Automotive Biolubricants – Soybean and Palm Oil as a Solution for Decarbonization

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ABSTRACT

The growing demand for sustainable alternatives has driven the development of automotive lubricants with a lower carbon footprint, and biolubricants emerge as a promising solution. This study evaluates the application of soybean and palm vegetable oils, both produced in Brazil, in formulations of next-generation lubricating oils for gasoline engines (API SQ/ILSAC GF-7A performance level SAE 5W-30), and lubricating oils for EURO VI diesel engines (API CK-4, SAE 15W-40). The API bench tests confirm their feasibility, highlighting that mixtures of both vegetable oils with Group II and Group III mineral base oils can be an effective alternative. In addition, a formulation containing 100% soybean oil as the base stock was also evaluated

RESUMO

A crescente demanda por alternativas sustentáveis tem impulsionado o desenvolvimento de lubrificantes automotivos com menor pegada de carbono, e os biolubrificantes surgem como uma solução promissora. Este estudo avalia a aplicação de óleos vegetais de soja e palma, ambos produzidos no Brasil, em formulações de óleos lubrificantes de última geração para motores a gasolina, com nível de desempenho API SQ/ILSAC GF-7A SAE 5W30 e óleos lubrificantes para motores diesel EURO VI, API CK-4 SAE 15W40. As análises físico-químicas e de desempenho, requeridas pela API, confirmam sua viabilidade, destacando que misturas de ambos os óleos vegetais com básicos minerais grupo II e grupo III podem ser uma alternativa eficaz. Além disso, também foi avaliado o uso de uma formulação contendo 100% óleo de soja.

INTRODUCTION

The lubricant industry has been under increasing pressure to reduce its environmental impact, particularly regarding greenhouse gas emissions and the use of non-renewable resources. This movement is aligned with global initiatives and regional policies such as MOVER PROGRAM launched in Brazil on December 2023, promoting carbon neutrality and renewable feedstocks in industrial applications. (Programa MOVER, 2025)

Traditionally, lubricants are formulated using mineral or synthetic base oils derived from petroleum. However, concerns related to the depletion of fossil resources and the need to reduce greenhouse gas emissions have stimulated research into alternative base oil sources.

Biolubricants, formulated using vegetable oils or esters derived from renewable sources, have gained attention due to their inherent biodegradability and potential for lower life cycle emissions when compared to conventional mineral and synthetic lubricants (Mang & Dresel, 2017).

Vegetable oils contain a high proportion of triglycerides with long-chain fatty acids, which provide good lubricity and high viscosity indices (Salimon et al., 2010). However, limitations related to oxidative stability and low-temperature behavior have historically restricted their application in high-performance engine oils (Randles, 2008). Recent advances in base oil processing, additive technology, and blending strategies have allowed partial incorporation of these bio-based materials into formulations that aim to meet modern specifications such as API SP/ILSAC GF-7A for gasoline engines and API CK-4 for heavy-duty diesel engines.

This study evaluates the feasibility of using soybean and palm oils, produced in Brazil, as components of engine oil formulations meeting API SP/ILSAC GF-7A and API CK-4 specifications. The research includes physicochemical characterization, and a comparative analysis with conventional mineral oil-based formulations. A fully bio-based formulation containing 100% soybean oil is also assessed to understand its potential and limitations.

BIOLUBRICANTS

The term biolubricants applies to all lubricants that are both rapidly biodegradable and non-toxic to humans and aquatic environments. A biolubricant may be plant oil-based (e.g., rapeseed oil) or derived from synthetic esters manufactured from modified renewable oils or from mineral oil-based products (Salimon et al., 2010).

Vegetable oils, particularly triglycerides composed of long-chain fatty acids, offer advantageous properties such as high viscosity index, good lubricity, and low volatility. These characteristics make them suitable candidates for base oil development. However, their application in automotive lubricants is limited by oxidative instability, poor cold flow behavior, and limited compatibility with high-performance additive systems (Fox & Stachowiak, 2007).

SOYBEAN OIL - From a technical standpoint, soybean oil has a relatively balanced fatty acid composition, with a significant amount of polyunsaturated chains (linoleic and linolenic acids), which improves lubricity but reduces oxidation stability.

Following the National Center for Biotechnology Information [10], soybean oil is a lipid emulsion composed of polyunsaturated and saturated fatty acids. Its most commonly known use is for cooking oil that can also be used as ingredient for paints and inks.

Brazil is a notable example of this advantage for sustainable alternatives. According to data from the Observatory of Economic Complexity [11], in 2023, Brazil was the 2nd largest exporter of Soybean Oil in the world with 2.6 billion dollars, behind Argentina with 4.39 billion dollars. Brazil is also the biggest exporter of soybeans and corn in the world.

PALM OIL - Palm oil, in contrast, contains more saturated and monounsaturated fatty acids (e.g., palmitic and oleic acids), which provide better oxidative stability and higher pour point (Salimon et al., 2010

Economically, both oils present viable options due to their local availability, existing processing infrastructure, and potential for co-processing in refineries or chemical modification to enhance stability. The use of domestically produced vegetable oils in lubricant formulations could reduce dependency on imported Group III base stocks and support national value chains aligned with sustainability goals.

MATERIALS AND METHODS

BASE STOCKS AND ADDITIVES - Five sets of formulations were developed for this study. All were blended using base oils and commercial additive packages selected to meet the performance targets defined by API SQ/ILSAC GF-7A for light-duty gasoline engines and API CK-4 for heavy-duty diesel engines.

The base oils included: group II Mineral Oil re-refined 6cSt, group III 4 cSt, Brazilian refined Palm Oil and Brazilian refined Soybean oil.

The additive packages were sourced from established suppliers and selected based on compatibility with the required specifications. The dosage followed the treat rates recommended for each API category.

LUBRICANT SAMPLES - Blending was performed under controlled conditions with temperature and mixing speed monitored to ensure homogeneity. The lubricant formulations were prepared in the following categories as described below in Table 1 to prepare a heavy duty diesel engine oil that meets API CK-4 SAE 15W40 and a passenger car engine oil that meets API SQ/ILSAC GF-7A SAE 5W30.

Table 1. Composition of Samples.

Source: From the Author.

Samples	HD 100	HD SOY10	HD PA10	PC 100	PC SOY10	PC PA10	PC SOY100
Palm Oil	-	-	10 %wt	-	-	10 %wt	-
Soybean Oil	-	10 %wt	-	-	10 %wt	-	80-90 %wt
Mineral Base Oil	-	-	-	-	-	-	0 %wt
Additive Package	-	-	-	-	-	-	20-30 %wt
Additive Package + Base Oil group II	100 %wt	90 %wt	90 %wt	-	-	-	-
Additive Package + Base Oil group III	-	-	-	100 %wt	90 %wt	90 %wt	-

All formulations were evaluated according to standard ASTM methods for API bench tests as described in Table 2.

Table 2. Bench tests

Source: From the Author

Test	Method
Kinematic Viscosity at 100 °C and 40 °C	ASTM D445
Viscosity index	ASTM D2270
Pour Point	ASTM D97
Flash Point	ASTM D92
Copper Corrosion	ASTM D130
Cold cranking Viscosity at -20 °C (for SAE 15W40) and at –30C (for SAE 5W30)	ASTM D5293
Basic Number	ASTM D2896
Acid Number	ASTM D664
Mini Rotary Viscosity (MRV)	ASTM D4684
NOACK	ASTM D5800

RESULTS

All blends containing mixtures of mineral base oils (Group II/III) and vegetable oils (soybean and palm) resulted in homogeneous and stable formulations under standard mixing conditions. However, the PC SOY100 sample, which was exclusively formulated with refined soybean oil and no mineral base oil, did not exhibit the same behavior. As shown in Figure 1, this formulation presented visible phase separation, indicating a lack of miscibility and homogeneity.

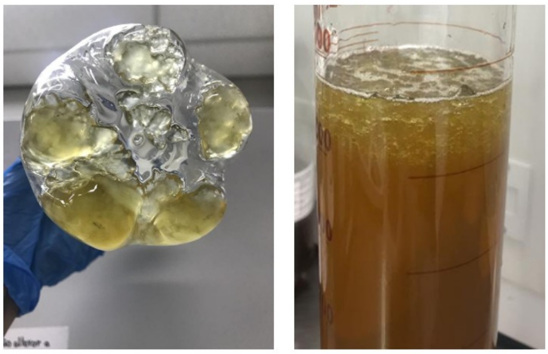

Figure 1. Visual appearance of the PC SOY100 sample (100% soybean oil) after mixing under standard laboratory conditions. Phase separation is clearly visible, indicating poor miscibility and lack of homogeneity.

Source: From the Author

To address this, two additional trials were conducted by incorporating 5% and 20% of a synthetic ester commonly used in PAO-based lubricant systems. Nevertheless, as illustrated in Figures 2 and 3, these modifications did not lead to a fully homogeneous mixture.

Figure 2. PC SOY100 formulation after addition of 5% synthetic ester. Partial improvement in dispersion was observed, but the mixture remained visibly heterogeneous.

Source: From the Author

Figure 3. PC SOY100 formulation with 20% synthetic ester. Despite the higher ester content, full homogenization was not achieved, suggesting limited compatibility between the soybean oil and the ester under the tested conditions.

Source: From the Author

The incompatibility observed in the PC SOY100 sample can be associated with the solubilization of the viscosity modifier, an olefin copolymer (OCP) commonly used in automotive lubricant formulations. The polar nature of the vegetable oil may reduce the compatibility with non-polar polymeric additives, affecting the stability of the final blend.

These results suggest that the formulation of 100% vegetable oil-based lubricants may require the use of specific dispersants or other type of additives to ensure blend stability and compatibility.

The physicochemical characterization of the developed formulations confirmed the technical feasibility of partially replacing mineral base oils (Groups II and III) with renewable raw materials such as soybean and palm oils. All samples met the required viscosity ranges for their respective SAE grades. Table 3 summarizes the main physicochemical results obtained for Heavy Duty sample oils.

Table 3. Bench tests Heavy Duty formulas

Source: From the Author

Tests / Samples	HD 100	HD SOY10	HD PA10
Kinematic Viscosity at 100 °C	14.75	14.73	14.86
Kinematic Viscosity at 40 °C	107.4	100.6	103.8

Viscosity index	143	152	149
Pour Point	-42	-39	-30
Flash Point	256	234	220
Copper Corrosion	1A	1A	1A
Cold cranking Viscosity at -20 °C	5200	4400	5000
Basic Number	9.6	9.4	9.7
Acid Number	0.3	0.3	0.3
MRV at -25 °C	16000	13000	21000
NOACK	7.2	6.9	6.8

The formulations intended for heavy-duty applications (HD 100 – fully mineral, HD SOY10, and HD PALM10) were evaluated for key physicochemical properties to determine the impact of incorporating 10% of refined soybean or palm oil into the base blend.

The results showed no significant differences in kinematic viscosity at 100 °C across the samples. However, a slight increase in viscosity index (VI) was observed in both HD SOY10 and HD PALM10 when compared to the fully mineral formulation (HD 100). This trend is consistent with the intrinsic properties of the vegetable oils used: the measured VI of the base soybean oil was 225 and palm oil was 192, which are substantially higher than the VI of the mineral Group II base oil, which was 115.

A small decrease in viscosity at 40 °C was also observed in both bio-based formulations. This can be attributed to the presence of lighter fractions in the vegetable oils, which also contributed to a reduction in the flash point when compared to the reference sample (HD 100).

As expected, differences were observed in low temperatures behavior. The formulations showed improved fluidity at low temperatures, particularly in the HD PALM10 sample. This correlates with the pour point values of the pure base oils: -9 °C for soybean oil, 3 °C for palm oil, and -16 °C for the mineral base oil. Despite the improvement in pour point, the MRV (mini-rotary viscometer) test showed a considerable increase in viscosity at low temperatures in the vegetable oil-containing formulations. This suggests that the current pour point depressant (PPD) used may not be fully compatible with the molecular structure of the vegetable oil fraction. These results point to the need for future optimization of the PPD system in formulations with significant bio-based content.

No measurable differences were found in TBN, TAN, or corrosion protection performance between the formulations. This indicates that the additive package maintained its functional performance despite the change in base oil propriety. These results are consistent with earlier studies showing that moderate inclusion of vegetable oils does not compromise the performance of well-balanced additive systems [9].

Table 4 shows the results obtained for Passenger car oils.

Table 4. Bench tests Passenger Car formulas

Source: From the Author

Tests / Samples	**PC 100**	**PC SOY10**	**PC PA10**
Kinematic Viscosity at 100 °C	10.8	10.8	10.8
Kinematic Viscosity at 40 °C	63.5	65.6	63.3
Viscosity index	166	155	162
Pour Point	-36	-33	-21
Flash Point	226	216	224
Copper Corrosion	1A	1A	1A
Cold cranking Viscosity at -30 °C	6000	6500	6700
Basic Number	7.3	7.5	7.5
Acid Number	0.4	0.4	0.4
MRV at -	15.800	20000	Freeze

25 °C			
NOACK	6.7	6.7	6.3

NOTE: PC SOY100 was not tested for performance due to lack of blend stability, as discussed in the beginning to this section.

The formulations for passenger car applications followed the same rationale as the heavy-duty samples, incorporating 10% of either soybean or palm oil into the Group III base oil blend. The samples evaluated were PC 100 (fully mineral), PC SOY10, and PC PA10.

No significant deviations were observed in kinematic viscosity, TBN or the VI.

However, in contrast to the HD samples, cold flow behavior showed greater sensitivity in the PCMO formulations. The increase in pour point was more pronounced, and differences in MRV performance were significant. In particular, the PC PA10 formulation failed the MRV test due to solidification at low temperatures, suggesting an incompatibility between the current PPD system and the molecular structure of the palm oil-based blend. These results reinforce that PCMO formulations—designed to meet more stringent fuel economy and low-temperature start-up performance—are more sensitive to variations in base oil structure and require tailored additive strategies. The improvement in low-temperature fluidity for soybean oil was also more marked in the PC formulations than in the HD samples, confirming this higher sensitivity.

Regarding the PC SOY100 sample, the lack of homogeneity discussed earlier is consistent with observations in literature and commercial practice. A review of the market and published data revealed that existing automotive biolubricants typically contain 30% to 40% of renewable content in the base oil. No automotive-grade lubricant using 100% vegetable oil as the base fluid was identified in the databases or technical documents surveyed. This suggests that miscibility and formulation stability remain key barriers to the full substitution of mineral oils in engine oil applications. Such limitations are commonly addressed in the literature by using chemically modified esters or co-solvents to improve additive solubility and blend compatibility.

CONCLUSION

The results obtained in this study demonstrate that the partial replacement of Group II and Group III mineral base oils with refined soybean and palm oils—both produced in Brazil—is technically feasible in the formulation of high-performance engine lubricants. Formulations with 10% vegetable oil content showed no significant degradation in key performance parameters, including viscosity, basicity, corrosivity and additive compatibility, for both heavy-duty (API CK-4 SAE 15W-40) and passenger car (API SP/ILSAC GF-7A SAE 5W-30) applications.

In particular, the lack of miscibility in the 100% soybean oil formulation reinforces the importance of co-solvents, dispersants, or esterified base oil fractions for full bio-based systems.

Additionally, the MRV behavior in PCMO formulations containing palm oil highlighted the need for improved compatibility between pour point depressants and base oil.

Going forward, the next phase of development will include targeted evaluation of thermal stability using Pressure Differential Scanning Calorimetry (PDSC), a method required for compliance with ACEA standards. This is considered a critical point in the use of vegetable oils due to their known sensitivity to oxidation at elevated temperatures. In parallel, a dynamometer test and field test will be conducted to assess the real-world performance of the developed formulations.

While lubricants represent a relatively small fraction of the automotive carbon footprint, their decarbonization plays a role in broader sustainability strategies. More importantly, the use of bio-based raw materials produced domestically opens opportunities to reduce Brazil’s dependency on imported Group II and Group III base stocks, while promoting innovation and value generation within the national agribusiness and chemical sectors.

These preliminary results provide a solid foundation for the continued development of tailor-made bio-based lubricant technologies adapted to local raw materials and performance demands. With ongoing scientific formulation and validation work, Brazilian vegetable oils can be part of a credible and scalable pathway toward sustainable automotive lubrication.

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