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DETERMINATION OF THE IMPACT OF ESSENTIAL OIL ON THE OXIDATION STABILITY AND ELECTRICAL PROPERTIES OF BIODIESEL

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Abstract: *The adoption of green alternatives in engineering applications has made significant contributions to environmental sustainability. This study was conducted to evaluate the effect of essential oil on the performance of biodiesel during storage. Two batches of biodiesel were manufactured using groundnut oil: one batch remained untreated, while the other was stabilized with 4% (by volume of the groundnut oil) of onion bulbs residue oil. The biodiesels underwent testing for their fuel properties, including acid value (AV), kinematic viscosity (KV), and induction period (IP), as well as their electrical properties, such as electrical conductivity (EC) and dielectric constant (ε'), following ASTM International standards. The results revealed that the onion oil had significant influence on the physicochemical and electrical properties of the biodiesel ($p \leq 0.05$). During 150 storage days the control batch exhibited an AV increment of 0.93 to 1.73 mg KOH/g, while the blended batch showed an AV increment of 0.85 to 1.4 mg KOH/g; the KV of the unfortified unit inclined from 4.27 to 6.57 mm/s, while in the fortified batch, the KV increased from 4.53 to 5.47 mm/s; and the IP of the untreated biodiesel declined from 3.33 to 2.17 hours, while the treated batch IP reduced from 3.9 to 3.63 hours. Regarding the electrical properties, the EC of the control and stabilized units increased from 8100 to 11533 pS/m and 7500 to 10133 pS/m, respectively. These findings highlight the potential of employing organic additives to improve the quality of biofuels, thereby enhancing their performance in automobile engines and electrical installations.*

1.0 Introduction

There is a growing interest in substituting traditional inorganic materials with green alternatives in engineering applications, aiming to advance sustainability and promote environmental friendliness. One major area of green revolution breakthrough is the utilization of biofuel and oils in the internal combustion engines and electrical installations (Awogbemi *et al*., 2021). Biodiesel are derived from various sources such as edible oils, non-edible oils, and recycled oils. Biodiesel are typically produced through transesterification, and after purification the product obtained should be able to attain ASTM D6751 and EN 14214 specifications for biodiesel fuel quality (Joshi *et al*., 2019). Some of the notable properties of biofuels revolve around their environmentally friendly characteristics and appreciable fuel properties (Eboibi *et al*., 2022). There are several types of biofuels, but biodiesel is one of the commonly used biofuels which is used to replace traditional diesel, due to its appreciable fuel qualities. These appreciable fuel qualities make it a preferable choice for both domestic and industrial applications (de Almeida et al., 2015; Fatt, 2017).

Storage has significant impact on the fuel and electrical properties of biodiesel, and the rate of depreciation is influence by the storage temperature, sunlight, water content and presence of contaminants. Exposure of biodiesel to prolong sunlight causes degradation of biodiesel, leading to changes in its chemical compositions, leading to severe alteration in its dielectric properties (Bibi *et al*., 2016). Biodiesel undergoes physiochemical changes during storage that results in increment of the acid value (AV), which is detrimental to the fuel quality and integrity. Elevated acid values in biodiesel can indeed accelerate corrosion of metallic vehicle parts, including storage tanks, fuel pipelines, and other engine components. Precision engine components such as injector pumps and nozzles are particularly vulnerable to corrosion (Sterpu *et al*., 2024). Biodiesel with high AV levels stimulate polymerization reactions, leading to the formation of gums and polymers. These compounds can have detrimental effects on the performance of diesel engines (Amran *et al*., 2022). High AV and FFA values fast-track oxidation reactions within the biodiesel, leading to excessive degradation of the fuel quality (Tomić *et al*., 2019).

Biodiesel with high AV and FFA tend to have greater dielectric constant values, which can be associated with the occurrence of polar constituents in the biodiesel. Polar molecules typically have higher dielectric constants when compared with nonpolar molecules. Biodiesel with a high acid value may have a higher dielectric constant due to the presence of polar components like free fatty acids; this increment in the dielectric constant may have negative implications for both engine performance and the effectiveness of bio-based electrical insulating fluids (Zulqarnain *et al*., 2021). Fluids with higher dielectric constant usually have weaker (lower) dielectric strength, leading to reduction in the insulating ability of the fluids. This can results in electrical failure or equipment damage. This scenario becomes more realistic when bio-oils are employed as the insulating material in transformers or capacitors (Rafiq *et al*., 2021). According to Corach *et al*. (2021), high acid values may contribute to non-linear increment in the electrical conductivity in biodiesel. This augmentation could be attributed to the detachment of the acidic constituents of the biodiesel, which will facilitate electrical charges motion. Furthermore, iodine value affects the electrical properties of biodiesel, as higher iodine level have some impact on the mobility of electron charges within fluid (Huang et al., 2022), consequently resulting in higher electrical conductivity.

Studies have shown that antioxidants have to ability of reducing (mitigating) some of the harmful physiochemical properties of biodiesel

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and bio-oil; therefore, improving their stability and engine performance. Antioxidants provide counterforce that hinders biofuels oxidation which has the capacity to degrade biofuels performances. This helps to enhance the biofuels integrity and fuel properties, and preserve them during storage (Amran *et al*., 2022). Antioxidants increase the cold flow parameters and oxidative stability of biofuels, leading to improvement in fuel properties and electrical behaviors of the biodiesel (Hosseinzadeh-Bandbafha *et al*., 2022). Antioxidants assist in retarding self-oxidation process of biodiesel, thereby sustaining a more tolerable limit of the fuel properties of biodiesel (Liu *et al*., 2014; Ibrahim *et al*., 2017). Antioxidants can be organic (natural) or synthetic, but the clamoring for the utilization of green (organic) antioxidants is increasing recently, due to the unhealthy environmental consequences associated with synthetic (inorganic) antioxidants.

Despite the numerous studies on the fortification of biodiesel to stabilize its fuel properties during storage, there is this knowledge gap regarding the impact of these blending materials on the electrical properties of biodiesel during storage. Therefore, the goal of this study is to investigate the impact of onions oil (natural antioxidant) on the fuel and electrical properties of palm oil biodiesel during storage.

This highlights the potential of natural antioxidants as effective additives in biodiesel production, offering a sustainable solution for enhancing both fuel stability and electrical performance.

2.0 Materials and methods

2.1 Materials

The groundnut oil was purchase from the local market; while the reagents were purchase from certify chemical shop. The chemicals utilized in this research were of analytical quality. Measurements were performed three times, showing a relative standard deviation below 5%. The recovery rates for the Certified Reference Materials (CRMs) fell within the range of 91% and 103%.

2.2 Methods

Biodiesel production

The groundnut oil biodiesel was produced using the transesterification method. In this process, methanol and groundnut oil were mixed in a ratio of 6:1, with 1% sodium hydroxide serving as a catalyst, as described by Eboibi *et al*. (2022).

Two units (sets) of biodiesels were produced: one was produced with 100% groundnut oil, and it was tagged “Control”; while the other was produced through blending 96% groundnut oil with 4% onion oil, and was coded “Blended”.

Biodiesel storage

The biodiesel units were stored in a dark cabinet at room temperature (30±5°C) for 150 days.

2.3 Laboratory analysis

2.3.1 Fuel properties

Acid value determination

The acid value (AV) of the biodiesel was measured through the titration procedure in accordance with the ASTM D664 (2018) approved guidelines.

Kinematic viscosity (KV)

The kinematic viscosity was evaluated at 40°C, following the approved procedures outlined in ASTM D445 (2023).

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Induction Period (IP) measurement

The IP of the biodiesel was determined in harmony with ASTM D7545-14(2019) guidelines.

2.3.2 Electrical properties

Electrical conductivity

The fuel electrical conductivity (EC) was determined in accordance with ASTM D2624 (2022) guidelines.

Dielectric constant (ε′)

The dielectric constant of the fuel was measured in accordance with ASTM D1531 (2017) procedures.

2.4 Statistical analysis

The one-way analysis of variance (ANOVA) was utilized to examine the impact of onion oil on the fuel and electrical properties of the biodiesel.

3.0 Results and discussion

3.1 Physiochemical properties

The ANOVA results of the effects of the blending material on the fuel properties are presented in Table 1. Interestingly, it was observed that the onions waste oil exhibits significant influence on the three fuel properties investigated in this research ($p \leq 0.05$). Figures 1, 2, and 3 depict the individual aspects of the physiochemical properties of biodiesel.

Table 1: The ANOVA results of the influence of the essential oil on the biodiesel

Parameter		Sum of Squares	df	Mean Square	F	p-value
AV	Between Groups	1.545	3	0.515	1188.429	6.18E-11*
	Within Groups	0.003	8	0.0004		
	Total	1.548	11			
IP	Between Groups	9.763	3	3.254	37.913	4.47E-05*
	Within Groups	0.687	8	0.086		
	Total	10.449	11			
KV	Between Groups	5.249	3	1.750	27.996	1.36E-4*
	Within Groups	0.500	8	0.063		
	Total	5.749	11			

* Significant at $p \leq 0.05$

Acid values

The results of the aid value of the biodiesel depicted that the onion oil significantly retards acid formation in the biodiesel during storage. On the production day, AV of 0.93 and 0.85 mg KOH/g were recorded for the control and blended biodiesel, respectively. Notably, at Day 150 the AV levels of the unblended and fortified biodiesel were 1.73 and 1.4 mg KOH/g, respectively. This could be attributed to the high antioxidants content of the onion bulb residues oil that acts as oxygen scavenger radicals (Uguru *et al.,* 2023), hence hindering the oxidation rate of the fatty acids in the biodiesel. It was noted that the acid value were of the biodiesel, regardless of the additives added, exceeded the maximum limit of 0.5 mg KOH/g approved by European biodiesel standard. Studies conducted by Zakaria *et al.* (2013) and Amran *et al.* (2022) provided valuable insights into the mechanisms by which antioxidants and other blending materials inhibit acid formation. This contributes immensely to the stability and durability of the biodiesel. Acid value is a critical biodiesel characteristic that has strong correlation with corrosion. Biofuels exhibiting

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elevated AV levels have a tendency to accelerate engine metallic components corrosion, significantly lowering the engine performance and durability.

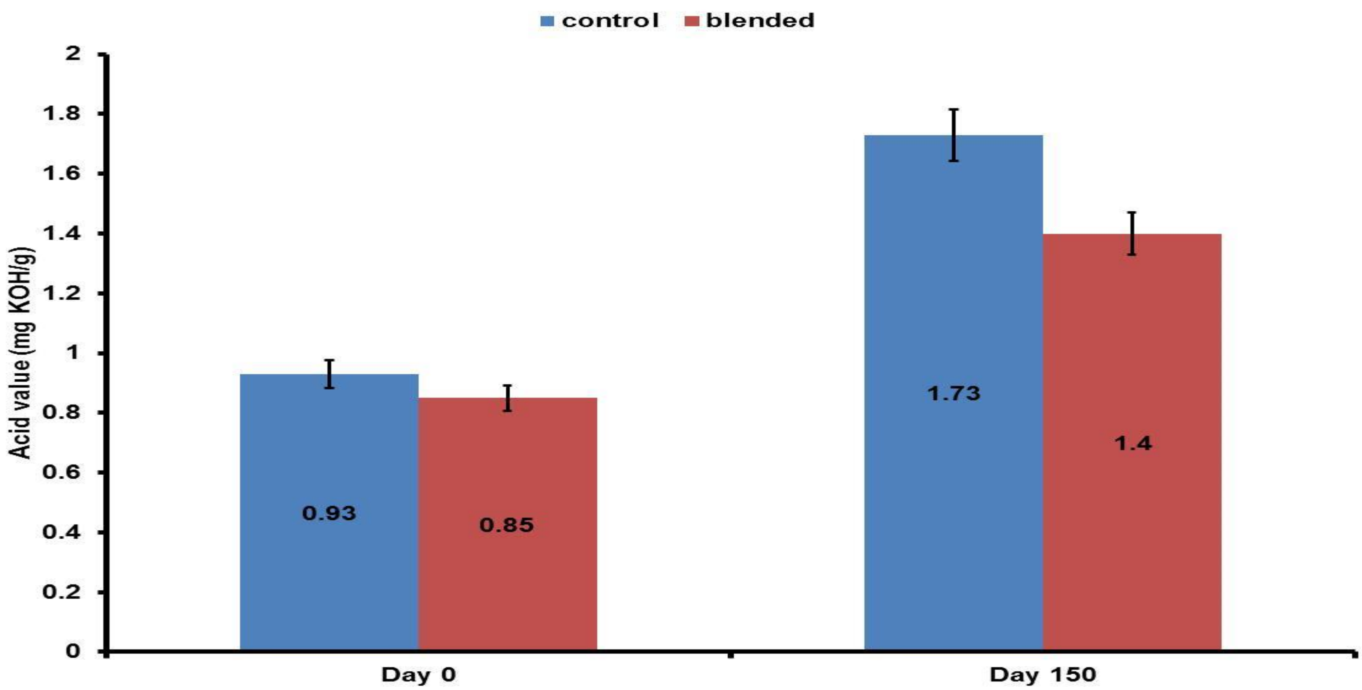

Figure 1: Acid values of the biodiesel units

Kinematic viscosity

The findings from the kinematic viscosity analysis of the biodiesel (as shown in Figure 2) illustrate that the onion oil has a notable impact on viscosity retardation during storage. On the production day, the KV values were recorded at 4.27 and 4.53 mm/s for the control and blended biodiesel, respectively. Remarkably, by Day 150, the KV levels had increased to 6.57 and 5.47 mm/s for the unblended and fortified biodiesel, respectively. Generally, the KV increment rate in the control unit was higher (54%), when compared to the blended unit (21%). David and Kopac (2023) reported similar advantageous impact of antioxidants on the KV values of different biodiesels and temperatures. Smaller KV values facilitate the easier atomization of fuels, which boosts fuel-air mixing procedure, thereby improving the combustion efficiency of the fuels and the overall engine performance (Chaudhari *et al.*, 2021). In addition to its antioxidant properties, onion bulb oil also exhibits appreciable antimicrobial effects (Sagar and Pareek, 2022). This antimicrobial activity effectively inhibits microbial actions that could otherwise lead to the degradation of biodiesel quality. By preventing microbial growth, the oil helps to maintain stable levels of AV and KV during storage (Beker et al., 2016).

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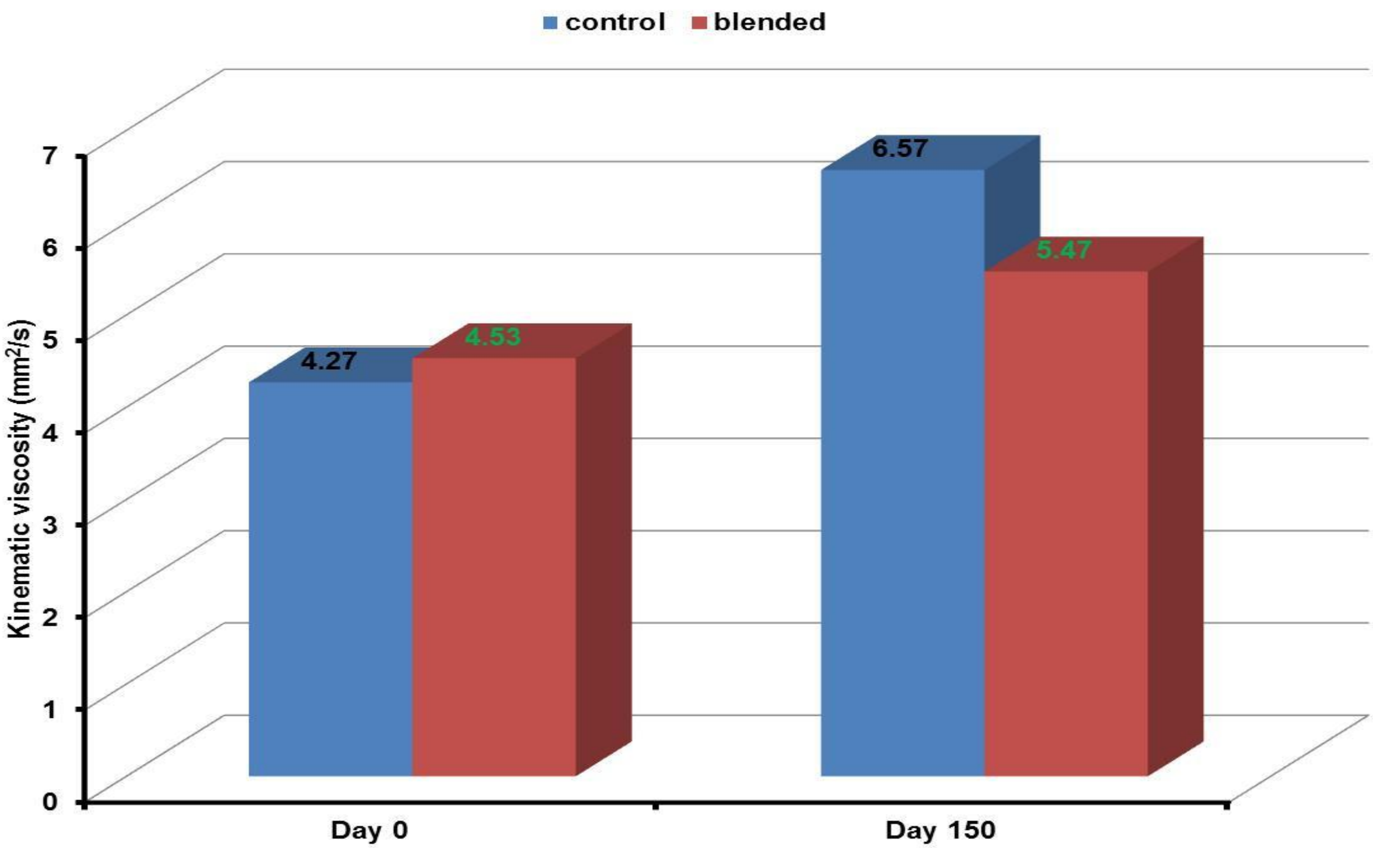

Figure 2: Kinematic viscosity values

Induction Period (IP)

The experimental results regarding biodiesel IP, as depicted in Figure 3, highlight the significant influence of essential oil on the fuel's induction time during storage. It was noted that at Day 0, the IP values were 3.33 and 3.9 hours for the unblended and blended units, respectively; then at Day 150, the IP values declined to 2.17 and 3.63 hours in the control and treated biodiesels. The reduction in the fuel IP values during storage can be associated with the formation of more FFA in the biodiesel, which is facilitated by factors such as temperature and microbial activity (Chozhavendhan *et al.*, 2020). Interestingly, it was noted that the IP attained by the blended biodiesel at the end of storage was about to meet the ASTM D6751 requirement of maximum oxidation stability duration of 3 hours. This is an indication that despite the storage conditions, the blended fuel retained an oxidation stability level compliant with the ASTM D6751 standard for biodiesel, which specifies the maximum duration it should resist oxidation. This study finding is similar to the observations made by Damasceno *et al.* (2013), where antioxidants have positive outcomes on the IP of soybean-based biodiesel. Additionally, Christensen and McCormick

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(2014) reported that integrating antioxidants into biofuels is crucial for enhancing their stability and performance; therefore it is essential to incorporate the right dose of antioxidants in biodiesel intended for long term storage duration.

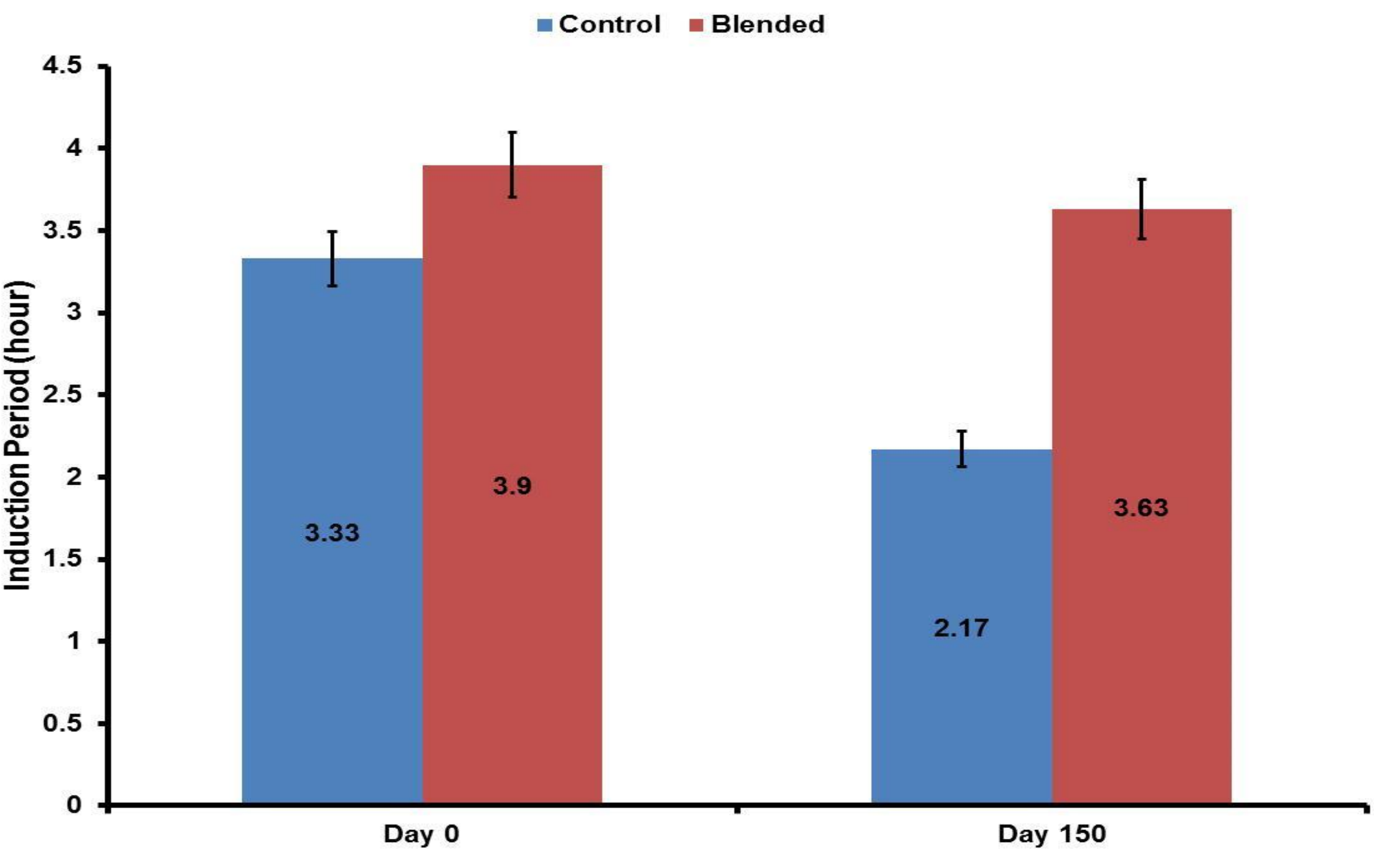

Figure 3: Induction period values

3.2 Electrical properties

The results of the ANOVA of the influence of the onion oil on the biodiesel electrical parameters are presented in Table 2. It's noteworthy that the onion oil showed a significant influence on both the EC and ε′ of the biodiesel ($p \leq 0.05$). The descriptive summary of the effect of the fortifying material on the biodiesel electrical behaviors are presented in Table 3. The 3 shows that both the EC and ε′ levels increases at the end of the experimental period, but the increment was much higher in the untreated fuel when compared to the treated fuel. The EC of the control rose from 8100 to 11533 pS/m, while in the treated biodiesel unit, the EC increased from 7500 to 10133 pS/m. This further confirms the effectiveness of onion oil in inhibiting acid formation (David and Kopac, 2023), which consequently contributes to the reduced electrical conductivity and dielectric

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constant of the biodiesel throughout the storage period. The study carried out by Darwin *et al.* (2023) indicated that electro-catalysts have the potential to marginally elevate the EC of biodiesel.

Table 2: The effect of the onion oil on the biodiesel electrical properties

		Sum of Squares	df	Mean Square	F	p-value
EC	Between Groups	31083333.33	3	10361111.11	78.69	2.80E-06*
	Within Groups	1053333.33	8	131666.67		
	Total	32136666.67	11			
ε′	Between Groups	2.850	3	0.950	66.01	5.51E-06*
	Within Groups	0.115	8	0.014		
	Total	2.965	11			

* Significant at $p \leq 0.05$

Table 3: Descriptive summary of the biodiesel electrical properties

Parameter	Biodiesel type	Storage day	Mean	Std. Error	Minimum	Maximum
EC (pS/m)	Control	0	8100[a]	57.74	8000.00	8200.00
	Blended	0	7500[a]	115.47	7300.00	7700.00
	Control	150	11533[c]	290.59	11000.00	12000.00
	Blended	150	10133[b]	272.84	9600.00	10500.00
ε′	Control	0	3.49[b]	0.077	3.38	3.64
	Blended	0	3.10[a]	0.021	3.06	3.13
	Control	150	4.44[d]	0.078	4.31	4.58
	Blended	150	3.76[c]	0.081	3.61	3.89

Means with the same common letter (superscript) within the same column are not significantly different ($p > 0.05$)

Similar reduction in biodiesel dielectric constant as a result of additives was recorded by Pakalapati *et al.* (2023). The high EC of unblended biodiesel serves as an indication of its capability to dissipate and diminish electrostatic charges during storage, which is crucial for improving safety measures, such as risks linked to fire hazards (Corach *et al.*, 2021). Though high EC is advantageous in enhancing the safety condition of the fuel system, by reducing the risk of electrostatic hazards, it was some serious drawbacks. Elevated EC encourages corrosion and material incompatibility within fuel storage and distribution networks (Polkowski *et al.,* 2022). Biodiesel with suitable dielectric constant provides effective insulating and ensures adequate compatibility with electrical systems, particularly in electrical applications such as transformers and capacitors (Obukoeroro and Uguru, 2021). This helps to prevent electrical breakdown challenges, safeguarding the integrity and functionality of electrical equipment. The findings of this study have shown the relevant of using natural oil rich in antioxidants to enhance the stability of biodiesel fuel and its electrical properties.

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4.0 Conclusion

The pursuit of a healthier environment has underscored the importance of producing engineering materials from organic and sustainable sources. This research was undertaken to assess the effectiveness of onion oil, an organic additive, in stabilizing the quality of biodiesel during storage. Two sets of biodiesel were manufactured from groundnut oil: one set was not treated while the other was stabilized with 4% (% volume of the groundnut oil) of onion bulbs residue oil. The results depicted that the additive effectively improved the fuel's resistance to degradation, by inhibiting the formation of acids and oxidation, thereby preserving the desirable electrical properties of the biodiesel. These results demonstrate the potential for utilizing organic additives to improve the quality of biofuels, thereby enhancing their performance in both internal combustion engines and electrical/electronic components.

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