DEVELOPMENT OF A COFFEE GRADER AND PULPER CUM WASHER

Thesis submitted in partial fulfilment of the requirements for the Degree of **MASTER OF ENGINEERING (AGRICULTURE)** in **AGRICULTURAL PROCESS ENGINEERING** to the Tamil Nadu Agricultural University, Coimbatore.

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CERTIFICATE

This is to certify that the thesis entitled **"DEVELOPMENT OF A COFFEE GRADER AND PULPER CUM WASHER"** submitted in partial fulfilment of the requirements for the degree of **MASTER OF ENGINEERING (AGRICULTURE) IN AGRICUTURAL PROCESS ENGINEERING** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **SUNDAR. B** (I.D. No. 94-625-010) under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific and popular journal or magazine.

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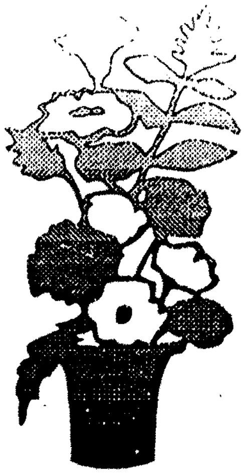

Dedicated to my Beloved Parents

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Abstract

ABSTRACT

DEVELOPMENT OF A COFFEE GRADER AND

PULPER - CUM - WASHER

BY

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The small and medium planters who account for 60 per cent of the total coffee produced in India face problems in processing their produce. To alleviate their problems research work was under taken to develop an efficient coffee pulping-cum-washing mechanism requiring less water, results in less damage to the parchment, and is within the economic reach of the planters.

The physical properties of the wet parchment like size, bulk density, crushing strength, content of mucilage and the kinetic coefficient of friction against mild steel and cast iron surfaces which are involved in the development of the coffee pulper-cum-washer were determined for arabica

parchments. In this present study a hand operated rotary grader and two washing mechanisms, viz., screw auger brush type (model-I) and roller type (model-II) were developed. The already developed drum type pulper was modified and evaluated. All these mechanisms were fabricated with simple components.

These mechanisms were tested for their performance at the Central Coffee Research Institute, Balehonnur and the Coffee Demonstration Farm, Coffee Board, Yercaud, for arabica coffee. The cost and the cost of operation of the units were worked out for these mechanisms.

The average values for the length, breadth and thickness of the arabica parchment with mucilage were 11.20, 8.49 and 5.47 mm respectively. The average bulk density of the partially fermented arabica parchment with mucilage was found to be 487.3 kg/m^3. The average kinetic coefficient of friction against cast iron and mild steel surfaces were 0.20 and 0.09 respectively. The content of mucilage in the arabica coffee was found to be 21.1 per cent.

The rotary grader when fitted with 25mm x 12mm and 25mm x 14mm sieves, gave a maximum overall effectiveness of 0.64 at a ground slope between 2 and 3.7 per cent for the capacity range of 660 to 900 kg/h.

The modified drum type pulper gave the highest pulping and separation efficiencies of 100 per cent at a speed of 373 rpm, feed rate of 576 kg/h and water requirement of 0.5 l/kg. The percentage broken was also the least at 2 per cent.

The maximum efficiency which could be obtained in a screw auger brush type washer was 85 per cent for arabica at a speed of 622 rpm. The water requirement was high but the per cent broken was negligible.

For the roller washer fitted with a helical roller and a helical roller having cross bars the highest washing efficiency of 91 per cent was obtained for arabica at a speed of 126 rpm, feed rate of 384 kg/h and water requirement of 1.2 l/kg. The per cent broken was 9.3 per cent at this condition. No choking was required at the outlet. When the same roller washer was operated at 311 rpm with the same combination of detachable rollers, the washing efficiency was 89 per cent at a feed rate of 576 kg/h and water requirement of 0.8 l/kg. The broken percentage was about 11 per cent at this condition.

These washers could be used for robusta fruits also by increasing the retention time in the washer.

The total cost of the modified pulper-cum-roller type washer excluding the common components was worked out to be Rs. 34,500. The cost of operation of this unit was Rs. 0.06/kg of fruits.

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LIST OF SYMBOLS AND ABBREVIATIONS

cm	:	Centimeter
g	:	gram
h	:	hour
hp	:	horse power,
kg	:	kilo gram
kPa	:	kilo Pascal
l	:	litre
m	:	metre
min	:	minute
mm	:	milli metre
m^3	:	Cubic metre
N	:	Newton
rpm	:	revolutions per minute
Rs	:	Rupees
s	:	Second
^{o}C	:	degree centigrade
%	:	Per cent

Introduction

CHAPTER I

INTRODUCTION

Coffee, which is one of the most widely consumed beverage in the world, belongs to the family Rubiacease. The coffee species is divided into different groups namely Eucoffea, Mascaracoffea, Agrocoffea and Paracoffea. The first three groups are native of Africa and the last groups are native of India, Indo-China, SriLanka and Malaysia respectively. The group Eucoffea includes the important species such as Coffea arabica. Coffea canephora, Coffea liberica and Coffea congensis. Arabica is the most widely cultivated coffee in the world and it also produces the best quality coffee. In India, Coffea arabica (arabica coffee), Coffea canephora (robusta coffee) and Coffea liberica (tree coffee) are the important commercial species grown.

Coffee is grown in 66 countries and in India arabica coffee was introduced towards the end of the seventeenth century by a Muslim pilgrim who brought seven seeds from Yemen and raised seedlings on the hills near the town of Chikmagalur (Bheemaiah, 1992). Robusta was introduced from Indo-china towards the end of the nineteenth century. The commercial coffee producing states are Karnataka, Tamil Nadu, Andhra Pradesh, Orissa, Assam, West

Bengal, Maharashtra, Nagaland, Tripura, Manipur, Himachal Pradesh and the Andaman and Nicobar Islands.

In India, Karnataka has the largest percentage of plantations followed by Kerala and Tamil Nadu. In 1993-94, coffee earned a foreign exchange of about Rs.585 crores (Anonymous, 1989). Coffee still remains as one of the chief foreign exchange earning crops for India apart from spices.

Hence, inorder to survive in the highly competitive international markets, the post-harvest technologies should be sound.

The bright red coffee fruits are harvested during November-February by hand picking and are processed either by washed method or by natural (dry) method (Anonymous, 1985). The harvested fruits of arabica consists of 39 per cent pulp, 17 per cent mucilage, 7 per cent parchment and skin and 37 per cent bean. The berry harvested in the correct stage contains about 65 to 70 per cent of moisture whereas the green coffee which is eventually exported has only 11 to 12 per cent moisture. About 500 to 600 kg of arabica or 450 kg of robusta are required to produce about 125 kg of dried parchment coffee, which finally yields 100 kg of green coffee (Gordon, 1988).

In the dry method, the coffee berry is dried and next the dried skin and the husk is removed by hulling. In the wet processing method, the pulp is first removed with the help of a pulper. Next the mucilage is removed by washing. Finally, the parchment is dried and the dried inner covering is removed by hulling. To avoid cuts on the bean and breakage of the bean, the coffee fruits fed into the pulper should be graded to a uniform size and the adjustments in the pulper should be carefully made.

Pulping is the removal of the epicarp (red skin) with the adhering mesocarp (pulp). There are three pulping mechanisms, viz., drum type, disc type and slotted type mechanisms. The disc coffee pulpers are widely used in India for pulping. The country made drum type pulper was replaced by disc type which is easily available in the market. The slotted type pulper are just being introduced in India. The disc type pulper is costly and requires more power. Washing is the process of removing the slippery mucilage present over the pulped parchment. If the mucilage is not removed, it will lead to 'sourness' in the parchment and will affect the final quality of the coffee brew (Menon, 1989).

Demucilaging is done by any one of the following methods:

(i) natural fermentation,

(ii) fermentation with added enzymes,

(iii) chemical methods,

(iv) warm water method and

(v) attrition or friction method

In the first method, the pulped coffee is placed in concrete or wooden tanks. The natural enzymes present in the mucilage accomplish the digestion in 36 to 48 hours for arabica but the mucilage in robusta coffee cannot be removed even after 70 hours of fermentation. To accelerate the digestion of the mucilage, small amounts of pectic enzymes containing pectase, proto pectinase, pectinase and pectinesterase as the chief active ingredients are added in the second method.

The removal of mucilage by treatment with alkali takes about half an hour for arabica and about one hour for robusta. Dilute acids can also be used. Normally 10 per cent NaOH (caustic soda) or 6 to 8 per cent sodium carbonate (Joshi and Banojbal, 1993) is used as alkali. But, the consumer acceptability is poor while going for chemical methods. Another method for removing coffee mucilage is to mix equal quantities of pulped coffee and water and heat to $50 \pm 3^{o}C$ as quickly as possible. After 3 minutes contact, the mucilage is removed.

In the attrition method, the mucilage is removed by friction developed between the parchments as well as the friction developed between the parchment and the wall of the machine. The process is carried out in the presence of clean water to wash away the mucilage (Anonymous, 1991). To complete all the above operations effectively, the clean water requirement is 80 m^3 to produce one tonne of clean coffee (Ananda Alwar **et al.,** 1992). Hence, the water requirement and labour involvement is more in estate level processing.

Though, all the above methods are available, the frictional method for demucilaging is found to be the best because of the unhygenic problem in fermentation method and chemical method (Anonymous, 1980) and more labour requirements are eliminated in this process. But the problems associated with the existing coffee washers are the high water requirement, the higher cost of the machine which discourages the medium and small planters to buy the washers. Thus, these planters prefer dry method of processing resulting in poor quality of the coffee and greater breakage to the parchment.

This research has been undertaken with a view of improving and simplifying the processing operations for coffee at the estate level by developing new mechanisms and improving the already developed mechanism for the benefit of small and medium planters.

The main objectives of this research project are:

(i) To study the various physical properties like size, bulk density, co-efficient of dynamic friction and the crushing strength of coffee fruits and parchments with mucilage.

(ii) To develop a hand operated rotary type coffee grading mechanism.

(iii) To incorporate necessary modifications to improve the performance of the drum type pulper.

(iv) To develop a coffee washing mechanisms with less water requirement, cost effectiveness, lesser damage to the parchments and to combine this unit with the modified pulper.

(v) To evaluate the performance of the developed hand operated rotary grader and the pulper cum washer at estate level.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

In India the two major commercial varieties of coffee, **Coffea arabica** and **Coffea robusta** are mostly grown. To increase the market value of coffee mostly wet processing of coffee is followed. Approximately 75 per cent of arabica coffee produced is converted into washed coffee or plantation coffee (Ananda Alwar, 1992).

Wet processing is done by pulping the selectively harvested fruits in a pulper followed by washing in a washer to remove the mucilage adhering to the parchment. The presence of mucilage results in poor quality of coffee parchment during storage and inturn a reduction in the market value of the parchment. Thus, the mucilage must be removed thoroughly before going for the next step in wet processing, ie; drying. Also, the parchment must not be damaged during washing as it makes the parchment susceptible to bacterial and fungal attack and subsequently in the blackening of the bean.

For the above mentioned processes, pulping and washing, large quantity of water is required. Owing to the water scarcity in the plantations during the early summer and the late pulping periods, the planters prefer to adopt dry processing. If a technology for pulping and washing with less water requirement is developed, it would be a boon to the medium and small planters to process their harvest by wet method.

To develop such a mechanism a knowledge of the physical properties of the wet parchment with mucilage like the size, bulk density, co-efficient of static and kinetic friction and the crushing strength of the parchment are very important. Therefore, the different methods developed by various research workers to study these properties, grading of coffee, pulping, demucilaging and washing of the coffee are reviewed and discussed in this chapter.

2.1 Physical Properties of Coffee Bean

The physical properties like size, bulk density and co-efficient of friction of coffee are useful in the design of a suitable grader for coffee fruits and washer mechanism for the parchment.

2.1.1 Size of the coffee bean

Ghosh (1966) determined the size of the beans at the fully wet stage by sieving a sample of the beans through a set of three square mesh sieves, namely 0.95 cm (3/8 inch), 0.79 cm (5/16 inch) and 0.64 cm (1/4 inch) thus separating them into four size groups. Also, Ghosh (1970) determined the length, width and depth of each parchment and the values which ranged from 1.03 to 1.20cm, 0.79 to 0.85 cm and 0.49 to 0.52 cm respectively.

2.1.2 Bulk density of the parchment

Ghosh (1966) obtained the volume of the parchment by recording the difference in the height of water column in a burette before and after immersing the parchment. The parchment density was calculated from the skin dry weight and the volume. The density ranged between 1098 and 1145 kg/m^3.

Sreenarayanan **et al.** (1988) determined the porosity, bulk density and true density of CO.1 variety soybean and reported that these properties decreased with increase in moisture content.

The bulk densities of coffee cherry and parchment were determined as 634 Kg/m^3 and 440 kg/m^3 respectively by Gumbe (1989). Chandrasekhar (1995) reported that the bulk density of arabica coffee ranged between 915.95 and 924.73 kg/m^3. For robusta the bulk density was found to be between 917.7 and 946.52 kg/m^3.

Madasamy (1996) obtained the mean value for the bulk density of arabica parchment as 681.37 kg/m^3.

2.1.3 Composition of coffee mucilage

Sivetz (1963) reported the chemical composition of mucilage as water 84.2 per cent, protein 8.9 per cent, sugars 4.1 per cent, pectic acid 0.9 per cent and ash 0.7 per cent.

According to Sivetz and Desrosier (1979) pulped coffee consisted chemically of protopectin, pectin, pectic esters and small amounts of sugar alongwith naturally occurring enzymes pectase, pectinase, pectinesterase and protopectinase.

Vania and Chalfoun (1989) reported that the coffee mucilage was composed basically of 85 per cent water and 15 per cent of soilds in the form of an insoluble and colloidal hydrogel. Of the solid portion, 80 percent were pectic substances and 20 per cent were sugars.

2.1.4 Coefficient of Kinetic /Friction

Mohsenin (1970) has consolidated the methods used by various investigators to determine the static and kinetic coefficient of friction of agricultural materials. To measure the kinetic coefficient of friction the material was placed in contact with a positively driven surface.

Mohsenin also conducted trials on the resistance offered by potatoes to skinning to determine the static and kinetic co-efficients of friction. He stated that this method could also be used for determining the static and kinetic co-efficients of friction for other fruits and vegetables.

Tests with a rotating cone in sand (Leviticuls, 1973) were conducted to verify the existence of velocity dependent soil-wheel interface parameters. The instrument consisted of a cone mounted on a shaft and driven by a servo-controlled motor. Drive motor, bearings, cone and velocity transducer were mounted on a plate, which was attached to a second plate by means of a set of radial arms which allow small radial movement. This movement was sensed by a Shaevitz Linear Variable Differential Transducer and calibrated with a known torque input. The penetration force on a cone was measured by a strain gauge type load cell mounted below the sample tray. The torque needed to rotate the cone, the rotational velocity and the sinkage of the cone were all measured. From the tests conducted with wet and dry sand it was concluded that there appeared to be linear relationship between the shear stress and normal stress for the cone in sand.

Chandrasekhar (1995) conducted experiments to find out the static coefficient of friction of coffee beans against stainless steel, aluminium, galvanised iron and mild steel surfaces and reported the values. He found that the friction coefficient was maximum against mild steel surface followed by galvanized iron, aluminium and stainless steel surfaces.

Madasamy (1996) determined the static co-efficient of friction for coffee parchment with mucilage against mild steel surface, mildsteel surface wound with coir rope and mild steel surface wound with nylon rope. The average static coefficient of friction against coir rope surface was found to be the highest followed by mild steel and nylon rope surfaces.

2.2 Grading of Coffee

Das and Bhattacharya (1984) have conducted studies to determine the optimum relative location of the handle to the operator under cranking and oscillating modes. They found that the cranking mode of operation was the best and the optimum location of the rotary device was at a point where the height of the centre of the crank was 77 per cent of the shoulder height and the horizontal distance between the operator's back and the centre of the crank was

77 per cent of arm reach. The optimum length of the crank was less than 30 per cent of arm reach.

Menon (1989) stated that as all the coffee berries may not be of uniform size, they should be sorted out into atleast two grades with the help of hand sieves and pulped separately. This would avoid cuts and unpulped fruits finding their way into the vats.

A rotary sieve type cleaner-cum -grader for sesamum seed has been developed (Visvanathan, 1994) and suitable for removing small and large-sized impurities from the seeds and grade the seeds into two sizes. The capacity of the unit was 125 kg/h and its effectiveness was 71 per cent. Also stated that as the seed is with flat surface and low weight the method of separation using vibratory or reciprocating screens and aspirators were difficult.

2.3 Pulping

According to Aiyer (1947) pulping is the operation of removing the sweet mucilagious flesh and the skin and freeing of the berries inside.

2.3.1 Pulper location

Haarer (1962) recommended that the pulper should be located at the lowest and the most central point on the estate where water exists.

2.3.2 Pulping methods

Bressani and Braham (1978) observed that the harvested coffee berries were dumped into a tank of water to remove the spoiled and green fruits and the foreign materials which rise to the surface, and the water was used to transport the beans. The berries were dumped into a water tank that resembled an inverted pyramid. From the bottom of the tank, the fruit was siphoned to the pulper which separated the beans from the pulp by mechanical friction.

Michael and Desrosier (1979) explained that the pulping operation was carried out in two steps. First, the fruit was squeezed between the roughened surface of either a rotating cylinder or a disc and a stationary member called a breast with a smooth, channelled or slotted surface sometimes lined with rubber. In the second step of operation, the seeds were separated from the skins. This was accomplished by means of a plate with a carefully ground straight sharp edge.

Manohar **et al.** (1988) stated that the ripe fruits were pulped using disc or roller type pulper through siphon arrangement to ensure uniform feeding and to separate lights and floats from the sound fruits.

Ananda Rao (1989) indicated that only the freshly picked ripe fruits were to be fed to the pulper and the overriped and under riped fruits were to be avoided to improve the quality. Usually, two different systems of pulping were applied, namely drum pulpers (Barrel or cylinder pulpers) and disc pulpers.

Gumbe (1989) stated that pulping was achieved by squeezing the coffee cherry between a moving rough surface and a stationary channelled or slotted surface. The clearance between the moving surface and the stationary channelled surface decreases until there was just room for the parchment to pass through.

2.3.3 Pulper product characters

It was observed that the immatured fruits did not possess any mucilage. While pulping these immatured green fruits, the seeds remained without protection and lubrication provided by the mucilage (Carvalho and Chalfoun, 1989). These green fruits got crushed or broken during pulping which affect the cup quality of coffee.

Menon (1989) indicated that the pulping should be carried out on the same day of picking. The pulper should be carefully adjusted and the feeding should be properly regulated to prevent damage to the parchment.

2.3.4 Coffee pulpers

Haarer (1962) stated that the coffee pulpers range from small hand operated 'baby' pulpers and small power-operated repasser pulpers to large hand-operated or power-driven machines. There were two main kinds of pulpers, the horizontal drum or barrel pulpers and the vertical disc pulpers.

2.3.4.1 Cylinder or drum pulpers

The barrel or drum type of pulper had a copper sheet attached to a rotating drum with projections punched on it (Haarer, 1962). The drum rotated against a breast plate in which there were slotted openings through which the parchment escaped. The cherries were directed by the slots in the breast plate until they were squeezed to free the parchment. The parchment shot out of the apertures while the skins were dragged away to the back of the machine by the punched projections on the drum.

Wrigley (1988) stated that the drum pulper was used generally for small volume of cherry. It consisted of a revolving drum with a close fitting copper cover which was punched with bulbs or buttons on the entire outer surface. The cylinder rotated horizontally and was placed near a fixed breast plate which had pulping channels with ribs at an angle of 45^{o}.

Rene coste (1992) explained that the cylinderical coffee pulper consisted essentially of a rotating metal cylinder coated with a thin, copper lining having a raised surface (buttons) and an adjustable plate (breast) on one side of the equipment. The cherries were pressed between the cylinder and the breast. The pulp was carried out by the rough surface of the rotating drum while the beans were held in the channel of the breast and were expelled through a lateral opening.

Two models of pulping mechanisms were developed by Chandrasekar (1995). The first pulper consisted of a cylinder covered with a dimple sheet and fitted with a handle for rotation, a feed hopper, concave and stand. The coffee fruits which enter between the concave and cylinder were pulped by squeezing. The per cent breakage was higher (11 %) in this model. The other model had a rotating cylinder whose outer surface was covered with elastic rubber material, a concave, feed hopper and stand. The operation of pulping was similar to the first model. The elastic rubber material reduced the breakage of the beans. The maximum separation efficiency obtained was 81 per cent with and without the use of water.

Chellamuthu (1996) evaluated the performance of drum, slotted and disc type pulping mechanisms. The drum pulper at 280 rpm gave a maximum separation efficiency of 98.7 per cent for arabica coffee and the pulping efficiency was 100 per cent. Similar results were also observed for robusta coffee. The slotted type coffee pulper was operated at a speed of 30 rpm. The maximum pulping efficiency observed was 92 per cent and the separation efficiency was not more than 75 per cent. The brokens percentage was also high at all feed rates. The disc pulper operated at 110 rpm and 150 rpm gave a separation efficiency of more than 95 per cent. The water requirement was also slightly high.

2.3.4.2 Disc pulpers

Haarer (1962) stated that the disc pulper had punched copper sheets attached to both the sides of the disc. The cherries were brought into contact with the discs so that the beans were separated in a similar way as that of drum pulpers.

Wrigley (1988) explained that the disc pulpers were more robust and less liable to damage from hard, extraneous objects fed in with the cherry. Disc pulpers have upto four rotating discs.

2.3.4.3 Slotted plate pulper

Sivetz and Desrosier (1979) stated that the slotted plate pulper consisted of a drum having dimples cast on it's entrie surface and rotating against a breast in the form of a slotted plate. When the pulp was rubbed off, the bean was small enough to pass through the slots while the skin was carried downward through the clearance between the plate and drum.

2.3.4.4 Vertical spiral drum pulper

Wrigley (1988) stated that the Penagos 2406 vertical drum pulper consisted of a vertical operating cylinder of small size (24 x 14 cm). The cherry traveled down in a spiral path over the roughened surface of the vertical cylinder along six independent cast iron channels (breasts). The breasts became shallower down the spiral to allow for pulping berries of different sizes. The channels were readily adjustable and could be replaced individually. The pulping was efficient with no damage to the beans and the water requirement was also less. The main problem in this machine was that the pulp tends to accumulate at the bean exit and caused problem to the movement of cherries from the hopper to the channel. Further development was required on this machine for the use of small growers.

2.4 Demucilaging

In wet processing of coffee, the mucilage is removed either by chemical or mechanical methods. Parchment coffee prepared by the wet method of processing is generally favoured by the market. Cherry coffee is rated next due to its longer contact with the mucilage and fruit skin, is usually associated with a characteristic flavour known as "Fruity flavour" (Bheemaiah, 1993).

2.4.1 Demucilaging by natural fermentation

Fermentation was the usual means of removing the sticky covering (Anonymous, 1947). It was generally thought that it was the diastases present in the cells of the mesocarp which brought about the disintegration of the mucilagious coating. If the fermentation process was prolonged the resulting coffee acquired a dark colour and a disagreeable odour. The best quality coffee was obtained after 12 to 24 hours of fermentation.

Haarer (1956) observed that when the pulped bean remained in a tank until fermentation was completed, the time of fermentation depended on seasonal variations and temperatures. The quality was improved by giving it a wash in the tanks every morning, irrespective of whether fermentation had been completed or not. At high altitudes it took more than 2 days for complete fermentation.

According to Sivetz and Desrosier (1979) the fermentation was done by placing the pulped coffee in concrete or wooden tanks and draining the water. The coffee was held in these tanks till the mucilage was acted upon by natural enzymes present in the mucilage and the mucilage is completely dispersed.

The natural fermentation was the most commonly used method for demucilaging coffee(Anonymous,1987). Fermentation took longer time in cool weather than in warm weather conditions. Over fermentation and under fermentation were avoided since it reduces the quality of the end product.

Gordon (1988) observed that the best quality coffee can be obtained from the fruit having bright red all over and glossy appearance. After pulping, the parchment coffee was heaped or placed in tanks. After a day the mucilage started decomposing and liquefy. This was later washed away from the parchment.

Menon (1989) reported that the wet parchment obtained after pulping was heaped in vats and allowed to undergo natural fermentaion as brought about by bacteria. The pectin and non-reducing sugars in the mucilage got digested by bacteria and the mucilage was rendered soluble after about 36 to 48 hours. In the case of arabica the fermentation was completed in about 36 hours while it took more than 72 hours for robusta.

2.4.2 Demucilaging with added enzymes

Haarer (1965) has stated that 0.2 per cent pectic enzyme produced from moulds, based on the weight of the pulped coffee beans was added experimentally to accelerate the fermentation process. Together, with a little warming, it succeeded in completely digesting the mucilage in less than one hour. If the pH of the bean was reduced from 6.7 or 6.8 to a value between 4.2 and 4.5 then the beans were ready for washing. He also mentioned that while considering sanitation, the elimination of fermentation and washing might be welcome.

Sivetz and Desrosier (1979) stated that inorder to accelerate the digestion of the mucilage, it was found to be advantageous to use small amounts of pectic enzymes probably containing pectase, protopectinase, pectinase and pectinesterase as the chief active ingredients. Used in small quantities and at ambient temperatures, the mucilage was digested completely in 5 to 8 hours at low cost.

2.4.3 Demucilaging by chemical methods

Sivetz (1963) stated that the mucilage was removed by treating the pulped coffee either with alkali or with dilute acids. Sodium hydroxide solution dissolved coffee mucilage rapidly and it is used commercially in a larger extent. Sodium carbonate might also be used.

The removal of mucilage by treating with alkali took about sixty minutes for arabica, and ninety minutes to two hours in the case of robusta. Ten per cent caustic soda was used for this purpose (Anonymous, 1987).

Menon (1989) reported that the removal of mucilage by treatment with alkali took about thirty minutes for arabica and forty five to sixty minutes for robusta coffee.

2.4.4 Demucilaging by warm water method

Sivetz and Desrosier (1979) proposed a simple method for removing coffee mucilage quickly. Equal weights of pulped coffee and water were mixed and heated to 50 ± 3^{0} C as quickly as possible. The warm water was able to break down the structure of the pectic materials of the mucilage gel and the coffee might be washed after as little as 3 minute contact with the water at this temperature.

2.4.5 Demucilaging by attrition

Sivetz and Desrosier (1979) stated that the pulped beans were pressed against each other and the roughened lining of the machine while being forcibly fed through the machine by a screw against resistance generated by a partially throttled discharge. The clearance should be carefully adjusted to reduce damage to the beans.

They also proposed the use of a Raoeng pulper which is an Aquapulper developed in Java and manufactured in Germany. This machine was originally designed to accomplish both pulping and mucilage removal in one operation. A standard model of this machine was equipped with a 30 to 40 hp motor and it's capacity is about the same as three regular pulpers requiring less than 1 hp each.

There was pulpers such as Raoeng and Aquapulper which pulped and demucilated the beans in one operation Anonymous (1987). These machines were especially suitable for demucilaging robusta parchment but the percentage of naked and bruised beans were higher in the parchment by these machines.

Gordon (1988) also stated that the Raoeng or Aquapulper was designed to remove the skin, pulp and the mucilage in one operation. It was suitable for both arabica and robusta coffee. He also reported that atleast $4m^3$ of water at a minimum pressure of 49 KPa was required for each tonne of cherry processed.

Menon (1989) observed that the pulped parchment coming out of the pulper was fed directly to the aqua washer, which removed the mucilage by friction. The coffee coming out of the machine was free from mucilage. It was also suggested that even if aqua washing was followed, the coffee might be first subjected to natural fermentation for 6 to 8 hours after pulping, after which the coffee could be passed through the aqua washer. This method would bring about an effective removal of the mucilage, especially from the centre cut of the bean.

Rene coste (1992) stated that the Raoeng pulper and mucilage remover simultaneously pulped, removed the mucilage and washed the coffee. The cherries, which were carried along with the water were compressed between the cylinder and the casing. It needed 309 m^3 of water for 750 to 3000 kg of fruit per hour and the power required was 8 to 25 hp. Madasamy (1996) developed a screw auger type model and a brush type model. The models worked on the principle of attrition and were evaluated for their performances. The screw auger type washer consisted of coir rope wound auger cylinder, outer cylinder with perforations, main shaft, bearing, water pipe, feed hopper and outlet. Brush type model consisted of a wooden roller mounted with nylon brush, wooden rubbing surface, outer casing, water pipe, feed hopper and outlet, bearings, motor and pulleys. At 40 rpm, 200 kg/h feed rate and water requirement of 7.9 l/kg, the screw auger type washer resulted in a washing efficiency of 95.3 per cent and negligible breakage of arabica parchments. The brush type model fitted with a hard brush gave a washing efficiency of 85.7 per cent at a brush speed of 620 rpm, feed rate of 25 kg/h and a water requirement of 43.2 litre per kg of fruits for robusta parchments and required two passes of washing. For arabica parchments a washing efficiency of 100 per cent was obtained in the brush type model fitted with both hard and soft brushes.

2.5 Final Washing of Mucilage

After fermentation the loosened mucilagae adhering to the coffee bean was washed away (Anonymous, 1947). Sivetz (1963) observed that the washing was done either in washing machines or in concrete tanks fitted with paddles or by hand or by mechanical paddles operating in long channels.

Haarer (1956) stated that there should be space between the pulper and fermentation tanks for the purpose of concrete channels in which the parchment coffee was made to flow. Inorder to accomplish preliminary washing and to have a rough grading of the coffee berries as it flows to the tanks, the conveying channel should be widened.

Gorden (1988) mentioned that as soon as the fermentation was complete the parchment had to be washed without delay, using three or four changes of clean water to remove all traces of mucilage on the parchment together with the breakdown products of fermentation of mucilage. The washing was easy when the coffee had been properly fermented. The beans were graded by density during washing. About 1300 litres of water was used to wash one tonne of wet parchment.

Rao (1989) reported that water consumption was less to an extent of 80 to 90 per cent in dry pulper cum washer when compared to a conventional washer.

Menon (1989) indicated that it was essential that the coffee beans were washed before the coffee was taken for drying, on completion of fermentation. The water utilised for washing had to be clean to prevent a 'muddy' taint that could be absorbed by the parchment resulting to an off-taste. It had been observed that improperly washed beans or unwashed beans could start fermenting again leading to 'sourness' of the entire lot.

The clean water should be used for washing coffee (Anonymous, 1991). Recycling of used water for pulping and washing should be avoided. If unavoidable, the re-cycling should be restricted to not more than 3 cycles. The parchment should be washed with clean water as many times as required to have a pebble clean parchment.

Ananda Alwar **et al.** (1992) observed that the clean water requirement for wet process was 80,000 litres to produce per tonne of clean coffee. Also stated that the large water consumption per unit weight of fruits processed and the resulting effluents caused water pollution when let into the natural water course. The Central Coffee Research Institute's constant endeavour was to reduce water usage for processing of coffee.

Rene coste (1992) reported that the water requirement for washing was about 10 litres per kg of coffee.

2.6 Soaking of the Washed Beans

Gordon (1988) stated that after mucilage removal, some processors soaked the coffee under water upto a day. If there was no drying space free for the wet parchment it was practiced to store it under water than in a heap. If the coffee was soaked or stored under water for more than 24 hours, the water must be changed.

Menon (1989) stated that if plentiful supply of water was available on the estate, underwater soaking of the parchment after washing would improve the appearance and the cup quality of the coffee beans. The beans were soaked underwater for about 5 to 6 hours.

The washed parchment had to be soaked either under water or under 1per cent sodium metabisulphite solution over night for enhancing the quality of coffee (Anonymous, 1991).

Narasimhan (1994) observed that the spread of the coffee berry borer can be controlled to a large extent in wet processing where soaking of the beans was practised. The chances of surival of the insects were very less when the beans were soaked .

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

In this chapter, the apparatus and techniques used to measure the various properties of the parchment with mucilage, the details of the grader fabricated, the modifications made to the pulper and the fabrication details of the washer mechanisms are discussed. The evaluation of the grader, pulper and the washer are also discussed.

3.1 Physical Properties of the Parchment with Mucilage

The various physical properties like the bulk density, the size and the dynamic coefficient of friction of the parchment with mucilage are very much essential for the development of grading, pulping and washing mechanisms for coffee.

3.1.1 Raw material

The arabica coffee berries were obtained from the coffee estates at Yercaud and were a mixture of partly ripened, just ripened and over ripened fruits. The berries were stored in a refrigerator at $5^{o}C$ for conducting experiments. For conducting experiments, the berries were pulped manually and the parchments were used along with the mucilage.

3.1.2 Size of the parchment

The size of the coffee parchment is essential in the design and development of a coffee processing mechanism where the adjustment of clearance is essential. Hence the size of the bean was measured. The length, breadth and the thickness of the coffee parchment with mucilage were measured using a vernier caliper with least count of 0.01mm. The measurements were done with twenty five samples and the mean was reported.

3.1.3 Crushing strength of the parchment

A grain hardness tester used for the determination of crushing strength of soybean (Sreenarayanan **et al.**, 1988) and neem nut (Visvanathan **et al.**, 1996) was used for measuring the crushing strength of the beans. The crushing strength is important in the design of pulpers and washers to prevent excessive loading which results in damage to the beans. The parchment with mucilage was gradually loaded and the load at which cracks begin to appear on the parchment was noted. The load was increased till the parchment underwent complete damage. This load was also noted down. The experiment was repeated with five different samples and the average value was reported.

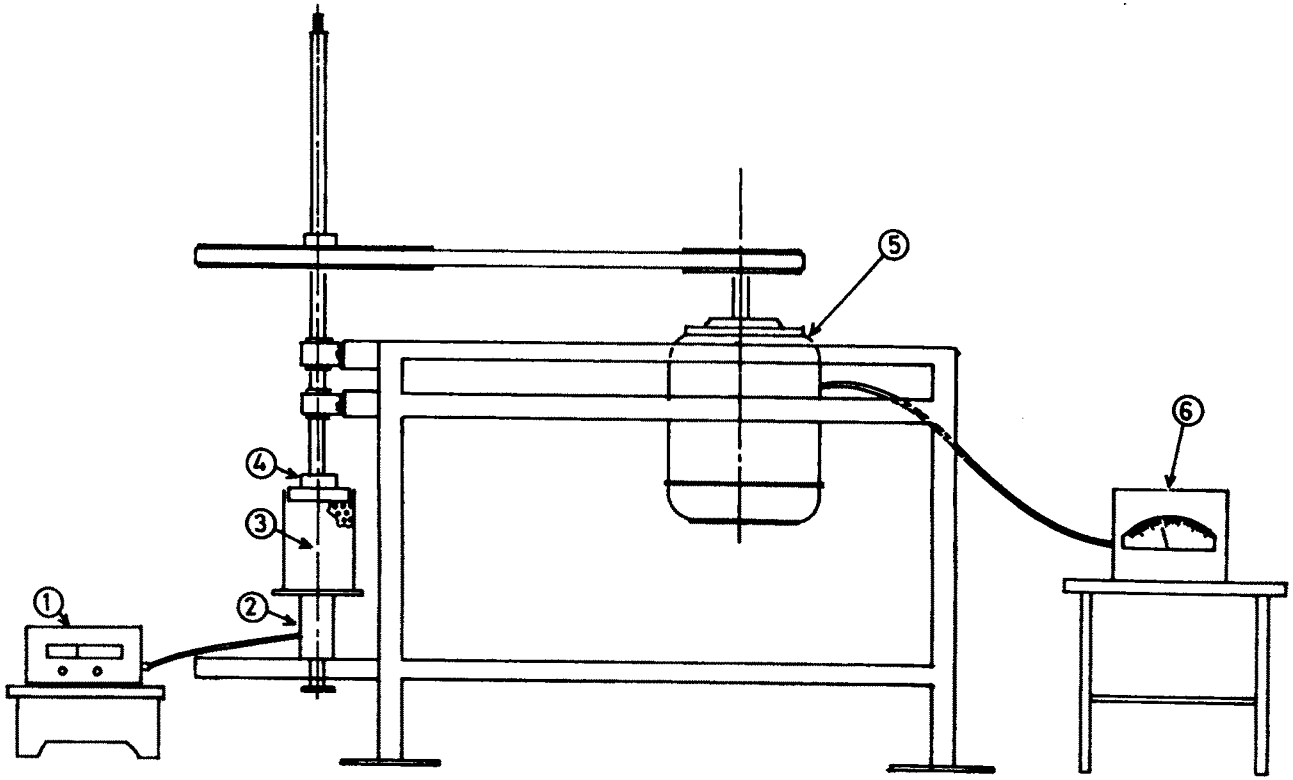
3.1.4 Bulk density

The bulk density of the coffee parchment with mucilage was determined after partial fermentation had taken place. The bulk density was determined by filling the wet parchments in a container of known volume and the content was weighed. The ratio between the mass and volume was calculated as bulk density. The experiment was repeated a number of times by emptying and filling with new samples each time. The mean value was reported.

3.1.5 Kinetic coefficient of friction

The apparatus consists of a disc rotating along a vertical axis and driven by a 1 hp motor. The container containing the parchment was placed above the strain gauge type load cell as shown in Fig.3.1. The container could be raised or lowered with help of a screw rod and the speed of rotation of the disc was varied by changing the pulleys on the motor and the shaft . A similar apparatus was fabricated and used by Gupta and Visvanathan (1993) to study the flow behaviour of puddled soil and kinetic friction.

The parchment with mucilage was filled in the container. The power under no load condition was first noted down. The rotating mild steel disc was made to contact the coffee parchment without touching the sides of the



1. Digital load indicater
2. Strain gauge type load cell
3. Specimen container
4. Rotating cast iron / mild steel disc
5. Motor
6. Watt meter

FIG. 3·1 SCHEMATICS OF THE EXPERIMENTAL SETUP FOR THE DETERMINATION OF KINETIC COEFFICIENT OF FRICTION

Plate 1 Experimental set up for the determination of the kinetic co-efficient of friction

container. The power in watts and the normal load were recorded from the wattmeter and load indicator. The speed of rotation of the disc (N_d) was noted using a tachometer.

From the power recorded (P) in watts, the torque (T) was calculated as given below.

$$T = \frac{0.97\ P}{N_d} \qquad \text{-------------(3.1)}$$

From the calculated torque (T) and the measured radius (r) of the rotating disc, the frictional force (F) was determined using the relation,

$$F \times r = T \qquad \text{--------------(3.2)}$$

Finally, from the normal load (H) and the frictional force (F), the coefficient of kinetic friction (μ) was calculated using the formula,

$$\mu = F/H \qquad \text{--------------(3.3)}$$

The experiment was repeated by increasing the normal load between the disc and the parchment by raising the container using the screw rod. The kinetic co-efficient of friction at different speeds of rotation of the mild steel disc was determined. Also, the experiment was repeated for cast iron disc. The mean values of five replications were reported. The overall view of the unit with instrumentation is shown in Plate 1.

3.2 Development of a Hand Operated Grader

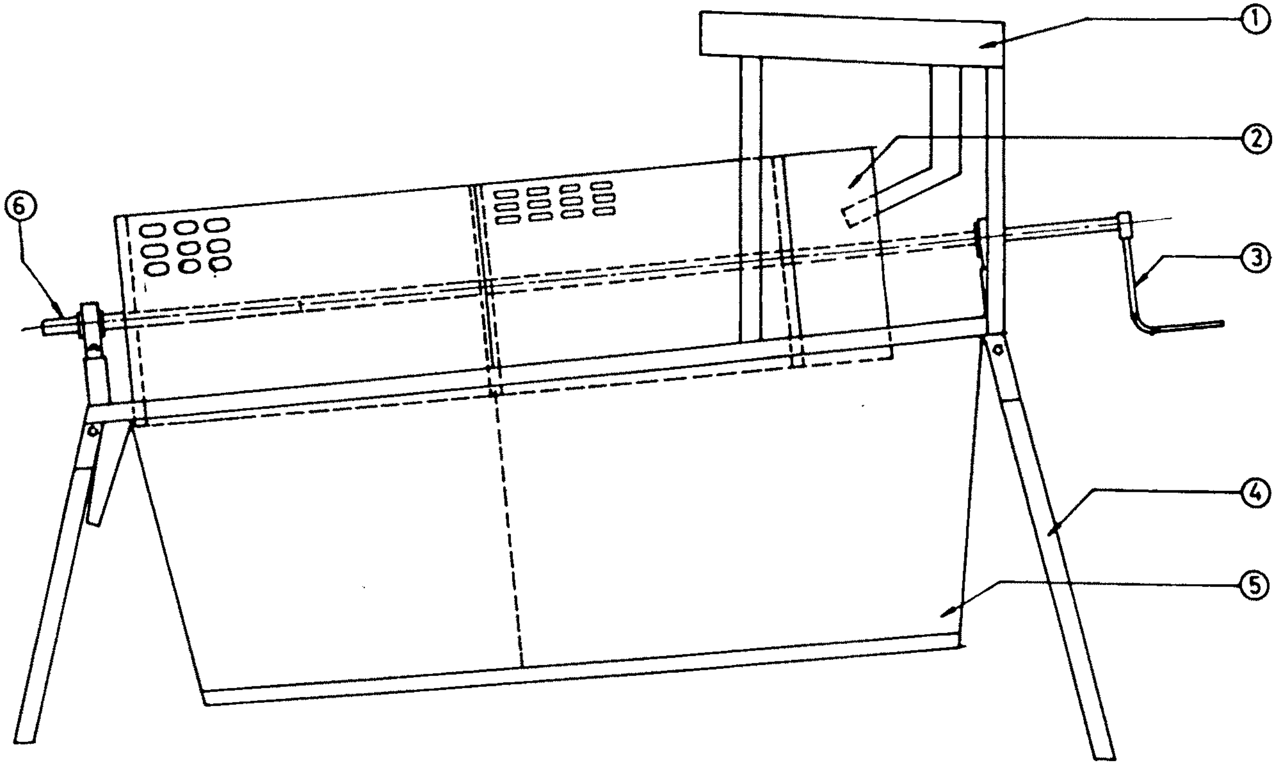
The use of an effective and simple grading mechanism was felt in the coffee estates in order to grade the harvested coffee berries according to size. The size graded coffee reduced the per cent breakage of pulped beans. This unit consists of a feed trough, rotary sieve assembly, main frame and outlets as shown in Fig.3.2.

3.2.1 Feed trough

The feed trough was made of mild steel sheet of 20 SWG thick to a size of 56 cm x 40 cm to a depth of 7.5 cm. At one bottom corner of the feed trough, a rectangular opening of 11 cm x 8 cm was made. A feeding chute was attached to this opening. The feed trough was mounted at a height of 44 cm from the main supporting frame.

3.2.2 Rotary sieve assembly

The sieve assembly has been made of two sieves. The sieves were with 25 x 12 mm and 24 x 10 mm, and 25 x 14 mm and 25 x 12 mm oblong holes on a 150 cm x 60 cm, 20 SWG thick mild steel sheet. The sieves were rolled and fixed on



1. FEED TROUGH
2. ROTARY SIEVES
3. HANDLE
4. MAIN FRAME
5. OUTLETS
6. CENTRAL SHAFT (G.I PIPE)

FIG. 3·2 HAND OPERATED ROTARY GRADER

Plate 2 Hand Operated Rotary Grader

a set of three mild steel rings having a diameter of 48 cm. These rings gave support to the sieves.

3.2.3 Main supporting frame

The main supporting frame was made of mild steel angle of 37 x37 x 3mm to a dimension of 163 cm x 56 cm. This frame was provided with four legs made of the same size of angle which raised the frame to a height of 60 cm. A central shaft made from 25 mm diameter galvanized iron pipe was mounted on two bush bearings which were fixed to the main frame, was fixed to the three rings which supported the rotary sieves. The length of the central shaft was 175 cm. A handle to rotate the shaft has been provided with a crank of 26 cm.

3.2.4 Outlets

There were two outlets below the rotary sieve. The top width of the outlet was 56 cm and the bottom width of the outlet was 16.5 cm. The graded coffee fruits were collected at the bottom through the outlets.

3.2.5 Operation

The coffee fruits was dumped on the feed trough. These fruits entered into the sieve drum through the feed chute. The crank was rotated at a constant speed (30 rpm).

The coffee fruits was carried along the surface of sieves due to the rotary motion and dropped off through the openings in the sieve. The two grades that pass through the sieves and one grade that passed over the sieves were collected separately.

3.2.6 Evaluation of grader

The grader divided the feed into three grades and were collected separately.

The grader was then evaluated for it's performance at the Coffee Demonstration Farm, Coffee Board, Yercaud by following the method of Chung Joo Chang (1986). This method was also followed by Visvanathan **et al.** (1994) to evaluate the performance of the grader for sesamum. A view of the grader being evaluated is shown in Plate 2.

A known weight (W_T) of freshly harvested fruits were taken. The mass of individual fractions of the feed material corresponding to the sizes of the two sieves, 24 x 10 mm and 25 x 12 mm were analysed as W_1 and W_2 and above the size of 12 mm as W_3. These individual fractions were mixed and fed into the grader and the handle was rotated. The time taken for grading was noted down.

After grading the feed material let the mass of the products obtained through the outlets (two sieves) are taken as Q_1, Q_2 and Q_3.

Thus,

$$W_1 + W_2 + W_3 = W_T \qquad \text{---------} \ (3.4)$$

$$Q_1 + Q_2 + Q_3 = W_T \qquad \text{---------} \ (3.5)$$

The material other than the specified size in the products Q_1, Q_2 and Q_3 of each outlet were separated manually and their masses were separately found as q_1, q_2 and q_3.

The purity of the product obtained at different outlets after grading was found out using the following relation:

$$P_1 = \frac{Q_1 - q_1}{Q_1} \qquad \text{-----------} \ (3.6.1)$$

$$P_2 = \frac{Q_2 - q_2}{Q_2} \qquad \text{-----------} \ (3.6.2)$$

$$P3 = \frac{Q_3 - q_3}{Q_3} \qquad \text{-----------} \ (3.6.3)$$

where,

P_1 = Purity of the product obtained from outlet 1,

P_2 = Purity of the product obtained from outlet 2,

P_3 = Purity of the product obtained from outlet 3,

Q_1 = The fraction of feed material obtained through the outlet 1,

Q_2 = The fraction of feed material obtained through the outlet 2,

Q_3 = The fraction of feed material obtained through the outlet 3,

q_1 = fraction of the material other than the required size available in the fraction Q_1

q_2 = fraction of the material other than the required size available in the fraction Q_2

q_3 = fraction of the material other than the required size available in the fraction Q_3

The fraction yield was calculated as follows:

$$Fr_1 = \frac{Q_1}{W_T} \qquad (3.7.1)$$

$$Fr_2 = \frac{Q_2}{W_T} \qquad (3.7.2)$$

$$Fr_3 = \frac{Q_3}{W_T} \qquad (3.7.3)$$

where,

Fr_1 = Fraction yield at outlet 1,

Fr_2 = Fraction yield at outlet 2,

Fr_3 = Fraction yield at outlet 3,

W_T = Total mass of feed to be graded

The fractions of each size corresponding to the sieves S_1, S_2 and above the size S_2 in the total feed was calculated by,

$$a_1 = \frac{W_1}{W_T} \qquad \text{-------------- (3.8.1)}$$

$$a_2 = \frac{W_2}{W_T} \qquad \text{------------- (3.8.2)}$$

$$a_3 = \frac{W_3}{W_T} \qquad \text{------------- (3.8.3)}$$

where,

a_1 = The fraction of each size corresponding to the sieve S_1 in the total feed,

a_2 = The fraction of each size corresponding to the sieve S_2 in the total feed,

a_3 = The fraction of each size above the size S_2 in the total feed,

W_1 = The mass of the individual fractions of the feed material corresponding to the sieve size S_1,

W_2 = The mass of the individual fractions of the feed material corresponding to the sieve size S_2.

W_3 = The mass of individual fractions of feed material above the sieve size S_2.

The degree of extraction, which is the ratio of the amount of the component in the yield fraction to the amount of the same component in the initial mixture is given by,

$$Ex_1 = P_1 \frac{Fr_1}{a_1} \qquad \text{--------------- (3.9.1)}$$

$$Ex_2 = P_2 \frac{Fr_2}{a_2} \quad \text{---------------} \quad (3.9.2)$$

$$Ex_3 = P_3 \frac{Fr_3}{a_3} \quad \text{---------------} \quad (3.9.3)$$

where,

Ex_1 = The degree of extraction of sieve S_1,

Ex_2 = The degree of extraction of sieve S_2.

Ex_3 = The degree of extraction of overflow of sieve S_2

The overall effectiveness of the sieve is calculated based on the expression,

$$E = \sum_{i=1}^{n} Fr_i \frac{(P_i - a_i)}{(1 - a_i)} \quad \text{----------} (3.10)$$

This method was followed for grading the coffee fruits at different ground slopes, 0, 2.57, 4.28 and 5.7 per cent .

The sieves were removed and the sieves of sizes 25 x 14 mm and 25 x 12 mm were fitted and the performance was evaluated at ground slopes 0, 2, 3.7 and 4.85 per cent.

The value of purity, fraction yield, degree of extraction and the overall effectiveness were found as done in the previous case. The values were reported and conclusions were drawn about the performance of the grader.

3.3 Development of a Pulper

The cylinder or drum pulper developed by Chellamuthu (1996) at the Department of Agricultural Processing, TNAU was initially evaluated for performance. The following parameters were assessed using the relationships given there in as used by Chandrasekar (1995).

(a) Pulping efficiency, $$E_p = \frac{P_f}{W} \quad \text{---------- (3.11)}$$

where,

P_f = quantity of fruits pulped, kg

W = Quantity of fruits fed, kg

(b) Separation efficiency, $$E_s = \frac{ad - bc}{(a+c) \quad (b+d)} \quad \text{---- (3.12)}$$

where,

a = Mass of beans in the bean outlet, Kg

b = Mass of skin in the bean outlet, Kg

c = Mass of beans in the skin outlet, Kg

d = Mass of skin in the skin outlet, Kg

(c) The overall effectiveness of the pulper

$$= E_p \times E_s \qquad \text{------------ (3.13)}$$

(d) The capacity of the pulper,

$$C = \frac{P_f}{T} \times 100 \qquad \text{------------ (3.14)}$$

where,

C = Capacity, kg/h

T = Time taken, h

The pulper (Chellamuthu, 1996) was trial run at Central Coffee Research Institute, Balehonnur, Karnataka. From the trials conducted the modifications required were identified and carried out.

3.3.1 Modified pulper

The modified drum type pulper comprised of a drum , cylinder, breast plate, feed hopper and stand.

The cylinder was made of mild steel sheet of 20 SWG thick to 20 cm diameter and 31 cm length. The outer surface was covered with dimpled sheet and welded. This cylinder was mounted on mild steel shaft of 3 cm diameter.

The breast plate was made up of cast iron. The breast plate had two pulping channels. The clearance between the breast plate and the drum was adjustable. The cylinder and the breast plate was completely covered on all four sides to prevent the throwing of the fruits away from the pulper when the fruits come in contact with the rotating pulper drum.

3.3.1.1 Modifications done in the pulper

To overcome the problem of choking of the fruits in the feed hopper of the pulper and achieve uniform flow of berries into the pulping drum, the hopper was modified by providing a feed roller. The details of the roller is shown in Fig.3.3. The feed roller is made of mild steel flat with four numbers of flutes. The power for the rotation of the roller is directly taken from the main shaft by friction drive and the roller rotated at 40 rpm speed.

The drum has been renewed with new dimple sheet. For proper alignment the plummer block type bearings have been replaced with pillow block type bearings. The covers and outlets for the pulper has been provided. The power for the pulper main shaft has been taken from the motor through a gear box. The construction of the pulping drum is shown in Plate 4.

3.3.2 Operation

The fruit was fed into the hopper and the feed roll uniformly conveyed the feed to the pulper drum. The

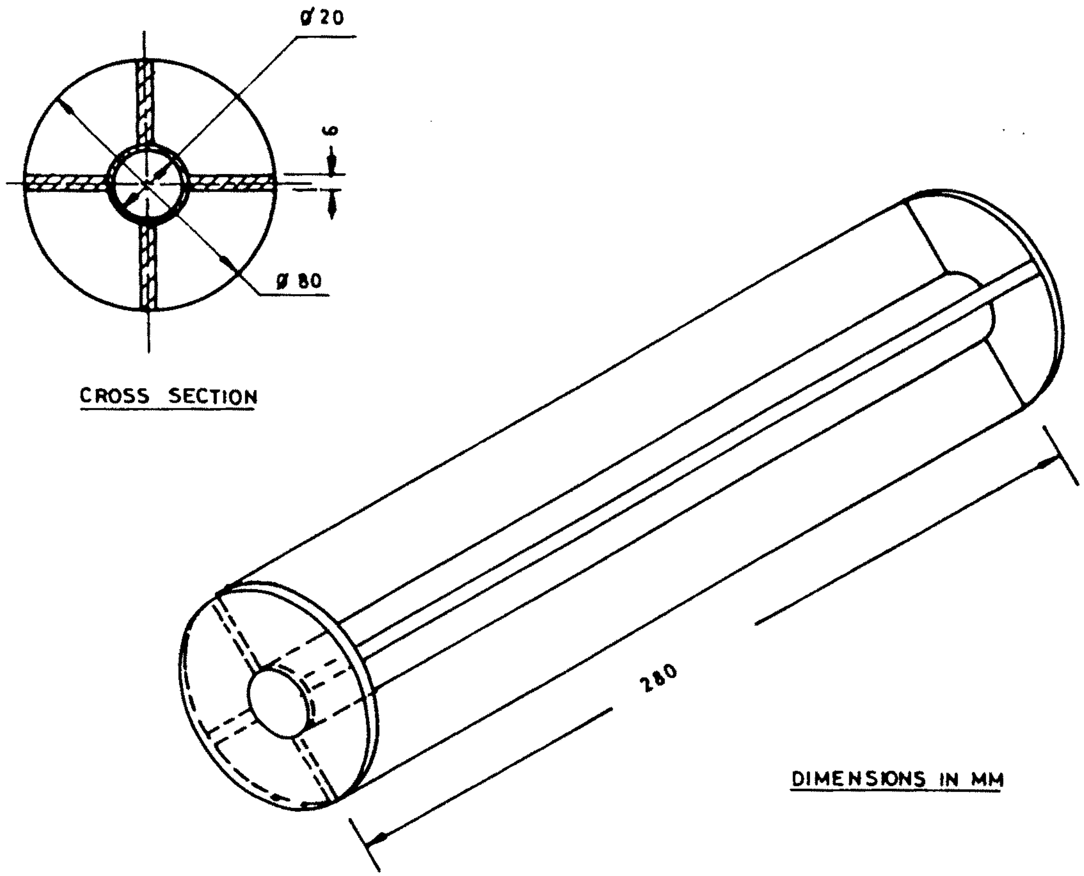


FIG. 3·3 FEED ROLLER

Plate 3 Feed Roller

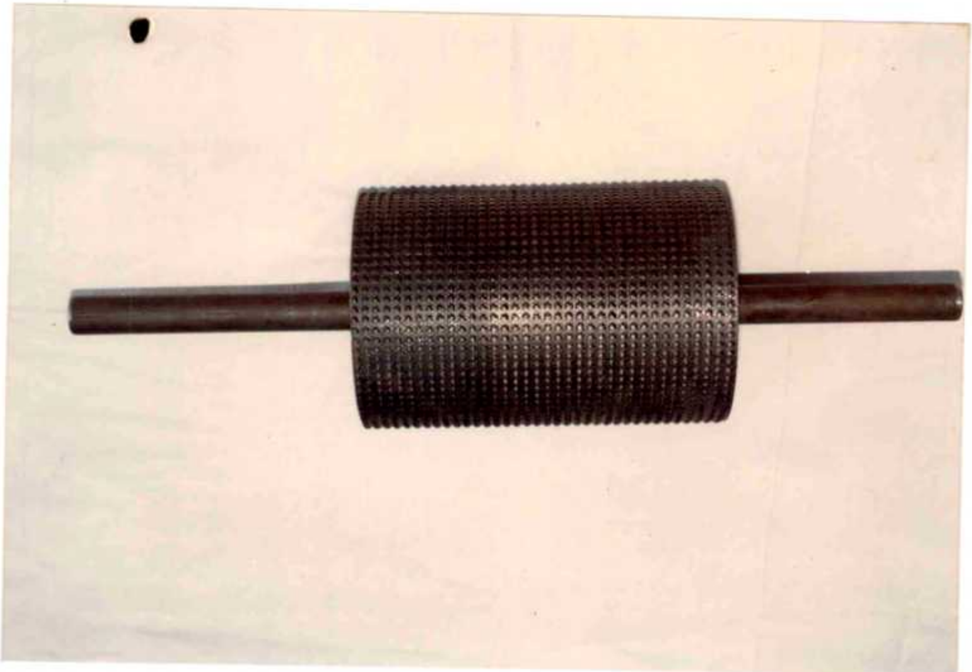


Plate 4 Pulper Drum

clearance between the breast plate and the drum was carefully adjusted so that no breakage occurred. As the fruit travels along the channel in the breast plate which became narrower towards the end, the parchment gets squeezed and passes out of the outlet and falls into the inlet of the washer situated below the pulper. The skin gets dragged along by the rotating drum and gets ejected at the outlet behind the drum.

3.4 Development of Demucilaging and Washing Mechanism

The existing demucilaging cum washers are very costly and require huge amount of water, 3 litres per kg of parchment (Rene coste, 1992). Two models of demucilaging cum washing mechanisms were fabricated aiming to minimise the cost and water requirement. Also the washing mechanisms developed by Madasamy (1996) at Department of Agricultural Processing, TNAU, were found to have a low washing efficiency and a higher breakage. Hence to do away with these drawbacks new washing mechanisms were developed.

3.4.1 Model I - Brush type washer

This model consisted of a roller provided with screw auger and nylon brush, outer cylinder with perforations, feed hopper, outlet with closing mechanism and a frame.

3.4.1.1 Roller with screw auger and brush

The roller was made of wooden blank machined for a diameter of 12 cm. The two ends of the roller has been extended with mild steel shaft of 25 mm diameter. A screw auger to a length of 15.5 cm with 2.6 cm of screw diameter has been mounted at the feed end. For the rest of the length of the roller (about 75.5 cm) a nylon brush in the form of a screw auger was formed for a height of about 2.5 cm. The formation of the nylon brush was executed with a local brush manufacturer. A view of the roller assembley is shown in Plate 6. This cylinder was mounted on pillow block bearings on either side.

3.4.1.2 Outer cylinder

The outer cylinder was made by rolling a mild steel perforated sheet of 20 SWG thick to a diameter of 17 cm and length of 92 cm. The perforations were of 25 x 3 mm oblong in size. The feed hopper and the three outlets were welded to this outer cylinder at opposite sides. The cylinder was mounted on a frame of size 115 x 31 x 50 cm and was held in place by the help of bolts and nuts. The side of the cylinder at the feed end was closed by welding with a mild steel sheet of 20 SWG thickness. The other end was closed with a removable cover fastened using bolts-nuts on a

Plate 5 Pulper-cum-screw auger brush type washer

Plate 6 Brush assembly in the Brush type washer

lange. A water pipe line of 15 mm diameter with perforations at the bottom was mounted on the outer cylinder for supplying water during the process.

3.4.1.3 Feed hopper and outlets

The feed hopper of dimension 23 x 17.5 cm was made from 20 SWG thick mild steel sheet. The feed hopper was of trapezoidal shape and had a bottom width of 14 cm. The three outlets were of rectangular shape and had a dimension of 10 x 18 cm. Two out lets were placed at 38 cm and 70 cm distance from the feed hopper. The last outlet was placed on the cover provided at the other end of the outer cylinder.

3.4.1.4 Operation

The raw parchment was fed into the washer and it was conveyed by the metal screw auger. Next, the brush type screw auger took over the beans and vigourously washed the beans. The mucilage was removed by the combined action of the water supplied by the water pipe line and the friction developed between the brush, the parchment and the surface of the outer cylinder. The removed mucilage was washed away by the water and discharged through the perforations provided on the outer cylinder. The washed parchment was discharged through the parchment outlet.

3.4.2 Model II - Roller type washer

This mechanism consisted of mild steel rollers, inner cylinder with screw, outer cylinder with perforations, feed hopper, outlet and stand.

3.4.2.1 Inner cylinder with screw

The inner cylinder consisted of a mild steel seamless pipe of outer diameter 12 cm and 70 cm length. A screw has been formed on it's surface to a length of 9.6 cm for a height of 2.6 cm. The two ends of the pipe was closed by welding a round mild steel plate to form a closed cylinder with a shaft. A key way of 10 mm x 10 mm has been taken by milling for fitting the rollers.

3.4.2.2 Detachable rollers

Four detachable rollers (Fig.3.4) were made using mild steel seamless pipe of thickness 9 mm and were 30 cm long. The outer diameter of each roller was 14 cm and the inner diameter was 12.2 cm. The surface of each roller had different patterns made with 20 mm mild steel round rods welded to the outer surface. One roller had six equally spaced horizontal bars welded on the surface. The other roller had six equally spaced horizontal bars welded on it's surface longitudinally, and in addition had short cross bars welded alternatively to the middle and to the sides of two

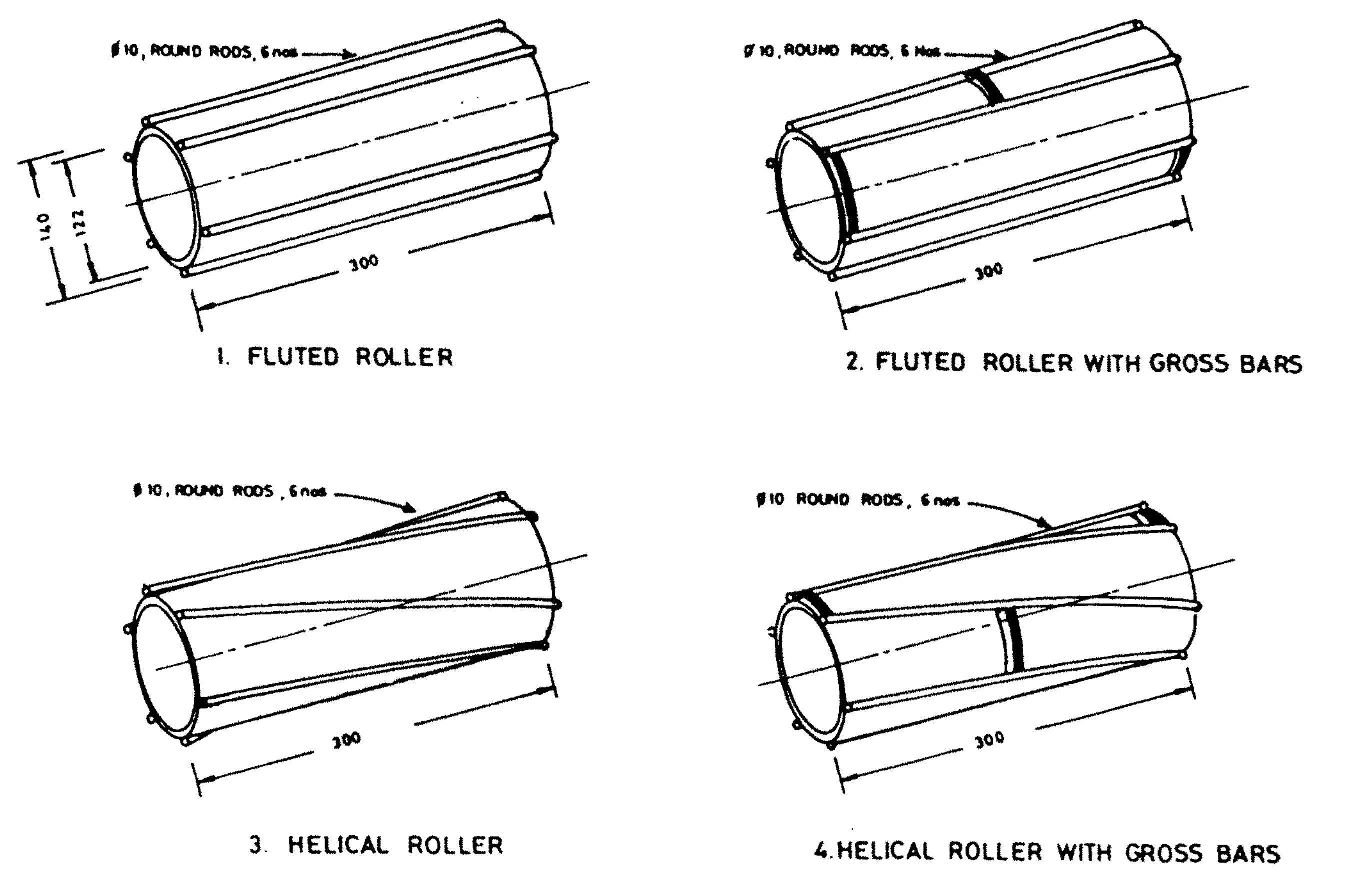


FIG.3·4 CONFIGURATION / GEOMETRY OF THE ROLLERS USED IN THE WASHER

Plate 7 Detachable Rollers

bars. The third roller had six equally spaced spiral bars and the last roller had six equally spared spiral bars as well as alternate cross bars. The bars were machined to 17 cm depth. Keyway slot of 10 mm x 10 mm for the length of the roller has been machined for connecting these rollers on the main roller by using a key of 10 mm square. A view of the various types of rollers are shown in Plate 7. At the discharge end of the main roller shaft a mild steel sing of 12.3 cm diameter on which six L-shaped mild steel flat sheet at equal spaces were welded, was fitted. These L-shaped sheets helped to lift the washed parchment to the outlet.

3.4.2.3 Outer cylinder with perforations

The outer cylinder was made of mild steel per forated sheet of 20 SWG thick. The perforations were of 25 mm x 3 mm oblong size. The diameter and the length were 21.5 cm and 70 cm respectively. The two ends of the cylinder were closed with mild steel sheet of 20 SWG thickness. The feed hopper and the outlet were welded on the opposite side of the cylinder. A water pipe line of 15 mm diameter and with six projecting nozzles was mounted at the top of the outer cylinder for spraying a jet of water during the operation.

3.4.2.4 Feed hopper and outlet

The feed hopper was made of 20 SWG thick mild steel sheet. A trapezoidal shape feed hopper of 23 cm top width and 14 cm bottom width was fabricated. It was mounted on the outer cylinder. A rectangular shape outlet 9.5 x 6.0 cm was welded at the top of the outer cylinder at the other end. A shutting device which will automatically open when the required pressure was developed was provided at the outlet. The device will open when the pressure exerted by the parchment was above the load (weight) exerted by the shutter.

3.4.2.5 Frame

The main frame was made of mild steel angle of 38 x 38 x 3 mm to a size of 85 x 31 x 50 cm to accomodate the washer. The pulper mechanism was also mounted the frame with suitable power drive arrangement.

3.4.2.6 Roller washer fitted with brush

A third model of washer developed, consisted of a single detachable roller of any one of the four patterns described in section 3.4.2.2 and nylon brushes attached to six teak wood reapers. The six wooden reapers containing the nylon brushes were fixed to the main roller longitudinally at equal spaces with screws. The nylon brush was of hard

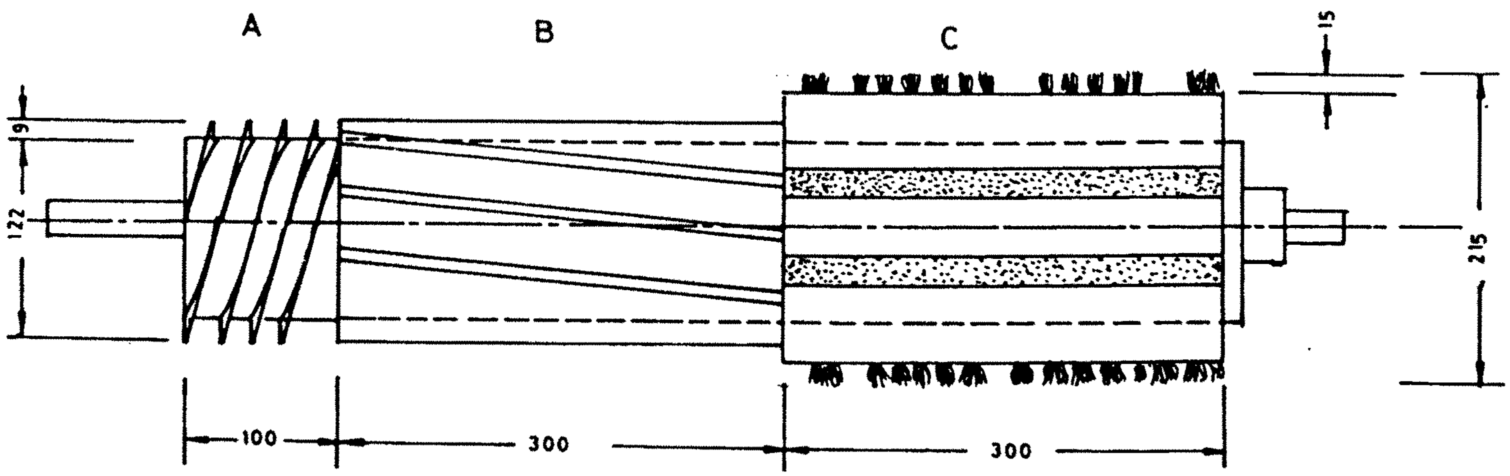


FIG. 3·5 ROLLER SHAFT WITH ONE DETACHABLE ROLLER AND BRUSH

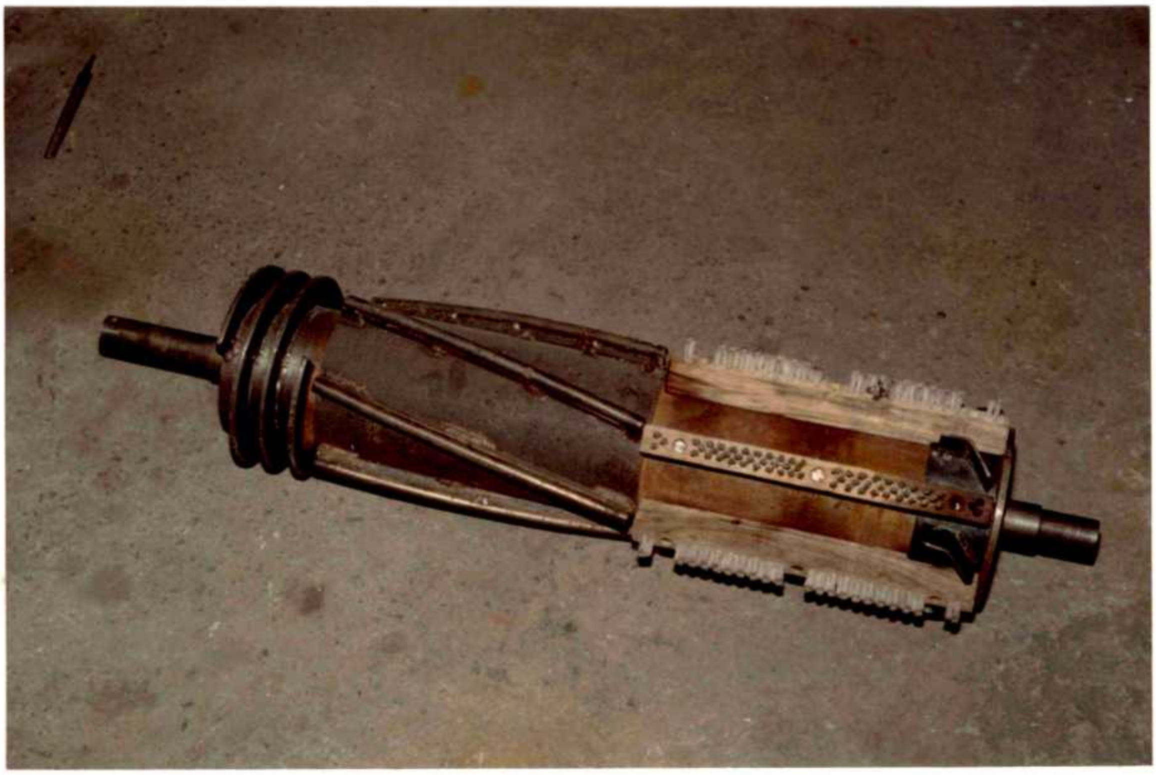


Plate 8 Brush assembly in Roller type washer

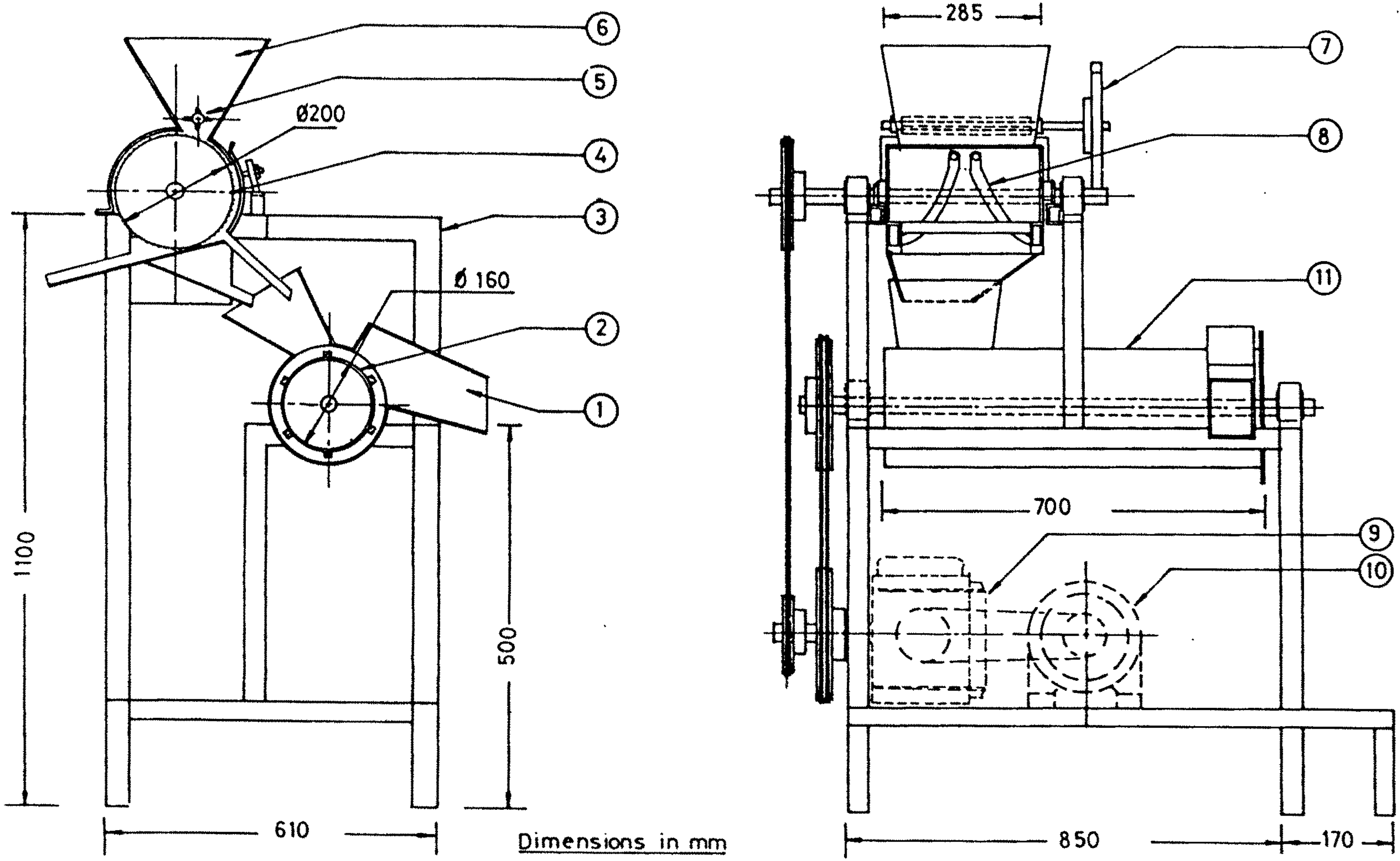
type and brush height was 15mm (Fig. 3.5). The wooden reapers with the brush was attached near the discharge end of the main roller as shown in Plate 8.

3.4.2.7 Operation

The raw parchment from the pulper was fed into the outer cylinder. For a short distance it was conveyed by means of the screw auger. Any two combinations of the rollers were fixed to the inner cylinder. The bars welded to the rollers conveyed the parchment to the outlet and at the same time rubbed the parchment against each other and against the wall of the outer cylinder. The attrition loosened the mucilage and the water supplied through the water pipe line washed away the mucilage. As the parchment reaches the outlet it gets collected there and initial loading occurs resulting in further attrition, thus effective washing occurs. When the pressure exerted by the parchment exceeds the weight of the shutter, the shutter opens and discharges the washed beans.

3.4.3 Development of a pulper and washer

The modified pulper and the washer mechanism developed were mounted on the same stand such that the pulper shaft was mounted at a height of 45 cm above the washer shaft. The centre of the pulper was 33.5 cm away from



Dimensions in mm

1. OUTLET
2. WASHER ROLLER
3. MAIN FRAME
4. PLUPER DRUM
5. FEED ROLLER
6. HOPPER
7. DRIVE FOR FEED ROLLER
8. BREAST PLATE
9. GEAR BOX
10. MOTOR
11. WASHER CASING

FIG3.6 COFFEE PULPER AND WASHER

Plate 9 Pulper-Cum-Roller-Washer

the centre of the washer. Both the pulper and washer are sun by a three phase 3HP electric motor. The pulper, washer, motor and the gearbox were mounted on a rigid stand made of mild steel angle of 38 x 38 x 3 mm having a dimension of 115 cm x 61 cm x 23.5 cm. The overall view of the unit is shown in Plate 9.

3.4.4 Evaluation of pulper and washer

The modified pulper and the developed washers were evaluated at the Central Coffee Research Institute (CCRI), Karnataka during December, 1996 and at Coffee Demonstration Farm, Coffee Board, Yercaud during February, 1997. The units were evaluated for their efficiency, capacity, per cent broken and water requirement.

The modified drum type pulper was evaluated at the Coffee Demonstration Farm, Coffee Board, Yercaud for its performance by using arabica coffee fruits.

Harvested arabica fruits were fed into the pulper at 384 kg/h and 576 kg/h at speeds 149 rpm and 373 rpm respectively. The water requirements for the pulper at 149 rpm were 0.31 l/kg 0.47 l/kg, 0.63 l/kg, 1.4 l/kg and also without water. For a speed of 311 rpm and a feed rate of 576 kg/h, the water requirements used were 0.23 l/kg, 0.31 l/kg, 0.5 l/kg, 0.62 l/kg, 0.93 l/kg and without water.

In each case, the number of beans in the skin outlet, skins in the bean outlet and the percentage of broken seeds were also noted as observations. These parameters formed the basis for evaluating the performance of the pulper.

The observations were used in the formulae proposed by Chandrasekhar (1995) to determine the pulping efficiency (Ep), separation efficiency (Es), the overall effectiveness of the pulper and the capacity of the pulper (C).

The brush type screw auger washer was evaluated for its performance at 186 rpm and 622 rpm at Central Coffee Research Institute, at a feed rate of 87 kg/h and a water requirement of 0.5 l/kg.

The mild steel roller washer was evaluated for it's performance at the CCRI for a feed rate of 87 kg/hr and water requirement of 0.5 l/kg. The speeds selected were 173, 213 and 622 rpm.

After making the necessary modifications, the roller type washer was again tested at the Coffee Demonstration Farm, Yercaud at two different speeds, 126 and 311 rpm. The feed rates were 6.4 kg/min and 9.6 kg/min. The water flow rates were 4 l/min, 7.5 l/min, 10 l/min, 15 l/min and 23 l/min for a feed rate of 6.4 kg/hr. For a feed rate of 9.6 kg/hr, the water flow rates used were, 7.5 l/min, 9.4 l/min, 10 l/min, 15 l/min, 20 l/min and 23 l/min.

The speed of the units was varied by changing the pulleys.

To evaluate the washers for their efficacy atleast five samples of known weight of the parchment with mucilage was taken in a container and kept for about 40 hours to undergo natural fermentation. Then the parchment was washed with clean water and weighed after keeping the cleaned parchment over a perforated sheet for 5 minutes to drain the water completely so that there might not be any water adhering to the parchment. The difference in the above two weights indicated the weight of mucilage present in the parchment immediately after pulping. By comparing the presence of mucilage in the parchment at the inlet and outlet of the washers, the efficiency of washing was calculated using the following equation,

$$n = \frac{A}{F} \qquad \text{------------ (3.15)}$$

n = Washing efficiency in percentage,

A = Percent mucilage present after washing,

F = Percent mucilage present in the feed.

The capacity of the washers was calculated using the following formula (Arnold, 1969) from the time taken for the known weight of feed to be washed as,

$$C_1 = \frac{P_w}{T_1} \times 60 \qquad \text{---------------- (3.16.)}$$

Where,

C_1 = Capacity of the unit in kg/h,

P_w = Weight of parchment washed in kg,

T_1 = Time taken in minutes.

The percentage brokens was calculated by taking three samples in random of 100 g each washed parchment and the brokens or damaged parchment were manually separated in each sample (Panesar and Pathak, 1974). The broken parchments of each sample was weighed and the per cent breakage was calculated using the following relationship (Rademachar, 1981).

$$B = \frac{D}{S} \times 100 \qquad \text{------------ (3.17)}$$

Where,

B = per cent broken,

D = weight of broken or damaged parchment in gm,

S = total weight of the sample in gm.

The mean value in each case was reported.

The water requirement was calculated by measuring the time required to fill a container of known volume. The flow rate was varied by regulating the opening of the valve according to the requirement.

3.5 Cost Economics of the Fabricated Units

The cost of the models developed were estimated by considering the cost of the raw material, overhead charges and labour charges. The cost of operation was calculated by estimating the fixed cost and variable cost. The following items of expenditure were considered for fixed cost and variable cost and the values assumed are given below.

Fixed cost

i) Depreciation - estimated by straight line method

ii) Life of the pulper and grader - 5 years
and life of washer - 10 years

iii) Salvage value - 10 per cent of the purchase value

iv) Interest - 12 per cent per annum on average investment.

v) Repair and maintenance - 10 per cent of initial cost

vi) Tax and insurance at the rate of 2 per cent of initial cost

Variable cost

i) Working hours per year - 500 hours (at the rate of 3 hours per day for 125 days in a year)

ii) Number of labour required and wages - 2 at the rate of Rs.60 per day

iii) Electricity charges - as consumed.

The calculation details are given in Appendices G and H.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, the results of the various experiments and the evaluation trials conducted are discussed.

4.1 Physical Properties of the Parchment with Mucilage

The various physical properties like the size, the bulk density, the crushing strength and the co-efficient of kinetic friction against mildsteel and cast-iron surfaces determined for the partly fermented parchment (15 hours) are discussed. The values of these properties are given in Table 4.1.

4.1.1 Size of parchment with mucilage

The size of the arabica parchment with mucilage was determined using a vernier caliper. The average length, width and thickness of the parchment with mucilage are 11.2mm, 8.49 mm and 5.47 mm respectively.

4.1.2 Bulk density of parchment with mucilage

The average value of bulk density for arabica parchment after 15 hours of fermentation was 487.3 kg/m^3.

4.1.3 Hardness (crushing strength) of parchment with mucilage

The crushing strength of the parchment was determined using KIYA grain hardness tester. During incremental, loading at a load of 0.37 N cracks begin to appear on the surface of the parchment. Complete failure of the parchment occurred at 0.97 N.

4.1.4 Kinetic co-efficient of friction of parchment with mucilage

The kinetic co-efficient of friction of the parchment determined against mild steel and cast iron surface are given Tables 4.2 and 4.3. Discs of 86 mm diameter made of mild steel and cast iron were rotated in the speed range of 0.81 m/s to 3.38 m/s at various normal loads. In each case statistical analysis was performed to test the significance of the speed and normal load on coefficient of friction. For mild steel disc, the overall mean for friction coefficient was 0.09 with a standard deviation of 0.03. Also the 'F' value was less than the table value indicating an insignificant relationship at 5 per cent level itself. As the normal load increased, the tangential load also increased proportionately giving a constant value of kinetic coefficient of friction (u). In

Table 4.1 Size, Bulk density and Crushing strength of parchment with mucilage

Sl.No.	Properties	Value
1.	Size	
	(a) Length, mm	11.20 (0.72)
	(b) Width, mm	8.49 (0.62)
	(c) Thickness, mm	5.47 (0.67)
2.	Bulk density after partial fermentation, kg/m^3	487.3 (5.05)
3.	Crushing strength, N	0.965 (0.017)

The values in the parenthesis are the standard deviation.

Table 4.2 Co-efficient of kinetic friction for parchment with mucilage against mild steel disc

Linear speed m/s	Normal load N	Tangential load N	Coefficient of friction [μ]	Mean [μ]	Standard deviation
0.86	0.66	0.03	0.045		
	1.17	0.09	0.0766		
	1.89	0.15	0.079	0.091	0.036
	2.04	0.27	0.132		
	2.45	0.30	0.123		
1.06	0.710	0.05	0.068		
	1.330	0.15	0.110		
	1.83	0.17	0.092	0.112	0.035
	2.45	0.31	0.129		
	2.75	0.44	0.159		
1.40	0.61	0.03	0.061		
	1.43	0.07	0.052		
	1.83	0.11	0.061	0.087	0.046
	2.24	0.22	0.10		
	2.75	0.45	0.163		
1.80	0.51	0.04	0.084		
	0.82	0.07	0.087		
	1.12	0.10	0.089	0.0881	0.0027
	1.73	0.16	0.90		
	2.04	0.18	0.0905		

Linear speed m/s	Normal load N	Tangential load N	Coefficient of friction [μ]	Mean [μ]	Standard deviation
2.60	1.43	0.16	0.112		
	1.73	0.18	0.104		
	2.04	0.24	0.118	0.109	0.0065
	2.34	0.25	0.107		
	2.65	0.27	0.102		
2.75	0.61	0.06	0.092		
	0.81	0.07	0.091		
	1.01	0.09	0.0914	0.090	0.0025
	1.43	0.13	0.0914		
	1.73	0.15	0.086		
3.38	0.71	0.05	0.074		
	1.01	0.06	0.060		
	1.33	0.08	0.057	0.057	0.0096
	1.63	0.08	0.051		
	2.04	0.09	0.045		

Overall Mean, (μ) = 0.0906

S.D = 0.029

Table 4.3. Kinetic co-efficient of friction for parchment with mucilage against cast iron disc

Linear speed m/s	Normal load N	Tangential load N	Coefficient of friction [μ]	Mean [μ]	Standard deviation
0.81	1.12	0.32	0.28		
	1.43	0.35	0.24		
	1.73	0.38	0.22	0.233	0.029
	2.04	0.44	0.217		
	2.75	0.57	0.206		
1.01	0.71	0.15	0.21		
	1.02	0.18	0.174		
	1.22	0.20	0.167	0.173	0.021
	1.43	0.23	0.160		
	1.63	0.25	0.156		
1.40	1.63	0.49	0.30		
	1.94	0.39	0.20		
	2.14	0.42	0.197	0.210	0.052
	2.45	0.46	0.188		
	2.85	0.48	0.167		
1.76	3.06	0.50	0.162		
	3.47	0.55	0.159		
	3.77	0.60	0.158	0.160	0.0016
	4.08	0.66	0.161		
	4.38	0.70	0.161		

Linear speed m/s	Normal load N	Tangential load N	Coefficient of friction [μ]	Mean [μ]	Standard deviation
2.50	0.71	0.12	0.170		
	0.91	0.15	0.159		
	1.94	0.32	0.164	0.145	0.0083
	2.24	0.41	0.181		
	2.65	0.46	0.172		
2.75	0.71	0.13	0.188		
	1.12	0.22	0.193		
	1.43	0.27	0.187	0.1866	0.0045
	1.94	0.35	0.181		
	2.24	0.41	0.184		
3.32	0.82	0.16	0.20		
	1.33	0.36	0.27		
	1.53	0.39	0.26	0.23	0.033
	1.83	0.40	0.22		
	2.04	0.42	0.20		

Overall mean, (μ) = 0.20

S.D = 0.04

the experiment using cast iron disc, the overall mean value of the friction co-efficient was 0.2 and the standard deviation was 0.04 and was significant at 5 per cent level. This indicates that the value of the friction co-efficient was nearly constant though not as pronounced in the case for mild steel.

4.2 Evaluation of Hand Operated Rotary Grader

The hand operated rotary grader developed was evaluated for its performances, viz., capacity and effectiveness at different slopes and sieve combinations at the Coffee Demonstration Farm, Coffee Board, Yercaud.

4.2.1 Grader fitted with 24 mm x 10 mm and 25 mm x 12 mm sieves

The grader was initially fitted with 24 mm x 10 mm and 25 mm x 12 mm sieves and operated at different ground slopes. The ground sloe was varied as 0, 2.60, 4.30 and 5.70 per cent. The data for the calculation of effectiveness are given in Appendix D. The capacity and the effectiveness of the grader in given in Table 4.4.

4.2.1.1 Effect of slope on capacity

From the Fig. 4.1 it can be seen that, as the ground slope increases the capacity of the grader also

Table 4.4 Performance of fruit grader

Sieve size	Slope %	Capacity kg/hr	Overall effectiveness
24mm x 10mm and 25mm x 12mm	0	474.5	0.41
	2.6	497.14	0.29
	4.3	614.10	0.28
	5.7	803.10	0.25
25mm x 12mm and 25mm x 14mm	0.0	448.40	0.60
	2.0	657.60	0.64
	3.7	896.70	0.64
	4.9	1233.00	0.53

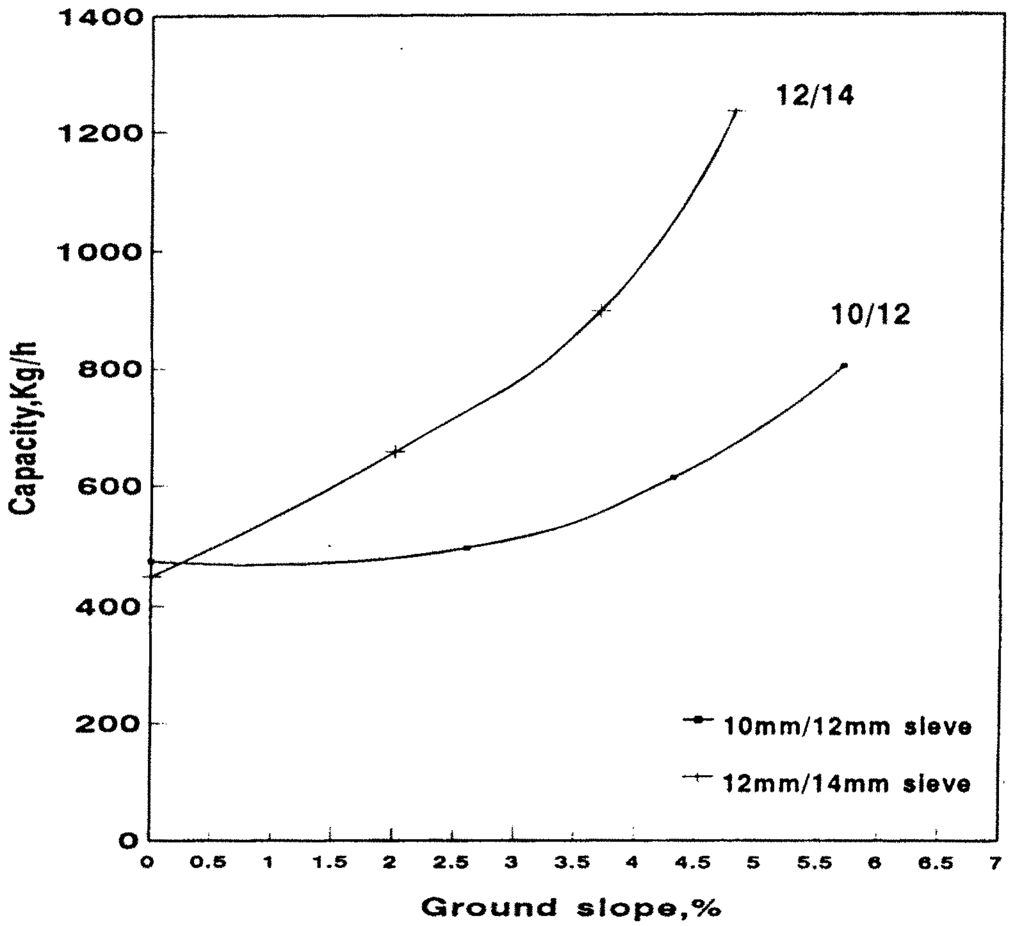


Fig.4.1. EFFECT OF GROUND SLOPE ON THE CAPACITY OF THE ROTARY GRADER FOR COFFEE FRUITS

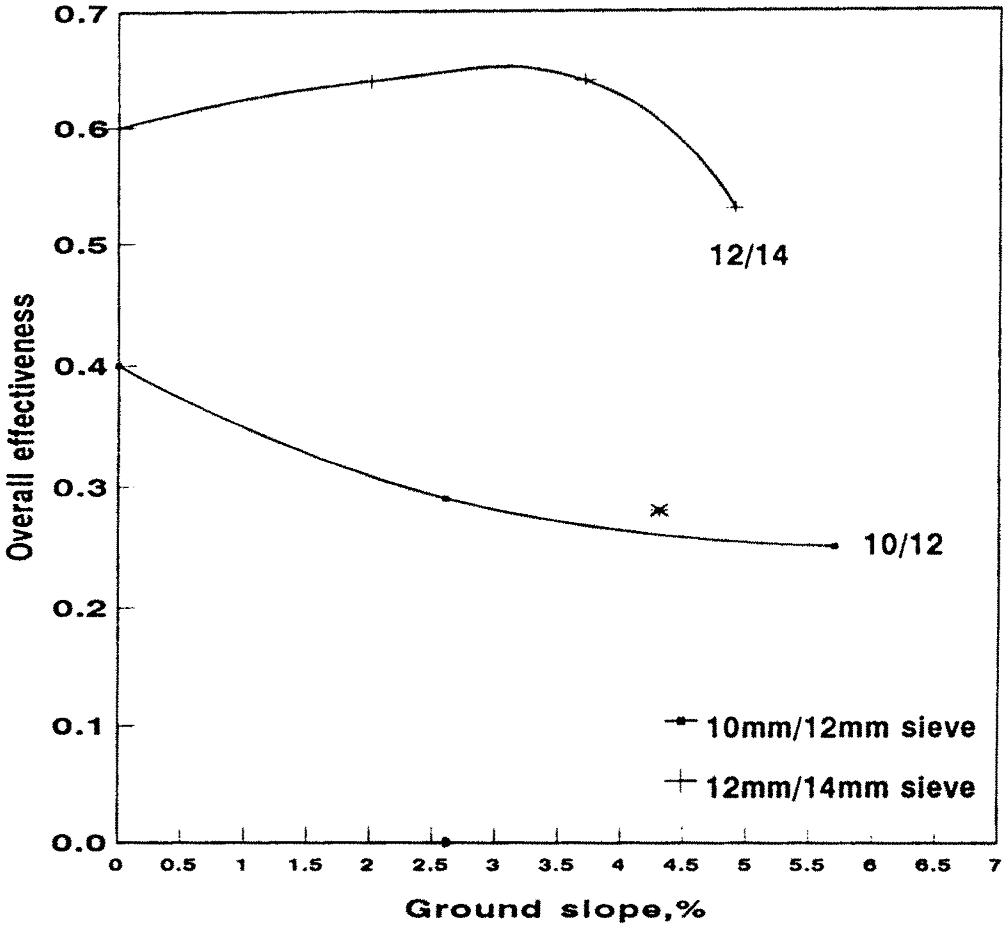


Fig.4.2. EFFECT OF GROUND SLOPE ON THE OVERALL EFFECTIVENESS OF THE ROTARY GRADER FOR COFFEE FRUITS

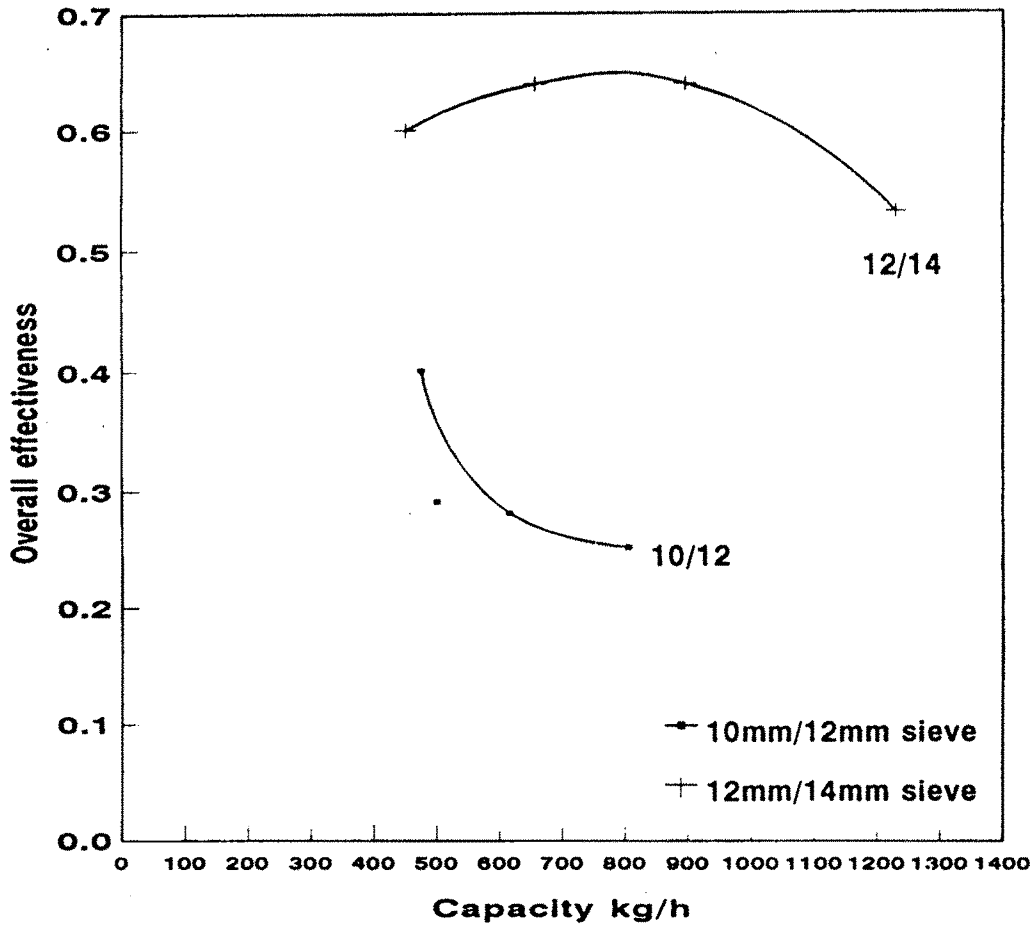


Fig.4.3. EFFECT OF CAPACITY ON THE EFFECTIVENESS OF COFFEE FRUIT GRADER

increases. It may be due to the fact that the slope influences the speed of travel of the fruits. The capacity ranged from 475 to 803 kg/h for the slope range of 0 to 5.7 per cent.

The maximum capacity of 803 kg/h is obtained for the ground slope of 5.7 per cent.

4.2.1.2 Effect of slope on overall effectiveness

The relation between the ground slope and the overall effectiveness of the grader is shown in Fig. 4.2. From the figure it can be inferred that the overall effectiveness decreases as the slope increases. The overall effectiveness is the highest at 0.41 for a ground slope of 0 per cent. When the ground slope is 5.7 per cent the overall effectiveness decreased to 0.25. At higher slopes, the retention time for the fruits on the sieves is less, resulting in non separation of the fruits in the sieve as per the size.

4.2.1.3 Effect of capacity on effectiveness

The relationship between the capacity of the grader and the corresponding overall effectiveness (Fig. 4.3) is negative. As the capacity of the grader increased due to the increase in the slope, the overall effectiveness decreased from 0.41 to 0.25. This may be due to the fact that at high capacities the purity of the separated products get affected causing a decrease in the overall effectiveness.

4.2.2 Grader fitted with 25 x 12 mm and 25 x 14 mm sieves

The grader was next fitted with 25 x 12 mm and 25 mm x 14 mm sieves and was evaluated at 0, 2, 3.7 and 4.9 per cent ground slopes for the overall effectiveness. The results of the trial can be seen from the Table 4.4.

4.2.2.1 Effect of slope on capacity

It can be seen from Fig. 4.1 that as the slope increases the capacity also increases. This is similar to the first set of sieves used. The maximum capacity of 1233 kg/h was obtained at a ground slope of 4.9 per cent. At a level ground (0%) the capacity was as low as 448.4 kg/h.

4.2.2.2 Effect of slope on overall effectiveness

The relation between the slope and the overall effectiveness (Fig. 4.2) showed encouraging results. In all cases an overall effectiveness of above 0.50 was realised. Between ground slopes of 2 and 3.7 per cent an overall effectiveness of about 0.64 was achieved. At a ground slope of 0 per cent the effectiveness was 0.60. As the slope increased beyond 3.7 per cent the effectiveness decreased which may due to the fact that the fruits fed tend to run over to the other end of the grader thus affecting the purity of the separated products.

4.2.2.3 Effect of capacity on overall effectiveness

From Fig. 4.2 it can be seen that as the capacity increases, the effectiveness increased initially and after reaching the maximum of 0.64 it begins to decrease rapidly. Hence if the grader is operated at a capacity between 650 and 900 kg/h the maximum effectiveness can be realised.

4.3 Evaluation of Pulper

The performance of the coffee pulper was evaluated at the Central Coffee Research Institute (CCRI), Balehonnur, Karnataka and the Coffee Demonstration Farm, Coffee Board, Yercaud. The pulper was operated at different speeds to evaluate for the pulping efficiency, separation efficiency, percentage of brokens, water requirement and capacity.

4.3.1 Evaluation of drum type power operated coffee pulper

The drum type coffee pulper was operated at 112 rpm and was tested with arabica fruits at the Central Coffee Research Institute, Balehonnur, Karnataka. The pulping efficiency was 98 per cent and the separation efficiency was 99.3 per cent. The optimum feed rate was found out to be 87 kg/h and the water required was 5.2 l/kg. When the fruits were pulped without water, the percentage broken was high. But at a feed rate of 87 kg/h and a water requirement of 5.2 l/kg, the percentage broken was 3.20 per cent.

The modifications required as seen from this trial were done as explained in section 3.3.1.1. The modified drum type pulper was further evaluated at Coffee Demonstration Farm, Yercaud.

When the drum type pulper was operated at 149 rpm, there was a marked increase in the separation efficiency and the pulping efficiency of the pulper. The separation and pulping efficiencies were both 100 per cent indicating that all the fruits fed into the pulper were pulped and also all the parchment and the skins came out of the pulper through their respective outlets. An interesting feature also noted was that even the leaves if fed came out through the skin outlet. Optimum conditions was achieved at a feed rate of 384 kg/h and at a water requirement of 0.60 l/kg. The per cent broken was 2.9 per cent.

Trials were done next at 373 rpm with an aim of increasing the feed rate, reducing the percentage broken and in reducing the water requirement without affecting the pulping and separation efficiencies. It was found that at a feed rate of 576 kg/h and a water requirement of 0.50 l/kg,

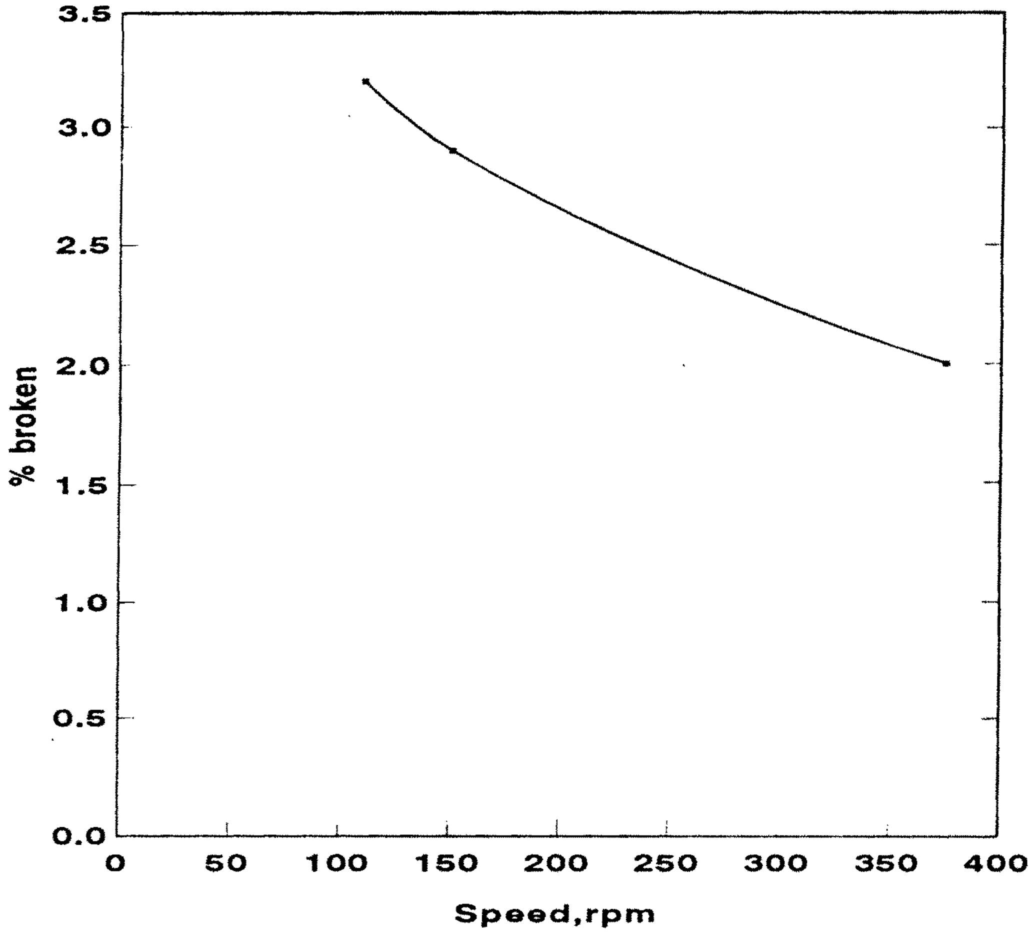


Fig.4.4. EFFECT OF SPEED OF THE DRUM ON THE PER CENT BROKEN IN DRUM TYPE PULPER

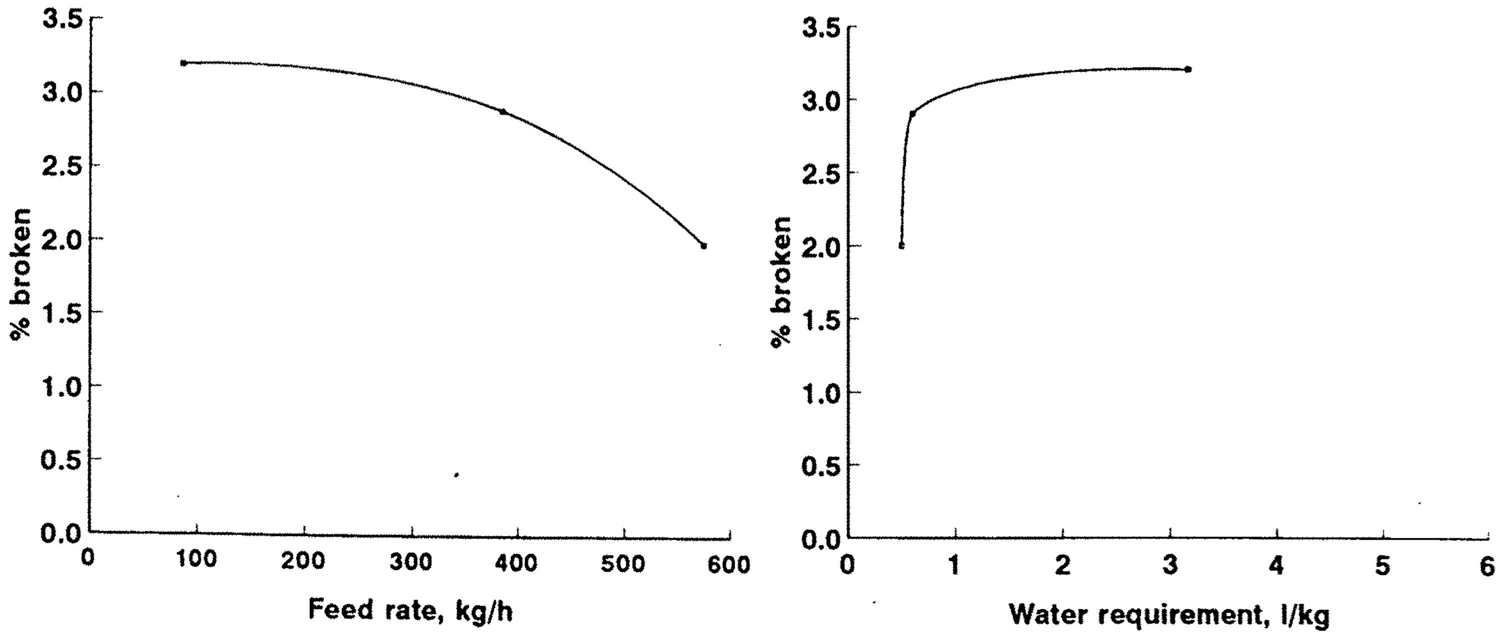


Fig.4.5 EFFECT OF FEED RATE AND WATER REQUIREMENT ON PER CENT BROKEN IN A DRUM TYPE PULPER

the percentage broken was 2.0 per cent. Both the pulping and separation efficiencies were 100 per cent. The performance of the pulper is given in Table 4.5.

Table 4.5. Evaluation of drum type power operated coffee pulper for arabica

Speed rpm	Feed rate kg/h	Water requirement l/kg	Percent broken %
112	87	5.20	3.20
149	384	0.60	2.90
373	576	0.50	2.00

It can also be seen from Fig.4.4 that as the speed of rotation increased the percentage of breakage decreased which is in contrast to the general belief that when the speed increases the incidence of breakage increases.

Fig.4.5 shows the relation between the feed rate and the percentage broken. It can be seen that as the feed rate increased the per cent broken decreased. The lowest percentage broken was achieved for a feed rate of 576 kg/h and the highest broken percentage was for a feed rate of 87 kg/h.

An abnormal relationship was noticed between the water requirement and the percentage broken (Fig.4.5). The highest broken percentage 3.20 per cent was obtained for a water requirement of 5.2 l/kg and the lowest broken percentage of 2.0 per cent was obtained for a water requirement of 0.5 l/kg. When the water requirement was about 0.6 l/kg the per cent broken obtained was between 2.0 per cent and 3.20 per cent.

4.4 Content of Mucilage

By following the method indicated in chapter III section 3.4.4, the average mucilage content in the arabica parchment was found to be 21.12 per cent.

4.5 Evaluation of Washers

The washing mechanisms developed were evaluated for their efficiency and breakage of beans. The trials were conducted at the central Coffee Research Institute, Balehonnur and the Coffee Demonstration Farm, Yercaud during December, 1996 and February, 1997. The results are discussed to optimize various parameters viz., speed, feed rate and water requirement with respect to the washing efficiency and breakage.

4.5.1 Model I - power operated screw auger brush type washer

The screw auger type washer was evaluated for its efficiency of washing for arabica fruits and per cent breakage. The trials were conducted at the Central Coffee

Research Institute, Balehonnur. This model was run at 186, 311 and 622 rpm speeds. The performance of the washer at 186 rpm speed was not satisfactory even though the outlet was choked. The maximum washing efficiency obtainable was 60 per cent. This indicated that a higher speed and more water are required . There was no brokens in this case indicating that virtually no friction was developed inside the washer.

When the speed was increased to 311 rpm, considerable washing occurred at a water flow of 3.5 l/min.

The next trial was conducted at 622 rpm speed. The results were similar to the washer run at 311 rpm. The washing efficiency obtained was about 85 per cent though the water requirement was infact high.

When robusta was used it was noted that virtually no washing occurred. The parchment coming out of the outlet had to be re-fed into the washer several times inorder to effect washing.

As this brush type washer was found to have a washing efficiency less than 85 per cent and the brush was found to have a lesser life, it was decided to use wooden reapers imbedded with brushes so that it can be easily replaced when worn. Also, the brush type washer resulted in a lesser percentage of brokens. So, it was decided to have a washing mechanism which used brushes as well as would be long lasting, results in lesser breakage to the beans and have a higher washing efficiency.

4.5.2 Model II-roller type washer

The roller type washer was evaluated for its performance using a combination of two out of the four rollers. The trials were conducted at the Central Coffee Research Institute, Balehonnur with arabica. First, the roller washer with a clearance of 5 mm between the inner roller shaft and the outer cover was used. The washer was tested at 173, 213 and 622 rpm speeds. At a speed of 173 rpm, the quantity of water required was high and the per cent broken was also very high. Hence the speed was increased to 213 rpm. At this speed also the washing caused high damage to the parchment and the washing was not perfect.

Hence, the detachable rollers were removed and twisted round rods of 10 mm diameter were welded on the main roller shaft. This increased the clearance between the inner roller shaft and the outer perforated cover. This roller washer was next tested at 173 and 213 rpm speeds. At both speeds the washing was not perfect, but the percentage broken was low. The speed was then increased to 622 rpm, the washing efficiency achieved was around 85 per cent and per cent broken was less than 8 per cent at a water requirement of 2 l/kg.

This roller washer was then modified by removing the welded rods and increasing the diameter of the outer cover. The clearance was thus increased to 20 mm when the detachable rollers were fitted. The modified roller washer was tested for its performance using arabica parchment.

4.5.2.1 Roller washer with both helical rollers at 126 rpm

The modified roller washer with an increased clearance was tested for its performance at the Coffee Demonstration Farm, Coffee Board, Yercaud. The two helical rollers were fitted to the main shaft and the washer was run at 126 rpm.

At 126 rpm, the feed rate was 384 kg/h.During the trials conducted using arabica, the highest washing efficiency of 91 per cent was observed at a water requirement of 1.2 l/kg. The per cent broken was rather high at 9.3 per cent at this water requirement.

The least washing efficiency of 64.5 per cent was observed when the water requirement was 0.6 l/kg and an efficiency of 66.7 per cent was observed when the water requirement was 3.6 l/kg. This indicated that a very high

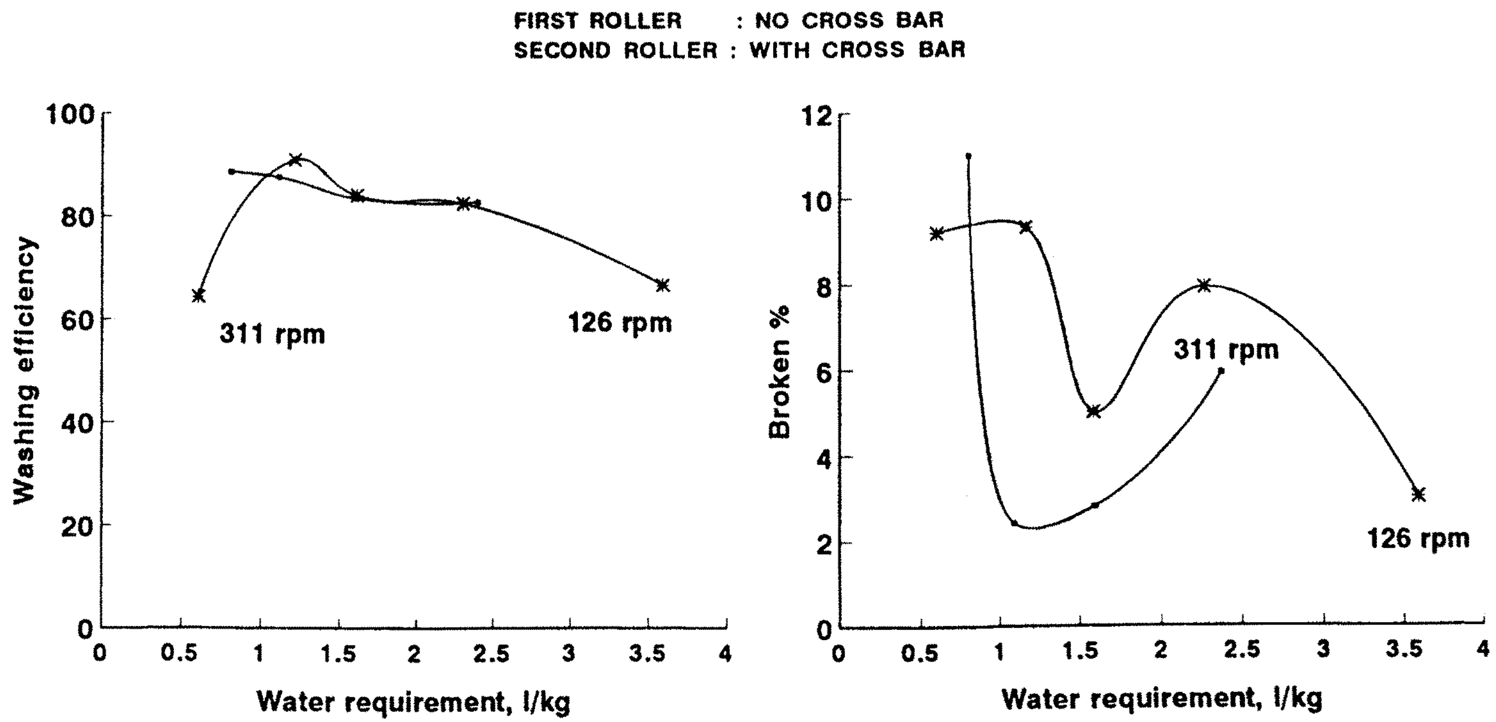


Fig.4.6 EFFECT OF WATER REQUIREMENT ON WASHING EFFICIENCY AND PERCENT BROKEN IN ROLLER TYPE WASHER FITTED WITH HELICAL ROLLERS

water requirement or at a very low water requirement resulted in inadequate washing. Water requirements of 1.6 l/kg and 2.3 l/kg resulted in efficiencies of 84.2 per cent and 82.6 per cent respectively.

The per cent breakage was least at 3.0 per cent when the water requirement was high, 3.6 l/kg and it gradually increased as the water requirement decreased. This indicated that a sufficient quantity of water was required to prevent breakage to the parchment during washing.

Fig. 4.6 indicates that as the water requirement increased the washing efficiency also increased gradually from 64.5 per cent to 91 per cent and then started to decrease from 91 per cent to 66.7 per cent.

Fig.4.6 indicated an abnormal relationship between the water requirement and the per cent broken. This may be due to the fact that the coffee fruits were not of uniform size and good quality due to the ending of the coffee season.

The performance of the helical roller washer at 126 rpm is presented in Table 4.6.

Table 4.6 Performance of roller washer with helical roller

Water requirement l/kg	Washing efficiency %	Percent broken %
Speed - 126 rpm; Feed rate - 384 kg/h		
3.6	66.7	3.0
2.3	82.6	7.9
1.6	84.2	5.0
1.2	91.0	9.3
0.6	64.5	9.2
Speed-311 rpm; feed rate - 576 kg/h		
2.4	82.9	5.9
1.6	83.6	2.8
1.1	87.7	2.4
0.8	88.7	11.0

4.5.2.2 Washer with both helical roller at 311 rpm

The washer was next tested at 311 rpm speed and a feed rate of 576 kg/h. The water requirements were 2.4, 1.6, 1.1 and 0.8 l/kg. The washing efficiency in all the cases was above 80 per cent and no choking was required at the outlet. The maximum washing efficiency of 88.7 per cent was achieved at a water requirement of 0.8 l/kg. The least washing efficiency achieved was 82.9 per cent at a water requirement of 2.4 l/kg.

In the case of per cent broken, the highest percentage of 11 per cent was obtained at a low water requirement of 0.8 l/kg. The least percentage of broken of 2.4 per cent and 2.8 per cent was achieved at water requirements of 1.1 l/kg and 1.6 l/kg respectively.

The performance of the washer at 311 rpm for arabica coffee is presented in Table 4.6.

The relation between the water requirement and the washing efficiency for the helical roller washer at 311 rpm is shown in Fig. 4.6. It can be seen that a nearly straight line relation was achieved.

Fig. 4.6 indicates the relation between the water requirement and the per cent broken. As seen in the case of the washer at 126 rpm speed, a highly abnormal relation can be observed at this speed also. As the water requirement increased the per cent broken decreased from a high of 11 per cent to a low of 2.4 per cent and gradually started to increase.

4.5.2.3 Washer with a helical roller with cross bars and fluted roller with cross bars at 126 rpm

This washer was tested at a feed rate of 384 kg/h and at water requirements of 2.3 l/kg, 1.6 l/kg and 1.2

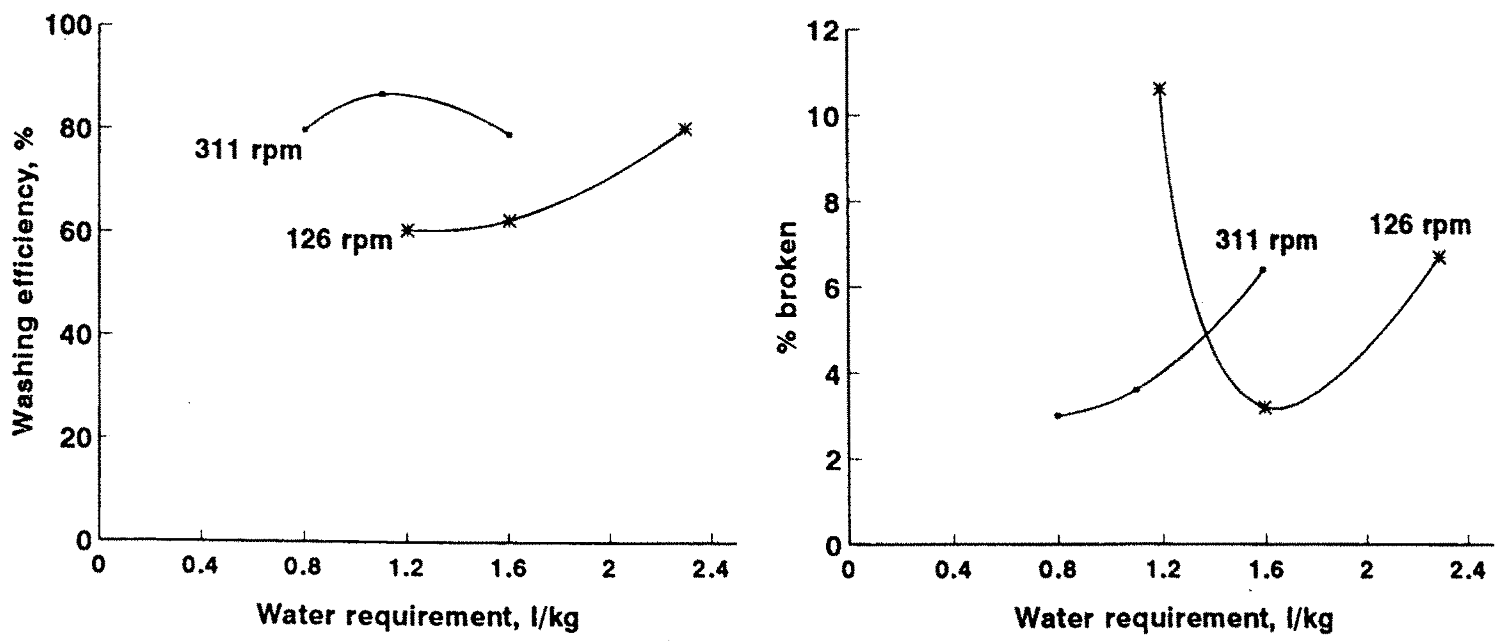


Fig.4.7 EFFECT OF WATER REQUIREMENT ON WASHING EFFICIENCY AND PERCENT BROKEN IN ROLLER WASHER FITTED WITH HELICAL AND HORIZONTAL ROLLERS WITH CROSS BARS

l/kg. The highest washing efficiency of 80.5 per cent was obtained at a water requirement or 2.3 l/kg. The lowest washing efficiency was of 60.7 per cent at a water flow rate of 1.2 l/kg. Choking at the outlet was also required. It can be seen that better washing was achieved when the water requirement was high.

The brokens percentage was high at 10.6 per cent for a water requirement of 1.2 l/kg. The least percentage of 3.2 per cent breakage was observed for a water requirement of 1.6 l/kg. The performance of this washer at 126 rpm and 311 rpm is shown in Table 4.7.

Fig. 4.7 indicates the relation between the washing efficiency and the water requirement at 126 rpm and 311 rpm. It can be seen that as the water flow rate increase the washing efficiency also increases.

In the relation between the water requirement and the per cent broken, it can be seen that the per cent broken decreases from a maximum value, reach a minimum and finally increase (Fig.4.7).

4.5.2.4 Washer with a helical roller having cross bars and fluted roller having cross bars at 311 rpm

The washer was fitted with a helical roller having cross bars followed by a fluted roller with cross bars. The speed of the washer was increased to 311 rpm and the feed rate increased to 576 kg/h. The water requirements were 1.6 l/kg, 1.1 l/kg and 0.8 l/kg. It was observed that only when sufficient choking was provided at the outlet, better washing was obtained. The maximum value of 87 per cent efficiency was obtained for a water requirement of 1.1 l/kg. At water requirements of 1.6 l/kg and 0.8 l/kg the washing efficiency was nearly the same at around 80 per cent.

In the case of per cent broken, the least value of 3.0 per cent was obtained at a water requirement of 0.8 l/kg.

The percentage broken steadily increased as the water requirement increased (Fig.4.7). The relation between the water requirement and the washing efficiency as shown in Fig. 4.7 indicates that as the water requirement increased the washing efficiency first increased to reach a maximum of 87 per cent at a water requirement of 1.1 l/kg and then gradually decreased to a low of 79.3 per cent at a water requirement of 1.6 l/kg.

Table 4.7 Performance of a roller washer with a helical roller having cross bars and fluted roller having cross bars for arabica

Speed rpm	Feed rate kg/hr	Water requirement l/kg	Washing efficiency	Percent broken %
126	384	2.3	80.5	6.7
		1.6	62.6	3.2
		1.2	60.7	10.6
311	576	1.6	79.3	6.4
		1.1	87.0	3.6
		0.8	80.0	3.0

4.5.2.5 Washer with both straight flutes at 126 rpm

The washer was next fitted with rollers which had straight flutes out of which one roller had cross bars also. The speed of rotation of the washer shaft was 126 rpm. The washer was evaluated at different water requirements. In all the cases the washing was inferior even though choking of the outlet was done. The parchment with mucilage fed into the washer was conveyed out of the washer without any washer. Hence the speed was increased.

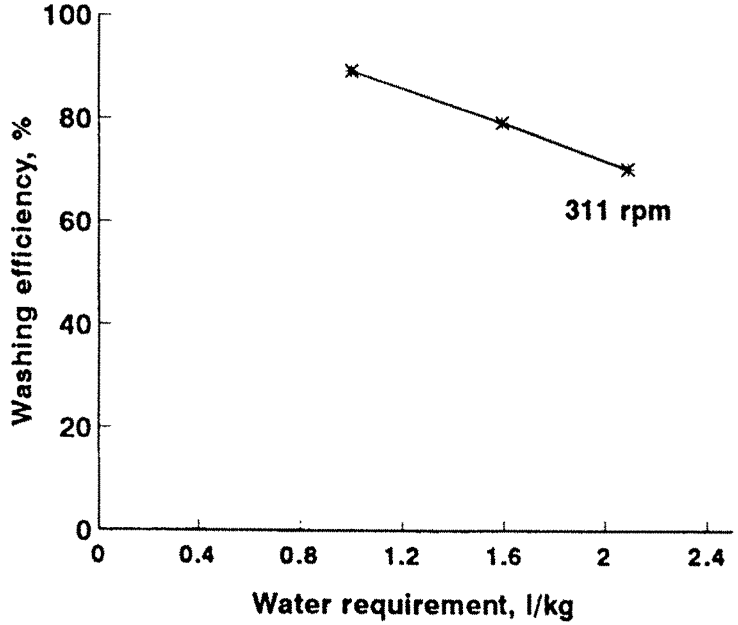
4.5.2.6 Washer with both straight flutes at 311 rpm

The washer fitted with straight flutes was next tested at 311 rpm (feed rate of 576 kg/h) at water requirements of 1 l/kg, 1.6 l/kg and 2.1 l/kg. Even without any choking at the outlet a washing efficiency of 79.3 per cent was achieved at a water requirement of 1.6 l/kg. This efficiency could be increased by choking the flow at outlet. When the water requirement increased to 2.1 l/kg the washing efficiency decreased to 70.4 per cent. This may be due to the fact that the increased water requirement increased the velocity of conveyance of the parchment inside the washer thus decreasing the retention time inside.

At a water requirement of 1 l/kg, the washing efficiency was only 52.3 per cent when mild choking was effected. On the other hand when the loading of the parchment at the outlet was increased by increasing the choking pressure by means of small weights, the washing efficiency increased to 89.3 per cent at the same water requirement of 1 l/kg. But an important fact to be noted was that the choking increased the incidence of breakage to the parchment. The per cent broken was high in the cases where choking was adopted.

The performance of this washer at 311 rpm is indicated in Table 4.8.

FIRST ROLLER : NO CROSS BAR
SECOND ROLLER : WITH CROSS BAR



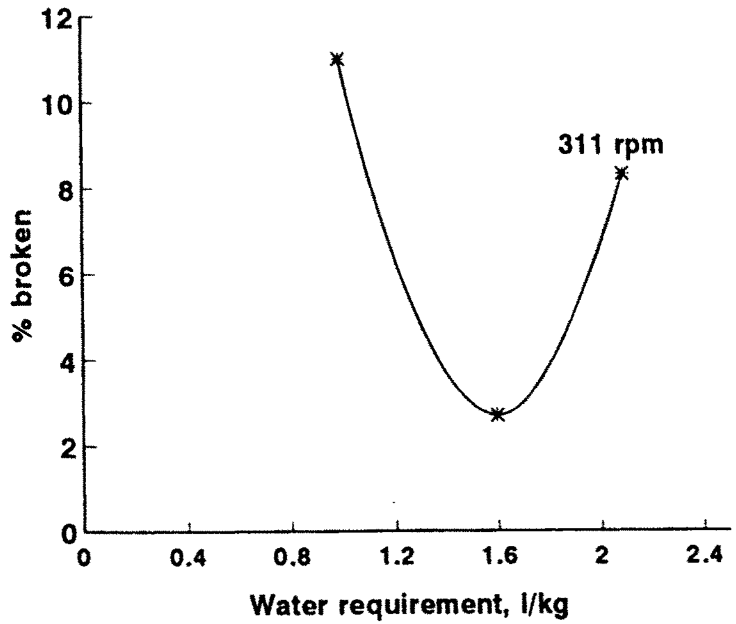


Fig.4.8 EFFECT OF WATER REQUIREMENT ON WASHING EFFICIENCY AND PERCENT BROKEN IN ROLLER WASHER FITTED WITH HORIZONTAL ROLLERS

Fig. 4.8 indicates a decreasing trend in the form of a straight line when the water requirement was increased. The washing efficiency was noted to decrease.

In the relation between the water requirement and the per cent broken, (Fig. 4.8) it can be seen that for a water requirement of 1 l/kg the per cent broken was high at 11 per cent and it decreased to 2.7 per cent for a water requirement of 1.6 l/kg. The curve then showed an upward trend when the water requirement increased to 2.1 l/kg.

Table 4.8 Performance of washer with both straight flutes at 311 rpm for arabica

Water requirement l/kg	Washing efficiency %	Percent broken %
2.1	70.4	8.3
1.6	79.3	2.7
1 (mild choking)	52.3	11
1 (Severe choking)	89.3	11

4.5.2.7 Roller washer fitted with nylon brush

The roller washer was next tried with a single roller at the feed end of the shaft followed by nylon brush on wooden reapers. It was desired to get a better washed parchment with less broken percentage in the case of nylon brush fitted washer. As there was no clearance between the brush and the outer perforated cover, and also as the wooden reapers were fixed horizontally, the parchment fed into the washer was not able to come out of the washer. This problem could be solved by providing a spiral arrangement of the brush instead of straight wooden reapers containing the brush.

4.6 Cost Economics of Rotary Grader

The grader developed had a total cost of Rs.5,600. The cost of grading one kilogram of coffee fruit works out to Rs. 0.02/kg. In the case of conventional method of grading about three labourers are required to grade 750 kg of fruit. So, the cost of operation incurred will be definitely high when we go for the conventional method of grading as the time required to grade 750 kg of fruit by three labourers is more than 3 hours while the rotary grader grades 850 kg of fruit in an hour. The details for the calculation of the cost and the cost of operation of the grader is given in Appendix G.

4.7 Comparison of Cost Economics

The cost of the modified pulper and the washer and their cost of operation in Rs/kg was calculated as given in

Appendix H. The cost of the pulper and the washer was found to be Rs. 22,000 and Rs. 23,000 respectively. If the pulper and washer are made as a single unit, the cost can be brought down to Rs. 34,500.

The cost of the pulper developed by T.Chellamuthu (1996) and of the washer developed by M.Madasamy (1996) at were Rs.21,000 and Rs.11,000 respectively. The life of the washer was only 5 years as the brush worn away whereas the life of the roller washer was 10 years due to its more durable components.

The cost of operation of these machines were high at Rs. 0.09/kg for the pulper and Rs. 0.96/kg for the washer. These values were higher than the values obtained for the newly developed mechanisms.

The cost economics of both the old and new pulping and washing mechanisms is given in Table 4.9.

The cost of operation and the total cost of the newly developed pulper and washer can be further reduced by combining the pulper and washer as a single unit.

Table 4.9 Comparison of cost economics

Machine	Total cost of unit Rs.	Capacity Kg/h	Cost of operation Rs/h	Rs/kg
1. Drum type pulper (Chellamuthu, 1996)	21,000	360	30.68	0.09
2. Drum type pulper modified in 1997	22,000	576	30.80	0.06
3. Brush type washer (Madasamy, 1996)	11,000	25	23.35	0.96
4. Roller washer developed in 1997	23,000	576	27.90	0.06

Summary and Conclusions

CHAPTER VI

SUMMARY AND CONCLUSION

Coffee is one among the chief foreign exchange earning commodities in India. Though India exports a large amount of coffee, quality wise the Indian Coffee is not internationally acclaimed to be of superior quality. Also, a huge amount of coffee is processed by the dry method of processing and hence is not exported. This is because more than 60 per cent of the coffee produced come from the category of small or medium planters.

The major problems faced by these small and medium planters are, the higher water required for pulping and washing of coffee which is scarce in the plantations in addition to the objection raised for letting the used water to mix with the natural streams and the higher cost of the existing machineries. These planters thus think it is not profitable to go in for wet method of coffee processing. With the price of coffee going up day by day, it is imperative to develop a suitable coffee pulper-cum-washer with a low water requirement, low cost and a capacity suited for small and medium planters inorder to encourage these planters to go for wet processing of their product.

In the development of these mechanisms, the physical properties of the wet arabica parchment with mucilage like size, bulk density, crushing strength and the co-efficient of kinetic friction are involved.

The size of the arabica parchment was determined using a vernier caliper. The length, width and thickness were determined and the average values were reported. The bulk density was determined by finding the ratio between the weight and the volume of the parchment. The crushing strength of the parchment was determined using KIYA grain hardness tester. The kinetic co-efficient of friction was determined using a setup designed for this purpose with provisions for varying the normal load and speed of rotation of the disc and with suitable instrumentation for measuring the power and normal load.

A hand operated rotary grader was fabricated to grade the harvested coffee fruits into three grades. The grader consisted a set of rotary sieves, mounted on a frame and rotated by means of a handle.

The drum type pulper which was developed by Chellamuthu (1996) was modified to improved its performance. A feed roller was provided in the feed hopper to overcome the problem of choking. The pupler drum was also renewed with a new dimple sheet and the plummer block type bearings were replaced with pillow block type bearings.

A brush type washer consisting of a roller provided with screw auger and nylon brush, outer cylinder with perforations, feed hopper, outlet with closing mechanisms and motor was fabricated and tested.

A power operated roller type washer consisting of mild steel detachable rollers of different surface configurations, inner cylinder with screw, outer cylinder with perforations, feed hopper and outlet was fabricated and evaluated for its performance. The same roller washer was again evaluated by removing one detachable roller and fixing in its place wooden reapers having nylon brushes. This washer was also tested.

The pulper and washer were combined as a single unit by mounting them on a common frame. Their efficiencies, water requirements and the percentage broken were determined.

The cost economics of the fabricated units was worked out and was compared with the already existing units.

The results of the various experiments conducted are summarised as below.

The average length, width and thickness of the arabica parchment with mucilage are 11.2 mm, 8.49mm and 5.47mm respectively. The average bulk density of the partially fermented arabica parchment with mucilage was found out to be 487.3 kg/m^3. At a load of 0.37 N cracks begin to appear on the surface of the parchment and complete failure of the parchment occurred at 0.97 N.

The test of the kinetic co-efficient of friction of the parchment with mucilage against mild steel and cast iron surfaces yielded an average value of 0.09 for mild steel and 0.20 for cast iron. Statistical analysis shows that the friction co-efficient was not significant with the speeds of rotation of the disc.

When the grader was fitted with 24mm x 10mm and 25 mm x 12 mm sieves the maximum overall effectiveness of the grader was 0.41 for the ground slope of 0 per cent. It was found that as the capacity of the grader increased, the overall effectiveness decreased.

The grader fitted with 25mm x 12mm and 25mm x 14mm sieves, gave a maximum overall effectiveness of 0.64 at a ground slope between 2 and 3.7 per cent.

The modified drum type pulper gave the highest pulping and separation efficiencies of 100 per cent at a speed of 373 rpm and water requirement of 0.5 l/kg. The percentage broken was also the least at 2 per cent. As the speed of rotation of the pulper decreased, the per cent broken increased and also the water required to pulp one kilogram of fruits increased.

The screw auger brush type washer did not give satisfactory results. The maximum washing efficiency obtained was 85 per cent for arabica at a speed of 622 rpm. The water required was high but the per cent broken was very less.

The roller washer was tested with different combinations of the four detachable rollers. When the roller washer was fitted with a helical roller and a helical roller having cross bars, the highest washing efficiency was obtained. At a speed of 126 rpm and water requirement of 1.2 l/kg an efficiency of 91 per cent was obtained in this washer. But the per cent broken was high (9.3%). At a speed of 311 rpm this washer had a washing efficiency of above 80 per cent at different water requirements.

When the roller washer was fitted with brushes, the coffee parchment did not come out of the washer. This was due to the fact that there was no clearance between the brush and the outer perforated sheet and because the brushes were fixed in a horizontal manner on the surface of the roller.

The performance of all the washers when tested with robusta fruits was not satisfactory. More modifications and improvements were required in this aspect.

From the present work as summarised above the following conclusions were drawn.

1. The average values of the length, width and thickness of the arabica parchment with mucilage were 11.20mm, 8.49mm and 5.47mm respectively. The bulk density of the arabica parchment with mucilage after partial fermentation was found to be 487.3 kg/m^3 and the strength of the parchment against crushing was found to be 0.97 N.

2. The kinetic cofficient of friction for the parchment with mucilage against a cast iron surface was found to be higher than against a mild steel surface. The average values for the kinetic co-efficient of friction against cast iron and mild steel were 0.20 and 0.09 respectively.

3. The hand operated rotary grader had a maximum overall effectiveness of 0.64 at a slope range of 2

to 3.7 per cent when fitted with 25mm x 12mm and 25mm x 14mm sieves.

4. The modified drum type pulper gave a pulping efficiency and separation efficiency of 100 per cent when the speed of rotation was 373 rpm and the water requirement was 0.5 l/kg. The per cent broken decreased as the speed of rotation increased.

5. The screw auger brush type washer gave a maximum washing efficiency of 85 per cent at a speed of 622 rpm. The per cent broken was very less.

6. The roller washer fitted with a helical roller and a helical roller having cross bars performed well. At a speed of 126 rpm and a water requirement of 1.2 l/kg the highest washing efficiency of 91 per cent was obtained for arabica.

7. The cost of operation of the developed pulper-cum-washer was worked out to be Rs. 0.06/kg of fruits.

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Appendices

APPENDIX A

Size of arabica fruits

Length mm	Width mm	Thickness mm
10.78	7.76	5.22
10.70	9.22	5.30
11.18	7.66	5.10
10.70	8.98	5.40
12.36	8.74	5.22
12.20	9.10	4.92
11.40	7.96	5.12
11.60	8.64	6.88
10.76	9.30	5.84
11.14	8.76	6.46
12.24	9.06	5.20
12.10	7.58	4.16
9.80	7.80	6.10
9.90	8.30	5.70
11.20	9.02	5.82
12.24	8.62	6.02
10.70	7.76	6.26
11.20	7.80	5.22
11.18	8.60	5.82
10.80	9.12	5.18
10.48	9.22	4.40

Length mm	Width mm	Thickness mm
11.14	9.22	4.62
12.36	8.42	5.24
10.70	8.12	5.16
11.20	7.50	6.44
Mean = 11.20mm	8.49mm	5.47mm
(0.72)	(0.62)	(0.67)

APPENDIX B

Bulk density of arabica parchment with mucilage

Weight of fruits $\times 10^{-3}$ kg	Volume of fruits $\times 10^{-6}$ m^3	Bulk density kg/m^3
102.79	209.85	489.80
102.04	209.85	486.30
102.58	209.85	488.80
102.94	209.85	490.50
100.98	209.85	481.20
102.64	209.85	489.10
101.94	209.85	485.80
102.32	209.85	487.60
100.96	209.85	481.10
103.43	209.85	492.90
	Mean =	487.3 (5.05)

Crushing strength of arabica parchment with mucilage

Load at which cracks appear N	Load at which complete failure occurs N
0.39	0.92
0.35	1.02
0.37	0.96
0.37	1.05
0.38	0.92
0.39	1.04
0.35	0.94
0.32	0.96
0.38	0.95
0.40	0.93
Mean = **0.37** (0.024)	**0.97** (0.017)

The values in the parenthesis are the standard deviation.

APPENDIX C

Kinetic coefficient of friction
disc diameter = 86 mm

i) against mild steel

Speed rpm	linear speed M/S	Normal load N	Power watts	Power H.P. $\times 10^{-3}$	Torque N-M	Tangential load N	Friction coefficient (μ)	Mean (μ)	S.D.
190	0.86	0.66	2.5	3.35	12.6	0.03	0.0450		
		1.17	7.5	10.05	37.9	0.09	0.0766		
		1.89	12.5	16.80	63.3	0.15	0.0790	0.091	0.036
		2.04	22.5	30.16	113.7	0.27	0.132		
		2.45	25.0	33.50	126.3	0.30	0.123		
235	1.06	0.710	5.0	6.70	20.42	0.05	0.068		
		1.330	15.0	20.10	61.26	0.15	0.110		
		1.830	17.50	23.46	71.50	0.17	0.092	0.112	0.035
		2.450	33.50	43.60	132.88	0.31	0.129		
		2.750	45.0	60.30	183.77	0.44	0.159		
310	1.40	0.61	5.0	6.70	15.48	0.03	0.061		
		1.43	10.0	13.40	30.96	0.07	0.052		
		1.83	15.0	20.10	46.44	0.11	0.061	0.087	0.046
		2.24	30.0	40.20	92.87	0.22	0.10		
		2.75	60.0	80.43	185.82	0.45	0.163		
400	1.80	0.51	7.5	10.05	18.00	0.04	0.084		
		0.82	12.5	16.75	30.00	0.07	0.087		
		1.12	17.5	23.46	42.00	0.10	0.089	0.0881	0.0027
		1.73	27.5	36.86	66.00	0.16	0.090		
		2.04	32.5	43.60	78.07	0.18	0.0905		
570	2.60	1.43	40.0	67.40	84.68	0.16	0.112		
		1.73	45.0	75.80	95.24	0.18	0.104		
		2.04	60.0	101.05	126.97	0.24	0.118	0.109	0.0065
		2.34	62.5	105.30	132.31	0.25	0.107		
		2.65	67.5	113.70	142.86	0.27	0.102		

Speed rpm	linear speed M/S	Normal load N	Power watts	Power H.P $\times 10^{-3}$	Torque N-M	Tangential load N	Friction coefficient (μ)	Mean (μ)	S.D.
610	2.75	0.61	15.0	120.1	23.60	0.06	0.092		
		0.81	20.0	26.8	31.47	0.07	0.091		
		1.01	25.0	33.5	39.33	0.09	0.0914	0.0904	0.0025
		1.43	35.0	46.9	55.07	0.13	0.0914		
		1.73	40.0	53.6	62.93	0.15	0.086		
750	3.38	0.71	17.5	22.4	21.39	0.05	0.074		
		1.01	20.0	25.6	24.45	0.06	0.060		
		1.33	25.0	32.0	30.56	0.08	0.057	0.057	0.0096
		1.63	27.5	35.20	33.61	0.08	0.051		
		2.04	30.0	38.40	36.67	0.09	0.045		
					overall mean, μ =		0.0906		
					S.D. =		0.029		

APPENDIX D

ii) against cast iron, disc diameter = 86mm

Speed rpm	linear speed M/S	Normal load N	Power watts	Power H.P. $x10^{-3}$	Torque N-M	Tangential load N	Friction coefficient (μ)	Mean (μ)	S.D.
180	0.81	1.12	25.0	33.5	133.30	0.32	0.28		
		1.43	27.5	36.9	146.82	0.35	0.24		
		1.73	30.0	40.2	159.95	0.38	0.22	0.233	0.029
		2.04	35.0	47.0	187.0	0.44	0.217		
		2.75	45.0	60.3	239.93	0.57	0.206		
225	1.01	0.71	15.0	20.10	63.98	0.15	0.21		
		1.02	17.5	23.46	74.68	0.18	0.174		
		1.22	20.0	27.0	85.94	0.20	0.167	0.173	0.021
		1.43	22.5	30.10	95.81	0.23	0.160		
		1.63	25.0	33.50	106.63	0.25	0.156		
310	1.40	1.63	37.5	80.9	186.90	0.49	0.30		
		1.94	52.5	70.4	162.65	0.39	0.20		
		2.14	57.5	77.07	178.06	0.42	0.197	0.210	0.052
		2.45	62.5	80.38	185.70	0.46	0.188		
		2.85	65.0	87.10	201.23	0.48	0.167		
390	1.76	3.06	85.0	114.00	209.35	0.50	0.162		
		3.47	95.0	126.00	231.39	0.55	0.159		
		3.77	102.5	137.00	251.59	0.60	0.158	0.160	0.0016
		4.08	112.5	152.00	279.13	0.66	0.161		
		4.38	12.0	161.00	295.66	0.70	0.161		
550	2.50	0.71	30.0	39.00	50.78	0.12	0.170		
		0.91	35.0	46.00	59.90	0.15	0.159		
		1.94	75.0	103.00	134.12	0.32	0.164	0.145	0.0083
		2.24	97.5	131.00	170.59	0.41	0.181		
		2.65	110.0	147.00	191.42	0.46	0.172		

Speed rpm	linear speed M/S	Normal load N	Power watts	Power H.P $\times10^{-3}$	Torque N-M	Tangential load N	Friction coefficient (μ)	Mean (μ)	S.D.
610	2.75	0.71	37.5	49.0	57.53	0.13	0.188		
		1.12	60.0	78.0	91.58	0.22	0.193		
		1.43	70.0	96.0	112.71	0.27	0.187	0.1866	0.0045
		1.94	95.0	126.0	147.93	0.35	0.181		
		2.24	110.0	148.0	173.77	0.41	0.184		
737	3.32	0.82	52.5	70.40	68.41	0.16	0.20		
		1.33	117.5	157.50	153.05	0.36	0.27		
		1.53	127.5	170.90	166.08	0.39	0.26	0.23	0.033
		1.83	130.0	174.30	169.38	0.40	0.22		
		2.04	135.0	180.96	175.85	0.42	0.20		

Overall mean, μ = 0.195

SD = 0.037

APPENDIX E

Performance of grader fitted with 24mm x 10mm and 25mm x 12mm sieves

Total weight of feed =14.5 kg

Slope %	Sieve size mm	Weight fraction in feed (W_i) kg	Fraction of feed in product outlet (Q_i) kg	Fraction of undesirable size available in product outlet (q_i) kg	Fraction of each size (a_i)	Purity (P_i)	Fraction yield (Fr_i)	Degree of extraction (Ex_i)	Overall effectiveness (E)	Capacity Kg/hr
0	10	1.85	1.95	0	0.128	1.0	0.134	1.05		
	10/12	4.95	4.05	0.95	0.341	0.765	0.280	0.630	0.405	474.50
	12	7.70	8.50	3.55	0.531	0.582	0.586	0.642		
2.60	10	1.85	1.60	0	0.128	1.0	0.110	0.860		
	10/12	4.95	4.25	1.05	0.341	0.753	0.293	0.650	0.294	497.14
	12	7.70	8.65	4.05	0.531	0.532	0.597	0.600		
4.30	10	1.85	1.97	0	0.128	1.0	0.136	1.06		
	10/12	4.95	4.10	1.05	0.341	0.744	0.283	0.620	0.284	614.10
	12	7.70	8.43	4.13	0.531	0.510	0.581	0.560		
5.70	10	1.85	1.75	0	0.128	1.0	0.121	0.95		
	10/12	4.95	4.95	1.90	0.341	0.62	0.341	0.620	0.25	803.10
	12	7.70	7.80	3.75	0.531	0.52	0.538	0.525		

Performance of grader fitted with 25mm x 12mm and 25mm x 14mm sieves

Total weight of feed = 13.7 kg

Slope %	Sieve size mm	Weight fraction in feed (W_i)kg	Fraction of feed in product outlet (Q_i)kg	Fraction of undesirable size available in product outlet(q_i)kg	Fraction of each size (a_i)	Purity (P_i)	Fraction yield (Fr_i)	Degree of extraction (Ex_i)	Overall effectiveness (E)	Capacity Kg/hr
0	12	9.35	7.30	0	0.682	1.000	0.533	0.78	0.604	448.40
	12/14	4.10	5.10	3.0	0.300	0.410	0.372	0.51		
	14	0.25	1.30	1.10	0.018	0.154	0.095	0.81		
2.0	12	9.35	6.70	0	0.682	1.000	0.490	0.72	0.64	657.60
	12/14	4.10	5.10	2.35	0.300	0.539	0.372	0.67		
	14	0.25	1.90	1.60	0.018	0.158	0.138	0.21		
3.7	12	9.35	6.75	0	0.682	1.000	0.493	0.72	0.64	896.70
	12/14	4.10	5.50	2.70	0.300	0.510	0.401	0.68		
	14	0.25	1.45	1.10	0.018	0.241	0.106	1.42		
4.9	12	9.35	6.50	0	0.682	1.00	0.474	0.695	0.53	1233.00
	12/14	4.10	5.00	3.20	0.300	0.36	0.365	0.440		
	14	0.25	0.20	1.85	0.018	0.16	0.161	1.420		

APPENDIX F

Performance of roller washer

Total weight of mucilage present in 100 g of parchment with mucilage = 21.12 g

Water requirement l/kg	Weight of mucilage removed g	Weight of parchment+ mucilage g	Weight of parchment after fermentation, g	Weight of good parchment, g	Weight of brokens g	% broken	Washing efficiency %
a) Both helical rollers, 126 rpm, 384 kg/h							
3.6	14.08	85.92	78.88	76.48	2.40	3.0	66.7
2.3	17 45	82.55	78.88	72.63	6.25	7.9	82.6
1.6	17.79	82.21	78.88	74.97	3.91	5.0	84.2
1.2	19.22	80.78	78.88	71.56	7.32	9.3	91.0
0.6	13.63	86.37	78.88	71.62	7.26	9.2	64.5
b) Both helical rollers, 311 rpm, 576 kg/h							
2.4	17.5	82.50	78.88	74.25	4.63	5.9	82.9
1.6	17.66	82.34	78.88	76.68	2.20	2.8	83.6
1.1	18.52	81.48	78.88	76.97	1.91	2.4	87.7
0.8	18.74	81.26	78.88	70.20	8.68	11.0	88.7

Water requirement 1/kg	Weight of mucilage removed g	Weight of parchment+ mucilage g	Weight of parchment after fermentation, g	Weight of good parchment, g	Weight of brokens g	% broken	Washing efficiency %
c) Both helical roller and horizontal roller having cross bars, 311 rpm, 576 kg/h							
1.6	16.75	83.25	78.88	73.81	5.07	6.4	79.3
1.1	18.37	81.63	78.88	76.02	2.86	3.6	87.0
0.8	16.89	83.11	78.88	76.54	2.34	3.0	80.0
d) Both helical roller and horizontal roller having cross bars, 126 rpm, 384 kg/h							
2.3	16.99	83.01	78.88	73.57	5.31	6.7	80.5
1.6	12.22	86.78	78.88	76.34	2.54	3.2	62.6
1.2	12.81	87.19	78.88	70.52	8.36	10.6	60.7
e) Both horizontal rollers, 311 rpm, 576 kg/h							
2.1	14.87	85.13	78.88	72.33	6.55	8.3	70.4
1.6	16.74	83.26	78.88	76.79	20.09	2.7	79.3
1.0 (Mild-choking)	11.05	88.95	78.88	70.18	8.70	11.0	52.3
1.0 (Severe choking)	18.86	81.14	78.88	70.23	8.65	11.0	89.3

APPENDIX G

Cost Economics of Rotary Grader

Component	Materilal	Unit cost Rs.	Total Cost Rs.
i) Punched sheet	Mild steel	1003.5/sheet	1003.50
ii) Bearings			1240.00
iii) Feed trough	Mild steel	1300/sheet	166.20
iv) Supporting rings	Mild steel	1400/sheet	22.00
v) Outlets	Mild steel	1300/sheet	1035.95
vi) Stand	L-angle (38x38x3mm)	16.5/kg	162.00
vii) Nuts and bolts		22/kg	22.00
vii) Miscellaneous			75.00

Total cost of material		Rs.	3,726.65
Labour charges at the rate of 1/3 of cost of material	=	Rs.	1,242.20
Overhead charges at the rate of 15 percent of cost of material	=	Rs.	559.00
Total cost of the unit	=	Rs.	5,528.00
	=	Rs.	5,600.00

I Fixed cost

i) Depreciation (5 years)	=	Rs.	995.04
ii) Interest at 12 per cent per annum	=	Rs.	276.40
iii) Repair and maintenance at 10% of initial cost	=	Rs.	552.80
iv) Tax and insurance at 2% of initial cost	=	Rs.	110.56
Total fixed cost	=	Rs.	1,935.00

Cost of grading per hour	=	Rs.	3.87/h
II Variable cost			
i) Labour charges	=	Rs.	15.00/h
Cost of operation			
Total cost of operation/h	=	Rs.	18.87/h
The capacity of the grader	=	Rs.	850 kg/h
Cost of grading of one kilogram of fruit	=	Rs.	0.02/kg

APPENDIX H

Cost Estimation of Developed Pulper and Roller Washer

a) Modified Drum type Pulper

Component	Material	Unit cost Rs.	Total Cost Rs.
i) Hopper	Mild steel	1300/sheet	145.88
ii) Pulper	Mild steel dimple sheet	1400/sheet 1000/sheet	102.60 75.00
iii) Bearings (Pillow block-type)	-	-	1240.00
iv) Breast plate	Cast iron	-	1500.00
v) Stand	L-angle (38x38x3mm)	16.5/kg	227.00
vi) 3 HP motor with cable	-	-	5550.00
vii) 5 HP Gear box	-	-	4600.00
viii) Feed roll	Mild steel flat Pipe	1400/sheet	25.50 10.00
ix) Pulleys (10inch, 5inch, 6inch, 4.5 inch)	-	-	530.00
x) Nuts, bolts	-	22/Kg	22.00
xi) Miscellaneous	-	-	200.00
	Total cost of materials Rs.		14,230.00
Labour charges at the rate of 1/3 of cost of materials		= Rs.	4,743.00
Overhead charges at the rate of 15 percent of cost of materials		= Rs.	2,134.50
Total cost of the unit		= Rs.	21,108.00
		= Rs.	22,000.00

I Fixed cost

i) Depreciation = $\frac{21,107.50 - 2,110.75}{5}$

= Rs. 3,800.00

ii) Interest at 12% per annum = Rs. 1,055.40

iii) Repair and maintenance at 10% of initial cost = Rs. 2,110.75

iv) Tax and insurance at 2% of initial cost = Rs. 422.15

Total fixed cost = Rs. 7,388.30/year

= Rs. 14.80/h

II Variable cost

i) Labour charges = Rs. 15.00/h

ii) Electric charges @ 2.50/kwh for 2kw/h = Rs. 5.00/h

Total = Rs. 20.00/h

Cost of operation

Total cost of operation/h = Rs. 34.80/h

The capacity of the pulper = 576 kg/h

Cost of pulping one kilogram of fruit = Rs. 0.06 kg

b) Roller washer with helical rollers

Component	Material	Unit cost Rs.	Total Cost Rs.
i) Hopper	Mild steel	1300/sheet	45.15
ii) Main shaft	Seamless pipe (126mm dia)		1250.00
iii) Rollers	Seamless pipe (140mm diameter)		850.00
iv) Over perforated sheet	Mild steel	900/sheet	49.00
v) 10mm diameter rods	Mild steel	20/m	52.00
vi) Screw augur	Mild steel	1400/sheet	16.70
vii) Water pipe, nozzles, regulator	-	-	150.00
viii) Bearings	-	-	1,240.00
ix) Pulleys with belt	-	-	825.00
x) 3 HP Motor with cable	-	-	5500.00
xi) 5 HP Gear box	-	-	5000.00
xii) Stand	L-angle (38mmx38mmx3mm)	16.5/Kg	118.80
xiii) Nuts and bolts	-	22/kg	22.00
xiv) Miscellaneous	-	-	250.00
Total cost of material		= Rs.	15,370.00

Labour charges at the rate of 1/3 of cost of material	= Rs.	5,123.00
Overhead charges at the rate of 15 percent of cost of material	= Rs.	2,305.50
Total cost of the unit	= Rs.	22,798.50
	= Rs.	23,000.00

I Fixed cost

i) Depreciation (10 years)	= Rs.	2,051.90
ii) Interest at 12 per cent per annum	= Rs.	1,140.00
iii) Repair and maintenance at 10% of initial cost	= Rs.	2,279.85
iv) Tax and insurance at 2% of initial cost	= Rs.	456.00
Total fixed cost	= Rs.	6000 / year
	= Rs.	12.00/h

II Variable cost

i) Labour charges	= Rs.	15.00/h
ii) Electric charges @ Rs. 2.50/kwh for 2kw/h	= Rs.	5.00/h
Total variable cost	= Rs.	20.00/h

Cost of operation

Total cost of operation/h	= Rs.	32.00/h
The capacity of the washer	= Rs.	576 Kg/h
Cost of washing one kilogram of fruit	= Rs.	0.06/kg