PLANT SCIENCE TODAY
Vol 12(sp3): 01–07
https://doi.org/10.14719/pst.8370

eISSN 2348-1900

RESEARCH ARTICLE

Improving efficiency of virgin coconut oil through process optimization in developing sustainable models for small scale production

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Received: 19 March 2025; Accepted: 16 May 2025; Available online: Version 1.0: 07 July 2025

Cite this article: Kamalasundari S, Babu R, ArunKumar R, Shanthi K, Jayaramachandran M. Improving efficiency of virgin coconut oil through process optimization in developing sustainable models for small scale production. Plant Science Today. 2025;12(sp3):01–07. https:/doi.org/10.14719/pst.8370

Abstract

Virgin coconut oil (VCO) "healthiest oil in the world", extracted from matured coconut kernel. The quality and quantity of VCO extraction is a major step in commercializing the product. If the process of VCO is made simple, coconut farmers will be able to reap the benefits. In this study, VCO production methods were optimized for micro and village scale processing that meets the international and domestic standards. Eight coconut varieties of Tamil Nadu Agricultural University were studied for VCO production using four processing methods *viz.,* Traditional boiling method (T1- WM-TB), Modern Kitchen method (T2- WM-MK), Solar drying method (T3- DM-SD) and Cabinet drying method (T4- DM-CD). Advantages and disadvantages of all the four methods were analyzed and the yield and cost economics and limitations in each processing methods were discussed. The highest yield was given by DM-CD (41.43 %) DM-SD (40.89 %), WM-MK (20.32 %) and WM-TB (8.8 %). Physio-chemical analysis and quality characteristics were checked and found that sixteen compounds were commonly present in more than 95 % of the VCO samples. The results revealed that except for moisture all the physicochemical parameters as specified by APCC standards (15 parameters out of 16 parameters) and as per FSSAI standards (8 parameters out of 9 parameters) were in the specified range. From this study it is concluded that most of the quality parameters can be easily met by following good manufacturing practices of VCO and it can be produced at home-scale which will directly increase the income of the coconut farmers.

Keywords: coconut farmers; global standards; models for small scale production; virgin coconut oil

Introduction

India ranked third in the list of global coconut-producing nations. In 2023, the coconut production in India accounted to 20535 million nuts (1). Coconuts are primarily used for oil extraction. There are two types of coconut oil, the refined oil extracted from copra and the second is the Virgin Oil (VCO), where the consumption is less because of its high cost (2). VCO is a superior edible oil extracted using, mature fresh coconut kernel with or without heat application either using machines or normal grinding method without undergoing chemical, refining, bleaching and which does not lead to alteration of nature of oil and used for human consumption without the need for further processing. VCO industry in recent years has pushed large processing and exporting companies through the value chain (3).

VCO is considered as the "healthiest oil in the world", due to its rich number of nutritional properties. Medium Chain Fatty Acids (MCFA) such as myristic, palmitic, lauric, capric, stearic, oleic and linoleic acids. Lauric acid in VCO is around 48 - 53 % and helps in immunity, digestibility and provide acceptable serum lipid profile (4,5). VCO has some specific nutraceutical and functional properties *viz.,* antibacterial, antiviral, antiplaque, antiprotozoal, anti-inflammatory antipyretic properties and helps in body weight. It is reported that antioxidant capacity of VCO could be due to phenolic compounds like ferulic acid and p coumaric acid (6).

Methods used in extraction of VCO play an influential part in commercializing the product as it affects the quality of VCO production (7). There are many latest technologies available to achieve higher extraction of VCO. Of which, simple and affordable techniques are to be standardized for small scale production at the village level in coconut producing countries (8). The two methods commonly employed for VCO production are wet and dry. In the dry method, the moisture is removed in the kernel by drying and pressed mechanically to get cold pressed oil. In wet method the coconut meat/kernel was ground to milk, chilled and destabilized the emulsion of coconut milk without requiring the process of drying. This study aims to compare extraction efficiency of VCO with the

National (Food safety Standard Authority of India - FSSAI) and International standards (Asian Pacific Coconut Community - APCC). It also assesses strategies for better price realization of VCO and its byproduct utilization through the value chain analysis.

Materials and Methods

Fully matured 11-12 months old (after pollination) coconuts from eight varieties (Hybrid- VHC2, VHC3, VPM 5, Kera Sankara) and tall varieties -VPM 3, VPM 4, ALR 1, ALR 2) were obtained from Coconut Research Station, Veppankulam, Tamil Nadu Agricultural University, Tamil Nadu, India.

Each variety of coconut were carefully chosen from 25 trees. The coconuts are broken and shell is removed by chisel type tool. Testa or brown layer is removed by hand peeler and washed in clean water and cut into small pieces. VCO is then produced using comminated coconut meat (grated, chopped, granulated) for dry method and for wet method from coconut milk as outlined in Fig. 1.

In the wet method two processes were carried out, Traditional Boiling (T1 WM-TB) and Modified Kitchen method (T2 WM-MK). The standard procedures for VCO extraction were followed for T1 (9) and T2 (10, 11).

In the dry process, moisture from the kernel of the coconut is removed by solar - drying method (T3 DM-SD) (12) and oven-dry method (T4 DM-CD) (13). In both these processes the dried coconut meat was stored inside a freezer for 1 week till final Moisture Content (MC) comes to 2-5 % and the oil extracted using a Direct Micro Expeller with maximum temperature of the oil not exceeding 47 °C. The details of the process flow diagram for wet and dry process methods of VCO production are depicted in Fig. 1. Oil yield was

$$\text{Oil yield(\%)} = \frac{\text{Weight of the VCO obtained in the process}}{\text{Weight of the coconut taken for extraction}} \times 100$$

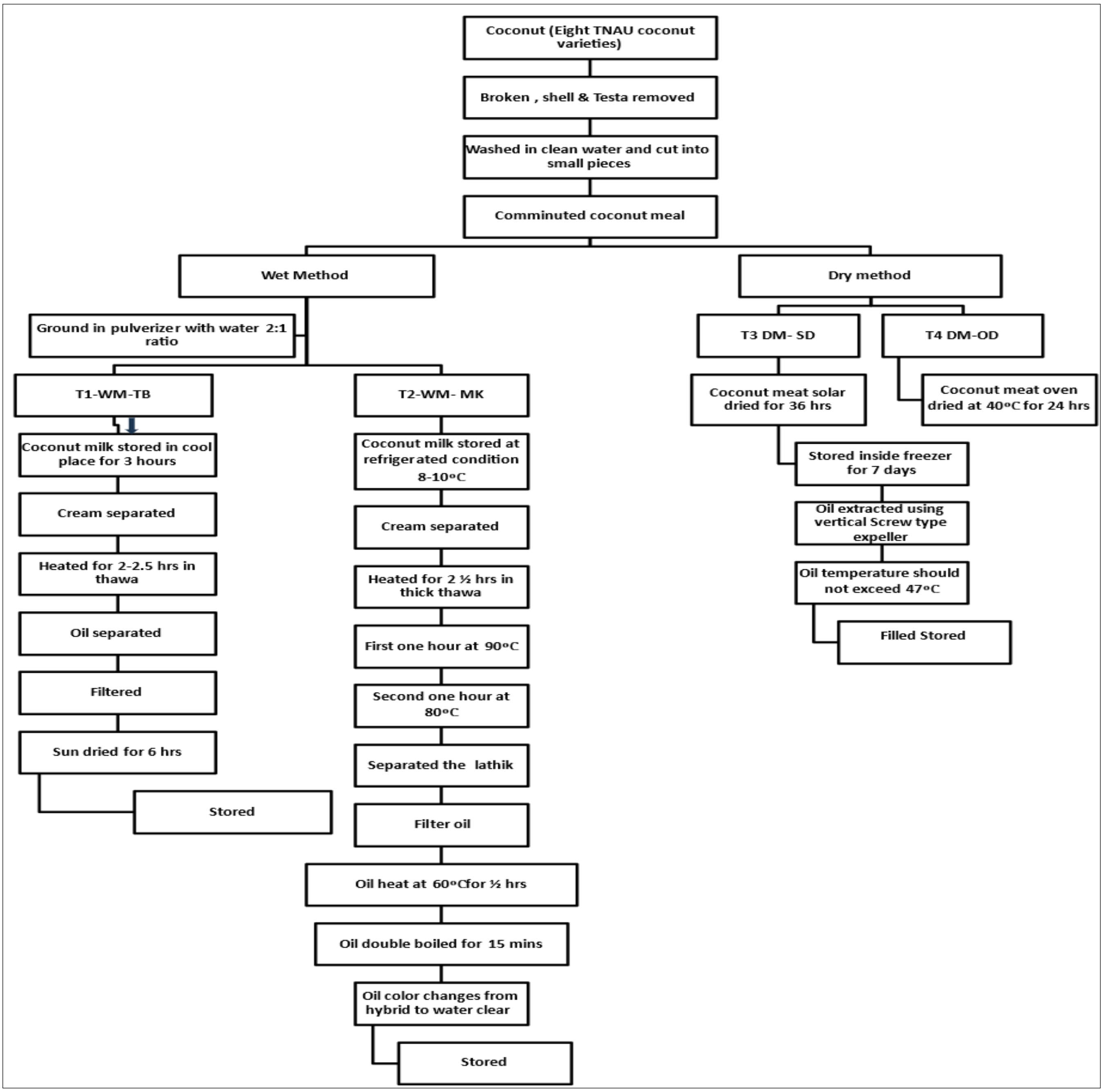

Fig. 1. Flow diagram for wet and dry process methods of VCO production.

estimated by using the following formula.

Physico-chemical analysis and quality characteristics

All the physico-chemical parameters were determined using the standard procedures (14). All analyses were done in triplicate. The quality characteristics as referred by APCC (15, 16) and FSSAI (17) were assessed for the best yield in both wet and dry process for each coconut varieties. For the physico-chemical analysis, the best treatments in wet method (T2 - WM-MK) and in dry method (T4 - DM-CD) were compared.

Microbial load Total plate count was analyzed VCO samples from T2 WM-MK and T4 DM-CD. Sodium citrate at 2 % was used as diluent for oil samples and the samples were diluted up to 10^{-3} dilution, plated in nutrient agar for bacteria and Sabourauds dextrose agar for fungal count. The plates were incubated at 37 °C for 1-5 days (15).

Statistical analysis

Data were analyzed by analysis of variance by adopting factorial Randomized Block Design (RBD) with coconut varieties as one factor and method of VCO extraction as the other factor. The means compared using least significance difference. For statistical analysis, the treatment T1 (WM - TB) was not included as the oil yield is very low and further it does not meet the standards of FSSAI and APCC.

Results and Discussion

Oil Recovery

Significantly the highest oil yield was recorded by DM-CD (41.43 %) and followed by DM-SD (40.89 %) for dry method. In wet method T2 (WM-MK) yielded 20.32 % and whereas T1 (WM -TB) yielded only 8.8 %. As T1 (WM - TB) gave very less yield and the colour of the oil was not matching the standards of FSSAI and APCC. In T2 (WM-MK) oil yield ranges from 14.76 to 18.22 %. In earlier studies VCO oil content of 20-22 % (11) and 39.37 % (18) were reported. Among the varieties/hybrid, VPM5 showed the highest oil yield of 29.07 % followed by VHC 3 with 24.04 %. In the dry method, there were not wider differences between solar (40.89 %) and oven drying (41.43 %) even though they were statistically significant. Hence, DM-CD method is suitable procedure for higher oil content and Hybrid VPM 5 recorded the highest oil recovery. The merits and limitations of extraction methods of VCO and the VCO oil content are presented in Table 1. In T3 (DM-SD) the VCO oil content ranges from 35.16 to 44.86 %. In T4 (DM-CD) it ranges from 35.55 to 45.15 %. The oil yield was higher in VPM 5 varieties in all three methods with an average mean of 39.69 followed by VHC 3 and mean of 37.69 %. The oil yield was higher in hybrid varieties when compared to tall varieties.

However, the maturity index plays an important role in yield of oil. Earlier studies indicated that the highest oil recovery was found in overlay matured coconut of 14 -15 months old and had no influence on properties, oxidative stability and sensory characteristics (19). Further, studies revealed that there is limitation in VCO production in dry methods since mechanical instruments were used that generate less temperature (frictional heat) and pressure and might be the reason for low yield (8, 18).

The details on the yield of VCO using three best production methods are depicted in Table 2. Among the varieties ALR 2 was significantly superior to all other tall varieties in yield of VCO. Likewise, among the hybrids VPM 5 recorded significantly the highest yield of VCO. Comparing the varieties and hybrids, hybrids outperformed in yield of VCO significantly. Among the method of extraction of VCO DM - CD recorded significantly the highest yield of VCO and it was

Table 1. The advantages and limitations of extraction methods of VCO

Advantages	Limitations	By products	BCR
Traditional boiling method -T1 (WM-TB)			
• Very low investment cost • Home scale production using ordinary kitchen utensils • Free from chemical treatment solvents	•Low yield •Heat changes the oil colour to yellow and antioxidant property gets reduced and only suitable for skin care and massage products. •After 5 days oil becomes rancid if it is not properly heated	•Coconut residue •Testa converted to testa oil •Coconut shell •Coconut vinegar •VCO soap	1:1.87
Modern Kitchen method -T2 (WM-MK)			
• Retains pleasant odour • Antioxidants properties not reduced • Free from chemical treatment solvents • Nutritious coconut milk containing part and micronutrients can be used as beverage	•Critical control points must be observed •This process requires 24-48 hrs	•Coconut milk •Coconut residue •Proteinaceous matter •Testa •Coconut shell •Coconut vinegar	1:2.65
Solar Drying method - T3 (DM-SD)			
• Longer shelf life • Mass production at a time • Easy to operate • It has lowest labour requirement and least energy input.	•Eight days process •High cost due to refrigeration •Prone to microbial contamination during drying	•Coconut shell •Coconut vinegar •Testa	1:3.15
Oven-dry method -T4 (DM-CD)			
• Longer shelf life • Mass production at a time • Easy to operate	•Seven days process •High cost due to refrigeration and cabinet dryer •Prone to microbial contamination during drying	•Coconut shell •Coconut vinegar •Testa	1:3.15

Table 2. Yield of VCO using three different production methods

Varieties	T2 WM-MK	T3 DM-SD	T4 DM-CD	Mean
Tall				
VPM 3	14.76 (3.842)	35.16 (5.923)	35.55 (5.962)	28.49 (5.242)
VPM 4	14.86 (3.855)	36.05 (6.004)	36.21 (6.017)	29.04 (5.292)
ALR 1	16.68 (4.084)	40.85 (6.391)	41.43 (6.437)	32.98 (5.637)
ALR 2	18.22 (4.268)	41.06 (6.408)	41.83 (6.468)	33.70 (5.715)
Hybrid				
VHC 2	22.43 (4.736)	42.16 (6.493)	42.74 (6.537)	35.78 (5.922)
VHC 3	24.04 (4.903)	44.10 (6.641)	44.92 (6.702)	37.69 (6.082)
VPM 5	29.07 (5.392)	44.86 (6.698)	45.15 (6.719)	39.69 (6.270)
Kerasankara	22.50 (4.743)	42.95 (6.554)	43.65 (6.607)	36.37 (5.968)
Mean	20.32 (4.508)	40.89 (6.394)	41.43 (6.437)	

	CD (P = 0.05)
Between varieties	0.004
Between methods of VCO	0.002
Interaction between varieties and methods	0.006

There is a statistically significant difference between the varieties and methods (CD = 0.004), (CD = 0.002) suggesting that the varieties and methods affect performance.

followed by DM- SD method. WM - MK method of extraction of VCO recorded the lowest yield of VCO. The interaction between coconut varieties/ hybrids and method of extraction of VCO was significant with hybrid VCO with DM - CD method of extraction of VCO recorded significantly the highest yield of VCO.

Physico-chemical properties of VCO

The selected processed VCO subjected to various physico-chemical analysis and results are presented. The values were compared with APCC and FSSAI standards. (Table 3)

Moisture Content (MC)

The quality of the VCO samples is determined by Moisture Content (MC). The MC of VCOs was in the range of 0.1 to 0.5 %. T4 (DM-CD) processing showed a less moisture content of 0.1 and 0.2 %. T2 (WM-MK) processing has the highest MC of 0.3 to 0.50 %, higher than the standards set by APCC but these values were within the limits of FSSAI standards. Earlier reports also reported that in wet methods there is high moisture in fresh coconuts resulting in less efficient oil purification (3, 6). Further, it was also suggested that drying the coconut meal to 3 % MC will meet international market requirements for VCO production (20).

Free Fatty Acid (FFA)

The taste and aroma of the oil can be known using FFA. The FFA percentage of the samples was in the range of 0.20 to 0.55 %, which was acceptable and within the recommended limit by APCC, of 0.2 % maximum. Similar results were also reported earlier (3, 11). The lowest FFA was obtained in the hybrid variety Keerasankara and ALR1. Production of FFA causes

Table 3. Physico-chemical properties of Virgin coconut oil obtained from Modern Kitchen method (T2 WM-MK) and oven-dry method (T4 DM-CD) are presented along with APCC* &FSSAI ** standards

S.No	Parameters /	Wet method				Dry method				Standards	
	Variety	Keerasankara H	VHC3 H	ALR2 TV	VPM3 TV	VPM5 H	VHC2 H	VPM4 TV	ALR1 TV	APCC	FSSAI
1	Moisture %	0.4.	0.4	0.3	0.5	0.2	0.1	0.1	0.2	Max 0.1%	>0.5%
2	Free fatty acid % (m/m)	0.20	0.30	0.40	0.30	0.41	0.30	0.55	0.20	Max 0.2	-
3	Peroxide value mEq/kg	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	Max 3.0	>15
4	Relative density @ 30°C	0.916	0.916	0.915	0.915	0.917	0.915	0.920	0.918	0.915 – 0.920	-
5	Refractive index at 40° C	1.4481	1.4481	1.4481	1.4481	1.4481	1.4481	1.4481	1.4481	1.4480 – 1.4492	1.4480 – 1.4492
6	Insoluble impurities 100 °C % (m/m)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	Max 0.05	>0.05% by wt
7	Saponification value g mol^{-1}	263	250	254	252	256	257	283	260	250 – 260 min	>250
8	Iodine value gI_2 /100	10.2	4.7	10.5	8.8	10.9	9.4	6.8	7.6	4.1 -11	4.0-11.0
9	Unsaponifiable matters % (m/m)	<0.1	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	max 0.2 - 0.5	>0.5% by wt
10	Specific gravity @ 30°C	0.916	0.918	0.916	0.915	0.917	0.915	0.920	0.918	0.915 – 0.920	-
11	Polenske value m-eqO2 /kg	13.8	14.7	14.2	13.5	13.7	13	13	13.9	min 13	Not less than13
12	Total plate count									< 0.5	-
13	Colour					Water clean					-
14	Odour and taste	Natural fresh coconut scent, free of sediment, free from rancid odor and taste									-
15	Acid value mg KOH/g	2.3	2.2	2.4	2.9	2.0	2.2	2.7	2.2		>4.0
16	Matters volatile at 120°C %	-	-	-	-	-	-	-	-	Max 0.2	-

hydrolytic rancidity (21, 22). When there is high moisture FFA gets altered. The difference in FFA values between the hybrid and tall varieties in this study may be due to the difference in enzyme lipase (23).

Peroxide Value (PV)

The early stages of oil rancidity can be known by peroxide value (24). All the samples tested recorded values below the detection limit of less than <1.0 mEq/kg and were very low compared to the APCC standards (Max 3.0mEq/kg) and as per FSSAI >15 mEq/kg. Earlier studies indicated PV of 0.87 ± 0.02 mEq /kg (20, 25).

Relative Density (RD)

The ratio of the density of a substance and the density of reference material can be read using relative density. The density of all varieties irrespective of processing ranged between 0.915- 0.920 and was in the ranges specified by APCC as 0.915-0.920 RD with 0.86 - 0.91 g is labeled as good (26).

Refractive Index (RI)

The RI was read at 40 ^{0}C. All the samples had the same RI of 1.4481 which was within the standard range 1.4480-1.4492 specified by the APCC standards and FSSAI standards. A study compared the RI of nine samples of coconut oil adulteration and they compared it with VCO as it is homemade and free from adulteration and it was observed that RI of selected VCO was 1.445 (27). Similarly, the value of 1.4486 in their VCO samples were observed in many studies (19)

Insoluble impurities

The APCC and FSSAI standards limit for insoluble impurities of maximum 0.05 %. All the varieties/hybrids tested, irrespective of methods, showed values of less than 0.02 %. In general, haziness is a common problem in expeller production, but it was not observed in the present samples (23).

Saponification Values (SV)

The SV was in the range 250 to 283 g mol^{-1}. Except the variety VPM 4 (283 g mol^{-1}) and Keerasankara (263 g mol^{-1}) all the samples had the value in the range. It is reported that VCO with high SV are best for food purposes. Earlier studies showed SV values of 203 g mol^{-1}(26) and 259 g mol^{-1}(3, 21) are common in VCO samples. Based on the results, VPM 4 is the best for soap production besides cooking.

Iodine Value (IV)

The IV of the VCO samples was at a permissible level and ranged from 4.7 gI_2 /100 g oil to 10.9 gI_2 /100 g. The values are in the range stated by APCC and FSSAI (4.1 gI_2 /100 g oil to 11 gI_2 /100 g). For IV, in ALR 2 variety from wet process and VPM 5 variety from the dry process had significantly higher IV of 10.5 and 10.9, compared to other varieties. The variation might be due to varietal differences (28).

Unsaponifiable matter

The value ranged from < 0.1 in all the samples and VHC 3 showed 0.3 and was within the range of APCC (0.2-0.5 %) and FSSAI (>0.5 %) by weight. This confirms that this oil is ideally suitable for soap production. Earlier studies reported values of 0.12 % in VCO oils (3, 23)

Specific gravity

The ratio of the oil to that of reference oil at the same temperature is specific gravity. The values were 0.915 to 0.920 which were close to the standard range (0.915 - 0.920). This was also conformity with the values of earlier studies which recorded a specific gravity of 0.921 (19).

Polenske Value (PV)

Polenske value refers to per cent of caprylic, capric and lauric acids free fatty acids. Therefore, increased PV indicates the high percentage FFA presence. Studies also revealed that that these fatty acids are steam volatile and insoluble in water and gives high polenske number and confirms that PV is directly related to FFA present in the sample (3). Like this, even in the present VCO all samples have slightly high PV (13.00 to 14.7) and FFA but also within the range specified by APCC and FSSAI standards of minimum 13 m-eqO_2 /kg. Among the samples VHC 3 (14.7 m-eqO_2 /kg) and ALR 2 (14.2 m-eqO_2 /kg) had the highest PV. Comparison of PV of commercial edible refined bleached and deodorized (RBD) coconut oil, virgin coconut oil and cold pressed coconut oil (CPO) revealed that VCO has slightly high PV of 14.6, in comparison with CPO and RBD oil having 14.5 m-eqO_2/kg and 14.0 meqO_2/kg respectively (3).

Acid Value (AV)

AV refers to oxidation of oil (28). AV is the number of mg of KOH required to neutralize the free acid in 1 g of the substance. The AV in all samples tested ranged from 2.0-2.9 mg KOH/g and as specified by APCC and FSSAI (>4.0 mg KOH/g). The greater the deviation in acid value, the lower the quality of the oil.

Microbial load

Microbial load was analyzed in VCO extracted using wet method T2 (WM-MK) and in dry method T4 (DM-CD). For all the samples, both bacterial and fungal count were found to be nil at 10^{-3} dilution. Whereas bacterial colony count of 1 - 3 were recorded at 10^{-1} dilution irrespective of sample types.

Organoleptic parameters

The VCO was analyzed for colour, odour and taste. All the samples were cleaned with water and tasted naturally fresh and free of sediments; rancid odour matched with APCC standards. As the testa is removed and low heat is applied the oil is colorless. This is a suggested recommendation of both APCC and FSSAI standards.

Matters volatile at 120 °C %

The formation of secondary volatile compounds due to fat oxidation occurs when the oil is old. The parameter 'Matters volatile at 120 °C %' refers the same. Since the oils are fresh and the peroxide as well as FFA values are at acceptable limits, the value is recorded as nil.

Cost economics

Training and demonstration were given to 200 coconut growing farmers on VCO production using all four methods. Training on byproduct utilization of VCO production was also imparted. Information on economic parameters, net-return, benefit-cost ratio BCR of the VCO and for value addition of byproducts was also calculated. Highest BCR was obtained in dry method as 1:3.15 because of larger production. In the wet process T1 (WM-TB) recorded BCR of 1:1.87 and T2 (WM-MK) recorded 1:2.65. This BCR value can be increased by engaging the farmers in the production of coconut products using coconut residues that range from 33-54 % of the weight of freshly extracted milk on a wet basis. This residue was extended in preparation of various home recipes (Coconut powder, coconut rice mix). This residue is rich in protein and fiber and is made into flour and it is incorporated into protein-based products. The oil can be used in VCO soap production. A total of 14 soaps were obtained from 1 L of oil. The Total Fatty Matter (TFM) of the soap was 79 %, which falls within the range for Grade A soap (76 % to 85 %). Prioritizing this model among coconut farmers and coconut FPO helps in boosting the rural employment and income thereby improving the productivity and competitiveness of the coconut industry.

Conclusion

The study evaluates three VCO production methods suitable for micro and village-scale operations, meeting the acceptable physico-chemical properties as per APCC and (15 parameters out of 16 parameters) and as per FSSAI standards (8 parameters out of 9 parameters) The DM-CD method yielded the highest amount of VCO, followed by the DM-SD method, while the WM-MK method had the lowest yield. All physico-chemical parameters, except for moisture, met the specified standards, assuring the quality and safety of VCO produced on a smaller scale. The dry extraction method is deemed most suitable for large-scale VCO production due to its cost-effectiveness, yield and longer shelf life, while the wet method better preserves the oil's natural properties without chemicals. Encouraging coconut farmers to adopt these methods can boost rural employment, increase income and enhance the competitiveness of the coconut industry in both domestic and international markets (29).

Acknowledgements

The authors express sincere acknowledgement to their institution, staff members and student friends for collecting this review material.

Authors' contributions

SK carried out the research studies; conducted outreach programme participated in the sequence alignment and drafted the manuscript. RB performed the statistical analysis. RAK helped in collection of coconut varieties. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests related to this research.

Ethical issues: None

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Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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