Effect of Packaging Materials on Storage Stability of Crude Palm Oil

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Lacquered metal cans, green glass bottles, amber glass bottles, clear glass bottles and clear plastic bottles filled with freshly produced Nigerian crude palm oil were stored in direct sunlight (40 ± 1°C) and in the dark (27 ± 1°C). Assessment of the stability of the oils towards hydrolytic and oxidative deterioration was made periodically by measuring the free fatty acid, peroxide and anisidine values over a period of 98 days. The study showed that crude palm oil packaged in plastic bottles and clear glass bottles recorded higher total oxidation values than oils packaged in either lacquered metal cans or amber and green glass bottles. Lacquered metal cans gave the greatest protection against oxidation. Oxidation proceeded faster in cases where the packaging materials were stored in direct sunlight.

Crude palm oil is an orange-red fruit fat derived from the species *Elaeis guineensis*, and it serves as a major source of dietary fat in Nigeria.

Light, oxygen, moisture and heat are some environmental factors that adversely affect the quality of fats and oils both during and after processing. Light is an initiator and a cause of reactions that ultimately result in the deterioration of fats and oils (1). Although fats do not absorb visible light, photosensitized oxidation can be induced by light-absorbing impurities, such as chlorophyll (2-5). It is generally accepted that autoxidation of lipids involves a free radical addition (6-8). The effects of heat, moisture, metals and enzymes on the stability and deterioration of lipids have been reviewed by Billek (9).

Oxygen can gain access to the oil in several ways. Atmospheric oxygen may be entrapped in the oil. Oxygen can also be available in the headspace of the container, and oxygen can permeate the walls of the container. Oxygen causes the formation of hydroperoxides, the components normally associated with rancid oil.

Although heat can also affect the stability of oils, the package can usually afford only minor protection in the form of insulation.

The crude palm oil for retail in Nigeria is packaged in clear or colored glass bottles, metal cans and certain plastics of polyurethane grade. In the open markets, oils packaged in the various containers are stored in direct sunlight, while in the homes of the consumers palm oil in these packaging materials may be stored for months in closed wooden cupboards.

The traditional methods of Production of crude palm oil have generally given way to the mechanized oil mill methods. Several studies have been carried out on the quality of palm oil during harvesting, processing and transportation (10-14), but relatively few packaging studies have been published which deal with the effect of the package system on oil quality. This paper focuses on the ability of the various locally utilized packaging materials to minimize hydrolytic and oxidative deterioration of Nigerian crude palm oil. It addresses storage in direct sunlight, which represents the prevailing condition in the open market, and in closed wooden cupboards, which represents the prevailing condition in the consumers' homes.

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MATERIALS AND METHODS

Freshly produced crude palm oil was purchased from the Abeokuta depot of the Apoje Oil Mill in Ogun State, Nigeria. The initial moisture content of the crude palm oil was determined by using a Dean-Stark apparatus and employing xylene as solvent. Free fatty acid, peroxide values and anisidine values were determined by standard methods (15,16). Total oxidation value was calculated from the peroxide and anisidine values: OV = 2 PV + AV (17).

The packaging materials were filled two-thirds full with about 540 g palm oil, such that the headspace in each container was about 150 ml. The containers were tightly capped and stored without agitation. One set of containers comprising lacquered metal cans (made of mild steel and coated on the inner walls), green and amber glass bottles and transparent glass bottles was stored in direct sunlight at temperatures of 40 ± 1°C, while an equivalent set of containers (also containing oil) was stored in the dark at temperatures of 27 ± 1°C. Enough containers for each oil sample were stored under each storage condition so that no container (once removed from storage and used for analysis) had to be reused. At fourteen-day intervals, oils in the two sets of samples were removed from storage, shaken vigorously and analyzed for the free fatty acid, peroxide and anisidine values.

RESULTS AND DISCUSSION

The initial free fatty acid, peroxide and anisidine values for the crude palm oil were 3.0% expressed as palmitic, 2.2 meq/kg oil and 3.4, respectively. The calculated initial total oxidation value was 7.8, and no moisture was detected.

Tables 1 and 2 show the results obtained for the free fatty acid profile when the various packaging materials containing the crude palm oil are stored for 98 days in direct sunlight at 40 ± 1°C and in darkness at 27 ± 1°C. It was observed that in all cases the free fatty acid of the oils increased throughout the storage period. At the end of the storage period the free fatty acid increased to between 33.2-36.7% from an initial value of 3.0%. Since the initial moisture content of the oil was too low to be detected, and almost all the packaging materials employed will prevent incursion of moisture vapor, it is reasonable to exclude water as the cause of the hydrolysis

TABLE 1

Free Fatty Acid in Crude Palm Oil Stored in Direct Sunlight at 40 ± 1°C

Packaging material	Free fatty acid (% palmitic acid)							
	Storage period (days)							Mean
	14	28	42	56	70	84	98	
Lacquered metal can	3.3	6.5	12.1	17.3	27.8	32.3	33.2	18.93[a]
Amber glass bottle	3.3	6.3	12.2	17.0	30.1	33.5	35.0	19.63[a]
Green glass bottle	3.5	6.7	11.8	17.7	30.2	33.5	34.7	19.73[a]
Clear glass bottle	3.5	6.7	11.8	16.8	30.5	34.0	35.1	19.77[a]
Clear plastic bottle	3.5	7.4	13.9	19.7	32.2	35.1	36.7	21.21[a]

[a]Values in the mean column with the same superscript are not significantly different at 5% level.

TABLE 2

Free Fatty Acid in Crude Palm Oil Stored in the Dark at 27 ± 1°C

Packaging material	Free fatty acid (% palmitic acid)							
	Storage period (days)							Mean
	14	28	42	56	70	84	98	
Lacquered metal can	3.3	6.4	11.9	17.4	28.7	32.0	33.0	18.96[a]
Amber glass bottle	3.2	6.1	11.3	15.3	28.1	32.2	34.0	18.60[a]
Green glass bottle	3.3	6.1	10.7	16.6	28.2	32.7	33.8	18.77[a]
Clear glass bottle	3.3	6.5	11.6	16.7	30.2	33.8	34.9	19.57[a]
Clear plastic bottle	3.7	7.3	12.0	16.6	31.2	34.4	35.5	20.10[a]

[a]Values in the mean column with the same superscript are not significantly different at 5% level.

of the triglycerides. Although it is possible that plastic packaging materials could allow varying amounts of moisture to pass through the walls, the effect of such moisture ingression on the rate of hydrolysis is negligible, as can be seen when comparing the results obtained for the glass bottles and those obtained for the plastic bottle. An analysis of variance was carried out on the data with Duncan's multiple range test. It was applied to determine differences in appropriate means at the 5% level. The results obtained are shown in Tables 1 and 2 under the mean column, and indicate that there is no significant difference in the abilities of the various packaging materials to minimize free fatty acid levels. It seems plausible to suggest that such observed increases in the free fatty acid of the samples investigated are due to the activities of endemic microorganisms, especially thermophilic lipolytic fungi, which may have gained access to the oil either during production or transportation at the oil mill. Coursey and Eggins (18) had reported that microorganisms were responsible for the alteration of palm oil during storage, while Eggins (19) reported the isolation of certain fungi responsible for the deterioration of Nigerian palm oil. More work is needed to ascertain the actual cause of this steady and high rise in free fatty acid during storage, especially in view of the published reports (18-21), some of which are conflicting, on lipase activity and lipolysis during palm oil processing. Traditionally among the Igbo people of eastern Nigeria, the general preference for cooking purposes seems to be crude palm oil having free fatty acid content between 5-7%. This limit is attained within the first month of storage, as can be seen in Table 1. While traditionally a free fatty acid level of between 5-7% may be optimum as a contributor to taste among the local population, oil mills must realize that for unrefined oil destined for export, the international trade expects free fatty acid levels to be reduced to a maximum of 2.5% upon arrival at the shores of the importing country.

Tables 3 and 4 present data obtained for peroxide formation when the crude palm oil samples in various packaging materials were stored for 98 days in direct sunlight at 40 ± 1°C and in darkness at 27 ± 1°C. From an initial value of 2.2 meq/kg, the peroxide values increased to between 17.5-44.0 meq/kg within 98 days. Higher peroxide values (22.4-44.0 meq/kg) were recorded when the packaged oil samples were stored in direct sunlight. Hence, the presence of light accelerates oxidative deterioration of the stored oil. The results agree with the findings of other workers (1,22,23). For any particular storage condition studied, it is found that lacquered metal cans offered the greatest protection to the oil against the deleterious effect of sunlight. Amber and green glass bottles gave fairly good protection although the data provided by the peroxide values do not clearly differentiate the better of the two containers. Whereas the plastic bottles gave the poorest protection to the oils when stored in direct sunlight, there was close parallel in the abilities of the plastic and clear glass bottles to protect the oil from oxidative deterioration when stored in darkness.

In order to ascertain whether or not differences in values are significant, a statistical analysis of variance was carried out on the data with Duncan's multiple range test. It was applied to determine differences in appropri-

TABLE 3

Peroxide Formation in Crude Palm Oil Stored in Direct Sunlight at 40 ± 1°C

Packaging material	Peroxide value (meq 0_2/kg oil)							
	Storage period (days)							Mean
	14	28	42	56	70	84	98	
Lacquered metal can	3.0	5.2	7.0	9.0	18.3	22.2	22.4	12.44[a]
Amber glass bottle	4.0	6.4	8.5	10.4	18.7	24.7	26.0	14.10[a]
Green glass bottle	4.2	6.8	8.9	10.6	22.0	25.5	26.8	14.97[a]
Clear glass bottle	5.0	10.0	14.2	18.3	24.4	30.7	33.8	19.49[a]
Clear plastic bottle	5.4	10.2	15.9	21.5	32.2	34.0	44.0	23.31[a]

[a]Values in the mean column with the same superscript are not significantly different at 5% level.

TABLE 4

Peroxide Formation in Crude Palm Oil Stored in the Dark at 27 ± 1°C

Packaging material	Peroxide value (meq 0_2/kg oil)							
	Storage period (days)							Mean
	14	28	42	56	70	84	98	
Lacquered metal can	3.0	3.0	3.0	3.7	13.0	16.5	17.5	8.53[a]
Amber glass bottle	3.2	3.2	4.8	5.2	15.9	18.0	19.5	9.97[a]
Green glass bottle	3.2	3.2	4.8	5.2	15.9	18.0	21.0	10.19[a]
Clear glass bottle	3.8	5.0	6.0	7.2	19.5	21.0	24.0	12.36[a]
Clear plastic bottle	3.8	5.4	7.2	9.4	21.0	23.5	24.0	13.47[a]

[a]Values in the mean column with the same superscript are not significantly different at 5% level.

TABLE 5

Anisidine Values for Crude Palm Oil Stored in Direct Sunlight at 40 ± 1°C

Packaging material	Anisidine value							
	Storage period (days)							Mean
	14	28	42	56	70	84	98	
Lacquered metal can	6.5	13.3	15.3	17.4	19.0	18.0	20.0	15.64[b,d]
Amber glass bottle	8.0	17.0	18.5	20.0	21.0	21.0	23.0	18.36[b,d]
Green glass bottle	8.5	17.0	19.6	21.8	24.0	23.5	25.0	19.91[b,d]
Clear glass bottle	12.0	28.0	28.0	29.0	29.5	30.0	30.5	26.71[a,c]
Clear plastic bottle	19.0	30.2	31.0	31.6	32.0	33.0	33.0	29.97[a]

Values in the mean column with the same superscript are not significantly different at 5% level.

ate means at the 5% level, and the results are shown under the mean column in Tables 3 and 4. Here again, as in Tables 1 and 2, the values under the mean column indicate that there is no significant difference in the abilities of the various packaging materials to prevent the formation of peroxides in the oil.

The data obtained for the anisidine values are shown in Tables 5 and 6. The anisidine values increased steadily under all packaging and storage conditions studied from an initial value of 3.4 to between 20.0–33.0 for oils stored in direct sunlight, and between 11.6–26.5 for oils stored in the dark. The results are parallel to those obtained for the peroxide values of the oils. Lacquered metal cans gave the lowest anisidine values under all conditions of storage, amber and green glass bottles gave the next set of lowest values, while the clear glass bottles gave the highest set of anisidine values. The statistical data under the mean column in Table 5, carried out by using Duncan's multiple range test, show a significant difference in the anisidine values for oils packaged in clear glass and clear plastic bottles on the one hand, and green and amber glass bottles and lacquered metal cans on the other hand. Thus the crude palm oil packaged in lacquered metal cans or amber and green glass bottles developed significantly lower anisidine values than the oil packaged in clear glass and clear plastic bottles when the oils were stored in direct sunlight at 40 ± 1°C. Similar statistical analysis of data for the oils stored in darkness at 27 ± 1°C, the results

TABLE 6

Anisidine Values for Crude Palm Oil Stored in the Dark at 27 ± 1°C

Packaging material	Anisidine value							
	Storage period (days)							Mean
	14	28	42	56	70	84	98	
Lacquered metal can	4.5	7.6	8.9	10.2	11.2	11.5	11.6	9.36[b,d,e]
Amber glass bottle	6.0	8.5	11.0	13.5	16.3	16.5	17.0	12.69[b,c,e]
Green glass bottle	6.0	9.7	13.0	14.5	17.0	16.5	17.5	13.46[a,c,e]
Clear glass bottle	7.0	10.8	15.5	20.0	23.5	24.0	25.5	18.04[a,c]
Clear plastic bottle	8.0	13.0	16.5	20.3	24.8	25.3	26.5	19.20[a]

Values in the mean column with the same superscript are not significantly different at 5% level.

TABLE 7

Total Oxidation Values for Crude Palm Oil Stored in Direct Sunlight at 40 ± 1°C

Packaging material	Total oxidation (twice peroxide value + anisidine value)							
	Storage period (days)							Mean
	14	28	42	56	70	84	98	
Lacquered metal can	12.5	23.7	29.3	35.4	55.6	62.4	64.8	40.53[b,c]
Amber glass bottle	16.0	29.8	35.5	40.8	58.4	70.4	75.0	46.56[b,c]
Green glass bottle	16.9	30.6	37.4	43.0	68.0	74.5	78.6	49.86[a,c]
Clear glass bottle	22.0	48.0	56.4	65.6	78.3	91.4	98.1	65.69[a,c]
Clear plastic bottle	29.8	50.6	62.8	74.6	96.4	101.0	121.0	76.60[a]

Values in the mean column with the same superscript are not significantly different at 5% level.

TABLE 8

Total Oxidation Values for Crude Palm Oil Stored in the Dark at 27 ± 1°C

Packaging material	Total oxidation (twice peroxide value + anisidine value)							
	Storage period (days)							Mean
	14	28	42	56	70	84	98	
Lacquered metal can	10.5	13.6	14.9	27.6	37.2	44.5	46.6	27.84[a]
Amber glass bottle	12.4	14.9	20.6	23.9	48.1	52.5	56.0	32.63[a]
Green glass bottle	12.4	16.1	22.6	24.9	48.8	52.5	59.5	33.83[a]
Clear glass bottle	14.6	20.8	27.5	34.4	62.5	66.0	73.5	42.76[a]
Clear plastic bottle	15.6	23.8	30.9	39.1	66.8	72.3	74.5	46.14[a]

[a]Values in the mean column with the same superscript are not significantly different at 5% level.

of which are shown under the mean column in Table 6, shows that the oil packaged in clear plastic bottles developed a significantly higher anisidine value than the values obtained for oils packaged in amber glass bottles and lacquered metal cans. While there was no significant difference in the anisidine values developed in the oils packaged in lacquered metal cans or amber and green bottles, the oil in the lacquered metal cans developed a significantly lower anisidine value than that obtained for the oil stored in clear glass bottles.

The combined effect of the peroxide and anisidine values of oils can be evaluated by calculating the total oxidation values as follows: Totox = twice peroxide value + anisidine value (17,24). The results obtained are shown in Tables 7 and 8. The values under the mean column in Table 8 show that there is a significant difference in the total oxidation values for oils packaged in lacquered metal cans and amber, green and clear glass bottles on the one hand, and in the values for oils packaged in clear plastic bottles on the other hand. It is clear that oxidative deterioration of the crude palm oil proceeded significantly faster when the oil was packaged in clear plastic bottles and stored in direct sunlight at 40 ± 1°C than when the oil was packaged in any of the other containers used in the studies. The glass bottles are transparent to sunlight but impermeable to oxygen, whereas the clear plastic bottle is transparent to sunlight and probably also permeable to oxygen. For conditions when the oils in the various containers were stored in the dark at 27 ± 1°C, the results of the statistical analysis shown in Table 8 indicate that there is no significant difference in the total oxidation values obtained for the oils in all the containers used.

This study has shown that the Nigerian crude palm oil used for these experiments is affected by light and oxygen in much the same way as other vegetable fats and oils are affected. In order to minimize oxidative deterioration of the oil after production and distribution, it is necessary that the widely prevalent practice whereby retailers expose the palm oil to direct sunlight in the markets be discouraged. Also, packaging the oil in clear plastic bottles enhances oxidative deterioration of the oil. Lacquered metal cans or amber and green glass bottles would be preferable as suitable packaging systems, while clear glass bottles could be tolerated.

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