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Research article

COMPARATIVE OXIDATIVE STABILITY OF SOYBEAN AND SUNFLOWER OIL DURING PROLONGED STORAGE UNDER VARIOUS STORAGE CONDITIONS

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ABSTRACT

This study assessed the oxidative stability of soybean and sunflower oils over an 8-week storage period in both dark and light conditions, using acid value (AV), free fatty acid (FFA) content, peroxide value (PV), and saponification value (SV) as indicators. Both oils quickly exceeded the acceptable AV limit of 0.6 mg KOH/g, showing rapid degradation. Soybean oil's AV rose from 0.87 (dark) and 0.67 (light) to 2.10 and 2.60, respectively, while sunflower oil's AV increased from 0.89 (dark) and 0.67 (light) to 2.29 and 2.75. FFA content also surpassed the 1% limit, with soybean oil reaching 1.05% (dark) and 1.3% (light), and sunflower oil reaching 1.15% (dark) and 1.38% (light). PV indicated significant oxidative degradation, especially in light, with soybean oil's PV rising from 0.15 meq O_2/kg (dark) and 0.22 meq O_2/kg (light) to 3.74 and 11.3 meq O_2/kg, respectively. SV values also exceeded acceptable ranges. Correlation analysis revealed strong positive relationships between AV and PV, AV and FFA, and moderate correlations between SV and AV, and SV and PV, emphasizing interconnected hydrolytic and oxidative degradation processes. The study found sunflower oil degrades faster than soybean oil, particularly under light exposure, due to its higher polyunsaturated fatty acid content.

1.Introduction

Edible oils play a fundamental role in the human diet, providing essential nutrients, energy, and bioactive compounds that are crucial for maintaining health and preventing disease (Mazzocchi *et al.,* 2021). Among the various types of edible oils, soybean and sunflower oils are particularly noteworthy due to their widespread consumption and nutritional benefits. Soybean oil, derived from the seeds of Glycine max, and sunflower oil, extracted from the seeds of *Helianthus annuus*, are renowned for their favorable fatty acid compositions and versatility in culinary applications (Nanelo *et al.,* 2023). Edible oils are a vital source of energy and essential fatty acids, such as linoleic acid (omega-6) and alpha-linolenic acid (omega-3), which the human body cannot synthesize (Molnár and Pal, 2022). In addition, edible oils are carriers of fat-soluble vitamins like A, D, E, and K, which are essential for vision, bone health, antioxidant defense, and blood coagulation, respectively. The nutritional significance of soybean and sunflower oils lies in their distinct compositions. Soybean oil is particularly rich in polyunsaturated fatty acids, with a balanced ratio of omega-3 to omega-6 fatty acids, making it beneficial for cardiovascular health (Deol *et al.,* 2017). Sunflower oil, on the other hand, is high in monounsaturated and polyunsaturated fats, with a substantial amount of vitamin E, a potent antioxidant that protects cells from oxidative damage (Raederstorff *et al.,* 2015). Soybean oil is widely used due to its neutral flavor, high smoke point, and economic accessibility, making it suitable for frying, sautéing, and as an ingredient in processed foods (Alam and Naser, 2000). Sunflower oil is also popular, particularly for its light taste and health

benefits, making it a preferred choice for salad dressings and light cooking. The stability of edible oils is influenced by various factors, including temperature, light exposure, oxygen, and the presence of metal ions (Choe *et al.,* 2005). These factors can accelerate the degradation processes, such as oxidation and hydrolysis, leading to the formation of free fatty acids, peroxides, and other degradation products that compromise oil quality (Erickson *et al.,* 2022). Oxidation is a major cause of oil spoilage, as it leads to the formation of rancid off-flavors and potentially toxic compounds (Ahmed *et al.,* 2025). Hydrolysis, on the other hand, results in the breakdown of triglycerides into free fatty acids and glycerol, increasing the oil's acidity and decreasing its sensory and nutritional qualities (Erickson *et al.,* 2022). Light exposure is a particularly critical factor in the stability of edible oils. When oils are exposed to light, particularly ultraviolet (UV) and visible light, the energy absorbed by the oil molecules can initiate and accelerate oxidative reactions. These photo-oxidative reactions produce peroxides and secondary oxidation products, which contribute to rancidity and off-flavors (Ahmed, 2016). The rate of oxidation increases with the intensity and duration of light exposure, making it imperative to store oils in light-protective packaging or dark environments to preserve their quality (Kishimoto, 2021). The consequences of consuming rancid oils are significant. Rancid oils not only have an unpleasant taste and odor but also pose health risks. The oxidation products formed in rancid oils, such as aldehydes, ketones, and peroxides, can have toxic effects on the body (Nam, 2011). These compounds have been associated with oxidative stress, inflammation, and cellular damage, which can contribute to chronic diseases such as cardiovascular disease, cancer, and neurodegenerative disorders (Uttara *et al.,* 2009). Moreover, the consumption of rancid oils can adversely affect liver and kidney function, as these organs are involved in detoxifying and excreting harmful substances from the body (Leong *et al.,* 2015). Therefore, ensuring the stability and quality of edible oils during storage is crucial for protecting consumer health and maintaining the oils' nutritional benefits. This research aims to investigate the stability of soybean and sunflower oils during prolonged storage under various conditions, with a focus on the impact of light exposure.

2.Materials and methods

2.1.Study design

It was an analytical study for analyzing the oxidative stability of edible oils (Soybean and sunflower oils) under various storage conditions e.g. light and dark storage. The overall study protocol is illustrated below in Figure 1.

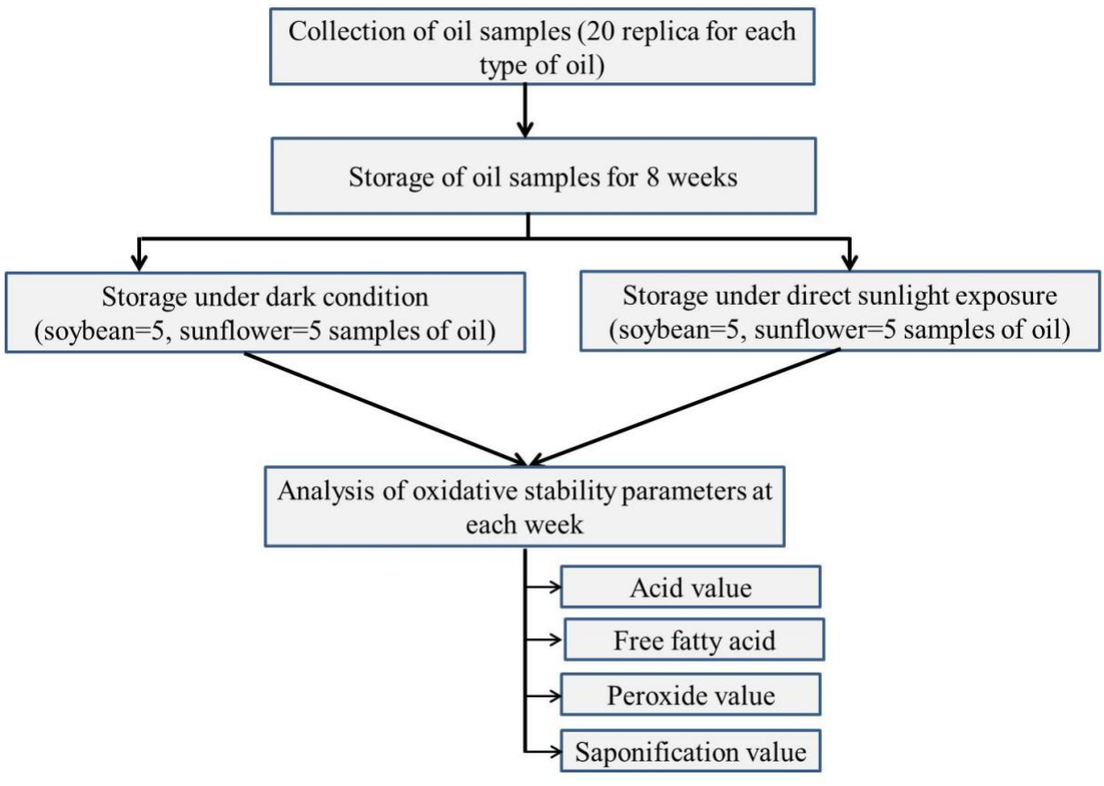

Figure 1. Flow chart of study design

2.2.Oil sample collection and storage

In total 20 samples from 02 brands (soybean=10, sunflower=10) were collected from local markets of Savar, Dhaka for analysis. Efforts were made to collect samples from same batches of production, as identified through production and expiration dates and/ or batch numbers. A minimum of 500 ml of two oil type (Soybean and sunflower oil) was purchased. Five samples from each type of oils

were kept in dark (cupboard) and light (direct exposure to sunlight) condition for 8 weeks. Analyses were conducted after each week.

2.3.Analysis of chemical quality parameters

2.3.1.Acid value and free fatty acid (%)

The acid value of edible oils was determined by titrimetric method according to AOAC (2010) and free fatty acid was determined using following mathematical expressions.

$$\text{Acid value} = \frac{(V \times N \times 56.1)}{W} \quad (1)$$

$$\text{Free fatty acid (as oleic acid)\%} = \frac{\text{Acid value}}{2} \quad (2)$$

Where, V= Volume of standard KOH solution in ml, N=Normality of standard KOH solution, W=Weight of oil sample in grams, 56.1= Equivalent weight of potassium hydroxide

2.3.2.Peroxide value

The peroxide value of edible oils was determined by titrimetric method according to AOAC, Official Method 965.33 (2000). The peroxide value was estimated using the following equation.

$$\text{Peroxide value} = \frac{V \times N \times 100}{W} \quad (3)$$

Where, V is volume of sodium thiosulphate, N is normality used for titre, and W is weight of the sample.

2.3.3.Saponification value

The saponification value of edible oils was determined by titrimetric method according to AOAC, Official Method 920.160 (2000). The saponification value was estimated using the following equation:

$$\text{Saponification value} = \frac{56.1 \times (B - A) \times N}{W} \quad (4)$$

Where, W is weight of sample, “B” is blank titre value, “A” is sample titre value, and N is 0.5 normality of HCl.

2.4.Statistical analysis

Data analysis was performed using Statistical Package for the Social Sciences (SPSS version 20.0 SPSS Inc. Chicago, Illinois, USA). Microsoft Excel version 10.0 was used for graphic illustration of edible oil parameters. Values were expressed as Mean followed by standard deviation. The significance level was set at 0.05 with 95% confidence interval.

3.Results and discussion

3.1.Acid value

This study investigates the acid value trends in soybean and sunflower oils over an 8-week storage period under dark and light conditions. The acid value is a critical indicator of oil quality, reflecting the degree of hydrolysis of triglycerides into free fatty acids; higher values suggest greater degradation (Mahboubifar *et al.,* 2016). According to CODEX and BSTI standards, the acceptable acid value for edible oils is 0.6 mg KOH/g (Begum *et al.,* 2024). Both oils exceed this standard early in the storage period, indicating rapid degradation.

For soybean oil stored in the dark, the acid value begins at 0.87 KOH/g, slightly increasing to 0.89 KOH/g by week 2, and then inconsistently decreases to 0.70 KOH/g by week 3 before steadily rising to 2.10 KOH/g by week 8. In light conditions, the acid value starts lower at 0.67 KOH/g but increases more sharply to 1.12 KOH/g by week 2 and further to 2.60 KOH/g by week 8, showing significant degradation due to oxidative rancidity. Sunflower oil shows a similar pattern but with generally higher values: starting at 0.89 KOH/g in the dark, it increases consistently to 2.29 KOH/g by week 8. In light conditions, the acid value starts at 0.67 KOH/g and rises sharply to 2.75 KOH/g by week 8. The observed trends can be attributed primarily to oxidative and hydrolytic rancidity. Light exposure accelerates the oxidation of unsaturated fatty acids, resulting in higher acid values (Gupta, 2017). This process involves the reaction of oxygen with the double bonds in unsaturated fatty acids, producing peroxides that decompose into various compounds, including free fatty acids (Ayala *et al.,* 2014). The presence of light significantly enhances this process, explaining the steeper increase in acid values under light conditions for both oils. Hydrolytic rancidity, driven by the presence of moisture and elevated temperatures, also contributes to the increase in acid values, though its impact is more pronounced under dark storage conditions where oxidation is slower (Goffman and Bergman, 2003). The initial presence of natural antioxidants in the oils may slow the degradation process initially, but as these antioxidants are consumed, the rate of acid value increase accelerates, especially noticeable from week 3 onward. Comparing the two oils, sunflower oil exhibits a higher initial acid value and a more consistent and rapid increase over the storage period compared to soybean oil. This can be attributed to the higher content of polyunsaturated fatty acids in sunflower oil, which are more susceptible to oxidation than the monounsaturated and saturated fatty acids predominant in soybean oil (Kozłowska and Gruczyńska, 2018). Consequently, sunflower oil degrades faster under both storage

conditions. In dark storage, soybean oil shows a slower increase in acid value, suggesting it is less prone to hydrolytic and oxidative rancidity than sunflower oil. However, under light conditions, both oils exhibit a significant increase in acid value, but the rate of increase is more pronounced in sunflower oil, reinforcing its higher susceptibility to oxidative degradation.

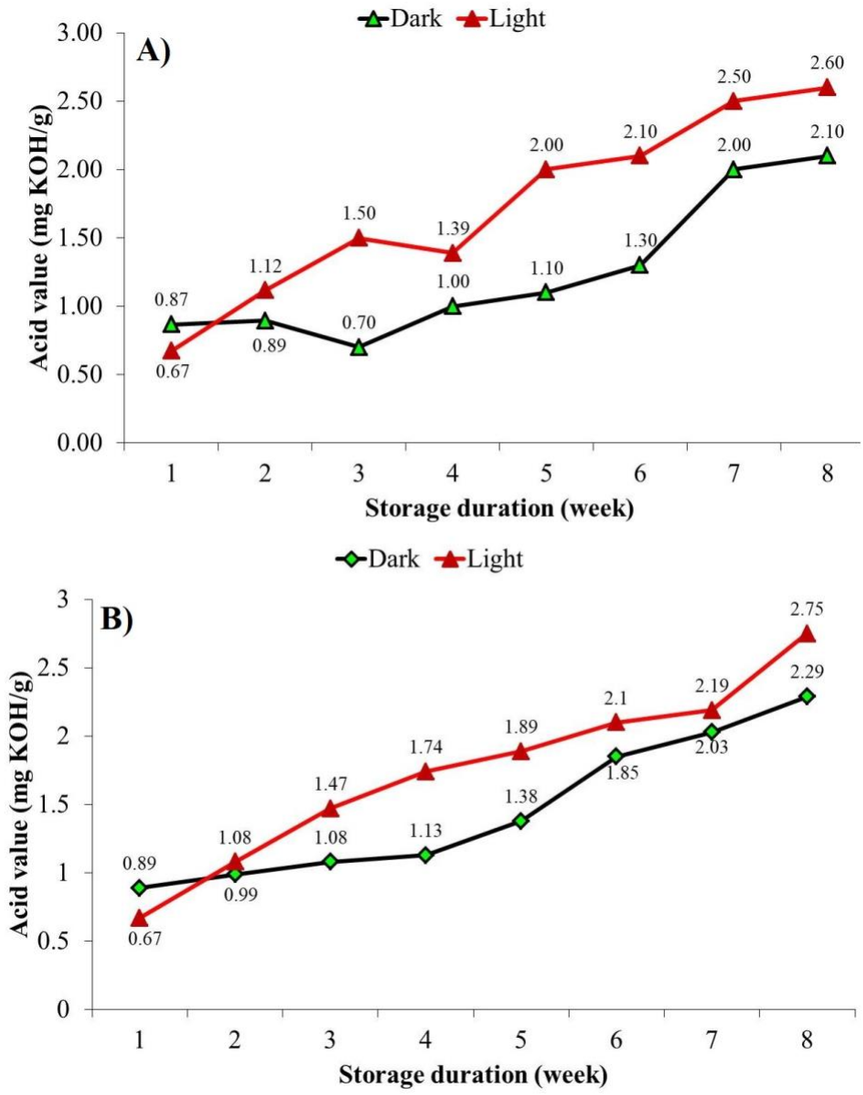

Figure 2. Acid value of A) Soybean and B) Sunflower oil during storage

3.2.Free fatty acid content

Figure 3 depicts the trends in free fatty acid (FFA) content (Oleic acid) of soybean and sunflower oils over an 8-week storage period under dark and light conditions. The FFA content is a crucial indicator of oil degradation, reflecting the hydrolysis of triglycerides into free fatty acids, and is closely related to the acid value, indicating the quality of the oil. According to the standards set by CODEX and BSTI, the acceptable FFA content for edible oils is 1% (Kozłowska and Gruczyńska, 2018).

In soybean oil stored in the dark, the FFA content starts at 0.43%, slightly increases to 0.48% by week 2, and then fluctuates with a notable dip to 0.35% in week 3, followed by a consistent increase, reaching 1.05% by week 8. Under light conditions, the FFA content begins lower at 0.34% but rises more sharply, surpassing the acceptable limit by week 5 (1%) and reaching 1.3% by week 8. Sunflower oil shows a higher initial FFA content in dark storage, starting at 0.45% and increasing consistently to 1.15% by week 8. In light conditions, the FFA content starts at 0.34% and rises rapidly, exceeding the acceptable limit by week 5 and reaching 1.38% by week 8. The observed trends in FFA content can be attributed primarily to oxidative and hydrolytic rancidity. Light exposure significantly accelerates the oxidation of unsaturated fatty acids, leading to higher FFA formation (Gupta, 2017). This is because light promotes the breakdown of lipid molecules into free fatty acids and other compounds (Aryee *et al.,* 2022). The higher rate of FFA increase under light conditions for both oils underscores the impact of oxidative rancidity. Hydrolytic rancidity, driven by moisture and temperature, also contributes to the increase in FFA content (Emebu *et al.,* 2022), particularly noticeable in dark storage where oxidation is slower.

Initially, natural antioxidants present in the oils can slow down the degradation process, but as these antioxidants are depleted over time, the rate of FFA increase accelerates particularly after the initial weeks of storage. Comparing the two oils, sunflower oil exhibits a higher initial FFA content and a more consistent and rapid increase over the storage period compared to soybean oil. This difference is due to the higher content of polyunsaturated fatty acids in sunflower oil, which are more prone to oxidation than the monounsaturated and saturated fatty acids in soybean oil (Roman *et al.,* 2013). Consequently, sunflower oil degrades faster under both storage conditions. In dark storage, soybean oil shows a slower increase in FFA content, suggesting it is less prone to hydrolytic and oxidative rancidity than sunflower oil. However, under light conditions, both oils exhibit significant increases in FFA content, but the rate of increase is more pronounced in sunflower oil, highlighting its higher susceptibility to oxidative degradation.

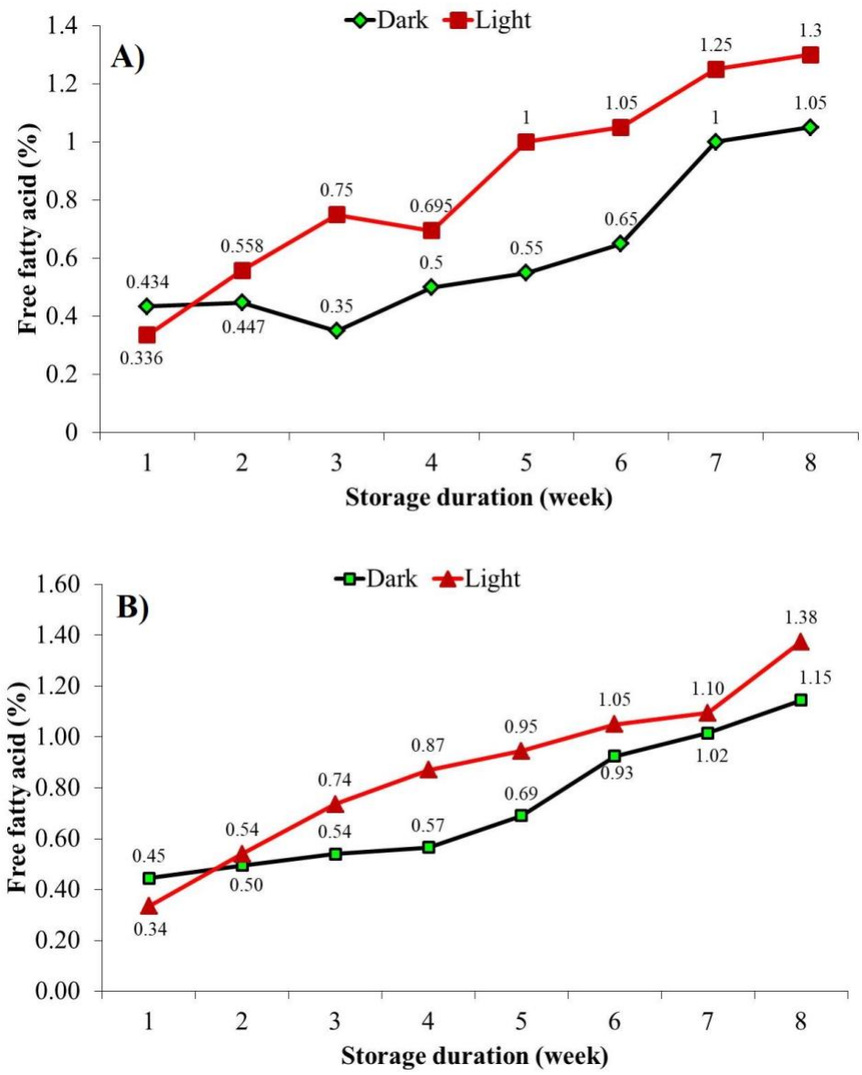

Figure 3. Free fatty acid content (%) of A) Soybean and B) Sunflower oil during storage

3.3.Peroxide value

This study also investigates the peroxide value trends in soybean and sunflower oils over an 8-week storage period under dark and light conditions, showing insights into the oxidative stability and degradation processes of these oils (Figure 4). The peroxide value (PV) measures the amount of peroxide oxygen per kilogram of oil, indicating the extent of primary oxidation and the onset of rancidity. According to CODEX and BSTI standards, the acceptable peroxide value for edible oils is 10 meq O_2/kg (CODEX-STAN 210-1999). In soybean oil stored in the dark, the POV starts at 0.15 meq O_2/kg and increases gradually to 3.74 meq O_2/kg by week 8, staying within the acceptable range throughout the storage period. However, under light conditions, the POV rises sharply from 0.22 meq O_2/kg at week 1 to 11.3 meq O_2/kg by week 8, significantly exceeding the acceptable limit after week 8. For sunflower oil stored in the dark, the POV begins higher at 1.79 meq O_2/kg and increases steadily to 4.79 meq O_2/kg by week 8, staying within the acceptable limit but approaching it closely. Under light conditions, the POV starts at 1.52 meq O_2/kg and escalates to 10.05 meq O_2/kg by week 8. The trends in POV can be attributed primarily to the susceptibility of the oils to oxidative rancidity, particularly under light exposure. Light accelerates the oxidation process by promoting the formation of peroxides, which are primary oxidation products (Aryee *et al.,* 2022).

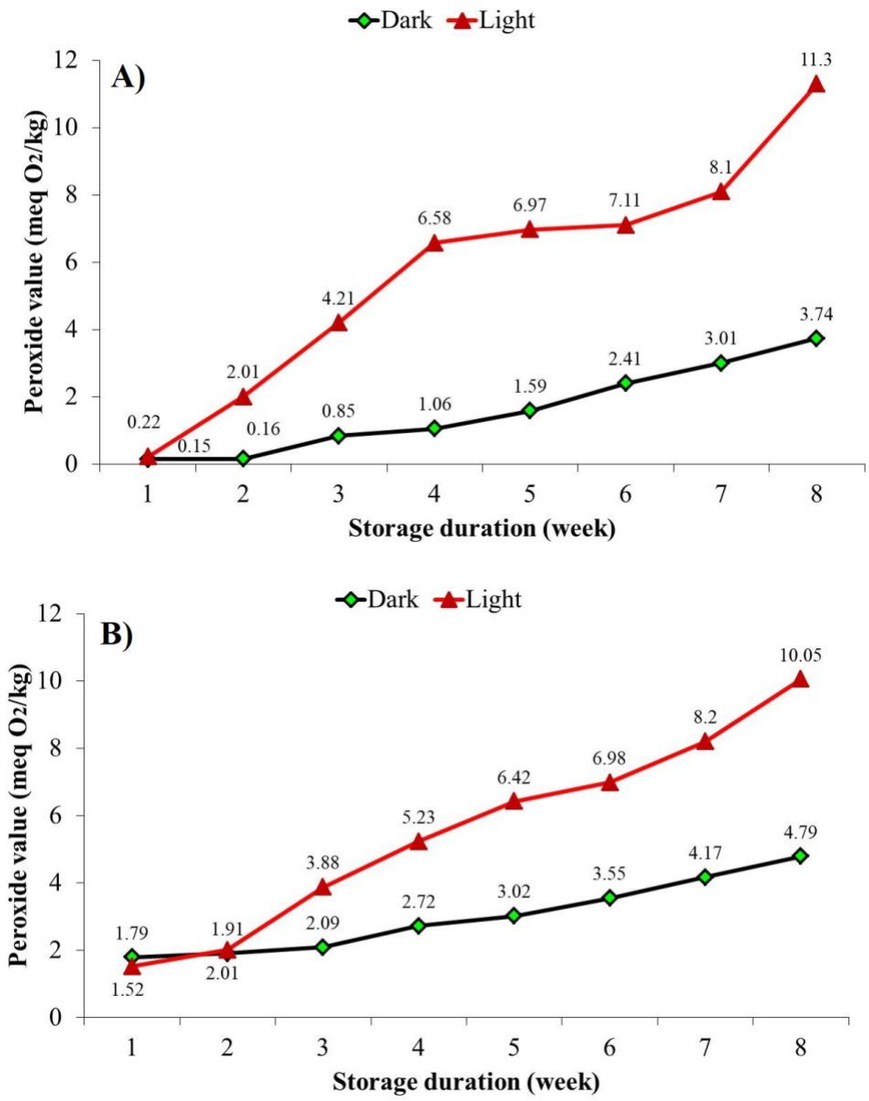

Figure 4. Peroxide value of A) Soybean and B) Sunflower oils during storage

This is evident in both oils, where light storage conditions result in significantly higher POVs compared to dark storage. The initial POV is higher in sunflower oil than in soybean oil, indicating that sunflower oil is more prone to oxidation from the start, likely due to its higher content of polyunsaturated fatty acids, which are more susceptible to oxidation than the monounsaturated and saturated fatty acids prevalent in soybean oil (Kozłowska and Gruczyńska, 2018). As the storage period progresses, the natural antioxidants present in the oils are depleted, leading to an accelerated increase in POV, especially under light conditions where the oxidative stress is greater. Comparatively, soybean oil exhibits a slower increase in POV under both storage conditions, suggesting it is less prone to oxidative rancidity than sunflower oil. This is likely due to its lower content of polyunsaturated fatty acids and higher stability of its monounsaturated fatty acids (Powell and Wallace, 2020). In dark storage, both oils remain within the acceptable POV limit for a longer period, with soybean oil demonstrating superior stability. However, under light conditions, both oils exceed the acceptable limit, with sunflower oil showing a faster rate of degradation. By week 8, the POV of sunflower oil reaches 10.05 meq O_2/kg, while soybean oil reaches 11.3 meq O_2/kg, indicating that both oils undergo significant oxidative degradation but with soybean oil ultimately exhibiting a higher POV due to its initially lower antioxidant capacity under oxidative stress.

3.4.Saponification value

The trends in saponification value of soybean and sunflower oils over an 8-week storage period under both dark and light conditions are depicted in Figure 5. The saponification value is a measure of the average molecular weight of all the fatty acids present in the oil and is indicative of its potential to produce soap. According to CODEX and BSTI standards, the acceptable saponification value ranges are 189–195 mg KOH/g for soybean oil and 188–194 mg KOH/g for sunflower oil (Begum *et al.,* 2024).

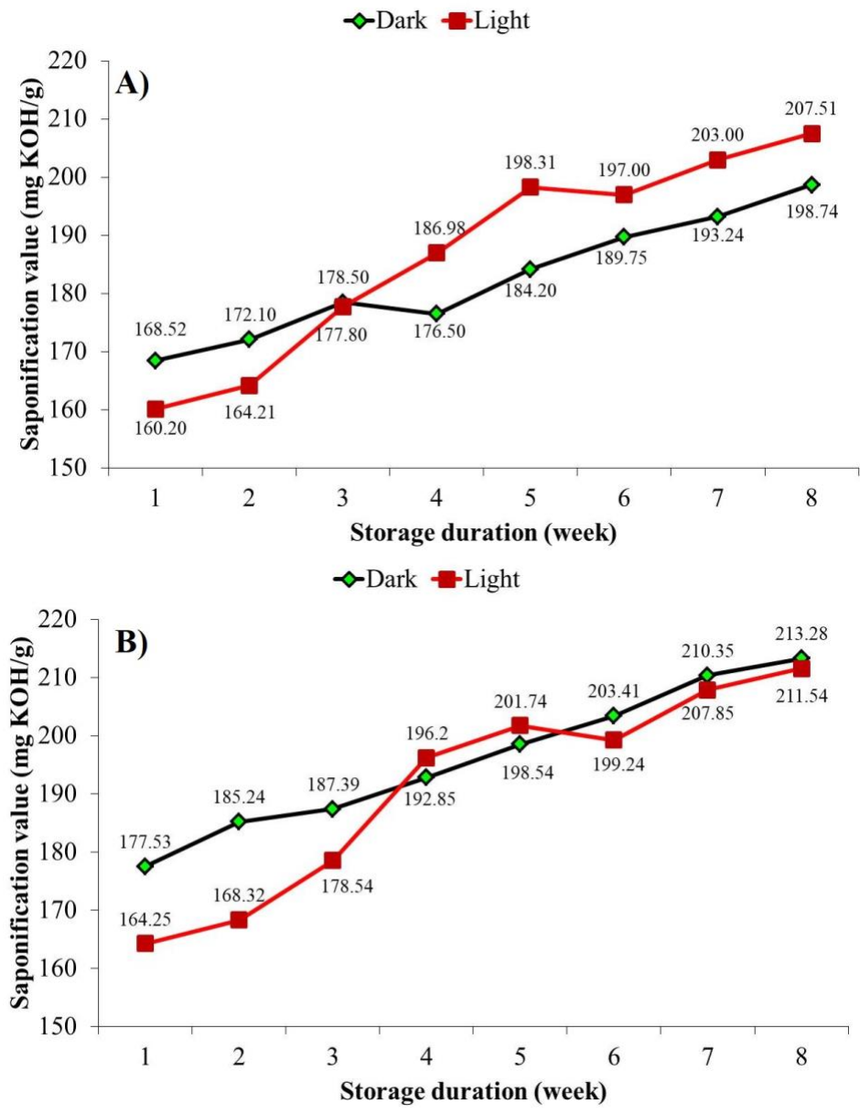

Figure 5. Saponification value of A) Soybean and B) Sunflower oils during storage

In soybean oil stored in the dark, the saponification value starts at 168.52 mg KOH/g and increases steadily to 198.74 mg KOH/g by week 8, surpassing the acceptable range after week 6. Under light conditions, the saponification value begins at 160.20 mg KOH/g and rises more rapidly, reaching 207.51 mg KOH/g by week 8, exceeding the acceptable limit after week 5. Sunflower oil shows a higher initial saponification value in dark storage, starting at 177.53 mg KOH/g and increasing consistently to 213.28 mg KOH/g by week 8, surpassing the acceptable range after week 4. Under light conditions, the saponification value starts at 164.25 mg KOH/g and escalates to 211.54 mg KOH/g by week 8, exceeding the acceptable limit after week 4. The observed trends in saponification value can be attributed primarily to the hydrolysis of triglycerides into free fatty acids and glycerol over time, which increases the amount of KOH needed to saponify the oil. This hydrolysis is accelerated by exposure to light and the presence of moisture, which promotes the breakdown of lipid molecules (Chheda *et al.,* 2004). The higher saponification value under light conditions for both oils underscores the impact of oxidative and hydrolytic rancidity. The increase in saponification value over time indicates that the oils are breaking down into smaller fatty acid components, which are more easily saponified, thus requiring more KOH for complete saponification (Sajjadi *et al.,* 2016). Comparing the two oils, sunflower oil exhibits a higher initial saponification value and a more rapid increase in both storage conditions compared to soybean oil. This difference is due to the higher content of polyunsaturated fatty acids in sunflower oil, which are more susceptible to oxidation and hydrolysis than the monounsaturated and saturated fatty acids in soybean oil (Sánchez-Muniz and Cuesta, 2003). Consequently, sunflower oil degrades faster under both storage conditions. In dark storage, soybean oil shows a slower increase in saponification value, suggesting it is less prone to hydrolytic and oxidative rancidity than sunflower oil. However, under light conditions, both oils exhibit significant increases in saponification value, but the rate of increase is more pronounced in sunflower oil, highlighting its higher susceptibility to degradation.

3.5.Correlation analysis

Figure 6 depicted the correlations which provide a comprehensive analysis of the relationships between various quality indicators of edible oils, specifically focusing on acid

value (AV), peroxide value (POV), free fatty acid (FFA), and saponification value (SV).

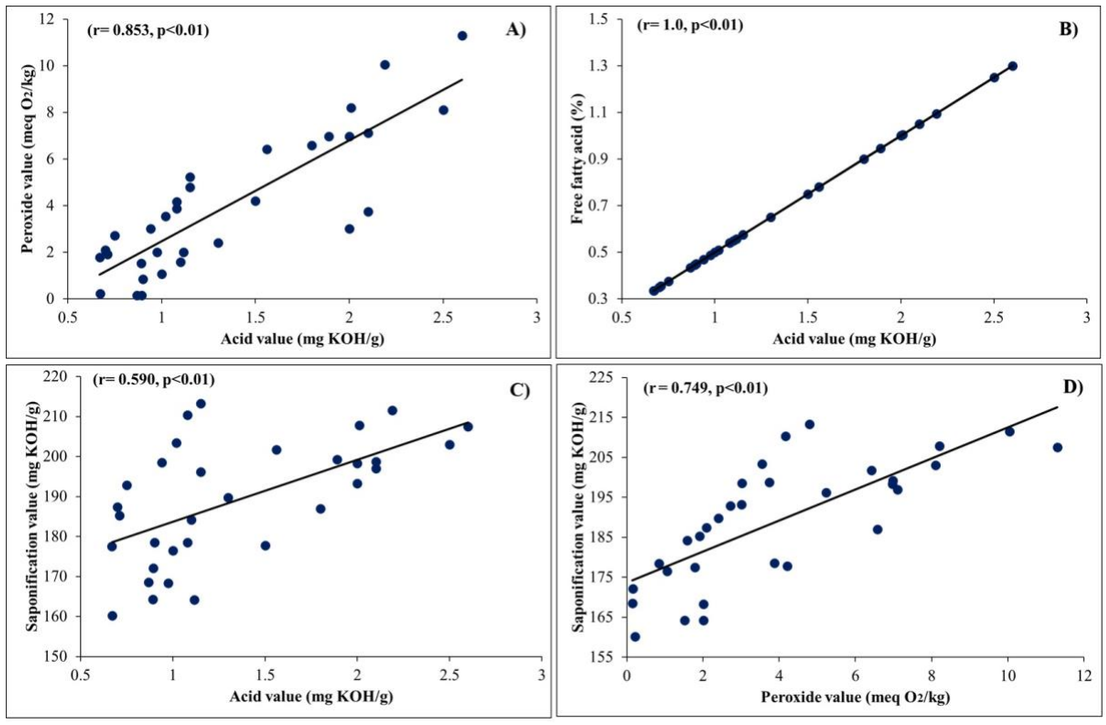

Figure 6. Correlation between A) Peroxide value and Acid value B) Free fatty acid and Acid value, C) Saponification value and acid value, D) Saponification value and Peroxide value

Figure 6 (A) shows a strong positive significant relationship ($p<0.01$) between AV and POV. This indicates that as the AV increases, indicating higher acidity due to the hydrolysis of triglycerides into FFAs, the POV also increases, signifying an increase in primary oxidation products. This strong correlation can be explained by the oxidative degradation of oils, where hydrolytic rancidity (increase in AV) often accompanies oxidative rancidity (increase in POV) (Zhang *et al.,* 2020). As the oil undergoes oxidation, hydroperoxides are formed, which eventually decompose into secondary oxidation products, increasing the POV (Grebenteuch *et al.,* 2021). This relationship highlights the interconnected nature of hydrolytic and oxidative processes in oil degradation, emphasizing the importance of monitoring both parameters to assess oil quality. Figure 6 (B) presents a correlation between AV and FFA at significant level of 0.01. This is expected since the acid value directly measures the amount of free fatty acids present in the oil. Therefore, any increase in AV is a direct result of an increase in FFA content, underscoring the direct link between these two parameters. Figure 6 (C) shows the correlation between SV and AV, showing a moderate significant positive correlation ($p<0.01$). This indicates that as the SV increases, the AV also tends to increase, although the correlation is not as strong as between AV and POV or AV and FFA. The saponification value reflects the average molecular weight of the fatty acids in the oil, with higher values indicating smaller molecular weight fatty acids (Sajjadi *et al.,* 2016). The moderate correlation suggests that as the oil undergoes hydrolysis (increasing AV), the breakdown of triglycerides into free fatty acids results in smaller fatty acids that contribute to a higher SV (Shahidi and Hossain, 2022). Figure 6 (D) also reveals a positive correlation between SV and POV ($p<0.01$). This strong correlation indicates that as the SV increases, the POV also increases, reflecting the combined effects of hydrolytic and oxidative degradation. The increase in SV due to the breakdown of triglycerides into smaller fatty acids is accompanied by an increase in POV due to the formation of primary oxidation products (van Dierendonck *et al.,* 2022). This relationship emphasizes the impact of both hydrolytic and oxidative processes on the overall quality of the oil, highlighting the need for comprehensive monitoring of both parameters to accurately assess oil stability and predict shelf life.

4.Conclusion

The study of soybean and sunflower oils during prolonged storage highlights their stability and degradation processes. Soybean oil stored in dark conditions showed a slower increase in acid value (AV), peroxide value (POV), and free fatty acid (FFA) content compared to light storage, indicating better stability without light exposure. This is supported by moderate correlations between saponification value (SV) and AV, and strong correlations between AV and POV, and AV and FFA. Sunflower oil exhibited higher initial SV and POV under both storage conditions, with more pronounced increases in light, showing greater susceptibility to oxidative degradation.

Strong positive correlations between AV and POV (r=0.853), and AV and FFA (r=1.000) suggest intertwined hydrolytic and oxidative processes. For optimal storage, both oils should be kept in dark, cool environments to prevent light-induced oxidative degradation. Regular monitoring of AV, POV, and FFA is essential to maintain quality. Using antioxidants and proper packaging can enhance shelf life. These findings are crucial for producers and consumers to ensure the preservation of edible oil quality.

5.References

Ahmed, M., Pickova, J., Ahmad, T., Liaquat, M., Farid, A., & Jahangir, M. (2016). Oxidation of lipids in foods. *Sarhad Journal of Agriculture*, 32(3), 230-238. https://doi.org/10.17582/journal.sja/2016.32.3.230.238

Ahmed, S., Hasan, M.R., Furquani, J. M. J., & Begum, R. (2025). Stability of vitamin A in fortified soybean oil during prolonged storage and heating. *Food and Humanity*, 4(2025),100512. https://doi.org/10.1016/j.foohum.2025.100512

Alam, S. M., & Naser, N. (2020). Role of traditional foods of Bangladesh in reaching-out of nutrition. In *Nutritional and Health Aspects of Food in South Asian Countries* ,pp.409-426. https://doi.org/10.1016/B978-0-12-820011-7.00025-3

AOAC. (2000). Official Method 920.160-Saponification Number of Oils and Fats. In IUPAC 2.202 I.S.I Handbook of Food Analysis (Part XIII 1984) (17th ed.).

AOAC. (2000). Official Method 965.33 Peroxide Value in Oils and fats. In Pearson's Composition and Analysis of Food (17th ed., p. 641).

AOAC. (2010). Official Methods of Analysis (15th ed.). Association of Official Analytical Chemists.

Aryee, A. N. A., Akanbi, T. O., Nwachukwu, I. D., & Gunathilake, T. (2022). Perspectives on preserving lipid quality and strategies for value enhancement. *Current Opinion in Food Science*, 44, 100802. https://doi.org/10.1016/j.cofs.2021.12.011

Ayala, A., Muñoz, M. F., & Argüelles, S. (2014). Lipid peroxidation: production, metabolism, and signaling mechanisms of malondialdehyde and 4-hydroxy-2-nonenal. *Oxidative Medicine and Cellular Longevity*, 2014,360438. https://doi.org/10.1155/2014/360438

Begum, R., Hasan, M., Akter, S., & Rahman, M. (2024). Fortified edible oils in Bangladesh: A study on vitamin A fortification and physicochemical properties. *Heliyon*, 10(3), e25489. https://doi.org/10.1016/j.heliyon.2024.e25489

Chheda, S., Keeney, S. E., & Goldman, A. S. (2004). Immunology of human milk and host immunity. In R. A. Polin, W. W. Fox, & S. H. Abman (Eds.), *Fetal and Neonatal Physiology* (3rd ed., pp. 1610-1620). W.B. Saunders. https://doi.org/10.1016/B978-0-7216-9654-6.50166-1

Choe, E., Lee, J., & Min, D. B. (2005). Chemistry for oxidative stability of edible oils. In C. C. Akoh & O. M. Lai (Eds.), *Healthful Lipids* (pp. 99-126). CRC Press. https://doi.org/10.1201/9781439822289.ch23

Codex Alimentarius Commission. (1999). Codex standard for named vegetable oils (CODEX-STAN 210-1999).

Deol, P., Fahrmann, J., Yang, J., Evans, J. R., Rizo, A., Grapov, D., Salemi, M., Wanichthanarak, K., Fiehn, O., Phinney, B., Hammock, B. D., & Sladek, F. M. (2017). Omega-6 and omega-3 oxylipins are implicated in soybean oil-induced obesity in mice. *Scientific Reports*, 7, 12488. https://doi.org/10.1038/s41598-017-12624-9

Emebu, S., Osaikhuiwuomwan, O., Mankonen, A., Udoye, C., Okieimen, C., & Janáčová, D. (2022). Influence of moisture content, temperature, and time on free fatty acid in stored crude palm oil. *Scientific Reports*. https://doi.org/10.21203/rs.3.rs-1300228/v1

Erickson, M., Yevtushenko, D., & Lu, Z. (2022). Oxidation and thermal degradation of oil during frying: A review of natural antioxidant use. *Food Reviews International*. https://doi.org/10.1080/87559129.2022.2039689

Goffman, F., & Bergman, C. (2003). Relationship between hydrolytic rancidity, oil concentration, and esterase activity in rice bran. *Cereal Chemistry*, 80. https://doi.org/10.1094/CCHEM.2003.80.6.689

Gupta, M. K. (2017). Basic oil chemistry. In M. K. Gupta (Ed.), Practical Guide to Vegetable Oil Processing (2nd ed.), pp. 7-25.AOCSPress. https://doi.org/10.1016/B978-1-63067-050-4.00002-7

Kishimoto, N. (2021). Light protection performance of wrapping films to prevent the photo-oxidation of extra virgin olive oil during storage in glass bottles. *AIMS Agriculture and Food*, 6(4), 786-796. https://doi.org/10.3934/agrfood.2021047

Kozłowska, M., & Gruczyńska, E. (2018). Comparison of the oxidative stability of soybean and sunflower oils enriched with herbal plant extracts. *Chemical Papers*, 72(10),2607-2615. https://doi.org/10.1007/s11696-018-0516-5

Leong, X. F., Ng, C. Y., Jaarin, K., & Mustafa, M. (2015). Effects of repeated heating of

cooking oils on antioxidant content and endothelial function. *Austin Journal of Pharmacology and Therapeutics*, 3(1), 1068.

Mahboubifar, M., Yousefinejad, S., Alizadeh, M., & Hemmateenejad, B. (2016). Prediction of the acid value, peroxide value and the percentage of some fatty acids in edible oils during long heating time by chemometrics analysis of FTIR-ATR spectra. *Journal of the Iranian Chemical Society*,13(12). https://doi.org/10.1007/s13738-016-0948-1

Mazzocchi, A., De Cosmi, V., Risé, P., Milani, G. P., Turolo, S., Syrén, M. L., Sala, A., & Agostoni, C. (2021). Bioactive compounds in edible oils and their role in oxidative stress and inflammation. *Frontiers in Physiology*,12,659551. https://doi.org/10.3389/fphys.2021.659551

Molnár, J., & Pal, M. (2022). The role of vegetable oils in healthy eating and disease prevention. *Journal of Food Health and Environmental*, 8(1), 48-49.

Nam, T. G. (2011). Lipid peroxidation and its toxicological implications. *Toxicological Research*,27(1),1-6. https://doi.org/10.5487/TR.2011.27.1.001

Nanelo, R., Júnior, A., & José, A. (2023). Quality of Glycine max (soybean) and Helianthus annuus (sunflower) oils stored in different environments and their suitability for consumption. *Research, Society and Development*,12(9),e42762. https://doi.org/10.33448/rsd-v12i9.42762

Powell, L., & Wallace, E. C. (2020). Fatty acid metabolism. In J. E. Pizzorno & M. T. Murray (Eds.), Textbook of Natural Medicine (5th ed.), pp.584-592.e4. Churchill Livingstone. https://doi.org/10.1016/B978-0-323-43044-9.00079-0

Raederstorff, D., Wyss, A., Calder, P. C., Weber, P., & Eggersdorfer, M. (2015). Vitamin E function and requirements in relation to PUFA. *British Journal of Nutrition*, 114(8), 1113-1122. https://doi.org/10.1017/S000711451500272X

Roman, O., Heyd, B., Broyart, B., Castillo, R., & Maillard, M.-N. (2013). Oxidative reactivity of unsaturated fatty acids from sunflower, high oleic sunflower and rapeseed oils subjected to heat treatment, under controlled conditions. *LWT - Food Science and Technology, 52*(1), 49-59. https://doi.org/10.1016/j.lwt.2012.12.011

Sajjadi, B., Abdul Raman, A. A., & Arandiyan, H. (2016). A comprehensive review on properties of edible and non-edible vegetable oil-based biodiesel: Composition, specifications and prediction models. *Renewable and Sustainable Energy Reviews*,63,62-92. https://doi.org/10.1016/j.rser.2016.05.035

Sánchez-Muniz, F. J., & Cuesta, C. (2003). Sunflower oil. In B. Caballero (Ed.), Encyclopedia of Food Sciences and Nutrition (2nd ed., pp. 5672-5680). Academic Press. https://doi.org/10.1016/B0-12-227055-X/01351-1

Shahidi, F., & Hossain, A. (2022). Role of lipids in food flavor generation. *Molecules*, 27(15),5014. https://doi.org/10.3390/molecules27155014

Uttara, B., Singh, A. V., Zamboni, P., & Mahajan, R. T. (2009). Oxidative stress and neurodegenerative diseases: A review of upstream and downstream antioxidant therapeutic options. *Current Neuropharmacology*, 7(1), 65-74. https://doi.org/10.2174/157015909787602823

van Dierendonck, X. A. M. H., Vrieling, F., Smeehuijzen, L., Deng, L., Boogaard, J. P., Croes, C. A., Temmerman, L., Wetzels, S., Biessen, E., Kersten, S., & Stienstra, R. (2022). Triglyceride breakdown from lipid droplets regulates the inflammatory response in macrophages. *Proceedings of the National Academy of Sciences of the United States of America*, 119(12), e2114739119. https://doi.org/10.1073/pnas.2114739119