

Review

Available information on the feeding value of coffee waste and ways to improve coffee waste for animal feed

Aklilu Skibba Wogderess

Wolaita Sodo University, P. O. Box 128, Wolaita Sodo, Ethiopia. E-mail: Aklilu.skibba@yahoo.com.

Accepted 25 May 2016

The objective of this review is to synthesize information available on the feeding value of coffee waste. In the diets of ruminants, waste and by-products of coffee have successfully used 10 to 30%. It has been claimed that the feeding of Coffee leaves extends the lactation period. Coffee pulp (dried or not), coffee hulls (sticky or dried) and coffee grounds (a by-product of instant coffee manufacture) have an overall deleterious effect on pigs. At certain growth stages, lower weight gain was attributed to phenolics in the coffee pulp. On the contrary, inclusion of dried coffee pulp rations at different levels had no significant influence on the feed intake, growth rate and feed conversion efficiency. Pigs fed with rations containing up to 15% of coffee pulp ensiled with 5% molasses had equal or better total weight gain than those fed commercial concentrates. At levels exceeding 10% in poultry diets, it produces toxic symptoms. Coffee pulp (13%) also did not affect the growth and feed efficiency of the fish *Tilapia aurea*. On the contrary, Caffeine dietary levels between 2.4 g/kg to 4.6 g/kg tended to reduce fish growth, feed intake and nutrient digestibility in tilapia fingerlings. Limiting the use of waste and by-products of coffee by the animals is due to their caffeine content which diminishes the palatability and acceptance of husk and pulp by animals. Tannin and alkaloids affect their health and negatively affect the palatability of the diets. But drying, silage, physical (percolation), chemical (alcohol extraction) or microbiological (fermentation with *Aspergillus niger*) methods contribute to lower levels/ 10% dietary level/ of caffeine and tannins of waste and by-products of coffee.

Key words: Feed value, coffee waste, anti-nutritional factors, livestock feeding.

INTRODUCTION

World population is clearly growing. For food, we need agricultural and animal production (Bouafou et al., 2011). Among the technical constraints limiting livestock productivity, issues related to feed are the major ones owing to biological and economic reasons. Feed cost usually accounts for 60-70% of the total cost of production and feasibility of livestock enterprise is largely a function of the type, quality of feed and the strategy of feeding (Seyoum et al., 2007). In other words, availability of animal feed and efficient feeding are the foundations of successful livestock production. The feeding of a balanced ration and correct feed formulation increases

animal productivity, quality of product and animal welfare. Optimal animal production is mainly determined by an adequate animal nutrition from a physiological, an economical and an ecological viewpoint. In order to provide animals with the necessary nutrients to meet their requirements for maintenance, growth, pregnancy and the production of meat, milk, eggs, wool and labour, to reduce the risks for animal health and to minimize the excretions and emissions into the environment, the nutritive value of the feeds used in the diet has to be precisely known (FAO, 2011).

Appropriate use of relatively inexpensive agricultural

and industrial by-products is of paramount importance for profitable livestock production and to reduce competition for food (Negesse et al., 2009). Moreover, the worldwide food, agricultural and forestry industries produce annually large volumes of wastes, which cause serious disposal problem (Rodríguez, 2008). Some examples of these wastes include the bagasse and peels generated in the beverages and juice industries, coffee pulp obtained in the coffee industry and husks from the cereal industries, classified as agro industrial by-products (Graminha et al., 2008; Orzua et al., 2009).

Coffee (*Coffea arabica* L.) is the world's favorite drink, the most important commercial crop-plant, and the second most valuable international commodity after oil. Worldwide there are about 20 million coffee farming families and around 100 million people depend on coffee for their livelihoods. Its export value alone is immense (US \$ 15.4 billion in 2009/10) and as such it plays a crucial role in the economies of several tropical countries (Davis et al., 2011).

Waste and by-products of coffee amount in the millions of tons in the world in terms of productions (Bouafou et al., 2011). Coffee fruits can be processed by either wet or dry processing methods. To obtain the seeds (beans) - the exocarp, mesocarp and endocarp of the dried cherry coffee have to be removed by hulling, originating the so-called husk. In the wet processing procedure the fruits are pulped, fermented, washed and sun or artificially - dried; the pulping procedure removes the exocarp and most of the mesocarp, resulting in the so-called coffee pulp. Therefore, husk and pulp are the main by-products of the coffee processing (Mazzafera, 2002). Therefore, by products such as coffee pulp, coffee hulls and coffee husks should be considered as a means of alleviating the scarcity of animal feeds.

To this end, the objective of this review is to synthesize information available on the feeding value of coffee waste including their production, physical characteristics/anti-nutritional factors, chemical composition, and ways to improve coffee waste for animal feed.

FEEDING VALUE OF FEEDSTUFF (COFFEE WASTE)

The feed value (nutritive value) of food is contained in DM, the remainder of food being water. The DM is expressed as a percentage (%) or as gram per kg of food. For instance, the DM of grass is 15% equals 150 g DM/kg grass. DM is very important to an animal as it is used to measure hunger or appetite (the amount of food an animal can eat per day). The daily amount of DM eaten per day is called *Dry Matter Intake* (DMI). The total composition of the daily ration should include all nutrients required necessary for *maintenance* and *production* purposes within the quantity of DM. Within the classification, suitability of feedstuffs for feeding can be categorized according various qualities: DM, feed value,

structure, maximum intake, tenability, preservation, labour at feeding and storage provision (https://www.google.com.et/?gws_rd=cr&ei=TPQ6U).

According to Payne and Wilson (1999), there are roughage feeds available at specific locations in the tropics such as the waste materials from oil palm processing plants, sisal waste, pineapple waste, bagasse, cocoa pods, coffee hulls, etc. The feeding value of these materials varies, but it is usually low.

As roughages are such an important feed source for livestock in the tropics there is a major interest in improving their digestibility and hence their feeding values. The methods being used are:

- Physical treatment such as chaffing and milling.
- Chemical treatment that may include enhancement.
- Biological treatment using organisms that can degrade lignin or break the bonds between lignin and cellulose in plant cell walls.
- An appropriate combination of two or all of these methods.

The nutritional value of waste and by-products of coffee has been studied by several researchers. Catie (1974) said that coffee pulp has a promising role in livestock feeding if it can be efficiently and economically dehydrated. Three years later, Cabezas et al. (1977) incorporated 20%, 40% or 60% of sun-dried coffee pulp in rations as (15% and protein) partial replacement of cottonseed meal and cottonseed hulls, enriched with a mixture of sugar cane molasses and minerals, and observed the intake and digestibility in calves. Protein was kept at 15%. Although the digestibility of the organic matter increased from 51.2% (0% coffee pulp) to 54% (60% coffee pulp) and the gross energy had not changed, the digestibility of protein decreased from 47% (0% coffee pulp) to 36.2% (60% coffee pulp). The authors suggested that the observed increase was a consequence of the reduction of the daily intake, since it dropped from 3.5 kg 100 kg⁻¹ live weight to 2.1, as the coffee pulp increased from 0 to 60% in the diet. Ingestion of coffee pulp was estimated to be 1.3 kg 100 kg⁻¹ live-weights at the 60% coffee pulp level.

Coffee production for human consumption gives rise to a number of byproducts that may be used as ruminant feeds. These include leaves, pulp from the bean, coffee residues, coffee meal and spent coffee grounds. The fresh fruit consists of 45% pulp, 10% mucilage, 5% skin and 40% bean. To produce coffee the fruit is processed to free the bean from the pulp, which accumulates in large quantities and is used in some areas as roughage for cattle. The fruit can be processed by either a dry method or by a wet soaking method. The pulp from the dry method is fibrous and rather poor roughage, whereas that from wet processing has much greater feed value. Coffee pulp from the wet method can be fed to lactating dairy cattle at levels below 20% of the diet without affecting

milk production. Digestibility of pulp (dry method) in sheep is crude protein 10.3%, crude fibre 27.9%, ether extract 53.2% and NFE 50.2%, with ME 1.33 MJ kg⁻¹ (The Encyclopedia of Farm Animal Nutrition, 2004). Coffee pulp contains proteins, carbohydrates and minerals that may favor its utilization in animal feeding. Pandey and Soccol (1998) reported (dry matter basis) the contents for carbohydrates (57.8%), proteins (9.2%), fat (2%), caffeine (1.3%), tannins (4.5%) and pectins (12.4%).

Coffee meal is a dark brown to black residue produced when coffee seeds are removed from the outer coating, dried and then roasted. Coffee meal is high in fibre and has a very low energy value. It is a bitter product that inhibits food intake and will reduce overall feed intake if fed at levels greater than 2-4% of the total diet. It has a strong diuretic effect, which encourages urinary nitrogen and sodium losses, making it unsuitable for feeding to horses. Coffee meal can contain high oil levels which interfere with fibre digestion in ruminants at high inclusion levels. In addition, the oil content may cause the product to become rancid in storage. Coffee meal can be fed to dairy cows, beef cows and ewes, but not at an inclusion level greater than 4% (The Encyclopedia of Farm Animal Nutrition, 2004).

Dried coffee leaves have a relatively low nutritional quality but they can be included in concentrates. The high tannin content of the coffee leaves reduces the digestibility of proteins and possibly of other dietary components. Spent coffee grounds, or cherko, are the waste product from instant coffee production. These are unpalatable and contain diuretics including caffeine, and tannins that reduce protein digestibility; inclusion rates should not exceed 2.5%. The nutritional composition of spent coffee grounds can be improved by solid fermentation (The Encyclopedia of Farm Animal Nutrition, 2004). Other study by Habtamu and Takele (2009) revealed that cattle fattening farmers use residues of *Haitta tukeea* (coffee drink made from leaves of coffee boiled together with spices such as ginger, red pepper, garlic and salt as flavors) as one of the supplementary feed types (5.86 %) fed for finishing cattle in Wolaita, Southern Ethiopia.

AGRO INDUSTRIAL BYPRODUCTS/WASTE AS ANIMAL FEEDS

The coffee by products

Historical perspective

Mankind has tried to use agricultural and industrial by-products as animal feeds. 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 (Braham et al., n.d).

The generation of residues and by-products is inherent in any productive sector. The agro-industrial and the food sectors produce large quantities of waste, both liquid and solid. Coffee is the second largest traded commodity in the world, after petroleum, and therefore, the coffee industry is responsible for the generation of large amount of residues (Nabais et al., 2008). In the last decade, the use of such wastes has been subject of several studies, but this concern did not exist in past decades (1930 to 1943) when 77 million bags of green coffee were simply burned and released to the sea and in landfills (Cunha, 1992). However, this is an important topic explored nowadays (Solange et al., 2011).

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 (Braham et al., n. d).

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 (Braham et al., n.d).

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 those 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 (Braham et al., n. d).

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 (Braham et al., n.d).

Coffee silverskin (CS) and spent coffee grounds (SCG) are the main coffee industry residues. CS is a tegument of coffee beans obtained as a by-product of the roasting process. It is a residue with high concentration of soluble dietary fiber (86% of total dietary fiber) and high antioxidant capacity, probably due to the concentration of phenolic compounds in coffee beans, as well as to the presence of other compounds formed by the Maillard reaction during the roasting process, such as melanoidins (Borrelli et al., 2004). Microscopic examination shows the presence of fibrous tissues from the surface layers of the CS. The main components of these fibrous tissues are cellulose and hemicellulose. Glucose, xylose, galactose, mannose, and arabinose are the monosaccharides present in CS; glucose being found in major amounts. Proteins and extractives are also fractions present in significant amounts in this coffee waste (Solange et al., 2011).

SCG is a residue with fine particle size, high humidity (in the range of 80 to 85%), organic load, and acidity, obtained during the treatment of raw coffee powder with hot water or steam for the instant coffee preparation. Almost 50% of the worldwide coffee production is processed for soluble coffee preparation (Ramalakshmi et al., 2009). Therefore, SCG is generated in large amounts, with a worldwide annual generation of 6 million tons (Tokimoto et al., 2005). Numerically, 1 ton of green coffee generates about 650 kg of SCG, and about 2 kg of wet SCG are obtained to each 1 kg of soluble coffee produced (Pfluger, 1975). It can be noted that SCG are richer in sugars than CS, among of which mannose and galactose are the most abundant. Proteins constitute also a significant fraction in SCG (Mussatto et al., 2011).

The possibility of SCG use as animal feed for ruminants, pigs, chickens, and rabbits (Givens and

Barber, 1986) have already been also verified, but the high lignin content ($\approx 25\%$) in this material was considered a limiting factor for its application (Cruz, 1983).

Description of the coffee by products

The coffee tree is native to the wet highland forests of Ethiopia, Sudan and Kenya (Ecocrop, 2009). It was introduced into Arabia in the 15th century and to West Indies and Central America in the 18th century, and then reached India and Sri Lanka (Orwa et al., 2009). It grows in subtropics within 22°N and 27°S in deep soils, from sea level to 1000 m and where annual rainfall ranges from 1500 mm to 2000 mm. In equatorial regions, it may be cultivated from 1300 m to 2800 m or even higher. A moderate dry period is necessary to induce flowering. It is also reported to withstand moderate frost but giving lower harvest (Ecocrop, 2009).

The coffee bean (*Coffea arabica* L.) is used to make one of the most popular beverages in the world and considerable amounts of coffee bean are processed every day, leading to large quantities of by-products that may be used to feed to livestock (Heuzé and Tran, 2011).

The coffee tree begins to bear fruits 6 to 7 years after seedling and will be productive during 30-40 years. Average yield in Kenya is 2 to 3 t/ha and 0.5 t/ha in Brazil (Ecocrop, 2009). The fruit, or cherry, is a reddish 2-seeded berry, 1 to 1.5 cm long and 6 to 7 mm broad (Ecocrop, 2009). The cherry contains 4 anatomical entities: the beans proper or endosperm (55% DM of the fruit), the hulls or endocarp (12% DM of the fruit), a mucilage or mesocarp also called pulp (5% DM of the fruit), and an outer skin or exocarp (9% DM of the fruit) (Heuzé and Tran, 2011).

The total amount of coffee by-products (coffee fruit without the beans) represents around 43 % of the fresh weight of the coffee fruit. Coffee pulp, also identified as coffee fruit without seeds, is an abundant agricultural by-product. It represents around 43% of the weight of the coffee fruit on a fresh weight basis, or approximately 28% (26-30%) of the coffee fruit on a dry weight basis. The other by-products of coffee fruit processing are the mucilage, about 5% (5-14%) of the dry weight of the fruit, coffee hulls, representing 12% (10-12%) of the weight of the fruit on a dry weight basis and coffee parchment (the parchment is the thin skin of the bean that is removed after bean milling, prior to roasting). There are also instant coffee by-products such as coffee grounds: their ether extract content is fairly high (Heuzé and Tran, 2011).

The world annual coffee production is around 7 million tons, of which Brazil produces one-third (Stanculescu, 2011). The largest suppliers outside Latin America are Ethiopia, Kenya, India and Papua New Guinea (Petit, 2007).

Table 1. Annual worldwide coffee production (million bags of 60kg).

Countries	Production					
	2004	2005	2006	2007	2008	2009
Brail	39.272	32.944	42.512	36.070	45.992	39.470
Vietnam	14.370	13.842	19.340	16.467	18.500	18.000
Colombia	11.573	12.564	12.541	12.504	8.664	9.500
Indonesia	7.536	9.159	7.483	7.777	9.350	9.500
Ethiopia	4.568	4.003	4.636	4.906	4.350	4.850
India	4.592	4.396	5.159	4.460	4.372	4.827
Mexico	3.867	4.225	4.200	4.150	4.651	4.500
Guatemala	3.703	3.676	3.950	4.100	3.785	4.100
Peru	3.425	2.489	4.319	3.063	3.872	4.000
Honduras	2.575	3.204	3.461	3.842	3.450	3.750
Cote d'Ivoire	2.301	1.962	2.847	2.598	2.353	1.850
Nicaragua	1.130	1.718	1.300	1.700	1.615	1.700
El Salvador	1.437	1.502	1.371	1.621	1.547	1.500
Other countries	15.713	15.799	16.019	16.138	15.680	15.455
Total	116.062	111.463	129.138	119.396	128.181	123.002

Source: ICO (2010).

Coffee pulp and hulls represent relatively underutilized feed resources in coffee growing areas (Adugna, 2008) (Table 1).

Coffee processing

The coffee pulp is obtained either by subjecting the coffee fruit to a depulping operation with the help of water, or by first drying the coffee fruit, followed by a dehulling operation.

Wet processing

The wet processing method of depulping follows the following operations: after harvest, the coffee berries are transported to the coffee processing plant, where they are dumped into a tank of water to remove spoiled, green fruits and foreign material. With the help of water, used as a transport mechanism, the berries are taken to the pulping machines which by pressure separate the beans from the coffee pulp. These two fractions are then separated by running water. The beans are dumped into a tank for fermentation that will remove the remaining mucilage and allow further processing, while the coffee pulp is transported by water to be piled for later removal or simply allowed to ferment naturally (Bressani, 1991).

Dry process

The dry process consists in either allowing the fruit to dry

in the trees, or by harvesting fresh to dry by solar dehydration or other means. Once it is dried, the fruit is dehulled. The high water content of the pulp from the wet process causes problems in handling, transport, stability and processing. For feed applications, the pulp should be dried as quickly as possible to avoid spoilage or should be preserved by other means. The wet coffee pulp has been subjected to a drying operation with or without a partial water removal, by pressure, with or without the aid of calcium hydroxide addition. Drying has been accomplished by solar dehydration, by forced hot air-drying, or both. The product obtained is dried coffee pulp (Bressani, 1991).

Ensiling

An alternative process is ensiling with 4-6% sugar cane molasses. Although fresh coffee pulp can be directly ensiled, better quality is obtained if moisture content is around 75%. A well-packed trench silo holds an average of 325 kg of coffee pulp per cubic metre. Other treatments include mixing with urea (10%), sodium metabisulphite (0.3-0.5%), calcium hydroxide (2%), and mixtures of inorganic acids (10% HCl + H₂SO₄).

A different and attractive ensiling process is to mix grasses, sorghum or corn, with coffee pulp in layers of about 30 cm with or without sugar cane molasses (4-6%). The silage, whether of coffee pulp alone, or mixed with grasses, is ready to be used in about 3 weeks and if well packed, it can be preserved for up to 18 months. The silage from coffee pulp alone or mixed with other forages can be used as such, or it can be dehydrated (but this

operation is not necessary) (Bressani, 1991).

CHEMICAL COMPOSITION OF COFFEE WASTE

Coffee husks

Coffee husks are the major solid residues from the handling and processing of coffee, since for every kilo grams of coffee beans produced, approximately one kilo grams of husks are generated. Proposed alternative uses for coffee husks include employing this solid residue as a supplement for animal feed, direct use as fuel and fermentation for the production of a diversity of products (enzymes, citric acid and flavouring substances), use as a substrate for growth of mushrooms and use as adsorbents. It presents a high concentration of carbohydrates and thus can be viewed as a potential raw material for bio-ethanol production (Franca and Oliveira, 2009).

On the contrary, NDDB (2012) mentioned that Coffee husk is not palatable to cattle, and they can form only a small portion of rations fed to unproductive animals. Under acute scarcity or famine conditions, the cattle may be able to consume this feed, if they are fed after mixing them with cereal straws. Even for maintaining animals, when this feed forms a part of the ration, the requirement of energy rich feeds will be more in order to make up the poor energy content of this husk. Coffee husk contains 7-8% CP. NDF and ADF contents are 60 and 49%, respectively. However, Ca and P content is 0.51 and 0.25%, respectively.

Coffee pulp

Coffee pulp is some of the most abundantly available agro industrial waste produced during the pulping operation of the coffee cherries to obtain coffee beans in many coffee-producing areas of the tropics. For every 2 tons coffee cherries processed, nearly 1 ton pulp is generated (Roussos et al., 1995).

Coffee pulp is essentially rich in carbohydrates, proteins and minerals (especially potassium) and it also contains appreciable amounts of tannins, polyphenols and caffeine (Bressani, 1979). Owing to the presence of anti-nutritional factors such as caffeine, tannins and polyphenols, its use as an animal feed has been restricted to a large extent. Hence, coffee pulp has to follow a preliminary treatment before is used. Moreover, this by-product can occur in the nature and spoiling hardly the environment (Roussos et al., 1998).

As the coffee pulp is rich in nutrients. It can be dried and used in animal feeds. Further application, the pulp needs to be treated as soon as possible to prevent the development of fungi. The pulp can be treated with Ca (OH)₂ and dried under pressure. Alternatively, the pulp

can be mixed with sugar cane molasses, or urea and other inorganic substances and put in silos. The silage can be used after 3 weeks, and can be stored up to 18 months. However, using coffee pulp as animal feeds is of limited value, since the cost for drying the pulp sometimes exceeds the gain. Besides, the effects of caffeine, tannin and the high level of potassium on the animal's health are unknown (Padmapriya et al., 2013).

In recent years, the number of studies on the chemical composition of coffee skin and pulp has been increasing due to their potential use in animal feeding, especially in coffee producer countries, where the disposal of wastes represents an important pollution problem (Ulloa et al., 2002). Tannins, which are the main phenolic compounds in these parts of the coffee fruit, have received a special attention because they are considered as anti-nutrients for ruminants (Barcelos et al., 2001; Ulloa et al., 2002, 2003). Soluble tannins may account for 0.8-2.8% of *C. arabica* and *C. canephora* skin and pulp, with higher contents observed in *C. canephora*, and with prodelphinidins exceeding procyanidins (Clifford and Ramirez-Martinez, 1991a; Barcelos et al., 2001; Ulloa et al., 2003). Small amounts of insoluble condensed tannins may be also found in the pulp (Clifford and Ramirez-Martinez, 1991a). Soaking the pulp in water, treatment with alkali solutions, ensilation with molasses, and inoculation with selected microorganisms may destroy or reduce the content of tannins (Ulloa et al., 2002; 2003). Storage of dehydrated arabica coffee skin and pulp also produced a linear decrease in tannins content (~39%/year) (Barcelos et al., 2001).

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. The cellular contents of coffee hulls amount to about 12%, while the cellular wall components, that are the neutral and acid detergent fibres, are found in amounts of 88 and 67%, respectively (Bressani, 1979).

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. Because of its structure and chemical composition, coffee hulls do not offer many other possibilities for use, although it is considered a good fuel (Bekalo and Reinhardt, 2010).

In Ethiopia, according to Seyoum et al. (2007), the chemical composition of Coffee hull, sun cured, dry processed, post ripe on percent dry matter basis is 90.1, 2.7, 6.6, 9.6, 46.4, 40.1, 5.3, 12.3, 59.9 and 9 for DM, EE, Ash, CP, NDF (Neutral Detergent Fiber), ADF (Acid DF),

Table 2. Chemical composition of coffee wastes (% dry basis).

Components	Coffee husks ^a	Coffee pulp ^b	Coffee hulls ^c
Carbohydrates	58-85	44-50	66.65
Proteins	8-11	8.5-12.1	-
Fibers	-	18-21	62.1
Fat	0.5-3	1.5-2.0	0.6
Caffeine	1.3	1.3	-
Tannins	4.5-5.4	1.8-2.4	-
Lignin	20	17.5	34.2
Cellulose	19-26	17.7	46.1
Pectins	12.4-13	12.4	-

Source: Gouvea et al., 2009^a; Bressani, 1979^b; Bekalo and Reinhardt, 2010^c.

Table 3. Typical composition of coffee products (g kg⁻¹ dry matter).

	Dry matter (g kg ⁻¹)	Crude protein	Crude fiber	Ash	EE	NFE
Dried leaves	936	99	187	130	59	525
Residue/meal	910	120	440	17	25	398
Pulp, wet method	230	128	241	95	28	508
Pulp, dry method	900	97	326	73	18	486
Skins, Colombia	900	24	952	4	6	214
Coffee ground	197	133	624	5	196	42
Coffee oil meal	898	174	270	55	18	483

EE, Ether extract; NFE, nitrogen-free extract. Source: The encyclopedia of farm animal nutrition 2004.

Table 4. Digestibility of coffee wastes.

Pulp, dry method	Digestibility %					
	Animal	CP	CF	EE	NFE	ME
	Sheep	10.3	27.9	53.2	50.2	1.33

	Nutritive value %					
	DM	N	CWC	IVDMD	Ca	P
Coffee pulp	20	2.13	21	61.2	0.55	0.11
Hulls	89.6	0.48	45.7	48	0.15	0.02

Source: Gohl Bo. 1981. CWC= Cell Wall Constituents, IVDMD= In vitro DM digestibility, Source: CAB International (1997).

Hemi-cellulose, Lignin, DOMD (Digestible Organic Matter in the DM) and ME (Metabolizable Energy) respectively. Different authors have worked on the chemical composition and digestibility of coffee wastes as shown in Tables 2-6.

Potential constraints associated with the use of waste and by-products of coffee

The cherry and the leaves contain caffeine, an alkaloid

that is a psychoactive stimulant drug, as well as tannins, polyphenols and high amounts of potassium (Bressani, 1982). The presence of these factors contributes to the antinutritional and antiphysiological activity of coffee by-products as observed in both monogastrics and ruminants, such as low palatability, feed intake, protein digestibility and nitrogen retention. Physical (percolation), chemical (alcohol extraction) or microbiological (fermentation) methods may help reducing caffeine content and enhance animal performances (Brand et al., 2000; Peñaloza et al., 1985; Molina et al., 1974). Fungi

Table 5. Nutrients, Minerals and caffeine contents of coffee hulls.

Nutrient	Value
Dry matter (DM) as fed (%)	88.4±3.2
Crude protein (%DM)	9.3± 1.0
Crude fiber (% DM)	37.2±7.6
Ash (%DM)	6.5±2.2
Mineral	Value
Calcium (%DM)	0.44±0.27
Phosphorus (%DM)	0.12±0.07
Potassium (%DM)	2.26±1.13
Sodium (%DM)	0.02±0.00
Magnesium (%DM)	0.09±0.04
Zinc (mg/kg DM)	31±15
Copper (mg/kg DM)	8±0
Iron (mg/kg DM)	20±1
Chloride (Expressed in NaCl (%DM)	0.16
Parameter	Value
Caffeine	0.90±0.05

Source: Feedipedia (2011).

may develop on coffee by-products, which produce toxins harmful to the animal (Bressani, 1991).

Coffee pulp (dried or not), coffee hulls (sticky or dried) and coffee grounds (a by-product of instant coffee manufacture) have an overall deleterious effect on pigs (Hutagalung, 1981; Balogun and Koch, 1975). The cherry and the leaves of coffee contain caffeine, an alkaloid that is a psychoactive stimulant drug, as well as tannins, polyphenols and high amounts of potassium (Bressani, 1982). The presence of these factors contributes to the antinutritional and antiphysiological activity of coffee by-products as observed in both monogastrics and ruminants, such as low palatability, feed intake, protein digestibility and nitrogen retention (Mazzafera, 2002; Brand et al., 2000). So limitations for the use coffee pulp in animal feeding are connected to its high contents on tannins and caffeine (Clifford and Ramirez-Menezes, 1991). Pandey and Soccol (1998) followed by Ramirez-Martinez (1999) reported (dry matter basis) respectively 4.5% and 2 to 4% tannins in coffee pulp. Tannins are known to confer astringency to foodstuffs and complex proteins, affecting food digestibility and decreasing nitrogen utilization animals. Similarly, they are reported to damage protein digestibility as well as assimilation either through interaction of tannin with dietary protein or through inhibition of digestive proteases (Bravo, 1998).

Although caffeine presents a somewhat bitter taste, thereby affecting palatability, the main limitations of this alkaloid for animal feeding are related to its physiological effects on the central nervous system (Bressani, 1982). Mazzafera (2002) also believes that the presence of tannins and caffeine diminish acceptability and palatability of husk by animals (Mazzafera, 2002).

According to Aregheore (1998) supported by Rathinavelu and Graziosi (2005), the use of coffee pulp in animal feeding makes the food less palatable and interferes with nutrient availability and absorption in the gastrointestinal tract. Nitrogen availability is certainly affected by formation of protein complex by tannins.

On the one hand, caffeine causes embryonic mortality in hens at levels of 0.05 and 0.1%. Those fed with the highest level produced a 38.2% mortality rate (Ax et al, 1974). On the other hand, dietary, coffee pulp severely decreased weight gain and caused 100% mortality in chicks (Bressani et al., 1973), which received diets containing 50% coffee pulp for 6 weeks. It should be noted that the ingestion of coffee pulp has no effect on blood biochemical parameters (glucose, protein, P, Ca, cholesterol) in pigs. However they had less back fat and higher liver weights (Okai and Dabo, 1991).

Ways to improve coffee waste as animal feed

Reducing levels of caffeine and tannin waste and by-products of coffee

It is possible to reduce the levels of caffeine and tannin waste and by-products of coffee to increase their use in animal feed. Physical (percolation), chemical (alcohol extraction) or microbiological (fermentation) methods may help reducing caffeine content and enhance animal performances (Brand et al., 2000). Drying followed by several months of storage may reduce the amount of antinutritional factors (Bressani et al., 1973). Coffee pulp fermented with *Aspergillus niger* was used successfully at

Table 6. Nutrients/ Minerals, Amino acids/ and Anti-nutritional factors contents of coffee pulp, dehydrated.

Nutrients	Value
Dry matter (DM) as fed (%)	91.8±2.8
Crude protein (%DM)	11.3±1.9
Crude fiber (%DM)	18.5±1.7
Ash (%DM)	8.9±2.8
Mineral	Value
Calcium (%DM)	0.32±0.03
Phosphorus (%DM)	0.13±0.00
Amino Acid	Value
Lysine (%protein)	3.4±1.1
Threonine (%protein)	3.1±0.4
Methionine (%protein)	0.3±0.1
Cystine (%protein)	0.3
Isoleucine (% protein)	3.3±0.7
Valine (% protein)	3.7±0.0
Leucine (% protein)	4.7±0.1
Phenylalamine (% protein)	3.0±0.2
Tyrosine (% protein)	1.9±0.5
Histidine (% protein)	2.5±0.5
Arginine (% protein)	2.8±0.8
Alanine (% protein)	3.5
Aspartic acid (% protein)	7.1
Glutamic acid (% protein)	7.7
Glycine (% protein)	4.2±0.4
Serine (% protein)	3.3
Proline (% protein)	3.7
Anti-nutritional factors	Value
Tannins, genetic (%DM)	0.92
Caffeine (%DM)	0.82±0.10

Source: Feedipedia (2011).

10% dietary level (Peñaloza et al., 1985).

Caffeine can be significantly reduced by microorganisms (Mazzafera, 2002). Several studies have shown that coffee fruits are a rich source of microorganisms. Boccas et al. (1994) isolated 248 fungal cultures from coffee plants and soil collected from plantation areas. Roussos et al. (1995) isolated 272 strains of filamentous fungi from soil, fruits and leaves using a culture media containing coffee extract, coffee extract plus sucrose, and coffee pulp extract. The fungi strains with the highest ability to degrade caffeine were identified as *Aspergillus* and *Penicillium*. Yamaoka-Yano and Mazzafera (1998) isolated more than 20 bacteria strains from soil collected under coffee plants, observing predominance of *Pseudomonas* sp., which was also the most efficient caffeine degrader. Yamaoka-Yano and Mazzafera (1998) used the same *P. putida* strain to study coffee husk decaffeination. Different proportions of inoculum and husk were incubated during 30 days,

resulting in a reduction of up to 80% of caffeine. At shorter incubation periods (9 days) a 40% reduction was observed.

In another study by (Orozco et al., 2008) revealed that there was remarkable decrease achieved in the total polyphenols (both monomethoxy- and dimethoxy-phenols) derived compounds after the growth of the strains after treating coffee pulp with *Streptomyces* strains. In addition, an increase in the microbial treated coffee pulp of protein content was detected by Kjeldahl method. In summary, changes evidenced in coffee pulp treated by *Streptomyces* through the application of analytical pyrolysis reveal the biotechnological interest of these bacteria to upgrade a usefulness and pollutant residue to be used for feeding purposes.

In another study by Ulloa et al. (2002), different chemical treatments (alkali, NaOH solutions; a combination of acid/ HCl and alkali; A combination of

alkali and ensilage with molasses were tested to improve the nutritional value of coffee pulp. The coffee pulp treated with NaOH alone or with the combination HCl–NaOH showed higher contents of ash, fat and cellulose but lower contents of antinutritional factors (ANFs) (polyphenols, tannins and caffeine) than oven-dried-coffee pulp. The true protein content in the coffee pulp was not affected by the alkali treatment but was reduced in the acid–alkali treated coffee pulp compared to oven-dried coffee pulp. A combined treatment with alkali-ensilage resulted in higher true protein, fat and ash contents and in similar contents of cellulose than in oven-dried coffee pulp. Polyphenols, tannins and caffeine contents were lower in treated than coffee pulp in oven-dried coffee pulp, but there was no difference in the size of the effect for caffeine between one treatment to the other. The higher ash content found in alkali-ensiled coffee pulp could result from the addition of the alkali. The reduction of ANFs was much higher in the chemical treated coffee pulp than in the alkali-ensiled coffee pulp. The alkali treatment yielded the best overall results in upgrading the nutritive value of coffee pulp.

Preparation of silage and processing of coffee waste and by-products

Coffee husk and coffee pulp are coffee processing by-products. Coffee husk is obtained when harvested coffee is processed by the dry method, and coffee pulp is produced by the wet method (Mazzafera, 2002).

The pulp from dry processing is fibrous and rather poor roughage: that from wet processing has a much higher feed value (FAO, 1981) but is high in moisture and does not store well. Ensiling with other feed resources appears to be the best method of preservation and improvement of the nutritive value of pulp (Bouafou et al., 2011).

In another study, two experiments were conducted with yearling rams to evaluate the nutritive value of coffee pulp ensiled on its own and ensiled in combination with either sugarcane stem, sugarcane top or elephant grass (*Pennisetum purpureum*) (Cabezas et al., 1979). Good quality silage was produced from coffee pulp alone and in combination with the forages. Percentage composition of lignin, lignified protein and caffeine were highest in pure pulp silage and decreased, as a result of dilution by forages, in the others (FAO, 1981). Silage process improved overall feed utilization comparing to fresh coffee pulp. However, better knowledge on modification occurring during silage process could allow finding the way to significantly improve nutritive value of coffee pulp by-products (Moreau et al., 2003). According to Bressani (1991), fresh coffee pulp can be ensiled with 4-6% sugar cane molasses. Although it can be directly ensiled, better quality is obtained if moisture content is around 75%. A well-packed trench silo holds an average of 325 kg of coffee pulp per cubic meter. Other treatments include

mixing with urea (10%), sodium metabisulphite (0.3-0.5%), calcium hydroxide (2%), and mixtures of inorganic acids (10% HCl + H₂SO₄). A different and attractive ensiling process is to mix grasses, sorghum or corn, with coffee pulp in layers of about 30 cm with or without sugar cane molasses (4-6%). The silage, whether of coffee pulp alone, or mixed with grasses, is ready to be used in about 3 weeks and if well packed, it can be preserved for up to 18 months. The silage from coffee pulp alone or mixed with other forages can be used as such, or it can be dehydrated (but this operation is not necessary) (Bressani, 1991).

Moreau et al. (2003) observed that silage process seemed to decrease parts of the anti nutritional effect observed with fresh coffee pulp. Coffee pulp ensilage is also a valid alternative to handling and storing the huge amounts of coffee pulp produced in the factories around the world which process coffee fruits. The inclusion of coffee pulp silage in the diets of some farm animals could contribute to lowering the meat and milk production costs, especially in developing countries (Rathinavelu and Graziosi, 2005).

FEEDING RUMINANTS AND NON-RUMINANTS

Coffee pulp from the dry method is fibrous and rather poor roughage, whereas that from wet processing has much greater feed value. For lactating cows coffee pulp can be fed at levels below 20% of the diet without affecting milk production. Beef animals show a decrease in feed intake and weight gain directly related to the level of pulp in the diet. Up to 16% dried coffee pulp from the wet process has been included in diets for swine with good results. Coffee pulp cannot be included in poultry feeds. Attempts to ensile coffee pulp have not been very successful as the silage becomes dark and unpalatable upon exposure to air (Gohl, 1981).

As there are occasionally large surpluses of coffee in coffee-growing countries, the possibility of using oil-extracted seeds for animal feed has been investigated. The oil cake is unpalatable to all farm animals, and if more than 35% is included in concentrates for cattle, the intake decreases. It cannot be fed to poultry as it likewise tends to depress the daily gain. The residue of the roused seeds in the production of instant coffee is unpalatable and depresses weight gains in all classes of livestock. At levels exceeding 10% in poultry diets it produces toxic symptoms (Gohl, 1981).

The first studies with ruminants showed that cattle accepts coffee pulp as food only when supplemented with highly palatable feeds, forage, and protein concentrate (Cabezas et al., 1987). In the same year, some studies have been carried out on the use of coffee pulp as food for animal husbandry (Cabezas et al., 1987). These studies were conducted in countries where coffee is processed mainly by the wet, method what explains the

Table 7. Recommended inclusion rate of coffee pulp in pig diets.

Product	Level	Country	Reference
Coffee pulp (dried or sticky)	5% in growing pigs	Brazil	Parra et al., 2008
Coffee pulp (dried or sticky)	9.5% in finishing pigs	Brazil	Parra et al., 2008
Dried coffee pulp	5% in growing and finishing pigs	Brazil	Oliveira et al., 2001
Dried coffee pulp	20% maize replacement in finishing pigs	Brazil	Oliveira et al., 2002
Dried coffee pulp	30% wheat bran replacement in growing pigs	Ghana	Okai et al., 1991

lack of information on coffee husk (Bouafou et al., 2011). Ranging from 15 to 20% Coffee hulls have been reported to replace several feeds in sheep diets. It is suggested to supply it with a high energy fodder (Brahan et al., 1973). Recommended inclusion rates 5% dietary level when replacing respectively concentrate and Berseem hay, or ground maize (Souza et al., 2004). Coffee pulp is a waste material from the coffee industry. Rathinavelu and Graziosi (2005) showed that it can replace up to 20% of commercial concentrates in dairy cattle feeding, with no adverse effects and a 30% cost savings.

Cattle

In steers, coffee hulls inclusion resulted in decreased body weight gain but replacing 20% ground ear maize was economically feasible (Nascimento et al., 2003). Other maximum recommendation levels are 30% (Ribeiro et al., 2000) and 42% (Vilela et al., 2001). In calves and dairy heifers, inclusion of coffee hulls appears to alter animal growth performances (Souza et al., 2006a; Teixeira et al., 2007). Recommended inclusion levels range from 7 % (Souza et al., 2006a) to 14% (Teixeira et al., 2007) when coffee hulls replace ground maize or maize silage.

In female cattle, coffee hulls can replace 15% (lactating dairy cows, Rocha et al., 2006), 18% (heifers et al., 2005) or 25% (lactating dairy cows, Oliveira et al., 2007) of the diet concentrate (maize). Higher levels result in decreased performances. The dark glossy green leaves of the coffee bush are sometimes dried and included in concentrates for cattle. They are reported to be palatable and can be fed without any unfavorable side-effects. It has been claimed that the feeding of Coffee leaves extends the lactation period. The dried leaves contain 93.6% DM, 9.9% CP, 18.7% CF, 13% Ash, 5.9% EE and 52.5% NFE as % of DM (Bohl, 1981).

Sheep

Coffee hulls have been reported to replace several feeds in sheep diets. It is suggested to supply it with a high energy fodder (Leitao et al., 2005). Recommended inclusion rates range from 15% to 25% dietary level when replacing

respectively concentrate and Berseem hay, or ground maize (Souza et al., 2004).

Pigs

Coffee pulp (dried or not), coffee hulls (sticky or dried) and coffee grounds (a by-product of instant coffee manufacture) have an overall deleterious effect on pigs (Oliveira et al., 2001). However, feeding pigs with coffee by-products may still be interesting and the Table 7 sums up some recommended levels of inclusion (Heuzé and Tran, 2011).

Dried coffee pulp is accepted by pigs from 8 to 16% in the ration (Jarquín et al., 1977). At certain growth stages, lower weight gain was attributed to phenolics in the coffee pulp, since a study with decaffeinated coffee pulp showed that its addition to the ration did not improve the performance of pigs in comparison to normal coffee pulp (Jarquín, 1987). Cunningham (1968) fed pigs with caffeine at the levels of 1.5 g kg⁻¹ and observed that nitrogen retention increased 7.9%, although a lower ration intake was detected. Therefore, considering the levels of coffee pulp used by Jarquín et al. (1977), it is probable that caffeine was not responsible for the diminished weight gain and feed conversion.

In 1985, a total of 40 Large White growing pigs were fed on diets containing either 0.5, 10, 15 or 20% dried coffee pulp (Okai et al., 1985). After a 12 week feeding trial, during which both feed and water were available ad libitum, half of the pigs (males) on each treatment were slaughtered. Average daily feed intake and weight gain, feed conversion efficiency and the various carcass traits measured were not significantly influenced by the inclusion of up to 20% dried coffee pulp. In another study, Okai and Dabo (1991) fed four groups of five pigs with rations containing 0, 10, 20, or 30% of dried coffee pulp over a period of 10 weeks. They concluded that the inclusion of these rations had no significant influence on the feed intake, growth rate and feed conversion efficiency.

Overall results from feeding studies with pigs indicated that corn can be substituted by dehydrated coffee pulp for up to 16% of the total ration, with no detrimental effect on weight gain or feed conversion. This means that at the end of the finishing period, each reared pig has left nearly

Table 8. Optimum rates of inclusion of coffee pulp and coffee grounds in diets for livestock and poultry.

Feedstuffs	Inclusion rate in diet (%)			
	Pigs	Poultry	Cattle/Buffalo	Goats/sheep
Coffee pulp (dried)	8-24	-	10-20	10-20
Coffee grounds	10-20	3-5	10-20	5-10

Sources: Hutagalung, 1981; Oliveira et al., 2001; Parra et al., 2008.

50 kg of corn available for human consumption or alternative uses (Rathinavelu and Graziosi, 2005). Pigs fed with rations containing up to 15% of coffee pulp ensiled with 5% molasses had equal or better total weight gain than those fed commercial concentrates (Rathinavelu and Graziosi, 2005) (Table 8).

Fish and poultry

Besides pigs, coffee pulp feeding trials were carried out with fish and chicks. Coffee pulp also did not affect the growth of the fish *Tilapia aurea*. Compared to chicken manure, there was higher weight gain with a diet consisted of pellets containing 30% of coffee pulp plus wheat bran, ground corn, molasses, cottonseed oil meal, urea, and bone meal. Chicken manure was similar to a control diet that did not receive any additional supplementation. The use of coffee pulp has been studied in tilapia (*Oreochromis aureus*). Its use is limited by the levels of tannins, caffeine and fiber. A dietary inclusion level of 13% coffee pulp in the diet did not affect growth and feed efficiency when compared with the control diet. Caffeine dietary levels between 2.4 to 4.6 g/kg tended to reduce fish growth, feed intake and nutrient digestibility in tilapia fingerlings. Bacterial inoculation was found to be a promising way to increase the nutritive value of coffee pulp for tilapias (Rojas, 2002). Dietary protein and energy utilization of diets containing fresh and ensiled coffee pulp were studied on 3.2 ± 0.2 g Nile tilapia for 28 days (Moreau et al., 2003). Fresh or ensiled coffee pulp should not be considered as suitable feedstuffs for Nile tilapia. Results showed that fresh or ensiled coffee pulp was not a suitable feedstuff for Nile tilapia (Moreau et al., 2003). In broilers, dried coffee pulp has a low nutritive value and the maximum recommended level is 2.5% (Donkoh et al., 1988).

In broilers, dried coffee pulp has a low nutritive value and the maximum recommended level is 2.5% (Donkoh et al., 1988). Drying followed by several months of storage may reduce the amount of antinutritional factors (Bressani et al., 1973). Coffee pulp fermented with *Aspergillus niger* was used successfully at 10% dietary level (Peñalozza et al., 1985).

The use of coffee pulp has been studied in tilapia (*Oreochromis aureus*). Its use is limited by the levels of tannins, caffeine and fibre. A dietary inclusion level of

13% coffee pulp in the diet did not affect growth and feed efficiency when compared with the control diet. Caffeine dietary levels between 2.4 to 4.6 g/kg tended to reduce fish growth, feed intake and nutrient digestibility in tilapia fingerlings. Bacterial inoculation was found to be a promising way to increase the nutritive value of coffee pulp for Tilapias (Rojas, 2002).

Conclusions

World population is clearly growing. For food, we need agricultural and animal production. Appropriate use of relatively inexpensive agricultural and industrial by-products is of paramount importance for profitable livestock production and to reduce competition for food. Moreover, the worldwide food, agricultural and forestry industries produce annually large volumes of wastes, which cause serious disposal problem. Among others, waste and by-products of coffee amount in the millions of tons in the world in terms of productions. Coffee waste contains proteins, carbohydrates and minerals that may favor its utilization in animal feeding. Limiting the use of waste and by-products of coffee by the animals is due to their caffeine and Tannin contents. But drying, silage, physical (percolation), chemical (alcohol extraction) or microbiological (fermentation with *Aspergillus niger*) methods contribute to lower levels/ 10% dietary level/ of caffeine and tannins of waste and by-products of coffee.

REFERENCES

- Aduagna Tolera (2008). Feed resources and feeding management: A manual for feedlot operators and development workers. USIAD SPS-LMM Program. Addis Ababa. Ethiopia.
- Alimuddin Naseri (n.d). Animal nutrition, with emphasis on dairy cows. Animal nutrition training manual. Afghanistan. https://www.google.com.et/?gws_rd=cr&ei=TPQ6U-
- Aregheore EM (1998). A review of implications of antiquality and toxic components in unconventional feedstuffs advocated for use in intensive animal production in Nigeria. Vet. Human Toxicol, 40: 35-39.
- Ax RL, Lodge JR, Bray DJ (1974). Increased embryonic loss in chickens from 0.05% dietary caffeine.

- Poultry Science, 53 : 830-831.
- Balogun TF, Koch BA (1975). Coffee grounds replacing sorghum grains in pig rations. *Tropical Agriculture*, 52 (3): 243-249.
- Barcelos AF, Paiva PCA, Pérez JRO, Santos VB, Cardoso RM (2001). Fatores antinutricionais da casca e da polpa desidratada de café (*Coffea arabica* L.) armazenadas em diferentes períodos. *Ver. Bras. Zootec.* 30:1325-1331.
- Bekalo SA, Reinhardt HW (2010). Fibers of coffee husk and hulls for the production of particle board. *Materials and Structures*. 43:1049–1060.
- Boccas F, Roussos S, Gutierrez M, Serrano L, Viniegra GG (1994). Production of pectinase from coffee pulp in solid-state fermentation system - selection of wild fungal isolate of high potency by a simple 3-step screening technique. *J. Food Sci. Technol.*, 31: 22-26.
- Borrelli RC, Esposito F, Napolitano A, Ritieni, A, Fogliano V (2004). Characterization of a new potential functional ingredient: coffee silverskin. *J. Agric. Food Chem.*, 52, 1338–1343.
- Bouafou Kouamé Guy Marcel, Konan Brou André, Zannou-Tchoko Viviane, Kati-Coulibally Séraphin (2011). Potential Food Waste and By-products of Coffee in Animal Feed. *Electronic J. Biol.*, 7(4): 74-80.
- Braham JE, Bressani R Editors (n.d). Institute of Nutrition of Central America and Panama Coffee Pulp. Composition, Technology, and Utilization.
- Brahan JE, Jarquín R, González JM, Bressani R (1973). Pulpa y pergamino de café. III. Utilización de la pulpa de café en la alimentación de rumiantes. *Turrialba*, 23: 41-47.
- Brand D, Pandey A, Roussos S, Soccol CR (2000). Biological detoxification of coffee husk by filamentous fungi using a solid state fermentation system. *Enzyme and Microbial Technol.*, 27(1-2): 127-133.
- Bravo L (1998). Polyphenols: chemistry, dietary sources, metabolism, and nutritional significance. *Nutr. Rev.*, 56, 317-33.
- Bressani R (1982). *Coffea arabica*. In: Les aliments du bétail sous les tropiques. Division de Production et Santé Animale, FAO, Rome, Italy.
- Bressani R (1979). Antiphysiological factors in coffee pulp. In: Coffee Pulp Composition, Technology and Utilization. (Braham, J.E. and Bressani, R. eds). IDRC Publisher. Canada. pp. 83–96.
- Bressani R, Estrada E, Elias LG, Jarquin R, Valle LU de (1973). Coffee pulp and husks. 4. Effect of dried coffee pulp in the diet of rats and chickens. *Turrialba*, 23 (4): 403-409.
- Bressani R (1991). Coffee, Coffee pulp. In: Tropical feeds version, FAO, Rome.
- CAB International (1997). Crop residues in sustainable mixed crop/livestock farming systems. CAB Publishing Ltd., UK.
- Cabezas MT, Flores A, Egana JI (1987). Use of coffee pulp in ruminant feeding. In: Brahan, J.E.; Bressani, R. (Ed.) Coffee pulp: composition, technology, and utilization. Guatemala City: Institute of Nutrition of Central America and Panama, 25-38.
- Cabezas MT, Vargas E, Murillo B, Bressani R (1977). Utilization of coffee fruit without seeds (coffee pulp) in ruminant feeding. First international symposium on feed composition, animal nutrient requirements and computerization of diets. Utah State University, Logan, USA.
- Cabezas MT, Vargas E, Murillo B, Bressani R (1979). Utilization of coffee pulp in ruminant feeding. Coffee pulp composition, technology and utilization. International Development Research Centre, Ottawa, Canada.
- Clifford MN, Ramirez-Menezes J.R.. (1991). Tannins in wet-processed coffee beans and coffee pulp. *Food Chem.*, 40: 35-42.
- Cruz GM (1983). Resíduos de cultura e indústria. Informe Agropecuário, 9, 32–37.
- Cunha MR (1992). Apêndice estatístico. In E. L. Bacha & R.Greenhill (Eds.), 150 anos de café (pp. 286–388). Rio de Janeiro: Marcellino Martins & E. Johnston.
- Cunningham HM (1968). Effects of caffeine on nitrogen retention, carcass composition, fat mobilization and the oxidation of C14-labeled body fat in pigs. *J. Anim Sci.*, 27: 242-430.
- Davis AP, Tosh J, Ruch N, Fay M (2011). Growing coffee: On the bases of plastid and nuclear DNA sequences; implication for the size, morphology, distribution and evolutionary history of coffee. *Botanical J. Linnean soc.* (4)167:pp.357-377.
- Donkoh A, Atuahene CC, Kese AG, Mensah-Asante B (1988). The nutritional value of dried coffee pulp (DCP) in broiler chickens' diets. *Anim. Feed Sci. Technol.*, 22 (1-2): 139-146.
- Ecoport (2009). Ecoport database. Ecoport. <http://www.ecoport.org>.
- FAO (1981). Tropical feeds. Food and Agriculture Organization of the United Nation. Rome, Italy.
- FAO (2011). Quality assurance for animal feed analysis laboratories. FAO Animal Production and Health Manual No. 14. Rome, Italy.
- Feedipedia (2011). Coffee hulls, fruit pulp and by-products. Tables Régions Chaudes. A project by Inra, Cirad and Afz with the support of FAO.
- Franca AS, Oliveira LS (2009). Coffee processing solid wastes: current uses and future perspectives. In: Agricultural Wastes. (Columbus, F. ed.). Nova Publishers, New York.
- Givens DI, Barber WP (1986). In vivo evaluation of spent coffee grounds as a ruminant feed. *Agricultural Wastes*, 18, 69–72.
- Gohl Bo (1981). Tropical feeds. Feed information summaries and nutritive values. FAO Animal production and health series. 12. Rome. Italy.
- Gouvea BM, Torres C, Franca AS, Oliveira LS Oliveira, ES (2009). Feasibility of ethanol production from coffee

- husks. *Biotechnol. Letter.* 31:1315–1319.
- Graminha EBN, Gonçalves AZL, Pirola RDPB, Balsalobre MAA, Da Silva R (2008). Enzyme production by solid-state fermentation: Application to animal nutrition. *Anim. Feed Sci. Technol.*, 144: 1-22. DOI: 10.1016/j.anifeedsci.2007.09.029.
- Habtamu Lemma, Takele Taye (2009). Traditional Backyard Cattle Fattening in Wolaita: Systems of operations and the routine husbandry practices. *Ethiopian J. Anim. prod.*, 9(1): 39-56.
- Heuzé V., Tran G. (2011). Coffee hulls, fruit pulp and by-products. *Feedipedia.org*. A programme by INRA, CIRAD, AFZ and FAO. <http://www.feedipedia.org/node/549> Last updated on April 8, 2011, 9:47.
- Hutagalung RI (1981). The use of tree crops and their by-products for intensive animal production. In: *Intensive animal production in developing countries* (A J Smith and R G Gunn ed.). *Brit. Soc. Anim. Prod. Occ. Publ.*, 4: 151-188.
- ICO, International Coffee Organization (2010). Available at: <http://www.ico.org/idl-bnc.idrc.ca/dspace/bitstream/10625/6006/1/IDL-6006.pdf>
- Jarquín R. Coffee pulp in swine feeding. In: Brahan, J.E.; Bressani, R. (1987). *Coffee pulp: composition, technology, and utilization*. Guatemala City: Institute of Nutrition of Central America and Panama, 39-49.
- Jarquín R, Gomes-Brenes L, Bressani R (1977). Efectos de los niveles proteínicos y de la pulpa de café en raciones para cerdos criollos. *Turrialba*, 27 : 179-185.
- Leitao RA, Paiva PC, de ARezende CAP de (2005). Nutritive value of coffee (*Coffea arabica* L.) hulls treated with sodium hydroxide and/or urea supplemented with alfalfa (*Medicago sativa* L.) hay. *Pesquisa Agropecuaria Tropical*, 35 (1): 31-36.
- Mazzafera P (2002). Degradation of caffeine by microorganisms and potential use of decaffeinated coffee husk and pulp in animal feeding. *Sci. Agri.*, 59: 815-821.
- Molina MR, De la Fuente G, Batten MA, Bressani R (1974). Decaffeination: a process to detoxify coffee pulp. *J. Agric. Food Chem.*, 22 (6): 1055-1059.
- Moreau Y, Arredondo JL, Perraud-Gaime I, Roussos S (2003). Dietary utilisation of protein and energy from fresh and ensiled coffee pulp by the Nile tilapia, *Oreochromis niloticus*. *Braz. Arch. Biol. Technol.*, 46, 223-231.
- Mussatto SI, Carneiro LM, Silva JPA, Roberto IC, Teixeira J A. (2011). A study on chemical constituents and sugars extraction from spent coffee grounds. *Carbohydrate Polymers*, 83, 368–374.
- Nabais JMV, Nunes P, Carrott PJM, Carrott MR, García, AM, Díez MAD (2008). Production of activated carbons from coffee endocarp by CO₂ and steam activation. *Fuel Processing Technology*, 89, 262–268.
- Nascimento CGH, Andrade IF de, Baiao AAF, Martins A E, Baiao EAM, Perez JRO, Teixeira JC, Baiao LA (2003). The use of coffee hulls as a supplement for Nelore crossbred steers kept on a *Brachiaria decumbens*, Stapf pasture in the dry season of the year. *Ciencia e Agrotecnologia*, 27 (Especial): 1662-1671.
- NDDB (National Dairy Development Board) (2012). Nutritive value of commonly available feed and fodders in India. Animal Nutrition group. India.
- Negesse T, Makkarb HPS, Becker K (2009). Nutritive value of some non-conventional feed resources of Ethiopia determined by chemical analyses and an in vitro gas method. *Animal Feed Science and Technology* 154 204–217.
- Okai DB, Dabo P (1991). Further studies on the effects of diets containing dried coffee pulp: growth performance, blood and carcass characteristics of pigs. *Beitrage zur tropischen Landwirtschaft und Veterinarmedizin*, 29 (2): 235-241.
- Okai DB, Bonsi MLK, Easter RA (1985). Dried coffee pulp as an ingredient in the diets of growing pigs. *Trop. Agri.*, 62 (1): 62-64.
- Oliveira V, Fialho ET, Lima JA, Oliveira AIG, Freitas RTF (2001). Substitution of corn by coffee hulls in isoenergetic diets for growing and finishing pigs: digestibility and performance. *Ciencia Agrotecnologia*, 25 (2): 424-436.
- Oliveira AS De, Campos JM de S, Valadares Filho S de C, Assis AJ de, Teixeira RMA, Valadares RFD, Pina D dos S, Oliveira GS de (2007). Replacing corn with coffee hulls or soyhulls in dairy cows diets: intake, nutrient digestibility, and milk production and composition. *Rev. Bras. Zootec.*, 36 (4 Supplement): 1172-1182.
- Orozco AL, Pérez MI, Guevara O, Rodríguez J, Hernández M, González-Vila FJ, Polvillo^c O, Arias ME (2008). Biotechnological enhancement of coffee pulp residues by solid-state fermentation with *Streptomyces*. *Py-GC/MS analysis*. 81(2): 247–252.
- Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S (2009). *Agroforestry Database: a tree reference and selection guide version 4.0*. World Agroforestry Centre, Kenya. <http://www.worldagroforestry.org/resources/databases/agroforestry>
- Orzua MC, Mussatto SI, Contreras-Esquivel JC, Rodriguez R, de la Garza H (2009). Exploitation of agro industrial wastes as immobilization carrier for solid-state fermentation. *Ind. Crops Products*, 30: 24-27. DOI: 10.1016/j.indcrop.2009.02.001.
- Padmapriya R, Jenny Anne Tharian and Thirunalasundari T. (2013). Coffee waste management-An overview. *INT J CURR SCI*, 9: E 83-91.
- Pandey A. and Soccol C.R. (1998). Bioconversion of biomass: A case study of lignocellulosics bioconversions in solid state fermentation. *Braz. Arch. Biol. Technol.*, 4: 379-390.

- Parra ARP, Moreira I, Furlan AC, Paiano D, Scherer C, Carvalho PL de O (2008). Coffee hulls utilization in growing and finishing pigs feeding. *Rev. Bras. Zootec.*, 37 (3): 433-442.
- Payne WJA, Wilson RT (1999). *An Introduction to Animal Husbandry in the Tropics*. Blackwell Publishing Ltd, UK.
- Peñaloza W., Molina M.R., Brenes R.G., Bressani R. (1985). Solid-state fermentation: an alternative to improve the nutritive value of coffee pulp. *Appl. Environ. Microbiol.*, 49(2): 388-393.
- Petit N (2007). Ethiopia's Coffee Sector: A Bitter or Better Future. *J. of Agrarian* 7: 225-263.
- Pflugger, R. A. (1975). Soluble coffee processing. In C. L. Mantell (Ed.), *Solid wastes: origin, collection, processing, and disposal*. New York: Wiley.
- Ramalakhmi K, Rao JM, Takano-Ishikawa Y, Goto M (2009). Bioactivities of low-grade green coffee and spent coffee in different in vitro model systems. *Food Chemistry* 115, 79-85.
- Ramirez-Martinez JR (1999). *Pulpa de café ensilada. Producción, caracterización y utilización en alimentación animal*. Universidad Nacional Experimental del Táchira (UNET), San Cristóbal, Estado Táchira, Venezuela.
- Rathinavelu R, Graziosi G (2005). Potential alternative use of coffee wastes and by-products. *International Coffee Organization*, 1967/ 05, 1-2.
- Ribeiro Filho E, Paiva PC de A, Barcelos AF, Rezende C AP, Cardoso RM, Banys VL (2000). The effect of coffee hulls on the performance of Holstein-zebu steers during the growing period. *Ciencia e Agrotecnologia*, 24 (1): 225-232.
- Rocha FC, Garcia R, Freitas AW de P, Souza AL de, Valadares Filho S de C, Pereira OG, Rigueira JPS, Tonucci RG, Rocha GC (2006). Intake and digestibility of lactating dairy cows fed diets containing coffee hulls. *Rev. Bras. Zootec.*, 35 (5): 2154-2162.
- Rodríguez Couto S (2008). Exploitation of biological wastes for the production of value-added products under solid-state fermentation conditions. *Biotechnol. J.*, 3: 859-870. DOI: 10.1002/biot.200800031.
- Rojas JBU (2002). Use of coffee pulp as feed ingredient for tilapia culture. *Fish Culture and Fisheries Group, Wageningen Institute of Animal Sciences*, Thesis, p.133
- Roussos S, Aquíhuatl MA, Trejo-Hernández MR, Perraud IG, Favela E, Ramakrishna M, Raimbault M, Viniegragonzález G (1995). Biotechnological management of coffee pulp-isolation, screening, characterization, selection of caffeine-degrading fungi and natural microflora present in coffee pulp and husk. *Appl. Microbiol. Biotech.*, 42: 756-762.
- Roussos S, Gaime IP, Denis S (1998). *Biotechnological Management of Coffee Pulp*. Pp. 151-161.
- Seyoum B, Zinash S, Dereje F (2007). Chemical composition and nutritive values of Ethiopian Feeds. *EIAR. Research Report 73*. Addis Ababa, Ethiopia.
- Solange I, Mussatto, Ercília MS, Machado, Sílvia Martins José A Teixeira (2011). Production, Composition, and Application of Coffee and Its Industrial Residues. *Food Bioprocess Technol* 4:661- 672.
- Souza AL de, Garcia R, Bernardino FS, Campos JM de S, Valadares Filho S de C, Cabral L da S, Gobbi KF (2006). Coffee hulls in dairy heifers diet: intake, digestibility, and production. *Rev. Bras. Zootec.*, 35 (3): 921-927.
- Souza AL de, Garcia R, Bernardino FS, Rocha FC, Valadares Filho S de C, Pereira OG, Pires AJV (2004). Coffee hulls in the diet of sheep: intake and apparent digestibility. *Rev. Bras. Zootec.*, 33 (6 Supplement 2): 2170-2176.
- Souza AL de, Garcia R, Valadares Filho S de C, Rocha FC, Campos JM de S, Cabral L da S, Gobbi KF (2005). Effects of feeding coffee hulls on intake, digestibility and milk yield and composition of lactating dairy cows. *Rev. Bras. Zootec.*, 34 (6 Supplement): 2496-2504.
- Souza AL, Garcia R, Bernardino FS, Rocha FC, Valadares Filho SC (2004). Coffee hulls in the diet of sheep: intake and apparent digestibility. *Rev. Bras. Zootec.*, 33 (6 Supplement 2): 2170-2176.
- Stanculescu D (2011). Ethiopian Coffee Quality Improvement Project. 2011 Aid for trade global review: case story. Africa, Ethiopia.
- Teixeira RMA, Campos JM de S, Valadares Filho S de C, Oliveira AS de, Assis A J, Pina D dos S (2007). Intake, digestibility and performance of dairy heifers fed coffee hulls replacing of corn silage. *Rev. Bras. Zootec.*, 36 (4): 968-977.
- The Encyclopedia of Farm Animal Nutrition (2004). CABI Publishing.UK.
- Tokimoto T, Kawasaki N, Nakamura T, Akutagawa J, Tanada S (2005). Removal of lead ions in drinking water by coffee grounds as vegetable biomass. *J. Colloid Interface Sci.*, 281, 56-61.
- Ulloa Rojas JB, Verreth JAJ, Amato S, Huisman EA (2003). Biological treatments affect the chemical composition of coffee pulp. *Bioresource Technol.* 89:267-274.
- Ulloa Rojas JB, Verreth JAJ, van Weerd JH, Huisman EA (2002). Effect of different chemical treatments on nutritional and anti nutritional properties of coffee pulp. *Anim. Feed Sci. Technol.*, 99:195-204.
- Vilela FG, Perez JRO, Teixeira JC, Reis ST (2001). Use of sticky coffee hull for feeding of steers in feedlots. *Ciencia e Agrotecnologia*, 25 (1): 198-205.
- Yamaoka-Yano DM, Mazzafera P (1998). Degradation of caffeine by *Pseudomonas putida* isolated from soil. *Allelopathy J.*, 5: 23-34.