

The hydrocyclone can be installed in angle structures, which can be located in the wet area of the processing plant, nearby the demucilager, or to the fermentation tanks, or to the pumping tank, in such a way that the classified coffee can be stored temporarily in a work tank. In this position the grain can be pumped at the proper time to the dryers. The water pressure to the entrance to the HC should be comprehended between 13.8 and 34.5 kPa (2 to 5 PSI). This pressure should overcome the heads represented by the difference of heights between the pumping tank and the superior discharge of the equipment, the losses of pressure in the pipe and the direction changes. This way the discharge in the apex should be in cone form with angles larger than 30° with respect to the vertical. This behavior indicates that the HC is working correctly and classifying coffee parchment with low contents of coffee grains complete covered with dried pulp or with strange materials. The flow of water evacuated by the apex, approximately 30% of the total used, should be returned to the pumping tank. In

Figure 30 the coffee is observed well classified by the form of the inferior discharge.

The discharge of the localizer might give a high percentage of low-grade coffee, grains very infested with the coffee borer, pulp residuals, a relatively low percentage of good grains (12.4%). These materials are recycled easily, obtaining the recovery of the good coffee (12). The localizer discharge accounts also for the remaining 70% of the flow of used water, which should be returned to the pump tank.

3.9.4. Evaluation of the hydrocyclone.

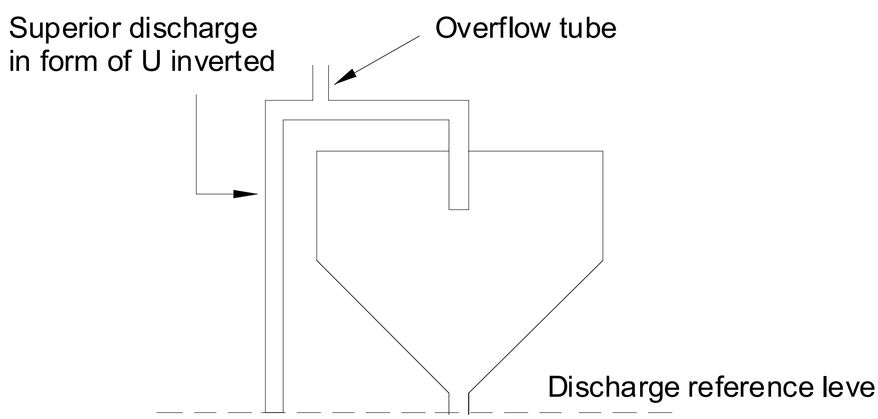


Figure 31. Detail of the superior discharge of the hydrocyclone classifying coffee.

Figure 32. Commercial operation of the hydrocyclone coupled to a BECOLSUB module, in CENICAFE.

The obtained results presented in the

Table 13 allow concluding that the HC presents real advantages with relation to the open channel, and the semi-submerged channel. In effect it presents smaller specific consumption of water, smaller losses of good coffee with the low-grade coffee, and better effectiveness in the separation of the coffee infested with the coffee borer. Although the percentage of low-grade coffee and strange materials obtained in the apex of the HC was of 7.3% in humid state, this coffee after dried remained inside the norms of FEDERATION type, because the strange materials presented very high values of moisture. In CENICAFE, two hundred (200) tons of cherry coffee were processed during the main crop of 1995 using pulping without water, mechanical demucilaging (demucilager DESLIM type) and the hydrocyclone, designed according to this article (

Figure *32*). A total water consumption of 3.8 liters for kilogram of dried parchment coffee were used to obtain 40 tons of dried parchment coffee, FEDERATION type.

Table 13. Performance of the hydrocyclone designed for washing and classifying parchment coffee.

Equip ment	Foreign material. %	CBS %	P S %	C.S.P %	P+ I %	Cap kg/h	CEA L/kg
HC*	71.6	24.8	28.2	12.4	7.3	1,640	1.9
Cco **	---	23.6	---	18.9	---	450	18.7
CSS***	86.5	---	85.2	19.8	3.2	7,000	3.2

*Sources: *(12) **(127) ***(63)*
Foreign Material=Separated foreign material
C.B.S. = Separated coffee with coffee borer
PS. = Separated low grade coffee
CSP = Good coffee mixed with low grade coffee
P. + I. = Foreign material + Low grade coffee mixed with good coffee
Cap = Capacity
CEA = Specific water consumption (liters per kg of wet parchment coffee.
Cco = Open channel
CSS = Semi-submerged channel

3.9.6. Advantages of the hydrocyclone.

The *main advantages* that the hydrocyclone presents to clean and to classify coffee originated in the processes of mechanical demucilaging or of natural fermentation, with respect to the open channel and the semi-submerged channel, are the following:

- Easy construction and installation.
- It can be build in iron sheet or in synthetic materials.
- The submergible pumps conventionally used in the coffee processing plant can be used to run the hydrocyclone.
- It operates in continuous form. Once the normal conditions of operation of the equipment are established with water, the classification of the coffee can be initiated.
- The separated low-grade coffee can be recycled after finishing the classification of the available coffee of the day, until getting nearly 100% recuperation of the good coffee.
- It occupies small space and it can be moved easily, from one place to another.
- It can be connected in the circuit that transports the washed coffee to the dryer.
- It is economic, it requires little maintenance and it saves manpower.

- It is the ideal complement for the demucilagers DESLIM types (3.8.4.) when the raw material is a low-grade coffee.
- It is very appropriate for the ecological processing of the coffee, since it uses a very small volume of water (<0.1 m^3), when operated with recirculation.

3.9.7. Disadvantages of the use of the hydrocyclone.

- To increase the capacity of the system it is not enough to increase its dimensions proportionally. It should be redesigned according to the characteristics of the bomb and the piping system.
- A constant flow of coffee to the pumping tank is required for the good performance the equipment.
- High rates of feeding of the coffee can cause plugging of the apex with the consequent evacuation of the total system.

3.10. PNEUMATIC TRANSPORTATION OF COFFEE PARCHMENT AND FRESH PULP OF COFFEE.

The pneumatic conveyors are systems that use the energy of the air inside a duct to displace materials from a place to another. The source of power for the air is a high-pressure fan.

In CENICAFE (123) studies on *pneumatic transport of wet parchment coffee and of fresh pulp* were performed using a positive pressure system of PVC pressure pipes of 107.7 mm (4") and 160 mm (6"). It can be observed,

Figure 33, the outline of the used positive pressure pneumatic conveyor.

It was found that the pneumatic system, using horizontal and vertical pipes of 4” of diameter was appropriate for the transport of the washed parchment coffee and the fresh pulp. The mechanical damage caused to the parchment in any state (washed, surface-dried and dried) was small when coffee was transported to distances smaller than 50 m and with a maximum of 6 elbows.

The results of this investigation related the flow and the necessary static pressure to achieve the transport of the materials. By using this information it is possible to select the appropriate fan in similar transporting systems.

In Table 14 the *minimum speeds of the air to propitiate the transport* are presented for the horizontal and vertical transport of the coffee parchment (recently washed, surface-dried and dried) and of the fresh pulp.

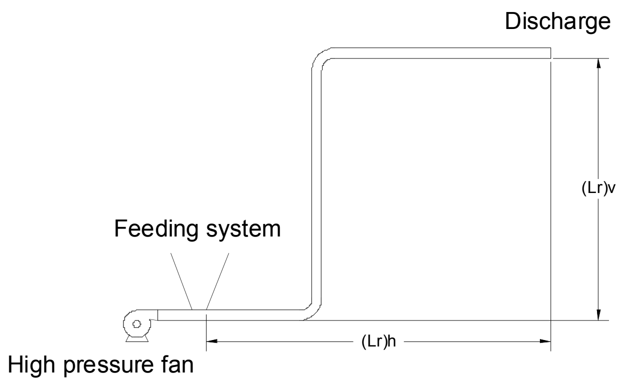


Figure 33. Outline of a pneumatic conveyor of positive pressure.

Table 14. Minimum speeds required of the air for the pneumatic transportation of coffee parchment and pulp of coffee, in vertical and horizontal piping systems.

Products	*Minimum Velocities (m/s)*			
	160 mm (6") pipe		*107.7(4") mm pipe*	
	Horizontal Transport	Vertical Transport	Horizontal Transport	Vertical Transport
Washed coffee	17.95	19.74	11.89	13.17
Skin dried coffee	17.06	19.25	11.56	12.83
Dried coffee	15.35	17.01	11.09	10.91
Fresh pulp	15.62	14.43	14.04	11.21

3.11. TRANSPORT AND MIXTURE OF THE PULP WITH THE SCREW CONVEYOR.

With the *same philosophy of the previews work, and to offer an alternative to the hydraulic transport* of the different states of the coffee and of the pulp, it was studied the viability of using the screw conveyor for the transport of these products inside the coffee processing plant.

The screw conveyor, Figure 34 is a transport system that consists of a continuous helix rotor (screw) supported in both ends inside a casing, in U form, or in a tube. It imparts an *axial movement to the deposited material*. This system was proven to work well to transport the pulp of coffee or the pulp mixed with the mucilage resulted from the BECOLSUB technology. This conveyor is characterized by the simplicity of its construction, assembly, handling and maintenance, being relatively economic and not very demanding in power.

When the screw conveyor is used for the transport and mixture of the pulp plus the very concentrated mucilage, a retention of the fluid in the pulp might be as much as 56%. When the addition of these components is done by gravity, the retention is of only 32% (84). The good mixing characteristic makes to the screw conveyor a fundamental piece in the ecological handling in the wet method of processing coffee, with a overall control of the contamination larger than 90% (41), (77), (96).

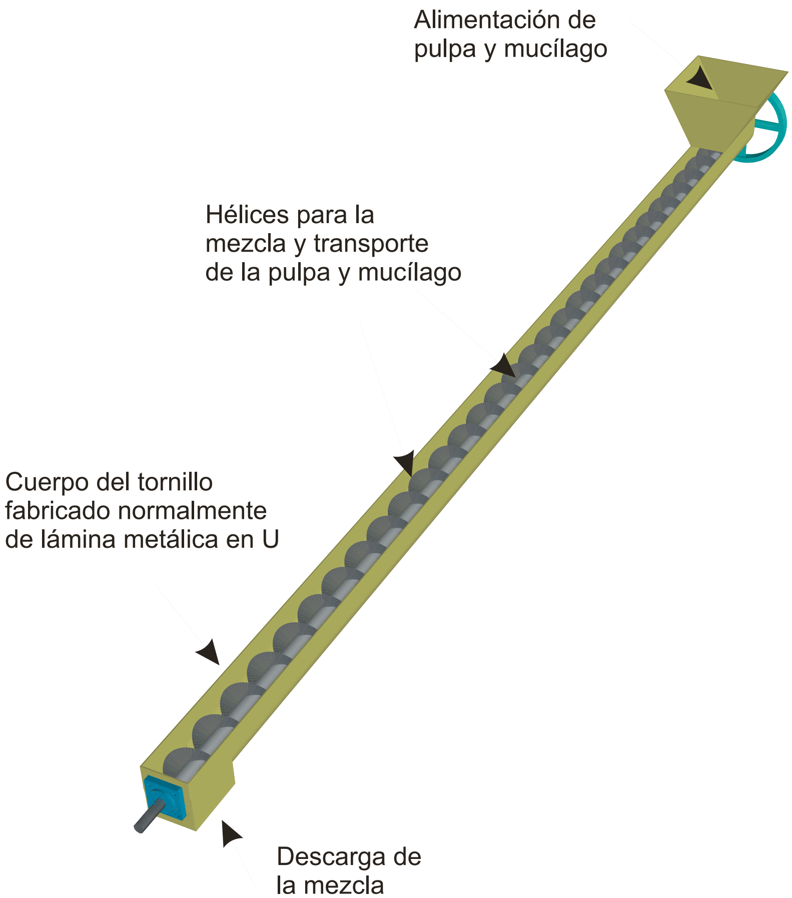


Figure 34. Screw conveyor for mixture and transport of the pulp with the mucilage.

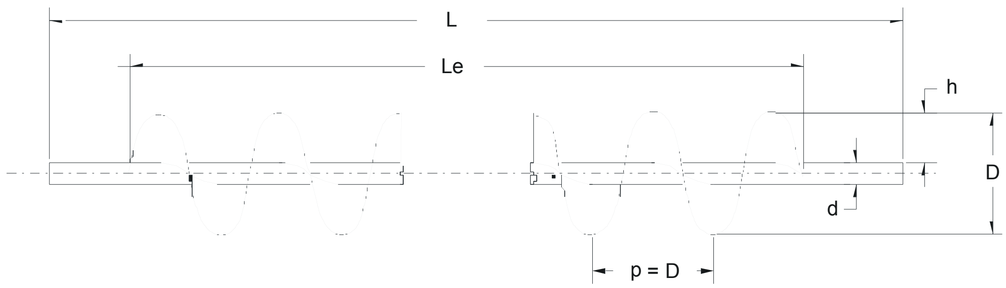


Figure 35. Main dimensions of the rotor the screw conveyor.

For long distances, it is recommended to use a short section of screw conveyor and another device, in series, as the band conveyors, of lower price.

3.11.1. Main dimensions.

In Figure 35 the main dimensions of the rotor of the screw conveyor are presented. It is denominated *D* to the external diameter, *d* to the interior diameter or diameter of the shaft, *p* to the pitch or advance per turn, *h* to the height of the helix, *Le* the effective distance the screw and L to its total length, including the supports spaces.

3.11.2. Selection of the external diameter.

To facilitate the *selection of the external diameter of the screw conveyor, it was prepared a graph,*

Figure 36, where, in its inferior part, the relationship of pulping time and the transport capacity, for different processing plant capacities in the maximum processing day (See section 3.14). The graph was constructed for an angular speed in the shaft of 180 rpm, screw pith equal to the external diameter and for

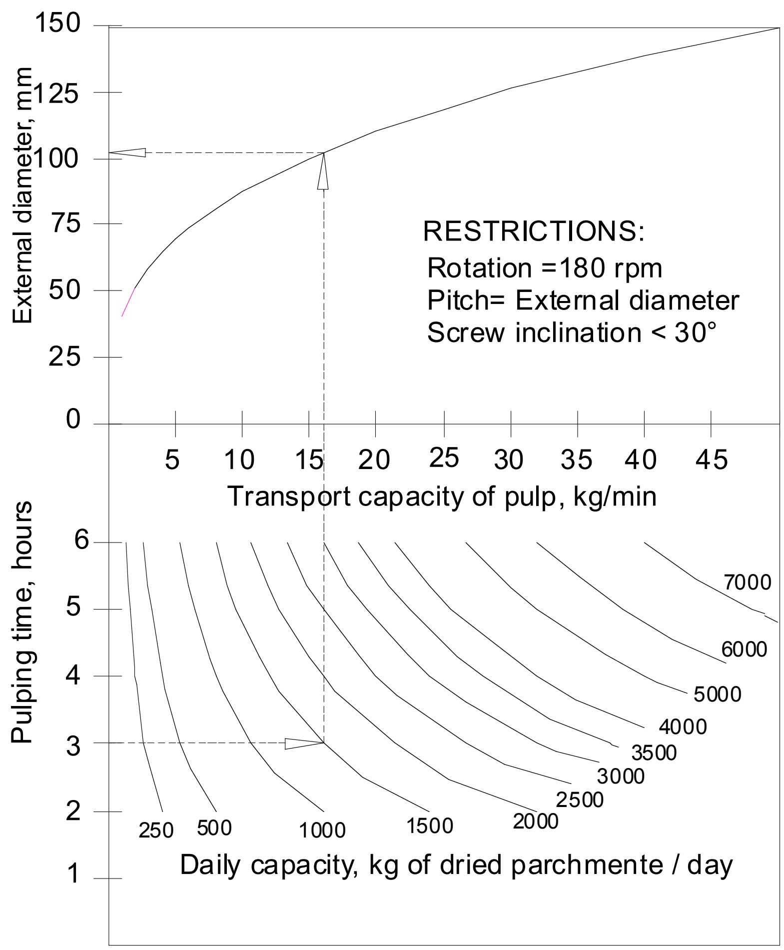


Figure 36. Graph for the selection of the external diameter of the screw conveyor for mixed pulp with mucilage.

The use of the graph, first an estimate of the number of hours needed to pulp the coffee in the maximum processing day is needed. From this point, located in the inferior part of the Y axis), we move horizontally to the right to cut the capacity, in kilograms of parchment dry coffee of the processing plant in the maximum day of production.

From this point we move vertically cutting the axis X and also cutting the superior curve. The intersection point in the axis X gives the transport capacity of the pulp and from the cut point with the superior curve we move horizontally toward the left to cut the Y-axis. In this new cutting point, the value of the external diameter of the screw conveyor is obtained. For practical effects, the external diameter obtained in this graph can be expressed as the nominal diameter (Dn) in inches, making the conversion by Table 15, and approximating the result to the superior integer number.

a maximum inclination of the screw, with the horizontal of 30°. In the superior part of the graph a curve of transport capacity is presented against the external diameter.

If the time used to pulp the cherry coffee in the day of maximum capacity is of 3 hours and the processing plant is designed for 1,500 kg of parchment dry coffee per day, the capacity of the screw conveyor should be equal or larger that 16 kg/min. This capacity is achieved with a screw equal or larger than 102.5 mm (4"), pitch equal to the diameter, 180 rpm and an inclination lower than 30°. The selection of the curve is marked in

Figure 36, with dotted lines.

Table 15. Powers and diameters of galvanized pipe shafts, recommended for screw conveyors to transport pulp mixed with concentrated mucilage

Effective distance, m	*Capacity range, kg/min*	*Recommended motor, kW, (hp)*	*Recommended, diameter, mm, (inches)*
2.00	30	0.30 (0.40)	26.67 (¾)
2.00	30-50	0.67 (0.90)	26.67 (¾)
2.50	20	0.30 (0.40)	26.67 (¾)
2.50	20-50	0.67 (0.90)	26.67 (¾)
3.00	20	0.30 (0.40)	26.67 (¾)
3.00	20-50	0.67 (0.90)	26.67 (¾)
3.50	10	0.30 (0.40)	26.67 (¾)
3.50	10-50	0.67 (0.90)	26.67 (¾)
4.00	10	0.30 (0.90)	33.40 (1)
4.00	10-50	0.67 (0.90)	33.40 (1)
4.50	10	0.30 (0.40)	42.16 (1¼)
4.50	10-50	0.67 (0.90)	42.16 (1¼)
5.00	10	0.30 (0.40)	42.16 (1¼)
5.00	10-50	0.67 (0.90)	42.16 (1¼)

3.11.3. Calculation of the diameter of the axle and power of the screw conveyor.

Because the shafts of the rotors of the screw conveyors are long, their own weight causes flexion problems and undesirable vibrations. For this reason and for economy, it is advisable to use galvanized pipes instead of solid shafts.

The diameter of the tube to be use as shaft of the screw conveyor depends on the distance and on the power that is required to move it. In Table 15 the diameters of the galvanized pipes and the recommended powers are presented, for different distances

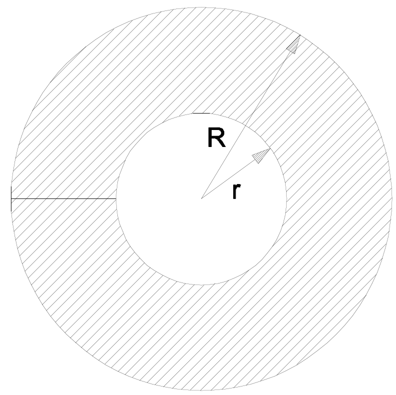


Figure 37. Dimension for the construction of the disks of the screw conveyor. (R = external radius, r = internal radius. See Table 16).

and capacities. Because of the requirements of power are so low, when the shaft of the pulpers and the shaft of the screw they are parallel, it is feasible to use the same motor to drive them simultaneously.

When the length of the screw conveyors overcome the values indicated in Table 15, intermediate supports for the shaft should be used. The design of these supports should be done carefully, because a reduction in the traverse area constitutes in a reduction of the capacity and might increase considerable the demanded power.

3.11.4. Construction of the screw conveyor.

A screw conveyor might be considered as a succession of disks,

Figure 37, with dimensions that correspond to the exterior and interior diameters of the rotor. The cut disks joining one with the other to form a helical spring stretched on the shaft.

Table 16. Dimensions of the disks for the construction of the rotor of a screw conveyor.

Dn mm and inches (")	*D = p mm*	*D mm*	*R mm*	*r mm*	*N units/ m*
60 (2")	50.49	26.67	28.88	16.97	18.16
60 (2")	50.49	33.40	28.44	19.89	18.45
60 (2")	50.49	42.16	28.05	23.88	18.70
82 (3")	72.19	26.67	42.52	19.75	12.34
82 (3")	72.19	33.40	41.72	22.32	12.57
82 (3")	72.19	42.16	41.00	25.98	12.79
114 (4")	103.70	26.67	63.13	24.61	8.31
114 (4")	103.70	33.40	61.83	26.67	8.48
114 (4")	103.70	42.16	60.57	29.80	8.66
168 (6")	156.04	26.67	98.65	33.96	5.31
168 (6")	156.04	33.40	96.64	35.32	5.42
168 (6")	156.04	42.16	94.56	37.62	5.54

The dimensions that the disks should have,

Figure 37, can be observed in the Table 15, where Dn is the nominal diameter of the rotor, D the real external diameter of the rotor (4 mm smaller that the interior diameter of the sanitary PVC pipe, p = D), d the diameter of the shaft in galvanized pipe, R is the larger radius of the disk, r the small radius of the disk and n the number of disks for lineal meter of the screw.

After joined and stretched the disks on the shaft of the galvanized pipe, it should be rectified the pith and the perpendicularity of the disks before being united rigidly with electric welding.

3.12. Ecological PROCESSING PLANT AND HANDLER OF BY-PRODUCTS - BECOLSUB Module.

The module BECOLSUB (*Ecological Processing Plant and Handler of By-products*) is a technology for the ecological processing of coffee that integrates the use of conventional pulpers (See Section 3.2.) for pulping the coffee without water, the use of the DESLIM equipment (See Section 3.8.4.) to detach the mucilage, to wash clean and classify partially or totally the coffee parchment. The use of the screw conveyor (See Section

3.11.) for the mixture and mechanical transport of the pulp, mucilage, and strange materials, ejected from the DESLIM equipment, to the deposit. When the raw matter is of poor quality, the use of the hydrocyclone (See Section

3.9.) for the final selection of the coffee parchment, Figure 39, Figure 40, Figure 41, Figure 42.

The main structure is conformed by two frames in metallic pipe. The electric motor (or a gasoline one, in the MOBILE BECOLSUB unit, (See next section) used to move the mechanical demucilager, the pulper and the screw conveyor, with a capacity indicated in Table 15, are mounted in a mechanical system to tension the band.

Figure 38. Demonstrative BECOLSUB module, located inside a processing plant built in bamboo. CENICAFÉ.

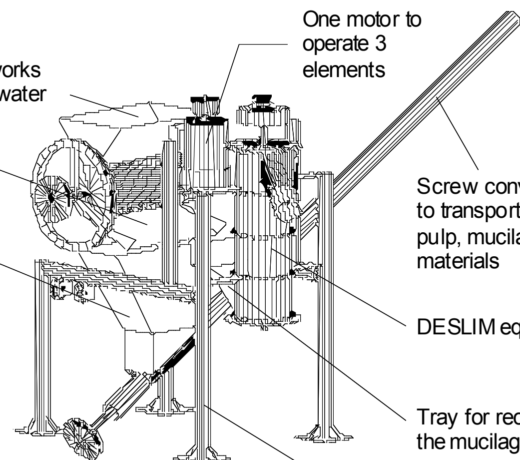


Figure 39. Three-dimensional sketch of the BECOLSUB module (Ecological Processing plant and handler of the coffee by-products.

The system of speed reduction between the electric motor and the mechanical demucilager (870 rpm) is made a transmission with plane band.

The low speed of the mechanical demucilager shaft is used to move the pulper and the screw conveyor.

Since the shafts of the mechanical demucilager, of the pulper (180 rpm), and of the screw conveyor (180 rpm), are non parallel, the power transmission among these elements is made by a circular cross section band.

Auxiliary pulleys supported by double ball bearings facilitate the direction changes that follow the band. In this form the losses for friction are kept to a minimum.

The length and inclination of the screw conveyor are variable depending on the infrastructure where it is necessary to take the mixed slurry.

BECOULSUB modules were designed to handle cylindrical sieves (See section 3.4.) to optionally classify the pulped grains, by separating grains that were not pulped, grains completed covered with dried pulp, immature grains and, in general, elements larger than the opening among bars.

Figure *24* and Figure 40.

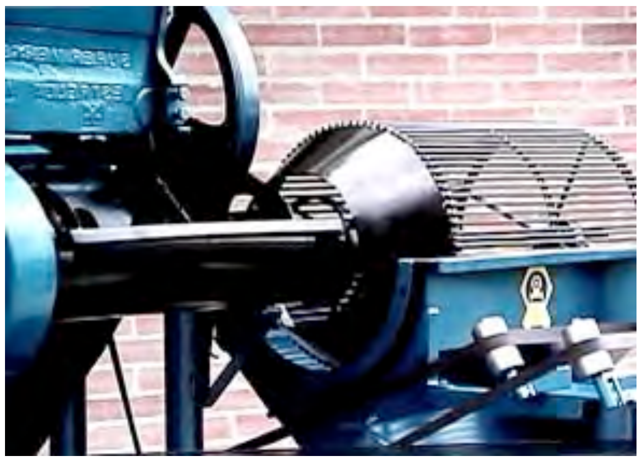


Figure 40. Module BECOLSUB, with optional cylindrical screen for the classification of the pulped coffee.

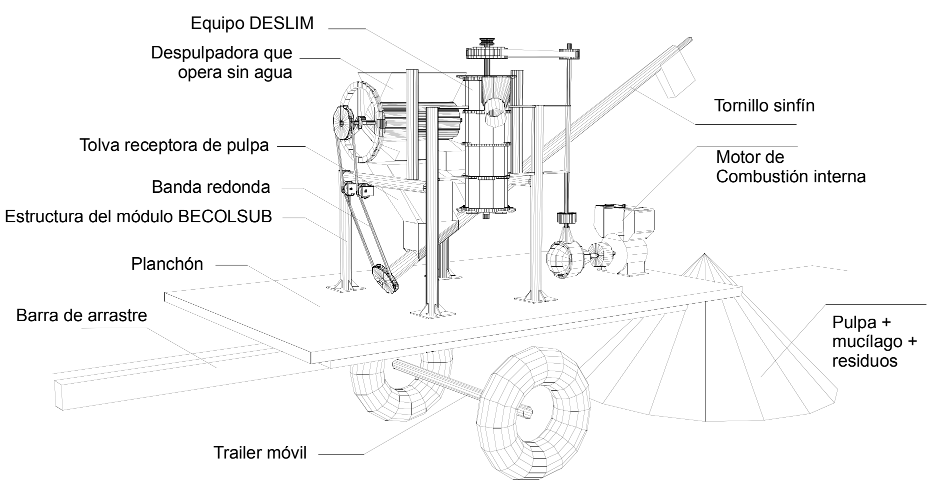


Figure 41. Outline of the BECOLSUB 600 MOBILE module.

Figure 42. Module BECOLSUB mobile towed by a country motorcar.

With the module BECOLSUB MOBILE, additional revenues can be obtained by the *reduction in the cost of the transport*. The pulp and the mucilage can be located in batches for later ecological handling. Only the washed coffee is transported to the dryers. Smaller weight and less capacity of transport are needed.

Figure 43. BECOLSUB mobile module for processing coffee under a hopper located in a farm's plot.

An example gives concrete figures to the exposed: if a property has production 125 ton of PDC a year, and collect 2%, during the maximum collecting day 12.5 kg of cherry coffee, seven trips of a 3 m^3 tilt-truck would be needed for transportation. With the MOBILE BECOLSUB module only 3.85 trips will only be required, with a saving of 45% of the transport volume.

The first prototype, was built in CENICAFE, Figure 41 Figure 42 and Figure 43 and used a BECOLSUB 600 model. An internal combustion gasoline motor (Kohler, 8 HP) drove it,. The same motor drove a screw conveyor and the pulper. This group of processing was installed and mounted on a two wheels small trailer. It was necessary to introduce a system of transmission of power (a self-driven standard reducer was used), to reduce the revolutions of the motor of 3,600 down to 1,800 rpm. Pulleys and bands (plane and round) reduced the angular speed up down to 870 rpm, to operate the demucilager. The quality of the processed coffee and the controlling characteristics of contamination of the system are discussed in the Section 3.15.

3.14. SELECTION OF THE BECOLSUB MODULE.

To *select the appropriate capacity of the BECOLSUB module* *Figure 44* was developed. It relates the annual production of the property expressed in tons of dried parchment coffee per year (axis X) with the capacity of the BECOLSUB equipment expressed in kilograms of cherry coffee per hour (axis Y). The number of daily hours of operation of the module (parameter included in the body of the graph) is selected to start the calculation.

The graph was built assuming that the maximum production day of the property is 2.5% and that the conversion of the cherry coffee to the dried parchment coffee is 5 to 1. If these values are not the conditions of the property, corrections are made easily by proportionality operations.

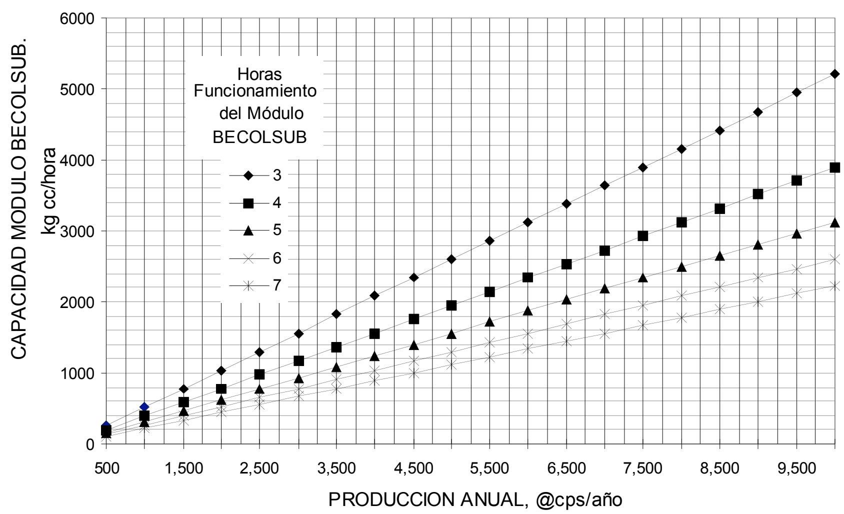


Figure 44. Selection of the DESLIM equipment and the BECOLSUB module as function of the property production and the number of hours of operation of the module.

The use of the graphic is indicated by this example. If the coffee grower hopes to produce 75 tons of dried parchment coffee in the year, by operating maximum 4 hours the module in the day, the value of 75 is located in the X axis and a perpendicular line is drawn until it cuts the 4 hours of operation line. From this point a horizontally line is drawn to the left until cutting the Y-axis. The value of 2,400 kilograms of coffee cherry per hour is read. The appropriate equipment to select is a BECOLSUB 3000. The operation time will be reduced to 4hours x (2,400/3,000) = 3.2 hours. By using similar correction procedures, it is possible to calculate the equipment for different conversion cherry/parchment, and different maximum day productions. In making the correction it has to be considered that to higher values of conversions of cherry coffee to dried parchment coffee and to larger values of the maximum picking day, proportionally, the larger capacity of the BECOLSUB module. The inverse is also correct. At lower values of conversions of cherry coffee to dry parchment coffee and to lower values of the maximum picking day, proportionally, the smaller the capacity of the BECOLSUB module.

3.15. EVALUATIONS OF THE MODULE BECOLSUB MOBILE IN THE FIELD. [8]

With the purpose of *evaluating in integral and in real form, seven trials with the BECOLSUB 600 Mobile equipment*, Figure 41, Figure 42, Figure 43, were run under real conditions of a farm. The evaluation work was done at a commercial farm located in the municipality of Chinchiná, Caldas, Colombia. The process was made with cherry coffee *Colombia variety* from December 11, 1996 to January 16, 1997. The observations were the following.

3.15.1. CHARACTERIZATION OF THE DIFFERENT OBTAINED TYPES OF COFFEE

The characterization of the raw matter and the evaluation of the BECOLSUB technology was carried out according to the methodology adopted conventionally for CENICAFE, in similar research projects, for the evaluation of the prototypes DESLIM and BECOLSUB (97), (5), (9).

The samples of coffee contained a high percentage of harvested mature grain (80.32%). The percentages of immature grains (1.3%) and half-ripens (6.8%) are considered normal. The (8.3%) of overmature grains was high and it might originate problems to the cup quality.

The after pulping results show that the hulled and bitten grains that conformed the mechanical damage, was very low (0.01%), in operation without water. The *pulp in the grain* (1.9%) was inferior to the allowed value (2%) according to the ICONTEC norm (55). The *mechanical damage* on immature grain (0.12%) is considered low, with respect to the initial percentage of immature grain (1.29%). Complete grain covered with dried pulp (2.05%) was also normal.

The *mechanical damage* caused by the demucilaging was very low (mean value of 0.16%). The *mechanical damage* originated from the immature grain hulled, infested with

[8] Prepared by Ramirez, G. C.A. Agricultural Engineering, CENICAFE.

coffee borer, immature infested with the coffee borer was only of 0.58%, percentage that is also considered low.

The demucilaging process *recovery 63.42% of the grains covered with dried pulp*. This implies the recovery of good grain, that otherwise could be classified as low-grade coffee.

The *pulp left in the grain after pulping (1.87%) was reduced after demucilaging (0.52%); the decrement was of 72.2%.* This is also very advantageous, for the physical quality presentation of the grain.

The difference on strange materials obtained in the demucilaging process indicates that there was a *removal of 51 % of the strange materials*.

In the characterization of the demucilaged sample an incidence of coffee borer of 2.3% was detected, being an acceptable percentage.

The BECOLSUB Mobile module process gave dried parchment coffee, FEDERATION type in all runs, the highest quality classification. It was observed that the capacity of the equipment, expressed in the transformation of the coffee cherry per hour, was of 596 kg/hour, that is, similar to the nominal capacity of design of the BECOLSUB 600 module.

3.15.2. Yields and performances.

The consumption of water was of 1.53 liter/min, for a total volume of 31.33 liters. The specific consumption of water was of *0.75 liter/kg of dry parchment coffee*, value very close to the minimum ever reached (0.6 L/kg).

Table 17 shows that the BECOLSUB technology caused a *physical retention of the leaving fluid of 73.6%, in volume*, and a physical *control of the contamination generated by the wet processing of the coffee of 90.53%*. Watering with the remaining fluids the worn culture can even increase this acceptable value.

Table 17. Control of the Generated Contamination, for the BECOLSUB Mobile module 600.

Variables	*Test # 4*	*Test #5*	*Test #6*	*Test #7*	*Average*
Total (mucilage + water), litters	70	68.39	68.39	79.58	71.59
Total (mucilage + pulp), kg	134	136	130	121	130.25
Total drains, L	17.33	26.15	18	13	18.62
Volume retention, %	75.24	61.76	73.68	83.66	73.59
Contamination control, %	92.85	87.59	89.11	92.59	90.53

3.15.3. Control of the contamination with the BECOLSUB 600 Mobile module.

Table 17 shows the fluxes of water and the mucilage measured. The water supplied was of 1.51 liter/min of water. The average value of contamination of the drained leaving fluid was of 118,750 mg of chemical demand of oxygen, QDO/L, very near to the normal reported values (72) (120,000 mg of D.Q.O./L).

The weight of dried parchment coffee was of 41.9 kg, which gave a yield or conversion of coffee cherry to dried parchment of 4.84 to 1

Table 18. General performance of the BECOLSUB technology by using the mobile unit.

Variables	*Test # 4*	*Test # 5*	*Test # 6*	*Test $ 7*	*Average*
Total coffee cherry, kg	201	208	200	200	202.25
Yield coffee cherry, kg/hr	574	543	600	667	596
Demucilaged coffee, kg/min	4.73	3.82	3.84	5.28	4.42
Total calculated washed coffee, kg	99.33	87.86	76.80	95.04	89.76
Total weighty washed coffee, kg	82.50	87	85	94	87.13
Total PDC, kg	39.80	43	41	43.70	41.88
Yield coffee cherry to dried coffee	5.05	4.84	4.88	4.58	4.84
Yield coffee cherry to dried coffee	2.07	2.02	2.07	2.15	2.08
Yield coffee cherry to washed coffee	2.44	2.39	2.35	2.13	2.33
Relationship water/kg PDC.	0.79	0.86	0.73	0.62	0.75
Consumption combustible gal/@	X	0.064	X	X	0.06
Combustible cost,, $/@ PDC	X	72.65	X	70	71.33

3.16. ECOLOGICAL CENTRAL PROCESSING COFFEE PLANT OF ANSERMA (CBEA), CALDAS. [9]

CENICAFE designed built, put into operation and continues evaluating (100) with the collaboration of the Coffee Extension Committee of Caldas and the Cooperative of Coffee growers of Anserma, the CENTRAL COFFEE MILL OF ANSERMA, located in the same municipality at 1,750 meters above sea level (

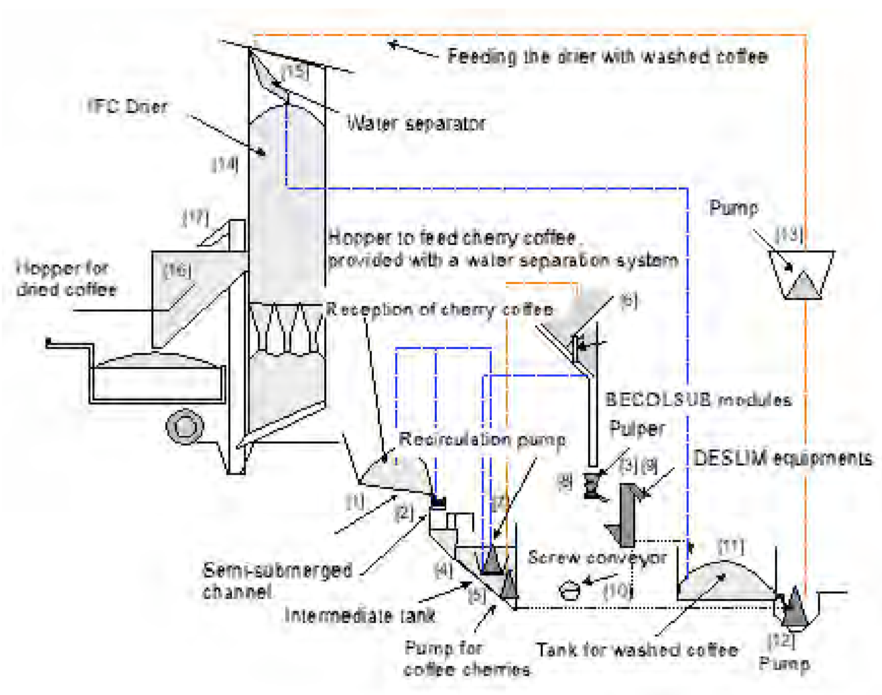
Figure 45 and Figure 46).

The objective of the project is to help marketing of the cherry coffee offered by the coffee growers of the region. To use the best processing technologies, to introduce the ecological concepts in the coffee process and to give an excellent service to the coffee grower, mainly to improve its revenues and to facilitate the processing administration (100). The coffee cherry was produced in different thermal floors, offered from numerous coffee growers of the region.

3.16.1. Components of the central processing mill of Anserma, Caldas.

The Central mill is constituted of the elements illustrated in the

Figure 45. The process is the following.



[9] Prepared by Roa, M. G. and Alvarez G. J. Agricultural Engineering, CENICAFE.

Figure 45. Sketch of the Ecological Central Coffee Processing Plant of Anserma. Anserma, Caldas.

Figure 46. Ecological Central Coffee Processing Plant of Anserma. Anserma, Caldas.

The cherry coffee is received in sacs or in bulk, in a hopper [1]. The water of transport leads the coffee cherry to the semi-submerged channel [2] to separate heavy and light materials and the coffee infested with the coffee borer. The low-grade coffee is deposited in a BECOLSUB module for low-grade coffee [3]. The heaviest grains pass through the grooves of the channel, and fall in an intermediate tank [4] whose level of water is controlled to use the minimum quantity and to guarantee that the pump of cherry coffee [5] maintains its proper level. The cherry coffee is transported hydraulically to the elevated hopper [6] where the water separates through two perforated false funds, arranged in series, and returns by gravity to a recirculation bomb confined in a small tank [7] that reuses the water received for this operation and from the semi-submerged channel. The coffee falls, without water, and by gravity, to the pulpers [8] of the two BECOLSUB modules for first-class coffees that also operate in absence of water. A hopper receives the pulped coffee and feeds two DESLIM 3000 demucilagers [9]. The removed pulp goes to another hopper that empties its content to a screw conveyor [10] that in turn receives the mucilage and strange materials of the three DESLIM equipment and transports them to the mixed pulp structure

Figure 47 y

Figure 73, [1]. The demucilaged coffee washed and clean is deposit into the work tank [11]. The handling of the coffee up to here constitutes a continuous process: from the receiving hopper through the hopper of coffee cherry passing by the classification system, the pulpers, and the DESLIM equipment that demucilage, washes and cleans. The coffee from the work tank is pumped by means of two bombs in series [12] and [13] to three CENICAFE-IFC dryers [14], with a static capacity of 12.5 ton of dried parchment coffee. The dried parchment coffee is transported to a dry hopper [16], by means of a conventional bucket elevator [17].

The transporting water used to load the dryers is separated from the coffee [15] and returns to the bomb tanks. It was necessary less than 3 cubic meters of water to run 24 hours the mill. The consumption of water for unit of coffee processed parchment, in case it works with only half of its capacity is only 0.4 liters of water/kg parchment dry coffee. This value corresponds to less than 10% of the total nominal water used in the plant.

3.16.2. Handling of the pulp, the mucilage and of the worms.

The mixed pulp and mucilage is transported by the screw conveyor to the storage structure [1],

Figure 47 and 

Figure 73, where is kept by several months, up to one year, to feed the worms continually (See chapter VI.). The design criteria to estimate the capacity of this structure the following: at the end of the main crop, after finishing the processing it should be completely filled and at the beginning of the next main crop it should be totally emptied. This way the needed area for the beds of the worn culture is minimized, the food is guaranteed for the worms all year and the production of the organic manure is also uniform.

The mixed pulp is transported manually, by cart, from the pulp structure to the worn culture litters [2] where layers, 4 centimeters thick, are applied regularly up to a maximum height of 40 cm.

At the end of the journey all residual waters are evacuated to a 30 cubic meter tank [3],

Figure *47*. Drained waters of the pulp storage structure [1] and from the worm's beds also go to the same tank. A pump will conduct these waters to a pumping and irrigating system for the worn culture [4]. The real contamination of the Central of Processing will be measured by the chemical demand of oxygen of the overflow of this tank. In a near future this unique source of contamination will be eliminated by the implementation of the anaerobic bioreactors. It is considered that this overflow, in term of contamination, is less than 10% of the total potential contamination.

3.16.3. Evaluation of the Central mill.

Between *October-95 and January-96, 670,000 kilograms of coffee cherry were processed* with all the components working, including the modifications of the CENTRAL MILL to the wet part to implement the BECOLSUB technology, the three IFC-tower dryers (See section

4.6.4.) and the handling of the worn culture.

13.16.3.1. Quality of the cherry coffee.

In general the coffee delivered to the CENTRAL MILL was of low quality, possibly because the coffee growers were aware that coffee was never rejected.

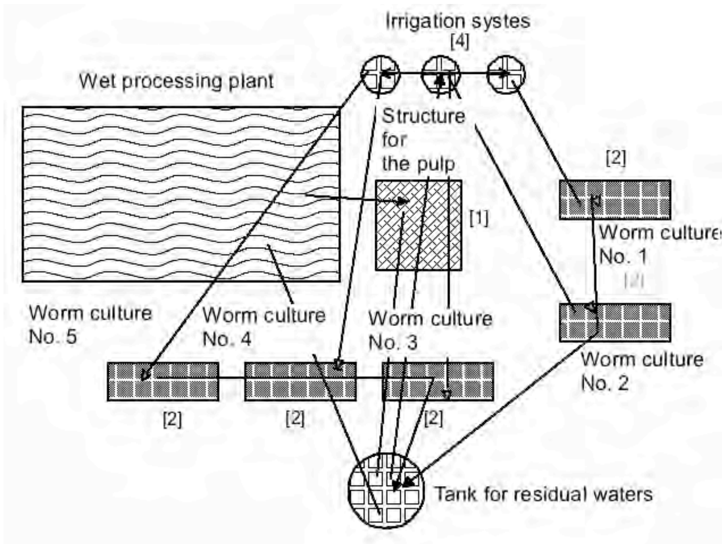


Figure 47. Sketch of the handling of the by-products pulp and mucilage in the CBEA.

Indeed, the average values of the sum of the immature grains, half-ripe, overmature, infested with the coffee borer and low grade coffee were of 35%, value too high to obtain a FEDERATION coffee type, in any conventional processing plants.

3.16.3.2. Quality of the coffee parchment with relation to the mechanical demucilaging.

It is observed, *Figure 48*, the benefic effect of the demucilaging process with relation to the increase (2.7%, in pondered average) of the good grains. Light increase (1.06%, in pondered average) of the hulled grains and bitten grains. *Notorious decrease (5.9%) of the grains without pulping*. *Decrease (3.7%) in the pulp in the grain and an increase (4.3%) in the percentage of the immature grain*.

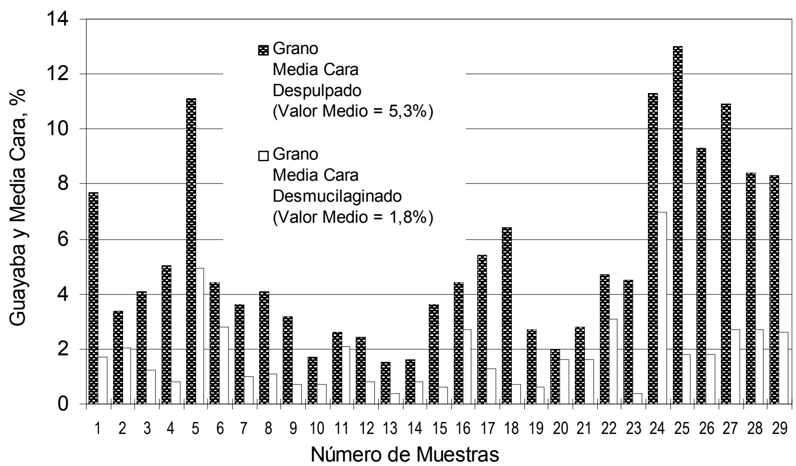


Figure 49, with the detail of 29 evaluations, the decrement of grains with complete or partial cover with dried pulp. These figures correspond also to a proportional increase of bigger quantity of the parchment coffee.

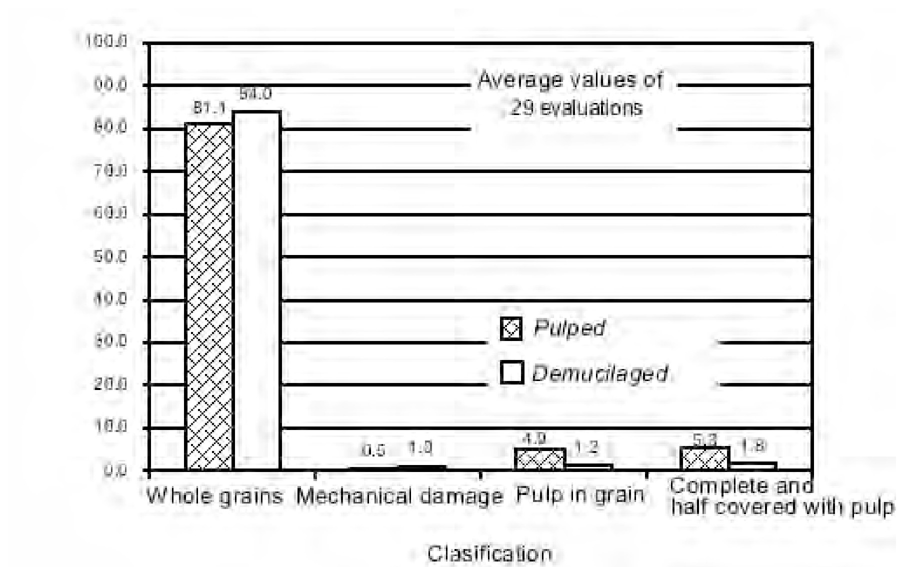


Figure 48. Influence of the mechanical demucilaging in to the physical quality of the parchment, after pulping and after demucilaging. (Average of 29 evaluations).

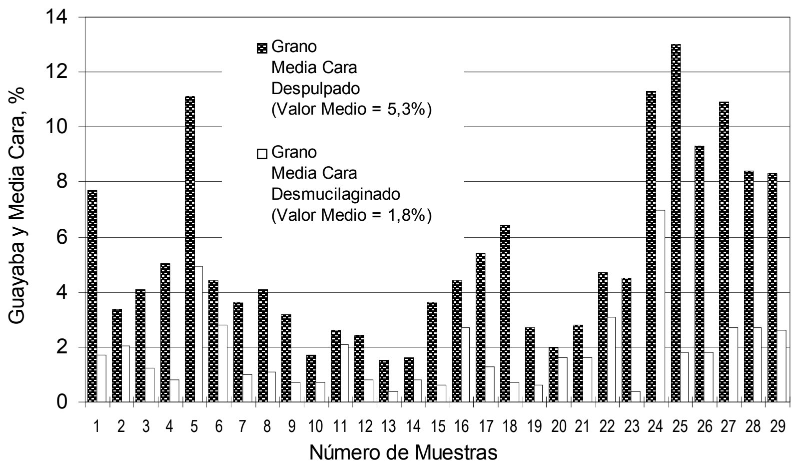


Figure 49. Influence of the mechanical demucilaging in the decrease of the grains covered completely or partially with dried pulp.

Figure 50 indicates in detail the increment (0.5%) of the mechanical damage (hulled and bitten grains) by the effect of the mechanical demucilager. This increase is balanced very favorably by the improvements of the quality of the grain indicated previously.

In Figure 51 the *high value of good grains (70%) obtained from the tank of low-grade coffee of the CBEA*. This fact together with the increment of the good grain quantity explains in general way, the beneficent effect of the mechanical demucilaging to improve the yield of the processing, in comparison with the traditional processing.

3.16.3.3. Drying of coffee in intermittent, concurrent flow type of dryers, CENICAFE-IFC,

The intermittent dryer of concurrent (air and grain) flows -IFC drier for coffee parchment was developed by CENICAFE to offer an alternative to the intrinsic non-uniformity of the final moisture content of the coffee that is dried in the static layer type of dryers, of common use for coffee. The characteristics of the design of the IFC-dryers are presented in the section

4.6.4.

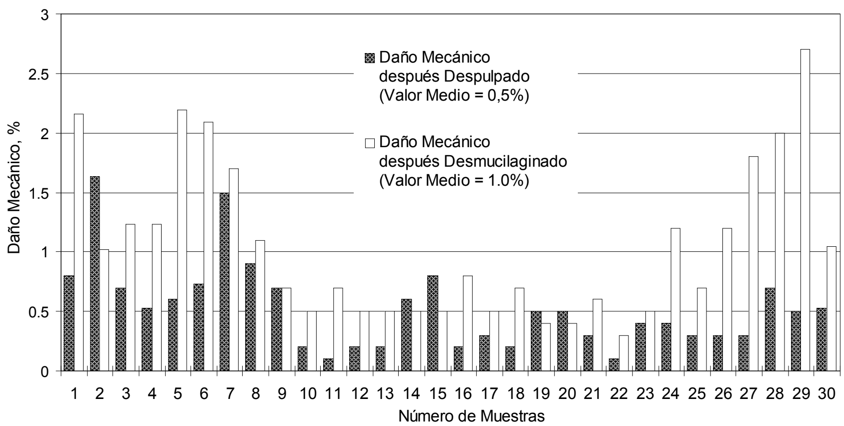


Figure 50. Influences of the mechanical demucilaging in increase of the mechanical damage of the coffee parchment.

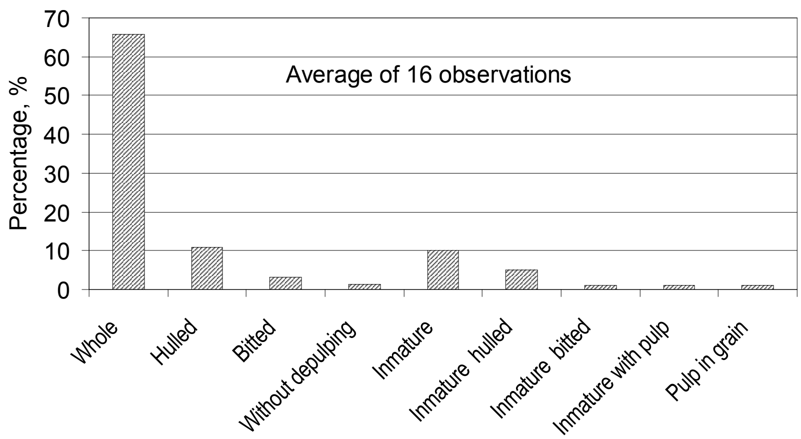


Figure 51. Recovery of good grains from the floats of the coffee processed in the Central Coffee Mill of Anserma.

The area of the section of the dryer is of $4m^2$. The volume of the effective drying volume is of $4m^2$ x 0.65m = $2.6m^3$. The resting volume (space where the coffee is not subjected to the flow of hot air is: 10.85 m^3. The relationship of drying volume to resting volume is 2.6 m^3/10.85m^3 = 0.24 ~ ¼. The used drying temperature was of 75°C, on the average. At the end of the drying, when the moisture was of the order of 14% the hot air generator was turned off and only natural air was forced through the grains, during two hours. At the end of this time, the grain presented uniform 12% moisture content.

The specific airflow in the dryer is 45 m^3/min-m^2 . When it is applied to a traverse area ($4m^2$) of the dryer, a total flow of 180 m^3/min is obtained.

The necessary power to force the resistance of the grains in this dryer is of 6.0HP. The power needed to force the air through the heat exchanger was 7.5 HP, given a total power of 13.5 HP.

The drying time, using temperatures of 75°C for a load of 3.4 tons of dried parchment coffee was of 28 hours. The time for loading the dryer by the pumps was of 45 minutes. The time of discharge was 30 minutes.

The quality of the dried parchment coffee obtained in the IFC dryer is indicated in Figure 52

It was also demonstrated, presents approximately 3 times more uniformity in the final moisture content than the conventional dryers of static layers.

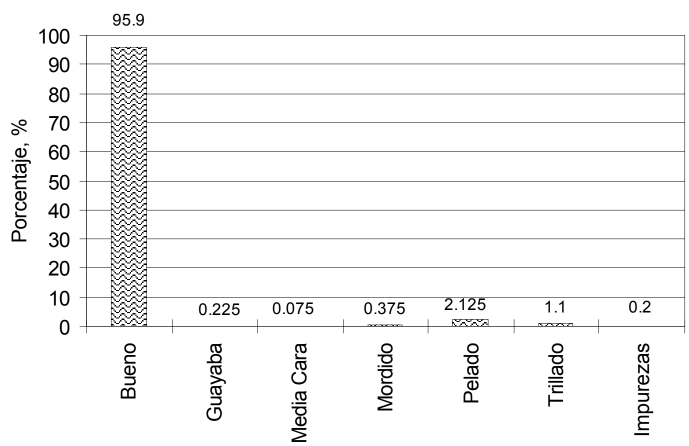


Figure 52. Quality of the coffee dried parchment in the drying IFC of tower of Anserma.

In it is indicated in *Figure 54* the *excellent quality of the green coffee obtained*. The coffee was classified as FEDERATION coffee type.

3.16.3.4. Parchment consumption.

All the dryers were heated with coffee parchment, as fuel. The parchment consumption was of 310 kg of parchment per ton of dried parchment coffee. In other words, the parchment content in the dried parchment coffee contains *61% of the necessary energy to dry the grain, in a burner with a thermal efficiency of 60%*.

3.16.3.5. Worm compost.

With the purpose of finding the most appropriate and efficient system for handling commercially the pulp and the mucilage, an investigation was carried out (Figure 72) by CENICAFE with the collaboration of the COOPERATIVE OF COFFEE GROWERS of ANSERMA, Caldas and the participation of two commercial worm growers, BIOAGRO DE COLOMBIA, Risaralda, and MI JARDIN, Risaralda. A general analysis of the worm compost enterprise is presented in the Chapter VI.

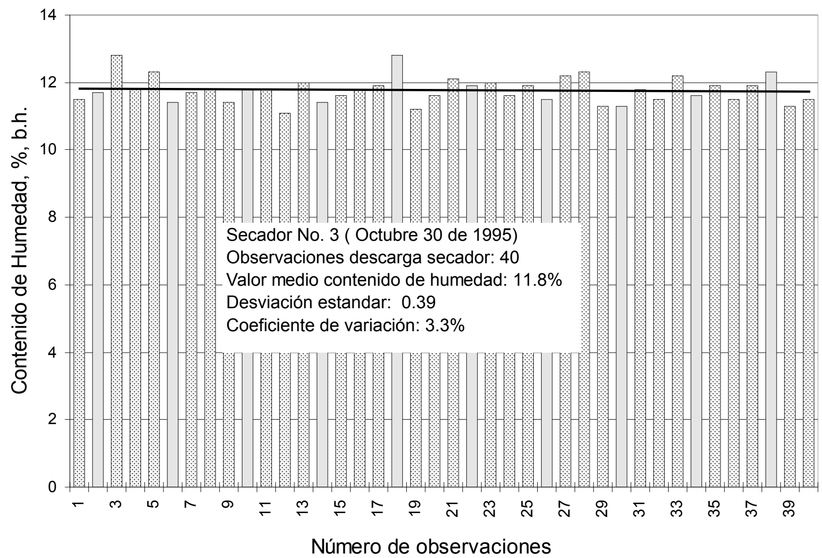


Figure 53. Complete uniformity of the parchment dried coffee in the IFC tower dryer. Anserma, Caldas.

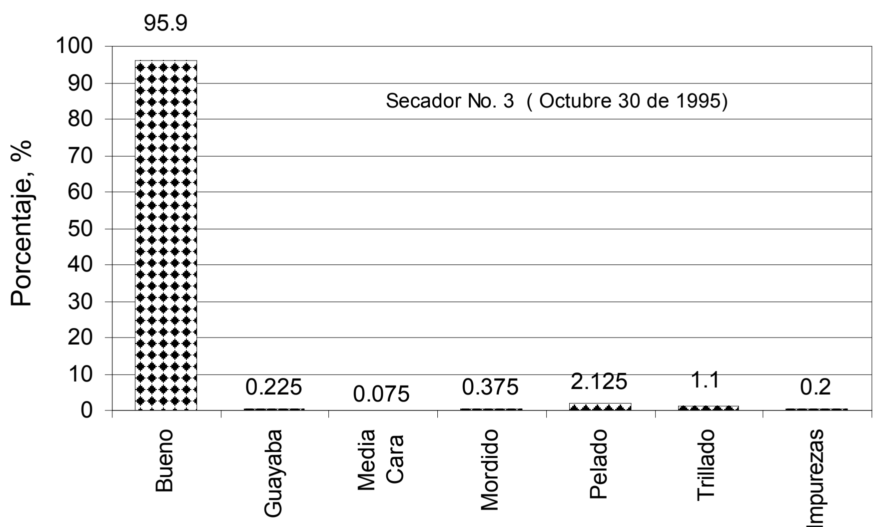


Figure 54. Quality of the kernel of the coffee dried in the IFC tower drier, Anserma, Caldas.

Table 19. Rates of worm compost production obtained in the CBEA, 1995.

SISTEM	*Production (kg m.s./m²-day*	*Production (kg m.h./m²-day*
CENICAFE	0.352	1.005
MI JARDIN	0.271	0.773
BIOAGRO	0.110	0.314

In accordance with the obtained results for the year of 1995, in the beds (2.6m long x 1m wide x 0.45m height) approximately 1 ton of mixed pulp and mucilage per square meter per year were handled. *Increments of 43% of worm were obtained of for a cycle of 4.5 months and 106.7% for a cycle of 6.1 months, with yields in the pulp conversion in worm compost of 62.9% and 52.6%,* dried base, respectively. Using irrigation with the residual water of the worn culture, it was possible to retain a volume of approximately 0.9 liter/m^2-día.

In summary, in accordance with the data obtained in the year 1995, the following rates of worm compost production, Table 19, were calculated

3.16.3.6. Consumption of water

The water consumed in the processes of demucilaging, washing and cleaning is of the order of 1 liter per kilogram of dried parchment coffee. This value rises to approximately 5 L/kg when added the consumption water for classification of cherry coffee, load of dryers, recirculation, losses and general cleaning of the mill. From the point of view of the contamination, *only the value of 1 L/kg was used in the contaminating process and most of it was retained in the pulp*, stored in the structure for the pulp to serve as feed for the worm culture. New modifications are in project to reduce the total consumption of water to less than 2 L/kg of parchment dried coffee.

IV. DRYING OF COFFEE.[10]

4.1. CONTENT OF MOISTURE OF COFFEE.

The content of moisture of the coffee cherry is of approximately 67%, base wet. This means that the quantity of water in the cherries of the coffee is approximately to two third parts of the total mass; the third remaining part are the solids. The content of moisture of the coffee cherry expressed in dried base is 200% (twice more water than dried matter). The coffee berry is highly perishable, and it presents an intense physiologic activity immediately after harvested. *To avoid losses of dried weight and what is much worse, the loss of its quality (process that starts after the first day of harvested), this large amount of water should be removed, hopefully immediately after being harvested*.

The most appropriate process to decrease the moisture of the cherry coffee consists first on *removing the pulp and the mucilage by quick means*. The wet parchment coffee obtained has moisture content of 52%, wet basis.

The quantity of water to retire in the drying of the wet parchment coffee is very superior to the water that it is necessary to extract from the cereals and leguminous. For example, to dry corn from 20% of moisture to 12%, it is necessary to evaporate 8 times less water in comparison with the water needed to evaporate to obtain dried parchment coffee with the same moisture of 12%.

The moisture content of coffee is an attribute of its physical quality. In Colombia the effective norms (47) for the commercialization of the coffee in parchment establish that their moisture content should be comprehended in the range from the 10 to 12% wet basis.

It is not by chance that this is the recommended range. The hygroscopic relationships of equilibrium, or of pressure of vapor, between the surface of the grain and the air that surrounds it, occur in this range of moisture content of coffee, according to the curves of equilibrium moisture obtained in CENICAFE (119), (Figure 66).

The moisture is the most important individual factor to control the grains to be conserved appropriately. The value of 12% of moisture corresponds to the maximum value at which coffee can be stored at normal ambient conditions, for several months, without deteriorating. Above this value the respiration rates of the living cells increase, simultaneously with production of heat and moisture, that are deposited into the proper mass, starting a deteriorative, increasing cycle.

Additionally, for values of grain moisture higher than 12%, the inter-granular air acquires levels of *relative equilibrium moisture higher than 70%, originating the activity of the microorganisms, especially fungi, molds and bacteria, that contribute to the deterioration*, sometimes total, of the quality of the product. These biochemical processes are more critical in regions of warm climate.

[10] Prepared por Roa, M. G. and Alvarez G. J., Ingeniería Agrícola. CENICAFE

4. 2. MOISTURE TESTER CENICAFE MH-2.

The instrumental testers of moisture and their applications in the drying of the grains have been studied intensively (54).

Nevertheless, today the coffee grower determine the moisture content of their product, when it is being drying, guided by subjective methods, such as the observation of the color of the kernel and from their hardness using the fingernails, the teeth or the edge of a knife. These methods give in general, erroneous results, like it was reported in a survey made by the Colombian Federation of Coffee Growers (45).

Indeed, of 623 samples of coffee parchment processed in the same number of properties, 25% had less than 10% of moisture and 13% they had more than 12%, that is, adding the two defect, 38% of the samples didn't have the appropriate final moisture content. This brings bad consequences for all, initially for the coffee grower that has problems with the commercialization of the grain and the loss of its quality.

A tester of moisture that for their precision and their price could be used at the property level, was considered of great importance, to permit the farmers to conduct adequately the process of drying, and also, like it will be seen in the section 5.3.1. make part of a technology for quickly estimating the yield from the cherry coffee to dry parchment coffee, FEDERATION type.

In the discipline of Agricultural Engineering a meter of moisture was developed,

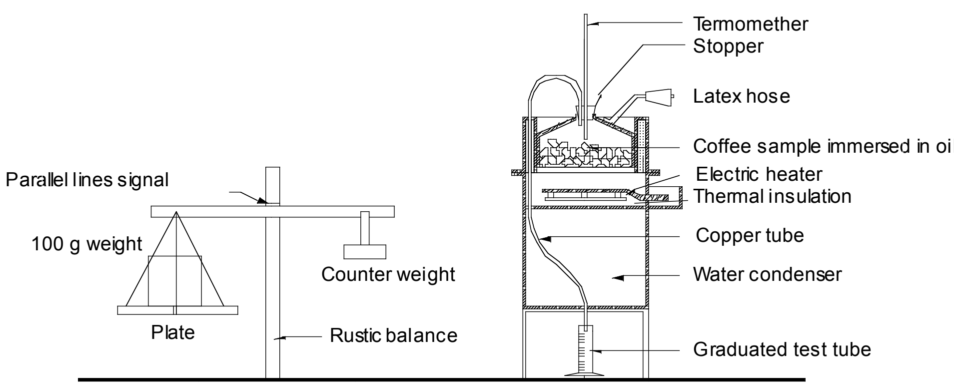


Figure 55 and Figure 56, *rustic, of low cost, accurate within ± 1.0%,* wet basis and of easy operation. The moisture meter was denominated CENICAFE MH-2 (78) y (79), and its operation principle is based in the standard method of distillation of Brown-Duvel (54).

It consists of a recipient for a mixture parchment coffee -oil, a condenser made by a tube of copper of 9.53 mm of diameter and of 25 cm long, bent L in form inside a water recipient. An electric resistance of 550 W, a deposit of water with capacity of 2.7 liters, a rubber plug for the opening of the recipient and a latex hose to connect the outlet of the recipient with the mixture to

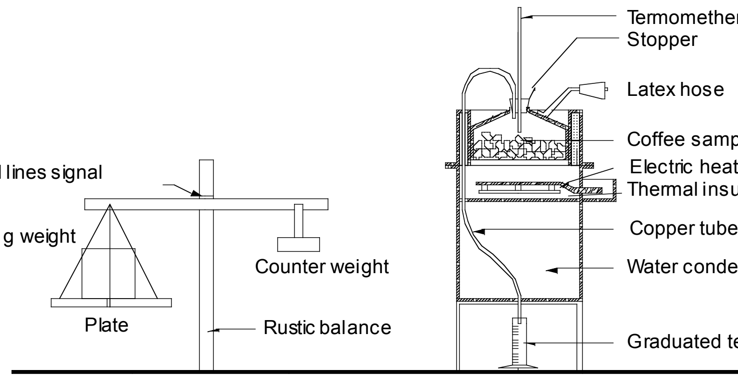


Figure 55. Tester of Humidity CENICAFE MH-2

the condenser tube. To reduce the heating of the water of the condenser tank, two thermal isolating plates 15-cm in diameter and 3.5 mm of thickness were placed between the electric resistance and the condenser. A rustic dish balance is able to weigh samples of 100 g of coffee, and a mercury thermometer, graduated from 0 to 250 degrees centigrade measures the temperature progress of the mix. A graduated test tube of 25 ml. permits to measure the condensed water.

The precision achieved with the tester of moisture in the range of 10% to 47% was of 0.51% w.b. A standard error of ± 1.0% w.b. was obtained.

The procedure to use the tester MH-2, consists in weighing a sample of 100 grams of parchment coffee with the rustic balance. Place the sample in the recipient with vegetable oil. The level of the oil should be enough to cover all the grains. The mixture is heated by turning the electric heater on until it reaches the value of 193° degrees centigrade, as measured by the mercury bulb thermometer. Care should be taken to avoid errors in the measurements, by putting the bulb to near to the heated walls. The transferred heat from the oil to the grains allows evaporating all their water, which is transformed into liquid in the water condenser. The volume is measured in the graduate test tube. The value measured expressed in milliliters

Figure 56. Bank of seven CENICAFE - MH2 moisture meters used in the Ecological Central Mill of Anserma.

coincides (the density of the distilled liquid is of 1.0 g/cm^3) with the coffee moisture content, expressed in percentage, wet base.

In the respective evaluation (79) of the tester CENICAFE MH-2, the following conclusions were drawn:

The tester *allows to determine with easiness, at the farmer's level, the moisture of the parchment coffee being dried accurately with errors of less than 1% compared with the method of the stove, requiring twenty minutes to obtain the result*.

The tester *can be used accurately in the whole range (50% to 10% w.b.) of the moisture*. This feature is not possible to obtain with the indirect testers that work based in the dielectric properties.

The tester CENICAFE MH-2 is lightly inferior in its precision compared with the indirect tester marks KAPPA, for low contents of moisture (10 to 28%), and for rested coffee (stored in stable conditions for more than 12 hours) but its cost is approximately 5 times cheaper.

4.3. INDIRECT MOISTURE TESTERS FOR PARCHMENT COFFEE.

The indirect methods for determining the content of moisture of the coffee, as their name indicate it, they measure a property of the grain that varies with their content of moisture. The most used properties are the electric conductivity and the dielectric capacitance.

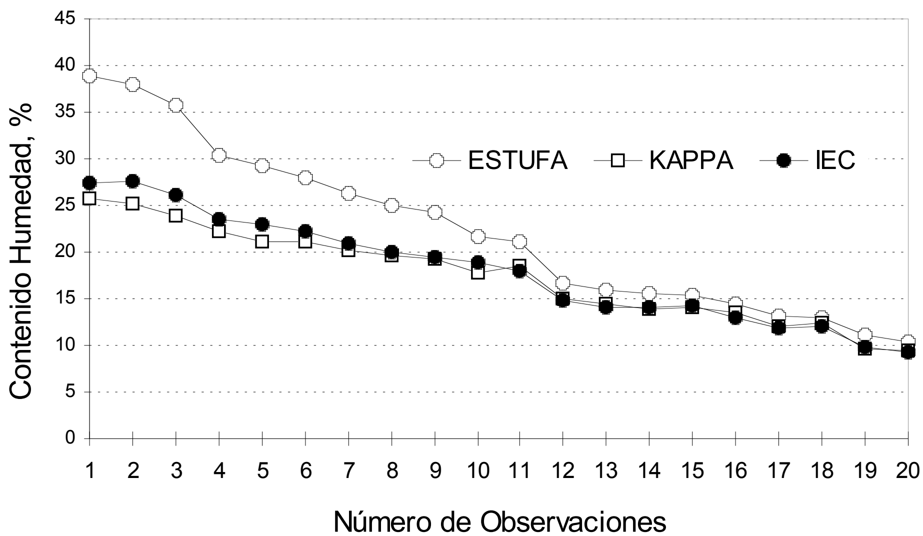
In Colombia the testers based in the capacitance, or dielectric characteristic of the coffee are used, They are used for the moisture determination in the receipt of the coffee in parchment in the established purchase sites of ALMACAFE. This type of meters work acceptable when the coffee is in rested state, that is, their humidity has not changed during the last day, or 12 hours.

For a long time a practical solution has been looked for the measurement, by indirect methods when the coffee is being drying, (the moisture distribution inside the kernels is not uniform) to be of help to conclude this important stage of the processing of the grain.

Recently another tester based in this same physical dielectric principle, proposed by "Industrias IEC", with more advanced designs, to correct the annotated measurements difficulties was proposed.

Experiments to compare the determinations of these type of testers of moisture where executed in CENICAFE (104) and their results were compared with the values obtained with the oven at 105 °C, during 16 hours.

Twenty samples of coffee were taken from commercial dryers. The results indicated in



the

Figure 57 show that *the tester IEC presented the same defects that the KAPPA, underestimating the real value of the moisture content of coffee, in the whole studied range of moisture*.

4.4. DIFFUSION OF MOISTURE IN THE GRAINS OF COFFEE.

During the mechanical drying of parchment coffee all the grains give most from their moisture to the hot air that is forced to pass among them. Initially the moisture of the surface of the grain is transferred easily to the air. As the drying process progress water from the internal part begins to migrate to the most external, to substitute the moisture lost at the surface. This phenomenon of movement of the moisture inside the grain is denominated *diffusion* (18) y (68). There are two periods of drying, the initial, where the resistance to the loss of moisture is presented at the surface, and afterwards, when the drying resistance is offered inside the grain. In the first phase the coefficient of transfer of mass for convection determines the drying rates. *In the second phase, that is the most extended for the case of the coffee, the coefficient of diffusion of moisture of the coffee grain (68), is the determinant factor*.

As a result of the diffusion, the moisture contents inside each grain, during the drying, are different, much higher in the interior and smaller at the surface. As the moisture of the grain decreases, the diffusion of the water is slower and to increase the drying rates it is necessary to increase the grain temperature. The increase of the temperature originates an increase in the pressure of the water vapor inside the grain, that is the driven force to expulse the water.

The increment of the temperature of the grains as the drying progresses occur naturally because when there is less humidity at the final drying stages, the lower the

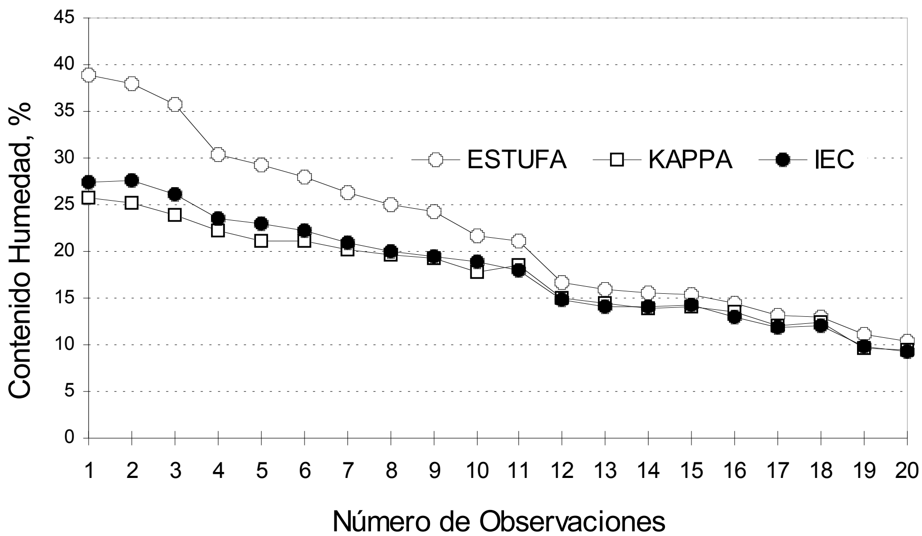


Figure 57. Comparison of two indirect testers of moisture with relation to the standard method of the oven.

drying rates, the lower the cooling effect, and the product temperature rises.

In section

4.7.1.3. the diffusion equation and other simplifying equations for calculation purposes, are presented.

4.5. RAKE STIRRERS FOR COFFEE.

The coffee grower use rakes, built traditionally in wood or in iron sheet, for the stirring of the coffee in the drying yards. The weight of the rakes and the resistance that product offer to their movement force to use rather short handles and the worker usually steps on the coffee to revolve it, resulting in hulling, crushed and contaminated grains. These defects decrease the physical quality of the coffee.

The *function of the stirring rakes is to move the grains that are at the bottom of the drying yard, to the surface. The reciprocal, to move the dried grains to the bottom is also desired*. By doing this new grain are exposed to the solar radiation and to the air currents increasing the average drying rates. Also the saturated air at the bottom is replaced with drier air, to increase the drying performance.

A new *rake stirrer,* with the form of a plow, (126), Figure 58, was developed at CENICAFE. The construction material is a PVC sheet extracted from a 6” PVC tube, subjected to a temperature of 150 centigrade degrees during five (5) minutes to make it malleable and to give it the appropriate form.

The rake was designed with eight teeth, 4 cm wide, turned 105 degrees. The rake is fastened to a 1-1/2" PVC T using a reduction from 1-1/2” to ½”, coupled to a wooden handle, 3 m long.

Five tests were made to evaluate the performance of the CENICAFE rake stirrer, comparing it with the traditional plain rake, built in a flat piece of wood. The same quantity of washed parchment coffee was placed In two drying cars, (120 kg/car) forming a layer of 3.5 cm of thickness and submitted to a simultaneous drying process. The mass of coffee was stirred, or revolved three times a day, with each one of the rakes.

To determine the effectiveness and uniformity of the overturning process of the grains using both rakes, the inferior part of the coffee layer was painted with a different color. By doing this it was possible to see a bigger and more effective result with the CENICAFE rake, Figure 58.

The numerical results showed that it was possible to dry the coffee, from 53% down to 12% moisture content, in seventy-two hours less time using the CENICAFE rake, with relation to the traditional rake. This means *that drying time decreased in 25%.* Also

Figure 58. Comparison of the effects of stirring of parchment coffee made by the conventional rake and the rake CENICAFE.

the CENICAFÉ *rake originated 46.2% less mechanical damage,* Table 20.

Also, because the design of the rake allowed stirring the coffee more smoothly, with less effort, it was possible to use larger handles, up to 3 m long. In this form it was possible to stir the layers from outside of the drying yards, avoiding the men to step on the coffee.

To avoid that the teeth break by fatigue, it was designed (8) a spring attached to the rake to absorb most of the energy, avoiding destructive stresses on the teeth.

4.6. MECHANICAL DRYING OF THE COFFEE.

The drying of the coffee in Colombia with the method of solar energy is viable for some small farmers, generally in properties with annual production of less than 12.5 tons of dried parchment coffee, per year.

The harvest of coffee generally coincides with the rainy season, and the drying under this technique is slow, sometimes null. Relative high investment is needed for the drying yards shortage of manpower makes solar drying unfeasible for most of the medium and large coffee producers.

Table 20. Comparison of the mechanical damage produced by the use of the traditional rake and the rake stirrer CENICAFE, with teeth.

Test Number	Mechanical damage, %	
	Traditional rake	CENICAFE rake
1	2.43	1.25
2	0.40	0.30
3	0.48	0.12
4	0.55	0.24
5	0.46	0.10
Average	0.864	0.402

Appropriate physical properties of the parchment coffee have permitted to use simple mechanical dryers as an alternative to solar drying. The large and uniform interstitial space among coffee grains (this volume corresponds approximately to 45% of the total volume) allows the passage of the air in uniform form and without excesses of requirements of mechanical power. Also the large surface area of the grains, approximately 780 square meters for cubic meter of coffee parchment allows efficient exchange of energy and humidity between the grains and the air that is forced mechanically to pass through.

A guide for the selection of solar or simple fixed layer drying systems and the fan specifications is presented in Table 21.

4.6.1. Airflow in mechanical drying systems.

The pass of the sufficient specific airflow by the mass of the coffee being drying is of the biggest importance for the success of the drying operation. The correct selection of the fan (Figure 59) it is the most important factor for the success of the operation.

The quantity of air that crosses the inter-granular space of the coffee mass is the responsible to give the energy, to produce the evaporation, and to retire the resultant humidity.

If the air is insufficient, the drying time is increased and the grains might present non-uniformity in the final moisture content. Of another side if the flow is greater than the necessary value, the fan will be overdimensioned, costly and will also cause waste of electrical and thermal energy.

Table 21. Selection of the drying system according to the farm's production. Characteristics of the drying system.

	Solar and mechanical drying			
Capacity	*System*	*Air flux*	*Pressure*	*Power*
Ton PDC/year	*Ton PDC/year*	*m^3/min*	*cm H_2O*	*hp*
Up to 2.5	SS* trays			
From 6.3 to 1000	SS* cars			
From 12.5 to 25	SM** 1 ton	80	6.2	2.0
From 25 to 37.5	SM** 1.5 ton	120	6.2	3.0
From 37.5 to 62.5	SM** 2.0 ton	160	6.2	5.0

** SS = Solar drying; **SM = Mechanical drying*

Figure 59. Centrifugal fan forcing air to a bin-dryer, CENICAFE. Observe the correct transition between the exit of the fan and the entrance to the dryer (The heat generator has being retired).

It is very important to operate the dryers of coffee with the *correct value of the air fluxes*. The results of the research work in CENICAFE (42) are presented in

Table 22. They indicate that for the drying of coffee parchment in static layers the recommended value is 25 cubic meters per minute for each cubic meter occupied by the grain. This value is equivalent to a flow of 66 cubic meters per minute per ton of dried parchment coffee. *Also equivalent to 20 cubic meters per minute per square meter, when the total layer height of the grains is 0.8 m (including the drying and pre-drying cameras). Or to 10 cubic meters per minute for square meter of dryer, when the grain layer height is 0.4 m. In*

Table 22 the recommended minimum air flows, in the different units, are presented.

4.6.2. Passage of the air through the coffee mass.

The passage of the air through the mass of grain located in any type of dryer is possible by the mechanical energy given by the fan. The resistance offered, per unit length in the direction of the airflow, is proportional to the air flow per unit area and it is measured by a air pressure drop. Experimental data was obtained to correlate the relationship between the variables. The mathematical expression between these variables were obtained at CENICAFE, (76).

Table 22. Minimum airflow recommended for drying of parchment coffee in static layers.

Flow *	*Equivalent units of specific flows*
25	$m^3/(min\text{-}m^3)$
66	$m^3/(min\text{-}ton\ PDC)$
20	$m^3/(min\text{-}m^2)$ for h=0.8m
10	$m^3/(min\text{-}m^2)$ for h=0.4m

(*) It is preferable to use the first two recommendations of specific flows (for unit volume occupied by the grain or for ton of dried parchment coffee) because these values are always constant, for any mass of coffee deposited in the bin-dryers.

The results (Equation 3) are shown graphically in

Figure *60*

$$\frac{Q}{A} = (9{,}523 - 0{,}0476\,M)\left|\frac{P}{L}\right|^{0{,}676}$$

Equation 3 Specific air flow as function of the loss of static specific pressure for parchment coffee.

Clearing for P / L:

$$\frac{P}{L} = \left|\frac{\frac{Q}{A}}{9{,}523 - 0{,}0476\,M}\right|^{1{,}4793}$$

Equation 4. Loss of specific pressure as function of the specific air flux, for parchment coffee.

Where:

- Q = flow of air, m^3/min
- A = traverse area to the flow of the air, m^2
- M = moisture content of coffee parchment coffee, %, w.b.
- P = drop of pressure, in centimeters of water
- L = distance between the measurement of the loss of pressure P, m.

4.6.3. Selection of the fan for drying parchment coffee.

The fan Figure 59 has the mission of forcing appropriate quantities of air through the mass of the grains.

The calculation and selection of the appropriate fan is a task for the designer that should know the requirements of the minimum air flow for drying of the coffee parchment and the calculation of the static and dynamic pressures losses of the air. The losses occur by the pass of the air by the layers of the coffee and by its pass for each one of the constituent elements of the pneumatic circuit (ducts, transitions, abrupt expansions, curves, gates, valves, etc.). The fan is selected by calculating the appropriate flow and the sum of all the partial pressures of the system (54), (18).

When the ducts and the gates are dimensioned appropriately, that is, when their area is approximately 50 % larger that the area of the suction of the fan, the pressure losses of the air to pass by these obstacles are small compared with the losses through the layer of grains. As practical rule they can be estimated, as 15% of the pressure needed to pass the grain.

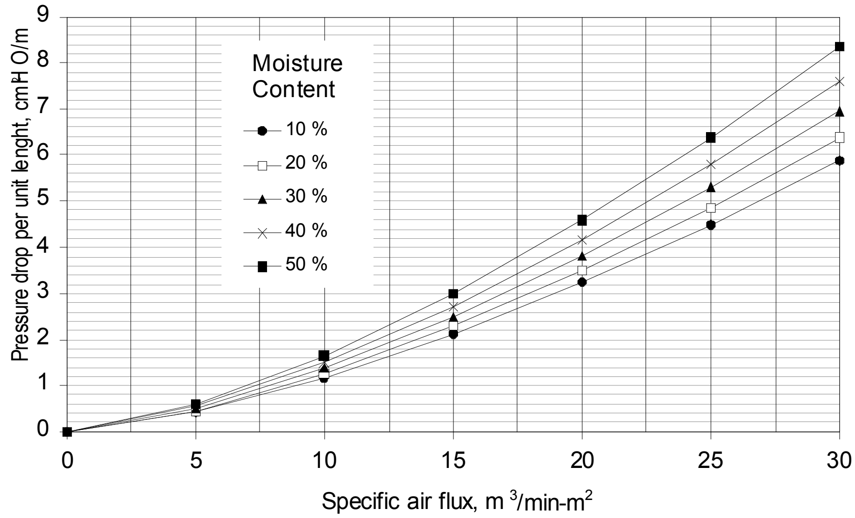


Figure 60. Relationship of air fluxes and pressure drop by the pass of the air through layers of parchment coffee.

Other important factors in the selection of the fan are the type (centrifugal, axial), the desired mechanical efficiency, the level of acceptable noise, the mechanical stability, the system type of connection between the motor and the fan, the position of the fan, etc.

The *total power to operate the fan*, considering its efficiency is calculated by the following form:

$$Pot = \frac{Q\ P}{458\ \eta}$$

Equation 5. Power of the fan as function of the airflow and the pressure drop, required for the correct drying of the parchment coffee.

Where

Pot	=	power in HP
Q	=	flow in cubic meters per minute
P	=	total static Pressure (cm of water)
458	=	conversion factor
h	=	mechanical efficiency of the fan, decimal

4.6.4. Intermittent dryer of concurrent flows, (IFC).

The fixed layer dryers occupy large transversal areas in the processing plant, even those of vertical design with two or more layers. Also the air, with high specific volumes, should pass simultaneously by all of the layers, to decrease the non-uniformity moisture characteristic of this type of dryers, and to guarantee an acceptable drying time. On other side, the dryers should be located inside the processing plant structures.

With the purpose of presenting alternatives to overcome the inherent limitations of the dryers of fixed layer and to obtain better drying technology, CENICAFE, after a complete exam on the different possible alternatives, began an investigation program to develop an intermittent concurrent flow dryer for parchment coffee (IFC) (46).

The IFC dryer (commercial performance and quality results were presented in section

4.6.4.) consists

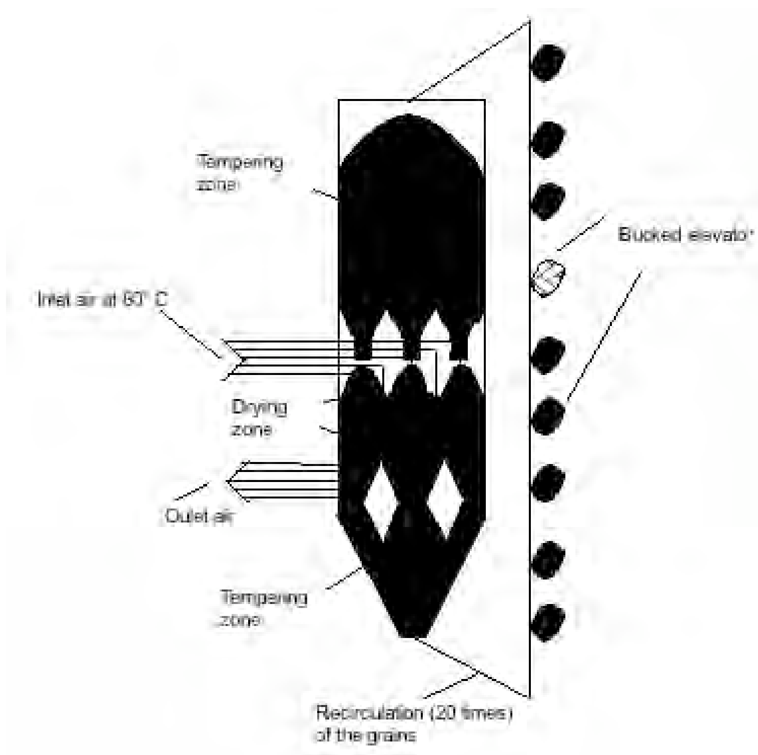


Figure 61. Outline of an intermittent dryer, of concurrent air and grain flows, CENICAFE - IFC.

Figure 61 and Figure 62, of *two main parts: the drying zone and the repose zone*. The repose zone is divided in two, inferior and superior. The mass of grains moves continually inside the dryer, by means of a system of inferior discharge and of a bucket elevator.

In the drying camera, both the air and the grain flow downwards, from where it originates its concurrent flow name. In this camera, the air at high temperature, coming from the generator of hot air, finds to the wettest possible grains and high moisture evaporation rates taking place. The high evaporation impede the excessive heating of the grain, so that their temperature doesn't surpass the value of 40°C, very distant from the temperature of the air that can reach 80°C Figure 65. In this way the quality of the coffee is conserved. Also the drying system with flows of air and grain in concurrent form and with relatively high temperatures is a very thermal efficient, because of thermodynamic considerations.

From the drying camera, the grain passes to the inferior rest camera, in which, the grain is not in contact with the hot air. In this space, *redistribution of moisture, from the interior to the exterior in each one of the grains, caused by the diffusion process* (See section 4.4.) takes place. The mass is discharged by gravity and controlled by a rotating vane feeder. The bucket elevator take the flowing mass and discharge it again to the superior part of the dryer, where it continues their periods of rest, in the superior rest camera. The system of *recirculation of the each grain through the dryer repeats 20 times*, when the drier capacity is complete. At this time the moisture content of the coffee is in the range of moisture of the 10-12%. All the grains receive the energy in discontinuous form, but all receive the same amount. These results in uniform final moisture content (*Figure 63*).

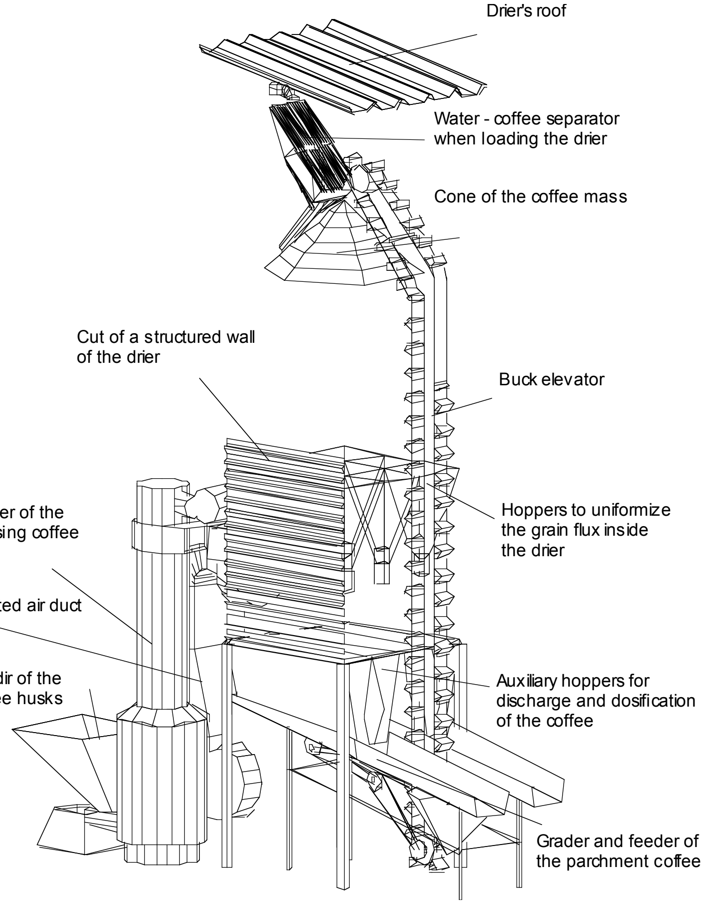


Figure 62. Tri-dimensional diagram of an intermittent, concurrent flow dryer, CENICAFE - IFC.

Initially it was built and evaluated (60) (34) an IFC prototype dryer with capacity of 500 kg of parchment dried coffee. Their technical performance and the final quality of the coffee gave good results. The same drying prototype was modified to improve the transport system of the grain. In an evaluation of the system operation and the product quality obtained (81), there were carried out 8 experiences with the dryer varying the temperatures of drying air from 80 to 86°C, the flow of grains from 0.024 to 0.048 m^3/min-m^2. The total time of drying varied between 26 and 32 hours. The final moisture content was 11.0% (5.72 coefficient of variance).

All of the drying curves (variation of the moisture with relation to the drying time) obtained in the IFC prototype and the commercial models showed the *same uniform characteristic of the lineal decrement of the moisture with relation to the time*,

Figure 64. Also the grain temperature stayed below the 40°C, when the temperature of the drying air did not surpass the 80°C value (Figure 65).

The tests of physical quality and of the cup quality they were always qualified as coffee of high quality (81). During these experiences it was developed a methodology to end the drying process by turning off the source of heat, when the coffee reached 14% moisture content. The fan continue forcing ambient air.

to reduce the last two degrees of moisture and to obtain the desired final moisture (11 to 12%, w.b.).

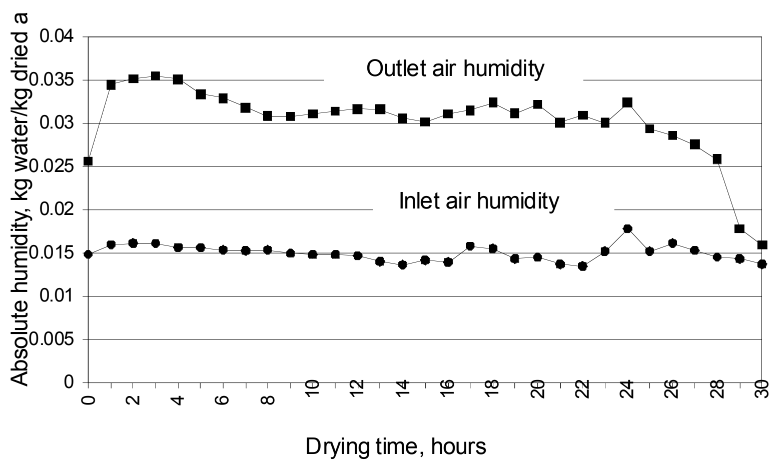


Figure 63. Uniform differences among the absolute moistures of entrance and exit of the air.

With base on the results of operational optimization of the IFC dryer (68) it was built and evaluated (71) an IFC of 1000 kg of parchment dried capacity similar to the prototype. In this second prototype reformations and innovations were made to optimize and to decrease to less than 1% the hulled grains, during the whole operation. To avoid the chemical reactions originated by the contact of the coffee wet parchment with the galvanized walls of the dryer it were added thin layers of stainless steel, of low cost.

The drying IFC 1000 model was evaluated with the mechanical optimizations and using a mineral coal.The efficiency of the dryer expressed in kJoules/kg of evaporated water was determined with the help of a psychometric package (18). The resulting *value of 3763 kJ/kg of H_20 indicates the high efficiency of the dryer*. In relative terms, *the efficiency of the dryer compared with the evaporation of free water, in which no diffusion resistance exist, is of 63.4%, a very high figure.*

4.7. DRYING CALCULATIONS.

For three decades now, when the massive use of the computers began, the mathematical models have been used to describe the drying and cooling processes of the grains.

It was indicated that drying and storage of grains (18) were very good examples of the great practical utility of the mathematical simulation. Indeed, the grains present ideal physical properties for drying, cooling and mathematical modeling, due to the uniformity of their physical dimensions. Their inter-granular space, their strong structure allow it to support the weight of layers of grains several tents of meters high and to force air uniformly through it. The large and uniform specific area by unit volume of grains, and in general thir physical properties facilitate the transfer of heat, moisture and of momentum when a current of air is forced, with controlled conditions when the grains are placed in the dryers and in the appropriate bins.

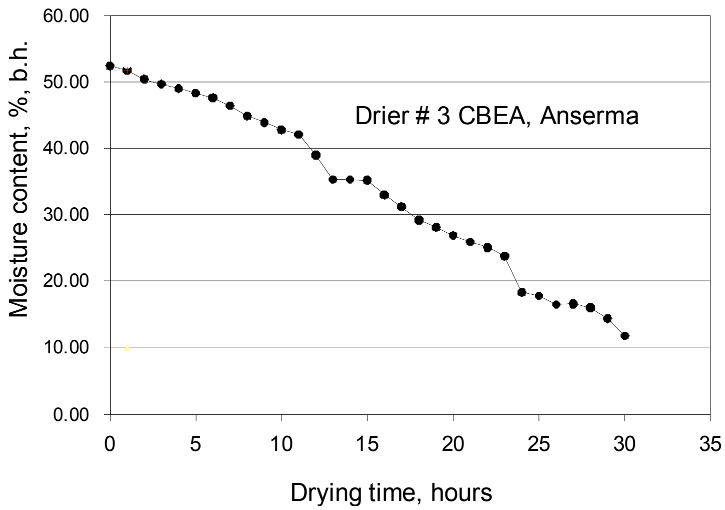


Figure 64. Curves of typical drying curve of CENICAFE – IFC dryer, showing the characteristic lineal uniform reduction of moisture along the time

It has been demonstrated in the drying and storage studies of grains with forced air that, whichever is the configuration of the dryer or the storage systems it is always possible to model the processes mathematically. They are obtained this way the variations of the moisture and temperature of the grains and of the air, at any instant and at any position of the equipment in a few seconds of mathematical simulation.

The mathematical simulation for the drying and the cooling of the parchment coffee has been applied with success at CENICAFE (68), (120). In these works the physical-mathematical foundation of the models is presented. In general form, the work carried out consisted of obtaining the physical properties of the coffee to build the models of transfer of heat, mass and momentum transfer, based on the best existent models for other grains.

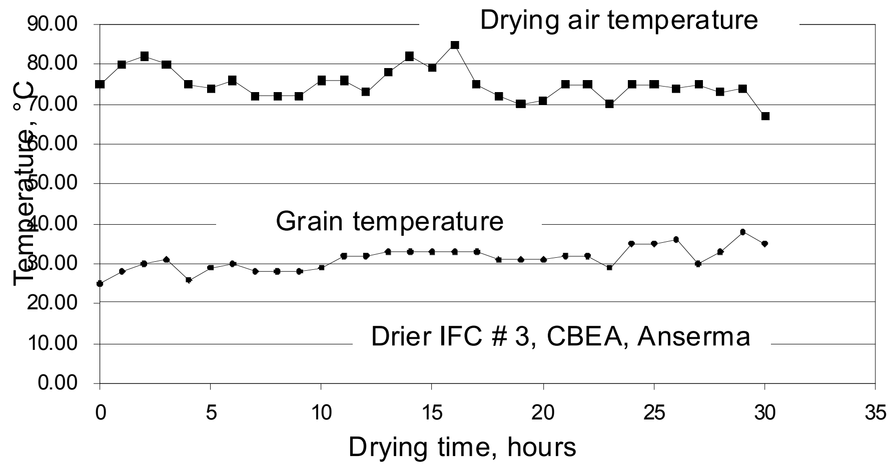


Figure 65. Comparison among the temperatures of the drying air and the temperatures of the grains in a typical operation of the CENICAFE – IFC drier.

The mathematical models of drying and cooling for the coffee parchment obtained at CENICAFE are modifications of the drying model of THOMPSON (117) and model of the Michigan State University, (18). The physical properties of the parchment coffee obtained at the laboratories of CENICAFE were incorporated.

4.7.1. Physical properties

4.7.1.1. Equilibrium moisture content.

The process of transfer of moisture from the grain to the air stop when the pressure of the water vapor in the surface of the grain is equal to the pressure of vapor of the air that surrounds the grain. This event that can be presented under different conditions and when the contact time is large enough to permit to develop the process. The value of equilibrium depends on the moisture of the air and the common temperature of the air and the grain.

In the mechanical dryers the hygroscopic equilibrium is not usually reached, because this is not necessary and because the equilibrium moisture could be near to zero (for air temperatures of 50°C, or higher). Nevertheless, the drying rates of the grains depend essentially on the potential values of the equilibrium moisture content, and the mathematical modeling could not be accomplished without the knowledge of this physical property.

It is possible also that the grain absorbs moisture of the air, when its vapor pressure in the surface is smaller than the pressure of vapor of the air.

The curves of equilibrium moisture for parchment coffee (119) they were extended to a wider range of temperature (5 at 55°C) and of moisture (10.5 to 26%. dried basis) (68), 108):

$$M_{eq} = (61.030848\,\varphi - 108.37141\,\varphi^2 + 74.461059\,\varphi^3)\,e^{(-0.037047\,\varphi + 0.070114\,\varphi^2 - 0.035177\,\varphi^3)\,\theta}$$

Equation 6. Equilibrium moisture content (%,dried basis) (121) of parchment coffee, as function of the relative moisture (decimal) and the temperature (°C).

Where,

Meq	=	content of moisture of equilibrium of the coffee parchment,%, base dried
f	=	relative Humidity, decimal
q	=	temperature of the air, centigrade degrees

The curves corresponding to this equation are presented in the Figure 66

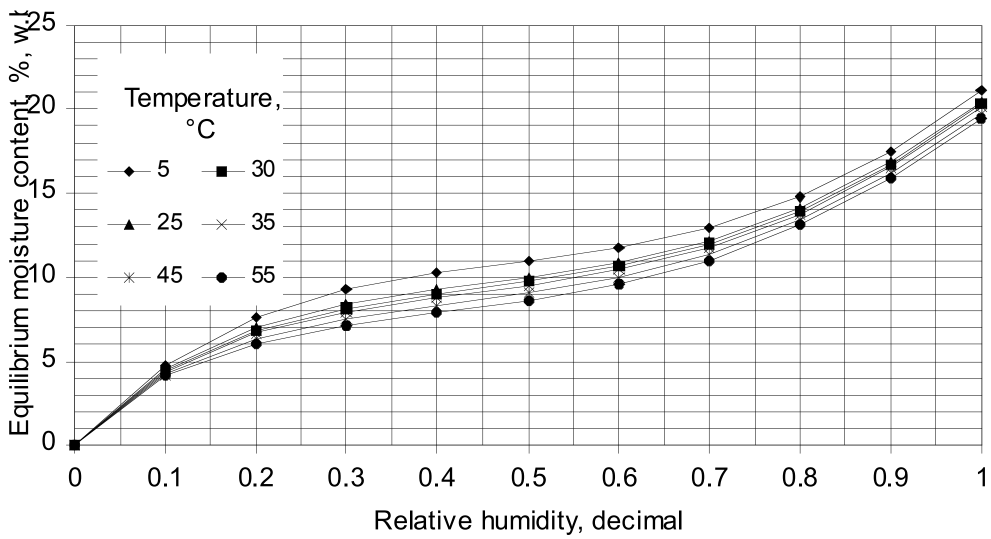


Figure 66. Curves of Equilibrium moisture content of parchment coffee, calculated with the Equation 6.

4. 7.1.2. Latent heat of vaporization

The latent heat of vaporization of the coffee parchment, is the physical property that indicates the *quantity of the necessary heat to evaporate the water contained in the grain*. It depends on the temperature and of the moisture of the product. This property is obtained from the data of equilibrium moisture (54) and it is represented by the following equation (119):

The obtained expression is:

$$L = (2502{,}4 - 2{,}4295\ \theta)\ [1 + 1{,}44408\ e^{(-21{,}5011\ M)}]$$

Equation 7. Latent Heat of vaporization of the parchment coffee.

Where,

L	=	Latent Heat of vaporization of the coffee parchment, kJ/kg
θ	=	Temperature, degrees centigrade
M	=	Moisture content of the coffee, decimal dried basis.

4.7.1.3. Drying thin layer of parchment coffee. Diffusion of moisture.

The *thin layer is an indispensable mathematical concept* to refer to the elementary part of composition of a disposed mass of grain in a dryer or in a storage bin, subjected to the action of forced air through the mass. The thickness of the thin layer can be assumed as the height of one grain.

The experimental drying thin layers curves were obtained in the laboratory, by placing several coffee grains in perforated mesh, and submitted to different conditions of temperature and of humidity of the air, in a laboratory dryer. *Thick coffee layers were located between three thin coffee lagers, to obtain real drying data similar to the conditions of the dryers, with time dependent variations of the air temperatures and humidities* (108). The values of the variations of the moisture content of the grain with relation to the variation of the conditions of temperature and moisture of the air have been correlated with success using the semi-empiric thin layer equation (101). This equation has also been used for coffee and many other products (56), (62), (68), (82), (101) y (108). Using this same technology, that include *simultaneous integration and optimization techniques, the thin layer equation was developed for parchment coffee* (56), (62), The equation in its differential form is given by:

$$\frac{\delta M}{\delta t} = -\, m q (M - M_{eq})(p_{vs} - p_v)^n t^{q-1}$$

Equation 8. Equation of drying of thin layer of parchment coffee.

Where,

$\delta M/\delta t$	=	Rate of the change of the content of moisture of the grain per unit of time
m, n, q	=	Parameters of the equation of thin layer that are obtained by means of procedures of lineal or nonlinear regression, and numeric integration.
M	=	content of moisture of the coffee in the time " t ", decimal bases dried
M_{eq}	=	Content of moisture of equilibrium of the coffee, dec., dried base
p_{vs}	=	pressure of the saturated vapor, kPa
p_v	=	partial pressure of the vapor of water, kPa
t	=	time, hours

If the conditions of temperatures and moistures are constant along the drying process, the differential equation can be integrated to obtain:

$$\frac{M - M_{eq}}{M_o - M_{eq}} = e^{-m(p_{vs} - p_v)t}$$

Equation 9. Equation of thin layer drying of parchment coffee, integrated, for constant conditions of the air.

The values of m, n and q for the range 40-60 °C and moisture contents from 5 to 55%, dried basis, were equal to (56): m = 0.014206; n = 1.2212; q = 1.00106. In spite that the equation was obtained with base in a high temperature range, it predicts with acceptable precision the drying curves at very low temperatures (10 °C) (Figure 67).

It was studied (68) the phenomenon of diffusion of moisture that describes the movement of water inside the coffee kernel, instead of the average values described by the Equation 8.

It was successfully used the law of Fick (18) to correlate the rates of drying of coffee assuming it an sphere:

$$\frac{\delta M}{\delta t} = - D \frac{\delta^2 M}{\delta r^2} + \frac{c}{r}\frac{\delta M}{\delta r}$$

Equation 10. Fíck's equation that describes the distribution of the moisture inside the coffee parchment kernel.

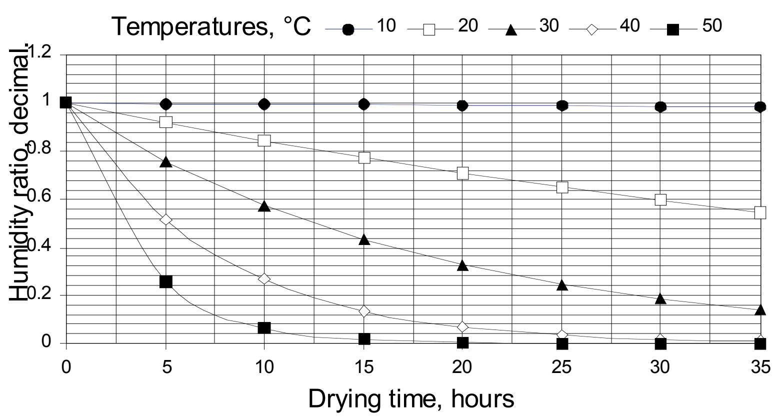


Figure 67. Curves of drying of thin layer of coffee parchment, calculated with the Equation 9

Where,

M	=	content of moisture, dry basis, decimal
t	=	time of drying, s
D	=	diffusion coefficient, $m^2.s$-1
r	=	space coordinate inside a sphere.

The coefficient of diffusion of moisture of parchment coffee was determined as function of the moisture content and the temperature of the product. The experimental data were obtained from the measurements of the time and the moisture content of the grain and of the air relative humidity, for common temperature for the air and for the grain. The used experimental camera (119) for taking of data was built in the own laboratories of CENICAFE. As a result of the analytic study the coefficient of diffusion of moisture was obtained (68). It was found that the coefficient of diffusion of the moisture inside the parchment coffee depends on the average moisture content and its temperature.

The model, for the *diffusion coefficient of the parchment coffee, according to the Arrenihus model is*

$$D = [4{,}15821]\, e^{(0{,}1346\Theta + 3{,}2055)M - \frac{1{,}184}{\Theta + 273{,}16}}$$

Equation 11. Diffusion coefficient of parchment coffee, as function of their moisture and temperature.

Where:

D	=	diffusion of moisture, (m^2.min-1)
M	=	content of mean moisture of the grain, decimal, b.s.
Θ	=	temperature of the grain, (°C)

The coefficient attains its biggest value when the moisture and the temperature are the highest.

4. 7.1.4. Superficial area

Considering the grain of coffee as a sphere, it was obtained (68) a *specific area* of 779.8 m^2/m^3 for parchment coffee, in the moisture range of 25.6%-10%.

4. 7.1.5. Specific heat

The expressions (68) to calculate the *specific heat* of the coffee parchment is:

$$CS = 1{,}3556 + 5{,}7859\ M$$

Equation 12. Specific heat of the coffee parchment

Where

CS	=	Specific heat of coffee, kJ/kg-°K
M	=	Moisture content, decimal, dry basis, decimal

4. 7.1.6. Apparent density

The apparent densities of the parchment coffee have been determined for (75), (56) y (121), for different moisture content values.

An expression was obtained (68) for the *apparent density of the coffee parchment as function of its content of moisture*:

$$D_{ap} = 365{,}884 + 2{,}707\ M$$

Equation 13. Apparent density of the coffee parchment, in function of its content of moisture.

Where,

D_{ap} = apparent density of the coffee parchment, kg/m^3
M = content of moisture of the coffee, %, dry basis, decimal

Several have been the applications of these physical properties, quantified in mathematical equations. They were used (120) to conform the drying and cooling model of THOMPSON (117), to predict the curves of cooling of the parchment coffee stored in the commercial bins of ALMACAFÉ, Bello, Antioquia, with very good accuracy. Based on the model, properly validated from laboratory data (See section

2.3.), it was generated by mathematical simulation to make the recommendations for day and night aeration procedures, with good results.

The equations of the physical properties of the coffee were used to conform the drying model of the Michigan State University (18). *The validity of the model was demonstrated in prototype IFC dryers and the model was used (68) optimize the CENICAFE-IFC dryers*.

V. YIELD OF THE COFFEE CHERRY TO COFFEE DRIED PARCHMENT. [11]

5.1. INTRODUCTION.

It is understood like *yield of the coffee cherry to dried parchment coffee* the relationship between the weight of the berries of the coffee cherry, just as they were harvested, on the weight of the dried parchment coffee expressed in form of FEDERATION type of coffee (or on other selected base).

The yield of the coffee can also be defined as the relationship among the weight of the berries of cherry coffee, just as they were harvested, on the weight of the coffee kernel obtained after the hulling process.

The yield of the coffee depends on several factors: variety, age of the plantation, handling of the cultivation, rain patterns, period of crop, moisture content of the cherry, quality of the harvest, processing system, delays and failures in the processing.

The effect of the diseases and plagues impair the normal development of the berries and the yield of the coffee decreases.

To obtain good yields from a plantation, enough reserves of nutrients for the maintenance of the crop should be provided. Cleves (31) attributed the low yields in the 67-68 crop to the low nutrition of the trees and to a large production, causing a physiologic unbalance that translated in immature, small and vain grains.

A good harvesting method is mandatory for a good processing of the coffee; the quality of the obtained dried coffee depends essentially on the quality of the harvested cherry.

A mass of coffee in a recently harvested cherry might be a heterogeneous group composed by coffee in different states of maturity. High percentages of immature coffee might cause a decrement in weight in the order of 8 to 20% with relation to the obtained dried parchment coffee (48), (52).

The delay time in processing of the coffee influences in the yield. Calle (20) reports losses of dried matter from the grain when subjecting the coffee to the process of fermentation. Boyce (16) reports a lost of 3.9% during normal fermentation. Coste (36) registered losses of 2%. Barbosa (13) registers lost of weight of 0.02% for hour of fermentation. Vasquez and Hidalgo (124) report losses of dried matter of 1.94% in natural fermentation. Carbonel and Vilanova (21) report earnings in weight when substituting the fermentation by a quick method for reducing the mucilage, like the chemical treatment with caustic soda.

Coincidence exists between the researches that *losses during fermentation are due to the normal metabolism of the grain*, that is, the use of the carbohydrates for the production of heat, humidity and of dioxide of carbon, during the respiration of the grains.

[11] Prepared by Alvarez G. and G. Roa M., Ingeniería Agrícola, CENICAFE.

If the grains are left under water to dissipate the heat of the temporally stored product, like it is sometimes practiced, additional losses occur by diffusion of the solids constituent of the coffee, into the water.

5.2. COMMERCIALIZATION of the COFFEE WASHED PARCHMENT.

The commercialization of the wet parchment coffee, or washed coffee, consists in the transaction by which the coffee grower sells its coffee, after being pulped, demucilaged, and washed to intermediate resellers.

In principle the method should not present difficulties, if the processes were made appropriately, at the correct time, *without delays and if the moisture of the product were known accurately*. Indeed, the moisture of the coffee that is being marketed, should be the known to predict the real weight of the dried parchment coffee that it is going to be obtained from the wet coffee.

This form of commercialization has presented many difficulties. *The coffee grower usually receives an inadequate payment for his coffee and also big quantities of coffee they have deteriorated for the excessive delays before the drying process start*.

A study was carried out in Santa Rosa de Cabal, Risaralda, 1986, by the Extension Coffee Committee of the Coffee Growers of Risaralda and the Technical Administration of the FEDERATION to find the causes of deterioration of the cup quality. It was concluded that the problem was caused because 63% of it had a delay in starting the drying process by more two days, after finishing the process of fermentation.

It is practice in this commercialization method that the coffee grower receives his payment with reference to the dried parchment coffee that it is considered to obtained of the washed coffee after the drying process. The factor used, that the buyer imposes is that the coffee after being dried will weight half of the washed parchment coffee. *For the values of moisture that the coffee usually has (52 and 48% of moisture, wet base) the coffee grower accepting the half weight criteria, loses between the 8 and 17% of the weight*.

Figure 68. If the coffee grower sells its coffee with a value of 40%, that is, dried of water, or surface dried, it loses 34.8% of its product. Of another hand, if the coffee is sold at higher moistures that the normal

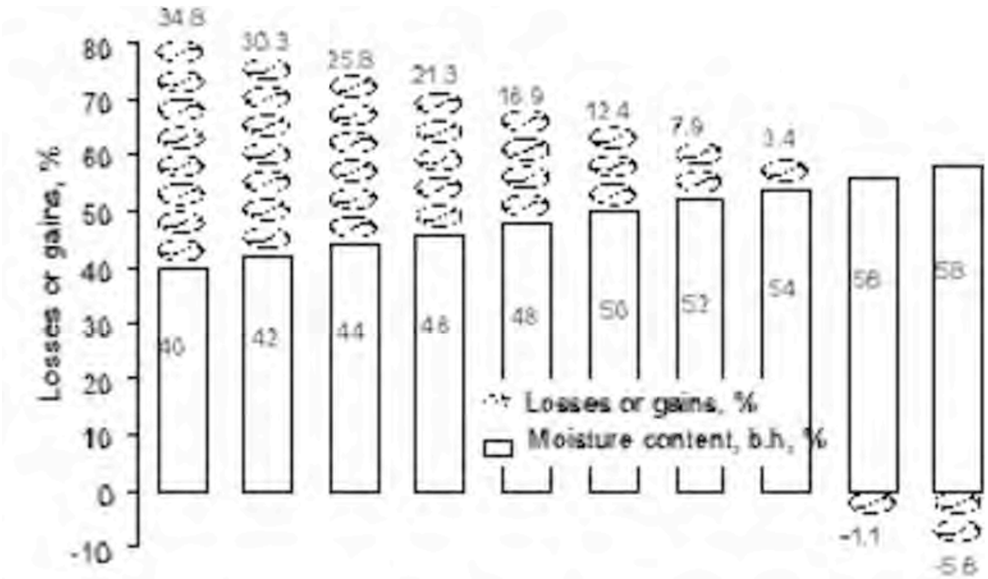


Figure 68. Loss or gain in the sale of washed coffee when receiving half of the weight like dried parchment coffee.

value, for example with 56%, the coffee grower can win 1.1% in the transaction.

5.3. MEASUREMENT OF THE YIELD CHERRY/PARCHMENT.

5.3.1. Method CERPER.

Two methods have been used traditionally in the commercialization of the cherry coffee to determine the yield, the wet and the dry methods. The wet method is the most used.

In the wet process method a 1,000 g sample of the cherries is put in water to separate the material that floats from the one that settles. It is considered that the 50% of the floats with good appearance are good grain, assuming that they have one good kernel. The weight of the immature grains, the dry ones and the damaged berries are selected manually from the settled samples and are added to the low grade samples that floated. With this value a table developed empirically gives the conversion factor for determining how much good dried coffee will be obtained from the coffee cherry.

5.3.1.1. METHOD CERPER.

The CERPER (*cherry/parchment*) methodology was developed by CENICAFE to predict in a short time the relation or yield *cherry coffee/dry parchment coffee.*

In the CERPER method the sample is pulped without water, with a traditional pulper that works according to the ICONTEC Norm (55). The coffee is demucilaged. The low-grade coffee is separated manually. The coffee is washed and the separated floats and foams are added to low-grade coffee. The good coffee is weighed and two samples drained and its moisture content determined using the CENICAFE - MH-2 (See section 4. 2.) tester

Figure 69 and

Figure 70.

Figure 69. Pulper, demucilager, moisture CENICAFE MH-2, tester. Elements of the CERPER yield method, Anserma, Caldas.

Taking into account the weight of the washed coffee, their moisture content, the final weight of the dried parchment coffee is calculated, wit 11% moisture content, wet basis. From this value the yield is established.

5.5.1.2. Method commercial CERPER in the central mill of ecological processing of Anserma

To confirm the veracity of the prediction of the CERPER method, the yield of the coffees received in the Central Coffee Mill of Anserma, were calculated and compared using three methods. 1) the CERPER method; 2) the real process, taking the real samples from the Central mill, and 3) the conventional method, wet way, used by the Cooperative.

Results,

Figure 71, show that *the CERPER method and the real processes present a high correlation, indicating that this method is the only adequate methodology to predict adequately the yield*.

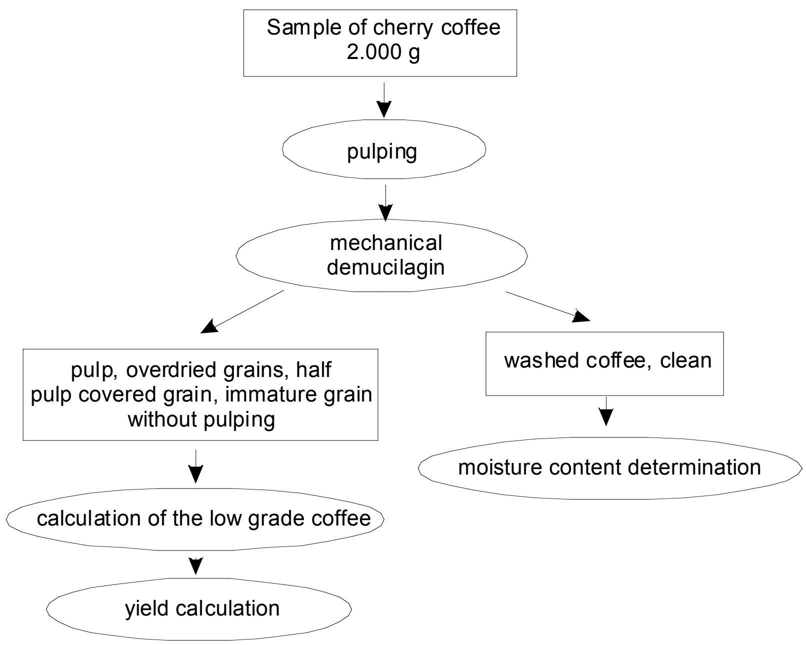


Figure 70. Flow diagram of the method CERPER.

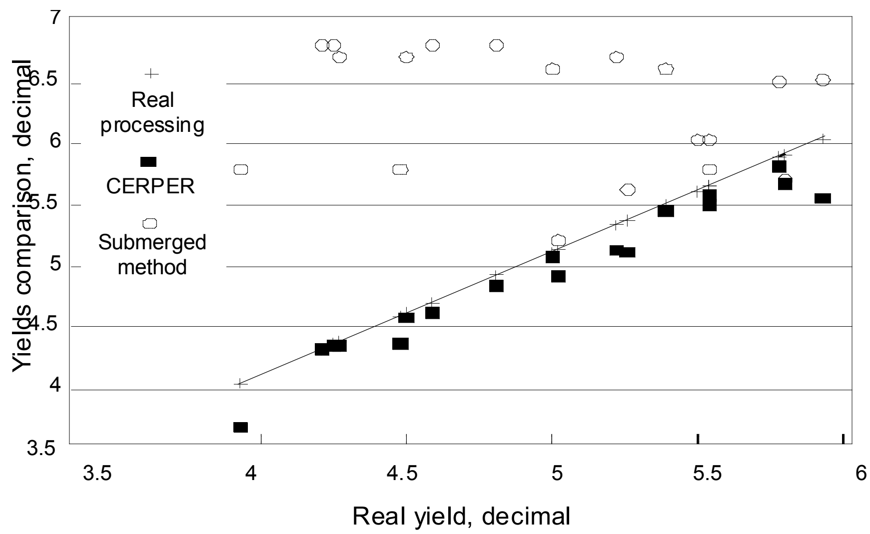


Figure 71. Comparison of real and estimated yields by two estimate methods, compared with the real process, as evaluated in the Central Coffee Mill, Anserma.

VI. WORM CULTURE WITH BY-PRODUCTS OF THE COFFEE. [12]

The worm culture consists on the intensive cultivation of the red worm *Eisenia foetida* in organic residuals (39), like the by-products pulp and mucilage in processing coffee. CENICAFE has studied this technology to find also a way to control the conventional contamination that these two products produce conventionally. The practical recommendations that are presented in this section, related with the construction of the infrastructure, handling of the pulp, the mucilage and the worn culture, were obtained from the *research experience of CENICAFE in the Ecological Coffee Mill of Anserma, Caldas, in collaborative* work done with the Cooperative of Coffee Growers of Anserma and two commercial firms, BIOAGRO DE COLOMBIA, Risaralda and WORM CULTURE - MY GARDEN, Risaralda.

6.1. INFRASTRUCTURE OF THE WORM CULTURE.

6.1.1. Area.

The pulp generated by a farm that produces 12.5 tons of dried parchment coffee a year (approximately 25 tons of fresh pulp), can use an effective area of 25 m^2 of worn culture. That is, 1 ton of pulp for square meter per year (28). The density of the initial pure worm of recommended is 5 kg/m^2.

6.1.2. Worm beds.

The beds or litters shown in Figure 72 and

[12] Prepared by Dávila, M. T. Química Industrial and Ramírez C.A. Ingeniería Agrícola. CENICAFE.

Figure 74, were the worn culture takes place, can be constructed in bamboo or brick. They are recommended to be built

Figure 72. Beds of the worn culture irrigated with residual waters that were non-controlled physically by the pulp and the mucilage.

of 1 m of wide and a variable length, according to the availability of the land; in general, modules are constructed 2 to 3 m long. The height of bed is 40 cm. The space among beds is 50 cm.6.1.3. Floors.

Inside the beds, it is recommended a *cement floor*, plastic cloth, bamboo mat or some material that allows to isolate the culture from the floor to *avoid the attack of possible plagues* (planarians, leeches, ants). The floor should be built with a slope between 2 and 5% to avoid floods of the beds, when irrigation is used.

6.1.4. Roofs.

The roof is *indispensable because it avoids that the rains wash the pulp and the mucilage, loosing the contamination control*. It also provides shade and better conditions for the general work of the worm. Also, the handling of the materials is facilitated (pulp, worm and compost). The roofs can be constructed in cardboard or zinc tiles. The roof height can be from 2.50 to 3 m.

6.1.5. Closure.

It is *convenient to close the space with a mesh* to avoid the entrance of birds and other predators.

6.1.6. Cultivation of the worm.

The speed of transformation of the pulp depends on the quantity of worms. When it is wanted a quick process, the density of worms should be high: around 5 kg of pure worm /m^2 (40). This corresponds approximately to 20 to 25 kg of mixed worm with substrate.

Because the red worm is a very productive animal, it is not convenient to start the worn culture with the total quantity of the worm; it is *more economic to multiply it in the own property* (See also section 3.16.3.5.)

For the case of a property of 12.5 tons of dry parchment coffee/year, 125 kilograms of pure worm will be needed (approximately 625 Kg of commercial worm). If the worn culture begins with 20% of the total quantity needed (25 kg of pure worm, that is 125 kg of commercial worm), the necessary size of worn culture to manage the whole pulp will be obtained in two years.

6.2. SYSTEM OF CULTIVATION.

The worn culture begins depositing the starting breeding in the beds, making sure that this *initial layer is approximately 10 to 15 cm tick*. To complete this height it might be necessary to deposit at the bottom of the bed, decomposed pulp. This way that the red worm has a way to take refuge if the conditions of the food are not appropriate momentarily.

To know the quantity of deposited initial pure worm, it is convenient to make a sampling (28) this way: the whole substrate is weighed with worms. Three samples of one kilogram of each bed are placed to the sun light on a plastic sheet until the worms concentrate at the bottom. An average of the worm weight is calculated. As the total weight of the substrate is known, the initial weight of the pure worm is calculated by multiplying by this factor.

6.3 HANDLING of the WORN CULTURE.

6.3.1. Feeding substrate.

Pulp of coffee alone, obtained by a traditional method or mixed with mucilage from the BECOLSUB technology, can be used. This last substrate might be taken from a process with pulping without water, mechanical demucilaging and mixture of the two by-products by means of a screw conveyor.

Worn cultures fed with the mixed pulp and mucilage substrate and irrigated with residual water from washing the coffee, showed larger increments in the weight of the worms and larger consumption rates. Also larger yields in the pulp conversion to worm compost were observed, with relation to the yields obtained with the use of pulp alone, irrigated with clean water (27), 96).

When the separation of the worms is terminated, the worm compost of the inferior part of the bed can be retired. The material can be used with the moisture obtained (around 80%). Also the *moisture can be reduced it to 50%, a more commercial moisture value (28)*. For this purpose a *solar dryer can be used, as the parabolic type* used to dry coffee constructed in bamboo and plastic designed by CENICAFE (Figure 75).

Figure 73. Storage of mixed pulp with mucilage of coffee in specially designed covered structure. Central Mill for Ecological Processing of Coffee. Anserma/

Caution should be taken with the use of contaminated substrata, as the pulp might have been treated with chemical insecticides for the control of the coffee borer. In this case it is necessary to wait at least 15 days before introducing the worn culture (38).

6.3.2. Temporary storage of the substrate.

To maintain the worn culture with constant feeding through the all year, a covered structure for the pulp, 

Figure 73 should be used. This procedure permits maintain the pulp in good nutritious condition, ready for the feeding of the worms, at any time, for one year (27). Although the capacity of the structure for the pulp depends on the distribution of the crop, in general its volume might be around 30% of the pulp produced in the year, for regions of two harvest periods. The worn culture can feed with pulp one week old, taking care that is not hot. It is more practical to use older pulp.

6.3.3. Feeding system.

Thin layers of food are used (*maximum 4 cm thick*), to avoid the heating when it is used very fresh. This form the aeration and cooling of the cultivation is facilitated, to assure the transformation of the material and to maintain the worms feeding in the superior part (39). It has been observed that it is possible to stimulate the worm reproduction, by periodically changing the normal feed by a mixture of the pulp and the mucilage with other residuals that are had frequently found at the farms, as manure of different animal species (bovine, swinish, equine) or residuals of other cultivation.

6.3.4. Frequency and quantity of food.

The worms might be *fed once or twice per week*, depending on the density of worms and the food type. In CENICAFE's cultures, feeding with pulp mixed with mucilage is practiced once per week. The quantity of the food is related directly with the consumption and the weight of the worms. It has been observed *that worms can eat half of their own weight, per day*, (26). It is advisable to take registrations of the feeding and the general operation of the worn culture.

The *feed should be prepared before giving it to the worms, by humidifying i*t, ideally with the processing residual waters, avoiding the dripping and the flooding of the beds. This humidifying process should correspond approximately to feed moisture content in the range 80 to 85%. The *irrigation process should be repeated continuously to conserve this moisture*. This watering is made with clean water, but is *preferably use residual waters of the coffee processing*. Depending on the environmental conditions and the thickness of the substrate layer with worms, a *watering of maximum 1 L/m^2-day can be made*. It is necessary to avoid the flooding, (28), Figure 72.

According with the studies, *the total contamination controlled by the BECOLSUB process is 92%*, if the mixed pulp with mucilage is used properly and the irrigation of the worn culture is made with the washing waters (27), (96).

6.4. GATHERING OF THE PRODUCTS.

The separation of the worm, and the harvest of the worm compost,

Figure 74, can be practiced two or three times a year, depending on the speed of decomposition of the pulp.

When the substrate reaches the maximum height of the bed, the feeding and the watering is suspended during one week, to force the worms to consume all the remaining food, not yet transformed. The following week, a mesh is extended on the bed and feeding is carried out again above the mesh; one week later the mesh is retired with the superior layer where the worms have climbed. Depending on the quantity of worms, it can be necessary to repeat this operation up to three times (28).

6.4.1. Increment of worms. Solar drying.

To estimate the quantity of the *separated worms*, a sampling technique is carried out in the same form that it was indicated to determine the initial weight. The increment in the weight of worms is given by (final weight of worms - initial weight of worms)/initial weight x 100 (28).

The separated worms might be used to multiply the cultivation, for new worn culture or used as a protein source for animal feeding (51), (99).

Figure 74. Gathering of the organic payment, result of the worn culture.

6.4.2. Yield in the production of the worm compost.

The yield in the production of the wet worm compost (with 80% of moisture basis), can be calculated by: (quantity of retired worm compost – initial quantity of worm)/amount of used pulp x 100 (28).

In general, the yields in the worm compost production obtained at CENICAFE, range from 35 to 40%, in wet basis (26), (27), (28). For a property of 12.5 ton of dried parchment coffee per year (approximately 25 tons of pulp/year), a production of 9 tons of fresh wet worm compost can be obtained per year.

The obtained worm compost is used like manure in vegetable gardens, tree nursery, etc. (51). In CENICAFE it has been found that the mixture of one part of worm compost with three parts of natural soil is the most appropriate form for the preparation of seedbeds of coffee (109).

Figure 75. Drying of the organic manure, in parabolic, rustic solar dryer.

According to preliminary economical studies by experts that evaluated economically the program of ecological processing of the coffee, *it has been demonstrated that the inclusion of the worm culture system for the handling of the by-products is profitable* (14).

VII. PROFITABILITY OF THE ECOLOGICAL TECHNOLOGY.

7.1. ECONOMIC BENEFITS OF THE NON CONTAMINANT TECHNOLOGY.

The projects of water *decontamination in development countries* are not carried out in general, or they are partially executed, with many delays. The costs of the projects are considered very high and the polluting agent usually doesn't accept its commitment of maintaining unaffected the environment. The laws, although existent, most of the times are not applied with the necessary rigor.

The BECOLSUB technology *avoids the implications of decontaminating the waters* because it simply does not contaminate them, or it does it in less than 10%, with relation to the conventional technologies. The farmer in varied forms, depending of his creativity can handle the remaining 10%.

It is not frequent to find solutions to maintain the quality of the environment without making big investments and *most uncommon is the case that the solution to the contamination generates utilities*, as the BECOLSUB technology does.

Indeed, in the BECOLSUB technology relatively small investments are made and additional advantages are obtained by the value that represents the worm compost and the worm animal protein. These two products are of real and potential use for most properties.

What might be even more important for the farmer is that the BECOLSUB technology *eliminates many of the physical losses* that occur in the traditional processing systems. These loses have been accepted traditionally by the farmers as a necessary expenditure to obtain coffee parchment of excellent quality.

In particular, the adoption of the non-contaminant BECOLSUB process *presents a great number of physical advantages that can be quantified easily as economic advantages* by the following reasons:

Reduction in the consumption of water, from 40 to approximately 0,7 L/kg of DPC.

Improvement of the quality and increment of the amount of the water for human and animal consumption.

Elimination of the payment of fines to the government by the contamination of the waters.

The value of the of larger amounts of worm compost obtained, in less time.

Easiness of the manual handling of the worm compost that weighs less, and presents better physical handling characteristics and the odorless operation.

Larger durability of the civil structures for management of the pulp without excess of water.

Elimination of the losses (of the order of 1,5%) of dried matter by the suspended respiration process during the natural fermentation.

Recuperation of approximately 60% of low-grade coffee grains, with complete of half of their face covered with dried pulp to FEDERATION type of coffee (3% of recovery losses) and the elimination of the lixiviation losses in the fermentation tanks.

By the decrement of the manpower in the overall process.

By the decrement of the necessary physical infrastructure for the process. (New processing plants occupy only one fourth of the traditional system).

By the portable character of the BECOLSUB mobile system.

7.2. GENERALITIES ON THE ECONOMIC EVALUATION OF THE INVESTMENT.

The economical analyses can be simplified, when the processes include some common technologies. It is possible then to eliminate the formulations that correspond to these characteristics. This is the case of the comparison of the technologies of the conventional processing and the BECOLSUB technology. The drying of the grains, the transport of the coffee to the processing plant, and still the transport of the coffee cherry and of the washed coffee, inside the processing plant, are common for both technologies.

A typical economical analysis of an investment, include some aspects that are not of strict technological or economic origin and might endanger the accomplishment of the project. These aspects are of different origin: the financial variables (possibility and cost of the necessary resources), the commercial factors, the legal aspects, and others topics of even more difficult quantification like the social and political considerations.

In the *case of the BECOLSUB technology*, nevertheless, according to the opinion of specialists in the economic analysis of environmental investment (14), indicate that *not such a variables or considerations might endanger the accomplishment of the BECOSLSUB projects*. *Just the opposite*, it seems that the new technology present advantages in all the mentioned fields. This is also the opinion of the executives of the Colombian Coffee Federation, agricultural specialists, scientific institutions, commercial institutions, extension workers and commercial manufactures.

As a matter of fact the technology that was introduced commercially only in 1996 is already being used in hundreds of satisfied farmers, in Colombia and overseas. FEDECAFE plans to participate directly in the *introduction of 17,000 new processing mills, in a four-year program* in Colombia. The *Post-Harvest Program* of CENICAFE, in reason of this development, received the distinction of excellence in research, given by the COLOMBIAN INSTITUTE OF SCIENCES ‘COLCIENCIAS’, December 1996. This research group also received the First Prize of *“PLANETA AZUL” (A specialized prize to distinguish the best ecological project of the Country)* instituted by the *BANCO DE OCCIDENTE* of Colombia, March 1997. In occasion of an International Course on Ecological Processing of Coffee, held at CENICAFE in October 1996, the technology was presented to the international community with representation of 26 countries.

7.3. PRELIMINARY ECONOMIC EVALUATION TO THE PROGRAM OF ECOLOGICAL PROCESSING OF THE COFFEE.

A Program of Incentives for Transformation to Ecological Processing Plant (48), was created by the Technical Management of the Colombian Federation of Coffee Growers in October of 1994 to apply the technology developed by CENICAFE. The Andes University, Department of Economy of the Environment and Natural Resources of Bogotá, was hired to evaluate the development of the program.

During the evaluation of the initial phase of the program, in 1994-1995, the equipment of *Andes University visited more than 3.000 coffee processing plants. They interviewed 370 coffee growers in all the coffee committees of Colombia*, (half of them had acquired the new technology). They interviewed the technical directors of the departmental coffee committees, the processing engineers and the extension workers.

The Andes University developed a software program for the economical and financial analysis, denominated *"Calculator of Costs of the Ecological Process*".

After having evaluated the software program numerous times, with the collaboration and the representatives' of the National Federation Managers, the *University team, concluded that the investment should be profitable for most of the coffee growers. It was concluded that the investment could be paid by itself in one, two or three years. In particular, it was concluded that the model BECOLSUB, that contained the optimized technology and that it was only implanted at the end of this first stage (1995), should be the basic technology that the all coffee growers should consider first* (14).

The computer program used by the university included the basic data to establish the comparative costs of the conventional processing and of the processing with the module BECOLSUB. CENICAFE and the Technical Management of the National Federation of Coffee of Colombia contributed with technical and general economic data.

The program included formulations of costs and of finances to calculate the marginal or additional utilities by the use of the new technology. It also included the earnings introduced by the ecological processing by more sales of coffee, larger production of organic manure and worms, savings in water consumption. All the analysis was discounted to the present value, during the years of the investment.

7.4. ECONOMIC EVALUATION BY THE CENICAFE SOFTWARE. THE " ANEFSUB " PROGRAM.

CENICAFE developed its own model for the Economic and Financial Analysis of the BECOLSUB module, the " ANEFSUB " program, written in Microsoft VISUAL BASIC 5.0 - WINDOWS 95. *The program was developed to be used as part of the CENICAFE research studies on the BECOLSUB technology*. The ANEFSUB model of CENICAFE is based on the original model of the Andes University, written in DOS-Quick Basic. The selection of the economic models, the development of the algorithms and the programming, nevertheless, were carried out completely by CENICAFE, using the fundamental principles of the economic theory of the analysis of investments (1)), (52)), (123).

The model was developed based in the technical results of the evaluations of the processing of the coffee cherry to washed coffee, carried out under the direction of CENICAFE, in experiences executed in the laboratories or in selected farms. The program has a dynamic character that is being modifying as new real field data is generated, at level of the coffee grower, and according to the development of specific research to evaluate the BECOLSUB technology handled by the proper coffee growers (5), (9), (97).

The program is written in general, wide form and of very easy modification that facilitate the studies of economic feasibility in all the possible ranges of the main variables of interest.

It is considered that this is the *beginning of a multidisciplinary work*. The knowledge should be shared among the researchers, generators of the technology, the different organisms that are interested in helping the farmers to consider the best option to adopt by substitution of traditional equipment of the processing of the coffee, and finally, the coffee growers.

In general, the results obtained by all preliminary studies using the program indicate that *the economic advantages of the BECOLSUB technology, make them to be paid from 1 to 3 years the investment made for the substitution of the technology*.

The ANEFSUB program is fully explained in a complete chapter in the original book of the BECOLSUB Technology (102). All studied variables for the inputs and outputs, to facilitate the use of the program, are illustrated in 10 Windows.

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