Development of an Oil Recovery Mechanism for Extraction of High Quality Oil from Processed Water of DC Mills

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ABSTRACT

Sri Lanka is the second largest producer of desiccated coconut (DC) in the world. A typical factory with a daily capacity of 50,000 nuts discharges 40,000 to 60,000 litres of wastewater per day. The high fat content of the wet processed water is the major environmental problem caused by the DC millers. A pilot scale system for recovery of high quality coconut oil from the DC processed water was developed aiming at the reduction of the environmental problems. The oil recovery system consists of four main successive sections. The first one included collection of wet processed water into a collection tank using PVC gutters and pipes. The second stage was separation of coconut milk (light cream) with 30% fat content and aqueous phase with 0.5% fat content using a gravity separation tank made of stainless steel. Third section of the system was concentration of the light cream and producing a thick cream containing 50% oil and 30% moisture. In the last stage, the thick cream was heated in a steam jacketed kettle using steam as the heating medium at 100±2 °C under different time periods to break the emulsion. The results showed that heating duration of 2 ½ hrs represented the most effective extraction conditions with an oil yield of 8 L from 20 L of concentrated thick cream.

Moisture content, colour, saponification value and iodine value of the extracted oil were 0.12%, 0.7 (Y+5R), 262 and 10 respectively. The result of the gas chromatography analysis showed that the oil contains high lauric acid content (46.03%). Evaluation of shelf life for 2 ½ months showed an increase in free fatty acid content from 0.2% to 0.28% and peroxide value from 0.9 to 2 (ml of 0.002 N sodium thiosulphate per one gram of oil). The results of sensory evaluation revealed that the extracted oil is acceptable for edible purposes. The technique for recovering oil from DC wet processed water is a significant improvement in profitability over the traditional method.

Key words: *Centrifugation, coconut oil, desiccated coconut processed water, gravity separation*

INTRODUCTION

Sri Lanka has about 50 desiccated coconut (DC) mills that process about 300 million nuts per year. Desiccated coconut production involve a number of steps, such as seasoning of fresh coconut, dehusking, deshelling, paring & splitting, washing and inspection, pasteurizing, size reduction and steam sterilization, drying, screening , grading and packaging. From each batch of operation, a large volume of liquid waste is generated due to the release of coconut water and process water from certain unit operations. A typical factory processes 50,000 nuts in its daily capacity and discharges around 40,000-60,000 L of waste water per day.

The process water from the DC mills is rich in organic matter. As a result, it often leads to a serious environmental problem faced by the most of DC millers. At present, DC mill effluent is arranged to pass through a series of tanks in the ground for treatment. In this method, poor quality oil is recovered from the scum layer separated at the top of the tanks. This kind of oil is unsuitable for edible purposes and mostly used as a lubricant in the manufacture of tiles. In this traditional method, significant oil content remains in the influent stream and inhibits microbial activity that degrades organic matter. Therefore, it is necessary to develop a mechanism to recover high quality coconut oil from DC processed water minimizing environmental pollution and overcoming above disadvantages.

MATERIALS AND METHODS

Location

This study was conducted at the Coconut Processing Research Division (CPRD) of the Coconut Research Institute (CRI), Lunuwila, Sri Lanka in collaboration with Baduwatte DC mill at Katana.

Materials

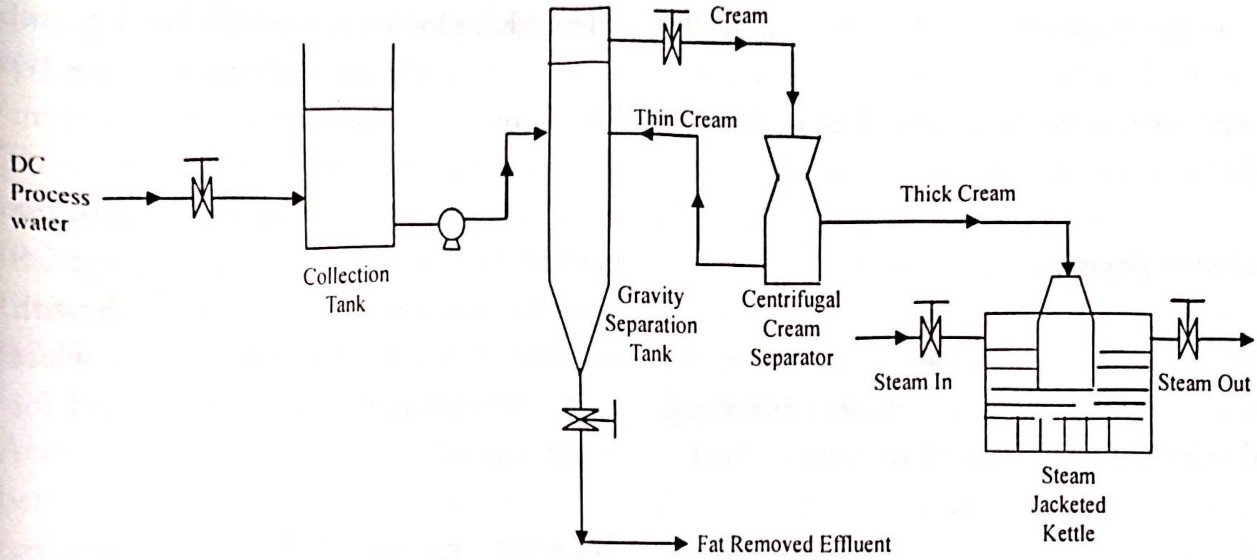
Desiccated coconut (DC) process water was collected from Baduwatte DC mill at katana. All the chemicals used are of analytical grade unless otherwise specified. All the instruments used in this study were made available at the CPRD, CRI, Lunuwila.

Coconut oil sample was bought from market and "Majan" oil sample (Oil extracted from DC process water by traditional method) was bought from Katana DC mill.

METHODS

Fabrication of the oil recovery system

The major components of the oil recovery system were collection tank, gravity separation tank, centrifugal cream separator and steam jacketed kettle. Collection tank was in cylindrical shape & fabricated using stainless steel (Grade 304). Capacity of the tank was 3000 L per batch. A gravity separation tank



Laboratory-scale experimental set-up of oil recovery system for DC wet process water

with 2000 L capacity was fabricated using Grade 304 SS and a small scale centrifuge used in domestic dairy industry having feeding capacity of 60 L/hr was used to concentrate the collected coconut milk. A 25 L capacity steam jacketed stainless steel kettle was fabricated.

Selection of the optimum heating time period for oil extraction

Coconut oil was extracted at different time periods using steam jacketed kettle to find out the best heating time period to extract coconut oil with minimum moisture content & minimum oil discoloration. Extracted oil samples were analyzed for moisture & colour.

Determination of quality parameters

(1) Moisture content and Colour of extracted oil was determined according to the Sri Lanka Standard (SLS 313:2001).

(2) Iodine value, Saponification value and free fatty acid content of extracted oil were determined according to the Sri Lanka Standard (SLS 32:1979).

(3) Peroxide value of extracted oil was determined according to the procedure adopted by Pearson (1973).

(4) Fat content of the processed water streams resulted from each unit operation in the developed system was analyzed according to Pearson's (1973) method.

Shelf life evaluation

The oil was analyzed for free fatty acid content and peroxide value at the ambient condition for three months at two weeks intervals.

Sensory evaluation

Sensory evaluation was carried out to test the organoleptic properties of the oil. The sensory attributes such as color, aroma, texture & overall acceptability were evaluated by using 30 semi trained panelists. The test samples were given a score 1 to 5 (1-Extremely dislike, 5- Extremely like). Ballet paper was used to get responses from the panel members.

Samples prepared from homogenous lot by identical method were coded according to 3 digit cording system & served on white color plates at room temperature.

Cost analysis

The cost of production is calculated for traditional 'majan' oil extraction process and developed high quality oil recovery method.

RESULTS AND DISCUSSION

Selection of the effective heating time period for oil extraction

Moisture content and colour of oil samples were analyzed to find out optimum heating time period to extract oil. According to the SLS standards moisture content of white coconut oil should be less than 0.4% and colour should be less than 4.

The scatter plot is given in the Fig. 1.1 and correlation coefficient confirms a strong (-) linear correlation between moisture content of oil and heating time period. The moisture content decreased at a rate of 0.055% with the heating time. All the oil samples were in SLS limit. But the energy cost will be high with the time of heating, therefore have to select economically feasible heating time period for oil extraction.

According to the ANOVA test results, difference between treatments was significant ($P<0.05$) in terms of moisture content. But, Tukey simultaneous test results revealed that the difference ($p>0.005$) between samples heated for more than 2.5 hrs was not significant in terms of moisture content. On the other hand, the Dunnett test also confirmed there was no significant difference between samples heated for more than 2.5 hrs. According to the statistical analysis, the economical heating time duration was 2.5 hrs to extract high

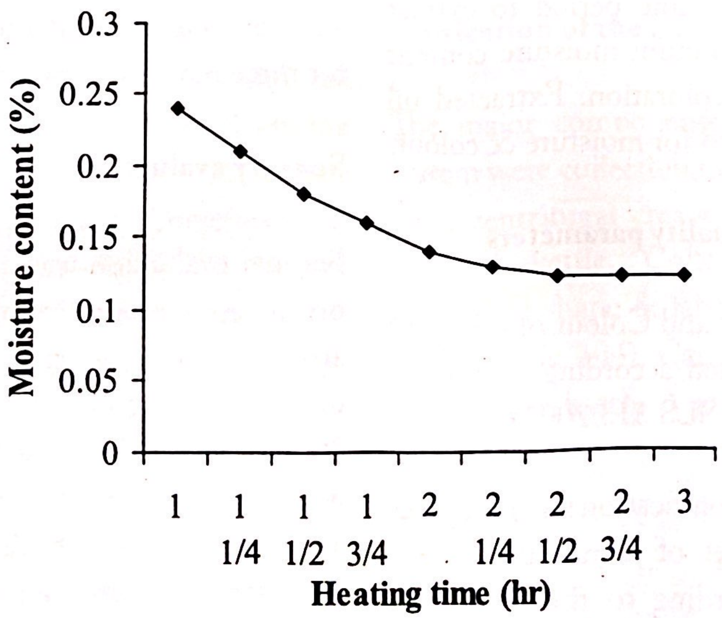


Fig. 1.1 - Variation of oil moisture content with heating time period

quality coconut oil using developed system in terms of moisture content.

The scatter plot is given in fig. 1.2 and correlation coefficient confirmed a strong (+) linear correlation between oil colour & heating time period. The colour increased at a rate of 0.357/h.

According to the analyzed data difference between treatments was significant ($p<0.05$) in terms of oil color. All the oil samples extracted at different heating time periods were within SLS limit. Color of the oil used for edible purposes is assumed to be not much important as moisture to its quality. It depends on the extraction procedure. Therefore, according to the statistical analysis 2.5 hrs of heating time period was selected as effective time period to extract high quality oil economically in terms of oil moisture and colour. The Selected heating duration was used to oil extraction for further analysis.

Oil yield

DC wet processed waste water normally contains about 2% fat content, so that a typical DC mill having a daily capacity of 50,000 nuts can produce an average amount of 1MT of coconut oil per day.

Quality of extracted oil

Basic quality parameters of oil which was extracted using selected heating time period were analyzed with comparing majan oil (Oil extracted from DC process water using traditional method) and coconut oil bought from open market.

Variation of oil moisture content

Results showed that moisture content of extracted oil was higher than that of market coconut oil & lower than that of majan oil (Table 1.1). Both extracted oil & market coconut oil were within SLS limits. Comparison of oil

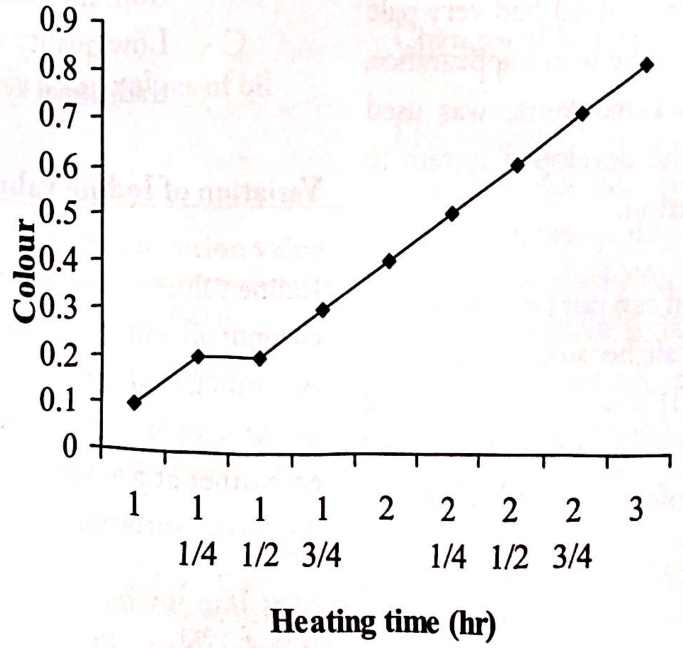


Fig. 1.2 - Variation of oil colour with heating time period

samples revealed that there was no significant difference ($p<0.05$) between extracted oil and market oil in terms of moisture content. On the other hand, majan oil was significantly different from market oil and extracted oil and it was not within the SLS limit.

Table 1.1 - Moisture content of oil samples

Oil type	Moisture (%)
Extracted oil	0.12±0.01
Market oil	0.08±0.03
Majan oil	1.80±0.04

Each value in the table represents the mean ± standard deviation of duplicate analysis

Variation of oil colour

Table 1.2 shows that the colour of oil samples on Lovobond colour scale. Results depicted that the colour of extracted oil was lower than that of Market oil and Majan oil. Both extracted oil & market coconut oil were within the SLS limits. Colour of extracted oil was significantly different ($p<0.05$) from market oil and majan oil. Extracted oil had very pale yellow colour similar to the water appearance, because the steam jacketed kettle was used for oil extraction in the developed system to prevent oil caramalization.

The colour of majan oil can not be expressed in Y+5R on Lovibond scale because it was similar to the Black colour. This is due to the use of direct heat during oil extraction in traditional method and anaerobic fermentation in the concrete tanks.

Table 1.2 - Colour of oil samples

Oil type	Colour
Extracted oil	0.6±0.02 (Y+5R)
Market oil	2.8±0.03 (Y+5R)
Majan oil	Y = 10.9, R = 9.9, B = 4

Each value in the table represents the mean ± standard deviation of duplicate analysis

Colour of oil samples

A - Market coconut oil sample
B - Coconut oil sample extracted from introduced system
C - Low quality oil extracted from traditional system

Variation of Iodine Value (IV)

Iodine values of extracted coconut oil, market coconut oil and majan oil are given in table 1.3. According to statistical analysis Iodine value of all the samples was significantly different from each other at 5% significant level. This may be due to the variation of extraction procedures.

Table 1.3 - Iodine Values of oil samples

Oil type	Iodine value (%)
Extracted oil	10.00±0.02
Market oil	9.77±0.01
Majan oil	16.20±0.03

Each value in the table represents the mean ± standard deviation of duplicate analysis

The critical limit for Iodine value was in between 7.5-11 in white coconut oil according to the SLS standard. This value indicates the degree of unsaturation of oil and can be used to identify unknown oil. Higher unsaturation was observed in Majan oil that may be due to the impurities or contamination in the extraction procedure. Both extracted oil and market coconut oil were within the SLS limits. Majan oil was belonging to Industrial grade according to the SLS standard.

Variation of saponification value (SV)

Changes of Saponification Value of oil samples are given in table 1.4.

Table 1.4 - Saponification values of oil samples

Oil type	Saponification value
Extracted oil	262±0.02
Market oil	250±0.01
Majan oil	136±0.04

Each value in the table represents the mean ± standard deviation of duplicate analysis

According to that extracted oil and market oil showed higher saponification value than majan oil. There was a significant difference ($p<0.05$) between oil samples in terms of saponifacation value.

According to the SLS standard saponification value of edible white coconut oil should be in between 248-264. Both extracted oil and market coconut oil were within the SLS limits. But majan oil has very lower saponification value and it was not within SLS limits. The saponification value is inversely proportional to the mean of the molecular weights of the fatty acids in the glycerides present in the oil (Pearson, 1973). According to that extracted oil and market oil have more number of fatty acids with lower molecular weight than majan oil. This value can also be used to identify unknown oil but less important than Iodine value.

Rancidity development during storage

Rancidity development of oils was estimated by analyzing the Free Fatty Acid content & Peroxide value.

Changes of free fatty acid (FFA) content

FFA value is measure the occurrence of hydrolytic rancidity in food. It is an indicator of the keeping quality of cooking oil. The SLS standard for the FFA content of edible coconut oil (white oil) is less than 0.8. The FFA content of the extracted oil, market coconut oil and majan oil were recorded, at two week intervals, over three months storage period.

The scatter plot (Fig. 1.3) and correlation coefficient confirmed a strong (+) liner correlation between FFA content and storage period. FFA content of majan oil increased at higher rate than market oil and extracted oil. This may be due to the higher moisture content in that oil sample. FFA content of extracted oil was not significantly different ($p<0.05$) from market oil sample at initial level and during storage. Even though initially lowest FFA increment was observed, it was recorded significantly higher increment after two months when compared with the initial value at 5% significant level.

The FFA values of extracted oil and market oil conformed to the SLS standard. Both extracted oil and market oil did not exceed SLS limit during the storage period of three months.

According to the fig. 1.3, FFA content of majan oil was always greater than market oil and extracted oil and it was not within SLS limit.

Majan oil shows high level of Rancidity, this is due to increase in hydrolysis of fat with long retention time in concrete tanks & poor sanitation in the processing steps.

Changes of peroxide value

The Peroxide Value is an index of amount of oxidation fat has undergone (Lawson, 1984).

Initial Peroxide values of Market oil (Mk oil), Extracted oil (Ex oil) and Majan oil (Mj oil)

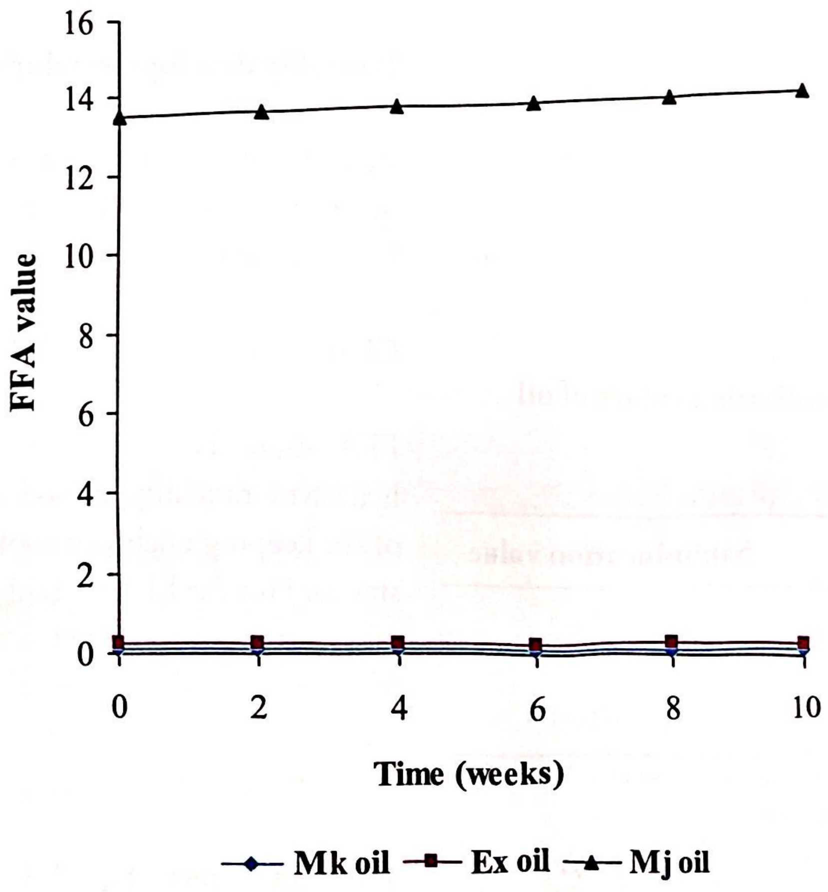


Fig. 1.3 - Effect of storage on the free fatty acid content of oil samples

were 0.7 meqv kg^{-1}, 0.9 meqv kg^{-1} and 1.9 meqv kg^{-1}, respectively. Peroxide value (PV) of the Extracted oil, market coconut oil and majan oil recorded, at two week intervals, over three months storage period are presented in fig. 1.4. Peroxide values were increasing in all oil samples during the period of storage.

According to the analyzed data, the PV of all oil samples was significantly correlated with the storage period ($p<0.05$). There was a strong (+) liner correlation between PV and storage period in all the samples. That may be due to the oxidative rancidity. PV of different oil samples were significantly different ($p<0.05$) from each other at initial level and during storage.

This showed that there was a higher tendency for the formation of hydro peroxides in the majan oil. This could be attributed to the differences in processing practices. In the case of majan oil production, there is a long retention time in the concrete tanks, and then oxidation takes place very easily.

Fatty acid composition of oil samples

Fig. 1.5 shows the chromatogram of the fatty acids of the extracted oil, significant peaks in Lauric (C12:0), Myristic (C14:0), Palmitic (C16:0), Caprilic (C8:0), Oleic (C18:1), Capric (C10:0), Stearic (C18:0) & Linoleic (C18:2) acids respectively. The major constituent of coconut oil samples was Lauric acid and those results were in agreement with Yalegama *et al.*, (2007), who worked with fatty acid composition of different oil blends.

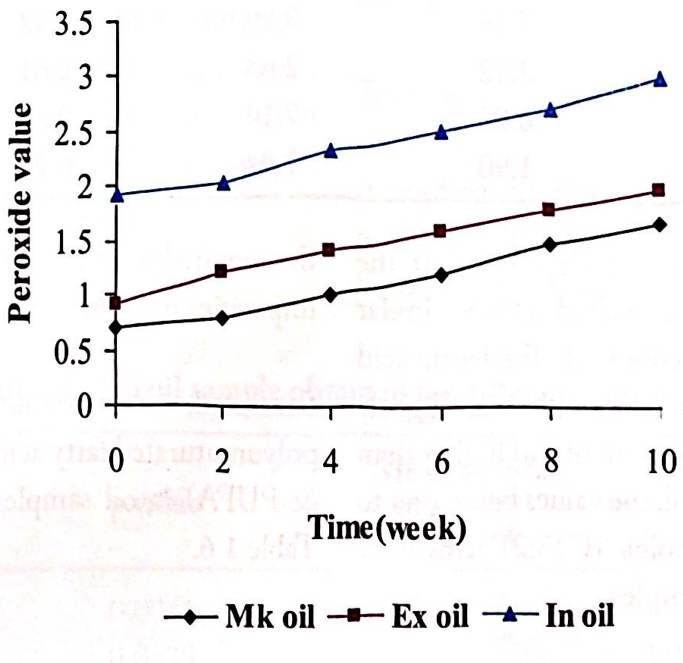


Fig. 1.4 - Effect of storage on the peroxide value of oil samples

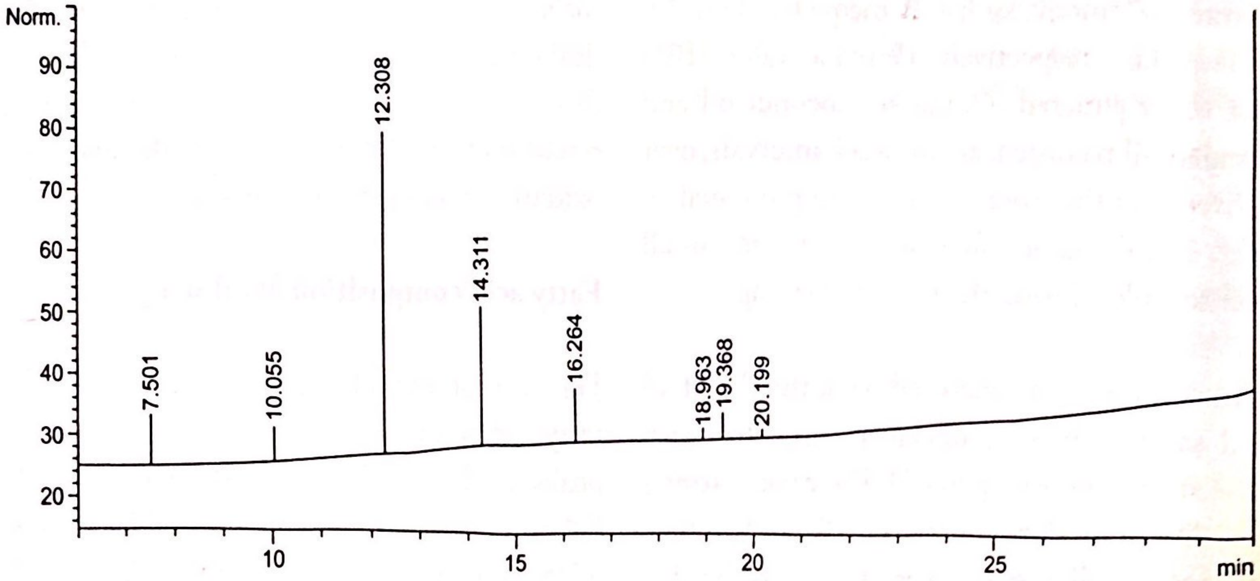


Fig. 1.5 - Typical chromatogram of fatty acids in the extracted oil

Table 1.5 - Percentage content of fatty acids in the oil samples

Fatty acid	Market oil	Extracted oil	Majan oil	Standard
Caprilic (C8:0)	8.65	8.30	7.79	4.6-10.0
Capric (C10:0)	5.52	5.50	4.97	5.0-8.0
Lauric (C12:0)	48.96	46.03	44.06	45.1-53.2
Myristic (C14:0)	19.46	19.57	16.76	16.8-21.0
Palmitic (C16:0)	7.19	8.89	7.82	7.5-10.2
Stearic (C18:0)	2.32	2.63	2.61	2.0-4.0
Oleic (C18:1)	6.00	7.14	9.28	5.0-10.0
Linoleic (C18:2)	1.90	1.94	6.71	1.0-2.5

Result given in Table 1.5 depicted that the FAs composition of extracted oil was similar to that of normal coconut oil. The lauric acid content of extracted oil sample was slightly lower than market coconut oil and higher than majan oil. In majan oil, the values belonging to oleic (C18:1) and linoleic (C18:2) acids were higher than other samples.

According to the standard given by Food & Agriculture Organization of the United Nations the extracted oil was within required limits. The majan oil sample was not within the required limit indicating that there can be impurities or contaminations in oil.

Saturated, monounsaturated and polyunsaturated fatty acid types (SFA, MUFA & PUFA) in oil samples are summarized in Table 1.6.

Table 1.6 - Percentage content of SFA, MUFA and PUFA

Fatty acid	Market oil	Extracted oil	Majan oil
SFA	92	91	84
MUFA	6	7	9
PUFA	2	2	7

In majan oil group, the amount of unsaturated FAs and long chain FAs were found to be increased when compared to those of saturated and small chain FAs, respectively. Comparison of market oil and extracted oil revealed that there is no significant difference in overall fatty acid composition.

Sensory evaluation

Non-parametric Sign test was used to find out whether there is any significant difference of consumer preference for organoleptic properties of extracted oil sample from developed system and market oil sample. Results are given in the Table 1.7.

Colour

According to the Table 1.7, the highest mean rank for colour was obtained by extracted oil sample. Results revealed that the colour of extracted oil sample was significantly different from that of market oil sample.

The colour of extracted oil sample was slightly similar to the watery colour; this may be due to use of indirect heat and not subjected to higher temperatures like in other processes.

Aroma

According to the result of sensory evaluation there was no significant difference in aroma among two oil samples. But the extracted oil sample was better than market oil sample in aroma according to the mean scores. Since higher temperature and chemicals were not used in develop system, the oil was not caramelized and it preserved the sweet coconut aroma.

Texture

According to the results of Sign test for texture, there was no significant difference between two oil samples. There was an equal

Table 1.7 - Mean ranks of each oil sample obtained for different sensory attributes

Parameters	p value	Mean scores	
		Market oil	Extracted oil
Colour	0.0041	3.333	4.367
Aroma	0.0639	3.233	3.967
Texture	1.0000	3.667	3.800
Overall acceptability	0.0290	3.467	4.033

Probability value ($p<0.05$) significant difference consumer preference for oil samples in terms of texture. This may be due to the similar moisture content in oil samples.

Overall

The overall acceptability of extracted oil scored higher mean rank than market oil. And the results of sign test depicted that there was a significant difference in overall acceptability among the two oil samples. The overall result of sensory evaluation is summarized in Fig. 1.6.

The extracted oil sample scored greater than that of market oil sample for all attributes except texture, indicating their acceptance by the consumers for edible purposes.

Cost calculation

Most developing countries do not have enough funds for good industrial wastewater treatment systems. Hence the development of low–cost high-efficient wastewater treatment systems is a real and timely need. The main attempt of this study was to develop a cost effective oil recovery system for DC wet process water as a waste treatment option. Table 1.8 shows the cost of production (COP) for developed system and traditional system for producing 1 L oil.

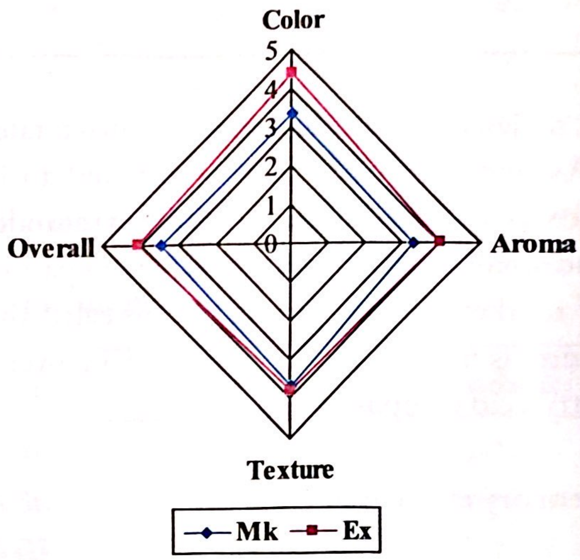


Fig. 1.6 - Mean rank of oil samples according to sensory attributes

Table 1.8 - Production cost for producing 1 L of oil using improved system and traditional system

Item	System			
	Traditional		Developed	
	Quantity	Value (Rs.)	Quantity	Value (Rs.)
Labor (@ Rs. 75/ labor hour)	5 labor hours	375.00	10 labor hours	750.00
Electricity (@ Rs. 10/ unit)	-	-	0.23 units	2.30
Coconut shells for steam generation (@ Rs.7/ Kg)	-	-	5kg	35.00
Fire wood (@ Rs: 4/ Kg)	10 kg	40.00	-	
Total cost for 8L		415.00		787.30
Total cost for 1L		52.00		98.41
Income from 1L		75.00		150.00
Profit from 1L		23.00		51.59

More operations were involved in the developed system comparing traditional system therefore, more labour hours were needed. In traditional system there was no any electricity power usage but in developed system electric power was needed to operate pumps and the cream separator. Steam was used in developed system as a source of heat energy alternative to the fire wood used in traditional method. The COP for developed system was higher than traditional oil recovery system. However, coconut oil extracted from developed system was in good quality therefore, its market value was higher than that of low quality oil extracted from traditional method. Ultimately profitability of developed system was higher than traditional method practiced by DC millers.

CONCLUSION

The oil recovery system introduced in this study was very simple, high efficient and it did not use advanced technologies. This system can be installed by any DC miller to minimize the problems faces in the traditional oil recovery system.

The average coconut oil production rate was 8 litres of coconut oil from 20 litres of concentrated thick cream.

The laboratory level experiments show significant removal efficiency of 75% for fat. Therefore this system acts as an efficient pre-treatment option for DC mill process water.
The extracted oil sample scored greater than that of market oil sample for all attributes except texture indicating consumer acceptance for edible purposes.

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