Faculty of Natural and Applied Sciences Journal of Scientific Innovations
Print ISSN: 2814-0877 e-ISSN: 2814-0923
www.fnasjournals.com
Volume 7; Issue 1; December 2025; Page No. 57-64.
DOI: https://doi.org/10.63561/fnas-jsi.v7i1.1103

Effects of Allura Red Dye Additive on Stability and Shelf Life of Palm Oil Sold in Selected Market in Obio/Akpor Local Government, Rivers State, Nigeria.

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Abstract
The increasing demand for palm oil in Nigeria has led to rising adulteration practices, particularly the use of synthetic dyes such as Allura Red to enhance visual appeal. This study examined the effects of Allura Red dye on the stability and shelf life of palm oil sold in selected market in Obio/Akpor Local Government Area, Rivers State, Nigeria. Key chemical quality indicators—moisture content, free fatty acid (FFA), acid value, and peroxide value—were evaluated to determine how dye addition influences oil deterioration. A 3 × 2 factorial experimental design was used, comparing palm oil samples with and without Allura Red dye through titration and oven-drying analytical methods. Results showed that untreated samples from the oil mill (OM) and the homemade control samples (CS) had lower moisture content than the dye-spiked samples (SS1–SS4), indicating better quality and longer shelf stability. The increased moisture in spiked samples suggests greater susceptibility to microbial growth and oxidative degradation. The untreated samples (OM1–OM4) had the lowest FFA values (0.034% and 0.07%), whereas the spiked samples recorded significantly higher FFA values (0.34% and 0.45%), reflecting faster hydrolysis. Similarly, acid values were higher in all spiked samples compared to un-spiked ones. Although peroxide values were generally higher in the dye-treated samples, the homemade control samples (CS1–CS4) exhibited the highest values (27.5 meq/kg and 17.5 meq/kg), indicating extremely poor quality likely caused by crude processing methods. The elevated FFA, acid value, and peroxide values in dyed samples indicate accelerated oxidation and reduced shelf stability. The study shows the need to prohibit the use of Allura Red dye in palm oil and enforcing stricter quality control and regulatory measures to prevent dye adulteration. Increased consumer awareness is also necessary to discourage the purchase of dyed oils and promote safer sourcing of edible palm oil from verified oil mills. Strengthening government regulations on food additives is essential to ensure the safety and quality of palm oil sold in local markets.

Keywords: Oil palm, Palm Oil, Allura red dye additive, Moisture content, Free fatty acid, Peroxide value, Acid value

Introduction
Oil palm (*Elaeis guineensis*) is a tropical tree which is cultivated for its fruit bunches whose flesh and seeds gives oils (palm oil and palm kernel oil). According to the Food and Agriculture Organization (FAO) publication, “the oil palm (Elaeis guineensis Jacq.) is a specie of palm that produces two types of edible vegetable oil: palm oil from the mesocarp and palm kernel oil from the kernel” (FAO, 2023; FAO, 2024). Processing of oil palm fruit is the process by which palm fruits is processed into palm oil through sterilization, trenching or stripping, milling and digestion, pressing and clarification, (Agbaire et al., 2020).

The main products of the oil palm industry are crude palm oil (CPO) and palm kernel (PK), which yields another type of oil known as palm kernel oil (PKO), and residue known as palm kernel cake (PKC), (Udensi & Iroegbu, 2019).

Palm oil is an edible vegetable oil produced from the mesocarp (flesh) of the fruit of the oil palm. It is reddish in colour when in its crude state and is widely used in food manufacturing, personal care and bio-fuel applications. The global market research report describes palm oil as “a reddish, edible vegetable oil produced from the mesocarp of oil palm fruits” (IMARC Group, 2024). It is a widely consumed edible oil worldwide and is an integral part of our daily meals.

Allura Red AC which is also known as Food Red 17, FD&C Red 40, E129 is a synthetic monoazo colouring agent approved as a food colourant in many jurisdictions and used in foods, beverages, cosmetics and pharmaceuticals. It occurs as a red powder/granule and is used as a water-soluble dye. (IACM, 2025). The dye may degrade under oxidative conditions, or produce degradation products which have greater biological reactivity such as enzyme inhibition) than the parent compound. Eddy et al. (2020), stated that additives are chemical substance that are intentionally added to food materials in known and regulated quantity for the purpose of assisting in processing, preservation, improving taste, and appearance of food.Moisture content represents the proportion of water contained in edible oil. High moisture values can speed up oxidative reactions, promote microbial contamination, and contribute to the deterioration of oil quality and reduction of shelf life (Murphy et al., 2021).

Free fatty acid (FFA) content indicates the amount of fatty acids that are unbound to glycerol molecules. An increase in FFA levels is often associated with lipid hydrolysis or improper storage conditions, both of which can compromise the oil’s flavour, texture, and oxidative stability (Jones et al., 2017). The acid value (AV) in respect to palm oil is a key indicator of the oil’s free fatty acid (FFA) content and overall quality or degree of hydrolytic rancidity. It is defined as the amount of potassium hydroxide (KOH) in milligrams required to neutralize the free fatty acids present in one gram of oil or fat (Aremu et al., 2022). This parameter provides information on the oil’s freshness and suitability for consumption or industrial use. Higher acid values indicate greater hydrolysis of triglycerides, often due to improper storage, processing, or microbial activity (Igbosoroeze & Okojie, 2024). In palm oil, maintaining a low acid value is important because a high value can affect flavour, stability, and shelf life, and may reduce its commercial grade. According to the Codex Alimentarius standard, the acceptable acid value for refined palm oil should not exceed 0.6 mg KOH/g oil, while crude palm oil typically has values below 5 mg KOH/g oil (Codex, 2020).

The peroxide value is defined as the amount of peroxide-oxygen per kilogram of fat or oil. It is used to assess freshness, storage/processing damage, and general oxidative stability. Fresh palm oils are expected to have relatively low values as higher PV suggests increased oxidation and risk of rancidity. (Smith et al., 2018). The stability of palm oil refers to the oil’s resistance to chemical degradation (e.g. oxidation, hydrolysis) over time and under storage conditions. Palm oil exhibits good oxidative stability partly because of its relatively low poly-unsaturated fatty acid content and moderate saturated fat level, which reduces the rate of rancidity. Palm oil is naturally resistant to oxidation. The low content of polyunsaturated fatty acids also makes it less prone to oxidative polymerization (Arab Food Insight, 2025). The shelf life of palm oil is the period during which palm oil remains within acceptable quality parameters (taste, colour, free-fatty acids, and peroxide value) under given storage conditions. Refined palm oil, when stored properly (cool, dark, sealed), can last up to 12 months or more unopened. (WellWisp, 2025) states that unopened palm oil can remain fresh for 12–18 months when properly stored. The focus of this study is to evaluate the effects of Allura Red dye additive on the stability and shelf life of palm oil using the key parameters or indicators such as Moisture Content, Free Fatty Acid, Peroxide Value and Acid Value. The stability and shelf life of palm oil is very important for its quality and nutritional value. The research was conducted over an eight-week period during the dry season when there is a little stability in the nature of crude palm oil. The objective was to determine the effects of Allura red dye additive on the Acid value (AV) and peroxide value of crude palm oil and the relationship between the dye and the stability and shelf life of palm oil.

The quest to make more gain in business through more sales has led many oil producers especially the small scale producers and retailers in the city into the practice of adding this synthetic dye such as Allura Red dye to commercial palm oil so as to enhance its appearance by improving the colour and thereby making it more appealing to the unsuspected consumers or customers. There is a great concern over the potential effects of this dye on the stability and shelf life of palm oil. Studies have shown that addition of Allura Red dye to palm oil alter some chemical and sensory properties, but there is not yet enough strong detailed evidence that it always significantly extends or drastically shortens shelf-life compared to untreated palm oil. Irrespective of the wide and indiscriminate use of this

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dye, this gap is yet to be satisfactorily filled. This study is significant as it brings into limelight the nature and quality of locally produced palm oil. Studying the effects of Allura Red dye additive on stability and shelf life of palm oil sold in the market will be beneficial to government in respect to public policy and consumer education. The results will shape government decisions on regulating food additives in essential food products, supporting improved safety standards in food handling and storage across local markets. It will raise public awareness and motivate consumers to make more informed and healthier buying choices.

Materials and Methods

Collection of Samples

The palm oil used in this study were obtained directly from the traders in the Rumuokoro market and from the mill in the same Obio-Akpor local government area as the market. Firstly, three samples of palm were collected, one was bought from traders in Rumuokoro Market, the second sample was bought from the oil mill where it was directly produced and the third sample was home-made but using palm fruits bought from the Rumuokoro market all in Obio/Akpor Local Government Area. The samples were collected in high density polyethylene bottles with tight-fitting lids, filled to the brim, firmly locked and properly labelled such as MS for Market sample, OM for Oil mill sample, CS for control sample. The samples were carefully taken down to the Biology research laboratory of Ignatius Ajuru University for laboratory analysis and were preserved in a cool and dark corner throughout the period. The traders were interviewed to find out what they know about the addition of the Allura Red dye in palm oil and what they think about it. The palm oils were physically examined before the laboratory analysis.

Experimental Design and Samples Treatment

The sampling was done using 3 x 2 Factorial experimental design. Each treatment was replicated four times.

Allura Red Dye Additive and Palm Oil sample preparation.

Allura Red Dye Preparation: Allura Red AC (E160a) was selected and weighed out 0.01g as weight with concentrations 0.5% as to have a known concentration, this is known as spiking method. The red dye was mixed with a very small amount of palm oil while stirring it to dissolve and avoid having seeds. The prepared red dye solution was added to the palm oil sample and mixed very well. (AOAC International, 2019, Method 983.23).

Palm Oil Sample Preparation: 2g of palm oil sample was weighed from the various sources into different conical flasks well labelled such as MS1-MS4, OM1-OM4 and CS1-CS4 for the analyses. For the spiked sample 2g of palm oil samples were weighed out into the well labelled conical flask such as SS1-SS4 for Treated/Spiked samples. Then the prepared allura red dye was added to the weighed palm oil sample in the labelled conical flasks for treated/spiked sample. To know the actual concentration of allura red dye in it, the spiked sample was prepared using oil that was home-made. All these samples during the analyses had a replica. A total of 17 samples were used in each set to analyse all the parameters including the blank. (AOAC International, 2019, Method 983.23).

Identification of Samples

S/N	Samples Identities	Samples Descriptions
1	B	Blank
2	OM1 – OM4	Oil mill samples
3	CS1 – CS4	Control samples
4	MS1 – MS4	Market (Rumokoro) samples
5	SS1 – SS4	Spiked samples (Treated with the allura red dye)

The samples were analysed for parameters such as Moisture Content (MC), Free Fatty Acid (FFA), Peroxide Value (PV) and Acid Value (AV). Colour stability over time was also checked.

Determination of stability and shelf life of Palm Oil with and without The Allura red Dye using the key indicators (Moisture content, Free fatty acid, peroxide and acid value).

I. Moisture Content

2g of oil samples were weighed (initial sample weight W1) separately into different conical flasks labelled (B, MS1, MS2, MS3, MS4, OM1, OM2, OM3, OM4, CS1, CS2, CS3, CS4, SS1, SS2, SS3, SS4) and dried in an oven at 105◦C

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(221◦F) for 1 hour. They were placed in a desiccator and allowed to cool and reweighed (Sample weight after drying W2). Representing the bulk sample with only 2g helps to minimize error. Temperature of 105°C was used because water boils at 100°C at standard atmospheric pressure. Drying at 105°C ensures that the water is fully vaporized because at this temperature, water vaporizes quickly and it is neither so hot to cause degradation or oxidation of the palm oil. 0ne (1) hour is sufficient for the water to be fully evaporated as the oil sample by this time has reached equilibrium (The rate of water evaporation equals the rate of water absorption from the air). Calculation for moisture content using the formula; Moisture lost (g) = W1-W2.

$$\text{Moisture content (\%)} = \frac{ML}{SW} \times 100$$ (AOAC International, 2005).

2. **Determination of Free Fatty Acid.**

5g of palm oil samples were weighed out respectively into different conical flasks labelled (B, MS1, MS2, MS3, MS4, OM1, OM2, OM3, OM4, CS1, CS2, CS3, CS4, SS1, SS2, SS3, SS4) and 25ml of ethanol (95%) was added and the mixture was dissolved by heating on a heating mantle. 2 drops of phenolphthalein indicator was added. 0.1N NaOH solution was used to slowly titrate the sample, while stirring continuously. Initial and final burette reading was recorded. Turning of the solution into pink colour indicates endpoint of the titration. Free fatty acid was calculated as follows:

$$\text{Free Fatty Acid (FFA) \%} = \frac{(V \times N \times 56.1)}{W \times 1000} \times 100$$ (AOAC International, 2005).

56.1 = Molecular weight of KOH. (This is used to convert the volume of the alkali required (A-B) from milliliters (ml) to milligrams (mg) of KOH.

1000 = Conversion value, from g to mg

100 = the value is expressed in percentage.

Free fatty acid is best expressed as palm oil oleic by multiplying with a constant 1.0143 when reporting.
(AOAC METHOD 940.28).

3. **Determination of Acid Value.**

A 25 mL volume of ethanol was added to 2 g of each oil sample placed in separate conical flasks, which were separately labelled as B, MS1, MS2, MS3, MS4, OM1, OM2, OM3, OM4, CS1, CS2, CS3, CS4, SS1, SS2, SS3, and SS4. Each mixture was heated in a water bath for about 10 to 15 minutes to ensure proper blending, then allowed to cool to room temperature. Upon cooling, two drops of phenolphthalein indicator was added to each sample. The contents were then titrated using 0.1N sodium hydroxide (NaOH) solution with continuous disturbance to ensure uniform mixing. The titration continued until a faint pink coloration appeared and remained visible for at least 30 seconds, indicating the endpoint. The volume of NaOH required for each titration were carefully recorded. The acid value of each oil sample were subsequently determined using the appropriate calculation formula.

$$\text{Acid Value} = \frac{V \times N \times 56.1}{W}$$

56.1= Molecular weight of KOH (Traditionally used even if you titrate with NaOH, (This is used to convert the volume of the alkali required (A-B) from millilitres (ml) to milligrams (mg) of KOH.

(AOAC International, 2005).

4. **Determination of Peroxide Value (PV)**.

Precisely 2 grams of each oil samples were measured into separate, well labeled conical flasks (B, MS1–MS4, OM1–OM4, CS1–CS4, and SS1–SS4). To each flask, 15 milliliters of a solvent mixture comprising acetic acid and chloroform in a 3:2 ratio was added. Then, 0.5 milliliters of saturated potassium iodide solution was introduced into each flask. The mixtures were kept in a dark compartment and allowed for five minutes to prevent light-induced decomposition of liberated iodine.

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After which, 15 milliliters of distilled water was added to each mixture. The solution was titrated with 0.1 M sodium thiosulfate ($Na_2S_2O_3$) until the initial yellowish coloration faded. At this stage, 0.5 milliliters of starch indicator was added, resulting in a blue-black coloration. Titration continued until the solution turned colorless, indicating the endpoint. The volume of sodium thiosulfate used was recorded for each sample.
The peroxide value of the oil samples was calculated using the following formula:

$$\text{Peroxide Value (meq/kg)} = \frac{(VS - VB) \times N \times 1000}{W}$$

This method was adopted from the AOAC Official Methods (2005) for determining peroxide value in fats and oils.

Results

Table 1: Determination of stability and shelf life of Palm Oil with and without The Allura red Dye using the key indicators (Moisture content, free fatty acid, peroxide and acid value).

S/N	Samples	Moisture Content Value (MCV) (%)	Free Fatty Acid Value (FFAV) (%)	Acid Value (AV) (mgKoH/g)	Peroxide Value (PV) (meq/Kg)
1	B				0.05
2	OM1	0.20 ±0.00071	0.090 ±0.00071	0.056 ±0.071	2.5 ±0.00
3	OM2	0.10 ±0.00060	0.12 ±0.00021	0.056 ±0.071	2.5 ±0.00
4	OM3	0.10 ±0.00060	0.09 ±0.00071	0.045 ±0.071	2.5 ±0.00
5	OM4	0.20 ±0.00071	0.12 ±0.00021	0.045 ±0.071	2.5 ±0.00
6	CS1	0.40 ±0.00071	0.034 ±0.21	0.17 ±0.35	27.5 ±0.35
7	CS2	0.40 ±0.00071	0.034 ±0.21	0.11 ±0.30	17.5 ±0.25
8	CS3	0.50 ±0.00065	0.07 ±0.42	0.17 ±0.35	17.5 ±0.25
9	CS4	0.50 ±0.00065	0.07 ±0.42	0.11 ±0.30	27.5 ±0.35
10	MS1	0.014 ±0.0028	0.30 ±0.71	0.34 ±0.14	7.5 ±0.014
11	MS2	0.012 ±0.0018	0.30 ±0.71	0.11 ±0.12	7.5 ±0.014
12	MS3	0.014 ±0.0028	0.19 ±0.50	0.34 ±0.14	7.5 ±0.014
13	MS4	0.012 ±0.0018	0.19 ±0.50	0.11 ±0.12	7.5 ±0.014
14	SS1	1.00 ±0.13	0.62 ±0.71	0.34 ±0.00	7.5 ±0.14
15	SS2	0.80 ±0.0014	0.51 ±0.71	0.34 ±0.00	2.5 ±0.14
16	SS3	0.80 ±0.0014	0.62 ±0.71	0.45 ±0.14	7.5 ±0.14
17	SS4	1.00 ±0.13	0.51 ±0.71	0.45 ±0.14	2.5 ±0.14
	Mean ± S.D	0.38 ±0.017	0.24 ±0.41	0.20 ±0.15	9.38 ±0.11

Table 2: Quality classification of palm oil by AOAAC International (2005)

Ranges	Moisture Content Value (MC) (%)	Free Fatty Acid Value (FFAV) (%)	Acid Value (AV) (mgKoH/g)	Peroxide Value (PV) (meq/Kg)
Classification				
High Quality	0.1 – 0.3	0.1 ≤ 0.2	0.1 ≤ 0.2	≤ 2
Good Quality	0.3 – 0.5	0.2 ≤ 0.5	0.2 ≤ 0.5	2 – 5
Fair Quality	0.5 – 1.0	0.5 ≤ 0.7	0.5 ≤ 1.0	5 – 10
Poor Quality	1.0 – 1.5	0.7 ≤ 1.0	1.0 ≤ 2.0	10 – 20
Extremely bad	≥ 1.5	>1.0	> 2.0	>20

(AOAC International, 2005).

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Discussion

Tables 1 and 2 shows the key indicators of stability and shelf life of palm oil with and without the allura red dye and the quality classification of palm oil by AOAC International (2005) respectively. The key indicators shows the level of oxidation and rancidity which determines the stability and shelf life of the oil.

Moisture Content Value (MCV)

The Moisture content of all the samples are relatively low, with range of values from 0.20% to 1.00%. This indicates good quality control in processing, as much moisture in oil can encourage microbial activity and hydrolysis, leading to rancidity. On the contrary the spiked samples (SS1, SS2, SS3 and SS4) showed highest moisture content values of 1.00%, 0.80%, 0.80% and 1.00% respectively which falls within the range of 0.5 – 1.0% indicating poor quality of palm oil base on AOAC International, 2005 quality classification of palm oil. This points to the fact that additives might have altered the oil's key parameter resulting in changes to moisture retention. This probably affects the oil's shelf life and oxidative stability thereby making it more prone to degradation, while the market samples (MS1, MS2, MS3 and MS4) recorded the lowest values of (0.014%, 0.012%, 0.014% and 0.012%) respectively, showing potentially better storage stability for these samples. The study results follows in line with findings by Zhang et al. (2020) who recorded higher moisture content in oils exposed to colorants.

Free Fatty Acid Value (FFAV)

Free fatty acid value is an important indicator of hydrolytic rancidity. From the result, its values ranges between 0.51% and 0.62% in the dyed samples. These values indicates relatively moderate level of oil degradation, probably due to natural enzymatic activity or long and poor storage. This increase in FFAS values is concerning as it may show that the oil is undergoing hydrolytic breakdown which negatively affects oil quality. This aligns with the work of Jones et al. (2017) who found that synthetic dyes such as allura red dye could promote the free fatty acid content in vegetable oils and increase the rate of hydrolysis in the oils. On the contrary, Home-made samples which were the control samples (CS1, CS2, CS3 and CS4) had the lowest FFAV (0.034%, 0.034%, 0.07% and 0.07%) respectively, showing better preservation or fresher extraction.

Acid Value (AV)

The acid value is related to FFAV directly, it shows the amount of potassium hydroxide (KOH) required to neutralize free fatty acids in the oil. From the results all the samples were relatively low and thus falls within a consumable quality. Samples from the oil mill (OM1, OM2, OM3 and OM4) had lowest values of 0.056mgKOH/g, 0.056mgKOH/g, 0.045mgKOH/g and 0.045mgKOH/g) respectively which falls within the range of ≤ 0.1 indicating high quality while the spiked samples (SS1, SS2, SS3 and SS4) had high value of 0.34mgKOH/g, 0.34mgKOH/g, 0.45mgKOH/g and 0.45mgKOH/g respectively which falls within the range of $0.2 \leq 0.5$ showing good quality. This contradicts the findings of Olatunde et al. (2021) who in his study found out that the acid value of palm oil increased after exposure to chemical agents. He also noted that higher acid values could lead to rancidity and affect the oil's flavor and even the nutritional quality.

Peroxid Value (PV)

In this study another significant finding was the increase in peroxide values in the treated oils, suggesting a higher degree of oxidation. This is consistent with the findings of Tahir et al. (2022) who observed that palm oil treated with artificial colorants exhibited higher peroxide values due to enhanced oxidation rates. They concluded that synthetic additives, especially those that involve chemical interactions with the oil, could reduce the shelf life and stability of palm oil. Moreover, Chukwuma et al. (2019) demonstrated that peroxide values are a key indicator of the extent of lipid oxidation, which, if left unchecked, could lead to rancidity and the formation of harmful compounds in oils. In this study, the peroxide values were notably higher in spiked palm oil samples, indicating a greater degree of oxidative stress. This is in line with the findings of Enyoh et al. (2017) they observed peroxide values of oil produced locally are high suggesting oxidation of the oil and therefore such oil should be avoided in our diet. These findings underscore the importance of controlling the use of synthetic dyes in edible oils to prevent quality deterioration over time.

Conclusion

The oil mill (OM) was not adulterated and was of good quality but the sample from the market was compromised. The home made that served as control had its peroxide value high suggesting either poor production technique or lipase enzyme activities. Conclusively, through my oral interview with producers the adulteration of palm oil is practiced among bulk buyers and retailers and most times from the producers (the oil mill).

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Results from the laboratory analysis, showed that an adulterated or deteriorated oil has the free fatty acid value higher because the dye or contaminant may hydrolyse triglycerides increasing FFA. The acid value was higher because increased FFA and hydrolysis contribute to higher AV. The peroxide value was higher because the dye or contaminant may have introduce pro-oxidants increasing PV.
Allura Red dye negatively impacts the quality, stability and shelf life of crude palm oil. The addition of the dye led to significant changes in the key parameters such as increases in free fatty acid, acid value, and peroxide value. These changes suggest a decrease in the oil's nutritional quality, oxidative stability, and shelf life. The results shows the potential risks associated with the use of artificial food dyes in edible oils such as tissue /organ injury leading to malfunctioning of the organs. Other health issues are digestive issues, unstable behaviour, birth defects, still births etc. Hence the need to enlighten the public to be careful in choice of where they get the palm oil they consume.
The peroxide value reflects the degree of primary oxidation, with higher values indicating initial stages of rancidity. The results showed PVs of 2.5meq/Kg, which are within acceptable limits for fresh edible oils. Samples (CS1 – CS4) showed highest PVs (27.5meq/Kg and 17.5meq/Kg), indicating an elevated oxidation level which might be as a result of poor production method and it suggest a higher degree of oxidation. This is in line with the findings of Enyoh et al. (2017) in which they observed peroxide values of oil produced locally are high suggesting oxidation of the oil hence such oil should be avoided in our meals. The spiked samples also had high values which is in line with the findings of Tahir et al. (2022) who observed in their studies that palm oil treated with artificial colorants exhibited higher peroxide values due to enhanced oxidation rates. These could reduce the shelf life and stability of palm oil. According to Chukwuma et al. (2019) if this is left unchecked, it can lead to rancidity of oil and formation of harmful compounds in palm oil.

Recommendations
From the research findings, we recommend the following:

1. The use of Allura Red dye in palm oil processing should be prohibited to avoid its adverse effects on oil quality and the consumers' health.
2. Producers should adopt better quality control measures to monitor the presence of additives in the mills and ensure that palm oil remains within the acceptable quality standards for consumers' health and safety.
3. NAFDAC (National Agency for Food, Drug, Administration and Control) should enforce stricter guidelines on the use of artificial dyes in food products, especially in oils, due to their negative effects on oil quality and consumers' health.
4. There is a need for increased consumer awareness regarding the use of artificial dyes in food products, as well as the potential health risks associated with their consumption.
5. Consumers should purchase their oil especially if buying in bulk from the oil mills which are genuine source and good quality oil as to avoid compromising their health by buying and consuming adulterated oil.
6. Government should regulate food additives in essential food products, supporting improved safety standards in food handling and storage across local markets.

Future research should assess the long-term health effects of consuming palm oil adulterated with synthetic dyes and explore safer, more stable natural colorants that do not compromise oil quality or consumers' health.

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Cite this article as:
Nnamdi, N. O., Ibara, J.O., & Wokoma, O.A.F. (2025). Effects of allura red dey additive on stability and shelf life of palm oil sold in selected market in Obio/Akpor Local Government, Rivers State, Nigeria. *FNAS Journal of Scientific Innovations, 7*(1), 57-64. https://doi.org/10.63561/fnas-jsi.v7i1.1103