Palm Oil Quality in Different Packaging Materials Sensory and Physicochemical Parameters

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ABSTRACT: Changes in stored palm oil were studied under three conditions in seven different structured film packages. Six chemical parameters including moisture, free fatty acids (FFA), peroxide values (PV), Kreis tintometric and absorbance/transmittance values, and sensory profiling were examined on a set of 13 odor notes at periodic intervals until the end of the shelf life of the oil or the end of 180 d. Correlation among all the parameters was determined. PV showed high correlations with Kreis test values (as absorbance at 547 nm), while Kreis test values correlated with heated oil and rancid and musty odors. The sensory attributes showed poor correlation among themselves indicating their independent identity and justifying their inclusion in the odor profile descriptors. FFA development positively correlated to harsh odor note. Among the sensory attributes of odor, distinct segregation of desirable notes from defective notes was used to classify different quality grades. Correlation between physicochemical and odor profiles of palm oil suggests that the Kreis test as optical density had the potential to predict deterioration in oil quality. Principal component analysis was carried out on 6 chemical parameters, 13 sensory attributes, and 2 physical properties of the films. The total dimensionality was reduced to 16 variables, and the pathway of quality change during oil storage was traced. Damage to oils was more pronounced when they were stored under 30–40% relative humidity (RH) and 45°C, showing a combined effect of moisture and temperature greater than high RH alone (92%), even at lower temperatures of 27°C. The quality deterioration was comparatively less in films containing polyamide as one of the layers, and leakage rates were minimal in films containing ethylene acrylic acid as the sealant layer.

Paper J9154 in *JAOCS 78*, 257–264 (March 2001).

KEY WORDS: Correlations, FFA, Kries test, odor quality, packaging film, palm oil, PV, principal component analysis, storage.

Palmolein, popularly called palm oil, has become one of the major edible oils in Indian homes in recent years. It has long been in use in Malaysia, Indonesia, and some other southeast Asian countries. The quality of palmolein is based on physical parameters such as color (the raw oil is rich in carotenoids), specific gravity and refractive index (winterized fraction of crude oil), proportion of palmitodiolein (mp 19°C) and stearine (mp 35°C) from the triglyceride of the crude oil, and the presence of other impurities.

In edible oils, the susceptibility to oxidation increases geometrically in relation to the degree of unsaturation. Because palm oil is high in oleic acid (*ca.* 35%), low in linoleic acid (10%), and linolenic acid is almost negligible (0.2%), it is not very susceptible to oxidation (1). Temperature of storage also has an effect on oxidative changes, as oxidation involves a low energy threshold (2), and the energy required for autooxidation is as low as 20 kJ/mol for the first step and 40 kJ/mol for the second step of oxidation. The reaction rate, however, is not significantly diminished by lowering storage temperature (3).

In monitoring the quality of oils, one of the specifications for odor and taste is the freedom from foreign or rancid odor (4). Limits for chemical tests are specified by Codex Alimentarius in terms of free fatty acids (FFA), peroxide value (PV), iodine value, and moisture. The usefulness of these tests was reviewed by Labuza (5). Recently, the Kreis test for palm oil was included with specifications where the degree of rancidity is determined by measuring the red color using a Lovibond tintometer. A maximum value of 8 is fixed by standards (6). This measure by tintometry involves matching the redness intensity in the field by the naked eye and is rather subjective, hence, measure of optical density at specific wavelengths (7) was adopted in this study.

In sensory methods, rancidity and deviations in quality are used to assign scores by a flavor profile panel according to the AOCS method (8) that differentiates "excellent" from "repulsive" grades. AOCS recommends testing the vegetable oils by mouth at 50°C and also combines flavor rating with scoring. The method is useful for routine sensory tests to look for rancidity but does not identify early stages of quality deterioration. Each edible oil has to be identified by its odor profile to grade it on odor quality as noticed by consumers (9). The sensory perception of initial breakdown products is a good indicator of the onset of oxidation as they have low flavor thresholds. The possible origin of aldehydes, at 0.09 ppm down to 0.00035 ppm, from various unsaturated acid hydroperoxides and their flavors were well illustrated by Maera (10). These scission products of fatty acids of palm oil (C16:1 and C18:2) as short-chain esters, oxoesters, or dicarboxylic acids are perceived better at elevated temperatures (11). Identification of breakdown products of oil by its odor profile is useful because nasopharyngeal response (odor) is

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more specific than gustatory response (tasting) (12,13).

In India, oil is stored and transported only in metal containers of 15 kg and above. The consumers who buy oils in lesser quantities have to carry their own containers to buy the oil from the vendor. This is very inconvenient and has many disadvantages. So, it is essential to design a functional and economical package for oil storage and distribution throughout the country. Packaging and storage studies of palm oil in seven different structured films under three storage conditions were carried out in order to design a suitable package for oil. In the present study the physicochemical properties and quality changes of palm oil in the various storage conditions were monitored during period withdrawals.

EXPERIMENTAL PROCEDURES

Palm oil. Refined palm oil packed in 8-L tins was imported from Malaysia. The initial quality was assessed and found to be within the prescribed limits of PV, FFA, Kreis value as optical density/transmission at 547 nm, and percentage moisture content. Initial color of the oil was measured by Lovibond tintometry as red units. The initial odor profile was also determined.

Packaging of experimental units. To select a functional and economical packaging material for palm oil that could be marketed through the public distribution system in India, the oil was repacked in units of 200 g in flexible pouches (160 × 100 mm) made of seven different packaging materials. Seven sandwiched/coextruded films that varied in their physicochemical properties were selected. They had the following configurations: (i) polypropylene (PP)/bonding agent (ba)/polyamide (PA)/ba/ethylene acrylic acid (EAA) (white); (ii) linear low-density polyethylene (LLD)/ba/PA/ba/EAA (white); (iii) high-density polyethylene (HD)/low density polyethylene (LD)/EAA (yellow); (iv) HD/ba/PA/ba/EAA (yellow); (v) HD/LD/HD (yellow); (vi) LLD/ba/PA/ba/EAA (green); and (vii) LLD/LD/HD/HD/EAA (yellow).

One hundred oil pouches containing 200 g of oil were packed in commercially used five-ply B-flute corrugated fiberboard boxes and closed with PP straps across the length and width of the boxes. These boxes were placed on a vibration table and subjected to repetitive shock tests to simulate the condition of transportation with the following standard test parameters: acceleration, 981 cm/s^2 (1 g); amplitude, 1.25 cm; duration, 30 min (14). The packages were evaluated for leakage by visual inspection, and intact pouches were taken for further study.

Storage condition and withdrawal schedule. India has a wide range of climatic conditions across the length and breadth of the country. The following storage conditions were selected to represent different climatic regions: (i) 92% RH, 38°C, accelerated storage condition simulating coastal area; 10 weekly withdrawals (72 d); (ii) 30–40% RH, 45°C, accelerated storage conditions simulating desert and summer conditions in some regions, withdrawals once in 10 d up to 70 d and monthly to 160 d (10 withdrawals); (iii) 65% RH, 27°C, Indian standard conditions (15), withdrawals once every 2 wk up to 210 d (15 withdrawals).

Physical and chemical tests. PV, FFA, and moisture content were estimated per the Bureau of Indian Standards methods (16). Kreis value, in a Lovibond tintometer, was measured as number of red units according to British standards (17) and expressed as K-LT. In this study the absorbance and transmittance were measured at 547 nm and expressed as K-OD and K-TR, respectively. These parameters were assessed both initially and at each periodic withdrawal.

Water vapor transmission rate (WVTR) and oxygen transmission rate (OTR) were tested for each packaging material according to ASTM standards (18).

Odor profile analysis. An odor profile was done after dispensing the samples in a citrate-phosphate buffer medium at room temperature. The initial pH of the media was selected by testing at two levels, acidic (pH 4.2) and neutral (pH 7.8). From the response of 30 untrained panelists, the acidic pH was better at bringing out the odor notes of oil. At this pH a number of palm oil samples, from fresh to stored, were examined by 20 selected panelists familiar with odor testing procedures. Oil (10 mL) was dispersed in 100 mL of buffer solution in a 250-mL conical flask and presented to the panelists along with a blank. Testing was carried out following the norms of sensory analysis procedures with coded samples and in individual booths. From the 20 odor descriptors generated, 13 descriptors used by more than one-third of the panelists were used to form the score card. A panel trained over repeated tests to identify intensity level of the descriptors was used in the final study. Panelists were required to mark the intensity of the odor notes using a 5-point scale, where 1 = none and 5 = very strong, as indicated in the score card. Eight to 10 samples were analyzed in each panel session. Samples were evaluated in duplicate by 13–15 panelists, and mean intensity values were calculated at each withdrawal period.

Statistical analysis. Means and standard deviations for each of the measured attributes over the storage periods were used in the statistical analysis. Pearson's correlation coefficients between each pair of attributes (variables) were estimated. The multivariate analysis of data by principal component analysis (PCA) was run on the physicochemical data and the means of the odor profile data over each storage period and each sample. Each principal component was a linear combination of all the variables. The first principal component accounted for the largest proportion of variance followed by the second and then the third and so on. Each was orthogonal to the others. The factor pattern and cumulative trace percentage were further segregated to facilitate dimensionality reduction (19). Pathway tracing was accomplished using the standardized scores in PCA space for each packaging film with the underlying PCA mapping the vectors shown only as labeled descriptors to facilitate visualization of the graph.

RESULTS AND DISCUSSION

The free choice odor profile provided 20 descriptors. From this, each of the terms used by more than one-third of the panel was included in the score card and comprised 13 descriptors for palm oil. They are nutty, earthy, green, grassy, haylike, sweet, cooking oil, hydrogenated fat, heated oil, harsh, reverted, rancid, and musty. Provision was also made for bland or almost odorless samples because the freshly refined oil is expected to be so.

Physicochemical tests. Table 1 gives the initial values and the number of days required to reach the specified maximum value of Indian Standards. The data indicates that the initial levels of moisture, FFA, PV, Kreis (K-LT), and sensory rating were 0.06%, 0.12%, 2.8, 2.4, and "very good," respectively. They corresponded to permitted limits (20) and reached the maximal limits of 0.10%, 0.25%, 10, 8, and "poor," respectively, on different days. Moisture crossed the maximal permitted value of 0.10% in 10 d at 38°C and 92% RH in all the packaging materials. At 27°C and 65% RH, it required 18–33 d in packaging materials 2 to 7 and 94 d in packaging material 1. At 45°C and 30–40% RH, more than 69 d were required for all the samples.

FFA. The limit of FFA of 0.25% was crossed after 41 d at 38°C and 92% RH storage, after 67–80 d at 45°C and 30–40% RH, and beyond 121 d at 27°C and 65% RH. A combined effect of temperature and RH increased FFA, but the more dominant effect was the moisture level in the oil.

PV and Kreis values. PV crossed the maximal limit of 10 in 26–40 d when stored at 45°C and 30–40% RH or 38°C and 92% RH. It took 76–94 d at 27°C and 65% RH storage to cross the PV of 10. Hence, it can be noted that both temperature and RH influenced the buildup of PV. Kreis values showed a similar trend.

Odor quality. The odor quality ratings showed quite a different picture. Depending on the packaging material, it took 30–70 d to deteriorate to "poor" from "fair" at 45°C and 30–40% RH, 38–73 d at 38°C and 92% RH, and more than 121 d at 27°C and 65% RH. This is in line with observations reported on moisture sorption behavior of oils and fat by Indiramma and Kumar (21), where water-holding capacity of oils increased with an increase in temperature and damage to the oil was more severe.

Correlations. The correlation analysis (based on the significant correlations $P \le 0.05$) between physicochemical and sensory data (based on 380 data points) is shown in Table 2. PV correlates negatively with FFA, K-LT, K-OD, and K-TR and positively with rancid and musty notes. FFA has positive correlations with K-LT, moisture %, and rancid and musty notes and a negative relationship with only K-TR. K-LT correlates negatively with K-OD and K-TR but positively with rancid and musty notes. K-OD correlates positively again with rancid and musty notes and negatively with K-TR. K-TR correlates negatively with rancid, musty, and cooking oil

TABLE 1
Number of Days Required to Reach Rejection Limits[a]

Storage conditions	Packaging[b] material	Moisture (%)	FFA (%)	PV	Kreis (LT)	Sensory grade
Initial values		0.06%	0.12%	2.8	2.4	Very good
92% RH, 38°C						
	PP/ba/PA/ba/EAA	<10	>45	31	>45	>73
	LLD/ba/PA/ba/EAA	<10	>41	33	>46	>73
	HD/LD/EAA	<10	>41	32	>46	>45
	HD/ba/PA/ba/EAA	<10	>41	30	>46	>59
	HD/LD/HD	<10	>41	38	>45	>38
	LLD/ba/PA/ba/EAA	<10	>41	40	>50	>59
	LLD/ba/PA/ba/EAA	<10	>41	34	>45	>38
30–40% RH, 45°C						
	PP/ba/PA/ba/EAA	>69	>72	31	>43	>60
	LLD/ba/PA/ba/EAA	>69	>76	40	>47	>60
	HD/LD/EAA	>69	>73	26	>32	>32
	HD/ba/PA/ba/EAA	>69	>80	30	>40	>60
	HD/LD/HD	>69	>72	34	>38	>32
	LLD/ba/PA/ba/EAA	>69	>69	32	>42	>60
	LLD/ba/PA/ba/EAA	>69	>67	27	>30	>30
65% RH, 27°C						
	PP/ba/PA/ba/EAA	34	>121	76	>121	>121
	LLD/ba/PA/ba/EAA	18–33	>121	85	>121	>121
	HD/LD/EAA	18–33	>121	78	>121	>121
	HD/ba/PA/ba/EAA	18–33	>121	84	>121	>121
	HD/LD/HD	33	>121	94	>121	>121
	LLD/ba/PA/ba/EAA	18	>121	93	>121	>121
	LLD/ba/PA/ba/EAA	18	>121	93	>121	>121
Rejection limit[a]		0.10%	0.25%	10	8	Poor

[a]Rejection limits according to Indian Standards (15).
[b]PP, polypropylene; ba, bonding agent; PA, polyamide; EAA, ethylene acrylic acid; LLD, linear low density polyethylene; HD, high density polyethylene; LD, low density polyethylene; FFA, free fatty acids; PV, peroxide value; LT, Lovibond tintometer.

TABLE 2
Correlation Matrix of Physicochemical and Sensory Data over Storage in Different Packaging Materials[a,b]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1.00																				
2	–0.77	1.00																			
3	–0.05	0.07	1.00																		
4	–0.02	0.07	–0.66	1.00																	
5	0.06	0.09	–0.93	0.54	1.00																
6	–0.09	0.11	–0.93	0.51	–0.98	1.00															
7	0.07	–0.10	–0.89	–0.56	–0.93	–0.97	1.00														
8	–0.01	0.04	–0.09	0.58	–0.24	–0.27	0.21	1.00													
9	0.01	0.00	–0.07	0.08	–0.06	–0.11	0.12	0.22	1.00												
10	–0.03	0.08	–0.21	–0.19	–0.22	–0.25	0.30	–0.01	0.27	1.00											
11	0.22	–0.22	–0.36	–0.19	–0.27	0.28	0.25	0.10	0.30	0.06	1.00										
12	0.10	–0.11	0.02	0.10	0.08	0.05	–0.11	0.12	0.23	–0.20	0.30	1.00									
13	0.12	–0.10	–0.18	–0.10	–0.22	–0.22	0.23	0.09	0.03	–0.07	0.01	0.14	1.00								
14	0.08	–0.04	–0.11	0.28	0.00	0.00	0.01	–0.28	–0.15	–0.10	0.20	0.19	–0.16	1.00							
15	–0.08	–0.01	0.31	0.34	0.37	0.40	–0.47	0.08	–0.01	–0.22	–0.05	0.18	–0.15	–0.02	1.00						
16	–0.06	0.71	0.06	0.00	0.11	0.11	–0.11	–0.17	–0.06	–0.066	–0.03	–0.08	–0.08	0.25	–0.09	1.00					
17	–0.04	0.05	0.48	0.11	0.54	0.51	–0.43	–0.22	–0.13	–0.12	–0.09	0.02	–0.14	–0.05	0.21	0.06	1.00				
18	–0.11	0.09	0.34	0.25	0.29	0.29	–0.23	0.01	–0.05	–0.05	–0.11	0.04	–0.07	–0.08	0.07	–0.03	0.26	1.00			
19	–0.14	0.25	0.23	0.35	0.19	0.18	–0.17	0.14	–0.04	–0.04	–0.07	–0.05	–0.05	–0.06	–0.11	–0.02	–0.05	0.21	1.00		
20	–0.13	0.17	0.78	0.41	0.77	0.76	–0.69	–0.20	–0.11	–0.15	–0.35	–0.02	–0.13	–0.09	0.18	–0.03	0.52	0.33	0.26	1.00	
21	–0.07	0.14	0.73	0.40	0.77	0.74	–0.64	–0.20	–0.04	–0.15	–0.26	–0.10	–0.16	–0.16	–0.18	–0.19	0.61	0.33	0.25	0.71	1.00

1. WVTR
2. OTR
3. PV
4. FFA
5. K-LT
6. K-OD
7. K-TR
8. MOISTURE %
9. NUTTY
10. EARTHY
11. GREEN
12. GRASSY
13. HAYLIKE
14. SWEET
15. COOKING OIL
16. HYDROGENDATED OIL
17. HEATED OIL
18. HARSH
19. REVERTED
20. RANCID
21. MUSTY

[a]WVTR, water vapor transmission rate; OTR, oxygen transmission rate; PV, peroxide value; FFA, free fatty acids; K-LT, Kreis value (Lovibond tintometer); K-OD, absorbance; K-TR, transmittance.
[b]Underlined correlations were significant at 5% level.

TABLE 3
Factor Pattern for First Three Factors

Parameter[a]	Factors[b]		
	1	2	3
WVTR	–0.15	–0.45	0.61
OTR	0.18	0.47	–0.64
PV	0.35	0.03	0.11
FFA	0.61	0.53	0.41
K-LT	0.96	-0.12	0.08
K-OD	0.96	-0.13	0.04
K-TR	–0.92	0.11	–0.12
Moisture %	–0.16	0.72	0.44
Nutty	–0.14	0.29	0.32
Earthy	–0.28	0.18	–0.23
Green	–0.37	–0.18	0.40
Grassy	0.02	–0.09	0.55
Hay like	–0.24	0.07	0.19
Sweet	–0.07	–0.58	–0.10
Cooking oil	0.40	0.00	0.32
Hydrogenated fat	0.11	–0.23	–0.31
Heated oil	0.59	–0.29	-0.07
Harsh	0.39	0.16	–0.02
Reverted	0.27	0.43	–0.10
Rancid	0.84	0.10	–0.09
Musty	0.82	–0.05	–0.10
% Trace	30.67	10.03	9.92

[a]See Table 2 for abbreviations.
[b]Larger loading was observed for the underlined vectors.

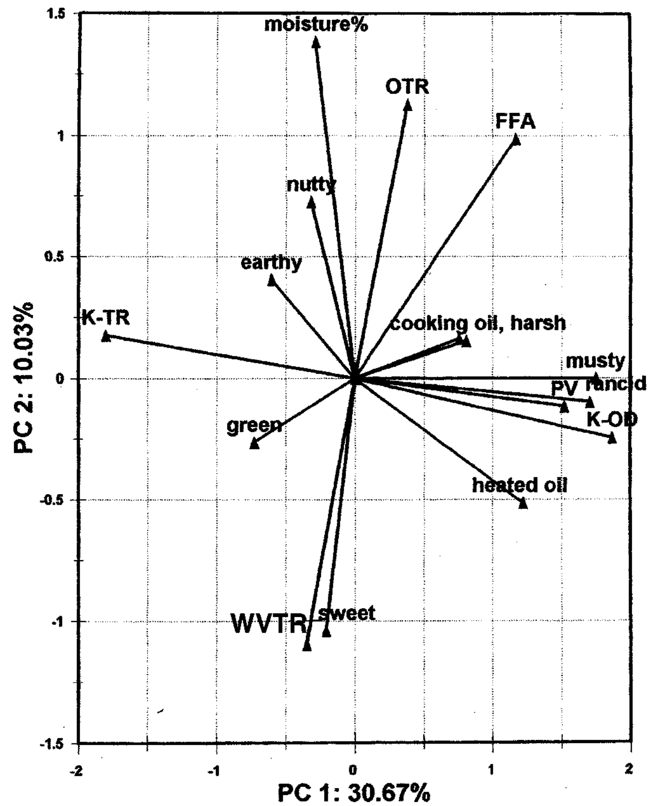

FIG. 1. Principal components (PC) mapping of 16 variables of palm oil projected onto two planes. PV, peroxide value; OTR, oxygen transmission rate; FFA, free fatty acids; K-OD, absorbance at 547; WVTR, water vapor transmission rate; K-TR transmission at 547 nm.

notes. Heated oil note, an early indicator of oil deterioration, also positively correlates with rancid and musty notes. Rancid and musty notes are also interrelated. No significant correlations were found among other attributes such as nutty, earthy, green, grassy, haylike, sweet, cooking oil, hydrogenated oil, harsh, and reverted odor notes.

PCA. The combined analysis of physicochemical and sensory data given in Table 3 shows that the first component root accounted for 30.6% of the variation of the data and included the variables K-OD, K-LT, K-TR, rancid, musty heated oil, FFA, cooking oil, and PV and the second component, which accounted for 10.03% of the variation, was composed of the variables moisture, sweet, FFA, OTR, and WVTR. The third component root was composed of grassy, WVTR, OTR, moisture, green, and FFA variables and accounted for 9.92% of variation. The rest of the roots were below 10% and hence do not contribute significant variations. The first three cumulatively accounted for 50.61% of the total of 86.43% traced from 10 roots. They are further discussed in this work.

As is evident from Table 3 and Figure 1, the important factors are OTR, FFA, cooking oil, harsh, musty, rancid, PV, K-OD, and heated oil on the positive side and moisture %, musty, earthy, K-TR, green, sweet, and WVTR on the negative side. Other factors have very small loadings and hence do not play a significant role. Though nutty, earthy, green, and cooking oil dip in factor loadings, they are nevertheless important as they represent good initial quality of oil. Hence, these factors have been taken into the PCA mapping for pathway tracing during storage in which quality changes from the initial quality are important.

The attribute K-LT was omitted as it did not provide extra information compared to K-OD, the determination of which was easier and more reproducible. The dimension was reduced from 21 to 16 variables based on these considerations. The characterization and classification of the pattern that surfaced from PCA is given in Figure 1. The directional vectors of the 16 major parameters show their significance (depicted by length) and correlations or orthogonality (depicted by positioning).

Pathway tracing of changes in quality in different packaging materials. With PCA mapping, the pathway of quality changes can be traced starting from the initial position, considered as "very good" with high green note, moderate sweet and earthy note, low intensity of all the other odor notes, and low PV, FFA, and K-OD. For ease of reading and clarity, the directional vectors were not drawn but their positions were indicated at their labeled end points.

Film 1, PP/ba/PA/ba/EAA (Fig. 2), showed that samples under 30–40% RH and 45°C could remain in the same quadrant up to 40 d. With increase in heated oil, harshness, and odor notes, it moved and finally occupied the position high in K-OD, PV, and musty and rancid odor by 69 d. The oil could therefore be considered to have above average quality up to 53 d. Deterioration of the oil in 92% RH and 38°C followed a different pattern. The samples became dominant in earthy and nutty note by 45 d and below average in quality by 66 d. The room temperature-stored sample remained in the same quad-

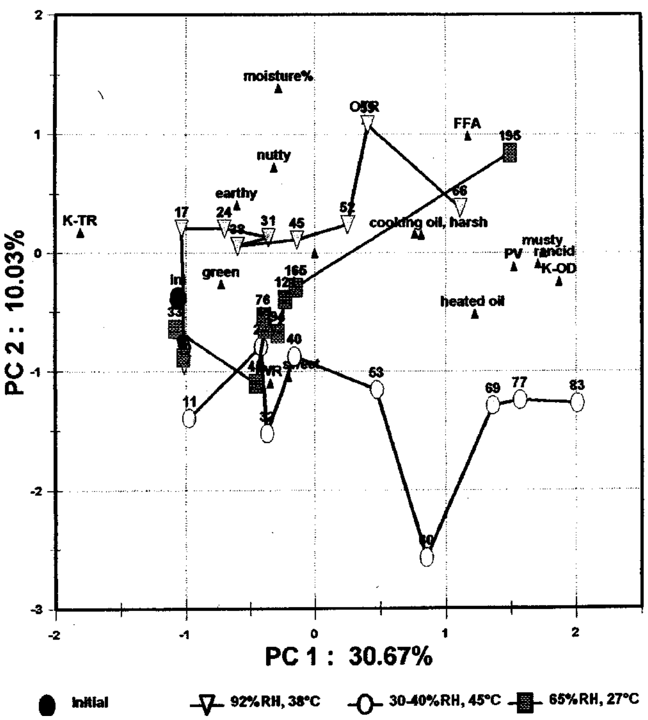

FIG. 2. Pathway tracing of palm oil stored in packaging film 1, PP/ba/PA/ba/EAA (white), pouches. Initial conditions are marked "ini" and the storage period is in days, as labeled. Principal component analysis vectors limits are as labeled. PP, polypropylene; ba, bonding agent; EAA, ethylene acrylic acid; RH, relative humidity; PA, polyamide; for other abbreviations see Figure 1.

rant as the initial sample up to 180 d.

Film 2, LLD/ba/PA/ba/EAA (Fig. 3), showed a similar pattern to the first packaging material under the first two storage conditions; deterioration was seen distinctly beyond 60 d. In ambient stored samples, the oil samples maintained good quality throughout the entire storage period.

Film 3, HD/LD/EAA (Fig. 4), showed the earliest signs of deterioration and all the samples moved away from their initial position by the end of 20 d. The undesirable odor notes, moisture level, FFA, and K-OD were recorded by the end of 40 d, which was when the oil was rated as poor.

Film 4, HD/ba/PA/ba/EAA (Fig. 5), allowed the oil to retain its original quality at room temperature until the end of the study, while the other two storage conditions moved the oil toward "below average" after 53 d from that of packaging film 1.

Film 5, HD/LD/HD (Fig. 6), was the least protective of quality in 30–40% RH and 45°C, where a very quick deterioration to harsh, musty notes and high K-OD and PV developed. Even in ambient temperature, the film could only protect the oil up to 30 d, when it was rated as "fair-average" quality. The damage in the 92% RH and 38°C stored sample was also severe by the end of 45 d.

Film 6, LLD/ba/PA/ba/EAA (Fig. 7), did protect the oil at ambient temperature and all the odor notes required in a very good grade sample were retained up to 165 d. However, the other two conditions followed the same pattern of deteriorative changes beyond 53 d as exhibited in packaging film 1.

Film 7, LLD/LD/HD/HD/EAA (Fig. 8), demonstrated simi-

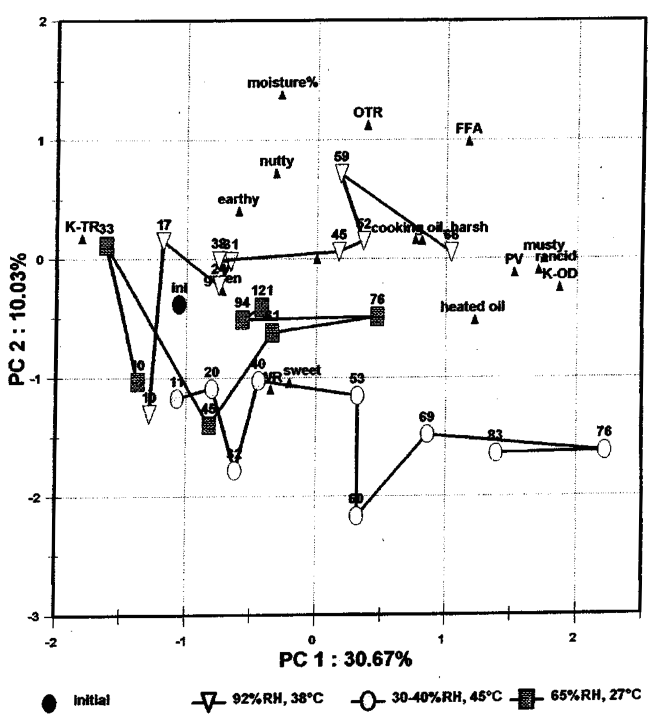

FIG. 3. Pathway tracing of palm oil stored in packaging film 2, LLD/ba/PA/ba/EAA, pouches. Initial conditions are marked "ini" and the storage period is in days, as labeled. Principal component analysis vectors limits are as labeled. LLD, linear low-density polyethylene; see Fig-

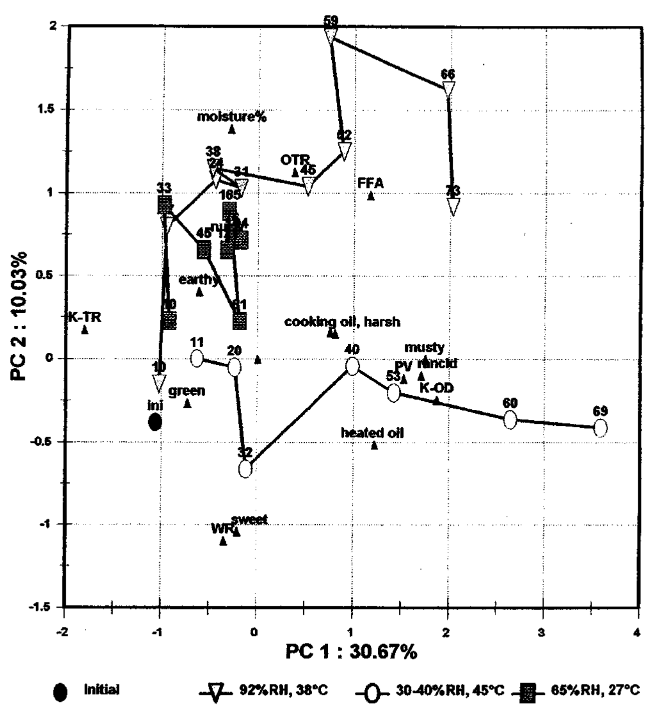

FIG. 4. Pathway tracing of palm oil stored in packaging film 3, HD/LD/EAA pouches. Initial conditions are marked "ini" and the storage period is in days as labeled. Principal component analysis vectors limits are as labeled. HD, high-density polyethylene; LD, low-density polyethylene; see Figures 1 and 2 for other abbreviations.

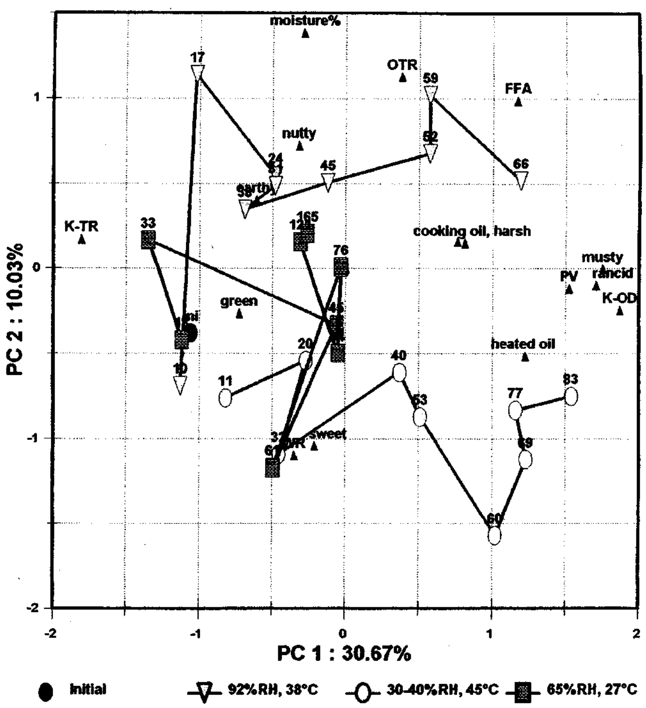

FIG. 5. Pathway tracing of palm oil stored in packaging film 4, HD/ba/PA/ba/EAA pouches. Initial conditions are marked "ini" and the storage period is in days as labeled. Principal component analysis vectors limits are as labeled. See Figures 1, 2, and 4 for abbreviations.

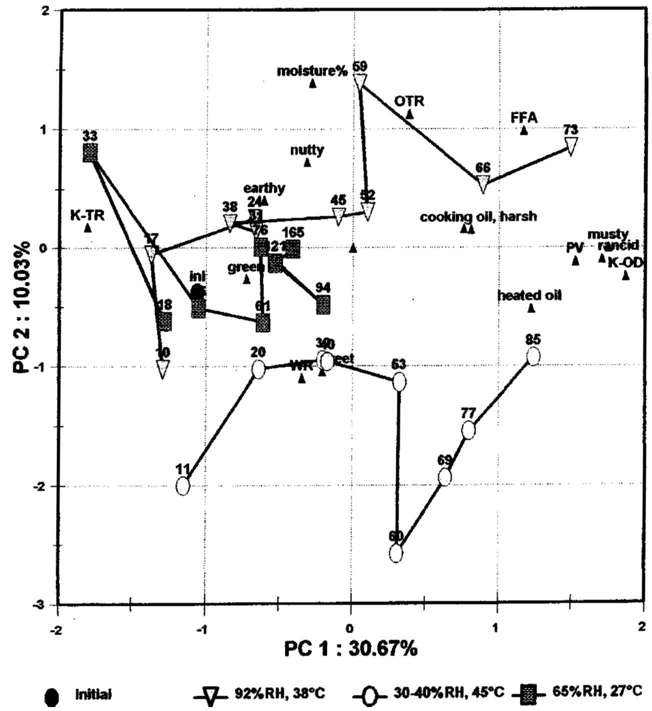

FIG. 7. Pathway tracing of palm oil stored in packaging film 6, LLD/ba/PA/ba/EAA pouches by days. Initial conditions are marked "ini" and the storage period is in days as labeled. Principal component analysis vectors limits are as labeled. See Figures 1–3 for abbreviations.

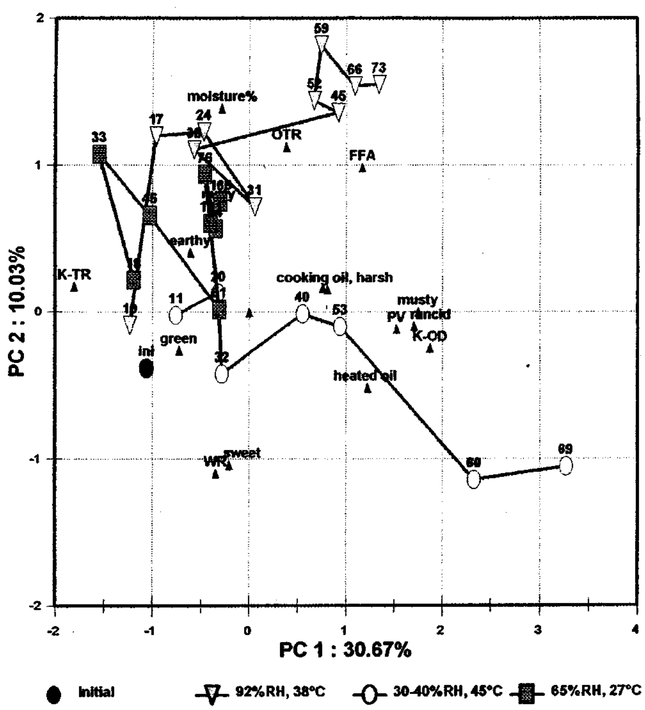

FIG. 6. Pathway tracing of palm oil stored in packaging film 5, HD/LD/HD (green) pouches. Initial conditions are marked "ini" and the storage period is in days as labeled. Principal component analysis vectors limits are as labeled. See Figures 1, 2, and 4 for abbreviations.

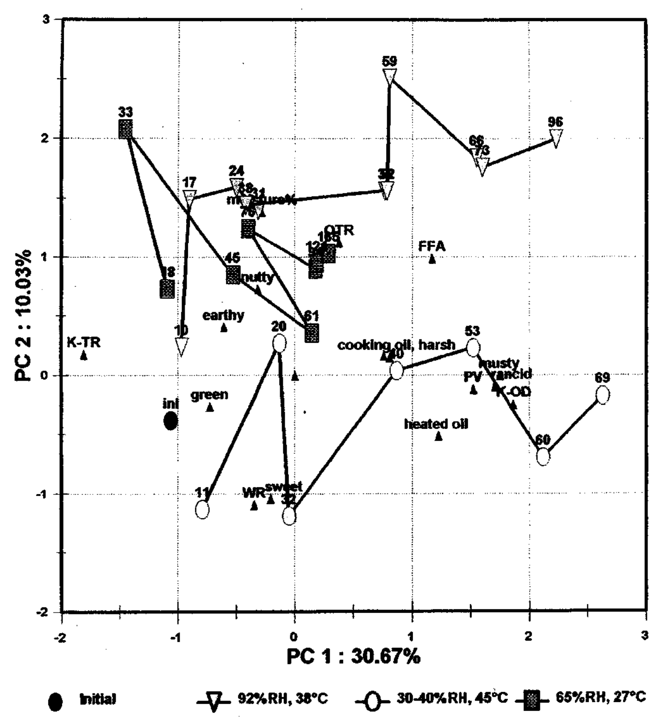

FIG. 8. Pathway tracing of palm oil stored in packaging film 7, LLD/ba/PA/ba/EAA pouches. Initial conditions are marked "ini" and the storage period is in days, as labeled. Principal component analysis vectors limits are as labeled. See Figures 1–3 for abbreviations.

lar quick and drastic quality changes in oil in sensory quality, and chemical parameters as film 3. The least damage was in the ambient condition stored sample, but even this sample changed from initial position after only 18 d. From this analysis, the order profile of palm oil indicative of different grades is as follows: very good, almost odorless, traces of earthy, sweet odor; good, mildly nutty, earthy, green, and haylike odor; fair, harsh, heated oil, and green odor; poor, dominantly heated oil, harsh, and clearly rancid odor; very poor; rancid, musty odor.

Packaging material 5 gave the poorest shelf life. Non-EAA and non-PA films with poor sealability and a poor barrier for oxygen do not provide functional packaging for oils. Films 3 and 7, which had EAA but not PA, also behaved in a similar way and shelf life was inferior to the PA-sandwiched films.

ACKNOWLEDGMENTS

The authors wish to acknowledge the participation of Dr. Narayaman Balasubramanyam and Putta Veeraraju, scientists, in planning the storage studies.

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[Received March 1, 1999; accepted November 15, 2000]