[a)]Exploring The Influence of UV-Light And Packaging on Virgin Coconut Oil Quality During Storage

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Abstract. .The study aimed to examine how UVe light treatment and different packaging types affect the quality of virgin coconut oil (VCO) during storage. The experiment involved two types of UV light with different wavelengths (253.7 and 352 nm) and intensities (325 and 396 lux), as well as various packaging bottles, including High-Density Polyethylene (HDPE), Polypropylene (PP), and Polyethylene terephthalate (PET). Storage was accelerated under high-intensity light exposure at room temperature for 4-5 weeks, with weekly VCO quality analysis. The quality parameters assessed were moisture content (MC), free fatty acids (FFA), acid value (AV), iodine value (IV), peroxide value (PV), and saponification value (SV). The findings showed that higher light wavelength and intensity led to lower VCO quality, as indicated by increased quality parameters (MC, FFA, AV, IV, PV, SV), suggesting decreased quality. The study also concluded that the type of UV light and packaging significantly influence the storage stability of virgin coconut oil. Extended storage time has negatively affected VCO quality. Additionally, the type of packaging played a crucial role, with HDPE packaging being more effective in maintaining VCO quality.

Keywords: Storage Stability, Types of Packaging. UV-light Treatment, Quality Parameter of VCO

INTRODUCTION

Coconut (Cocos nucifera) is a tropical fruit that grows on coconut palm trees, which belong to the Arecaceae family. It is known for its versatility and nutritional benefits [1]. Coconuts are a significant agricultural product in many tropical countries. Major producers include Indonesia, the Philippines, India, and Brazil. Every year, Indonesia produces approximately 17 million metric tons of coconuts. The production of coconuts in Indonesia has remained relatively stable over the past five years. In 2020, India produced approximately 14.7 million metric tons of coconuts, which is significantly behind Indonesia but ahead of most other countries. The Philippines also produces a similar number of coconuts to India, with 14.4 million metric tons produced in 2020.The versatility of coconuts makes them a valuable commodity in both local and international markets.

Virgin Coconut Oil (VCO) is pure coconut oil obtained by separating the emulsion in coconut milk. VCO is extracted from coconut milk by breaking up the emulsion through methods such as heat application, centrifugation, fermentation, inducement, and acid utilization [1], [2]. VCO is considered a valuable functional food due to its high content of medium-chain fatty acids (MCFAs), particularly lauric acid (C12:0, approximately 48-53%), caprylic acid (C8:0, 5.22%), and capric acid (C10:0, 5.41%) [3], [4]. An important component of the fatty acids in virgin coconut oil that is beneficial for health is lauric acid. In the human body, lauric acid can be converted into a monoglyceride compound called monolaurin, which has antiviral, antibacterial, and antifungal properties. Monolaurin works by damaging the lipid membranes of viruses, including HIV, influenza, and several others [1].

The quality of oils can decline due to chemical hydrolysis, chemical oxidation, polymerization, pyrolysis, absorption of external flavour and odors, and also microbial action [3], [4], [5], [6], [7], [8]. These processes can be accelerated by enzymes, metals, heat, light, and air. Hydrolysis of oil occurs when acids or bases, in the presence of water, react with glyceryl esters of a tri-, di-, or mono-acylglyceride, releasing free fatty acids (FFA). The accumulation of FFA contributes to the sour smell and taste of VCO. Heat and moisture accelerate hydrolysis. Among vegetable oils, virgin coconut oil appears particularly susceptible to hydrolysis when subjected to heat. The standard method for determining the extent of hydrolysis is by titrimetry. Beyond its role in the stoichiometry of hydrolysis, water is essential to the activity of enzymes and microorganisms. Chemical oxidation in VCO

occurs when oxygen (O_2) in the air reacts with unsaturated fatty acids in the presence of light, heat, ionization, traces of metals, and metaloprotein, oxygen reaction with unsaturated lipids, and by chemical, and enzymatic mechanisms such as autoxidation, photo-oxidation and lipoxygenases [7]. This reaction leads to the formation of hydroperoxides as the primary products in the initiation step. The hydroperoxides are then converted to aldehydes, epoxides, acids, alcohols, and other hydrocarbons. Aldehydes are particularly important as they contribute to rancid odor and taste. Hexanal, derived from the oxidation of linoleic acid, is commonly used as an indicator of vegetable oil oxidation [9]. There are various standard methods for monitoring the level of oxidation in vegetable oils. The most commonly used method, the peroxide value (PV) test, measures the amount of hydroperoxides. PV is expressed in mmol of peroxide per kg of oil sample or mmol of O_2 per 2 kg of oil. However, PV only partially assesses the extent of oil oxidation, as hydroperoxides can further decompose into aldehydes[7].

The quality and shelf-life of packaged food are also determined by the package's ability to protect against moisture, oxygen, and the interaction between the food and the packaging materials. Therefore, the main purpose of packaging is to minimize reactions that can affect the stability of the contained products. Packaging does not affect stability in cases where reactions occur spontaneously without external agents. However, gaseous reactants such as water vapor and oxygen, which are always present in the environment, can seriously affect stability under standard food storage and distribution conditions. Srivastava et al. (2013) studied the influence of packaging types (PE, MP, and PET) on VCO quality. However, they did not investigate the effect of PP plastic packaging on VCO quality [10].

The current study aimed to evaluate the effects of various factors on the stability and quality of virgin coconut oil during storage. Only a few studies have explored the impact of UV light on the quality of VCO, whereas numerous studies have focused on the quality reduction during the heating treatment. These factors include type of packaging material: such as High Density Polyethylene (HDPE), Polyethylene terephthalate (PET), and polypropylene (PP); and explores variations in UV lamps and light intensity. Test parameters include moisture content (MC), free fatty acids (FFA), acid value (AV), iodine value (IV), peroxide value (PV), and saponification value (SV).

MATERIAL AND METHODS

Materials

The VCO samples used in this study were provided by SMI Surabaya and prepared by fermentation without heat methods. Some of the chemicals used for analysing VCO deterioration parameters include ethanol (95%, Jayamas Medica Industri, Indonesia), ethanol (absolute for Analysis, Sigma-Aldrich, Germany), Phenol Phthalein Indicator (Supelco, UK), NaOH (Pellets, Sigma-Aldrich, Germany), chloroform (99.5%, Sigma-Aldrich, Germany), iodine (99.8%, Supelco, UK), acetic acid glacial (absolute for Analysis, Supelco, UK) , cyclohexane (99%, Sigma Aldrich Germany), Potassium Iodide (99 %, Sigma-Aldrich, Germany), distilled water, Sodium thiosulfate (99%, Sigma-Aldrich, Germany), starch indicator 1%, Hydrogen chloride (99%, Sigma-Aldrich, Germany), NaCl (99%, Sigma-Aldrich, Germany), and wijs solution (Supelco, UK).

Experimental Setup

Virgin coconut oil (VCO) was stored in 50 ml containers made of different packaging materials, including high-density polyethylene (HDPE), Polyethylene Terephthalate (PET), and Polypropylene (PP). The containers were stored in a different UV box with UV A (352 nm) and UV C (253.7 nm) light, and UV C with intensities of 325 and 396 nm, respectively. The headspace oxygen was minimal as the containers were filled just below the seal line, creating anaerobic conditions. The samples were initially analysed and then analysed weekly for moisture content (MC) using the AOAC (1999) method[11], [12] , free fatty acid (FFA) using the AOCS (1990) method, Acid Value (AV) using the AOAC (1999) method [12], [13], Iodine Value (IV) using the AOAC 993.20 (1996) method[12], peroxide value (PV) using the AOAC 965.33 (1969) method [14], and saponification value (SV) using the AOAC 920.160 (1920) method [12]. Each experiment and analysis were conducted in duplicate.

RESULTS AND DISCUSSION

In a study conducted by Srivastava et al. (2013), it was found that storing VCO in different types of packaging at room temperature (30°C) for 12 months did not cause significant changes in VCO quality parameters [10].
To expedite the observation process, the study introduced variations in the type of UV lamp and its intensity in the VCO storage box. This served as an accelerator, significantly reducing VCO quality changes and making them observable in a shorter period of time.

The Effect of storage period on the VCO quality parameter at different packaging

Moisture Content

The moisture content refers to the percentage of water that evaporates during heating at a specific temperature and time. Changes in the water content can significantly affect the quality of a food product. High moisture content in VCO can cause a hydrolysis reaction, leading to the production of glycerol and free fatty acids, which can result in rancidity.

TABLE 1. Moisture content (MC) of VCO at different UV light

UV Type (Wavelength)	Storage Period (Weeks)	Moisture Content of VCO at different packaging type (%)		
		PET	HDPE	PP
UVA (352 nm)	0	0.52 ± 0.02	0.52 ± 0.02	0.52 ± 0.02
	2	0.63 ± 0.03	0.56 ± 0.24	0.60 ± 0.30
	3	0.72 ± 0.08	0.62 ± 0.22	0.67 ± 0.07
	4	2.16 ± 0.16	1.15 ± 0.75	1.81 ± 0.81
	5	3.10 ± 1.70	1.86 ± 1.46	2.01 ± 0.38
UV C (253.7 nm)	0	0.52 ± 0.02	0.52 ± 0.02	0.52 ± 0.02
	2	0.65 ± 0.05	0.58 ± 0.02	0.61 ± 0.18
	3	0.73 ± 0.53	0.70 ± 0.30	0.70 ± 0.10
	4	3.54 ± 0.14	1.63 ± 0.17	2.04 ± 0.15
	5	3.60 ± 0.38	2.02 ± 0.38	2.36 ± 0.03

The analysis results presented in Table 1 and Table 2 indicate that the initial moisture content of virgin coconut oil (VCO) exceeded the standards set by the Asia and Pacific Coconut Community (APCC) and the Indonesian National Standard (SNI), with a measured value of 0.52%. This initial moisture content can be influenced by several factors, including coconut variety, geographical location, maturity level, and the method of VCO extraction. During storage, the moisture content of VCO tends to increase. When the moisture content exceeds the recognized standards, significant hydrolysis reactions can occur. The rate of increase in moisture content is influenced by the duration of storage and the permeability of the packaging materials. Specifically, packaging permeability follows the order: polyethylene terephthalate (PET) > polypropylene (PP) > high-density polyethylene (HDPE). Prolonged storage time and higher permeability increase the likelihood of water vapor diffusion from the environment into the packaging, leading to elevated moisture content in VCO.

TABLE 2. Moisture content (MC) of VCO at different intensities of UV C

UV C Intensities (Lux)	Storage Period (Weeks)	Moisture content of VCO at different packaging type (%)		
		PET	HDPE	PP
325	0	0.52 ± 0.02	0.52 ± 0.02	0.52 ± 0.02
	1	0.90 ± 0.10	0.69 ± 0.09	0.79 ± 0.01
	2	1.19 ± 0.21	0.89 ± 0.11	0.95 ± 0.04
	3	4.19 ± 0.21	2.28 ± 0.12	3.68 ± 0.28
	4	6.74 ± 0.06	3.98 ± 0.02	4.23 ± 0.17
396	0	0.52 ± 0.02	0.52 ± 0.02	0.52 ± 0.02
	1	1.00 ± 0.005	0.76 ± 0.16	0.85 ± 0.05
	2	1.84 ± 0.04	0.92 ± 0.12	1.02 ± 0.18
	3	5.19 ± 0.20	3.35 ± 0.25	5.41 ± 0.21
	4	7.21 ± 0.59	5.40 ± 0.21	5.79 ± 0.39

Acid Value

The free fatty acid (FFA) value, also referred to as the acid value, quantifies the amount of fatty acids that have been hydrolysed from triacylglycerols [15]. The presence of FFA in oil is indicative of incomplete processing, lipase activity, or other hydrolytic actions

TABLE 3. Acid Value (AV) of VCO at different UV light

UV Type (Wavelength)	Storage Period (Weeks)	Acid Value of VCO at different packaging type		
		PET	HDPE	PP
UV A (352 nm)	0	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00
	2	0.58 ± 0.00	0.58 ± 0.00	0.56 ± 0.71
	3	0.65 ± 0.04	0.60 ± 0.07	0.60 ± 0.00
	4	0.70 ± 0.07	0.60 ± 0.07	0.85 ± 0.18
	5	0.86 ± 0.07	0.65 ± 0.04	0.85 ± 0.18
UV C (253.7 nm)	0	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00
	2	0.69 ± 0.04	0.59 ± 0.04	0.59 ± 0.04
	3	0.70 ± 0.07	0.61 ± 0.04	0.77 ± 0.04
	4	0.85 ± 0.04	0.64 ± 0.00	0.83 ± 0.04
	5	0.93 ± 0.25	0.87 ± 0.04	0.92 ± 0.00

According to the Indonesian National Standard SNI 7381:2008 [16], the acceptable limit for free fatty acid content is 0.2%. If the acid value exceeds this threshold, the VCO is considered unsuitable for use. Elevated levels of free fatty acids are of concern because they can accelerate the oxidation process, given that free fatty acids are more prone to oxidation compared to their esterified counterparts. The analytical results presented in Table 3 and Table 4 demonstrate a trend of increasing acid values with prolonged storage durations. This increase can be attributed to the enhanced exposure of VCO to oxygen and water vapor during storage, which catalyses the oxidation process. The rise in acid value over time underscores the critical importance of optimal storage conditions to minimize contact with oxygen and moisture. This can be achieved through the use of packaging

materials with low permeability to gases and vapours, as well as storage in environments with controlled temperature and humidity.

Table 4. Acid Value (AV) of VCO at different intensities of UV C

UV C Intensities (Lux)	Storage Period (Weeks)	Acid Value of VCO at different packaging type		
		PET	HDPE	PP
352	0	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00
	1	0.84 ± 0.00	0.77 ± 0.04	0.81 ± 0.11
	2	0.84 ± 0.07	0.79 ± 0.04	0.81 ± 0.11
	3	0.85 ± 0.18	0.79 ± 0.04	0.81 ± 0.11
	4	0.90 ± 0.00	0.84 ± 0.14	0.87 ± 0.04
396	0	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00
	1	0.85 ± 0.18	0.84 ± 0.00	0.86 ± 0.21
	2	0.90 ± 0.00	0.87 ± 0.04	0.87 ± 0.04
	3	0.90 ± 0.00	0.87 ± 0.04	0.89 ± 0.04
	4	1.07 ± 0.04	0.86 ± 0.71	1.02 ± 0.07

Iodine Value

The iodine value quantifies the degree of unsaturation in fatty acids present in fats and oils. It measures the amount of iodine, in grams, that can be absorbed by 100 grams of fat or oil. Unsaturated fatty acids contain double bonds that can react with iodine, leading to the formation of saturated compounds. Consequently, the iodine number directly reflects the number of double bonds present in the fatty acids. A higher iodine number indicates a greater degree of unsaturation, which is characteristic of oils with a higher content of monounsaturated and polyunsaturated fatty acids.

TABLE 5. Iodine Value (IV) of VCO at different UV light

UV Type (Wavelength)	Storage Period (Weeks)	Iodine value of VCO at different packaging type (g/100 g oil)		
		PET	HDPE	PP
UV A (352 nm)	0	6.66 ± 0.00	6.66 ± 0.00	6.66 ± 0.00
	2	4.57 ± 0.14	6.22 ± 0.14	5.40 ± 0.35
	3	4.26 ± 0.32	5.08 ± 0.71	4.38 ± 0.64
	4	2.86 ± 0.35	5.20 ± 0.14	4.51 ± 0.07
	5	2.76 ± 0.04	4.74 ± 0.04	3.74 ± 0.78
UV C (253.7 nm)	0	6.66 ± 0.00	6.66 ± 0.00	6.66 ± 0.00
	2	4.13 ± 0.32	5.49 ± 0.25	5.58 ± 0.14
	3	2.75 ± 0.04	5.17 ± 0.39	3.98 ± 1.20
	4	2.41 ± 0.14	5.08 ± 0.14	3.93 ± 0.42
	5	2.73 ± 0.21	2..86 ± 0.00	0.73 ± 0.07

The data presented in Table 5 and Table 6 indicates that the iodine value decreases as the storage time increases. Exposure to oxygen, especially when combined with light, can initiate the oxidation of unsaturated fatty acids. This oxidative process breaks the double bonds, resulting in the formation of peroxides and other oxidative products, thereby decreasing the iodine value. Additionally, ultraviolet (UV) light acts as a catalyst in the oxidation of unsaturated fatty acids, accelerating the breakdown of double bonds and generating a range of oxidative compounds. Consequently, both oxidative reactions reduce the number of unsaturated bonds, leading to a lower iodine value.

TABLE 6. Iodine Value (IV) of VCO at different intensities of UV C

UV C Intensities (Lux)	Storage Period (Weeks)	Iodine value of VCO at different packaging type		
		PET	HDPE	PP
352	0	6.66 ± 0.00	6.66 ± 0.00	6.66 ± 0.00
	1	3.45 ± 0.78	6.00 ± 0.35	4.16 ± 0.32
	2	3.36 ± 0.92	4.22 ± 0.04	3.58 ± 0.92
	3	3.45 ± 0.78	4.13 ± 0.32	3.54 ± 0.99
	4	1.10 ± 0.18	2.81 ± 0.25	1.52 ± 0.42
396	0	6.66 ± 0.00	6.66 ± 0.00	6.66 ± 0.00
	1	3.05 ± 1.27	4.22 ± 0.04	4.00 ± 0.21
	2	3.43 ± 0.28	4.13 ± 0.32	3.49 ± 0.78
	3	2.35 ± 0.21	3.74 ± 0.78	3.24 ± 0.92
	4	1.27 ± 0.71	2.70 ± 0.11	1.43 ± 0.53

Peroxide Value

In addition to hydrolytic processes, oil degradation is significantly influenced by oxidative reactions. Unsaturated fatty acids are particularly prone to oxidation due to the presence of double bonds that can readily react with molecular oxygen, leading to the formation of peroxide compounds. The extent of oxidative damage can be quantitatively assessed by measuring the peroxide value, which indicates the concentration of peroxides and serves as a critical parameter in evaluating the oxidative stability of oils.

TABLE 7. Peroxide Value (PV) of VCO at different UV light

UV Type (Wavelength)	Storage Period (Weeks)	Peroxide Value of VCO at different packaging type (mg eq/kg)		
		PET	HDPE	PP
UV A (352 nm)	0	2.63 ± 0.13	2.63 ± 0.13	2.63 ± 0.13
	2	3.91 ± 0.66	2.89 ± 0.14	3.62 ± 0.64
	3	10.00 ± 0.00	2.49 ± 0.00	4.47 ± 0.03
	4	17.40 ± 0.54	5.00 ± 0.75	6.25 ± 0.50
	5	22.4 ± 0.82	7.50 ± 0.25	10.80 ± 0.25
UV C (253.7 nm)	0	2.63 ± 0.00	2.63 ± 0.00	2.63 ± 0.00
	2	4.08 ± 0.32	3.85 ± 0.08	6.13 ± 0.09
	3	10.70 ± 0.32	3.75 ± 0.23	7.16 ± 0.26
	4	18.7 ± 0.79	7.46 ± 0.25	10.70 ± 0.23
	5	24.5 ± 0.75	8.63 ± 0.37	12.50 ± 0.19

According to the Indonesian National Standard (SNI) and the Asia and Pacific Coconut Community (APCC) standards, the maximum allowable peroxide value is set at 0.2 mg eq/kg and 3 mg eq/kg, respectively. The analysis presented in Table 7 and Table 8 indicates that the initial peroxide value of 2.625 mg eq/kg meets the APCC standard but exceeds the SNI standard. This discrepancy may be attributed to the processing conditions of virgin coconut oil (VCO), which might involve open processing methods that facilitate contact between the oil and atmospheric oxygen. The data further reveal an increase in peroxide value during the storage period, indicating that VCO underwent oxidation under various storage conditions. This increase in peroxide value suggests that the oil is susceptible to oxidative degradation, which is influenced by factors such as exposure to light, temperature, and the presence of oxygen.

TABLE 8. Peroxide Value (PV) of VCO at different intensities of UV C

UV C Intensities (Lux)	Storage Period (Weeks)	Peroxide Value of VCO at different packaging type (mg eq/kg)		
		PET	HDPE	PP
352	0	2.63 ± 0.13	2.63 ± 0.13	2.63 ± 0.13
	1	5.00 ± 1.75	2.93 ± 0.43	3.95 ± 0.20
	2	12.50 ± 0.23	3.84 ± 0.14	5.00 ± 0.25
	3	20.50 ± 0.54	16.50 ± 0.22	19.50 ± 0.49
	4	26.2 ± 1.18	18.8 ± 0.75	26.10 ± 0.13
396	0	2.63 ± 0.13	2.63 ± 0.13	2.63 ± 0.13
	1	7.50 ± 0.21	4.86 ± 0.14	7.99 ± 0.49
	2	13.70 ± 3.73	7.48 ± 0.27	8.32 ± 0.18
	3	26.20 ± 1.27	19.60 ± 0.73	23.60 ± 0.42
	4	28.6 ± 1.27	20.00 ± 0.75	27.40 ± 0.69

Saponification Value

The saponification value quantifies the amount of alkali necessary to completely saponify a given oil sample. This value is inversely related to the molecular weight of the triglycerides present in the oil; a lower saponification value indicates a higher average molecular weight of the fatty acids. Consequently, this parameter is essential for characterizing the composition and properties of fats and oils in various analytical and industrial applications.

TABLE 9. Saponification Value (PV) of VCO at different UV light

UV Type (Wavelength)	Storage Period (Weeks)	Saponification value of VCO at different Packaging Type		
		PET	HDPE	PP
UV A (352 nm)	0	207.90 ± 95.00	207.90 ± 95.00	207.90 ± 95.00
	2	223.70 ± 10.50	213.20 ± 11.80	225.70 ± 6.25
	3	352.80 ± 27.40	237.70 ± 23.10	249.00 ± 6.31
	4	371.70 ± 0.00	267.20 ± 2.10	331.00 ± 19.60
	5	383.60 ± 13.30	313.50 ± 6.31	347.20 ± 24.50
UV C (253.7 nm)	0	207.90 ± 95.00	207.90 ± 95.00	207.90 ± 95.00
	2	317.70 ± 7.71	245.80 ± 8.07	253.20 ± 2.10
	3	356.30 ± 14.00	242.70 ± 35.10	273.50 ± 46.30
	4	384.30 ± 8.42	271.40 ± 16.10	341.50 ± 11.90
	5	405.30 ± 9.72	314.20 ± 23.80	347.90 ± 72.90

The APCC standard stipulates a minimum saponification value of 250-260 mg KOH/g of oil. However, the analysis results presented in Tables 9 and 10 reveal that the saponification value of the tested virgin coconut oil (VCO) was only 207.93 mg KOH/g, which is below the APCC standard. This deficiency suggests that the VCO produced is not yet optimal and likely contains a lower concentration of fatty acid components. The saponification value is influenced by the presence of fatty acids, and it typically increases with higher water content in VCO. This elevated water content can promote hydrolysis reactions, leading to the formation of short-chain fatty acids. As a result, a higher saponification value is associated with a greater concentration of these short-chain fatty acids. During the storage period, the saponification value of the VCO increased and eventually exceeded the APCC standard. This increase is indicative of the ongoing oxidation and hydrolysis processes, which contribute to the formation of additional short-chain fatty acids. Thus, the observed rise in saponification value reflects the progressive degradation of the VCO due to these chemical reactions over time.

TABLE 10. Saponification Value (PV) of VCO at different intensities of UV C

UV C Intensities (Lux)	Storage Period (Weeks)	Packaging Type		
		PET	HDPE	PP
352	0	207.90 ± 95.00	207.90 ± 95.00	207.90 ± 95.00
	1	386.40 ± 33.00	227.50 ± 1.71	280.50 ± 2.81
	2	417.30 ± 9.05	293.90 ± 9.05	318.40 ± 143.10
	3	478.30 ± 1.40	327.50 ± 0.70	365.00 ± 2.51
	4	540.2 ± 10.0	404.8 ± 0.69	433.4 ± 1.40
396	0	207.90 ± 95.00	207.90 ± 95.00	207.90 ± 95.00
	1	399.80 ± 4.21	241.3 ± 1.40	290.30 ± 74.3
	2	420.80 ± 81.40	300.90 ± 3.51	321.90 ± 0.70
	3	501.40 ± 35.80	359.80 ± 30.20	368.20 ± 77.80
	4	579.40 ± 1.48	416.6 ± 42.10	440.40 ± 19.60

The Effect of UV light and intensities on the VCO quality parameter at different packaging

Exposure of virgin coconut oil (VCO) to light triggers the activation of light-sensitive molecules. These molecules absorb light and subsequently interact with molecular oxygen, leading to the generation of singlet oxygen. Singlet oxygen then reacts with the fatty acids present in the oil, resulting in the formation of peroxides [17]. The presence of light-sensitive molecules significantly enhances the efficacy of visible light, especially ultraviolet (UV) light, in accelerating the degradation of VCO. Rukmini and Raharjo (2010) [18] report that the rate of photooxidation in VCO is approximately 1,000 to 1,500 times greater than that of autooxidation. Quality assessments of VCO stored under various UV lamps indicate that those exposed to UV C light (352 nm) exhibit lower quality parameters compared to those exposed to UV C light (253.7 nm). This discrepancy arises because UV C light, with its shorter wavelength, carries higher energy, thus acting as a more potent catalyst for lipid oxidation. Furthermore, variations in the intensity of UV A light affect the quality parameters of VCO, with higher intensities generally leading to increased deterioration, particularly at 396 Lux. This suggests that higher light intensity accelerates the decline in VCO quality over time. As light intensity increases, light-sensitive compounds in VCO, such as riboflavin, absorb more light energy. This energy is then converted into chemical energy, which can initiate oxidative reactions. Prolonged exposure to higher light intensities results in greater chemical energy accumulation and, consequently, a more rapid oxidation process.

The permeability value of packaging materials quantifies their capacity to permit the passage of water vapor and oxygen, which is critical for assessing the shelf life and stability of the packaged product. A lower permeability value indicates superior barrier properties, which help in preserving product quality and extending

shelf life. Analysis of the packaging materials described in all data reveals that High-Density Polyethylene (HDPE), Polypropylene (PP), and Polyethylene Terephthalate (PET) exhibit varying degrees of effectiveness in maintaining the quality of Virgin Coconut Oil (VCO). Specifically, HDPE demonstrates the lowest permeability value, indicating its superior performance in preventing water vapor and oxygen access. HDPE's lower permeability is attributable to its dense polymer structure. This material possesses a linear polymer configuration, which facilitates closer packing of polymer chains and enhances molecular bonding. The tighter bonding results in a more compact polymer matrix with reduced free volume, thereby impeding the diffusion of water vapor and oxygen. Consequently, HDPE provides optimal protection for VCO by minimizing exposure to external factors that could degrade the product. The relationship between permeability and storage time is significant; prolonged storage durations intensify the diffusion of water vapor and oxygen through the packaging. As illustrated by the permeability values (PET > PP > HDPE), materials with higher permeability allow greater amounts of water vapor and oxygen to penetrate, potentially accelerating oxidation and hydrolysis reactions in VCO. Additionally, exposure to ultraviolet (UV) light can further compromise packaging integrity. UV radiation induces photooxidative degradation, leading to the breakdown of polymer chains, formation of free radicals, and a decrease in molecular weight. This degradation reduces the crystallinity of the polymer, diminishing its resistance to permeation. Lower crystallinity increases the material's susceptibility to water vapor and gas penetration due to decreased density in crystalline regions, which ordinarily provide better barrier properties. In summary, HDPE packaging is superior in maintaining VCO quality due to its low permeability and strong molecular structure, which collectively ensure prolonged shelf life and protection against external degradation factors.

CONCLUSION

Exposure of Virgin Coconut Oil (VCO) to ultraviolet (UV) light leads to significant quality degradation, as evidenced by increased values of several key parameters, including water content, acid value, iodine value, and peroxide value. Specifically, UV exposure results in elevated water content due to hydrolytic processes, higher acid values from fatty acid hydrolysis, increased iodine values indicating greater levels of unsaturation, and elevated peroxide values reflecting oxidative rancidity. The development of a rancid odor is a qualitative indicator of these chemical changes and compromised oil quality. Extended storage durations intensify these quality issues, as prolonged exposure to environmental factors such as oxygen and moisture further accelerates oxidation and hydrolysis reactions. The quality deterioration is quantitatively measurable through increases in the aforementioned parameters.

Moreover, the type of packaging employed plays a critical role in preserving VCO quality. Packaging materials with lower permeability are more effective in maintaining the integrity of VCO by minimizing the access of water vapor and oxygen, thus reducing the probability of oxidative and hydrolytic degradation. In contrast, packaging with higher permeability allows greater exposure to these deleterious factors, accelerating quality deterioration.

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