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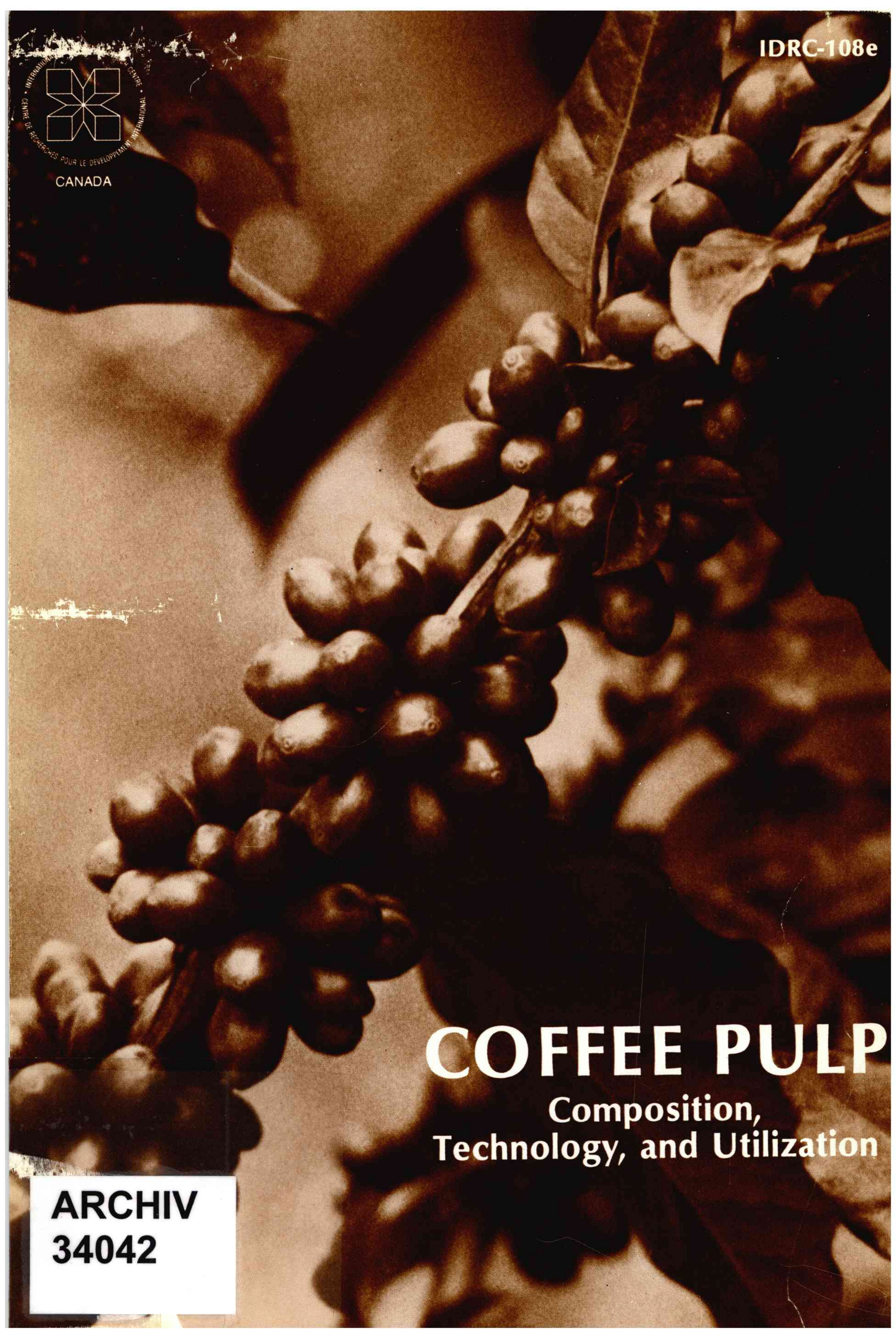

COFFEE PULP

Composition, Technology, and Utilization

IDRC-108e

Coffee Pulp

Composition, Technology, and Utilization

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[1]*The Institute of Nutrition of Central America and Panama (INCAP) is a scientific international organization created to study the nutritional problems of the region, seek ways and means of solving these problems, and provide member governments with advice and cooperation. Through an extensive educational program the Institute also contributes to the training of personnel in nutrition and allied sciences.*

The member countries of INCAP, which is administered by the Pan American Sanitary Bureau, Regional Office of the World Health Organization, are: Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama.

Contents

Foreword

The subject of this monograph is by no means new, because, from the beginning, mankind has tried to use agricultural and industrial by-products as animal feeds, nor is it the first time that coffee pulp has been considered as a potential material within this context. What is perhaps novel is that, to our knowledge, this is the first time that this agricultural waste has been studied from both the scientific and practical approaches.

Coffee pulp first came to the attention of workers in animal husbandry several decades ago, but discouraging results plus lack of adequate analytical methodology and the indifferent attitude of cattlemen soon dampened whatever interest there was in pursuing further studies. Over the years, sporadic attempts were reported that dealt with the uses and drawbacks of coffee pulp in animal feeding and the possible factors interfering with animal performance. Finally, in 1971 the Division of Agricultural and Food Sciences of INCAP, with the generous support of the International Development Research Centre (IDRC), Canada, the Organization of American States (OAS), and Pulpa de Café, S.A. of Costa Rica, embarked on an ambitious research program to study this by-product from a chemical, biological, and technological point of view. A summary of this research is presented here. If definite answers in some aspects are still not forthcoming, it is because the material has proven complex and difficult, but continuing research will eventually provide answers to most of these questions.

Interest in coffee pulp did not arise merely out of scientific curiosity, but was rather the result of a concomitance of several factors. On the one hand, there was the pressing need for food for an ever-increasing population and for raw materials for an animal industry beset by the spiraling of international prices, and on the other hand, the economic fluctuations of developing countries that have led to the constant search for new export products, such as beef, as sources of revenue.

Coffee pulp has always presented a serious disposal problem, which has become increasing more important as greater quantities of coffee are produced and processed in centralized mills. Pollution awareness and policies have played a minor role in finding uses for coffee pulp as availability of the product has been of paramount importance. Because coffee is grown for the bean, this defines the economy of its production. But the rational utilization of coffee processing by-products, in particular coffee pulp, also has some economic implications that may become evident as their use is increased. From the point of view of the total energy input going into coffee cultivation, including the cost of the land, the utilization of by-products will make the whole process more efficient.

Of the above factors, it is evident that the first two are the most relevant, and that the root of the problem lies in the fact that in these countries humans and animals compete for the same foods. Corn is a staple for both; therefore, any product that may spare corn for human consumption is worthy of attention, especially when there is little likelihood that such a product will be used as a component of human diets. This is an important consideration, because industrial and agricultural by-products that decades ago were used exclusively as animal feeds, such as cottonseed and soybean meals, nowadays are being increasingly used, directly or indirectly, for human consumption. Thus, the resources for animal rations become more restricted and expensive, and the price of the final product proportionally higher.

One way to break this vicious circle is to use local materials, not intended as human foods, as components of animal rations. This is one of the many reasons why a product such as coffee pulp, whose only use for years has been as a fertilizer for the coffee plant — a practice dictated more by the lack of an alternative usage of the pulp than by its effectiveness as a fertilizer — should be considered as a means of alleviating the scarcity of animal feeds. Although its composition suggests that coffee pulp has industrial potential, the main emphasis of the research has been on its possible uses in animal rations.

It is the purpose of this book to review the advances that have been made, to point out ways of utilizing coffee pulp and the problems that may be encountered, and to discuss the areas requiring additional research. The monograph starts with a description of the by-product, how it is obtained, its availability, and its chemical composition. The potential uses of the pulp and a description of the research findings on its use as a feed for monogastric animals, poultry, and ruminants follow. Other chapters describe the effects of preservation, processing, and ways of dehydration prior to its use as a feed ingredient or as an industrial raw material. Finally, attempts are made to describe the physiological role that the chemical compounds contained in the pulp play when the latter is used as a feed.

It is our hope that the information presented here will stimulate further research into making coffee pulp a useful by-product in food production systems in the developing countries.

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1

The By-Products of Coffee Berries

Ricardo Bressani[1]

Depending on altitude, coffee berries are harvested in Central America from late August to March, with lowland coffee maturing earlier than highland coffee. The berries are harvested upon reaching maturity, which is indicated by an intense dark red colour of the fruit (although there are coffee varieties that are yellow when mature).

In cross section the coffee berry (Fig. 1) shows four anatomical fractions: the coffee bean proper or endosperm; the hull or endocarp; a layer of mucilage or mesocarp; and the pulp or esocarp. Coffee beans have a flat surface, and in the fruit these flat surfaces face each other. Each bean is completely surrounded by a delicate spermoderm tissue known as the silver skin and is held in place by the membranous endocarp; also known as the parchment or coffee hull, that surrounds the individual beans and is brittle when dried. The hull in turn, is surrounded by a layer of mucilage 0.5–2 mm thick that itself is enclosed by a thick layer (approximately 5 mm) of spongy cells called the pulp. Because of the viscous nature of the mucilage, a slight pressure applied to the berry is enough to expel the two beans from the fruit. This characteristic has been used to advantage in the process that has been practiced for a long time to separate the beans from the rest of the fruit's structural components. Anatomical details of these fractions are well described in books dealing with coffee agriculture and processing technology.

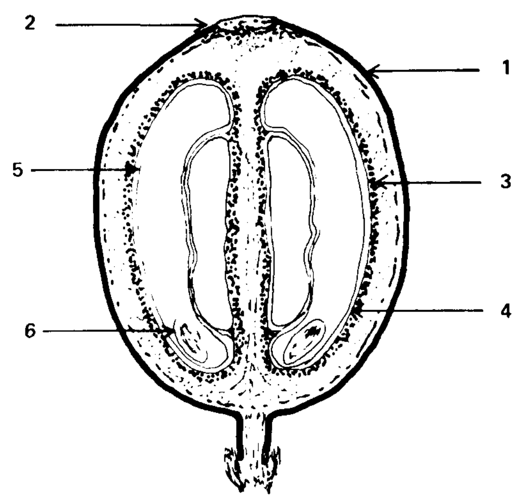

Fig. 1. Longitudinal section of a coffee berry (Coffea arabica): 1. epicarp; 2. disk or "navel"; 3. mesocarp; 4. endocarp (coffee hull); 5. spermoderm or "silver skin"; 6. embryo.

Processing of Coffee Berries

After harvesting, the coffee berries are transported to the coffee processing plant where they are dumped into a tank of water to: (1) remove spoiled or green fruit and foreign material, which rise to the surface; (2) serve as a transport mechanism. Basically, coffee-fruit processing to obtain the commercial beans consist of two operations

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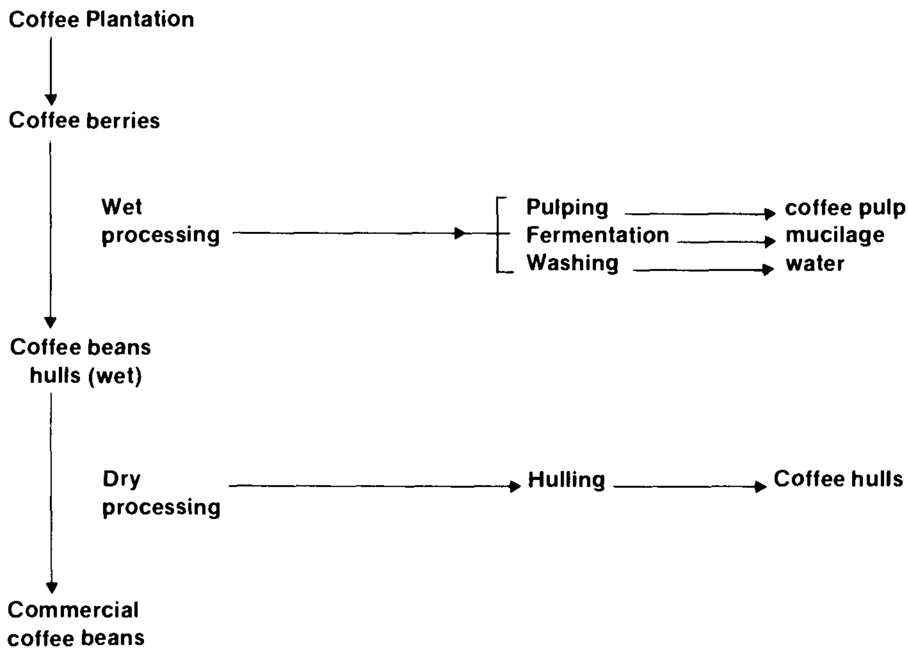

Fig. 2. Steps involved in coffee-berry processing showing the various by-products that are produced.

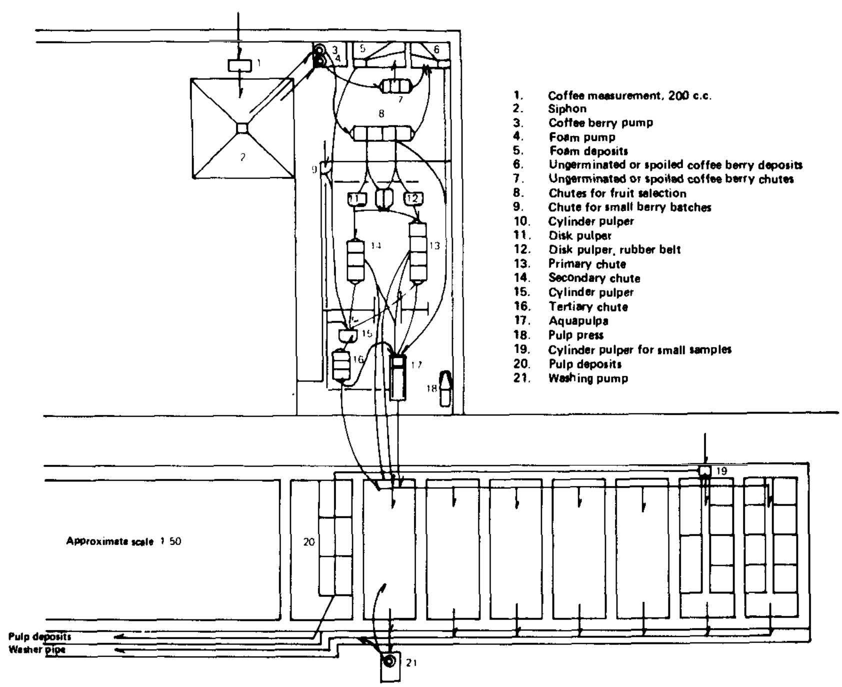

Fig. 3. Experimental coffee processing plant (flow diagram).

(see Fig. 2). The first is a wet processing step yielding coffee pulp, mucilage, and waste waters on the one hand, and coffee beans with hulls on the other; the second operation is a dry processing step that separates the hulls from the coffee beans. A more detailed flow diagram is shown in Fig. 3 (Cleves 1976). This is a modern pilot plant established to introduce more efficient operations into a process that, basically, has not been modified since coffee became an important economic crop in Central America. In this plant, the berries are dumped into a water tank that resembles an inverted pyramid. From the bottom of the tank, the fruit is syphoned to the pulpers, which separate the beans from the pulp by mechanical friction.

The pulp is then transported by water to a disposal system (which may be a trailer) or simply piled for later removal. It is important to understand this operation because it is the initial step in coffee-pulp utilization.

The coffee beans once separated from the pulp are transported by water either to fermentation tanks for mucilage breakdown and removal, or to machines that serve the same purpose. The fermentation process, which is almost anaerobic in nature, is carried out for 48–72 h and causes the breakdown of the mucilage. The products of this hydrolysis remain in the water. The mucilage can also be separated mechanically. In this case, the mucilage is removed by friction as the beans pass between a revolving perforated drum and an inner perforated tube with a counterflow of water. The mucilage, either whole or hydrolyzed, is the second by-product of coffee berries. The process described above is commonly used in coffee mills that have abundant water supplies. However, where water is a limiting factor it tends to be recycled and Fig. 4 diagrammatically describes such a recycling process, which also presents the possibility of utilizing the water for industrial purposes. This recycling produces a solution that according to some investigators contains a chemical oxygen demand (COD) volume of 20–50 g/litre, and consequently, it could possibly be used for the production of microbial protein (Altamirano 1973; Rolz 1973; Cleves 1975). On the other hand, treatment of such waters with calcium hydroxide de-

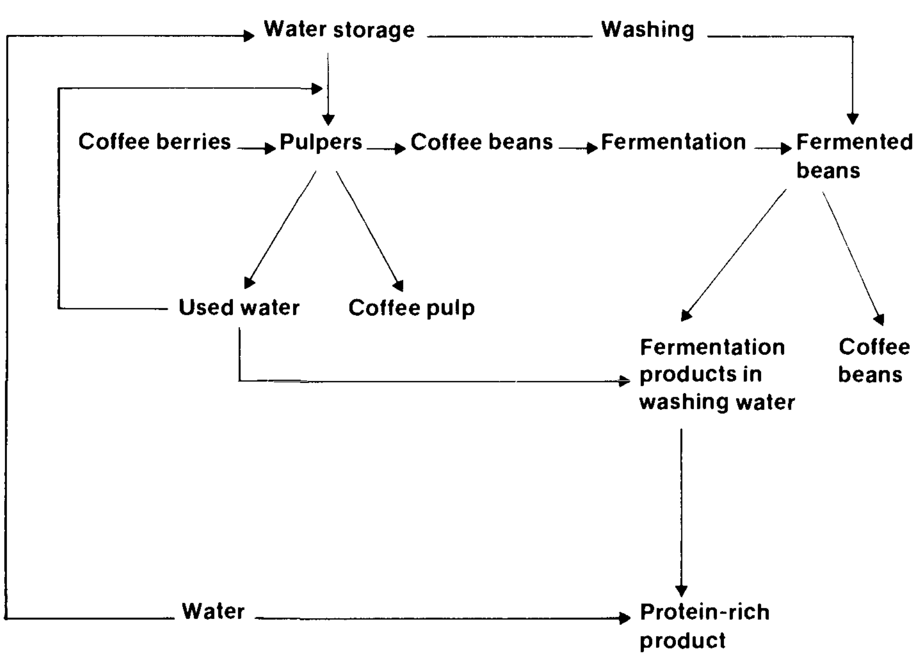

Fig. 4. Pattern of water usage in a typical coffee mill.

Table 1. Material balance of coffee processing (Bressani et al. 1972).

	Fresh wt (g)	Weight (%)	Moisture (%)	Dry wt (g)	Percentage
Coffee berry	1000	100.0	65.5	345	—
↓ pulper					
Coffee pulp	432	43.2	77.0	99	28.7
+					
Coffee beans + mucilage + coffee hulls	568	56.8	56.0	250	72.2
↓ Fermentation and washing					
Mucilage	—	—	—	17	4.9
+					
Coffee beans + coffee hulls	450	—	50.0	225	—
↓ Dehulled					
Coffee hulls	61	6.1	32.0	41	11.9
+					
Coffee beans	389	38.9	51.0	191	55.4

creases the COD concentration, and mucilage carbohydrates can be recovered (Cleves 1975, 1976a).

After removal of the mucilage, either mechanically, chemically, or by fermentation, the coffee beans are washed prior to dehydration. The initial step in dehydration is sun-drying, during which the beans are constantly turned. They are then dried with hot air in a specially designed revolving perforated cylinder. Once dried, the beans are dry processed, which consists mainly of the removal of the hull fraction, the third by-product of the process.

Material Balance

In terms of the yield of coffee beans and the other fractions, the material balance of the process as obtained in the laboratory is shown in Table 1 (Bressani et al. 1972). The process is described under the first column; whereas, the other columns show the quantities of the products expressed on either a fresh-weight or dry-weight basis. From 1000 g of coffee berries, 432 g of coffee pulp are obtained by pulping, which on a dry-weight basis represents 28.7% of the weight of the fruit. Of the 568 g of depulped coffee, the process of fermentation and washing results in a recovery of 450 g. The loss in weight, expressed on a dry-weight basis, is 4.9%, which comprises the mucilage and free sugars. Further processing of the coffee beans yields 61 g of coffee hulls and 389 g of coffee beans. These yields are equivalent on a dry-weight basis to 11.9% hulls and 55.4% coffee beans.

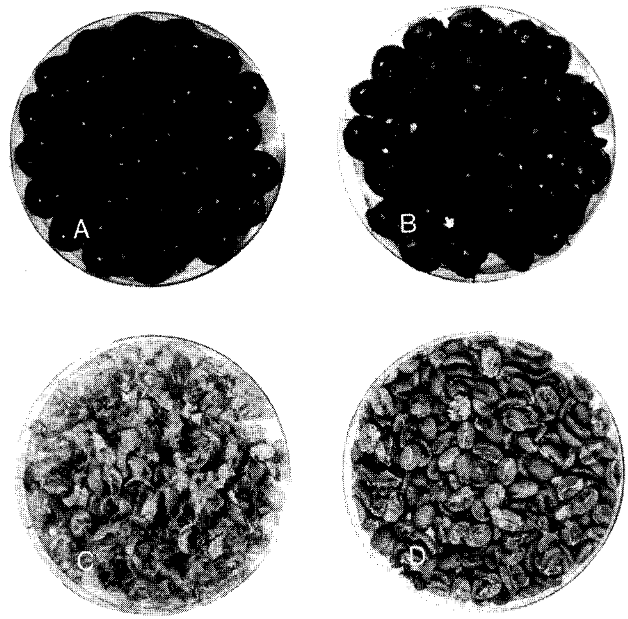

Fig. 5. Coffee berries and the three main fractions obtained by processing: A. ripe coffee berries; B. coffee pulp; C. coffee hulls; D. coffee.

The results obtained by other investigators are summarized in Table 2 (Aguirre 1966). Here, the percentage distribution of the fractions from two well-known coffee varieties and from the example given in Table 1 (representing a mixture) are compared. There is actually very little difference between the values, with the exception of the mucilage, and this difference may be due more to the process itself than to the variety of coffee. The main fractions are shown in Fig. 5.

In summary, out of 1000 g of coffee berries, about 29% of the dry weight is represented by coffee pulp, 12% by coffee hulls, 55% by coffee beans, and approximately 4% by mucilage.

Table 2. Percentage distribution of the main fractions of coffee berries (dry-weight basis).

	Arabic	Bourbon	Mixture
Pulp	26.5	29.6	28.7
Hulls	10.0	11.2	11.9
Mucilage	13.7	7.5	4.9
Coffee beans	50.0	51.7	55.4

Although this book deals specifically with coffee pulp, it is of interest to present the changes that take place, in terms of weight, during coffee roasting and brewing. Brewing, which is the process used to make the drink, yields by-products that may be utilized. Green coffee, the end product of the overall process, is roasted prior to the preparation of the drink, and on average a loss in weight of about 16% takes place. For purposes of taste trials to evaluate the quality of coffee, 7.5 g of roasted coffee is utilized per cup (Menchú 1975). From this amount only 1.8 g of solids (23.5%) are recovered per cup, most of it being the infused residue.

Coffee Production and Pulp Availability

Coffee represents an agricultural crop of significant economic importance to the coffee-producing countries of Central America. Because of this, National Coffee Associations have been active in promoting higher yields per hectare, and, therefore, the tend-

Table 3. Coffee production in some Central American countries (metric tonnes of berries).

	Costa Rica	El Salvador	Guatemala	Honduras
1970/71	396 922	757 523	64 436 068	192 273
1971/72	483 652	917 214	73 958 862	202 273
1972/73	427 505	860 152	70 367 265	250 000
1973/74	519 459	822 329	—	250 000
1974/75	460 398	995 354	—	272 727
1975/76	431 845	784 500	—	305 682
Average	453 297	857 679	69 587 398	245 492

Table 4. Availability of coffee-berry by-products in four countries in Central America (dry metric tonnes).

	Coffee pulp	Coffee hulls	Mucilage
Costa Rica	45 330	18 132	9 066
El Salvador	85 768	34 307	17 153
Guatemala	6 958 398	2 783 496	1 391 748
Honduras	24 549	9 820	4 910

ency during the last few years has been for increased yields, see Table 3 (Oficina del Café 1977; ISIC 1976; ANACAFE 1974; IH Café 1977). These data show the production of coffee berries, and on the basis of the percentage distribution of coffee pulp, coffee hulls, and mucilage, average availability figures for these three by-products are presented in Table 4. The availability of dried coffee pulp, coffee hulls, and mucilage is relatively high and thus of economic importance.

Although the price of coffee beans is still the main reason for maintaining and increasing production, the availability of coffee pulp and other by-products in such large quantities certainly warrants efforts to develop profitable uses for these products.

2

Chemical Composition of Coffee-Berry By-Products

Luiz G. Elías[1]

Coffee has been for many years one of the most profitable crops in Latin America, as well as in other areas of the world. However, although productivity has been increasing, the method used to process the fruit into beans has not changed over the years, and at the same time little attention has been given to the use of coffee processing by-products. Recently, because of problems such as by-product disposal, contamination of the environment, and a lack of ingredients for animal feeds, more attention has been given to these materials. Obviously, to utilize these by-products more efficiently it is necessary to understand their potential both in terms of available nutrients and other useful components. The objective of this chapter, therefore, is to review and discuss the chemical composition of the different coffee processing by-products: coffee pulp; coffee hulls; and mucilage.

Coffee Pulp

Proximate Composition

Coffee pulp is the first product obtained during processing, and it represents on a dry-weight basis about 29% of the weight of the whole berry. Representative values of the proximate chemical composition of fresh pulp, dehydrated pulp, and pulp 2-3 days after being obtained from the berry are given in Table 1. The moisture content is very high in coffee pulp, and as a matter of fact, this high moisture level represents the main drawback in the utilization of this product from the point of view of transportation, handling, processing, and direct use as an animal feed. The dried material, however, has about 10% crude protein, 21% crude fibre, 8% ash, and 44% nitrogen-free extract. It is also interesting to note that the chemical composition of the fermented and dehydrated coffee pulp is very similar to dehydrated and nonfermented coffee pulp. Other investigators (Aguirre 1966) have reported similar values for the protein content

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

	Fresh	Dehy-drated	Naturally fermented and dehydrated
Moisture	76.7	12.6	7.9
Dry matter	23.3	87.4	92.1
Ether extract	0.48	2.5	2.6
Crude fibre	3.4	21.0	20.8
Crude protein (N×6.25)	2.1	11.2	10.7
Ash	1.5	8.3	8.8
Nitrogen-free extract	15.8	44.4	49.2

[1]Chief, Program of Basic Food, Division of Agricultural and Food Sciences, INCAP.

of dehydrated coffee pulp, although variations from 9.2 to 11.2% have also been reported (Aguirre 1966, Bressani et al.1972). As far as crude fibre content of the dehydrated pulp is concerned, values vary from 13.2 to 27.6% (Aguirre 1966), with Jaffé and Ortiz 1952 giving an average of 18.1%. Variations in the carbohydrate fraction are also found in the literature; for example, an average value of 46% was given by Jaffé and Ortiz (1952), whereas Aguirre (1966) suggested values of 57.8-66.1%. Fat content seems to be less variable (Jaffé and Ortiz 1952), with values ranging from 2.3 to 2.5% on a dry-weight basis. It should be expected, however, that these values will change according to coffee variety, location, and agricultural practices.

Organic Components

Some of the other organic components present in coffee pulp are listed in Table 2. These substances are of interest in terms of their potential use as industrial raw materials and animal feedstuffs, and are believed to be responsible for the toxicity observed in coffee pulp. Values reported in the literature for these substances are variable. Caffeine has been reported by Jaffé and Ortiz (1952) to be 0.51% on a dry-weight basis; whereas, others have given values of 1.3% (Bressani et al.1972; Bressani 1974), also on a dry-weight basis. Regarding tannin content, the following levels have been found: 4.5% (Aguirre 1966); 1.44% (Jaffé and Ortiz 1952); and 2.4% (Molina et al. 1974). Chlorogenic and caffeic acids have been reported to be 2.71 and 0.31% by Molina et al. (1974): on the other hand, Bressani and Elías (1976) gave values of 2.6 and 1.6% for the same components.

Table 2. Other organic components present in coffee pulp.

	% dry weight
Tannins	1.80–8.56
Total pectic substances	6.5
Reducing sugars	12.4
Nonreducing sugars	2.0
Caffeine	1.3
Chlorogenic acid	2.6
Total caffeic acid	1.6

Table 3. Ash and mineral content of coffee pulp (Bressani et al. 1972).

Ash (g%)	8.3
Ca (mg%)	554
P (mg%)	116
Fe (mg%)	15
Na (mg%)	100
K(mg%)	1765
Mg	traces
Zn (ppm)	4
Cu (ppm)	5
Mn (ppm)	6.25
B (ppm)	26

Additional information on the concentrations of these substances is needed in order to associate them with coffee variety, agricultural practices, or processing techniques. The possible role of these components in the utilization of coffee pulp, either in animal nutrition or by industry, is discussed elsewhere in this monograph.

Mineral Matter

Table 3 summarizes the average content of minerals in the ash fraction of coffee pulp. The high potassium content, about 1765 mg%, can impair the use of coffee pulp as an animal feed. Besides this high amount of potassium Aguirre (1966) reported 11.1% salicylic acid in the ash fraction. It can also be observed that the ratio of calcium to phosphorus is about 4 to 1. Coffee pulp also contains other elements in different concentrations, but they probably do not have nutritional implications.

Carbohydrate Fractions

The main constituents of the carbohydrate fractions on a dry-weight basis have been reported to be: cellulose 27.65%; reducing sugars as glucose 12.40%; nonreducing sugars 2.02%; and total pectic substances 6.52% (Wilbaux 1956).

Fractionation of the cellular wall and structural polysaccharides of coffee pulp by

Table 4. Cellular wall constituents and structural polysaccharides (g%) in coffee pulp.

Cellular content	63.2
Neutral detergent fibre	36.8
Acid detergent fibre	34.5
Hemicellulose	2.3
Cellulose	17.7
Lignin	17.5
Lignified protein	3.0
Crude protein	10.1
Insoluble ash	0.4

the Van Soest method indicates a cellular content of 63%, suggesting that the material has a relatively high level of nutrients (Table 4). The levels of lignocellulose, hemicellulose, and lignin indicate that the product is superior to various other feeds. However, it is of interest to point out that because about 3% of the protein is found in a lignified form it is probably not really available (Murillo et al. 1977).

The Van Soest method indicates the true constituents of the cellular wall in addition to the cellulose and lignin content. Furthermore, the method shows that in the cellular walls of this material some of the cellulose, hemicellulose, and lignin is solubilized by the acid and alkaline treatments carried out during the crude fibre determination. The method has been used to show that there is a decrease in the crude fibre fraction of both ensiled and sun-dried coffee pulp due to the fermentation process (Murillo et al. 1977).

These findings may have nutritional implications on the utilization of coffee pulp for animal feeding. Mucilage is also a component of the carbohydrate fraction, and its composition as well as its importance will be discussed later.

Amino Acid Content

Table 5 shows the essential and nonessential amino-acid composition of coffee-pulp protein, as well as the amino acid content of other important sources of protein (Bressani et al. 1972). The data indicate that coffee-pulp protein has similar or higher levels of amino acids than other products such as cottonseed and soybean flours. Likewise, coffee pulp generally has higher concentrations of amino acids than corn. On the other hand, coffee-pulp protein is de-

Table 5. Amino-acid content (g/16 g N) of coffee-pulp protein compared to other important protein sources (Bressani et al. 1972).

	Coffee pulp	Maize	Soybean meal	Cotton-seed meal
Lysine	6.8	1.7	6.3	4.3
Histidine	3.9	2.8	2.4	2.6
Arginine	4.9	3.1	7.2	11.2
Threonine	4.6	3.3	3.9	3.5
Cystine	1.0	1.0	1.8	1.6
Methionine	1.3	1.6	1.3	1.4
Valine	7.4	5.0	5.2	4.9
Isoleucine	4.2	4.3	5.4	3.8
Leucine	7.7	16.7	7.7	5.9
Tyrosine	3.6	5.0	3.2	2.7
Phenylalanine	4.9	5.7	4.9	5.2
Hydroxyproline	0.5	—	—	—
Aspartic acid	8.7	—	—	—
Serine	6.3	—	—	—
Glutamic acid	10.8	—	—	—
Proline	6.1	—	—	—
Glycine	6.7	—	—	—
Alanine	5.4	—	—	—

Table 6. Amino-acid content (g/16 g N) of fresh pulp and pulp treated with calcium hydroxide ($Ca(OH)_2$) by immersion and by spraying for two lengths of time and at three concentrations (T = trace).

	Soaking								Contact (spraying)								
	0 h				16 h				0 h				16 h				
	0	1%	2%	3%	0	1%	2%	3%	0	1%	2%	3%	0	1%	2%	3%	Control
							7.37 2.40 1.78										
Aspartic acid	3.82	6.98	4.49	6.06	5.34	6.06	8.28	7.61	6.60	6.52	6.10	5.18	6.50	4.85	7.23	8.20	6.45
Threonine	1.89	2.89	1.80	2.92	2.47	2.42	2.44	2.63	2.55	2.01	2.58	2.26	3.09	2.11	2.67	3.56	2.94
Serine	1.69	2.47	1.38	2.44	2.28	2.18	1.94	2.41	1.72	1.57	2.18	1.93	2.32	1.76	2.07	2.57	2.14
Glutamic acid	6.81	9.50	5.60	8.25	7.34	7.50	5.00	8.40	7.91	8.75	8.63	7.07	8.41	7.35	9.16	9.90	8.73
Glycine	4.96	4.48	3.17	5.55	5.37	4.57	—	6.00	4.30	4.53	4.85	4.61	5.27	4.18	5.07	5.65	4.40
Alanine	3.13	3.87	2.65	4.41	4.14	3.15	—	4.66	3.95	4.00	4.16	3.99	4.48	3.49	4.72	5.17	3.46
Valine	4.66	5.33	3.26	6.01	5.44	4.33	4.42	5.37	4.84	5.15	4.71	4.95	5.62	2.28	5.14	5.68	4.89
Cystine	T	—	—	—	T	0.18	4.89	0.42	—	—	—	—	—	0.28	0.26	0.25	0.33
Methionine	T	—	—	—	0.22	0.11	2.35	0.17	—	—	0.09	—	—	—	0.33	0.19	0.10
Isoleucine	4.05	4.73	2.67	5.05	4.01	4.50	3.52	3.12	3.59	4.93	3.95	3.89	4.05	3.34	5.34	4.76	4.60
Leucine	4.96	5.82	4.03	5.52	4.80	4.52	3.36	6.19	4.84	4.11	5.33	5.45	5.18	5.37	4.98	5.79	4.73
Tyrosine	2.13	2.30	1.56	2.56	2.35	2.22	2.88	2.40	1.33	2.14	2.24	1.74	2.49	2.08	2.96	2.81	2.29
Phenylalanine	3.12	3.89	2.19	3.80	3.14	3.49	3.47	3.61	2.60	3.13	3.38	3.34	3.46	2.91	3.47	3.73	3.24
Lysine	4.08	5.26	2.82	4.13	4.40	3.93	47	4.14	3.75	4.08	4.36	3.59	5.15	4.11	3.32	3.97	3.96
Histidine	2.54	2.60	1.82	3.12	2.83	2.35	47	3.29	1.34	1.94	1.88	2.40	2.20	2.39	2.89	2.62	2.64
Arginine	2.86	3.61	4.33	3.41	3.67	3.25	47	3.56	1.84	2.60	3.44	3.20	3.42	3.30	3.03	3.69	3.82

ficient in sulfur-containing amino acids. It is of interest to note, however, the relatively high level of lysine present in coffee pulp, which is as high as that found in soybean meal on a per gram of nitrogen basis. More research is needed on the amino-acid composition of coffee pulp because there is a lack of research in this area.

Recently, Bendaña and Gómez-Brenes (1977) reported the amino-acid composition of fresh coffee pulp treated with calcium hydroxide (Table 6). In general, the values are lower than those previously described by Bressani et al. (1972) for coffee pulp. According to these investigators about 40% of the total nitrogen in the coffee pulp, as measured by the Kjeldahl method, is nonprotein nitrogen. This nonprotein nitrogen includes caffeine, trigonelline, niacin, purines, pyrimidines, inorganic nitrogen, and other fractions not yet identified. Therefore, the lower amino-acid concentration could be due to the fact that only about 60% of the nitrogen comes from protein (they reported that nitrogen recuperation from the sum of all the amino acids accounted for only 60% of the total nitrogen concentration in the coffee pulp). These results seem to partially explain the biological effect of coffee pulp in animal feeding, where it has been found in several studies (Bressani 1975) that there is a beneficial effect of protein level in counteracting coffee-pulp toxicity. These findings could be related to the fact that protein values for the experimental diets have been calculated on the basis that all the nitrogen in the coffee pulp is protein. Therefore, to clarify the adverse physiological effects of coffee pulp, as well as to ascertain its real protein digestibility and true protein value, it is important to identify and determine the nonprotein nitrogen compounds. It was also concluded in the same study that the chemical treatment applied to the coffee pulp did not change the amino-acid content of this material.

Besides the amino-acid composition, it is also of interest to point out that the biological availability of these amino acids is not known. Because of the relatively high tannin content in coffee pulp, and the fact that it is known to react with protein (Tamir and Alumet 1969; Van Buren and Robinson 1969), it is possible that this reaction may render its amino acids partially unavailable to the animal. This requires further investigation.

Mucilage

The other by-product of interest is the mucilage, which is located between the coffee pulp and the coffee hulls and represents about 5% of the dry weight of the coffee berries (Bressani et al. 1972).

Mucilage constitutes a layer approximately 0.5–2 mm thick that is strongly attached to the coffee hulls. From the physical point of view it is a colloidal liquid system, and being a hydrogel it is lyophilic. Chemically the mucilage contains water, pectins, sugars, and organic acids. During maturation of the coffee berry, calcium pectate located in the middle lamella and protopectin from the cellular wall are converted into pectins. This transformation or hydrolysis of the protopectins results in a disintegration of the cellular wall, leaving the cellular plasma free. Besides pectins, this plasma contains sugars and organic acids derived from the metabolism and conversion of starches into sugars (Carbonell and Vilanova 1974).

The composition of this material is shown in Table 7. Total pectic substances run as high as 39% with an average value of 35.8%. Most of the total sugar content is in the reducing form. The chemical composition of the mucilage has also been reported by Nadal (1959) as being: 84.2% water; 8.9% protein; 4.1% sugar; 0.91% pectic acid; and 0.7% ash. This fraction apparently has neither tannins nor caffeine, but contains pectin-degrading enzymes that so far have not been well identified (Aguirre 1966).

Table 7. Composition (%) of mucilage.

Total pectin substances	35.8
Total sugars	45.8
Reducing sugars	30.0
Nonreducing sugars	20.0
Cellulose + ash	17.0

These pectin enzymes can hydrolyze the pectic constituents in this material, and their activity seems to be important in the fermentation that occurs during coffee processing (Wilbaux 1956). However, it is believed that these enzymes do not exist in the mucilage itself, but migrate from the pericarp or the endosperm through a process of osmosis and diffusion (Wilbaux 1956). Wilbaux (1956) also reported that these enzymes only catalyze the removal of the methoxyl groups from the pectin molecule, and do not act on the glycosidic linkage of the polygalacturonic acid (pectic acid). Therefore, the enzymes in the mucilage probably belong mainly to the pectin-methylesterase group.

It has been reported that the pH of the mucilage varies according to the degree of ripeness, as well as the method used for coffee processing (Wilbaux 1956). In *Coffea arabica*, manual processing of the ripe coffee berries results in a mucilage pH of about 5.6–5.7; whereas, mechanical processing using water with pH 6.4 results in pH values of 5.0–5.2. Variations in pH should have an influence on the enzyme activity in the fermentation process, as well as on the components of this by-product.

More studies are needed to establish the effect of variety, time of harvest, and processing conditions on the chemical composition of the mucilage. Furthermore, this aspect should be ascertained not only from the academic point of view, but also because industrial utilization of this material as a commercial source of pectins has been proposed by several investigators (Bressani and Elías 1976; Cleves 1974). These methods are based on the precipitation of the pectin fractions either by the use of calcium hydroxide, which forms calcium pectate, or the addition of alcohol followed by agitation. In this latter process, wads of precipitated pectins are obtained (Cleves 1974).

On the other hand, more studies on this subject are justified, because the mucilage must be withdrawn as quickly as possible after the removal of the pulp from the coffee berries. Prolonged contact at this stage results in drawbacks in coffee-bean dehydration, in a staining of the dried product, and in deterioration of the coffee beans because the mucilage is an excellent substrate for the growth of fungi, bacteria, and other microorganisms.

Table 8. Chemical composition of coffee hulls, corncobs, and cottonseed hulls (Bressani et al. 1972).

	Coffee hulls	Corn-cobs	Cotton-seed hulls
Moisture (%)	7.6	8.1	10.4
Dry matter (%)	92.8	91.9	89.6
Crude fat (%)	0.6	0.9	1.1
Nitrogen (%)	0.39	0.39	0.58
Ash (%)	0.5	1.6	2.5
NFE (%)	18.9	48.1	56.7
Ca (mg)	150	765	160
P (mg)	28	274	80

Table 9. Fractionation of the carbohydrate content of coffee hulls (%) (Murillo et al. 1977).

Soluble carbohydrates	
Hexoses	0.45
Structural carbohydrates	
Pentoses	20.30
Hexoses	45.90
Lignin	24.40
Total	91.05
NFE + crude fibre	96.21

Coffee Hulls

As described earlier, coffee hulls enclose the coffee beans and represent about 12% of the berry on a dry-weight basis.

The gross chemical composition of this material (Bressani et al. 1972) has been compared to corncobs and cottonseed hulls (Table 8). Protein concentration is similar in all three by-products, but crude fibre is significantly higher in coffee hulls. The nitrogen-free extract of coffee hulls is the lowest, therefore, their value as a feed is questionable. Table 9 summarizes the fractionation of the carbohydrates of coffee hulls. Because lignin, pentose, and hexose concentrations are very high, it may be possible by some chemical treatment to increase the energy value of this potential feed (Murillo et al. 1977).

3

Potential Uses of Coffee-Berry By-Products

Ricardo Bressani[1]

In Central America, coffee berries are processed either at the mill of the coffee plantation or at mills that are located within relatively short distances of both small and large coffee-producing areas. In the first case, the mill has the capacity to process all the coffee harvested at the farm. The amounts processed are quite variable, but in most cases not large enough to warrant investment in processing equipment for the industrial utilization of the by-products. However, the coffee harvest may last up to 5 months because the fruit does not ripen all at once, which makes the possibility of using coffee pulp for animal feed appear more promising. Under these conditions, the constant but small amount of pulp produced can be easily handled and dried without additional equipment.

On the other hand, the centrally located industrial-type coffee mills have a larger capacity and process coffee produced by both small and large farms. As the quantities processed are relatively large, the possibilities for economic investment in the industrialization of coffee by-products are better than in the former case. Based on these considerations, as well as on the availability of the by-products and their chemical composition, various schemes for by-product utilization have been published. Fig. 1 summarizes a series of possibilities supported by experimental work.

In most cases, the processes have been designed to render coffee pulp suitable for animal feeding, either in the form of silage or as a dried product (Bressani et al. 1974; Ruiz 1974). This aspect will be discussed in later chapters of this publication. Coffee pulp contains from 80 to 88% water (Bressani et al. 1972); therefore, an operation such as pressing may reduce moisture to 55–60%. The residue of this operation could be utilized as an animal feed, as such, ensiled, or dried, and the extracted juice could be converted into other products or used for other purposes.

Coffee pulp may also be extracted with water or organic solvents to obtain caffeine and other compounds. The residue of such a process may again be utilized as an animal feed. Some attempts have also been made to extract the protein from coffee pulp as well as the pectic substances, including pectinolytic enzymes. Other approaches include hydrolysis to produce molasses, fermentation to yield alcohol, and a variety of extracts for soft drinks, jams, and similar types of foods (Aguirre 1966). Natural fermentation produces a good organic fertilizer and at the same time evolves biogas. This last approach is attractive because of the ever-increasing scarcity and high cost of the

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more common energy sources.

The second coffee by-product of importance in terms of amounts available is coffee hulls, and their possible uses are shown in Fig. 2. Because of their chemical composition, coffee hulls do not offer as many useful possibilities as coffee pulp. As an animal feed the hulls can play a role as a filler only for ruminant rations. Their chemical composition (Bressani et al. 1972) indicates that the amount of ether-extractable substance is too small to be of economic importance. At present, hulls are used as a fuel in the drying of the coffee beans (Aguirre 1966).

The potential for utilization of the mu-

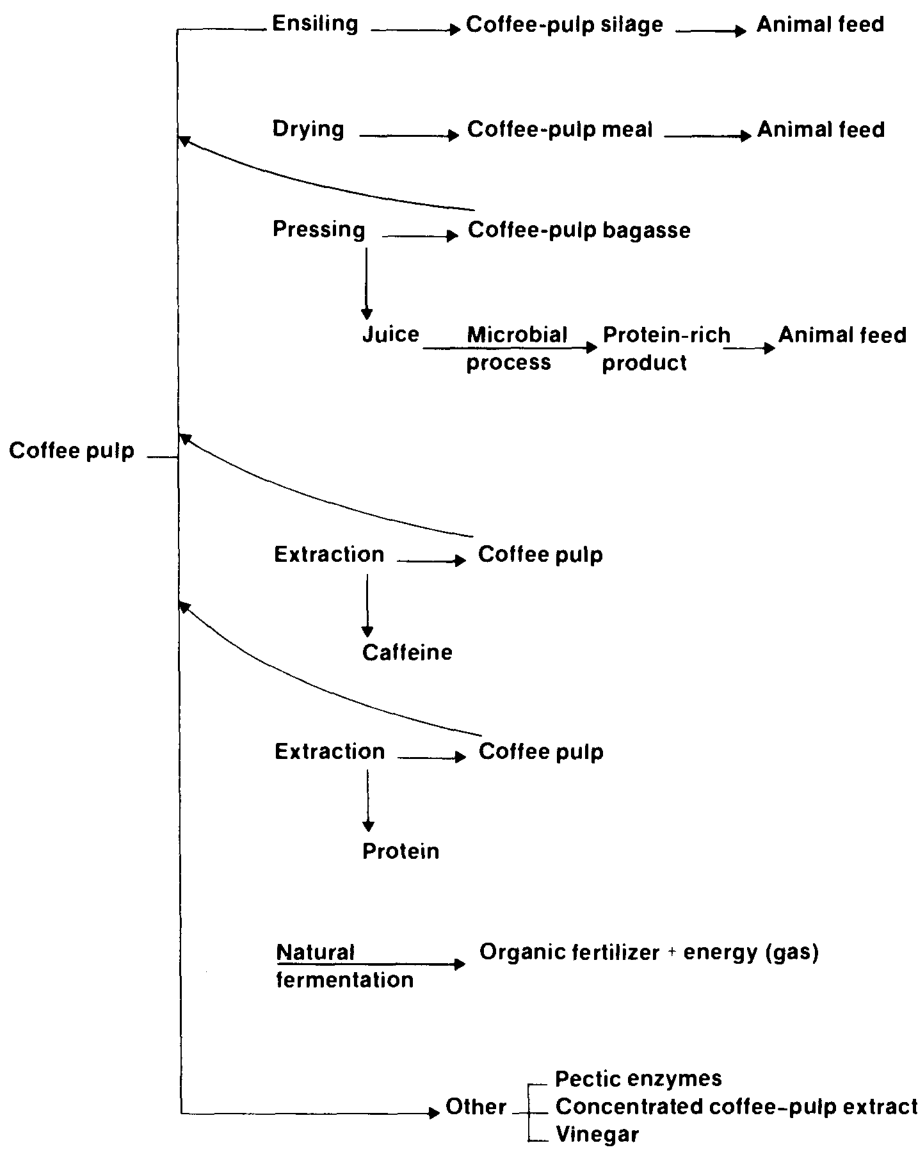

Fig. 1. Possibilities for the utilization of the by-products of coffee.

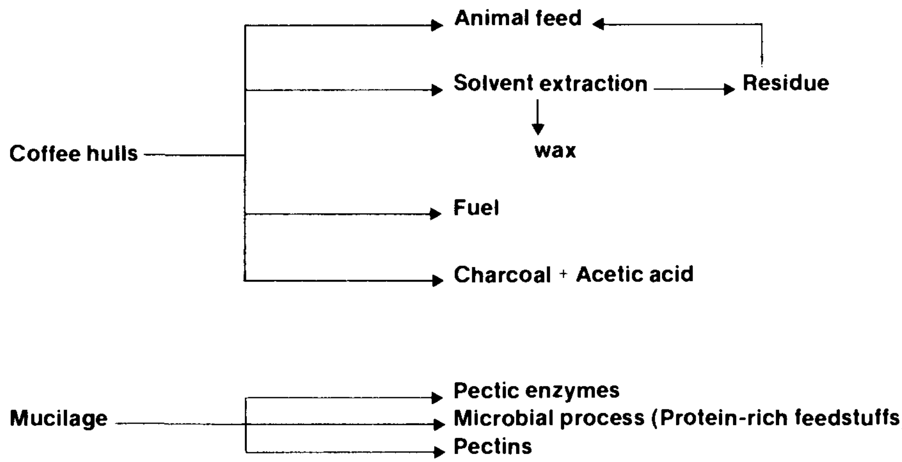

Fig. 2. Possible uses for coffee hulls and mucilage.

cilage and coffee processing waters is shown schematically in Fig. 2 and 3. The use of these materials to produce pectins is quite attractive. On the other hand, these by-products have been tested as substrates in microbial processes for the production of protein (Aguirre 1966; Rolz 1973).

Coffee Pulp

Microbial Growth

Because coffee pulp is a relatively rich source of sugars, its use for microbial growth is of interest. Some work was carried out in Colombia (Calle 1951, 1954) for the pro-

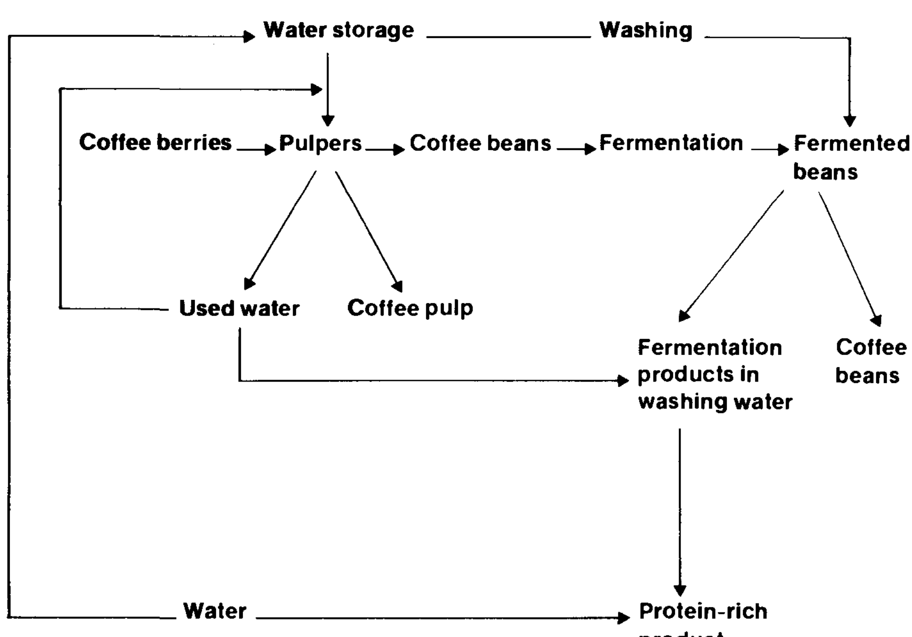

Fig. 3. Potential use of coffee-processing waste waters.

duction of yeast. The fresh pulp was boiled for about 1 h, then the water was removed, adjusted to pH 4.5, and inoculated with *Torulopsis utilis*. The water extract was supplemented with 0.5% ammonium phosphate. After 24 h the yield of yeast was 7.5 mg (dry weight)/cm^3 of liquor, which originally had contained about 1.2% sugar. Pilot-plant trials yielded about 750 g of dried yeast per 100 kg of coffee berries. Table 1 gives the gross chemical composition of the yeast. Samples produced in Colombia and Costa Rica have practically the same composition, with a protein concentration above 45%. Others (INCAP 1970; Calle 1974) have suggested that coffee pulp is a relatively good substrate for *Aspergillus oryzae*, *Bacillus megatherium*, and *Saccharomyces carevisae*.

Protein Extraction

Because of the attractive essential amino-acid pattern of coffee-pulp protein, attempts have been made in our laboratories to prepare protein concentrates from fresh coffee pulp (De la Fuente et al. 1974). So far, the studies have indicated that although relatively high nitrogen extractions can be obtained, only small amounts of protein are recovered (see Table 2). Water extraction with constant agitation released on average about 42% of the original nitrogen. Increasing the pH of extraction decreased the amount of nitrogen extracted. To learn if higher amounts could be obtained, the pulp was treated with cellulase and maceroenzymes for various periods of time. These treatments increased total extraction up to 71% of the nitrogen in the pulp; higher extractions have been difficult to obtain, and problems have been found in precipitating the protein. The reason for this is that coffee pulp contains high levels of tannins, which bind the protein and make it difficult to extract and precipitate. An additional problem is that the free phenols in coffee pulp become oxidized to quinones. Quinones are oxidizing agents that may oxidize essential groups of the proteins; more important, they polymerize rapidly, and react to form covalent bonds with the protein. Studies are under way to block such reactions, which may result in higher extraction rates of the nitrogen as well as in precipitation of the protein in a more concentrated form. In these experiments, sulfite treatment is used to inhibit oxidation of the phenols, and polyvinyl pyrrolidone, preferentially binds tannins, allowing the protein to be extracted.

Table 1. Proximate composition of torula yeast produced from coffee pulp (dry weight, %) (Calle 1951; INCAP 1970).

	Colombia	Costa Rica
Ether extract	—	1.3
Crude fibre	3.4	7.5
Ash	8.5	8.9
Crude protein	44.8	46.4

Caffeine Extraction

Caffeine has been identified as one of the components in coffee pulp that is responsible for some of its adverse physiological effects on animal nutrition. On the other hand, the market price of caffeine is relatively high and the alkaloid has a variety of uses. Studies have been carried out to learn if caffeine could be easily and economically extracted from coffee pulp (Molina et al. 1974; Cuevas 1976). Various solvents and methods of extraction were tested on fresh and dried coffee pulp. These were alcohol extraction, water at 25 °C, water

Table 2. Preliminary results for protein extraction from fresh coffee pulp using different solvents (Bressani 1975).

	Number of extractions	pH	Extraction (%)
Water	1	5.0	41.7
Water	2	5.0	51.6
Water	2	6	36.6
Water	2	9	35.1
Water	2	10	32.1
3%NaCl	2	—	30.2
Cellulase + maceroenzymes	—	7	70.6

Table 3. Chemical analysis (%) of coffee pulp extracted by different methods (Molina et al. 1974).

	Dehyd. pulp	Percol.	Extract. at 25°C	Extract. at 25°C + alcohol	Alcohol extract.
Water	5.02	6.21	7.02	8.43	8.63
Protein	11.90	11.19	11.25	9.75	11.19
Caffeine	1.27	0.02	0.31	0.29	0.76
Tannins	2.40	0.53	1.81	0.93	1.00
Chlorogenic acid	2.60	0.35	1.42	0.35	0.90
Caffeic acid	0.24	0.00	0.35	0.00	0.10
Total caffeic acid	1.56	0.18	1.06	0.18	0.56
Total soluble sugars	8.83	1.54	3.70	3.21	6.04

extraction at 25 °C followed by alcohol, and pure alcohol extraction. The effects of the various methods on the chemical composition of the residue are summarized in Table 3. Percolation carried out in three stages of 1-h duration each, gave a residue lower in caffeine, tannins, and chlorogenic and caffeic acids than extraction with water at 25 °C, water extraction at 25 °C and alcohol, and pure alcohol extraction.

Table 4 summarizes the extraction efficiency of the four procedures. Percolation resulted in an almost complete removal of caffeine, with 29% extraction of total solids. The percolation process is now being optimized at the pilot-plant level in our laboratories (Cuevas 1976), and the extract is under study for practical food applications for removal of caffeine.

Table 4. Extraction efficiency of the four procedures used for coffee pulp.

	Caffeine ext. (%)	Total solids ext. (%)
Alcohol	69.53	19.10
Water (25 °C)	78.11	28.33
Water (25 °C) + alcohol	84.65	35.50
Percolation	99.06	29.01

Organic Fertilizer

Maintenance of organic matter in tropical soils is considered particularly important because the soils are rapidly depleted by high year-round bacteriological activity. Because of this, and to avoid the environmental problems coffee pulp causes when it is piled up to decompose, the pulp is utilized as an organic fertilizer in coffee plantations. Different methods are used: one of them is to apply fresh pulp directly from the pulpers to the coffee trees; a second approach is to dry the pulp before application. Suárez de Castro (1960) has indicated that 45 kg of dried coffee pulp is equivalent, on the basis of its chemical composition, to 4.5 kg of an inorganic fertilizer

Table 5. Chemical composition (%) of various organic fertilizers (Suárez de Castro 1960).

	Coffee pulp (El Salvador)	Cow manure	Compost. farm resid. (El Salvador)	Chicken manure	Compost. wastes (Puerto Rico)	Compost. wastes (El Salvador)
Organic matter	91.20	—	15.60	—	36.42	54.37
Nitrogen	1.94	0.50	1.20	1.6	2.28	1.23
Phosphorus (P_2O_5)	0.28	0.25	0.83	1.5	4.71	0.79
Potassium (K_2O)	3.61	0.50	0.98	0.8	2.87	0.87
Calcium (CaO)	—	—	—	—	—	5.32

14-3-37 or to 9 kg of 7-1.5-18.5. This reflects the high potassium content of coffee pulp (Bressani et al. 1972). The organic matter of coffee pulp contains more nitrogen and potassium than other common fertilizers (Table 5), and various experiments have indicated that coffee pulp is a valuable organic fertilizer particularly for the coffee tree. Handling is the problem in its use because of its high moisture content (Bressani et al. 1972).

Other Uses

Coffee pulp has been tested as a raw material for the production of a variety of products (Aguirre 1966). Of particular interest is the production of coffee-pulp molasses (Molina et al. 1974), which has been produced by hydrolyzing coffee pulp for 4–6 h with a 6% HCl solution at 121 °C and 1.05 kg/cm² (15 psi). Besides this type of molasses, other types have been produced by concentration of the sugars and the breakdown products from mucilage and coffee pulp extracts. The molasses has been evaluated with swine at up to 30% of the diet, and the results suggest that it is as good as sugarcane molasses (Buitrago et al. 1968). Also of some interest is the finding that the roasting of coffee pulp as well as of coffee beans results in a significant increase in niacin content (Bressani et al. 1962). For coffee pulp after 20 min of roasting there was a 15-fold increase; whereas, for coffee beans, the increase was about 19-fold. The niacin produced during roasting was biologically available as tested in growing chickens.

Also of interest is the utilization of coffee pulp to produce biogas. Calle (1955) reported the production of 670 litres of methane in 72 days from 30 kg of coffee pulp mixed with cow manure. The residue of this process was rich in nitrogen and was suitable as an organic fertilizer.

Coffee Hulls

Coffee hulls are characterized chemically by a high concentration of crude fibre and in this respect they are similar to various other by-products used as fillers in animal feeds (Bressani et al. 1972). The cellular contents of coffee hulls amount to about 12%, while the cellular wall components, that is the neutral and acid detergent fibres, are found in amounts of 88 and 67%, respectively (Jarquín et al. 1974).

Cellulose can be utilized by ruminants as a source of energy; however, the utilization of coffee hulls is limited by lignin, silica, and other compounds. Lignin content runs as high as 18% and insoluble ash about 5%.

To increase the metabolic utilization of coffee hulls it is necessary to hydrolyze cellulose and similar compounds. Preliminary results (Table 6) indicate that alkaline treatment increases the percentage of soluble carbohydrates. Hydrolysis by 10% solutions of sodium or calcium hydroxide, reduced the crude fibre content from 62.1% to 34.1 and 35.8%, respectively (Murillo et al. 1975).

Because of its structure and chemical composition, coffee hulls do not offer many other possibilities for use, although it is considered a good fuel. In fact, the most common way for the hulls to be used in coffee mills is to provide the energy needed for the final dehydration of the coffee beans (Aguirre 1966).

Coffee-Processing Waste Waters

In many centralized coffee-berry processing mills the disposal of the water used for pulping and washing of the fermented coffee beans presents serious problems. Therefore, efforts are being made to use these waters as a substrate for microbial growth that in turn would be used as a protein-rich animal

Table 6. Effect of alkali treatments at four different levels on the crude fibre (%) of coffee hulls.

	Percentage of hydroxide			
	0	2.5	5.0	10.0
Sodium hydroxide	62.1	50.5	42.5	34.1
Calcium hydroxide	62.1	52.6	45.6	35.8

feed. The Central American Research Institution for Industry (ICAITI) is active in this project (Buitrago et al. 1968; ICAITI 1973). In cooperation with the Denver Research Institute, a project was developed to design a process by which a microorganism growing in a continuous, nonaseptic, simple fermentor could significantly reduce the chemical oxygen demand (COD) of the coffee-processing waste waters. From a group of 21 fungi and yeasts, four were selected that produced acceptable COD reductions and yields of mycelia: *Aspergillus oryzae* I-14; *Myrothecium verrucaria* P-9; *Palcitomyces elegans* I-134; and *Trichoderma viride* I-189. With these four microorganisms COD reductions of 56–83% were obtained using shake-flask experiments. Increases in insoluble solids ranged from 3.95 to 5.32%. For further work, *A. oryzae* (I-14) was selected because it gave a mycelium with a higher protein content and lower levels of cellulose than the others. Using batch operations with experimental-scale fermentors, specific growth rates ranged from 0.04 to 0.1 g/h.

From studies carried out using continuous operations various problems were encountered; however, COD reduction varied from 50 to 75% and dry-mass yields were close to 0.40 g/g COD removed. The chemical composition and amino-acid content of the product are shown in Table 7. Protein content was 41.2%, fat 4.2%, cellulose 4.7%, and ash 15.3%. The amino-acid content was similar to that reported for other fungi with 4.7 and 1.1 g/100 g protein of lysine and methionine, respectively. Rat feeding tests indicated no accute toxic symptoms from diets containing the dry mycelia (Buitrago et al. 1968; ICAITI 1973).

Table 7. Chemical composition (%) and amino acids (g/16 g N) in dry mycelia of *A. oryzae* I-14 grown in coffee-processing waste waters (Rolz 1973).

Moisture	1.7
Total N	7.5
Inorganic N	0.9
Organic N	6.6
Protein (organic N × 6.25)	41.2
Fat	4.2
Cellulose	4.7
Ash	15.3
Amino acids	
Alanine	6.0
Arginine	2.9
Aspartic acid	7.9
Glutamic acid	9.3
Glycine	4.7
Histidine	1.2
Isoleucine	4.0
Leucine	5.8
Lysine	4.7
Methionine	1.1
Phenylalanine	3.5
Proline	3.6
Serine	3.2
Threonine	3.8
Tyrosine	2.4
Valine	4.9

The laboratory experience was used to design, construct, and operate a pilot plant in El Salvador with a capacity of 38 000 litres (10 000 gal) of waste water per 24 h. This plant has been in operation since 1973, which has permitted the calculation of material balance and costs of operation (Table 8). From a total of 33.8 tonnes of COD processed, 13.5 tonnes of total mycelia were produced, which is equivalent to 4.7 tonnes of protein. Each pound of mycelia that was produced cost about $U.S.0.09 (ICAITI 1973). These results show that it is possible to use the waste waters to produce feed-grade protein concentrates.

The same workers are also attempting to isolate pectic enzymes; however, enzymatic activity is quite low in comparison with

Table 8. Material balance and costs for the production of microbial protein from coffee-processing waste waters (ICAITI 1973).[a]

Total processed COD (tonnes)	33.8
Total mycelia produced (tonnes)	13.5
Total protein produced (tonnes)	4.7
Cost of installed equipment ($U.S.)	8240
Operation costs ($U.S.)	1790
Cost of mycelia/lb ($U.S.)	0.09

[a] Base: 100 days of continuous operation; 10 000 gal/day; initial COD 15 g/litre; reduction of COD 60%; yield 40%.

commercial preparations. Further studies are being carried out to concentrate the enzymes by saturation with ammonium sulfate (ICAITI 1973).

Mucilage

Coffee-berry mucilage is very rich in pectic substances, which could yield pectins. These substances, however, are somewhat difficult to recover at present because during the pulping and washing operation (see Chapter 1) they are carried away with very large volumes of water and are most probably well advanced in fermentation. Therefore, if the pectic substances are to be utilized, it will be necessary to either recycle the water as described in Fig. 3 or use coffee pulp as the raw material.

Various researchers have attempted to recover the pectic substances from the mucilage of coffee. Menchú et al. (1974) acidified the mucilage to pH 2 immediately after extraction to reduce enzymatic breakdown. The material was then centrifuged to separate the pectic substances from impurities, and treated with ethyl alcohol, which precipitated the pectin. Recovery was achieved by filtration followed by drying at low temperature. The total pectin obtained, expressed as galacturonic acid, was 17 g/100 g of mucilage. The problem with this approach is the high cost of ethyl alcohol. Orozco (1974), whose objective was to purify the residual waters from coffee processing, added calcium oxide to obtain a pH of 12. The calcium oxide coagulated the pectin substances and caused them to sediment as calcium pectate, which was separated by filtration.

On the basis of these and other studies, as well as on the price of pectin, Cleves (1975) calculated the economic feasibility of pectin recovery and concluded that the possibilities were promising. Much work is still needed, however, to put the process into practice.

The information presented in this chapter indicates that because of the relative richness of coffee pulp and other coffee-processing by-products, in both carbohydrates and other organic compounds, these by-products may have useful industrial applications. These uses may be as a raw material for the isolation of specific substances or as a substrate for the production of other materials. The research carried out so far has not been detailed enough to be able in most instances to permit the application of the results to the establishment of an appropriate industry. Furthermore, because of the relatively high price paid for coffee beans, there has been little interest in the industrial utilization of the by-products. There is, however, increased awareness in coffee-producing countries of the public health problems coffee by-products originate as well as of the need to make the industry more sound by utilizing the fruit as much as possible. If economic feasibility studies show that industrialization is possible, coffee pulp will be used for more than an organic fertilizer or animal feed.

4

Use of Coffee Pulp in Ruminant Feeding

M.T. Cabezas,[1] A. Flores,[2] and J.I. Egaña[2]

This chapter reviews the nutritional characteristics of coffee pulp for ruminants, and attempts to draw conclusions about the potential, as well as the limitations, of this material in feeding systems in Central American countries. The greater part of this information was obtained from research done with cattle. In all cases, coffee pulp sun-dehydrated immediately after being produced (DCP), sun-dehydrated after being ensiled (EDCP), or fresh ensiled coffee pulp (ECP) was employed. Animal nutrition research has not been conducted with pulp processed by other means.

Nutritive Quality of Coffee Pulp

Voluntary Feed Intake

One of the principal factors used to determine the nutritive value of a feed is the quantity of the feed animals consume when they have free access to it. The first studies done on coffee pulp (see Squibb 1950) indicated that one of the limitations for the use of this material as a feedstuff for cattle was the reluctance of the animals to consume it when it was supplied as the main ingredient of their ration. However, voluntary feed intake improved when the pulp was supplemented with highly palatable feeds, forages, and protein concentrates (but the quantities of these materials necessary to adequately balance a ration based upon coffee pulp was not specified). These studies pointed out that the decrease in consumption brought about by coffee pulp was due to its low palatability, and, possibly, to adverse effects on the digestion and metabolism of the animals.

More recent studies (Osegueda et al. 1970; Ayala 1971; Ledger and Tillman 1972; Jarquín et al. 1972; Cabezas et al. 1974b, 1976; Vargas 1974; Flores Recinos 1973, 1976; Ruiz and Ruiz 1975) have supplied additional information on the negative effects of the pulp on voluntary consumption and on the best methods of supplementation to counteract these effects. The main objective of these studies was to investigate the effects of the pulp on the performance of beef cattle upon the addition of other ingredients to the rations (see section on cattle feeding).

Effect of Coffee Pulp on Digestibility of Rations

The first study published on the digestibility of coffee pulp was done by Lewy Van Severen and Carbonell (1949) who used female goats fed a ration of 62% DCP and 38% banana leaves. The digestibility coefficients calculated for crude protein, dry matter, nitrogen-free extract, fat, and crude fibre of DCP were 34.0, 76.3, 76.4, 97.9,

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and 87.7%, respectively. In a trial with wethers using DCP, Rogerson (1965) obtained coefficients of 7-13.5% for crude protein, 26.1-29.6% for crude fibre, 48.7-51.6% for nitrogen-free extract, and 38.2-41.9% for organic matter. Caielly et al. (1974) fed 2-year-old sheep rations, based on Bermuda grass, hay, and sugarcane molasses, that contained 0, 10, 20, and 30% DCP. They determined that the total digestible nutrients (TDN) of these rations were 41.8, 44.8, 42.9, and 44.2%, respectively. The dry-matter digestibility of the pulp and the hay, calculated by regression, was 57.1 and 46.5% in each case.

These values show a great variability in the digestibility of the nutrients present in the coffee pulp, which may have been due to differences in the origin and processing of the pulp and the composition of the basal rations.

Cabezas et al. (1977) determined the digestibility of rations, containing 0, 20, 40, and 60% DCP, fed to different groups of growing calves (Table 1). The pulp was incorporated into the experimental rations in partial substitution for cottonseed hulls and cottonseed meal, which, together with sugarcane molasses and a mixture of minerals, constituted the basal ration. The total dry-matter intake decreased linearly ($r = 0.89$) as the DCP increased in the rations, but the consumption of this material was higher ($p < 0.05$) with the rations that contained a greater proportion of DCP. The digestibility of the organic matter was higher ($p < 0.05$) with the rations containing 40 and 60% DCP than with the other two rations. The same tendency was observed with the digestibility of the gross energy, although the difference was not significant. The digestibilities of the organic matter and of the DCP energy, calculated by difference, were 54.8 and 51.1%, respectively (Table 2).

The increases in digestibility observed in the rations that contained greater proportions of DCP may have been a consequence of the reduction in intake caused by the pulp. Nevertheless, at the same levels of intake, the digestibility of the protein decreased significantly to 47.0 and 45.7% in the rations with 0 and 20% DCP to 37.8 and 36.2% in those that contained 40 and 60% DCP. This decrease can be attributed to the low digestibility of the DCP protein (27%, Table 2).

The digestibility values of the DCP (Table 2) show that the dry matter contains 2.2 Mcal of digestible energy (DE)/kg and 3.8% digestible protein, which means that, in terms of digestibility, DCP is equivalent to a good quality tropical grass.

Daqui (1974) used young steers to determine the digestibility of a mixture of silages that contained, on a dry basis, 61% coffee pulp and 39% corn plant ensiled when that grain was in its milky phase (CS). The

Table 1. Dry-matter intake and digestibility of rations containing from 0 to 60% dry coffee pulp (from Cabezas et al. 1977).

	0%	20%	40%	60%
Protein content of the complete ration (%DM)	14.4	14.4	15.0	15.0
DM intake/day (kg/100 kg live weight)				
Complete ration	3.5^a	3.2^b	2.6^c	2.1^d
Coffee pulp	0.0	0.6^a	1.0^b	1.3^c
Digestibility (% DM)				
Organic matter	51.2^a	50.6^a	54.0^b	53.9^b
Gross energy	48.0	48.4	49.6	51.4
Protein	47.0^a	45.7^a	38.7^b	36.2^b

NOTE: Numbers on the same line with different superscripts are significantly different ($p < 0.05$).

Table 2. Apparent nutrient digestibility of coffee pulp.

	Dry coffee pulp (Cabezas et al. 1977)	Ensiled coffee pulp (Daqui 1974)
Apparent digestibility (% DM)		
Organic matter	54.8	64.1
Gross energy	51.1	58.4
Protein	27.0	40.3
Digestible energy content (Mcal/kg DM)	2.2	2.6
Digestible protein content (% DM)	3.8	4.5

digestibility of the same forage mixture supplemented with four isocaloric concentrates with different protein levels was also determined. The quantity of concentrate supplied daily to each animal was 1.5 kg; thus, the supplementary energy was the same in all cases (4.2 Mcal DE/day), while the supplementary protein was different in each case. The rations contained levels of crude protein that varied from 9.0% when the mixture of silages was not supplemented to 18% when the supplement with the highest protein content was used. In the same experiment, trials excluding the ECP were carried out to determine the influence of this material on the digestibility of the nutrients.

Nutrient digestibility in the rations increased with supplementation, reaching its maximum when the protein content of the dry matter was 13.6% in the ration containing ECP, and 14.6% in that which contained only CS (Table 3). The protein content of the silage mixture was higher than that of CS because, on a dry basis, the coffee pulp contained 11.1% protein. The dry matter intake of the silages was controlled at a level equivalent to 90% of the ad libitum consumption, which was higher in the presence of ECP. The organic matter

Table 3. Effect of energy and protein supplementation on intake and digestibility of rations containing coffee pulp and corn silages (from Daqui 1974).

	ECP + CS[a]		CS[b]	
	No suppl.	With suppl.[c]	No suppl.	With suppl.[c]
Protein content of the complete ration (% DM)	9.1	13.6	7.3	14.6
DM intake/day (kg/100 kg live wt)				
Complete ration	1.73	2.38	1.49	2.02
ECP	1.19	1.20	—	—
CS	0.54	0.54	1.49	1.48
ECP or CS intake (% of complete ration)	68.8	50.4	100.0	73.3
Digestibility (% DM)				
Organic matter	56.3[x]	63.1[y]	50.9[x]	59.8[y]
Gross energy	51.7[x]	57.8[y]	44.4[x]	55.7[y]
Protein	20.1[x]	48.7[y]	32.6[x]	62.0[y]

[a] Coffee pulp and corn silages mixed in the proportion of 69:31 (dry basis).
[b] Corn silage.
[c] 1.5 kg supplement giving 4.2 Mcal digestible energy per day.
NOTE: Numbers with different superscripts on each line and each silage are significantly different ($p < 0.05$).

and energy digestibilities of the supplemented and nonsupplemented ECP + EC were superior to the corresponding values determined with only CS. The inverse effect was obtained for protein digestibility, even when the value for ECP was higher than that reported by Cabezas et al. (1977) for DCP with rations of similar protein content.

The digestibility of the ECP nutrients calculated by Daqui (1974) at a level of 13.6% protein of the total ration is shown in Table 2. Compared to the data obtained by Cabezas et al. (1977) with DCP, there is a greater digestibility of the ECP nutrients. It is not known whether this difference is due to an effect of the silage process or to differences in the original composition of the materials employed in the studies.

Utilization of Nitrogen in Coffee-Pulp Rations

The effects of DCP on the nitrogen balance in growing young steers were studied by Cabezas et al. (1977) (Fig. 1). The quantities of ingested, absorbed, and retained nitrogen diminished significantly with each increase of DCP in the ration. The proportions of ingested nitrogen that were absorbed and retained, and the proportion of absorbed nitrogen that was retained, were not affected by the 20% level of DCP, but they diminished significantly when the percentage of DCP in the ration was greater. The 60% level of DCP decreased, even more than the 40% level ($p < 0.05$), the proportion of nitrogen that was retained after being ingested and absorbed. The effects of the same treatments on urine excretion and urinary nitrogen are shown in Table 4. Coffee pulp produced significant increases in both the amount of urine excreted daily and the amount excreted per unit of dry matter ingested. These increases reduced the urinary nitrogen concentration; nevertheless, the proportion of absorbed nitrogen excreted in the urine increased ($p < 0.05$) with 40 and 60% DCP, producing the effects on nitrogen retention that were previously noted.

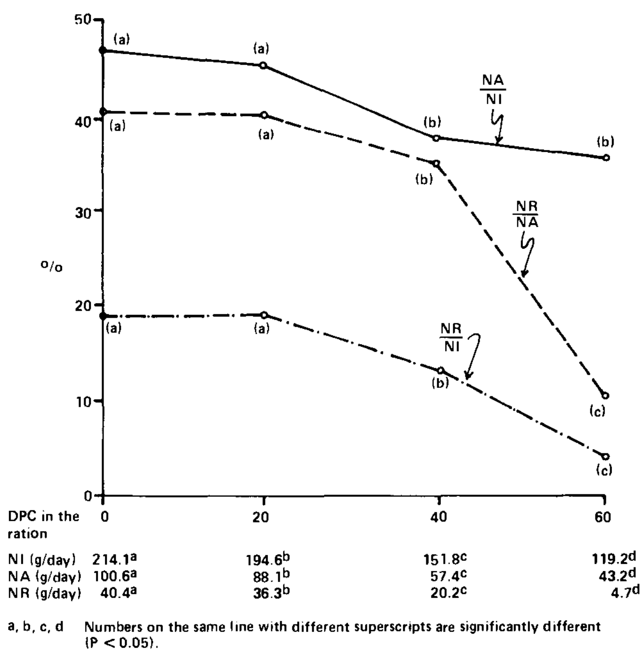

Fig. 1. Nitrogen utilization by steers fed rations containing different levels of dry coffee pulp: NI nitrogen intake; NA nitrogen absorbed; NR nitrogen retained; DPC dry coffee pulp (adapted from Cabezas et al. 1977).

These results are similar to those obtained by Cabezas et al. (1974a), who found that calves fed a ration containing 24% DCP ingested the same quantity of nitrogen as calves that did not receive DCP. García Rodríguez (1975) also found a decrease in nitrogen retention and an increase in urine excretion in sheep fed diets containing chicken litter and approximately 31% DCP.

Daqui (1974) determined the amount of nitrogen retained by young bulls fed either ECP + CS or CS with or without supplementation. With ECP + CS as with CS by itself, the nitrogen balance was negative, but nitrogen retained (NR) increased with increases in nitrogen intake (NI) as expressed by the following equations:

for ECP+CS

$$NR = -154.18 + 0.7970NI \quad (r = 0.96)$$

for CS

$$NR = -79.54 + 0.3643NI \quad (r = 0.90)$$

The relationships between NR and nitrogen absorbed (NA) were:

for EPC + CS

$$NR = -44.35 + 0.5232NA$$

for CS

$$NR = -37.11 + 0.4624NA$$

These equations indicate that although the coffee pulp induced greater losses of nitrogen through the urine, the supplementary nitrogen was used more efficiently by the animals that received the pulp.

Daqui (1974) also found that fecal metabolic nitrogen and urinary endogenous nitrogen were higher with ECP + CS than with only CS, but the difference was significant only for fecal metabolic nitrogen. It was also established that the optimum utilization of dietetic nitrogen was obtained when the rations contained 9–10% crude fibre. Urine excretion was higher in animals that consumed coffee pulp, but in these as well as in those that received CS, protein supplementation decreased urine excretion.

Biochemical Parameters in Blood Plasma and Ruminal Contents

In some feeding trials, blood plasma metabolites have been used to evaluate the effects of coffee pulp on the metabolism of ruminants. Braham et al. (1973) and Cabezas et al. (1976) did not find differences in the concentrations of glucose, protein, albumin, urea nitrogen, calcium, phosphorous, or glutamic-oxaloacetic or glutamic-pyruvic transaminases in calves fed with and without coffee pulp.

The findings of Braham et al. (1973) showed a significant increase in the concentration of free fatty acids in the plasma of calves fed coffee pulp, which, according to these authors, might help to explain the decreases in feed intake produced by coffee pulp.

Blood plasma sodium and potassium levels in young steers that consumed different quantities of DCP (Vargas 1974) did not reveal differences in the serum concentrations of those elements. However, as DCP intake increased the consumption of sodium decreased and that of potassium increased, and the quantity of sodium excreted in the urine increased.

Table 4. Urine and urinary nitrogen excretion by steers fed rations containing from 0 to 60% dry coffee pulp (from Cabezas et al. 1977).

	0%	20%	40%	60%
Urine excretion				
litres/day	8.2^a	10.7^b	11.4^b	18.6^c
litres/kg DM intake	1.0^a	1.4^b	1.8^c	33.8^d
Urinary nitrogen excretion				
g/litre urine	7.3^a	4.9^b	3.3^c	2.1^d
% of nitrogen absorbed	59.8^a	58.8^a	64.8^b	89.1^c

NOTE: Numbers on the same line with different superscripts are significantly different ($p<0.05$).

Vargas (1974) and Daqui (1974) determined the pH and the volatile fatty acid concentration in the ruminal contents of young steers fed with DCP and ECP, and obtained values similar to those found with rations that did not contain coffee pulp (Table 5). These results indicate that the ruminal fermentation produced by coffee pulp is the same as that produced by highly fibrous forages (Church 1969). More studies are required to determine the effects of coffee pulp on the pattern of ruminal fermentation and its possible relation to animal performance.

Table 5. Rumen volatile fatty acids and pH of steers fed dry or ensiled coffee pulp (from Vargas 1974; Daqui 1974).

		Volatile fatty acids (moles%)		
	pH	Acetic	Propionic	Butyric
0% DCP	7.1	74.0	16.0	10.0
20% DCP	6.9	73.6	17.4	9.0
40% DCP	6.8	72.6	19.1	8.3
60% DCP	7.1	75.4	16.7	7.9
68% ECP	7.2	73.5	15.5	10.6
100% CS	7.3	75.5	14.1	10.4

Substances Affecting Nutritive Value of Coffee Pulp

The specific causes of the adverse effects of coffee pulp on intake, digestion, and animal metabolism are unknown. Nevertheless, some substances present in the pulp may be responsible for these effects, such as tannins and other polyphenols, caffeine, and potassium.

The effect of tannic acid and caffeine on feed intake and the performance of ruminant calves was studied by Cabezas et al. (1977). Pure caffeine and tannic acid were added to the rations at levels representative of those supplied by coffee pulp when it is included in rations at levels higher than 20%. The concentration of caffeine varied between 0.12 and 0.24% and that of tannic acid between 0.75 and 1.50% of the ration whether by themselves or combined. When combined, tannic acid was kept at 0.75% and the caffeine was increased from 0.12 to 0.24% of the ration. In the concentrations used, tannic acid by itself did not affect the performance of the animals. Although a level of 0.12% caffeine did not cause negative effects, higher levels produced significant decreases in the animals' growth as

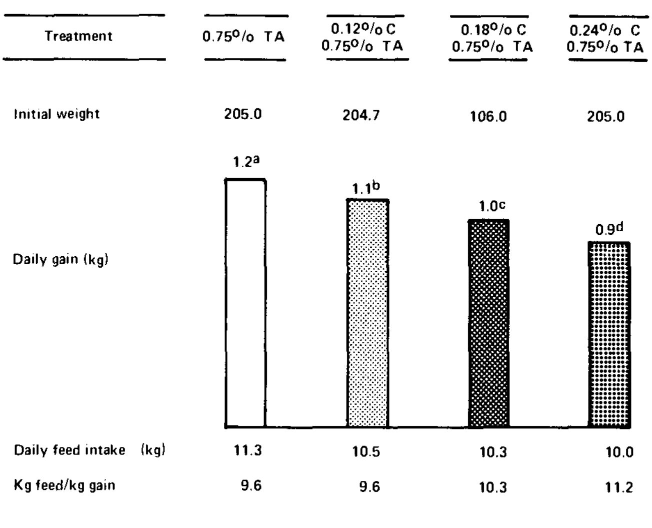

Fig. 2. Performance of steers fed caffeine (C) and tannic acid (TA) (from Cabezas et al. 1977).

a result of lower feed consumption. Combinations of both compounds produced adverse effects on the calves' performance, which were more severe as the caffeine concentration increased (Fig. 2), demonstrating the importance of these factors in influencing the nutritive value of coffee pulp.

Vargas (1974) found that daily consumption of 8.9 g of caffeine and 76.5 g of tannin derived from DCP produced adverse effects on the performance of young steers. These quantities corresponded to rations that contained 40% DCP, which supplied 0.15% caffeine and 1.24% tannin.

The site in the animal that is affected and the manner in which the caffeine and the polyphenols affect the nutritive value of the pulp are unknown. Both substances can decrease the palatability and, consequently, the feed intake. On the other hand, the low digestibility of pulp protein can be attributed to the formation of polyphenol complexes that incorporate themselves into the fraction analyzed as lignin, which is not digestible. Determinations of lignified nitrogen in DCP and ECP (Murillo et al. 1977; Daqui 1974) show that this fraction constitutes more than 50% of the total nitrogen of the pulp, affecting not only the digestibility of the protein but also that of the organic matter in general.

The caffeine might be responsible for the decreases in nitrogen retention produced by coffee pulp, in view of its recognized diuretic effect (Sollman 1957), and the evidence (Bressani and Braham 1972) that increments in urine excretion increase nitrogen losses via the same route in other species. Also, the increases in free fatty acids, which were observed by Braham et al. (1973) in calves fed coffee pulp, can be attributed to the lipolytic action of caffeine, such as was demonstrated by Bellet et al. (1965) and by Hawkins and Davis (1970) in studies with monogastrics and ruminants, respectively.

It is also known (Sollman 1957) that caffeine accelerates the basal metabolic rate, which might have caused the nervousness in animals fed coffee pulp that was reported by Flores Recinos (1976). This phenomenon has also been observed in trials conducted by Jarquín et al. (1972), Braham et al. (1973), Cabezas et al. (1974a, 1976), and Vargas (1974), but its consequences on animal performance are not known.

The results of Vargas (1974) indicate that the increases in potassium consumption, due to the ingestion of coffee pulp, might affect the ionic balance in the tissues, which might have negative effects on animal performance. It should be mentioned that Osegueda Jiménez et al. (1970) found that the consumption of mineralized salt, ground shell, and bone meal increased by 100% or more when young bulls were fattened with rations containing 30% DCP.

Another aspect in which the previously mentioned substances might be involved is in the animals' adaptation to the coffee pulp. According to Vargas (1974) the quantities of pulp necessary to induce adaptation are determined by the caffeine and polyphenol levels, which vary according to pulp origin and processing method (Bressani 1972). This may be the cause of the differences in adaptation responses found in the experiments referred to previously.

In Chapter 10 of this monograph, Bressani discusses the different mechanisms through which some of the substances present in coffee pulp can produce adverse effects on animals and reduce its nutritive value.

Pathology

According to Flores Recinos (1976), the absence of forage in rations with high levels of coffee pulp and molasses provokes bloat. This effect, together with the poor performance observed when the coffee pulp is the sole fibrous material in the ration (Ruiz and Ruiz 1975), indicates that the fibre of this material has characteristics different from other forages. This difference ought to be confirmed by means of chemical and digestibility studies on the fibrous fraction of the pulp.

Other problems that Flores Recinos (1976) found in beef cattle confined and fed rations containing coffee pulp were inflammation of the extremities and the appearance of skin sores or ulcers. Inflammation has been observed in corrals with concrete floors and inadequate drainage, which favours the accumulation of the urine that is excreted in greater quantities by animals consuming coffee pulp (Cabezas et al. 1974a, 1977). Apparently, the contact of the hooves with the urine produces the inflammation, but the fundamental reason for this is unknown. In any case, the ailment disappears when the animals are transferred to corrals having dirt floors and good drainage.

The appearance of sores on the skin has been observed sporadically under both experimental and commercial conditions (Flores Recinos 1976). According to this author, such a phenomenon might be caused by the aflatoxins produced by fungi that grow on coffee pulp that has been left in the open for several days before being dehydrated or ensiled.

Feeding Coffee Pulp to Beef Cattle

DCP has been employed up to now as a substitute for different ingredients in complete rations or as part of forage supplements in feeding trials with beef cattle in confinement. Studies under grazing conditions are unknown.

In a series of studies conducted by Jarquín et al. (1972), Braham et al. (1973), Cabezas et al. (1974b, 1976), and Vargas (1974), DCP or EDCP was incorporated into complete rations for Holstein calves and young dairy cows, within an intensive system of beef production that required high animal performance. In these studies, the age of the animals varied between 3 and 12 months and their initial weight was between 90 and 232 kg. The control rations contained sugarcane molasses, cottonseed meal, cottonseed hulls, and minerals. Wheat bran was also used in rations for the younger calves. The TDN and the crude protein of these rations varied from 50 to 60% and 13 to 17.8% of the dry matter, respectively. Under the management and feeding conditions employed, the dry-matter intake of the control ration exceeded 3.5 kg/100 kg of live weight, and produced weight gains of at least 1.0 kg/day and feed efficiencies that varied between 6.3 and 8.6. In the experimental rations, the pulp was included at levels that varied from 10 to 60% in partial or total substitution for cottonseed hulls, and, in the case of Vargas' study for part of the cottonseed flour. The experimental period varied from 84 to 168 days. The pulp was obtained from a plant that processed different varieties of coffee coming from different plantations, and was then sun-dried, before or after having been ensiled. The chemical composition of the dry pulp was similar to that reported by Bressani et al. (1972).

In all these trials, DCP and EDCP induced reductions in feed intake, which were directly related to their concentration in the rations, and negatively affected weight gain and feed conversion by the animals. These effects were more severe when the pulp exceeded 20% of the ration, and were related to the lower nitrogen retentions observed with high levels of pulp (Cabezas et al. 1974a, 1977).

In the study by Vargas (1974) in which young steers received rations with 0, 20, 40, or 60% DCP, the following correlations between the level of coffee pulp in the ration and the performance of the animals were found:

$$Y_1 = 4.24 - 0.030X \ (r = 0.79)$$
$$Y_2 = 1.63 - 0.023X \ (r = 0.91)$$

in which: Y_1 = dry-matter intake per 100 kg of live weight per day; Y_2 = daily weight gain; and X = percentage of DCP in the ration.

The decrease in weight gain was principally due to the negative effect of the DCP and the EDCP on feed intake, as indicated by the high index of correlation ($r = 0.92$) between these parameters. A similar correlation was obtained by Flores Recinos (1973) with steers fed EPC. The adverse effect of the DCP on feed intake and weight gain of growing and fattening cattle has been reported by other authors who have used it in complete rations in substitution for cereals or forages (Echeverría 1947;

Osegueda Jiménez et al. 1970; Ayala 1971; Ledger and Tillman 1972).

As was previously mentioned, the data reviewed by Squibb (1950) indicated that coffee-pulp intake improves when the ration contains highly palatable feeds, forages, and protein concentrates. Flores Recinos (1976) recommended including at least 20% sugarcane molasses in the rations based on coffee pulp to ensure adequate consumption. The addition of molasses to pulp silages does improve their palatability (González 1973); nevertheless, animals do not eat these silages if they are not mixed with another forage (González, J.M., Division of Agricultural and Food Sciences, INCAP, personal communication).

To study the effect of green forage on DCP intake, Ruiz and Ruiz (1977) fed growing young steers a mixture of tropical grasses at decreasing levels from maximum consumption to zero. All the experimental groups had free access to a supplement that contained 66.8% DCP, 24.6% sugarcane molasses, 4.1% meat and bone meal, 2.5% urea, and 2% minerals. The inclusion of green forage resulted in increased consumption of both DCP and the total ration up to 600 g green forage/100 kg live weight (Fig. 3). At this level, the total ration contained approximately 55% DCP and 15% forage on a dry basis. Any further increase of forage beyond this point decreased DCP intake although the consumption of total dry matter increased. Because the consumption of total dry matter per 100 kg live weight was low (0.85-2.44 kg), the authors concluded that the decrease in DCP intake could not be attributed to a substitution phenomenon between both materials, but to specific negative effects of DCP on appetite. The average daily gains in the absence of forage were negative and increased logarithmically as the levels of forage and the total consumption of dry matter increased (Fig. 4). At forage intakes lower than 600 g/100 kg live weight, the relationship between weight gain and consumption of coffee pulp was positive, but at higher levels of forage intake when the weight gains were positive, the relationship was negative. These results agree with those obtained with complete rations containing 15% or more dry forage. The feed conversion efficiency behaved in a similar way to the weight gains when the forage consumption was less than 600 g/ 100 kg live weight, reaching its maximum value at this level. Greater proportions of

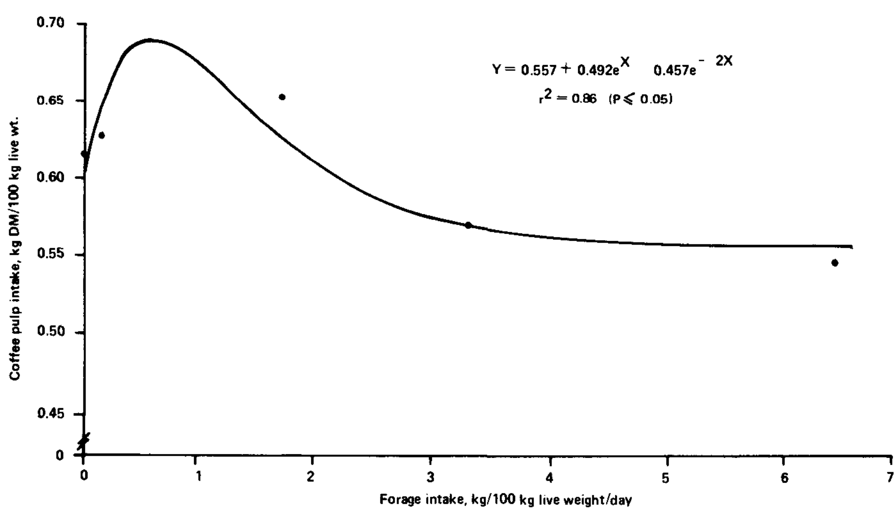

Fig. 3. Effect of green forage intake on coffee-pulp consumption (from Ruiz and Ruiz 1977).

forage did not noticeably change the feed-conversion efficiency. The results of this study explain those obtained by Madrigal (1974) and by Echandi and Fonseca (1974), in which the absence of forage produced low consumptions of DCP and weight losses in steers.

The relationship between crude-protein consumption and rations containing different levels of ECP was studied by Flores Recinos (1973) who found that with steers there was a highly significant correlation between these variables. Dry-matter intake increased linearly from 1.65 to 2.14 kg/100 kg of weight when protein consumption was increased from 104 to 315 g/100 kg live weight by using rations that contained from 6 to 15% protein on a dry basis. Dry-matter intake tended to stabilize at 15% protein, reaching a maximum of 2.23 kg/100 kg live weight. The same tendency was observed for weight gain and feed conversion efficiency. Coffee pulp negatively affected feed consumption and weight gain, but these effects decreased ($p < 0.01$) with the addition of protein.

Maximum economic benefit was obtained with the consumption of 315 g protein and 504 g coffee pulp dry matter per 100 kg live weight, quantities which corresponded to 15 and 30% of the dry matter, respectively. The rest of the ration consisted of 26% cottonseed meal, 40% sugarcane molasses, and 4.0% minerals. Weight gain with this ration was 500 g/animal/day, indicating that it is possible to design profitable feeding systems based on coffee pulp, especially during seasons when forage is scarce.

Similar results were obtained by Daqui (1974) upon supplementation of a mixture of ECP and CS with different quantities of protein. In this case, the total dry-matter intake when the ration contained 14% protein was greater than that obtained by Flores Recinos (1973), possibly due to the presence of other forage.

The increase in consumption produced by the protein supplementation can be explained in part by increases in ration digestibility (Table 3) and by improvement in the nitrogen status of the animals (Daqui 1974). Both effects are recognized as factors that stimulate the voluntary intake of rations having low protein contents (Blaxter and Wilson 1963; Egan 1965). The protein content of coffee pulp averages 11% (Bressani

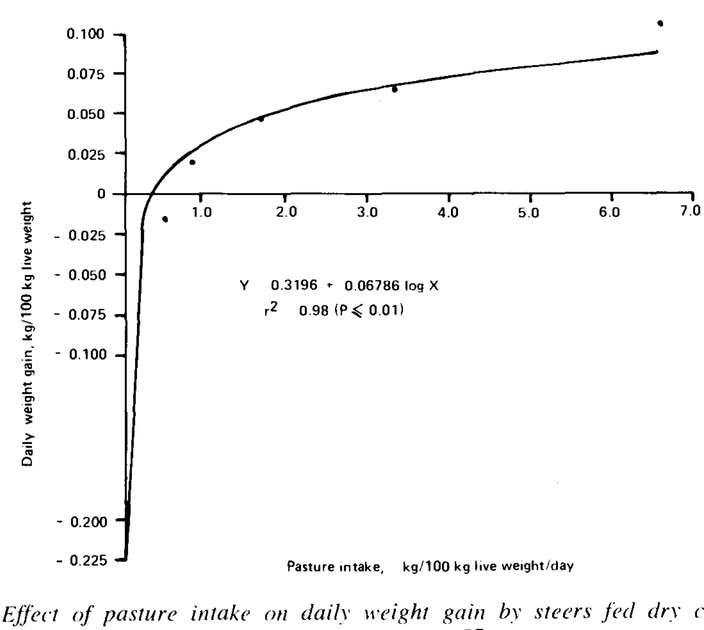

Fig. 4. Effect of pasture intake on daily weight gain by steers fed dry coffee pulp (from Ruiz and Ruiz 1977).

et al. 1972), which ought to be sufficient to supply the protein requirements of growing and fattening steers (NRC 1970). Nevertheless, the low digestibility of the protein of the pulp (Tables 1-3), just as it has a negative effect on nitrogen retention (Fig. 1), can affect the nitrogen status and the voluntary feed intake of the animals.

Other factors that apparently affect the consumption and utilization of coffee pulp by animals are the time during which they consume it and the method employed to introduce it into the ration. Osegueda Jiménez et al. (1970), Jarquín et al. (1972), Cabezas et al. (1974b), and Vargas (1974) indicate that animals tend to consume greater quantities of pulp and to utilize it more efficiently in proportion to the length of time that they are consuming it. This phenomenon has been interpreted as an adaptation from the ruminal flora and of the animal itself to the pulp. According to Cabezas et al. (1974b) the animals ought to consume a minimum quantity of pulp to facilitate the adaptation process, which gradually enables them to ingest and utilize higher quantities. In this study, the quantity varied between 2.3 and 2.8 kg of DCP per day, and was supplied by rations that contained between 20 and 30% DCP, respectively. Quantities and levels lower than those did not adapt the young steers to consume and utilize larger quantities of pulp. Nevertheless, observations made in practical feeding trials with beef and dairy cattle by Cabezas (unpublished data, 1977), have demonstrated the convenience of gradually incorporating the coffee pulp into the rations, beginning with a level of 10%, to accustom the animals to the presence of pulp in their feed, and to pave the way for greater pulp intakes with time. Differences found in this regard may be due to variations in the origin, processing, and chemical composition of the pulp.

Some trials have compared the performance of animals fed with DCP and ECP. Bará et al. (1970) fed 203-kg steers rations in which DCP and ECP replaced elephant grass *(Pennisetum purpureum)* in proportions of 15 and 30% of the total ration. The consumption of the rations containing pulp was greater by 6–21% than the ration with elephant grass. The weight gains and feed conversion of the groups that received 15% pulp were similar to those of the control ration, but the performance of those fed 30% pulp was inferior to that of the other groups although there were no differences in the feeding value of DCP and ECP in any of the treatments.

In research carried out by Cabezas (unpublished data, 1976), DCP and ECP ensiled with 5% sugarcane molasses were compared with ground sorghum grain at a level of 30% in rations for fattening steers. Dry-matter intake of the rations with coffee pulp was lower at the beginning of the trial, but gradually increased until it reached a higher level than the control ration (Fig. 5). As a consequence, the average intake for the whole trial was greater for the animals that consumed coffee pulp (Table 6). These groups did not gain weight in the first 28 days of the study, but they later recuperated and gained at a rate equal or superior to the group that received sorghum (Fig. 6) indicating that they had adapted to the coffee pulp. The groups fed coffee pulp reached slaughter weight 28 days after those fed sorghum; still, the general performance of the group that received ECP was comparable to those receiving sorghum. On the other

Table 6. Performance of finishing steers fed rations containing sorghum grain (SG), dry coffee pulp (DCP), or ensiled coffee pulp (ECP) (from Cabezas et al. 1976).

	30% SG	30% DCP	30% ECP
Feeding period (days)	140	168	168
Initial weight (kg)	298.5	305.4	299.9
Final weight (kg)	422.8	415.0	445.8
Daily gain (kg)	0.89^{a}	0.65^{b}	0.87^{a}
Daily dry matter intake (kg)	9.5	10.4	10.2
kg dry matter/ kg weight gain	10.7	16.0	11.9
Dressing percentage	53.1	52.0	52.1

NOTE: Numbers on the same line with different supercripts are significantly different ($p < 0.05$).

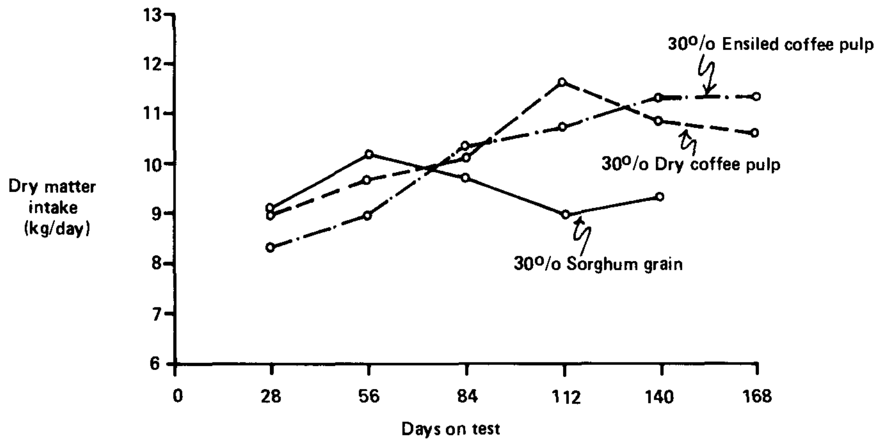

Fig. 5. Dry-matter intake of finishing steers fed rations containing sorghum grain, dry coffee pulp, or ensiled coffee pulp (from Cabezas et al., unpublished data).

hand, the weight gain and feed conversion efficiency of the group fed DCP was inferior to that of the other groups. In a study with calves by Cabezas et al. (1976), better performance was also observed with EDCP than with DCP. Similar results were also noted with calves by González (personal communication, 1974) in studies in which DCP and ECP were compared at levels of up to 40% of the ration dry matter. The better response to ECP might be related to better palatability, to better digestibility (Table 2), and to the changes in chemical composition that the pulp undergoes during ensilage, especially those having to do with its caffeine and tannin content (Murillo et al. 1977).

Because of the differences in price between sorghum and coffee pulp, coffee pulp can be profitably added to fattening rations at levels of 20–30% when it replaces high-energy feeds that are high-priced.

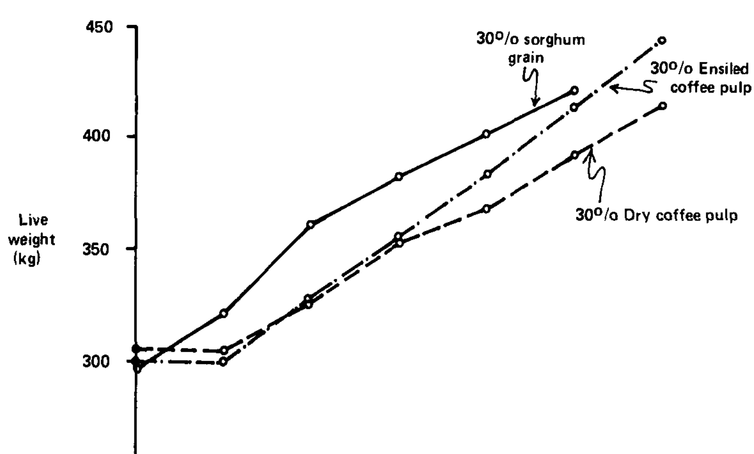

Fig. 6. Live weight gain of finishing steers fed rations containing sorghum grain, dry coffee pulp, or ensiled coffee pulp (from Cabezas et al., unpublished data).

Feeding Coffee Pulp to Dairy Cattle

Coffee pulp has been employed, whether ensiled or dehydrated, in concentrates that are normally used to supplement forages fed to dairy cows. The first reports on this subject (Squibb 1950), just as recent studies (Flores Recinos 1976), indicate that coffee pulp can be incorporated at levels of 20–40% of the concentrate, without decreasing milk production. To obtain better results, Flores Recinos (1976) recommends the gradual introduction of coffee pulp into the rations. According to Fonseca (1973), the feeding of dairy cows for several years with commercial concentrates that contain up to 20% ground DCP does not produce detrimental effects on milk production, nor apparent physiological disturbances in the cows. This information has been corroborated by Cabezas et al. (1977) in an experiment conducted at a dairy farm integrated with a coffee processing plant in El Salvador. Coffee-pulp silage with 2% molasses was used to replace sorghum silage and elephant grass at a level of 20% of the ration on a dry-weight basis. Consumption of dry matter decreased when coffee pulp was incorporated in the ration, but milk production was between 6 and 7 litres/day with or without coffee pulp. Inclusion of coffee pulp in the ration decreased the cost of feeding by about 30%. During the 1-year trial there were no problems in performance, reproduction, or health in the herd and, on this basis, it was concluded that coffee pulp could be used economically in the feeding of dairy cattle of low and medium production (which is representative of most of the herds in the country). The response obtained with cows with a higher milk-production level, and the use of levels of coffee pulp above 20% of the ration, must yet be studied.

Perspectives on the Use of Coffee Pulp as Cattle Feed

Despite its limitations, coffee pulp can play an important role in both intensive and extensive beef and dairy cattle production systems in tropical countries. At present, the use of 20–30% coffee pulp in rations for beef cattle can be recommended. In the future, greater proportions will surely be recommended as soon as better ways are developed to counteract the nutritional deficiencies and adverse effects that the pulp induces in the animals.

Presently, INCAP and the Ministry of Agriculture and Livestock of El Salvador are carrying out a project aimed at demonstrating and encouraging the processing and use of coffee pulp as a feedstuff for both beef and dairy cattle in El Salvador. The same will be done in Costa Rica in the near future. This type of activity will establish the biological and economic feasibility of using coffee pulp in practical feeding systems and orient new investigations aimed at solving the problems encountered in the field. As well, new publications resulting from these projects will draw together the available information on the subject.

Conclusions

- The total and digestible nutrient content of coffee pulp shows that this agricultural by-product has a potential nutritive value similar to that of good quality tropical forages. The digestibility of ensiled pulp is superior to that of the dehydrated pulp but, in both cases, the availability of protein is affected by high levels of lignified nitrogen.
- The utilization of absorbed nitrogen is less efficient in animals fed rations that contain more than 20% coffee pulp. This effect is accompanied by increases in urinary excretion, possibly caused by the caffeine in the pulp.
- An inverse relation exists between the concentration of coffee pulp in the ration and the performance of growing and fattening cattle, which becomes more marked when the pulp concentration in the ration is greater than 20%.
- The principal cause of the poorer performance of animals fed coffee pulp is a reduction in voluntary feed intake. At concentrations higher than 20% of the ra-

tion, coffee pulp might also influence animal performance by lowering nitrogen utilization.

- The adverse effect of coffee pulp on voluntary feed intake is related to its poor palatability and possibly to some responses of the protein and lipid metabolism of the animal. Both factors might be related to the presence of caffeine and tannins and other polyphenols, as well as to the high level of potassium in the pulp.
- The adverse effects of coffee pulp on animal performance decrease when the rations contain at least 20% molasses, 15% of other forages, and 14% crude protein. Also, these effects tend to decrease when the consumption time of the pulp by the animals is prolonged and when the pulp is gradually introduced as a component of the ration.
- The absence of other forages in the ration can produce bloat. Also, the accumulation of urine in corrals with concrete flooring and without adequate drainage can produce inflammation of the extremities of animals fed coffee pulp.
- Ensiled coffee pulp produces better performance than dehydrated pulp, due possibly to its better palatability, better digestibility, and lower content of caffeine and tannins.
- In intensive systems of beef production, the use of coffee pulp at levels between 20 and 30% of the ration might be convenient and profitable when it is substituted for cereals or other high quality feedstuffs that are expensive.
- It is possible to design feeding systems in which coffee pulp is the main ingredient of the ration for the maintenance and growth of cattle at times when forage is scarce, if the requirements to reduce the adverse effects of the pulp are taken into consideration.
- Coffee pulp ought to be properly processed, avoiding accumulation over long periods of time before dehydration or ensiling, to obtain the greatest benefit from its nutritional potential. Otherwise, its adverse effects on animal performance will be more pronounced.
- Feeding coffee pulp to cattle, especially coffee-pulp silage, can be integrated with coffee-pulp processing plants so that the available resources in the coffee-producing countries can be more effectively utilized.
- It is necessary to conduct studies to identify the factors that interfere with the consumption and utilization of coffee pulp by the animals, and to develop processing methods and feeding systems that will eliminate or counteract these factors.
- There is a need to determine the long-term effects of coffee pulp on the productivity of beef and dairy herds.

5

Coffee Pulp in Swine Feeding

Roberto Jarquín[1]

Swine require a great deal of energy and moderate amounts of protein for growth and development, therefore, it is a generalized practice to use cereal grains as the energy source in swine nutrition. Among cereals, corn is preferred as a source of carbohydrates, but the increasing demand for corn for human consumption and its high market price justify any effort toward the total or partial substitution of corn in swine formulations.

The search for new sources of protein and energy has led nutritionists to study some agricultural and industrial by-products that could be incorporated into animal rations.

The use of coffee pulp in animal feeding drew the attention of several research workers in the 1940s (Choussy 1944; Echeverría 1947; Madden 1948; Van Severen and Carbonell 1946; Work et al. 1946), but in spite of these efforts the results did not meet the expected goals because of a lack of pressure from both the coffee growers and the feed manufacturers, and because availability of feed ingredients was not a limiting factor at the time. However, relatively recent research using coffee pulp in beef cattle rations (Braham et al. 1973; Cabezas et al. 1974, 1976; Estrada 1973; Jarquín et al. 1973) has attracted feed manufacturers and cattlemen. Naturally, with continuous shortages of feed ingredients, a waste material such as coffee pulp, whose dry matter contains about 10% crude protein and less than 25% crude fibre, has a great potential as a ruminant feed.

Most of the animal-feeding work carried out using coffee pulp has been performed with dehydrated material (Braham et al. 1973; Cabezas et al. 1974, 1976; Estrada 1973; Jarquín et al. 1973; Urizar 1975). One should always consider that dehydration implies energy expenditure, especially for a material like coffee pulp whose separation from the coffee bean commonly requires a wet process yielding a by-product with a moisture content of 76–85% (Bressani et al. 1972; Molina et al. 1974). This means that the costs of transportation and dehydration raise the price of the final product. Consequently, to use dry coffee pulp effectively and economically research must be devoted to finding wider uses for this ingredient, as well as to finding out which animal species perform best when fed coffee pulp. Therefore, it was decided to study the effect of incorporating dehydrated coffee pulp in swine rations.

It was known that the use of dehydrated coffee pulp for monogastric formulations might have certain limitations because of its relatively high fibre content, especially as swine do not have either the physiology or the microflora to handle materials of this nature. However, analysis of the protein fraction of coffee pulp showed an essential

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amino acid pattern on a protein basis comparable to those of soybean and cottonseed meal (Bressani et al. 1972), both of which are commonly used in swine nutrition.

The use of a new ingredient for animal feeding requires a comprehensive understanding of its nutritive value, which implies good acceptability of the product by the animal, as well as an adequate content and efficient utilization of its nutrients. In swine nutrition, common sense indicates that dehydrated coffee pulp must be ground to an acceptable particle size before it is fed (this can be done in a regular hammer mill with an appropriate screen set). Acceptability, which mainly involves palatability, may be improved by supplementing with sugarcane molasses. An alternative is to find a processing technique that will improve palatability.

Another important factor that must be taken into consideration is how much can be incorporated into a ration for certain animal species, or how much of a product or ingredient to be tested can be used in a given formulation. In the case of dehydrated coffee pulp, just by examining the proximate chemical analysis data, one may say that for swine feeding it cannot be incorporated in quantities higher than 24% in a given formulation because fibre content limits its use. Besides high fibre content, coffee pulp also contains caffeine, tannins, and caffeic and chlorogenic acids, that in one way or another may limit its use (Molina et al. 1974).

Dehydrated Coffee Pulp

Growth Studies

Till now, little work has been carried out using dry coffee pulp in swine feeding. Jarquín et al. (1974), reported the performance of Yorkshire pigs fed ad-libitum the formulations described in Table 1.

These formulations were designed according to the nutrient requirements for the different stages of growth of the animals. From 17 to 30 kg of live weight, the animals received the formulation with 18% protein; from 34 to 60 kg live weight, the diet with 15% protein; and from 66 kg to market weight, the diet with 12% protein. Nevertheless, the coffee pulp levels used (8.2, 16.4, and 24.6%) were kept constant throughout the experimental period.

To achieve the desired protein concentration in the diets according to the state of growth, the corn-soybean mixture incorporated in the diet was decreased and the level of molasses increased. Crude fibre was equalized in all diets using finely ground corncobs, and cornstarch was used to adjust to 100 g of ration. Although these are not practical swine rations, our purpose was to obtain information on the effect of different levels of coffee pulp on the animals according to physiological age or state of growth. The diets were changed when the control groups reached the average weights of 30 and 60 kg. Prior to each stage of growth the animals were fed a commercial diet for approximately 7 days, and then randomized by sex and weight into new groups for the next growth period.

Table 2 summarizes growth responses both to the different levels of coffee pulp and to the changes in the protein concentration. Performance in feed conversion and average daily weight gain observed through the different stages of growth as reported by Bressani et al. (1974) are diagrammatically presented in Fig. 1.

In general, at each growth stage, weight gain and feed conversion were inversely related to the level of coffee pulp in the diet; however, as far as weight gain was concerned no significant differences were found between the control and the diets with 8.2 and 16.4% coffee pulp at levels of 18 and 15% protein. Daily gains obtained during the first stage of growth, when 8.2 and 16.4% coffee pulp were introduced in the diet, were comparable to those that are normal for pigs of that age (NRC 1968).

No abnormal symptoms were detected during the study except that animals fed the diet with 24.6% coffee pulp showed a skin rash between their legs; however, this disappeared promptly with a change in diet.

Analysis of jugular-vein blood samples drawn at the end of each state of growth indicated an increase in free fatty acids and

Table 1. Composition of diets used to meet the nutritional requirements of the three stages of growth of swine (from Jarquín et al. 1974).

	First stage treatment				Second stage treatment				Third stage treatment			
	1	2	3	4	1	2	3	4	1	2	3	4
Corn-soybean blend	74.3	70.6	66.9	63.2	61.9	58.2	54.4	50.8	49.5	45.8	42.2	38.4
Coffee pulp (sun dried)	—	8.2	16.4	24.6	—	8.2	16.4	24.6	—	8.2	16.4	24.6
Fibre source (corncobs)	15.1	10.3	5.5	0.7	15.1	10.3	5.5	0.7	15.1	10.3	5.5	0.7
Starch	—	0.3	0.6	0.9	5.2	5.5	5.8	6.1	10.4	10.7	10.9	11.3
Vitamins and minerals[a]	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Aurofac	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sugarcane molasses	7.2	7.2	7.2	7.2	14.4	14.4	14.4	14.4	21.6	21.6	21.6	21.6
Minerals[b]	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Protein content (%)	18.3	19.5	17.9	17.9	16.0	14.8	14.5	14.8	12.1	12.5	11.8	12.1
Crude fibre content (%)	5.8	6.1	7.3	7.3	6.2	7.5	7.4	7.8	4.9	6.0	6.4	6.9

[a]Dohyfral/Duphar, Amsterdam, Holand. Contains per kg: vitamin A, 2 000 000 I.U.; vitamin D_3, 400 000 I.U.; vitamin E, 1000 I.U.; vitamin B_{12}, 3 mg; Fe, 20 000 mg; Mn, 10 000 mg; Cu, 1500 mg; I, 150 mg; Zn, 40 000 mg.

[b]Bone meal 33%, iodized salt 32%, $CaCO_3$ 33%, minor elements 2%.

Table 2. Performance of swine fed different levels of coffee pulp during the three stages of growth (from Jarquín et al. 1974).

	First stage treatment				Second stage treatment				Third stage treatment			
	1	2	3	4	1	2	3	4	1	2	3	4
Average initial weight/ pig (kg)	12.2	12.2	12.3	12.3	34.4	34.3	34.5	34.2	65.8	65.8	65.8	65.8
Average final weight/ pig (kg)	31.2	31.9	30.3	26.9	61.4	58.2	57.0	54.3	92.5	87.1	87.1	83.4
Feed consumption/pig (kg)	53.7	56.3	54.9	47.8	105.6	101.5	102.0	92.4	154.5	138.4	140.7	126.1
Daily food consumption/ pig (kg)	1.5	1.6	1.6	1.4	3.0	2.9	2.9	2.6	4.4	4.0	4.0	3.6
Weight gain/pig (kg)	19.0[a]	19.7[a]	18.0[a]	14.6[b]	27.0[a]	23.9[a]	22.5[a]	20.1[b]	26.7[a]	24.8[a]	21.3[b]	17.7[b]
Daily weight gain/ pig (kg)	0.54	0.56	0.51	0.42	0.77	0.68	0.64	0.57	0.76	0.71	0.61	0.51
Feed efficiency	2.82	2.87	3.04	3.26	3.92	4.25	4.53	4.59	5.79	5.58	6.60	7.11
Number of animals	8	8	8	8	8	8	8	8	8	8	8	8
Death rate	0	0	0	0	0	0	0	0	0	0	0	0
Daily coffee pulp consumption/kg/pig	0	0.131	0.262	0.344	0	0.238	0.476	0.640	0	0.328	0.656	0.886

NOTE: Numbers with different letters are significantly different.

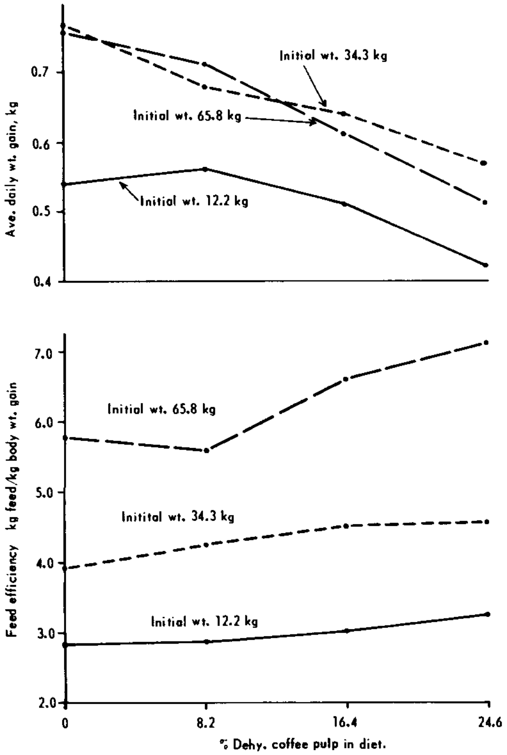

Fig. 1. Performance of swine fed different levels of coffee pulp.

glucose and a decrease in urea nitrogen, both of which were directly related to coffee pulp level. The ratio of nonessential to essential amino acids was normal in all three stages of growth of the animals fed either level of coffee pulp, suggesting that the by-product does not interfere with the nutritional condition of the animals. The increases observed in the free fatty acid concentration of the blood serum are in accordance with results reported by others working with ruminants (Hawkings and Davis 1970; Braham et al. 1973) where the effect was attributed to caffeine.

Dry coffee pulp has also been fed to young native pigs at levels of 12, 18, and 24% where it replaced equal amounts of protein from a basic soybean-maize blend as in the former experiment. Jarquín et al. (1977) in a 12-week trial used a control diet with 16% protein and experimental diets with 12 and 24% dry coffee pulp. The results (Table 3) showed a positive response when 12% dry coffee pulp was included in the diet, because growth and feed consumption as well as feed conversion were comparable to those obtained with the control ration. Statistical analysis did not show

Table 3. Growth response and blood serum protein and albumin in native pigs fed different levels of coffee pulp for 12 weeks.[a]

	Coffee pulp in diet (%)		
	0	12	24
Initial weight (kg)	7.4	7.8	8.6
Final weight (kg)	34.9	37.4	21.6
Weight gain (kg)	27.5 ± 2.9[b]	29.6 ± 7.6[b]	13.0 ± 5.3[b]
Feed consumption (kg)	123.0	133.0	85.7
Feed conversion	4.5	4.5	6.6
Initial serum protein (g/100 ml)	6.75	6.86	6.73
Final serum protein (g/100 ml)	7.37 ± 0.44[b]	7.64 ± 0.17[b]	7.63 ± 0.24[b]
Initial serum albumin (g/100 ml)	2.77	2.46	2.92
Final serum albumin (g/100 ml)	3.43 ± 0.26[b]	3.13 ± 0.46[b]	3.86 ± 0.56[b]

[a]Protein content of the diets: 16.4, 16.8, and 16.4, corresponding to 0, 12, and 24% of coffee pulp, respectively.
[b]Mean and standard deviation.
[c]Feed conversion: g of feed consumed/g weight gain.

differences with respect to weight gain between the control and the lower level of coffee pulp; on the other hand, there was a highly significant difference ($p < 0.01$) between these two groups and the one fed 24% dry coffee pulp.

These results led the same investigators (Jarquín et al. 1977) to study an intermediate level of coffee pulp; therefore, 12, 18, and 24% of this material was incorporated into the different formulations and fed to young native pigs for a period of 10 weeks. Their results (Table 4) indicated an inverse relationship between weight gain, feed conversion, and feed consumption with respect to the level of coffee pulp in the diet; nevertheless, the results reached statistical significance only at the 24% level of coffee pulp. On the other hand, the inclusion of 12 and 18% of the material did not result in any difference with respect to the control group.

Initial and final values in blood serum samples from the experimental animals are also included in Tables 3 and 4. The biochemical parameters measured in both experiments with native pigs were quite similar, and the values obtained for serum protein and albumin did not show any significant difference among treatments, in spite of the fact that the growth performance of the pigs fed the 24% level of dry coffee pulp was statistically different ($p < 0.01$) from that obtained in the other groups in both experiments.

Metabolic Studies

To achieve a more critical evaluation of the by-product when fed at different levels in a given diet, metabolic studies were carried out with each of the diets with 18% protein that were used in the first stage of growth (Table 1). Two young pigs were assigned to each of the diets and five consecutive metabolic studies were performed. Each metabolic trial required 7 days, three for adaptation and four for quantitative collection of feces and urine. The results of the first, third, and fifth metabolic trial are shown in Fig. 2 (Bressani et al. 1974). Although feed intake was intended to be equal in all the groups, the animal consuming the highest level of pulp showed 14% less feed intake. This decrease in feed intake may be partially responsible for the lower nitrogen retention that was observed.

Table 4. Growth response and blood serum protein and albumin in native pigs fed different levels of coffee pulp for 10 weeks.[a]

	Coffee pulp in diet (%)			
	0	12	18	24
Initial weight (kg)	9.9	9.9	10.0	9.9
Final weight (kg)	37.0	34.9	32.4	29.1
Weight gain (kg)	27.1 ± 3.2[b]	25.0 ± 1.3[b]	22.4 ± 7.8[b]	19.2 ± 4.6[b]
Feed consumption (kg)	104.4	103.8	97.4	84.1
Feed conversion (kg)	3.9	4.2	4.3	4.4
Initial serum protein (g/100 ml)	7.46	7.78	8.25	7.82
Final serum protein (g/100 ml)	3.48 ± 0.49[b]	8.20 ± 0.48[b]	9.07 ± 0.14[b]	8.65 ± 0.74[b]
Initial serum albumin (g/100 ml)	2.14	2.15	1.71	2.25
Final serum albumin (g/100 ml)	3.17 ± 0.26[b]	3.42 ± 0.53[b]	3.10 ± 0.5[b]	3.33 ± 0.44[b]

[a]Protein content of the diets: 16.5, 16.6, 16.7, 16.7 corresponding to 0, 12, 18, and 24% of coffee pulp, respectively.

[b]Mean and standard deviation.

[c]Feed conversion: g of feed consumed/g weight gain.

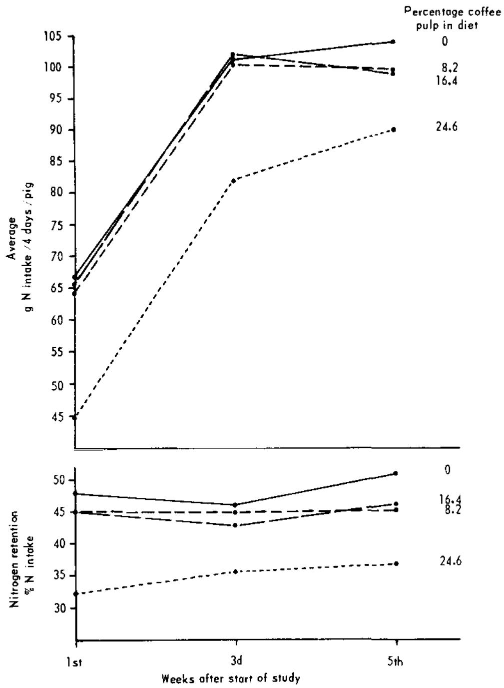

Fig. 2. Nitrogen balance of swine fed different levels of coffee pulp.

These findings are quite similar to those reported by Cabezas et al. (1974) who fed coffee pulp to young calves and found that nitrogen absorption and retention also decreased with respect to coffee-pulp level in the diet. Additional information on metabolic trials with the same diets was reported by Rosales (1974) and is described in Table 5, which indicates that digestible energy, as well as dry matter digestibility, decreases in direct relation to the level of coffee pulp in the diet. In this regard, Vohra et al. (1966) found that tannic acid reduced both metabolizable energy and nitrogen retention in chicks. Thus, is should be remembered that coffee pulp contains variable levels of tannins whose concentration depends upon varieties, location of the crop, and processing procedures after separation from the bean.

The levels of sodium and potassium excretion in the 4 days of urine collection are also included in Table 5. The results indicate a decrease in sodium and an increase in potassium excretion in relation to coffee pulp in the diet. These findings require further research, but they are interrelated with the mineral content of the by-product reported by Bressani et al. (1973) and Molina et al. (1974).

Dry Coffee Pulp Silage in Swine Feeding

Previous experience with this by-product has suggested that ensiling is one of the best ways to handle and preserve this material, and a well-packed trench silo can hold an average of 30 kg of coffee pulp per cubic foot (González et al. 1973). Recently, it has been found that the addition of sodium metabisulfite to the fresh pulp prior to dehydration exerts some physical and chemical changes on the pulp that improve its regular structure and alter its chemical composition (Murillo et al. 1977). Based on these findings, Jarquín and Bressani (1976) investigated the response of pigs fed the formulations described in Table 6. An additional

Table 5. Dry-matter digestibility, digestible energy, and total excretion of sodium and potassium in swine fed different levels of coffee pulp (Rosales 1974).

	Levels of coffee pulp in diets (%)			
	0	8.2	16.4	24.6
Digestible energy (%)	79.0[a]	79.0[a]	75.0[b]	70.0[b]
Dry-matter digestibility (%)	80.0[a]	79.0[a]	73.0[b]	68.0[b]
Sodium (g)	10.9[a]	10.1[a]	8.6[b]	8.6[b]
Potassium (g)	2.0[a]	2.0[a]	2.3[b]	2.9[b]

NOTE: Numbers with different letters on the same line are significantly different.

Table 6. Formulations (%) for swine using coffee pulp exposed to different treatments (from Jarquín and Bressani 1976).

	Treatments				
	1	2	3	4	5
Corn/soybean blend	50.00	50.00	50.00	50.00	50.00
Coffee pulp (sun dried)	—	16.00	—	—	—
Coffee pulp (ensiled with sugarcane molasses)	—	—	16.00	—	—
Coffee pulp (ensiled with 1.5% $Na_2S_2O_5$)	—	—	—	16.00	16.00
Corn tops	8.00	—	—	—	—
Sugarcane molasses	15.00	15.00	15.00	15.00	15.00
Minerals[a]	3.00	3.00	3.00	3.00	3.00
Corn	23.75	15.75	15.75	15.75	15.50
Vitamins + minor elements[a]	0.25	0.25	0.25	0.25	0.25
DL-methionine	—	—	—	—	0.25

[a]Same as in Table 1.

group of pigs whose ration included 0.25 DL-methionine was incorporated into the experiment because preliminary results from our laboratories indicated increased excretion of sulfates in the urine of animals fed coffee pulp (Bressani 1975).

The response of the pigs fed the different experimental diets is presented in Table 7 (Jarquín and Bressani 1976). Although statistical analysis did not show significant differences in relation to weight gain among the different treatments, there was a tendency for better performance of the animals fed dehydrated pulp or ensiled and dehydrated pulp without additives. The best response, as far as weight gain was concerned, was in the group fed the dehydrated pulp, followed by the group fed the ensiled dehydrated pulp. In both these groups, greater feed consumption was also observed.

The results also show that the addition of 0.25% DL-methionine does not improve the utilization of the material. This is an area that requires further research because the amino acid analysis reported by Bressani et al. (1972) indicated the pulp to be deficient in sulfur-containing amino acids. Nevertheless, the findings related to sun-dried coffee pulp, or coffee pulp ensiled with molasses and later sun dried, are en-

Table 7. Growth response of swine fed coffee pulp exposed to the different treatments described in Table 6 (from Jarquín and Bressani 1976).

	Initial weight (kg)	Final weight (kg)	Feed conversion	Daily gain (g)	Feed consumption (kg)
(1) Control	61.4	104.9	4.9	691	213.6
(2) Coffee pulp (sun dried)	60.9	105.1	5.1	701	223.8
(3) Coffee pulp (ensiled with sugarcane molasses	61.3	100.6	5.6	623	221.7
(4) Coffee pulp (ensiled with 1.5% $Na_2S_2O_5$)	60.9	98.4	5.2	295	194.0
(5) Coffee pulp (ensiled with 1.5% $Na_2S_2O_5$ + DL-methionine)	61.6	94.1	5.3	517	174.0

couraging because these processes are the cheapest. Furthermore, ensiling keeps the material in good condition, especially when sun drying has to be delayed because of rain.

Coffee Pulp Subjected to Different Processing Conditions

Decaffeination

The toxic factors in coffee pulp are still unknown, although caffeine and tannins, which are present at relatively high levels, have been suspected (Bressani et al. 1972, 1973). The toxic effects of caffeine in swine have been reported by Cunningham (1968) and in dairy cattle by Hawkings and Davis (1970), and the symptoms are similar to those observed in animals fed diets containing coffee pulp (Braham et al. 1973; Bressani et al. 1973). Therefore, Molina et al. (1974) and Cuevas García (1976) studied the possibility of detoxifying coffee pulp through a decaffeination process, to obtain on the one hand an extract containing caffeine, tannins, and soluble sugars for industrial purposes, and on the other, a residue that was a better quality animal feed, and, consequently, made better use of its nutrient content.

The nutritive value of coffee pulp subjected to a decaffeination process was compared to that of coffee pulp dried at 100 °C (Cuevas García 1976). Levels of 24% coffee pulp were substituted for an equal amount of corn from the control ration. Using a Latin square design nine young pigs were fed the diets described in Table 8 in a nitrogen balance study. As the statistical design implies, each group of three animals received the different rations in the three matabolic studies carried out. The results (Table 9) indicated that the rations containing coffee pulp were inferior to the control with respect to dry-matter digestibility and percentage of nitrogen absorption, which is related to nitrogen digestibility. Using these figures, biological value was calculated. As can be seen, nitrogen retention, which is a measure of protein quality, is higher for the diets containing coffee pulp.

Table 8. Formulations (%) used for swine feeding in which coffee pulp was substituted for corn (Cuevas García 1976).

	Control	Dehydrated pulp	Decaffeinated pulp
Soybean meal	26.0	26.0	26.0
Ground corn	50.0	26.0	26.0
Coffee pulp	—	24.0	24.0
Corncobs	11.8	4.7	—
DL-methionine	0.3	0.3	0.3
Vitamins and minor elements[a]	0.2	0.2	0.2
Minerals[b]	3.0	3.0	3.0
Sugarcane molasses	8.7	8.7	8.7
Starch	—	7.1	11.8
Protein	18.0	17.1	17.0
Crude fibre	6.1	7.61	9.0

[a] Premix Pfizer 500.
[b] Mineral Master Mix 12: Ca. 24%; P, 12%; NaCl, 18%; I, 0.009%; Fe, 0.2%; Cu, 0.01%; Co, 0.01%; Mn, 0.006%; Zn, 0.01%; Vitamin D, 10 000 I.U./kg.

Dehydration

Nitrogen balance studies were carried out by Urizar (1975), who studied the nutritive value of rations containing 24% coffee pulp

Table 9. Results of the metabolic studies carried out using the rations described in Table 8 (from Cuevas García 1976).

	Nitrogen ingestion (g/kg/day)	Dry-matter digestibility (%)	Nitrogen absorption (%)	Nitrogen retention (%)	Biological value (%)
Control	0.56048[a]	78.3[a]	78.8[a]	40.0[a]	50.6[a]
Dehydrated pulp	0.59321[a]	71.8[b]	68.5[b]	43.7[a]	63.6[b]
Decaffeinated pulp	0.49069[a]	72.9[b]	63.0[c]	42.1[a]	66.3[b]

NOTE: Different letters mean statistically significant difference ($p < 0.05$).

dried under different dehydration processes. The results obtained with respect to nitrogen balance (Table 10) indicated no statistical difference in nitrogen retention between the control and the rations containing coffee pulp; nevertheless, the group fed the pulp dried on a tray drier showed the highest level of nitrogen retention. The groups fed the pulp processed by freeze-drying, the sun-dehydrated pulp, and the drum-dried pulp showed lower nitrogen retention values. Caffeine analyses indicated similar levels for all diets containing coffee pulp, and no differences in urine volume were found between treatments with respect to the control. This is contrary to the high diuretic effect reported by Cabezas et al. (1974) when coffee pulp was fed to young calves.

Two points deserve mention: (1) in all nitrogen balance studies carried out with swine, protein digestibility is lower in diets containing coffee pulp; and (2) even with the low digestibility, nitrogen retention is similar or higher than that observed with the control diet. These results and those obtained with coffee pulp processed by different methods, including the removal of high amounts of caffeine and polyphenols, suggest that the low digestibility may be due to undesirable changes in nutrient availability during dehydration. However, this does not affect the nutrients absorbed through the gastrointestinal tract; therefore, a high nitrogen balance is maintained. Studies of this nature are needed to understand the effect of coffee pulp on animal performance and to increase the efficiency of its nutrient utilization.

Table 10. Nitrogen balance of swine fed coffee pulp dehydrated by different processes (from Urizar 1975).

Treatments[a]	N absorption (%)	N retention (%)
1	93.2[a]	54.3
2	80.6[b]	48.9
3	83.4[b]	47.5
4	79.9[b]	55.9
5	81.5[b]	51.4

[a]Treatment 1, control; treatment 2, ration containing 24% sun-dehydrated coffee pulp; treatment 3, ration containing 24% drum-dried coffee pulp; treatment 4, ration containing 24% tray-dried coffee pulp; treatment 5, ration containing 24% freeze-dried coffee pulp.

NOTE: Numbers with different superscripts are significantly different.

Discussion

Although little research has been conducted using coffee pulp as a swine feed, the results observed in the three stages of growth with different levels of coffee pulp in the diets presented in Tables 1 and 2 can be considered acceptable for the levels of 8 and 16% coffee pulp.

The low weight gain obtained in the third stage of growth for all groups was unexpected; however, the one fed the higher level of coffee pulp was more difficult to explain because the protein concentration of the diet was adequate for animals of that age. It may be that the level of coffee pulp used supplied a high percentage of lignified protein, which is unavailable to the animals. It must be pointed out that Bressani et al. (1973) reported that high levels of protein increased tolerance to high levels of coffee pulp in the diet. Furthermore, the results of studies with older animals have shown that they are more resistant to coffee pulp (Bressani et al. 1973); therefore, these results should be reevaluated.

The results obtained when native pigs were fed diets containing coffee pulp showed the same tendency as those obtained with Yorkshire pigs. One must bear in mind though that native pigs have not been genetically improved or selected, and consequently the poor feed conversion and weight gain figures shown in Tables 3 and 4 should not be striking. This kind of animal probably has the ability to tolerate a higher concentration of fibre in the diet, and, as reported by Gómez Brenes et al. (1974), their protein requirement is lower. This emphasizes the need for further research in this area because Leal and Amado (1972) reported that 90% of the swine in Guatemala are native.

The information shown in Table 7 clearly indicates that sodium metabisulfite addition at the time of ensiling did not improve the final biological results. Furthermore, it shows that methionine or total sulfur in the diet was not a limiting factor. Nevertheless, the findings related to dry coffee pulp and pulp ensiled with molasses and sun dried are encouraging because both processes can be implemented at the farm level.

The nitrogen balances reported by Bressani et al. (1974), Urízar (1975), and Cuevas García (1976), were obtained at different times, with different animals, and the origin of the test material was also different (in the case of the work by Cuevas García even a decaffeinated pulp was evaluated). In spite of this, their results indicate that there were no significant differences in nitrogen retention in any of the experiments. The results seem to indicate that under the prevailing experimental conditions, the rations containing coffee pulp were as efficiently utilized for protein synthesis as the control rations. If a comparison is made between the nitrogen balance in swine and that reported by Cabezas et al. (1974) for calves, one may conclude that the former species is much more efficient in utilizing coffee pulp. This conclusion is based on the fact that in spite of the lower protein digestibility in the rations containing coffee pulp, nitrogen retention was similar to the control. These results may be affected in one way or another by the low level of protein ingestion, suggesting a more efficient utilization of available protein for maintenance and growth. Furthermore, Cunningham (1968) working with swine reported that 1.5 g of caffeine per kilogram of diet increased nitrogen retention 7.9% although feed consumption decreased. Considering the levels of caffeine in coffee pulp, the percentage of the by-product used in the rations, and the feed intake of the animals, caffeine ingestion is very low in all the studies presented here.

Like coffee pulp, there are other feed ingredients that contain certain undesirable components for animal nutrition; as an example, tannin compounds are common to coffee pulp as well as to some sorghum varieties. Schaffert et al. (1974) reported that rats fed high-tannin sorghum showed poor weight gain and feed conversion when compared to those fed a low-tannin variety. However, the response was improved when the protein level was increased using soybean meal, indicating that the tannin present was not a toxic factor. This is just an indication of the need for further research with ingredients of this nature. Studies of combinations with protein sources other than soybean meal, as well as of the interactions between levels of caffeine, tannins, and chlorogenic acid are recommended for wider and more reliable use of coffee pulp in swine feeding.

Conclusions

- Coffee pulp, a waste product that has been used to a limited extent as a fertilizer of the coffee plant, can be used at levels up to 16% in swine rations without any detrimental effect on weight gain and feed conversion. However, higher levels decrease these two variables.
- Nitrogen balance values were not affected by 16% coffee pulp in the ration indicating that the protein of this by-product is well utilized up to that level and that the other constituents in coffee pulp such as tannins and caffeine do not interfere, at the levels fed, with the utilization of the other sources of protein in the ration tested. Dry matter and digestible energy also indicate that the 16% level of coffee pulp was adequate for a diet based on a mixture of corn and soybean meal.
- It is estimated that from weaning to market weight a pig needs 320 kg of feed. If a concentrate were made containing 16% coffee pulp instead of corn, there would be 52 kg of coffee pulp used for each pig delivered to the market, and the saving of the same amount of corn that could be used for human consumption or industrial utilization. The economical implications are obvious.

6

Coffee Pulp in Other Species

J. Edgar Braham[1]

Developing countries, and especially the Central American countries, must rely on the import of protein sources for poultry rations; therefore, poultry is expensive. Likewise in these areas, animals compete with humans for the same source of energy — corn — which is an indispensable poultry-feed component. Therefore, any attempt to use local sources of plant protein and/or energy for feed manufacturing, or to spare corn for human consumption would, on the one hand, lower the price of poultry and make this animal protein more accessible, and on the other hand, make more energy available for human consumption. Although corn cannot be considered as a good protein source, the amounts eaten by these populations are such that corn does become a source of both protein and calories for the human population.

Although most corn substitutes cannot be used at levels higher than 20% in poultry rations (Squibb and Wyld 1951), even this percentage would significantly increase the availability of corn for humans. Coffee pulp contains about the same amount of protein as corn, but at the same time its crude fibre content is more than four times as high. In addition, and as discussed elsewhere in this book, this by-product contains other factors, such as caffeine, tannins, and polyphenols, that interfere at some level, whether digestive or metabolic, with the proper utilization of some nutrients, and that, depending on the level fed, can produce toxic symptoms and even result in death.

Monogastric animals, unlike ruminants, are incapable of handling certain feed constituents, or, in the best of cases, are capable of handling them only in limited amounts. Cellulose, the main constituent of the fraction known as crude fibre, can be hydrolyzed by ruminants to its simplest constituent, glucose. Monogastric animals can handle cellulose to a much lesser degree than ruminants because the enzyme responsible for its breakdown — cellulase — is not a constituent of their digestive enzymatic complex. Monogastric animals can handle small amounts of cellulose as a result of cellulase activity in the intestinal microflora, especially that present in the cecum of those species possessing this anatomical diverticulum, such as rabbits, horses, and, to a certain extent, chickens.

The amount of crude fibre in a potential feed ingredient for monogastric animals must, therefore, be taken into consideration in the formulation of a ration. All animals need a certain amount of crude fibre in their diet to add bulk and ensure adequate peristalsis; however, the more fibre a ration contains, the less digestible the ration. This in itself would not be a problem, because what is not digested is excreted, were it not for the fact that fibre contributes volume that helps fill the animal and consequently

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causes it to eat less of the other nutrients in a given ration. The net result is that the animal will thrive less on a high-fibre diet than on a ration containing an adequate amount of crude fibre.

Coffee Pulp in Poultry Rations

Fibre content is very important in considering ingredients for poultry rations. Chickens do not tolerate large amounts of crude fibre; therefore, if a ration is to be economically feasible, its crude fibre content should be kept at a level of 6% and not exceed 8% of the ration. A large proportion of a chick ration is of plant origin; therefore, crude fibre does pose a problem when plant sources containing high levels of it are incorporated into poultry feeds.

On this basis, the prospect of using coffee pulp as a constituent of poultry rations does not appear very promising, and this has been corroborated by experimental evidence. Bressani et al. (1973) fed chicks for 8 weeks with a complete ration in which corn was replaced by 10, 20, 30, 40, and 50% dehydrated coffee pulp (Table 1). Weight gain and feed intake decreased as the level of coffee pulp in the ration increased. Mortality increased with increasing levels of coffee pulp to the extent that at the end of 6 weeks all animals fed 50% coffee pulp in the ration had died. Even 10% coffee pulp affected growth negatively. The results indicate that factors other than crude fibre are involved because the level of fibre in the rations could hardly account for the observed mortality. These results are in agreement with earlier findings by Squibb (1950), Squibb and Falla (1949), and those conducted by the USDA at Beltsville, Maryland cited by Madden (1948). In these experiments dry coffee pulp depressed growth, increased mortality, and decreased feed efficiency in chickens.

Table 1. Feed consumed, average final weight, and mortality of chicks fed different levels of dehydrated coffee pulp (from Bressani et al. 1963).

Coffee pulp in ration (%)	Feed consumed per group (g)	Average final weight (g)[a]	Mortality (live/dead)[b]
0	15702	825	10/0
10	15909	796	9/1
20	14955	557	10/0
30	7720	348	7/3
40	2069	158	2/8
50	710	0	0/10

[a]Average initial weight: 47 g.
[b]At 6 weeks.

Solís (1977) treated coffee pulp with different levels of sodium metabisulfite because this compound has a beneficial effect on the by-product (see Chapter 9). He found that the treatment resulted in an increase in cellular contents and a decrease in most crude fibre fractions and in lignified protein. Because crude fibre and lignified protein are not susceptible to enzymatic digestion, the treatment was thought to result in an improvement of the digestibility of coffee pulp. However, when coffee pulp either treated with sodium metabisulfite or untreated was fed at a 20% level in a starting chick ration (Table 2), the animals gained less weight than controls and feed conversion was also lower. Nevertheless, as the level of metabisulfite increased, chicks performed a little better than animals fed untreated pulp. It is interesting to note that when crude fibre in the form of pure cellulose was added to the control ration at the same level as that provided by 20% coffee pulp, weight gain and feed conversion were not as adversely affected as when coffee pulp was fed. Crude fibre can, therefore, be assumed to be only partially responsible for the detrimental effects observed in chicks fed coffee pulp.

Similar results were obtained by Bressani and González (1977) who fed chickens from 15 days to 10 weeks with graded levels of coffee pulp treated with 1 and 2% levels of sodium metabisulfite. In general, increasing the levels of coffee pulp in the ration decreased weight gain and feed conversion; mortality, however, did not occur even in those groups fed as high a level of coffee pulp as 30%. The authors concluded that if coffee pulp was adequately dried and treated, 10% could be included in chick rations without any interference with performance. These authors also found that as the level of coffee pulp increased in the ration there was an increase in water uptake. This observation has also been made in ruminants, and is probably due to the combined diuretic effect of caffeine and tannins in the diet.

Treatment with metabisulfite did not affect the caffeine content of coffee pulp, but it did increase the levels of tannins and other polyphenols, such as caffeic and chlorogenic acids. The alkaloids and tannins, whether singly or through a synergystic effect, are probably responsible for the detrimental effect of feeding coffee pulp to chicks.

Caffeine has proven to affect other functions besides growth in chicks. Ax et al. (1976) showed that caffeine fed at a level of 0.05 and 0.1% to layers and roosters had a detrimental effect on reproductive performance. Although fertility of incubated eggs did not differ significantly, there was a significant increase in embryonic mortality as the level of caffeine was raised. The percentage of dead embryos for the group fed the highest level of caffeine was 38.2 as compared to 5.2 for the control group. When caffeine was given to males and their semen used to fertilize pullets not fed caffeine, there was a significant decrease in fertility values and embryonic mortality was high but not significantly different from control eggs. Semen output and sperm concentration dropped markedly, and after 30 days of feeding caffeine no semen could be collected at all. Histology of the testes showed that spermatogenesis was markedly disrupted. All these effects were reversible after caffeine was removed from the diet.

Tannins too have been shown to impair performance when fed to chicks at levels as low as 0.5% of the ration (Vohra et al. 1966). Higher levels resulted in mortality. Chang and Fuller (1964) found that the addition of methionine and choline alleviated tannin toxicity when high-tannin sorghums were fed to chicks. However, they also found that the growth depression was only partially alleviated by the addition of methionine and choline when pure tannin was fed. Other authors (Vohra et al. 1966), on the other hand, have found that these two compounds, or other methyl donors, have no effect whatsoever in counteracting tannin toxicity. Besides growth depression, some workers have found decreased nitrogen retention and increased cholesterol serum levels (Vohra et al. 1966) and a reduction in metabolizable energy values (Vohra et al. 1966; Yapar and Clandinin 1972). Others have found no effect of tannins on nitrogen absorption (Yapar and Clandinin 1972).

Conflicting results upon feeding tannic acid are to be expected because tannic acid from different plant sources is a different chemical entity and, therefore, degrees of toxicity as well as general effects will vary with the source of tannic acid. The different studies, however, agree on the depressing effect that tannins have on growth, whatever

Table 2. Weight gain and feed conversion (feed consumed/weight gain) of chicks fed rations with 20% coffee pulp treated with different levels of sodium metabisulfite ($Na_2S_2O_5$) (from Solís 1977).

	Final weight (g)	Weight gain (g)	Feed conversion
Control	1666	1548	2.43
Control + cellulose	1521	1403	2.80
Untreated coffee pulp	841	723	4.28
Coffee pulp + 0.025% $Na_2S_2O_5$	778	660	4.43
Coffee pulp + 0.050% $Na_2S_2O_5$	841	723	4.38
Coffee pulp + 0.100% $Na_2S_2O_5$	866	748	4.08
Coffee pulp + 0.300% $Na_2S_2O_5$	822	704	4.21
Coffee pulp + 0.500% $Na_2S_2O_5$	867	749	3.86

their source, when fed to growing chickens.

Coffee pulp contains two substances, caffeine and tannins, that individually have been shown to exert a detrimental effect on the growth of chickens. Therefore, it is understandable that feeding coffee pulp to this species should interfere with adequate performance; more so, as the synergytic effect between these substances is not known.

Coffee Pulp in Fish Diets

Fish could contribute a significant amount of high-quality protein to the diet of developing countries. If, until now, fish have played a minor role in some countries it has been due to the technology involved in catching and processing them. However, new technologies are constantly being devised that tend to lower prices and introduce fish as a regular item in the diet. One of these technologies is the growing of freshwater fish not in ponds but in makeshift corrals of wood and plastic.

One of these varieties is tilapia (*Tilapia aurea*). Studies were carried out by the Ministry of Agriculture and Animal Husbandry of El Salvador using the above mentioned technology and species (García and Bayne 1974). A total of six corrals were used, two for each of three treatments; one, a control group, received no additional feed besides that naturally present in the corrals, while a second group was fed with chicken manure. The third treatment consisted of a pellet containing 30% coffee pulp plus wheat bran, ground corn, molasses, cottonseed oil meal, urea, and bone meal. The corrals were sown with 300 fish per corral and the experiment lasted for 5 months, which is enough time for the species to achieve its market weight (Fig. 1). Weight gain was higher for the animals fed the concentrate with coffee pulp than for the other two treatments. No toxicity was observed, and total yield for the coffee pulp-fed group was 5171 kg/ha/year as compared to 3375 kg/ha/year for the control and 2789 kg/ha/year for the group fed chicken manure. Coffee pulp seemed to be totally digested, and apparently, fish can tolerate higher levels of this agricultural by-product than chickens or other monogastric animals.

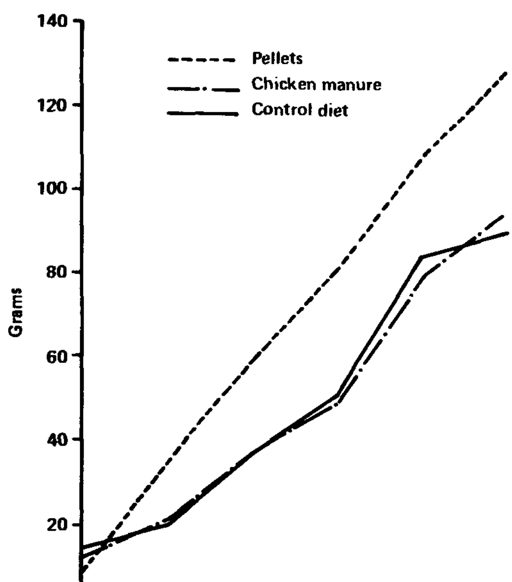

Fig. 1. Growth response of Tilapia aurea fed different diets.

It is evident that no conclusive statement can be made at present concerning the use of coffee pulp in other species of monogastric animals. There is little experimental data and more studies are needed on the possibilities of using coffee pulp in chick and fish diets. Safety levels have not been determined, and the effect of caffeine and tannins, as well as their interaction, is still at best a moot question. Nevertheless, and in spite of some of the negative results obtained thus far, coffee pulp cannot be completely discarded as a component of poultry rations because technology could greatly improve its potential as a feed. No data are available, for example, on the effect of decaffeination of coffee pulp on its nutritive value for chicks, nor is it known if coffee-tannin toxicity can be counter-balanced by the addition of methyl donors such as methionine or choline. Processing and technology can probably give the answer to these and other questions related to the utilization of coffee pulp as a component of diets for small animals.

7

Coffee-Pulp Silage

Beatriz Murillo[1]

Seasonal production and high water content hinder the utilization of coffee pulp in cattle feeding. There is no efficient mechanical means of effectively dehydrating the large amounts of coffee pulp produced during the coffee harvesting and processing season, which lasts 2–3 months, and it is not possible to use the drying patios for dehydrating coffee pulp by sun exposure because the coffee producer is naturally more interested in drying the coffee beans.

To make use of coffee pulp in animal feeding on a commercial scale it is necessary to use processing conditions and equipment that are not used for coffee bean processing and that, at the same time, maintain or improve the nutritional value of the pulp as a cattle feed without increasing the cost of the processed product too much.

A possibility with a good chance of successful implementation is ensiling. This process, widely known and used for the conservation of seasonal forages in cattle farms, consists of preserving fresh forage by partial fermentation (Barnett 1954). The fermentation is the result of the action of anaerobic bacteria on the soluble carbohydrates contained in plant cells. During the process, acid is produced, mainly lactic acid, which lowers the pH of the ensiled material and depresses the growth of other strains of bacteria. In this manner, further decomposition of the material is arrested and once ensiled it can be kept for long periods of time.

The ensiling process has been exhaustively discussed by different authors (Barnett 1954; Watson and Smith 1965). In general, it involves simple technology and can be effectively used by both coffee growers and processors and by cattlemen. This means that coffee pulp could be stored during the harvesting season and used later as fresh or dehydrated silage. In the latter case, sun dehydration could be carried out on the coffee drying patios that are part of the infrastructure of every coffee processing farm, and which are seldom used outside of the coffee harvesting season.

Coffee-Pulp Silage

The process for ensiling coffee pulp is described in Fig. 1. The pulp obtained from the coffee-processing plant contains 80–85% water. This must be lowered to 60–70% to ease handling of the material, improve the quality of the silage, and permit the storage of larger amounts of dry matter. Therefore, the pulp is spread in thin layers and sun-dried for 4–6 h, or temporarily stored in special draining chutes. Once the desired moisture content is reached, the pulp can be ensiled without additional processing, with or without additives.

Bohkenfor and Fonseca (1974) compared the quality of coffee-pulp silage made using

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coffee pulp that was: (1) recently harvested; (2) pressed; or (3) partially dehydrated by sun exposure. On the basis of quality control parameters, they concluded that the best silage was obtained from fresh coffee pulp because of its high content of fermentable carbohydrates; second-best was pressed coffee pulp; whereas, sun-dried coffee pulp was the least adequate. These results were confirmed by Rodríguez et al. (1974).

Coffee pulp is ensiled in both underground trench- and pit-type silos. In both cases the procedure is the same as the one used with other materials, i.e. the silo is filled with successive layers that are packed to ensure the exclusion of air (González 1973). Good compressibility and silage have been obtained with 60–65 lb of pulp per cubic foot (960–1040 kg/m^3). Trench silos require special construction, which increases the cost of the silage. Pit silos, on the other hand, are made of the septic tanks that are a required pollution control mechanism in every coffee processing farm. Their size varies, but the ones used successfully by

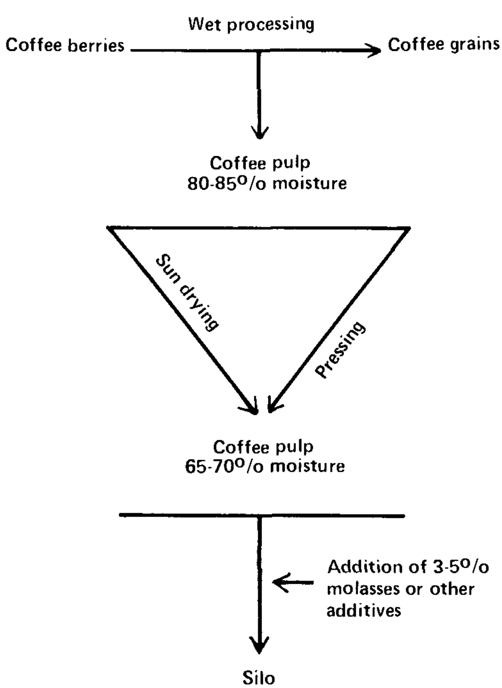

Fig. 1. The process for ensiling coffee pulp.

Menjívar et al. (unpublished data) were 6–8 m wide, 12–15 m long, and 1.5–2.0 m deep. The pits have dirt walls and floor, so it is necessary to cover them with a plastic sheet to protect the silage from contamination with dirt and air.

It is also necessary to open a drain at the bottom of the pit so that the drainage liquids can be removed. The silage can be piled to a height of 2 m above ground level, so that almost 60% of the silage is above ground and outside the pit (Fig. 2). As in the case of trench silos, the surface must be covered with a plastic sheet, rough forage, and a layer of dirt.

Pit silos are less expensive than trench silos because the pits are already part of the facilities of the processing farm and require few alterations to be transformed into silos. They have the disadvantage, however, that during heavy rainfall seasons rainwater may seep in and spoil the silage. Therefore, if the walls and floor of the silo are not covered with brick or stone, the silage must either be dehydrated or used before the rainy season. Coffee pulp can be ensiled either alone or with forages of adequate chemical characteristics for a good quality silage, such as corn fodder. In both cases, it is better to add sugarcane molasses, to stimulate fermentation, in amounts that vary between 3 and 5% of the fresh weight of the material to be ensiled (González 1973).

Additives

When raw materials are ensiled that have a low carbohydrate content they tend to increase the pH due to the evolution of ammonia during the fermentation of proteins (Barnett 1954).

Sugarcane molasses is the source of carbohydrate most commonly used because its high soluble sugar content promotes fast bacterial growth and it has the added advantage of increasing the nutritive value of the silage as well as its digestibility and palatability. The amount of molasses that is added is equal to 3–5% of the fresh weight of the coffee pulp. To facilitate its incorporation into the silage the molasses is usually diluted to 50% with water.

Fig. 2. A pit silo for coffee pulp.

The use of forages for ensiling coffee pulp is also very successful because the forage is a good source of soluble carbohydrates (Daqui 1975). Among the forages used are corn or sorghum fodder, sugarcane tips, napier grass, etc. These forages can be included in many proportions, but to use coffee pulp adequately it is recommended that forages not exceed 50% of the total ensiled material.

Another way to preserve the forage in the silo is by the addition of mineral acids — "artificial acidification." In this case, the acid is not produced during fermentation but is added directly at the time of ensiling (Virtanen 1933). This method is used for forages with a low dry-matter content (16–20%).

Another additive used for coffee pulp is sodium metabisulfite, which, when used at a concentration of 0.3%, produces carbon dioxide that inhibits the growth of undesirable organisms (Barnett 1954). Studies by Jarquín and Bressani (1976) showed that coffee pulp ensiled with metabisulfite had a higher free tannin content (2.0–3.1%) due to the splitting of the protein-tannin complex (Murillo 1977).

Bohkenfor and Fonseca (1974) studied the effect of adding 2% urea plus 3% calcium carbonate ($CaCO_3$), and 2% urea plus 2% $CaCO_3$ plus 1% $CaHPO_4$, to coffee pulp before ensiling. Two months later samples were taken for analysis. The authors concluded that none of the additives improved the quality of the silage.

Chemical Changes

The effect of fermentation on the chemical composition of coffee pulp has been studied by Choussy (1944), Jaffé and Ortiz (1952), and Bressani et al. (1972) (Table 1). The observed differences may be due to differences in the raw materials used and to the treatments applied. It is interesting to note the decrease in caffeine content induced by aerobic fermentation in the results of Jaffé and Ortiz and Bressani et al.

Rubio and Pineda (1973) compared the proximate chemical composition of fresh and ensiled coffee pulp and fresh pulp inoculated with yeast. The results of this

Table 1. Variations in the chemical composition (% dry matter) of coffee-pulp silage.

	Choussy (1944) (ensiled for 10 months)	Jaffé and Ortiz (1952) (aerobic fermentation, 3 days)	Bressani et al. (1972) (aerobic fermentation)
Ether extract	1.7	1.8	2.8
Crude fibre	13.2	32.1	22.4
Protein	11.2	15.2	11.6
Ash	6.9	13.3	9.5
Nitrogen-free extract	66.0	36.6	53.1
Caffeine	0.9	0.8	0.6
Tannins	—	1.0	—

Weende analysis showed no marked differences in the different chemical fractions between fresh and ensiled coffee pulp. Fresh coffee pulp inoculated with yeast showed increased nitrogen and decreased crude fibre contents.

Murillo et al. (1976) identified and quantified the physical and chemical changes that occurred when coffee pulp was ensiled with molasses and forages in laboratory silos. Mixtures of pulp, molasses, and forages were ensiled (Table 2). Total losses were lower in the silages containing coffee pulp alone (CPS). It is possible that the larger losses observed in the coffee pulp plus napier grass (CPNS) and coffee pulp plus corn fodder (CPCS) silages were due to better utilization of the materials by the fermentating organisms, which resulted in a significant decrease in dry-matter content. The pH values of the three silages exceeded the maximum limits (4.2) considered appropriate for the production of a good silage (Watson 1965); however, the appearance and colour of all of them were characteristic of silages where an adequate anaerobic fermentation has taken place (Braham et al. 1973; Squibb 1945, 1950). The better characteristics of CPNS and CPCS silages as compared with CPS were due to the fact that both napier grass and corn fodder provided larger concentrations of chemical compounds susceptible to fermentation (Table 3). As a result of the fermentation

Table 2. Fermentation characteristics of coffee-pulp silage alone and mixed with napier grass or corn fodder in laboratory silos.

	CPS[a]	CPNS	CPCS
Period of ensiling (days)	141	140	132
Weight difference (kg)	1.1	4.3	4.3
Loss in drainage (%)	4.8	18.9	23.2
pH	4.3	4.1	3.8

[a] CPS coffee-pulp silage; CPNS coffee pulp-napier grass silage; CPCS coffee pulp-corn fodder silage.

Table 3. Chemical characteristics of coffee pulp ensiled alone or mixed with napier grass or corn fodder.

	CPS[a]	CPNS	CPCS
Dry matter	33.2	30.1	20.1
Composition of dry matter			
Protein	13.8	9.4	8.1
Ether extract	2.2	2.1	2.6
Crude fibre	20.0	34.0	26.1
Ash	10.9	9.8	9.9
N-free extract	43.1	44.7	53.3
Cellular content			
Soluble carbohydrates	0.3	1.8	2.8
Cellular walls	61.2	63.2	50.2
Hemicellulose	0.4	8.0	7.0
Lignin	29.5	22.5	15.7
Cellulose	30.0	30.0	24.9
Caffeine	0.6	0.3	0.4
Tannins	2.4	1.5	1.2

[a] CPS coffee-pulp silage; CPNS coffee pulp-napier grass silage; CPCS coffee pulp-corn fodder silage.

process, the three silages showed a decrease in dry matter, cellular content, and soluble carbohydrates, as well as an increase in cellular walls and their components, and protein. The magnitude of these changes was directly related to the losses observed in dry matter.

The caffeine content of the CPNS and CPCS silages decreased approximately 30% as compared to CPS. This effect was the result of the dilution brought about by the napier grass and corn fodder.

Daqui (1975) ensiled coffee pulp with corn fodder on a 60:40 proportion, on an "as is" basis, in a trench silo, and obtained a silage with very good appearance and colour and a pH of 3.8 (indicating an adequate fermentation). The caffeine and tannin levels depended on the quantity of these compounds present in the coffee pulp that was used, and were of the same order as those found by Bressani et al. (1972) and Estrada (1973).

Murillo (1974) ensiled coffee pulp in laboratory silos without any additives, with 10% molasses, with a 10% solution of hydrochloric or sulfuric acid following the methodology proposed by Virtanen, and with a mixture of both acids and 10% molasses. Percentage loss in the silo was 26.8 when the mixture of acids was used (Table 4). Cellular content of dry matter varied from 66.0 to 67.5% for the treatments containing 10% sugarcane molasses; whereas, crude protein was higher for coffee pulp alone and for coffee pulp with either acid. Caffeine

Table 4. Chemical composition of coffee pulp ensiled alone or with sugarcane molasses and/or an acid mixture.

	Coffee pulp	Coffee pulp + 10% molasses	Coffee pulp + 10% acid mixture[a]	Coffee pulp + molasses and acid mixture
Period of ensiling (days)	90	90	90	90
Total weight				
Initial (kg)	22.0	22.0	22.0	22.0
Final (kg)	18.5	17.4	16.1	17.6
Difference (kg)	3.5	4.6	5.9	4.4
Loss (%)	15.9	20.9	26.8	20.0
Dry-matter composition				
Cellular content (%)	55.9	66.0	58.5	67.5
Cellular walls (%)	41.1	24.0	41.5	32.5
Hemicellulose (%)	3.0	2.7	2.8	2.9
Cellulose (%)	19.4	15.2	19.7	14.2
Lignin (%)	20.5	14.6	17.7	14.0
Crude protein (%)	10.6	9.0	10.8	9.2
Lignified protein (%)	4.1	3.0	3.5	2.9
Caffeine (%)	0.7	0.5	0.5	0.5
Tannins (%)	1.6	1.6	1.6	1.5
pH	4.3	4.1	3.7	3.8
Composition of draining liquors				
Soluble sugars (g/litre)	22.0	21.4	15.1	19.3
Caffeine (g/litre)	2.2	2.7	3.4	3.2
Tannins (g/litre)	3.7	3.7	3.1	4.0

[a] Sulfuric: hydrochloric, 50:50, 10%.

Table 5. Changes in the chemical composition (% dry matter) of coffee pulp ensiled in pit silos.

	Original pulp	Ensiled pulp
Dry matter	17.4	19.7
Cellular walls	48.0	55.2
Crude protein	12.2	13.9
Lignified protein	4.5	6.1
Caffeine	0.9	0.6
Tannins	1.6	1.3
In vitro digestibility of dry matter	67.8	61.7
pH	5.6	4.2

content decreased in the presence of additives; tannins were not altered. Values for pH were lower for the silages containing the mixture of acids.

The silage obtained from pit silos had a pH of 4.2 and excellent characteristics of odour and colour. Likewise, tannin and caffeine, compounds that have shown toxic effects on animals, decreased significantly (Table 5). Both compounds are water soluble, so they are lost in the draining liquids (Murillo 1974). In vitro digestibility of dry matter decreased from 67.8% for fresh unsiled coffee pulp to 61.7% in coffee-pulp silage.

Nutritive Value of Coffee-Pulp Silage

Although this subject has been more thoroughly discussed in other chapters of this monograph, particularly with respect to ruminant and swine utilization, additional information will be discussed in this section.

As has already been indicated (Chapter 4), coffee-pulp silage results in better performance of calves, as measured by weight gain and feed efficiency, than sun-dried coffee pulp (Cabezas et al. 1976). There are, however, certain discrepancies, as this effect has not been consistently observed in all cases (Braham et al. 1973). What has been ascertained is that coffee-pulp silage is not nutritionally worse than fresh coffee pulp, and that when coffee-pulp silage has been found wanting, it is probably due to the drying of the silage by sun exposure. During sun-drying, the natural colour of the fresh coffee-pulp silage turns dark brown or black, suggesting enzymatic browning of the product.

In swine (Chapter 5), the evidence indicates that there is no difference in nutritive quality between sun-dried coffee pulp and sun-dried coffee-pulp silage. If the fresh silage turns out to be superior, it can be ascribed to the enzymatic browning of the sun-dried silage, a point that still needs verification.

Recent studies with rats (Bendaña García 1977) have shown that coffee-pulp silage is superior to dry coffee pulp with respect to mortality, weight gain, and feed efficiency. At a constant level of coffee pulp (30%) and a protein level in the ration of 10, 15, 20, or 25% there was less mortality and better weight gain with coffee-pulp silage at any level of dietary protein (Table 6). Thus, the evidence obtained with different animal species seems to indicate that coffee-pulp silage is superior to dry coffee pulp in terms of nutritive quality. However, it is necessary to carry out further studies

Table 6. Effect of dry coffee pulp (DCP) and dry coffee-pulp silage (DCPS) on mortality and weight gain of rats.

Protein level in diet (%)	Coffee-pulp level in diet (%)	Mortality		Weight gain	
		DCP	DCPS	DCP	DCPS
10	30	62.5	12.5	−12	18
15	30	12.5	0	34	74
20	30	25.0	0	66	113
25	30	37.5	12.5	72	126

Table 7. Comparative cost of nutrients ($U.S./100 kg of nutrient) from coffee pulp and from other forages.

	Original material	Dry matter	Crude protein	Total digestible nutrients
Coffee-pulp silage	0.36	1.64	15.58	3.64
Corn-fodder silage	0.60	2.40	38.10	4.21
Sorghum silage	0.50	1.67	25.69	3.04
Cottonseed hulls	2.50	2.77	48.73	6.94
Cottonseed oil meal	10.00	11.11	27.10	15.22
Sugarcane tops	0.45	1.43	62.17	2.70
Sugarcane molasses	2.00	2.60	61.84	2.71

to determine if the dehydration process reduces the nutritive potential of coffee-pulp silage.

Cost of Coffee-Pulp Silage

To calculate the cost of ensiling coffee pulp two important aspects must be considered: the nature of the raw material, and the cost of silage processing.

Coffee pulp is an abundant product that in coffee-growing countries usually causes pollution problems. It is used to a limited extent as a green fertilizer and in industry; therefore, it is considered as an agricultural by-product of low commercial value. For this reason, its efficient use in animal nutrition would turn coffee pulp into a valuable new resource that could be used to produce foods for human consumption. In this sense, coffee-pulp silage and its use as a cattle feed offer good prospects, not only because of the simple technology needed for its processing, but because of its nutritive value as well (Braham 1973; Bressani 1975; Cabezas 1974; Daqui 1975; Flores Recinos 1973; Jarquín 1973.)

Table 8. Cost per tonne of coffee-pulp silage produced in a pit silo.

	$U.S./tonne
Fresh coffee pulp	2.00
Transportation	1.00
Plastic sheets	0.20
Sugarcane molasses	0.26
Filling the silo [a]	0.05
Covering of silo [b]	0.13
Total	3.64

[a] Cost of labour.

[b] Cost of dirt to cover silo.

The cost per tonne of coffee-pulp silage was determined for pit silos located 3 km from the coffee-processing farm (Table 8). The total cost per tonne of fresh silage under these conditions was $U.S.3.64 of which $2.00 accounted for the raw material and $1.64 for processing.

Table 7 shows the cost of 100 kg of nutrients from coffee-pulp silage in comparison with those for some of the most common forages in Central America. Coffee-pulp silage competes in price per 100 kg of dry matter with sorghum-plant silage and sugarcane tips. Coffee pulp is the cheapest source of crude protein and in total digestible nutrients it is similar to sorghum-plant silage. Coffee pulp is, in summary, a low-cost forage with very good potential for cattle feeding.

It can be concluded that ensiling can be used for the conservation and preservation of coffee pulp as cattle feed. However, it is necessary to subject coffee pulp to the same treatments used with other materials to obtain a suitable product. It is impossible to obtain a good quality feed simply as a waste product. Like any other feed, it requires adequate processing subject to strict quality standards. If these standards are not enforced, coffee pulp acquires undesirable characteristics that affect animal production.

8

Drying of Coffee Pulp

Mario R. Molina[1]

In considering the utilization of coffee pulp we should take into account several aspects: (1) coffee pulp is a by-product of the coffee berry, which is available in large amounts at the time of harvesting and processing; (2) as indicated in previous chapters, coffee pulp has a relatively high moisture content (75–85%); (3) the most immediate utilization of coffee pulp reported to date is as an ingredient for animal (ruminants and/or monogastric) rations (Bressani 1975; Bressani et al. 1973; Cabezas et al. 1974; Carew et al. 1967; Jarquín et al. 1973, 1974; Robayo 1961; Rosales 1973); and (4) the animal producer is not necessarily a coffee processor nor are the animal production facilities necessarily located at the same site as the coffee processing industry.

It is evident that a drying operation must be considered for coffee pulp to reduce the costs of transporting the material from the coffee processing site to where the animals are produced, and also to reduce the possibility of microbiological contamination. However, the rationale in the drying of coffee pulp is not that straightforward. It should be noted that the process must be economical if the cost of the final by-product is to compete favourably with the cost of the constituent(s) it is to replace in the animal ration. Furthermore, the drying operation must be implemented at the coffee processing site where any improvement and/or investment in drying would preferentially be directed to the coffee grain, which is the main product of the coffee berry. Therefore, alternatives for "storing" the coffee pulp and drying it after the grain has been dried using the same facilities would perhaps be considered favourable by the coffee processor. Among these alternatives the most promising is ensiling, which is discussed in Chapter 7. When drying an ensiled product (about 70% moisture), consideration should be given to the "additives" in the silage (e.g. molasses), as well as to the changes that occur during the fermentation, because they could yield a product with completely different drying characteristics than the original raw material.

Drying Characteristics of Coffee Pulp

Very little information is available on the basic drying characteristics of coffee pulp. Molina et al. (1974a,b) reported that by using a convection oven with an inlet air temperature of 75 °C and an air velocity of 2.47 m/s, the moisture content of coffee pulp could be reduced from 70 to 12% (on an "as is" basis) at a constant rate of 1.16 kg H_2O/kg dry matter/h when using a load of either 454 g (1 lb) or 908 g (2 lb) of wet material (85% moisture) per 0.09 m^2 (1 ft^2).

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The authors indicated that the reduction in moisture from 85 to 70% occurred during the heating or warming up period; whereas, the reduction from 70 to 12% moisture occurred during the constant-rate drying period. The diffusion drying period manifested itself until the material reached 6% moisture at which time the falling-rate drying period, averaging 0.12 kg H_2O/kg dry matter/h, ended. From these results it is evident that the drying of coffee pulp to 10–15% moisture, which is considered necessary for its microbiological stability, could be achieved through a constant-rate drying period.

Recently, preliminary observations in our laboratories have indicated that the above drying characteristics of coffee pulp are not true when air with a higher inlet temperature (170–200 °C) is used. In this case, the constant-rate drying period appears to end with a product at about 40–45% moisture. These observations suggest a possible effect of temperature on the drying behaviour of the pulp, or, because the samples used were different and possibly from different localities, a possible effect of the sample itself (altitude at which it is grown, degree of ripeness, agricultural practices, time of storage prior to processing, degree of fermentation, etc.) on its drying characteristics. Both effects require further study. The implications of these studies are considerable because it has been reported that as the inlet air temperature increases, the concentration of insoluble, noncytoplasmatic (lignified) protein in the pulp increases (Ruiz and Valente 1974). Therefore, it is doubtful whether an inlet air temperature higher than 125–150 °C for drying coffee pulp in a batch-type drier would be advisable because such a temperature might significantly decrease the constant-rate drying period, and thus proportionally increase the retention time of the material in the drier.

Molina et al. (1974a,b, 1976) using a vertical tunnel-tray drier with a countercurrent arrangement, an inlet air temperature of 75 °C, and a load of 681 g/0.09 m^2 (1.5 lb/ft^2), showed by the Van Arsdel analogue method (Van Arsdel 1963) that with a similar drier and drying conditions, 10 7.2-m^2 trays would have an estimated production rate of 824 kg of dry material per 24 h. Using a loading of 1136 g/0.09 m^2 (2.5 lb/ft^2) and an inlet air temperature of 120 °C, the same authors reported an estimated yield of up to 477 kg of dry material per 24 h in a total drying area as small as 5.6 m^2. Considering that the volumetric air velocities used by Molina et al. (1974b) were relatively small (4.5–5.0 m^3/s), these data also indicate the relative ease of drying coffee pulp under these conditions. The general chemical composition (Table 1) of the mechanically dried pulp did not show any appreciable variation from the fresh sample when compared at a similar moisture level (Molina et al. 1974b).

Drying Technologies Applicable to Coffee Pulp

Five possible drying technologies applicable to coffee pulp have been investigated based on both technical and economic considerations: batch or bin (deep bed) driers, sun drying, tunnel driers, belt driers, and rotary driers (Molina and Avendaño 1976). When considering a batch or bin drier as a possible alternative, more research is needed to determine the degree of compressibility of the coffee pulp and thus the design and capacity limitations of this type of drier as applicable to coffee pulp. When the other four drying technologies were considered on a similar capacity basis (removal

Table 1. Chemical composition of fresh and mechanically dehydrated (at 120 °C) coffee pulp (from Molina et al. 1974b).

	Fresh pulp (%)	Dehydrated pulp (%)
Water	81.21	5.11
Ether extract	0.72	4.61
Crude fibre	2.79	15.87
Protein (N × 6.25)	2.31	12.22
Ash	1.29	7.91
Caffeine	0.28	1.31
Tannins	—	2.60
Chlorogenic acid	—	2.71
Caffeic acid	—	0.30
Total soluble sugars	—	9.03

of 52 163 kg of water in 8 h, which is the necessary capacity for drying 63 503 kg (140 000 lb) of coffee pulp (85% moisture) to produce of 11 340 kg (25 000 lb) of dried product (10% moisture) in the same period), Molina and Avendaño (1976) arrived at the following conclusions.

Sun Drying

The area required to sun dry the established amount of coffee pulp in an environment of 60–65% relative humidity is presented in Table 2. As well, the estimated drying time for the total load (8 days), the load per square metre (22.7 kg or 50 lb), and the fixed and operational (13 men/day) cost estimates (based on Guatemalan prices and salary standards) are included. The estimate of the total area that is required has a capacity for eight times 63 504 kg of fresh pulp so as to keep the production rate at 11 340 kg of dried product per day. The estimated drying time (8 days) is an average obtained practically (Guatemalan National Coffee Association, ANACAFE, personal communication). Experimental results obtained during good, dry weather indicate that coffee pulp can be dried to 10–15% moisture after 2 days or 16 h of sun exposure (Fig. 1). However, considering that the fields intended for drying pulp may be preferentially used (during good weather) for the drying of coffee grain, the period of 8 days may be a realistic average. This factor gives a relatively high inversion fixed cost ($U.S.112 000) when considering the field cost at an average of $U.S.5.00/m^2 ($U.S.0.10/m^2 land and $U.S.4.90 construction costs). However, the operational costs are relatively low ($U.S.52.00/day at a rate of $U.S.40.00/man-day).

Table 2. Economic and technological data related to coffee-pulp drying by sun exposure to yield 11 340 kg of dry pulp per day.[a]

	Calculated data	Cost (in $U.S.)
Load	22.7 kg/m^2	
Drying time[b]	8 days (average)	
Total area	22 400 m^2	
Investment	—	112 000[d]
Operational costs [c]	13 men/day	52.00/day [d]

[a]On the basis of fresh coffee pulp with 85% moisture and a dry product with 10% moisture.

[b]Data obtained from ANACAFE, Guatemala. The average high figure was used for this calculation.

[c]Only operational, not maintenance or administrative costs are considered.

[d]Considering an average life of 10 years for the drying patio, a charge of $U.S.0.33/22.7 kg was added.

Assuming an average life span of 10 years for the field this would add roughly $U.S.30.68/day to the cost of the product. Therefore, the total base (operational plus fixed) cost per 100 kg of product would be $U.S.0.73. Other cost components such as administration costs, building(s), and the like were not taken into account because it was assumed that they could be absorbed, to a large extent, by the system already developed by the coffee processor for the coffee grain. These production costs in fact agree with those obtained in a small industry for the production of dry coffee pulp in El Salvador.

Although the production costs cited above for the sun drying of coffee pulp sound economically attractive it should be noted

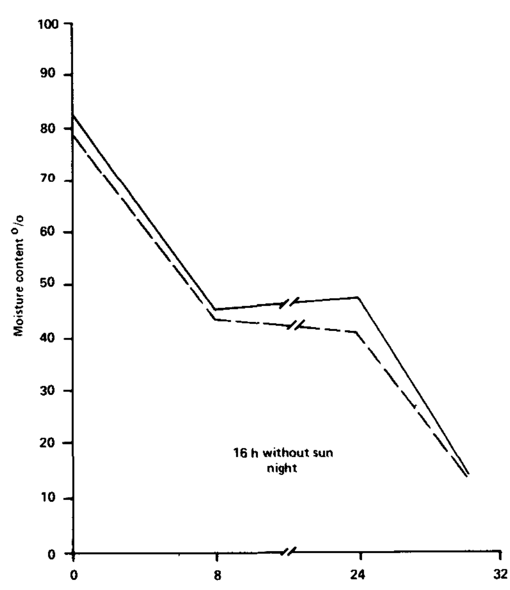

Fig. 1. Reduction in moisture content of coffee pulp during sun drying.

Table 3. Economic and technological data for tunnel, belt, and rotary driers used to produce 11 340 kg of dry coffee pulp per day (from Molina and Avendaño 1976).[a]

	Countercurrent tunnel drier	Belt tunnel dier	Louvre-type rotary drier
Load (kg/m²)	7.3	7.3	—
Drying time (min/load)	185	25–35	25–35
Total area (m²)	613	27.3	33.4
Number of tunnels	2	2	—
Length (m)	13.1	79.2	5.8
Diameter (m)	—	—	0.9
Cost per unit ($U.S.)	18 564	27 500	—
Total cost ($U.S.)[b]	37 128	55 000	28 000

[a] On the basis of coffee pulp with 85% moisture and dry coffee pulp with 10% moisture, average air velocity of 82.3 m/min, and incoming air temperature of 120 °C.

[b] These figures include an additional charge on the dry product of $U.S. 0.024, 0.04, and 0.024 in the case of the countercurrent tunnel drier, belt tunnel drier, and rotary drier, respectively. The life span of the driers was calculated to be 20, 20, and 15 years, respectively.

that they are dependent, to a large extent, on fluctuations in weather. Moreover, under bad weather conditions drying times of up to 15 days have been encountered for coffee grain (ANACAFE, personal communication). This could considerably increase the possibility of microbial deterioration of the coffee pulp, which in turn could adversely affect its general quality and its possible utilization as an animal feed.

Countercurrent Tunnel Driers

The total drying area (based on commercial tunnel driers 6.5 m long, with 7 cars/tunnel and 50 0.84-m² trays/car), number of tunnels, cost per unit, and total inversion cost for the drying of 63 504 kg of fresh (85% moisture) coffee pulp in 6 h are presented in Table 3. This would allow 2 h a day for charging and discharging, cleaning, etc. The conditions used in this estimate were: air velocity, 82.3 m/min (270 ft/min), inlet air temperature, 120 °C, and load of fresh pulp, 681 g/0.09 m² (1.5 lb/ft²). The inversion (or fixed) cost of this system ($U.S.48 470) is substantially lower than that for sun drying. With a life span of 20 years for the equipment, this would add $U.S.0.053 per 100 kg of dried product, including depreciation on the building housing the equipment.

The operational (fuel, electricity, maintenance, hand labour at a rate of 0.5 man/day, etc.) costs appear in Table 4. When diesel is considered as fuel (representing 90.25% of the total operational costs) the cost added per 100 kg of product is $U.S.2.67; whereas, if a mixture of 50% diesel and 50% coffee grounds (11% moisture) is considered, the operational costs per 100 kg of dry product can be lowered to $U.S.1.06 (even considering the relatively low caloric value of coffee grounds, 3307

Table 4. Operational costs ($U.S.) of tunnel, belt, and rotary driers per 45.4 kg of dry pulp (from Molina and Avendaño 1976).[a]

	Without recirculation	With recirculation (71%)
Labour	0.0338 (2.8)[b]	0.0338 (3.8)
Electricity	0.0034 (0.3)	0.0034 (0.4)
Fuel (diesel)	1.0920 (90.2)	0.7640 (86.6)
Maintenance	0.0422 (3.5)	0.0422 (4.8)
Supervision	0.0034 (0.3)	0.0034 (0.4)
Miscellaneous	0.0352 (2.9)	0.0352 (4.0)
Total	1.2100[c]	0.8820[c]

[a] For coffee pulp (85% moisture) dried to 10% moisture content by an air temperature of 120 °C.

[b] Figures in parenthesis represent the percentage of the total cost.

[c] Using a mixture of diesel and coffee hulls (50:50) the total operational cost per 45.4 kg of dry product can be lowered to $U.S.0.48 without air recirculation and $U.S.0.35 with air recirculation.

cal/kg, compared to diesel fuel, 10 556 cal/kg). By implementing a 71% air recirculation, these costs could be lowered to $U.S.0.771 per 100 kg of dried product using the 50:50 diesel:coffee grounds mixture as fuel.

To obtain an economically attractive figure for drying coffee pulp with this technique, it is necessary to reduce fuel costs by utilizing by-products. The lowest total (fixed plus operational) cost figure mentioned ($U.S.0.824 per 100 kg of product) is an attractive one that is competitive with that derived for sun drying ($U.S.0.73 per 100 kg of product), considering the possible problems and large limitations of sun drying that are avoided when using mechanical drying.

Belt Drier

Considering the belt drier in a similar fashion, and under the same operational conditions as those given for the countercurrent tunnel drier, the data on total drying area, number of tunnels, cost per tunnel, and total inversion (fixed) cost involved in drying 63 504 kg of fresh (85% moisture) coffee pulp in 6 h are presented in Table 3. The total inversion cost in this case ($U.S.55 000) is almost double that for the countercurrent tunnel drier, but is still lower than that for sun-drying facilities. With a life span of 20 years for the drier and its installations, the cost added to 100 kg of dry product would be $U.S.0.088.

The operational costs for this type of drier are considered to be practically the same as those cited for the tunnel drier. Therefore, the total (fixed plus operational) cost to produce 100 kg of dried product, using a 50:50 mixture of diesel:coffee grounds as fuel and 71% recirculation of air, would be $U.S.0.859. Although attractive, the production costs in this case are higher than those attained for the countercurrent tunnel drier under similar conditions.

Rotary Drier

Considering a rotary drier of the Roto-Louvre type and similar operating conditions as those cited previously for the countercurrent tunnel drier (air velocity, 82.3 m/min and inlet air temperature, 120 °C), the peripheral area, residence time of the material, length, diameter, and total cost of the drier with a production capacity of 11 340 kg of dried product per 6 h are presented in Table 3. The total inversion (fixed) costs in this case ($U.S.28 000) are significantly lower than those cited for the other drying systems. Assuming a life span of only 15 years for this equipment (it could be 20 years as in the previous cases), the cost added from the investment (or fixed) costs to 100 kg of dried product would be $U.S.0.053, including depreciation on the building. In other words, the fixed costs for 100 kg of dried product, considering the rotary drier with a life span of 15 years, would be the same as those for the countercurrent tunnel drier, with a calculated life span of 20 years.

Because the operational costs are considered to be basically the same as those cited for the tunnel drier (Table 4), the total (fixed plus operational) production costs of 100 kg dried (10% moisture) product would be the same as for the tunnel drier ($U.S.0.824) — when using a 50:50 diesel:coffee grounds mixture and 71% air recirculation. Due to its relatively low investment (fixed) costs this drying system is considered to have high potential for the mechanical drying of coffee pulp. However, it should be emphasized that the processing costs of the product are affected mainly by the fuel used as the energy source, not by the type of drier.

In Costa Rica a rotary drier has been used on a pilot scale for the drying of coffee pulp (Alvarado 1974, 1975; Cherñacov 1974). This drying system, which has a production capacity of 324 kg/h (714 lb/h), uses air recirculation, and burns diesel fuel, is reported to have a fuel expenditure of 28.88 litres per 100 kg of dried product (7.63 gal/100 kg, 3.46 gal/100 lb) (Alvarado 1974, 1975). Again, this underlines the importance of fuel in the operational costs because the present Central American cost of 28.89 litres (7.63 US gal) of diesel would put the operational costs of this rotary drying system well above $U.S.2.00/100 kg, which is far too high for drying a by-product intended for use as an animal feed.

Preliminary efforts are being made in our laboratories to design an energy efficient rotary drier of a Roto-Louvre type that can be coupled to a burner designed to use a mixture of diesel fuel and finely ground, dried, by-products (coffee grounds, wood by-products, and the like). The intention is to be able to offer, in the near future, a mechanized, economically sound, drying system of coffee pulp, which would solve the limitations of the sun-drying system. At present, however, sun drying is the most common system, and it is still the most viable one.

Drying Aids

Several aids have been considered in an effort to facilitate and/or accelerate the drying operation, and, therefore, lower its costs.

A pressing action prior to drying has been among the most investigated and/or considered techniques for lowering the initial moisture content of the pulp. Preliminary results in our laboratories indicate that using a hydraulic-type press prior to drying can lower the drying time of coffee pulp by one-eighth to one-sixth. A possible explanation for this phenomenon is that the pressing eliminates some of the mucilaginous pectin-like constituents of the pulp and some of the simple sugars, and thus makes the pulp easier to dry. Whether pressing will allow, through this mechanism, the use of higher inlet air temperatures (up to 200 °C) without the problem of lowering the constant-rate drying period, still must be elucidated. The pressing liquors, on the other hand, have been found to be a good substrate for the production of yeasts and other possible microbial or unicellular protein sources (Aguirre 1966; Calle 1974). As well, Díaz (1977) reported the possible use of the pressing liquors from coffee pulp as an "extender" of molasses for the production of bakers' yeast.

Experiments run with a Protessor Laboratory Model Press (E.H. Bentall & Co. Ltd., Essex, England) have shown that although, when the moisture is expressed on a dry-matter basis, the pressing action is capable of lowering it to 34–36%, when the results are expressed on an "as is" basis the decrease in moisture content only amounts to 6–8% (i.e. from 85 to 78%) (R. Cleves, personal communication). Similar results have also been reported by Alvarado (1974, 1975) and Cherñacov (1974). However, all these authors have indicated that the pressing action decreases the pulp volume 20–50%, which facilitates the drying operation and increases the capacity of the drier(s).

Further experiments using this type of press have shown that the time required to sun dry coffee pulp during good, dry weather is reduced from 16 to 4 h of sun exposure (a 75% reduction in drying time). Such an effect can be attributed not only to the elimination of sugars and pectin substances through the pressing action, but also to the disaggregation of the pulp (and consequent increase in drying area). Furthermore, when coffee pulp with 5% molasses has been ensiled for 3 months prior to pressing, the drying time of the material is reduced by up to 2 h. These findings underline the impact that a pressing operation using a Protessor-type press can have on the drying time, and thus drying costs, of coffee pulp. They also underline the necessity of further research concerning the possible chemical-nutritional changes in material subjected to pressing so that a cost-benefit figure for the system as a whole can be calculated.

The addition of calcium salts ($CaCO_3$ or $Ca(OH)_2$) to coffee pulp prior to drying has also been investigated. It has been reported that the addition of either calcium hydroxide or calcium carbonate at levels of from 2 to 5% to coffee pulp significantly reduces drying time (Bendaña 1977; Fonseca and Aguilar 1974). Possible explanations for this effect are absorption of water by the calcium compounds or the formation of a calcium pectate or calcium complex with the mucilaginous constituent(s) of the pulp, facilitating the removal of water. However, the exact mechanism still remains a mystery (Bendaña 1977; Fonseca and Aguilar 1974).

However, treatment(s) with calcium compounds has been reported to be detrimental to the nutritional quality of coffee pulp when such compounds are added in excess of 5% of the wet weight of the pulp (Fonseca and Aguilar 1974). Using lower levels, no detrimental effect was observed (Bendaña 1977). These observations indicate the need for examining the benefit of these additives not only from a drying point of view, but also from a nutritional and chemical one, when doing cost-benefit analyses.

Other treatments, such as the addition of enzymes like Ultrazym-100 (Ciba-Geigy, Switzerland) to fresh coffee pulp to accelerate its drying have been examined, but the results have been poor (Fonseca et al. 1974).

Ensiling, as previously mentioned, has been considered as a way to store coffee pulp for later drying using the same facilities used for the coffee grain (especially sun drying). Preliminary observations have indicated that the ensiled material requires a relatively shorter (about one-tenth) drying time than fresh coffee pulp when sun dried (Bendaña 1977). This may be due to the breakdown of the pulp structure during the fermentation associated with ensiling. As well, an ensiling operation prior to pressing increases the effectiveness of this operation in reducing the drying time of the pulp.

In summary, sun drying of coffee pulp is still the most common and viable system used, in spite of the long (weather dependent) drying time, which may lead to microbial contamination. Because of this, and the cumbersome aspects inherent to sun drying, continuous efforts are being made to develop mechanical drying and/or drying-aid systems for coffee pulp. Fresh coffee pulp is a relatively easy material to dry by mechanized drying using inlet air temperatures of about 75–150 °C. Preliminary evidence indicates that significantly increasing the temperature decreases the constant-rate drying period, proportionally increasing the drying time, and possibly having adverse effects on the nutritive value of the dried pulp. This limitation may be overcome by pressing the fresh pulp using a Protessor (modified screw-type) press, or by using other techniques to lower the level of pectin and other mucilaginous constituents and to disaggregate the pulp to increase the drying area. The effectiveness of the pressing process on the characteristics of the final product should be evaluated, and suitable quality control parameters should be devised. The addition of calcium compounds with the intent of reducing the drying time should be further studied in nutritional terms. Ensiling and/or ensiling and pressing prior to drying considerably shorten the drying time. These operations should be evaluated on a technical, nutritional, and economic basis because ensiling seems to be a suitable "storage" process for coffee pulp, especially when the drying facilities are used first for coffee grain and only afterwards for pulp.

Looking at mechanized drying systems, a rotary drier, coupled to a burner that utilizes agricultural, agroindustrial, or industrial by-products either alone or in combination with petroleum-based fuels, appears to be the most technically and economically sound. This is considered imperative as it is the fuel source that is the main component that affects the cost of drying coffee pulp. In this respect, because an ensiling and/or ensiling and pressing operation, or the addition of calcium compounds prior to drying could lower drying costs, these operations should be evaluated as part of the drying system to arrive at a final cost-benefit estimate.

Efforts to devise a suitable and viable drying system with the above characteristics should continue. In this respect, it should be noted that, as stated by Echeverría (1974), a mechanized drying system intended for coffee pulp should also be suitable for other products (i.e. corn, beans, etc.) that are available to the coffee processor either before or after the coffee-harvest season. This would avoid having the equipment sit idle for approximately 6 months of the year.

The search for a suitable and viable drying system should continue so that in the near future a good quality, dry coffee pulp, which can be easily transported and successfully used as an animal feed, can be produced.

9

Processing of Coffee Pulp: Chemical Treatments

Roberto A. Gómez Brenes[1]

Fresh coffee pulp is an abundant by-product of the coffee industry, but its nutritive value as an animal feed is limited by the presence of antiphysiological factors such as caffeine, tannins, chlorogenic acid, caffeic acid, and an excess of potassium (Aguirre 1966; Bressani et al. 1972; Bressani 1974; Bressani and Elías 1976; Jaffé and Ortiz 1952; Molina et al. 1974). If these factors could be eliminated or at least neutralized, coffee pulp could be used safely as an important ingredient of monogastric and ruminant rations.

Toxic compounds present in materials that are potentially good sources of nutrients can be eliminated by physical or chemical means such as: dry and wet heat; dehydration; extraction with different solvents; and maceration with acids or alkalies. Good examples of these procedures are cooking legumes, such as beans, where the cooking eliminates the toxic factors (Bressani et al. 1972a) and cooking corn with lime and water, which makes its nutrients more available for humans and monogastric animals (Bressani et al. 1961).

Great efforts have been made to eliminate the antiphysiological compounds of coffee pulp by physical methods (see Chapters 7 and 8) and by chemical substances such as calcium and sodium hydroxide, sodium metabisulfite, water, and the combination of these compounds with physical treatment such as grinding, extrusion, heating, and drying.

The purpose of this chapter is to review and discuss the chemical treatments utilized to detoxify coffee pulp, and to summarize the changes in chemical composition and nutritive value that occur.

Treatment with Calcium Hydroxide

Calcium hydroxide ($Ca(OH)_2$) has been frequently utilized for food treatment because of its numerous advantages. It is a very cheap product that is available in all parts of the world, and it is not toxic to humans and animals in the quantities normally used. In many cases, the calcium hydroxide develops desirable organoleptic characteristics in the food, and it is, at the same time, a source of available calcium. Some studies with pigs have demonstrated that $Ca(OH)_2$ decreases the toxic effects of the gossypol contained in cottonseeds (Braham et al. 1965).

Fresh coffee pulp accumulated in the coffee processing plant has a very high water content that favours two types of microbial fermentation: an aerobic one on the surface, and an anaerobic one in the layers of the

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pulp. The products of these two fermentations, together with the high concentration of natural acids in the pulp, are responsible for the low pH of the coffee pulp even after it has been dehydrated.

Tannins are powerful reducing agents that tend to absorb oxygen and give strongly coloured products, especially in alkaline solutions (Joslyn 1950). Because the coffee pulp from the processing plants and that obtained from the silos is acidic, and in this form it has some limitation in its biological utilization for animal feeding, the question arises as to what would happen to the toxic compounds, chemical composition, and nutritive value of the coffee pulp if an alkaline treatment was applied to the pulp.

Bendaña 1977 and Gómez Brenes et al. 1977 tried to answer these questions by studying fresh and ensiled coffee pulp that was treated by immersion and by spraying for two lengths of time (0 and 16 h) with three concentrations (1, 2, 3%) of calcium hydroxide in water. The effects of these treatments on coffee pulp were evaluated by measuring the chemical changes that took place and the feeding value of the pulp. The chemical components analyzed were the proximate chemical composition, Ca, K, and P, caffeine, total tannins, chlorogenic acid, caffeic acid, and amino acid content. For the biological test, diets containing 15% protein with two levels of coffee pulp, 15 and 30%, were used. The evaluation consisted of measuring mortality rates, feed intake, weight gain, feed efficiency, and apparent protein digestibility.

Chemical Evaluation

The results of the chemical analyses showed an inverse relationship between calcium hydroxide concentration and content of ether extract, crude fibre, and protein (Table 1). No changes were observed in caffeine, chlorogenic acid, and caffeic acid contents (Table 2). Slightly lower values

Table 1. Proximate chemical composition (g%) of sun-dried fresh (FP) and ensiled (EP) coffee pulp treated with $CaOH_2$ (from Bendaña 1977).

	Time (h)	$CaOH_2$ conc. (%)	Water		Ether extract		Crude fibre		Protein (N×6.25)	
			FP	EP	FP	EP	FP	EP	FP	EP
Immersion	0	0	11.2	9.1	3.9	3.5	18.8	16.5	10.1	10.6
		1	10.2	9.0	3.6	2.7	16.4	15.6	9.2	9.7
		2	9.8	9.3	3.9	2.8	15.6	15.3	10.4	9.2
		3	10.3	7.8	3.8	2.8	15.5	15.6	8.3	9.2
	16	0	9.4	9.3	3.9	3.1	18.1	20.5	10.5	10.5
		1	8.3	8.6	3.6	2.8	17.5	20.3	9.4	10.1
		2	9.5	9.3	3.0	2.4	14.8	17.6	8.6	9.1
		3	10.8	8.8	3.0	2.6	14.2	14.5	7.6	9.4
Contact	0	0	7.8	10.8	4.0	3.7	18.3	16.8	12.3	10.4
		1	8.5	10.7	3.4	3.3	17.6	15.5	10.2	7.8
		2	11.1	9.1	3.1	3.0	16.7	12.1	10.8	10.4
		3	10.1	10.0	3.3	2.5	16.3	11.9	9.8	9.5
	16	0	0.5	9.6	3.8	3.3	17.6	14.6	11.0	9.7
		1	9.7	9.6	3.1	4.2	17.4	14.8	10.3	9.7
		2	9.7	10.5	3.0	2.7	17.6	16.1	10.0	8.6
		3	9.8	9.6	3.0	2.9	15.8	13.7	9.4	8.8
Control	—	—	11.5	11.7	2.8	4.0	21.0	19.6	12.3	10.0

Table 2. Caffeine, tannin, and chlorogenic and caffeic acid concentrations (%) in fresh (FP) and ensiled (EP) coffee pulp after alkaline treatments (from Bendaña 1977).

	Time (h)	$Ca(OH)_2$ (%)	Caffeine		Tannins		Chlorogenic acid		Caffeic acid	
			EP	FP	EP	FP	EP	FP	EP	FP
Immersion	0	0	0.68	1.08	1.50	2.27	1.40	1.67	0.14	0.15
		1	0.68	1.08	1.46	1.46	1.35	1.65	0.15	0.13
		2	0.73	1.20	1.34	0.89	1.33	1.55	0.11	0.16
		3	0.68	0.98	1.35	0.69	1.28	1.52	0.16	0.16
	16	0	0.69	0.98	1.34	1.89	1.38	1.70	—	0.17
		1	0.63	0.98	1.33	1.50	1.37	1.70	0.09	0.15
		2	0.62	0.98	1.31	0.92	1.25	1.49	0.10	0.17
		3	0.71	1.05	1.28	0.63	1.33	1.45	0.10	0.17
Contact	0	0	0.63	1.10	1.35	2.10	1.49	1.71	0.16	0.18
		1	0.63	0.96	1.30	1.54	1.46	1.68	0.15	0.17
		2	0.62	0.98	1.31	1.21	1.41	1.65	0.16	0.19
		3	0.70	0.98	1.30	1.31	1.41	1.68	0.15	0.19
	16	0	0.63	0.96	1.35	2.54	1.39	1.74	0.16	0.19
		1	0.65	0.98	1.37	1.46	1.40	1.69	0.13	0.17
		2	0.65	1.20	1.33	0.94	1.40	1.61	0.14	0.19
		3	0.67	0.98	1.29	0.96	1.38	1.63	0.14	0.19
Control			0.65	0.98	1.35	2.20	1.48	1.73	0.16	0.19

were obtained when the pulp was treated by immersion, which was attributed to leaching rather than to a direct effect of calcium hydroxide. Total tannin concentration decreased significantly with respect to calcium hydroxide treatment (Table 2). Determinations of P, Na, and K in the control pulp were similar to those published in the literature (Aguirre 1966; de Alba 1971).

Biological Evaluation

Calcium hydroxide treatment did not improve the quality of coffee pulp (Tables 3 and 4). As with other studies, ensiled coffee pulp was superior to fresh coffee pulp (Table 5). Further studies were carried out by the same investigators to measure the effects of increasing the content of coffee pulp by grinding it before mixing with calcium hydroxide. The results of these experiments also showed no beneficial effects of calcium hydroxide treatment on the nutritive quality of coffee pulp.

From these studies Bendaña 1977 and Gómez Brenes et al. 1977 reached the following conclusions:

The nutritive value of ensiled coffee pulp is superior to fresh coffee pulp.

Alkaline treatment with calcium hydroxide does not improve the nutritive value of fresh or ensiled coffee pulp.

The technique of immersion of the coffee pulp in water solutions of chemical compounds eliminates many substances from the pulp. This technique can be used to detoxify coffee pulp using combinations of different chemical compounds and prolonged immersion times.

Grinding the coffee pulp before alkaline treatment does not improve the effects obtained with whole coffee pulp.

The addition of calcium hydroxide to the coffee pulp, decreases the time required for sun dehydration, which may be very important from an industrial point of view.

Table 3. Average amino-acid content of fresh coffee pulp after alkaline ($Ca(OH)_2$) treatments (g AA/16 g N) (from Bendaña 1977).

	Immersion		Contact		
	0 h	16 h	0 h	16 h	Control
Aspartic acid	5.34	6.60	6.10	6.70	6.45
Threonine	2.38	2.48	2.35	2.86	2.94
Serine	2.00	2.16	1.85	2.18	2.14
Glutamic acid	7.54	7.88	8.09	8.70	8.73
Glycine	4.54	4.60	4.57	5.04	4.40
Alanine	3.52	3.47	4.02	4.46	3.46
Valine	4.82	5.04	4.91	4.68	4.89
Cystine	Trace	0.30	Trace	0.26	0.33
Methionine	Trace	0.17	Trace	0.26	0.10
Isoleucine	4.12	4.01	4.09	4.37	4.60
Leucine	5.08	5.10	4.93	5.33	4.73
Tyrosine	2.14	2.33	1.86	2.58	2.29
Phenylalanine	3.25	3.44	3.11	3.40	3.24
Lysine	4.07	3.96	3.94	4.14	3.96
Histidine	2.52	2.84	1.89	2.52	2.64
Arginine	3.55	3.49	2.77	3.36	3.82

Effect of Sodium Metabisulfite Treatment

The presence of *o*-dihydroxyphenyl derivatives such as catechol, protocatechuic acid, caffeic acid, and the esters of hydroxygallic acid, like chlorogenic acid, are responsible for the enzymatic browning of vegetable tissue by air. All these phenolic substances, and others of similar structure like tannins, are abundant in nature and are possibly formed from the degradation of anthocyanins and flavonoids. The enzymes that catalyze the oxidation of these com-

Table 4. Average amino-acid content of ensiled coffee pulp after alkaline ($Ca(OH)_2$) treatments (g AA/16 g N) (from Bendaña 1977).

	Immersion		Contact		
	0 h	16 h	0 h	16 h	Control
Aspartic acid	5.02	5.61	6.14	6.30	7.75
Threonine	1.82	1.78	1.91	1.98	3.78
Serine	1.00	1.00	0.97	0.94	1.19
Glutamic acid	7.01	7.92	7.72	7.96	7.44
Glycine	4.18	4.47	4.10	4.64	3.37
Alanine	3.95	3.77	4.34	4.10	3.42
Valine	4.08	4.72	4.54	4.33	2.59
Cystine	0.40	0.57	0.24	0.29	0.32
Methionine	0.19	0.32	0.19	0.19	0.22
Isoleucine	3.25	3.88	3.10	3.10	3.10
Leucine	4.59	5.24	4.23	4.83	4.59
Tyrosine	1.51	1.90	1.48	1.38	1.48
Phenylalanine	2.63	3.34	2.76	2.77	3.04
Lysine	3.32	4.45	3.52	3.54	4.42
Histidine	2.02	2.51	2.28	2.19	3.06
Arginine	2.43	2.89	2.73	2.45	2.70

Table 5. Feed efficiency index (g food consumed/g weight gain) of rats fed 15% protein diets with 15 and 30% fresh or ensiled coffee pulp treated with alkali (from Bendaña 1977).

	Time (h)	$Ca(OH)_2$ (%)	Fresh pulp 15%	Fresh pulp 30%	Ensiled pulp 15%	Ensiled pulp 30%
Immersion	0	0	6.0[a]	38.6	5.8[a]	8.2
		1	6.9[a]	16.2	5.9[a]	8.1
		2	6.4[a]	—	5.6[a]	9.8
		3	6.3[a]	**	5.5[a]	10.7
	16	0	6.0[a]	11.5	6.0[a]	7.4
		1	6.3[a]	14.3	6.3[a]	8.2
		2	6.6[a]	58.4	6.4[a]	12.5
		3	6.4[a]	**	6.4[a]	15.4
Contact	0	0	5.6[b]	11.6	5.9[a]	7.2
		1	6.2[a]	60.8	5.8[a]	8.2
		2	6.6[a]	46.6	5.9[a]	8.2
		3	6.9[a]	24.3	6.3[a]	8.4
	16	0	5.7[b]	27.1	6.0[a]	8.3
		1	5.9[b]	40.1	6.1[a]	7.8
		2	6.7[a]	114.2	5.8[a]	10.2
		3	6.4[a]	—	6.6[a]	11.1

NOTE: ** indicates 100% mortality; different superscripts indicate significant differences ($p < 0.05$).

pounds belong to the polyphenoloxydase group. The food industry uses gaseous sulfur dioxide as well as sulfite to inactivate the phenolases and prevent them from browning vegetables before freezing or drying (Braverman 1967).

Coffee pulp is rich in phenolic compounds and many investigators (Bressani 1974; Jarquín et al. 1976; Murillo et al. 1977; Solis 1977) have studied the effects of sodium metabisulfite treatment on fresh and dehydrated coffee pulp to determine the

Table 6. Effect of type of dehydration and addition of sodium metabisulfite on the proximate analysis of coffee pulp (from Murillo et al. 1977).

	Water (%)	Ether extract (%)	Crude fibre (%)	Nitrogen (%)	Ash (%)	N-free extract (%)
Mechanical drying						
0.0 metabisulfite	12.0	2.6	23.9	2.0	5.7	40.5
0.5 metabisulfite	9.0	2.6	18.6	1.6	9.5	49.2
1.0 metabisulfite	10.0	2.8	17.1	1.5	10.2	50.3
1.5 meabisulfite	9.6	2.5	16.3	1.5	12.6	49.7
Sun drying						
0.0 metabisulfite	10.2	3.1	23.4	1.6	5.8	46.5
0.5 metabisulfite	8.9	2.6	19.2	1.7	9.6	49.3
1.0 metabisulfite	8.6	2.7	18.0	1.5	10.0	51.0
1.5 metabisulfite	8.8	2.6	17.1	1.5	13.2	49.8
2.0 metabisulfite	9.1	2.3	16.5	1.5	13.7	49.1

Table 7. Fractionation of cellular walls of coffee pulp treated with sodium metabisulfite (from Murillo et al. 1977).

	Cellular content (%)	Cellular walls (%)	Hemi-cellulose (%)	Cellulose (%)	Lignin (%)	Insoluble ash (%)
Mechanical drying						
0.0 metabisulfite	39.1[a]	57.1	3.8	28.4[a]	24.2[a]	0.7
0.5 metabisulfite	52.1[b]	44.9	3.0	20.6[b]	20.2[b]	1.1
1.0 metabisulfite	53.5[b]	43.3	3.2	20.2[b]	18.5[b]	1.4
1.5 metabisulfite	55.9[b]	41.1	3.0	18.4[b]	18.1[b]	1.6
2.0 metabisulfite	56.3[b]	40.9	2.8	18.3[b]	18.1[b]	1.7
Sun drying						
0.0 metabisulfite	43.7[a]	53.3	3.0	29.9[a]	19.5[b]	0.9
0.5 metabisulfite	52.3[b]	44.6	3.1	22.3[b]	17.7[b]	1.5
1.0 metabisulfite	55.3[b]	41.9	2.8	22.2[b]	15.6[bc]	1.3
1.5 metabisulfite	57.6[b]	39.5	2.9	21.2[b]	14.1[c]	1.3
2.0 metabisulfite	58.7[b]	38.4	2.9	20.0[b]	14.1[c]	1.4

NOTE: Numbers with different superscripts are statistically different.

ability of this compound to prevent the darkening of coffee pulp and its effect on the chemical composition and nutritive value of the pulp.

Bressani 1974 and Murillo et al. 1977 treated fresh coffee pulp with 0.5, 1.0, 1.5, and 2.0% sodium metabisulfite and compared the effects of drying by two methods, solar energy and a drum drier (Tables 6, 7, 8).

Proximate chemical composition did not reveal significant differences between dehydration procedures. Sodium metabisulfite treatment resulted in a decrease in crude fibre, nitrogen, cellular walls, and cellulose, and an increase in ash and nitrogen-free extract. Likewise, tannins and cellular content were higher and lignin and lignified protein were lower in metabisulfite-treated samples. Lignified protein was higher in sun-dried pulp than in those samples dried by drum drying. These authors suggested the use of this salt ($Na_2S_2O_5$) when dehydrating with a drum drier or solar energy, or when ensiling coffee pulp.

In another study, Jarquín et al. 1976 and Solis 1977 treated fresh coffee pulp with sodium metabisulfite. In one system the chemical was added in concentrations of 0.025, 0.05, 0.1, 0.3, and 0.5% sodium metabisulfite on a weight basis using a Hobart mixer. In the other system, sodium metabisulfite was dissolved in water in amounts of 0.025, 0.05, 0.1, 0.3, and 0.5% on a weight basis. Fresh coffee pulp was immersed in these solutions for 20 min so that for each litre of solution 1 kg of coffee pulp was used. After treatment, the coffee pulp treated under the two systems was sun dried and ground.

The concentrations of crude fibre, nitrogen, cellular content, cellular walls, cellulose, and tannins showed similar results to those described previously (Bressani 1974; Murillo et al. 1977); however, an increment in caffeic and chlorogenic acids was found in direct proportion to the concentration of metabisulfite used. This increase was higher when the chemical was added directly. Caffeine increased in the pulp treated with dry metabisulfite, but no effect was observed in the concentration of this alkaloid when the metabisulfite was used in solution. The biological evaluation of these materials is described in Chapters 4–6.

Treatment with Water

In the last few years great efforts have been made to detoxify coffee pulp for use

Table 8. Lignin content, lignified protein, caffeine, and tannins in coffee pulp treated with sodium metabisulfite (from Murillo et al. 1977).

	Crude protein (%)	Lignified protein (%)	Caffeine (%)	Tannins (%)
Mechanical dehydration				
0.0 metabisulfite	12.3	7.2[a]	0.74[a]	1.80
0.5 metabisulfite	10.2	4.0[b]	0.68[b]	3.15
1.0 metabisulfite	9.6	2.8[b]	0.62[b]	3.60
1.5 metabisulfite	9.3	2.9[b]	0.65[b]	3.15
2.0 metabisulfite	9.2	2.9[b]	0.65[b]	3.40
Sun drying				
0.0 metabisulfite	10.0	6.3[a]	0.72[b]	1.85
0.5 metabisulfite	10.4	4.0[b]	0.67[b]	3.20
1.0 metabisulfite	9.7	3.3[b]	0.66[b]	3.75
1.5 metabisulfite	9.5	3.4[b]	0.63[c]	3.40
2.0 metabisulfite	9.3	3.3[b]	0.65[b]	3.50

NOTE: Numbers with different superscripts are statistically different.

in the animal industry. Water is one of the most useful solvents for this purpose because it is abundant, economic, and the toxic compounds of coffee pulp are highly soluble in it. Therefore, the detoxification of coffee pulp through the use of water for extracting the antiphysiological substances of coffee pulp would permit the use of this by-product as another source of caffeine besides improving its quality as an animal feed. Molina et al. (1974a) studied the effect of a decaffeination process on the toxicity and nutritive value of coffee pulp as measured in rats. The decaffeination of the material was performed by extraction at 25 °C and by percolation at 94 °C. Chemical analyses showed that percolation at 94 °C was more efficient than extraction at 25 °C for reducing the concentration of caffeine, total tannins, and chlorogenic and caffeic acids in the coffee pulp, and that percolation did alter the protein content of the pulp (Table 9). In biological tests with rats it was found that decaffeination by percolation at 94 °C

Table 9. Chemical composition of coffee pulp treated with water by percolation at 94 °C and by extraction at 25 °C (from Molina et al. 1974).

	Percolation (94 °C)	Extraction (25 °C)	Control, dehydrated pulp (75 °C)
Water	6.21	7.02	5.02
Ether extract	4.50	5.03	4.00
Crude fibre	28.11	24.83	16.40
Protein (N×6.25)	11.19	11.25	11.90
Ash	2.71	3.43	8.71
Caffeine	0.02	0.31	1.27
Tannins	0.53	1.81	2.40
Chlorogenic acid	0.35	1.42	2.60
Caffeic acid	0.00	0.35	0.24
Total caffeic acid	0.18	1.06	1.56
Total soluble sugars	1.54	3.70	8.53

increased the nutritive value of coffee pulp in comparison with that observed with dehydrated coffee pulp and with pulp decaffeinated by extraction at 25 °C. From the results of this study it was concluded that decaffeination of coffee pulp offered an opportunity for the industrial use of coffee pulp.

The same investigators (Cuevas 1976; Molina et al. 1976) evaluated the percolation of coffee pulp to obtain more information on detoxification by this process, and to evaluate its feasibility. For this purpose, samples of fresh sun-dried and oven-dried coffee pulp were studied. The percolation process used boiling water (96 °C) as the solvent, and ratios of solid:solvent of 1:10 and 1:20 and two particle sizes (crushed pulp and whole pulp) (0.5–3.0 and 3.0–5.0 mm, approximately).

By means of a flow diagram the ideal number of stages for a 99% extraction was determined. Best results were obtained when using a solid:solvent ratio of 1:20 and whole coffee pulp dried at 100 °C. The extraction efficiency was 81.6% for caffeine, 44.3% for total soluble solids, and 39.9% for tannins in 1 h (Fig. 1). The residue from the extraction showed a protein content very similar to that of the untreated pulp. The residue from the extraction process was tested in pigs and its results are discussed in Chapter 5.

These authors concluded that: (1) the soluble compounds of the coffee pulp could be easily extracted with hot water, and that the most important factor was the solid: solvent ratio; (2) the extracts from coffee pulp were suitable for the production of single-cell protein, using moulds and yeasts, after crystallization of the caffeine; and (3) the residue from the percolation could be used in porcine nutrition.

Other Chemical and Physical Treatments

Sodium Hydroxide

To evaluate changes in the chemical composition and in vitro digestibility of coffee pulp that had been subjected to alkaline treatment with sodium hydroxide (NaOH), Egaña et al. (1977) treated, for 24 h, coffee pulp that had been previously dehydrated and ground with solutions containing 2.5, 5.5, and 7.5% NaOH. One part coffee pulp was mixed with one part of each of the NaOH solutions. After treatment, the samples were neutralized with 0.2*N* HCl and air dried at 50 °C for 24 h. Samples drawn before and after each treatment were analyzed for ash, total nitrogen, lignified nitrogen, crude fibre, cell walls, hemicellulose, cellulose, lignin, soluble carbohydrates, total tannins, caffeine, and in vitro dry matter digestibility (Table 12).

The authors of this study concluded that alkali treatment of coffee pulp as carried out did not improve the nutritive value as measured by chemical analysis and in vitro dry-matter digestibility.

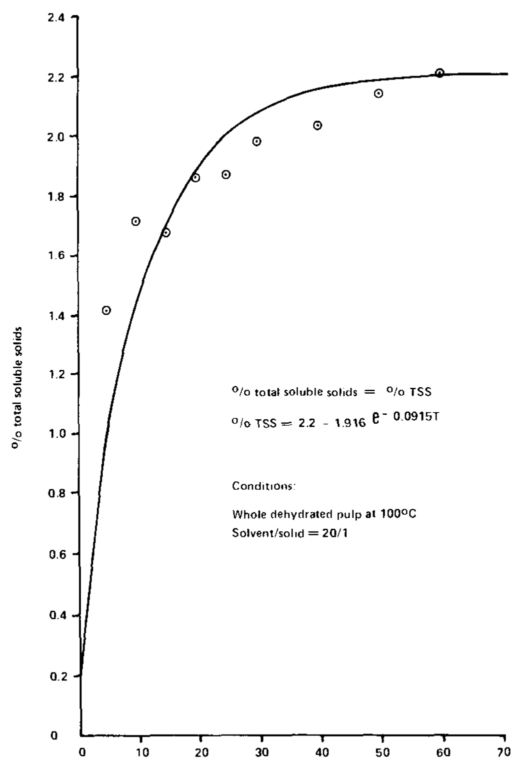

Fig. 1. Water extraction of coffee-pulp solids by percolation at 94 °C (from Molina et al. 1976).

Table 10. Feed consumed (FC), weight gain (WG), and feed conversion efficiency (CE) of rats fed diets with different protein levels and with alkaline-treated dehydrated (DCP) or ensiled (ECP) coffee pulp (from Egaña et al. 1977).

	10% protein			15% protein			20% protein		
Diets	FC	WG	CE	FC	WG	CE	CF	WG	CE
Control	678.5	164.8	4.4	700.0[a]	195.6[a]	3.8[a]	643.6[a]	185.3[a]	3.9[a]
DCP	575.7[b]	64.1[c]	11.7[d]	720.1	159.8	4.6	768.6	190.3	4.2
ECP	521.9[b]	49.0[c]	14.2[d]	707.8	159.4	4.5	761.0	189.0	4.1
DCP+5.5% NaOH	553.3[b]	49.1[c]	14.7[d]	767.4	174.9	4.6	823.5	195.3	4.3
ECP+5.5% NaOH	567.4[b]	53.4[c]	13.3[d]	770.6	165.8	4.6	815.9	202.9	4.1

NOTE: Superscripts indicate significant difference from control diet (10% protein).

Table 11. Summary of chemical and physical treatments given to coffee pulp.

Type of pulp	Treatment	Results	References
Whole, fresh and ensiled	$Ca(OH)_2$ Immersion: 1, 2, & 3% sol. (solid/solvent = 1/2.5) Contact: add. of 1, 2, & 3% $Ca(OH)_2$ to fresh pulp Treatment time: 0 & 16 h Dehydration: sun	As the conc. of $Ca(OH)_2$ increased, dehydration time, ether extract, crude fibre, protein, and tannins decreased Biological tests with rats showed no increase in nutritive value of pulp	Tables 1–5 Bendaña 1977 Gómez Brenes et al. 1977
Whole, fresh	$Na_2S_2O_5$ Contact: Add. of 0.5, 1.0, 1.5, 2% $Na_2S_2O_5$ Dehydration: sun and drum Contact: Add. of 0.025, 0.05, 0.1, 0.3, 0.5% $Na_2S_2O_5$	Crude fibre, nitrogen, cellular walls, cellulose, lignin, and lignified protein decreased, ash, nitrogen-free extract, cellular content, and tannins increased Same results as above	Tables 6–8 Bressani 1974 Murillo et al. 1977 Jarquín et al. 1976 Solis 1977
Whole, fresh	$Na_2S_2O_5$ Immersion: Add. of 0.025, 0.05, 0.1, 0.3, 0.5% sol. (solid/solvent = 1 kg/litre) Treatment time: 20 min Dehydration: sun	Increase in chlorogenic and caffeic acids Increase in caffeine content of pulp was greater when treated by contact with $Na_2S_2O_5$	Jarquín et al. 1976 Solis 1977
Ground, sun dried	Water Percolation: 94 °C (solid/solvent = 1/20) Extraction: 25 °C	Ether extract and crude fibre increased, protein, ash, caffeine, tannins, chlorogenic and caffeic acids, and total soluble sugars decreased	Table 9 Fig. 1 Molina et al. 1974, 1976 Cuevas 1976
Ground, sun dried	NaOH Immersion: 2.5, 5.5, & 7.5% NaOH (solid/solvent = 1/1) Treatment time: 24 h, neutralized after treatment with 0.2 *N* HCl Dehydration: oven at 50 °C for 24 h	Ash, lignified nitrogen, cellular walls, hemicellulose, and lignin increased, soluble carbohydrates, tannins, and in vitro dry-matter digestibility decreased	Table 12 Egaña et al. 1977
Whole, sun dried	Ground Ground and extrusion Ground and 5.5% NaOH Ground, extrusion, and 5.5% NaOH	Biological evaluation with rats showed no statistical differences among the treatments	Egaña et al. 1977

Table 12. Changes in chemical composition and in vitro digestibility (% dry matter) of coffee pulp treated with sodium hydroxide (from Egaña et al. 1977).

	Control (dehydrated coffee pulp)	Sodium hydroxide solutions		
		2.5%	5.5%	7.5%
Ash	7.60[a]	8.70[b]	10.90[c]	12.90[d]
Nitrogen	1.74	1.78	1.76	1.79
Lignified nitrogen	0.86[b]	1.08[a]	1.05[a]	1.02[a]
Crude fibre	24.30	26.70	23.90	23.80
Cellular walls	50.50[c]	63.10[b]	68.50[a]	62.90[b]
Hemicellulose	2.10[c]	3.00[c]	8.90[a]	5.90[b]
Cellulose	25.60	26.90	27.40	25.60
Lignin	21.80[b]	32.20[a]	31.70[a]	30.80[a]
Soluble carbohydrates	3.50	3.10	3.10	2.90
Tannins	2.70[a]	2.10[b]	1.80[b,c]	1.60[c]
Caffeine	0.64[b]	0.68[b]	0.64[b]	0.73[a]
In vitro digestibility	57.8[a]	54.7[b]	52.2[b]	53.4[b]

NOTE: Numbers in each line with different superscripts are statistically different ($p<0.01$).

Sodium Hydroxide and Extrusion

To determine the effect of processing on the nutritive value of dehydrated coffee pulp, Egaña et al. (1977) ground dehydrated coffee pulp and then divided it into three parts. The first one was treated with 5.5% NaOH, the second was extruded in a Brady Crop Cooker, and the third was first extruded and then treated with 5.5% NaOH. The effects of these processes were evaluated in rats (Table 10). In general, no statistical differences were found in food intake, weight gain, or feed efficiency for the different treatments.

In conclusion, to determine and understand the effects of chemical and physical treatments on the chemical composition and nutritive value of coffee pulp (Table 11), it is necessary to have a better identification and chemical characterization of the material. If environmental and genetic effects on the toxic compounds of coffee pulp were well known, it would be possible to apply different treatments to different pulps and not to apply the same detoxifying treatment to any pulp regardless of its origin. It is possible that calcium and sodium hydroxide, sodium metabisulfite, water, or any other chemical substance might be more effective in detoxifying one type of coffee pulp than another. Unfortunately, heterogeneous samples are obtained from the coffee processing plants, a fact that emphasizes both the need for more research in analytical methodology to better identify the materials, and for studies taking into consideration genetic and environmental factors that affect the coffee plant and consequently the pulp.

10

Antiphysiological Factors in Coffee Pulp

Ricardo Bressani[1]

Examination of the gross chemical composition of coffee pulp (Chapter 2) suggests that this by-product can play a useful role in animal production. Evidence presented in previous chapters of this monograph, however, shows that the amount of coffee pulp consumed, or that can be incorporated into compounded feeds, is limited by undesirable effects on animal performance. If the amount is excessive, mortality of small animals, such as rats (Bressani et al. 1973) and chickens (Chapter 6), often takes place, although some investigators have reported mortality of ruminants fed exclusively on coffee pulp or with rations with high levels of pulp (Squibb 1945). At present, there is no evidence that conclusively indicates that substances in the coffee pulp are responsible for these observations. Furthermore, it is even possible that such effects may have been induced by compounds acquired during the handling and processing of the coffee pulp. As indicated previously, because of its high moisture and sugar contents, coffee pulp is easily contaminated by fungi and other microorganisms that may produce the toxins that are responsible for the observed effects (Chapter 7).

This chapter will attempt to review the available information on the relationships that may exist between the various substances in coffee pulp, and the pathological observations made with various experimental animals, and their performance with respect to weight gain, feed conversion efficiencies, and utilization of the nutrients present in coffee pulp.

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Adverse Effects Observed in Animals

Published results on the utilization of coffee pulp as a feed ingredient show that this material causes a variety of undesirable effects (Table 1). The animal species used were rats, chicks, swine, beef and dairy cattle, goats, and fish. In all studies, as described in the various chapters of this monograph, the presence of coffee pulp in the diet, in amounts varying with the species, induced low feed intake. Most of the studies with beef cattle describe this effect as being due to poor palatability of the coffee pulp, which can be partially corrected by feeding the pulp with molasses, mixed with grass, or as silage. There is a tendency by all animals to adapt to coffee pulp, but low feed intake results in low weight gains and poor feed conversion efficiencies.

The reports also indicate that for a certain period of time after initiation on a coffee-pulp diet, the animals are more active than usual and in beef cattle a temporary increase in libido has been reported (Osegueda et al. 1970). This increased libido starts sooner with higher levels of coffee pulp, but it is only a temporary effect. Increased urine volume for swine and beef cattle and higher water intake by chicks have been recorded.

High levels of coffee pulp, usually above 30%, cause high mortality in young rats and chicks; however, adult animals are more resistant. No mortality has been reported with swine and only some with beef cattle. In rats, mortality occurs within 5 days after initiation of intake. The animals show irritability, itching, and develop blisters on the inside of their paws and legs. Bleeding occurs next. In cattle, high intakes cause emaciation and skin lesions, as well as hair loss or hair with an abnormal structure (Madden 1948). In all cases, there is low digestibility of the diet, and low nitrogen retention, which in young animals is negative. The substances responsible for these observations have not been identified. However, the addition of caffeine and tannins together have been shown to reduce animal performance (Estrada 1973), and these two substances are present in relatively high amounts in coffee pulp.

With all animal species, high protein intakes reduce the adverse effects of a fixed level of coffee pulp or permit the inclusion of higher levels in the diet. Several studies have been performed to find practical methods of reducing the adverse effects of coffee pulp. In some reports, ensiling has proven to be of some benefit in improving animal performance. The biological effects of sodium metabisulfite addition to coffee pulp have been contradictory, and no beneficial biological effects have been observed by treating coffee pulp with alkaline substances. However, changes in chemical constituents have been reported (Chapter 9).

Substances with Possible Antiphysiological Action

The number of substances with possible antiphysiological activity in coffee pulp has not been determined, but on the basis of the chemical analysis of coffee beans, some have been studied to determine their correlation with the effects observed in animals. These include: (1) caffeine; (2) the free or monomeric phenols, chlorogenic, caffeic, and tannic acid; and (3) the polymeric phenols, the hydrolyzable and the condensed tannins. Caffeine in sun-dried coffee pulp is present in concentrations varying from 0.6 to 1.2%; chlorogenic acid is found in concentrations that vary from 0.18 to 3.16%; caffeic acid or 3,4-dihydrocinnamic acid is present in amounts of from 0.28 to 2.58%; and tannic acid, or digallic acid or gallotannic acid, in concentrations from 2.30 to 5.56% (Chapter 2).

In addition to the above compounds, coffee pulp presumably contains a certain amount of polymeric tannins and relatively high amounts of potassium. All of these substances may have some direct or indirect antiphysiological effect, the mechanism of which is still under study. It is possible that coffee pulp may contain other substances that are responsible for the observed effects. Little is known, however, about the toxic chemicals in coffee pulp because not enough research has been carried out on their identification and antiphysiological action, and the emphasis on coffee pulp has been utilization research. Therefore, what follows is based on literature reports of the effects of the above substances. Although they may be somewhat speculative in nature, these reports may provide some basis for future research and help increase the efficiency of utilization of other nutrients in coffee pulp and of the by-product.

Physiological Role of Selected Substances

Feeding trials with coffee pulp and evidence from the effects of plant phenols have made it possible to develop a scheme showing the possible antiphysiological action of the various components of coffee pulp (Table 1). This scheme should be taken as a working hypothesis to help design further studies aimed at increasing our knowledge of the practical use of coffee pulp (Bressani 1975).

Caffeine

The physiological role of this well-known alkaloid of the methylated purine type is well documented, and no attempt will be made to review it here. However, three factors appear to be important in relation to coffee pulp and the effects observed in various animals: (1) the relatively high concentration of nitrogen in caffeine; (2) its known effect of stimulating increased activity; and (3) its well-known diuretic effect.

Caffeine contains 26.38% N and is found in an average concentration of 1.0% in dehydrated coffee pulp (Chapter 2). This means that caffeine nitrogen is present in amounts of about 0.26%, which is equivalent to a crude protein value of 1.6%. On the other

Table 1. Adverse physiological effects observed in animals fed coffee pulp (CP).

	Symptoms and observations
Rats	Low feed intake Low conversion efficiency Blisters on underside of paws and legs Bleeding and skin irritation Death above 30% CP in diet High protein induces protection Silage better utilized than dry Quality protein improves utilization
Chickens	Low feed intake Low conversion efficiency High water intake No mortality up to 30% if protein quality is high, high mortality above 30% Recommended level in diet: not more than 10% Metabisulfite treatment of CP may improve performance
Swine	Low feed intake Low conversion efficiency No mortality observed Recommended level between 15–20% of diet Metabisulfite: no effect Methionine: no effect Nervousness Increased urine output Low nitrogen balance, digestibility
Cattle (Beef, Goats)	Low feed intake, low palatability Low conversion efficiency Some reports of mortality Emaciation when intake of CP is high Skin lesions, loss of hair, peculiar hair structure, adaptation to CP Increased output of urine Low N balance Low protein digestibility Caffeine and tannic acid together: active Recommended level: 20% Silage better than sun-dried CP Palatability poor: temporary increase in libido
Dairy cattle	No adverse effects Normal milk production Levels used: not determined More work needed

hand, it has been reported that coffee pulp contains on average 11.0% crude protein. Of this, about 15% is from caffeine and should not be considered as protein nitrogen in formulating diets and in balance studies as this will influence digestibility values. However, the significance of this is small and obviously has no direct antiphysiological effect.

Ruminants and rats, but not pigs, fed coffee pulp show increased motor activity; however, no measurements have been taken on these animals to quantify this activity. This increased activity, however, results in increased use of energy, which may have the ultimate effect of decreasing weight gain and feed conversion efficiency. Caffeine is not the only substance in coffee pulp that causes these effects: chlorogenic acid has also been reported to act in a similar way.

One consistent observation made during feeding trials, particularly with ruminants, is increased urine output directly related to the concentration of coffee pulp in the diet (Chapter 4). In one study, 3-month-old calves on a diet containing 24% coffee pulp excreted 3832 ml of urine/day in comparison with 2652 ml/day by those not fed coffee pulp. This increased output of urine carried with it increased amounts of nitrogen (Chapter 4), which if not compensated for by increased intake might easily deplete the animal of protein. This may explain in part the emaciated state reported in animals fed very high levels of coffee pulp (Madden 1948). It may also explain the results of studies in which it has been shown that high levels of protein in the diet increase tolerance to higher concentrations of coffee pulp (Flores Recinos 1973). The high protein content may very well compensate for the losses of nitrogen caused by higher urine excretion. These effects of coffee pulp, however, should not, at least at the present time, be attributed to caffeine alone, because results with swine have indicated that small amounts of caffeine increase nitrogen balance (Cunningham 1968).

In studies with chickens, it was reported that those fed 20 and 30% coffee pulp in the ration had lower weight gains, poorer feed conversion efficiencies, and higher water intakes than those fed 0 and 10% coffee pulp (Bressani et al. 1977). This increase in water consumption was taken as an indirect measurement of increased urine output, which cannot be measured directly in the chick because urine is excreted with the feces. An additional aspect that may be of importance if coffee pulp enters production systems is its possible interference with reproduction. Ax et al. 1974 reported that 0.05% dietary caffeine increased embryonic loss in chickens; therefore, it would be of interest to learn if coffee pulp fed to pregnant animals would result in similar losses.

A final point with respect to caffeine is increased levels of free fatty acids in the blood plasma (Cunningham 1968). Such effects from coffee pulp have not been consistently demonstrated with ruminants (Estrada 1973; Braham et al. 1973; Jarquín et al. 1973), and in any case, their significance in terms of coffee pulp is not yet clear.

Free Phenols

The roles of the three polyphenols found in coffee pulp, caffeic, chlorogenic, and tannic acids, have not as yet been defined. However, investigations carried out with these substances indicate that in coffee pulp their action is related to: (1) the biochemistry of coffee pulp, itself; (2) the effect that this may have on the utilization of nutrients in coffee pulp; and (3) their antiphysiological effects

With respect to the biochemistry of coffee pulp, fresh or properly ensiled coffee pulp, upon contact with the air, changes from the deep bloodred colour it has when fresh to a dark brownish or black hue. This change in colour has been attributed to enzymatic browning reactions caused by oxidation of the polyphenols to quinones, which in turn combine with free amino acids and protein to give dark-coloured complexes. The protein binding of these oxidation products has an effect on protein digestibility and thus on the amount absorbed to meet physiological needs. That this reaction takes place upon contact with air is shown by the fact that the enzymatic browning reaction is inhibited by sulfite treatment, which increases the content of the three phenols and lowers the amount of "lignified protein" (Murillo et al. 1977). Free polyphenols may interfere with protein utilization by binding protein, but they may also interfere by binding digestive enzymes (McLead 1974; Loomis and Battaile 1966) and interfering with the metabolic activity of microorganisms (McLead 1974; Loomis and Battaile 1966). Decreased digestibility of protein may also explain the fact that increasing the protein content in diets containing coffee pulp maintains animal performance (Flores Recinos 1973). The effects of these polyphenols in interfering with nutrient utilization is not limited to protein because other nutrients may be interfered with as well. There are reports that caffeic acid acts as an antithiamine substance (Somogyi and Bönicke 1969; Davis and Somogyi 1969; Somogyi and Nägeli 1976). In these studies it was shown that phenolic compounds having the hydroxyl groups on an ortho position inhibit thiamine. These tests have been carried out by in vitro techniques; however, very little evidence is available on in vivo studies.

Bönicke and Czok (1970) showed that high doses of chlorogenic acid given orally to rabbits caused their blood serum to exert an antithiamine effect as measured in vitro. Recently, however, the same group of investigators (Somogyi and Nägeli 1976) presented evidence that strongly suggests that orthodiphenols, such as chlorogenic, caffeic, and tannic acids, exert an antithiamine effect in humans. In recent trials with ruminants carried out in our laboratories, injection of the animals with 100 mg of thiamine stimulated pulp intake. These observations are being verified because ruminants are known to be able to synthesize thiamine. It is possible that orthophenols inhibit the microflora because studies by Somogyi, using the microbiological method for thiamine assays and a common component of intestinal microflora (*Lactobacillus casei*) as the test organism, have shown this kind of inhibition (Somogyi and Bönicke 1969; Somogyi and Nägeli 1976).

Polyphenols are substances found in most plant materials, including coffee pulp, and animals have pathways to eliminate them once they have been absorbed from the gastrointestinal tract. It is possible that not all polyphenols react with protein in coffee pulp because varying amounts are found in dehydrated pulp (Chapter 8). Higher amounts are found if the pulp is treated with sulfite (Murillo et al. 1977), and they may also arise from hydrolyzable tannins (McLead 1974). These phenols would then be free in the gastrointestinal tract and a certain amount would probably be absorbed. The body eliminates these phenolic compounds as conjugates with sulfuric or glucuronic acid (Williams 1964). The phenolic compounds also undergo methylation and dehydroxylation reactions. When the detoxication pathway is by means of the conjugation of the phenols with sulfuric acid, ethereal sulfates appear in the urine, which could be used as a test to evaluate the role of the phenols in coffee pulp. The sulfur in sulfuric acid is probably derived from the metabolism of cystine. Whether the mechanism is through the formation of glucuronates or sulfates, it has implications concerning the nutritional value of the coffee pulp and its effect on animal performance. There is some biochemical evidence to suggest that animals fed coffee pulp have low blood-glucose levels (Jarquín et al. 1973). On the other hand, detoxication as sulfates implies that sulfur amino acids are being utilized, and thus the need for methionine would probably be increased. Preliminary results indicate that ethereal sulfate excretion in the urine may increase in animals fed coffee pulp; however, no response has been observed upon methionine supplementation (Jarquín et al. 1977). If sulfur requirements were found to be increased, sulfite treatment of coffee pulp would be advantageous, not only to serve as a source of sulfur, but also to block the phenol-protein reaction and make the protein more available to the animal.

Tannins

The phenolic compounds discussed in the previous section are monomeric compounds, but in plant tissue, there are also two groups of polymeric substances of a phenolic nature. Lignin, derived from polymerization of phenyl propanoid units, and cellulose constitute the structural material of all higher plants. The second group of polymeric phenolic substances are known under the poorly defined name of tannins. Chemically, tannins may be grouped into two types: the hydrolyzable tannins, which yield gallic acid and sugars on hydrolysis; and the condensed tannins, which are derivatives of flavonoid monomers. The possible role of hydrolyzable tannins as related to the adverse effects of coffee pulp on animal performance have already been discussed.

The most important characteristic of tannins is probably their high capacity to bind proteins, making them unavailable to the organism, but they also act as enzyme inhibitors. Dietary proteins can, by complexing with tannins, be protected from hydrolysis by proteolytic enzymes in the rumen (Leroy et al. 1967). These polymeric compounds can, therefore, interfere with animal performance by lowering the availability of the protein that is consumed, by inactivating enzymes, or by acting as sources of free phenolic compounds. Evidence of their particular role is not available; however, dehydrated coffee pulp contains about 50% of its protein in a lignified form.

Potassium

Coffee pulp is known to contain relatively high levels of potassium, but the role this mineral may play in coffee-pulp feeding is unknown. There are reports that high potassium intakes increase magnesium needs. On the other hand, it is possible that this may not be detrimental at all, because other feeds, such as sugar beet and sugarcane molasses, are also high in potassium.

In summary, it is considered important to be able to determine the role all these substances play in the context of coffee-pulp utilization as an animal feed. Once this information is available, systems to remove these substances can probably be developed to permit the use of higher levels of coffee pulp in mixed feeds.

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