Melisa Kalsum

37136-105484-3-ED-Rio(layout).edited

GENAP 2024/2025 (42)

Document Details

Submission ID

trn:oid:::3618:126953046

Submission Date

Jan 27, 2026, 12:01 PM GMT+7

Download Date

Jan 27, 2026, 12:05 PM GMT+7

File Name

37136-105484-3-ED-Rio(layout).edited.docx

File Size

1.5 MB

14 Pages

5,994 Words

36,575 Characters

17% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Filtered from the Report

- Bibliography
- Quoted Text
- Cited Text

Exclusions

- 16 Excluded Sources

Match Groups

82 Not Cited or Quoted 17%
Matches with neither in-text citation nor quotation marks

0 Missing Quotations 0%
Matches that are still very similar to source material

0 Missing Citation 0%
Matches that have quotation marks, but no in-text citation

0 Cited and Quoted 0%
Matches with in-text citation present, but no quotation marks

Top Sources

12%	Internet sources
12%	Publications
9%	Submitted works (Student Papers)

Integrity Flags

0 Integrity Flags for Review

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.

Match Groups

82 Not Cited or Quoted 17%
Matches with neither in-text citation nor quotation marks

0 Missing Quotations 0%
Matches that are still very similar to source material

0 Missing Citation 0%
Matches that have quotation marks, but no in-text citation

0 Cited and Quoted 0%
Matches with in-text citation present, but no quotation marks

Top Sources

12%	Internet sources
12%	Publications
9%	Submitted works (Student Papers)

Top Sources

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

1	Internet	**www.ajol.info**	**1%**
2	Internet	**file.scirp.org**	**1%**
3	Internet	**ejurnalunsam.id**	**1%**
4	Internet	**www.scienceijsar.com**	**<1%**
5	Internet	**www.iaeme.com**	**<1%**
6	Internet	**www.mdpi.com**	**<1%**
7	Publication	**S. W. Dean, Ester Carvalho de Souza, Mauro R. Fernandes, Sylvana C.M. Augustinh...**	**<1%**
8	Publication	**S. W. Dean, K. Narayan Prabhu, Peter Fernandes. "Heat Transfer During Quenchin...**	**<1%**
9	Internet	**scienceq.org**	**<1%**
10	Internet	**doaj.org**	**<1%**

11	Internet	
pdxscholar.library.pdx.edu		<1%
12	Internet	
www.scirp.org		<1%
13	Internet	
iaeme.com		<1%
14	Publication	
Joel Passanha, Sathyashankara Sharma, Ananda Hegde, Bhagya Lakshmi, Gowri S...		<1%
15	Internet	
journal.uad.ac.id		<1%
16	Internet	
media.neliti.com		<1%
17	Publication	
Winnie Queiroz Brandão, Elton Marlon Araújo Lima, Rafaela Teixeira Alves, Italo ...		<1%
18	Publication	
Rosa Lucia Simencio Otero. "Calculation of Kobasko's Simplified Heat Transfer Co...		<1%
19	Internet	
theses.hal.science		<1%
20	Student papers	
Kaplan International Colleges on 2023-08-13		<1%
21	Student papers	
University of Leeds on 2024-12-10		<1%
22	Student papers	
University of the Philippines Diliman on 2024-01-14		<1%
23	Internet	
pubs.rsc.org		<1%
24	Internet	
www.fjs.fudutsinma.edu.ng		<1%

25	Internet	
	www.iosrjournals.org	<1%
26	Internet	
	www.sv-jme.eu	<1%
27	Student papers	
	Deakin University on 2024-05-19	<1%
28	Student papers	
	Kaplan International Colleges on 2023-07-30	<1%
29	Student papers	
	National Institute of Technology Karnataka Surathkal on 2014-06-02	<1%
30	Student papers	
	Swinburne University of Technology on 2024-11-03	<1%
31	Internet	
	matmatch.com	<1%
32	Internet	
	www.hindawi.com	<1%
33	Publication	
	Alka Mahajan, B.A. Modi, Parul Patel. "Technology Drivers: Engine for Growth", CR...	<1%
34	Publication	
	Bajaj, Sarvesh. "Austempering of Low-To-High Carbon Steels in Oil: Processing – ...	<1%
35	Publication	
	Luis Humberto Campos Becerra. "A review of heat treatments applied to low and ...	<1%
36	Student papers	
	Michigan State University on 2025-11-21	<1%
37	Publication	
	Oluwagbenga T. Johnson, Enoch N. Ogunmuyiwa, Albert U. Ude, Norman Gwang...	<1%
38	Publication	
	R. L. Simencio Otero, L. C. F. Canale, G. E. Totten, L. Meekisho. "Vegetable Oils as ...	<1%

39 Publication

Rosa Lucia Simencio Otero, Lemmy Meekisho, Lauralice De Campos Franceschini ... <1%

40 Publication

Teba Ahmed. "Effect of Heat Treatment on the Microstructure and Hardness of L... <1%

41 Student papers

UIN Syarif Hidayatullah Jakarta on 2025-06-02 <1%

42 Publication

Zongxiu Zhu, Weiyi Zhang, Dewen Zhang, Zhan Gao et al. "Experimental study of ... <1%

43 Internet

iieta.org <1%

44 Internet

jmes.ump.edu.my <1%

45 Internet

mafiadoc.com <1%

46 Student papers

universititeknologimara on 2025-08-06 <1%

47 Internet

www.journal.staihubbulwathan.id <1%

48 Publication

Maruf Yinka Kolawole, Suleman Adeniyi Aliyu, Sefiu Adekunle Bello, Kamoru Oluf... <1%

49 Publication

Misali Joel Madu, Oyewole Adedipe, Sunday Albert Lawal, Asipita Salawu Abdulra... <1%

50 Student papers

University of Sheffield on 2019-08-23 <1%

51 Publication

G. Ramesh, K. Narayan Prabhu. "Effect of Addition of Aluminum Nanoparticles on... <1%

52 Publication

Karan Sotoodeh. "Safety Engineering in the Oil and Gas Industry", CRC Press, 2023 <1%

53	Publication	
S. W. Dean, Lauralice C. F. Canale, Xinmin Luo, Xin Yao, G. E. Totten. "Quenchant C...		<1%
54	Student papers	
University of Malaya on 2023-01-27		<1%
55	Student papers	
University of the Philippines Diliman on 2024-12-20		<1%
56	Publication	
Jamal Nayief Sultan, Iman Zaidan Alshih Yahya, Emad Toma Karash, Majid Khaleel...		<1%

JURNAL TEKNIK MESIN
(JOURNAL OF MECHANICAL ENGINEERING)

VOL. 15, NO. 01, February 2026
https://publikasi.mercubuana.ac.id/index.php/jtm/index
DOI :10.22441/jtm.v5i1.37136

Evaluating Vegetable Oils as Eco-Friendly Alternatives in Metal Heat Treatment : Review

Sukendar[1], Sagir Alva[1], and Dianta Ginting[1*]
[1]Mechanical Engineering Departement, Faculty of Engineering, Mercu Buana University Jakarta, 11650, Indonesia

*E-mail: dianta.ginting@mercubuana.ac.id

***Abstract--**Mineral oils are still widely used as quenching media in steel heat treatment; however, their use raises environmental, health, and fire-safety concerns, motivating interest in vegetable oils as biodegradable and renewable alternatives. Recent studies indicate that vegetable oils can provide cooling performance comparable to or better than petroleum-based oils. However, a comprehensive framework linking their molecular structure to cooling behavior and steel properties remains limited. This review aims to develop a quantitative, mechanistic understanding of how vegetable-oil chemistry controls thermophysical behavior, quenching severity, microstructural evolution, and mechanical performance in low- and medium-carbon steels. A systematic synthesis of experimental and modeling studies published between 2010 and 2024 was performed, focusing on thermophysical properties, cooling curves, phase transformations, and mechanical test results of steels quenched in various vegetable oils. The analysis shows that vegetable oils exhibit higher quenching severity than mineral oils, with Grossmann H values of 0.17–0.21, mainly due to suppressed film boiling and dominant nucleate boiling heat transfer. Their relatively high thermal conductivity (0.13–0.18 $W\,m^{-1}\,K^{-1}$) and high viscosity index enable more uniform heat extraction during the martensitic transformation, resulting in finer martensitic–bainitic microstructures. As a result, vegetable-oil-quenched steels commonly achieve hardness above 40 HRC, tensile strengths above 800 MPa, and improved impact toughness compared with mineral-oil-quenched steels. Oleic-rich oils, such as palm and canola, also show better oxidative stability and cooling performance than highly polyunsaturated oils, such as soybean. Properly stabilized vegetable oils are environmentally benign and scientifically engineerable quenching media capable of delivering high and tunable thermal–mechanical performance for industrial steel heat treatment.*

Article History:
Received: December 05, 2025
Revised: January 10, 2026
Accepted: January 12, 2026
Published: xxxx, xxxx

***Keywords:** Vegetable oils, quenching media, mechanical properties, thermal stability, heat treatment of steels*

1. INTRODUCTION

Vegetable oils as environmentally friendly alternative quenching media have gained increasing attention in steel heat-treatment processes in response to the growing demand for high-performance materials and sustainable manufacturing [1]. Steel remains one of the most widely used engineering materials due to its low cost and the versatility of its mechanical properties, which can be tailored through control of chemical composition, microstructure, and heat-treatment conditions [2, 3, 4]. Among the various strengthening techniques, quenching is the most widely used because it effectively modifies the steel microstructure by rapidly cooling from the austenitic region [5, 6]. However, the success of this process strongly depends on the selection of the quenching medium, as different cooling rates result in varying degrees of martensitic transformation, hardness, and microstructural stability [7, 8]. Therefore, choosing an appropriate quenching medium, including the use of vegetable oils as alternatives to mineral oils, is a critical factor in achieving optimal mechanical performance, particularly for components subjected to severe service conditions [9, 10, 11].

Water and mineral oils are widely used as conventional quenching media in steel heat treatment; however, both exhibit significant limitations [12, 13]. Water provides a high cooling rate but often generates large temperature gradients between the steel surface and the cooling medium. This condition induces excessive thermal stresses, thereby increasing the risk of distortion and cracking, particularly during low-water-temperature quenching [14]. Attempts to mitigate this risk by increasing the water temperature instead reduce the cooling rate, which may lead to incomplete phase transformation and deterioration of the steel's mechanical properties [15]. Therefore, although water is adequate for rapid cooling, its practical application is limited by concerns related to dimensional stability and structural integrity after heat treatment [16, 17, 18, 19, 20, 21]. In contrast, mineral oils provide slower and more controlled cooling, thereby reducing the risk of cracking [22]; however, they are relatively expensive, toxic, and flammable, and pose significant environmental concerns due to their poor biodegradability [23, 24].

To address the limitations of conventional quenching media, such as water and mineral oils, biodegradable vegetable oils have emerged as promising, environmentally friendly alternatives. Vegetable oils are non-toxic, renewable, and readily biodegradable, making them safer and more environmentally benign than petroleum-based oils. In steel quenching, vegetable oils can provide adequate cooling, although their cooling rates are generally lower than those of water. Their viscosity and thermal conductivity characteristics allow more uniform and controlled heat extraction, thereby reducing thermal gradients, residual stresses, and the risk of distortion and cracking in quenched steels. Numerous studies have demonstrated that vegetable oils such as canola, soybean, and palm oil can produce martensitic and Bainitic microstructures with hardness and tensile strength comparable to or superior to those obtained using mineral oils. Furthermore, by selecting appropriate oils and incorporating antioxidant additives, the oxidative stability and cooling performance of vegetable oils can be engineered to meet industrial requirements, making them not only environmentally friendly alternatives but also high-performance quenching media [25, 26].

This review aims to provide a comprehensive, mechanistic, and performance-oriented overview of recent Research on vegetable oils as alternative quenching media, elucidating how their thermophysical properties and heat-transfer behavior govern cooling kinetics, microstructural evolution, residual stresses, and the mechanical performance of quenched steels, while also identifying key challenges and opportunities for future Research and industrial implementation.

2. LITERATURE SEARCH STRATEGY

This review examined scientific articles from various platforms and databases, including ScienceDirect, SpringerLink, Taylor & Francis, ResearchGate, and Google Scholar, on the use of vegetable oils as quenching media for steel. The selected articles were peer-reviewed publications from 2010 to 2024 that reported mechanical properties or microstructural data. From this selection, five key studies were analyzed to compare the performance of pure vegetable oils and bio–mineral oil blends. The analysis was conducted narratively to evaluate the effectiveness, limitations, and development potential of vegetable oils as more sustainable quenching media.

3. SYNTHESIS OF THE LITERATURE

Steel remains the dominant engineering material due to its superior mechanical properties, wide availability, ease of fabrication, and low cost. To meet the demands of heavy-load applications, improvements in hardness and tensile strength are commonly achieved through heat-treatment processes such as quenching. The use of vegetable and animal oils as quenching media dates back thousands of years. Although cold water has historically been the most frequently used cooling medium, its extremely high cooling rate often causes thermal cracking and embrittlement in steel, thereby encouraging the use of natural oils to achieve more controlled cooling. Although the industrial use of natural oils declined after the Second World War, Research interest has resurged over the past decade due to their renewable nature, biodegradability, and strong potential as environmentally friendly quenching media.

Vegetable oils offer several advantages, including high biodegradability, low toxicity, and stable viscosity across temperature variations, enabling more uniform cooling and reducing the film-boiling phenomena commonly observed in mineral oils. These advantages make vegetable oils strong candidates for environmentally friendly quenching media. However, their primary limitation lies in their low thermo-oxidative stability, particularly in oils with a high degree of unsaturation, such as soybean oil, which leads to rapid degradation when used or exposed to elevated temperatures [26]. The following presents a comparison between vegetable oils and mineral oils:

Table 1. Comparison between vegetable oils and mineral oils [26, 27].

ASPECT	VEGETABLE OILS	MINERAL OILS
Sustainability & Environmental Impact	Renewable, biodegradable, environmentally friendly	Non-renewable, potential environmental pollutant
Film-Boiling Behavior & Cooling Performance	Thin and short-lived film-boiling; more uniform cooling	Thick and persistent film-boiling; less stable initial cooling
Resulting Microstructure	Produces finer and more homogeneous martensite/bainite; lower distortion	Less uniform microstructure; higher dimensional distortion
Hardness & Mechanical Properties	Generally yields higher hardness; improved mechanical performance	Lower hardness under comparable quenching conditions
Thermal & Oxidative Stability	Low without additives; prone to oxidation	High thermal and oxidative stability; suitable for long-term use
Operational Safety (Flash Point)	Higher flash point; lower fire risk	Lower flash point; higher fire hazard

Vegetable oils demonstrate strong potential as next-generation, sustainable quenching media, although improving their oxidative stability, particularly through the incorporation of appropriate additives, remains essential for ensuring long-term performance [27].

To understand the cooling behavior of quenching media at various stages of the process, it is necessary to measure viscosity at 40 °C and 100 °C. At 40 °C, higher viscosity indicates the fluid's ability to effectively wet the metal surface, while at 100 °C, the decrease in viscosity enhances fluid flow and accelerates heat transfer through convection. The comparison of these two values produces the Viscosity Index (VI), which reflects the stability of viscosity with respect to temperature changes. Quenching media with a high VI exhibit more consistent cooling performance and can minimize the risk of distortion and defects in steel during the quenching process [28, 29, 30, 31, 32].

Table 2. Viscosity Characteristics of Vegetable Oils at 40 °C and 100 °C

QUENCHED SAMPLE	Viscosity at 40˚C (cSt)	Viscosity at 100˚C (cSt)	Reference
Palm kernel oil	41.69	8.94	[33]
Cottonseed oil	34.8	6.9	[33]
Palm oil	39.7	8.2	[33, 34, 35]
Neem seed oil	32.41	7.89	[33]
Neem oil	20.78		[36]
Watermelon Seed oil	35.355	7.90	[36]
Marula oil	68.92	23.40	[37]
Shea butter oil	70.40	28.90	[37]
Peanut oil	90.53	33.65	[37]
Cottonseed oil	110.35	33.50	[37]
Cottonseed oil	33.86	7.75	[38]
Soybean oil	31.49	7.51	[34, 35, 38]
Canola oil	34.92	7.91	[38]
Sunflower oil	33.21	7.78	[38]
Corn oil	33.51	7.70	[38]

Vegetable-oil-based quenching media exhibit distinctive heat-transfer behavior compared to conventional mineral oils, primarily due to the absence of a stable film-boiling phase. As a result, the cooling process is governed predominantly by nucleate boiling and convective heat transfer, enabling relatively rapid cooling within the critical transformation temperature range. The cooling characteristics of these bio-based quenchants are evaluated using the ASTM D6200 cooling curve methodology, which provides key parameters, including cooling rates at critical temperatures and the vapor–to–boiling transition time (t_{A–B}). To obtain a more comprehensive thermophysical assessment, the cooling analysis is strengthened through regular-condition heat-transfer modeling, allowing quantitative estimation of the effective heat flux at the probe surface [38].

The transient heat-conduction phenomenon inside the probe is described by the one-dimensional heat equation,

$$\frac{\partial T}{\partial t} = a\nabla^2 T \tag{1}$$

T = Temperature inside the probe (K or °C), t = time (s)
$\frac{\partial T}{\partial}$ = Rate of change of temperature with respect to time
α = Thermal diffusivity of the probe material (m²/s), representing the ability of the material to conduct heat relative to its heat storage
$\nabla^2 T$ = Spatial variation of temperature inside the probe

Subject to a convective boundary condition

$$\lambda\frac{\partial T}{\partial t} = -\alpha(T - T\mathrm{m}) \tag{2}$$

Tm = Temperature of the quenching medium (K or °C)
λ = Thermal conductivity of the probe material (W m⁻¹ K⁻¹)
α = Heat transfer coefficient between the probe and the quenching medium (W m⁻² K⁻¹)
(T−Tm) = Temperature difference driving heat transfer

The corresponding solution under regular conditions is expressed using the cooling constant m

$$\frac{T-T\mathrm{m}}{T_0-T\mathrm{m}} = A_0\mathrm{e}^{-mt} \tag{3}$$

$\boldsymbol{T_0}$ = Initial temperature of the probe, A_0 = Constant depending on initial conditions, t = Time
m = Cooling constant

The value of m is experimentally obtained from two points on the cooling curve.

$$m = \frac{\ln(T_1-T_\mathrm{m})-\ln(T_2-T_\mathrm{m})}{t_2-t_1} \tag{4}$$

T_1, T_2 = Probe temperatures at times t_1 and t_2, t_1, t_2 = Two selected times on the cooling curve
m = Experimentally determined cooling constant

Alternatively, through the instantaneous cooling rate

$$m = \frac{\omega}{T-T_\mathrm{m}} \tag{5}$$

ω = Instantaneous cooling rate $\frac{\partial T}{\partial t}$, T = probe temperature, Tm= medium temperature

The resulting cooling constant is then used to calculate the Kondratiev number.

$$Kn = \frac{m}{m_\infty} \text{ where: } m_\infty = \frac{\alpha}{K} \tag{6}$$

Kn = Kondratjev number, m = cooling constant, m∞= limiting cooling constant
α = heat-transfer coefficient, k = thermal conductivity of the probe

The relationship between Kn and the generalized Biot number is given by

$$Bi_\mathrm{V} = \frac{Kn}{1+1.437Kn+0.52Kn} \tag{7}$$

Bi_V = generalized Biot number, Kn = Kondratjev number

From this, the effective heat-transfer coefficient can be calculated.

$$\alpha = \frac{Bi_V \lambda S}{V} \quad (8)$$

α = heat-transfer coefficient, Bi_V= generalized Biot number, λ = thermal conductivity of the probe
S = surface area of the probe, V = volume of the probe

This parameter represents a critical indicator of the quenchant's cooling capacity. The evaluated vegetable oils consistently exhibit higher α and Grossmann H-severity values (0.17–0.21) than conventional mineral oils (0.11–0.14). These findings suggest that vegetable oils deliver stronger quenching severity while maintaining high viscosity stability across temperatures. Collectively, the thermal performance, environmental compatibility, and stable viscosity behavior strongly position vegetable oils as promising sustainable quenchants suitable for the heat treatment of low- and medium-carbon steels.

To evaluate the effectiveness of quenching media in transferring heat from the steel surface during cooling, precise information regarding their thermal conductivity is essential. The rate of heat extraction directly governs microstructural evolution, achieving target hardness levels, and minimizing distortion or thermal cracking. Accurate thermal conductivity data are also fundamental for maintaining process stability and controllability, selecting appropriate oils, designing additive formulations, and developing simulation-based thermal models. Consequently, thermal conductivity represents a critical parameter in determining the suitability of vegetable oils as quenching media for industrial applications [41].

Table 3. Thermal Conductivity of Various Quenching Media from Previous Studies

QUENCHED SAMPLE	**Stabilitas Termal**	**Thermal Conductivity (W/m ˚C)**	**Reference**
water	Very unstable	0.6	[42]
SAE40 Engine Oil	Stable	0.145	[43]
Palm kernel oil	Very stable	0.131-0.182	[33, 44]
Cottonseed oil	Stable	0.139	[33]
Palm oil	Less stable	0.169	[33]
Neem seed oil	Less stable	0.152	[33]
Sunflower Oil	Less stable	0.17–0.19	[45]

Matijevic et al. compared the quenching intensity of palm oil, canola oil, and petroleum oil using the industrial Liscic/Petrofer probe. Palm oil showed the best performance, bypassing film boiling and entering nucleate boiling directly, with higher ΔT10 and ΔTmax values, a maximum HTC of ~3000 W/m²K, and the shortest cooling time. Canola oil exhibited intermediate performance, slower than palm oil but better than petroleum oil. Petroleum oil displayed the weakest quenching behavior due to prolonged film boiling, slow initial cooling, and a lower maximum HTC of ~1940 W/m²K. Water served as a reference, providing extremely rapid but overly aggressive cooling. Overall, the study highlighted palm oil as a strong, environmentally friendly candidate to replace petroleum oils, particularly for low-hardenability steels. [46].

To ensure long-term stability, operational safety, and the effectiveness of vegetable oils as environmentally friendly alternatives to industrial quenching media, the evaluation of Acid Value and Iodine Value is critical. These parameters provide comprehensive insight into the degree of degradation and oxidative stability of the oils during repeated thermal exposure. A high Acid Value indicates an increasing concentration of free fatty acids resulting from hydrolysis or oxidation, which can alter viscosity, reduce cooling quality, and ultimately lead to inconsistent quenching performance. Meanwhile, a high Iodine Value reflects a greater proportion of unsaturated fatty acids, making the oil more susceptible to thermal oxidation, sludge formation, and reduced heat-transfer efficiency.

Table 4. Acid Value and Iodine Value of Vegetable Oils

QUENCHED SAMPLE	Acid Value	Iodine Value	reference
Palm kernel oil	Low	Low	[33]
Cottonseed oil	Medium	Medium	[33]
Palm oil	Low	Low	[33]
Palm oil (murni)	45.18	57.36	[34, 35]
Soybean Oil	15.90	124.74	[34, 35]
Neem seed oil	High	Medium	[33]
Neem Oil	13.945	74.9	[36]
Watermelon Seed Oil	3.08	121.8	[36]

A comparative study by Agboola et al. (2015) examined the feasibility of several Nigerian vegetable oils as alternative quenching media for the industrial heat treatment of medium-carbon steel. The study involved characterizing the physicochemical properties and fatty acid profiles of cottonseed oil, palm kernel oil, neem seed oil, and palm oil. The quenching performance of these vegetable oils was tested at bath temperatures of 34°C, 50°C, 70°C, and 100°C, with SAE40 engine oil (as the standard medium) and tap water used as controls. Similarly, Sani and Aminu performed a comparative analysis of other Nigerian vegetable oils as alternative quenchants to replace salt baths for the heat treatment of ductile and grey cast irons. Their study involved characterizing the physicochemical properties and fatty acid profiles of marula seed oil, cottonseed oil, groundnut oil, and shea butter. The samples were austenitized at 900°C, soaked for 1 hour, and subsequently austempered by quenching separately at 250°C, 260°C, and 270°C for 1, 2, 3, and 4 hours [33, 37].

Salihu, S. A. et al. investigated and compared the performance of neem seed oil and watermelon seed oil as alternative quenching media to SAE40 mineral oil for the heat treatment of medium-carbon steel. The steel samples were austenitized at 800–900°C, quenched in each oil, and then tempered at 250–400°C. Meanwhile, Kolawole, M. Y. et al. examined the effect of bio–mineral oil blends, groundnut oil and SAE40 on the mechanical properties of low-carbon steel carburized using a mixture of eggshell and date seed. The samples were carburized at 950°C for 3 hours and then quenched using six media: water, 100% SAE40, 100% groundnut oil, and three blends (70/30, 60/40, 50/50). All samples were subsequently tempered at 200°C. Additionally, E. A. Pérez R. et al. assessed the performance of vegetable blend oil, soybean, canola, and sunflower oils, as well as 10W30 mineral oil, as quenching media for AISI 1045 steel. Quenching was performed after heating the steel to 870°C, holding for 50 minutes, and cooling in each medium. [36, 48, 49].

Rahardja and Prumanto examined the Influence of heating temperature variation on the hardness improvement of ST37 steel through quenching using Crude Palm Oil (CPO). Specimens were heated to 200, 400, 600, 800, and 965°C, then immediately quenched in CPO. Belinato et al. expanded the investigation into oxidative stability. They found that soybean oil is highly prone to degradation due to its high degree of unsaturation, whereas palm oil is naturally more stable. The addition of antioxidants (Irganox L109, propyl gallate, TBHQ) significantly increased the oxidation onset temperature without reducing cooling performance. Civera et al. confirmed that olive and sunflower oils provide sufficient cooling for martensite formation while minimizing residual stresses and dimensional distortion, reinforcing the environmental and industrial viability of vegetable-based quenchants [34, 50, 51]

O. T. Johnson et al. studied marula oil, a local Namibian vegetable oil, as a potential alternative to SAE 40 engine oil for the heat treatment of medium-carbon steel. Samples were heated to 850°C, 900°C, 950°C, and 1000°C with holding times of 45 and 90 minutes, then quenched using marula oil and SAE40 oil. Ajiboye and Abdulsalam evaluated the use of mixed vegetable oils as quenching media for medium-carbon steel. Four vegetable oils were blended into two mixtures: Blend A (cottonseed oil + neem oil) and Blend B (cottonseed, neem, palm kernel, and shea butter oils). Samples were heated to 850°C and quenched in the various oil blends to determine their effects on mechanical properties and microstructure. Consistently, K. J. Franklin et al. analyzed the Influence of biodegradable oil–based quenching media on the microstructure and hardness of EN 31 steel. The steel was heated to 1000°C, held for 30 minutes, and quenched in four different media: 100% groundnut oil, 100% neem oil, a 60% groundnut + 40% neem blend, and a 40% groundnut + 60% neem blend. In parallel, I. Y. Suleiman et al. evaluated the effectiveness of coconut oil and ghee oil as quenching media for hardening and tempering of plain carbon steel containing 0.35% C. The steel samples were austenitized at 850°C, soaked, and then quenched accordingly [12, 52, 53, 54, and 56].

Overall, these studies indicate that the quenching medium plays a critical role in controlling the microstructural evolution and mechanical properties of heat-treated samples. Variations in cooling rate, viscosity, thermal conductivity, and wetting behavior across different quenching media strongly Influence phase transformations, grain refinement, and precipitate formation, ultimately governing the strength, hardness, and toughness of the material. In this respect, vegetable oils have attracted increasing attention because their cooling behavior can be tailored by composition and temperature, enabling more uniform and controlled heat extraction compared to conventional mineral oils. As a result, hardness measurements consistently show that vegetable oils can outperform mineral oils under certain processing conditions, thereby reducing thermal stresses and the risk of cracking. However, despite these advantages, water quenching still yields the highest hardness values due to its exceptionally rapid cooling rate, which promotes the formation of more challenging phases such as martensite. Nevertheless, this aggressive cooling often leads to severe thermal gradients, making water quenching more prone to distortion, residual stresses, and microcrack formation, thereby highlighting the need to balance hardness with overall structural integrity in practical heat-treatment applications.

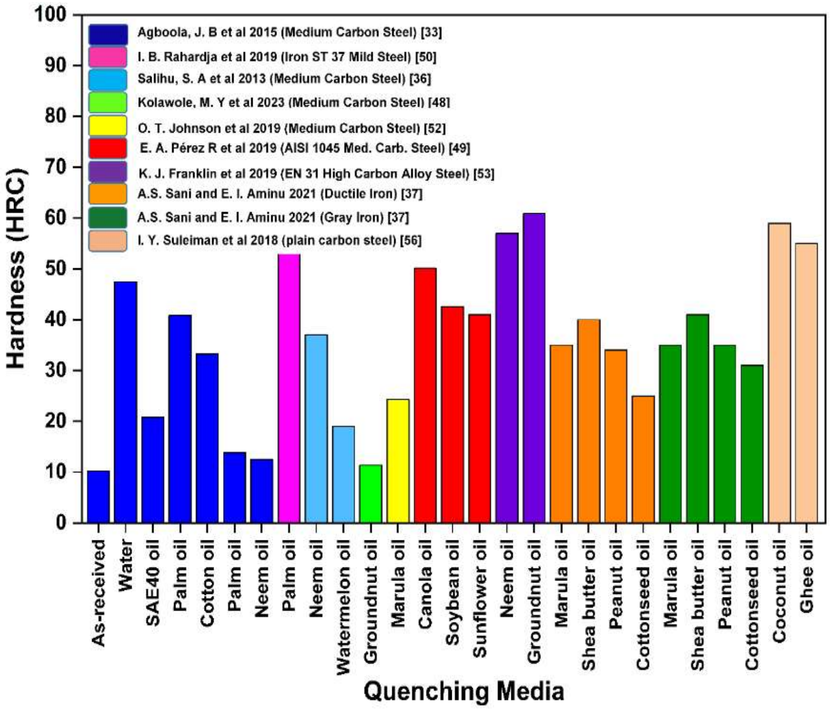

Figure 1. Influence of Vegetable-Oil Quenching Media on Hardness Development: A Comparative Analysis from Multiple Studies [33, 36, 37, 48, 49, 50, 52, 53, 56]

Impact testing is essential in analyzing vegetable-oil quenching media because it reveals the material's toughness and ensures an optimal balance between hardness and ductility, which is influenced by the vegetable oils' cooling rates.

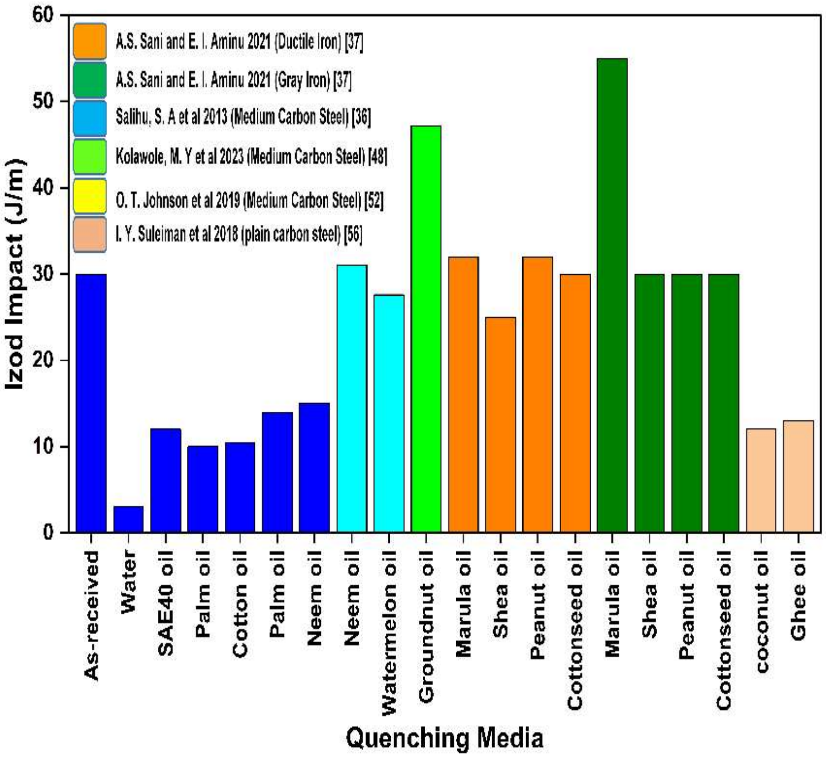

Figure 2. Influence of Vegetable-Oil Quenching Media on Izod Impact Performance: A Comparative Analysis Across Multiple Studies [36, 37, 48, 52, 56]

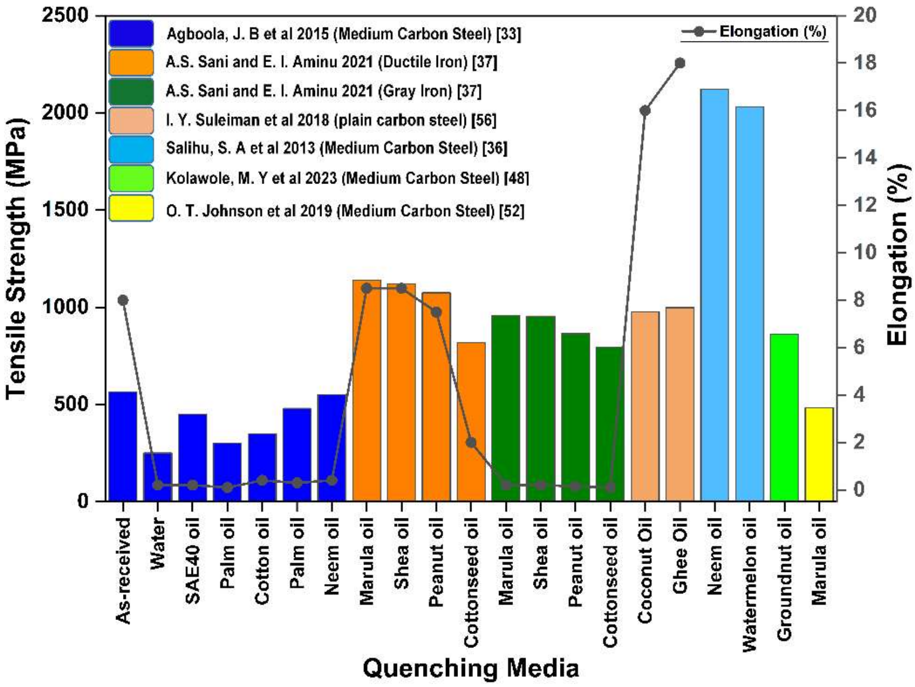

Figure 3. Influence of Vegetable-Oil Quenching Media on Tensile Strength and Elongation: A Comparative Multi-Study Evaluation [33, 36, 37, 48, 52, 56]

In addition, the tensile strength and yield strength of several specimens quenched in vegetable oil media also increased, indicating that vegetable oils can enhance hardness while maintaining ductility through their more controlled cooling rates.

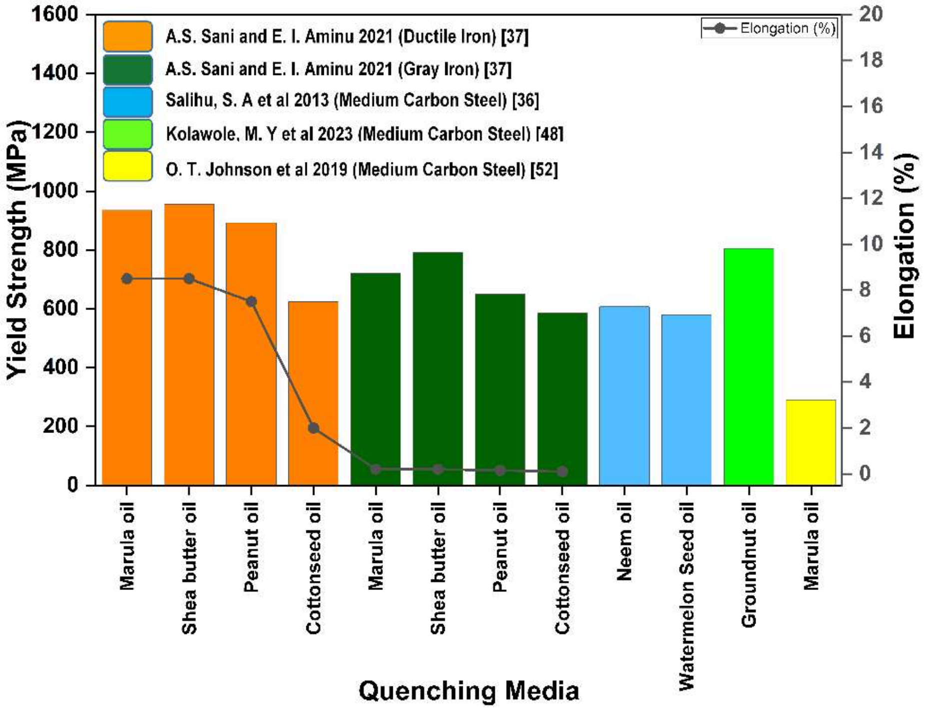

Figure 4. Influence of Vegetable-Oil Quenching Media on Yield Strength and Elongation: A Comparative Multi-Study Evaluation [36, 37, 48, 52]

Further studies have highlighted the physicochemical factors influencing the quenching process. Kobasko et al. compared five vegetable oils with mineral oils and found that vegetable oils exhibit higher viscosity indices and faster cooling rates, thereby suppressing pearlite formation and providing greater quench severity. Passanha et al. evaluated coconut, karanja, and pinnay oil emulsions mixed with brine and egg yolk, showing that a 25% coconut oil emulsion produced the highest hardness, while lower oil fractions enhanced cooling performance due to reduced viscosity. Overall, these findings consistently indicate that vegetable oils, particularly when formulated as blends or emulsions or supplemented with antioxidants, can serve as effective, environmentally friendly, and mechanically advantageous quenching media for various steels [38, 55].

The physicochemical properties of oils—including oxidative stability, viscosity, and their tendency to degrade under repeated thermal exposure—are strongly influenced by their degree of unsaturation and fatty acid composition. In the context of quenching, these molecular variations play a critical role: oils with high bis-allylic carbon content and polyunsaturation are more susceptible to oxidation and viscosity increases, ultimately reducing cooling rates and leading to less consistent quenching performance. Conversely, oils with a higher proportion of oleic acid exhibit superior thermal stability and more favorable viscosity behavior, thereby maintaining a more stable cooling rate that supports martensite formation. These chemical characteristics explain differences in cooling rate and quench severity among vegetable oils and underscore their potential as effective, environmentally benign quenching media. This phenomenon is clearly illustrated in Figure 5, which presents the 13C NMR spectra of five vegetable oils—cottonseed, canola, sunflower, corn, and soybean—revealing variations in triglyceride structures through differences in the intensity of olefinic, allylic, bis-allylic, saturated, and carbonyl carbon peaks, all of which directly correlate with the physicochemical behavior of the oils during quenching [57].

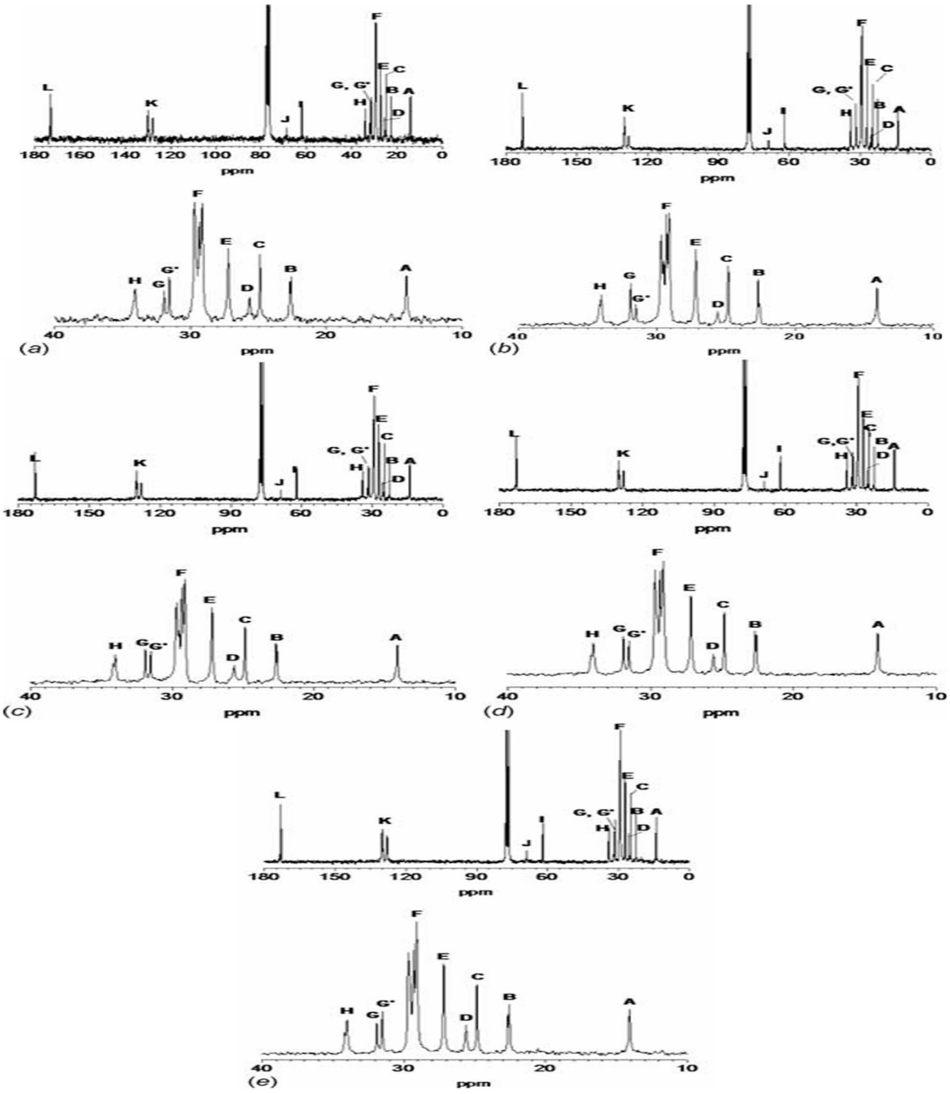

Figure 5 (a) Cottonseed oil 13C NMR spectra. (b) Canola oil 13C NMR spectra. (c) Sunflower oil 13C NMR spectra. (d) Corn oil 13C NMR spectra. (e) Soybean oil 13C NMR spectra. [Excerpted from Journal 57]

4. CONCLUSIONS

This review demonstrates that vegetable oils possess favorable thermophysical properties, high biodegradability, and effective cooling performance, collectively supporting their use as sustainable alternatives to conventional mineral-oil quenchants. The analysis confirms that vegetable oils can achieve competitive hardness, improved microstructural refinement, and reduced distortion, thereby addressing the Research objective of identifying environmentally friendly quenching media with adequate thermal performance. These findings highlight the practical potential of vegetable oils to minimize environmental impact while maintaining quenching efficiency, and they also contribute theoretically by strengthening the understanding of how viscosity, thermal conductivity, and oxidative stability Influence quenching behavior. To maximize their applicability, antioxidants, optimized blends, or tailored formulations are recommended to address the challenge of low thermo-oxidative stability in highly unsaturated oils. The primary limitations of current Research include the lack of standardized cooling-curve evaluation and limited industrial-scale validation; thus, future studies should focus on enhancing high-temperature stability, real-time heat-transfer modeling, and large-scale implementation across different steel grades. Overall, vegetable oils represent a promising pathway toward greener, safer, and high-performance quenching technologies.

REFERENCES

[1] B. Bhagyalaxmi, S. Sharma, P. K. Jayashree, and A. Hegde, *“Vegetable oil quench effect on impact toughness and hardness of 42CrMo4 steel,”* Materials Today: Proceedings, vol. 63, pp. 113–116, 2022, https://doi.org/10.1016/j.matpr.2022.02.349.

[2] Zurnadzhy, V., Ставровская, B. Chabak, Y., Petryshynets, I., Efremenko, B., Wu, K., … & Brykov, M. (2024). *Enhancing the tensile properties and ductile-brittle transition behavior of EN S355 grade rolled steel via cost-saving processing routes*. Materials, 17(9), 1958. https://doi.org/10.3390/ma17091958.

[3] Guo, H., Li, Q., Su, J., & Feng, X. (2021). *Microstructural characterizations and kinetics model of isothermal bainite formation with the presence of prior martensite in high-carbon nanostructured bainitic steel. Steel Research International, 92*(7). https://doi.org/10.1002/srin.202000708.

[4] Siwiec, D., Dwornicka, R., & Pacana, A. (2020). *Improving the process of achieving the required microstructure and mechanical properties of 38MnVS6 steel*. https://doi.org/10.37904/metal.2020.3525.

[5] Valentino, J., Pramono, A., Syaifudin, A., Kis, A., Shalahuddin, L., Windharto, A. & SASAKI, K. (2024). *Enhancing S45C steel for the primary component of an automatic coupler using quench-tempering techniques.* Istrazivanja I Projektovanja Za Privredu, 22(2), 215-222. https://doi.org/10.5937/jaes0-43988.

[6] Hằng, P. (2021). *Effects of the heat treatment process on the mechanical properties of medium-carbon steel.* Vietnam Journal of Agricultural Sciences, 4(4), 1283-1292. https://doi.org/10.31817/vjas.2021.4.4.07.

[7] Priyambodo, B., Margono, M., & Yaqin, R. (2022). *Gabungan quenching-variasi tekanan shot peening terhadap kekerasan permukaan dan struktur mikro permukaan baja s45c*. Quantum Teknika, 4(1), 27–34. https://doi.org/10.18196/jqt.v4i1.16170.

[8] Patil, J., et al. (2023). *A review of the effect of different quenching media on the properties of steel*. IRJMETS. https://doi.org/10.56726/irjmets39954.

[9] F. Lenzi, G. Campana, A. Lopatriello, M. Mele, and A. Zanotti, “About the use of mineral and vegetable oils to improve the sustainability of steel quenching,” Procedia Manufacturing, vol. 33, pp. 701–708, 2019, doi: 10.1016/j.promfg.2019.04.088.

[10] Riza, R., Putra, W., & Harjanto, S. (2020). *Cooling rate observation during the quenching process using carbon nanofluids for S45C carbon steel*. Key Engineering Materials, 833, 13–17. https://doi.org/10.4028/www.scientific.net/kem.833.13.

[11] Putra, W., et al. (2025). *The effects of leaching and pyrolysis on particle synthesis and their impact on thermal conductivity and cooling rates of waste PCB-dispersed quenchants*. Materials Research Express, 12(1), 016502. https://doi.org/10.1088/2053-1591/ada48e.

[12] Buczek, A. and Telejko, T. (2004). Inverse determination of boundary condition during boiling water heat transfer in quenching operation. Journal materials Processing Technology, 155-156; 1324-1329

[13] Feng, C. and Tahir, I.K. (2008). The effect of quenching medium on the wear resistance of a Ti-6Al-4V alloy. Journal of Materials Science, 43, 788-792

[14] Ajiboye, T. & Abdulsalam, A. (2019). Mechanical characteristics of heat-treated medium carbon steel quenched using a blend of different types of vegetable oils. *International Journal of Engineering Materials and Manufacture*, 4(4), 146-153. https://doi.org/10.26776/ijemm.04.04.2019.02.

[15] Boyer, H. E. (1984). Practical Heat Treating, 1st ed., American

[16] Araoyinbo, A. (2023). Low-temperature heat treatment of steel and the effect of quenching on strength and oxidation behaviour. Mehran University Research Journal of Engineering and Technology, 42(1), 32. https://doi.org/10.22581/muet1982.2301.04.

[17] MacKenzie, D. S. (2021, December 22). Using water as a quenchant. *Heat Treatment and Surface Engineering*. Retrieved from http://thermalprocessing.com.

[18] Zheng, H., Yang, Y., Li, J., Zuo, X., Wan, J., Rong, Y., & Chen, N. (2025). Mechanisms of secondary crack initiation, propagation and closure during the water quenching process in medium-carbon martensitic steel. *Journal of Materials Science and Engineering*, Advance online publication. https://doi.org/10.1016/j.ijplas.2025.104240

[19] Zheng, H., Zeng, L., Zuo, X., Rong, Y., Wan, J., & Chen, N. (2023). Water-quenching cracking mechanism and prevention in steels. *Heat Treatment and Surface Engineering*, *5*(1), 2280352. https://doi.org/10.1080/25787616.2023.2280352.

[20] Liščić, B., Totten, G. E., & Thornton, S. (1992). *Theory and technology of quenching*. Metals Park, OH: ASM International. (Halaman 117–181, 248–340, 341–389)

[21] Lopez-Garcia, R. D., Medina-Juárez, I., & Maldonado-Reyes, A. (2022). Effect of quenching parameters on distortion phenomena in AISI 4340 steel. *Metals, 12*(5), 759. https://doi.org/10.3390/met12050759.

[22] Grishin SA, Churyukin YN. Evaluation of the cooling capacity of quenching media based on water. Met Sci Heat Treat. 1986;28:744-5.

[23] Fernandes, P., & Prabhu, K. N. (2008). Comparative study of heat transfer and wetting behaviour of conventional and bioquenchants for industrial heat treatment. *International Journal of Heat and Mass Transfer,* *51*(3–4), 526–538. https://doi.org/10.1016/j.ijheatmasstransfer.2007.05.018.

[24] Prathviraj, M. P., Samuel, A., & Prabhu, K. N. (2020). Reprocessed waste sunflower cooking oil as a quenchant for heat treatment. *Journal of Cleaner Production, 269*, 122276. https://doi.org/10.1016/j.jclepro.2020.122276.

[25] R. L. S. Otero, L. Meekisho, L. C. F. Canale, and G. E. Totten, “Vegetable oil quenchants: a review,” International Journal of Microstructure and Materials Properties, vol. 14, no. 4, pp. 307–360, 2019.

[26] P. Brito, P. A. Ramos, L. P. Resende, D. A. de Faria, and O. K. Ribas, “Experimental investigation of cooling behavior and residual stresses for quenching with vegetable oils at different bath temperatures,” Journal of Cleaner Production, vol. 216, pp. 230–238, Apr. 2019, doi: 10.1016/j.jclepro.2019.01.194.

[27] Andriollo, J.P., Parodi, A., Baglietto, L. and Bianchi, S. (2012) ‘Vegetable oil vs mineral oil in quenching applications’, in MacKenzie, D.S. (Ed.): Conf. Proceed. 6th International Conference on Quenching and Control of Distortion, 9–13 September 2012, Chicago, IL, ASM International, Materials, OH, pp.606–620, ISBN: 9781615039807.

[28] A. Saka, T. K. Abor, A. C. Okafor, dan M. U. Okoronkwo, “Thermo-rheological and tribological properties of low- and high-oleic vegetable oils as sustainable bio-based lubricants”, RSC Sustainability, vol. 3, hlm. 1461–1476, 2025. DOI: 10.1039/D4SU00605D.

[29] D. Filon, M. Pietrzak, dan kolega, “Synthesis and Evaluation of Bio-Lubricants from Vegetable Oils”, Lubricants, vol. 12, no. 12, artikel 446, 2024.

[30] J. Pichler, “Green Chemistry Letters and Reviews: Biodegradable Lubricants from Plant Oils”, Green Chemistry Letters and Reviews, 2023.

[31] Y. H. Tsai, “Thermal Degradation of Vegetable Oils”, Foods, vol. 12, no. 9, artikel 1839, 2023. DOI: 10.3390/foods12091839.

[32] I. Stanciu, “Viscosity Index for Oil Used as Biodegradable Lubricant”, Indian Journal of Science and Technology, vol. 13, no. 03, 2020.

[33] Agboola, J. B., Abubakre, O. K., Mudiare, E., Adeyemi, M. B., & Afolabi, S. A. (2015). Performance assessment of selected Nigerian vegetable oils as quenching media in the hardening process for medium carbon steel. Journal of Minerals and Materials Characterization and Engineering, 3(2), 85–93. https://doi.org/10.4236/jmmce.2015.32011.

[34] G. Belinato, L. C. F. Canale, and G. E. Totten, “Effect of antioxidants on oxidative stability and quenching performance of soybean oil and palm oil quenchants,” Journal of ASTM International, vol. 8, no. 9, pp. 1–15, 2011.

[35] Simêncio, E., Otero, R. Canale, L., Totten, G. (2016). Stabilization of vegetable oil-based quenchants to thermal-oxidative degradation: experimental strategy and effect of oxidation on quenching performance. La Metallurgia Italiana, 3.

[36] Salihu, S. A., Sulaiman, Y. I., & Hassan, S. B. (2013). Comparative study of neem seed oil and watermelon seed oil as quenching media for thermal processing of steel. IOSR Journal of Pharmacy and Biological Sciences (IOSR-JPBS), 7(2), 103–110.

[37] A. S. Sani and E. I. Aminu, "Comparative Analysis of Hot Vegetable Oils Used as Quenchants for Austempering of Nodular (Ductile) and Grey Cast Irons," *International Journal of Science Academic Research*, vol. 2, no. 2, pp. 1093–1106, Feb. 2021. [Online]. Available: http://www.scienceijsar.com

[38] N. I. Kobasko, E. Carvalho de Souza, L. C. F. Canale, and G. E. Totten, "Vegetable Oil Quenchants: Calculation and Comparison of The Cooling Properties of a Series of Vegetable Oils," *Strojniški vestnik - Journal of Mechanical Engineering*, vol. 56, no. 2, pp. 131–142, 2010.

[39] A. Olagunju, “Chemical and physical characterization of watermelon (Citrullus lanatus) seed oil,” Saudi Journal of Chemistry and Materials Science, vol. 8, no. 3, pp. 70–76, 2023.
[40] J. A. Odeyemi and O. A. Adeyemi, “Physicochemical properties and thermal behavior of watermelon seed oil for engineering applications,” Journal of Newviews in Engineering and Technology (JNET), vol. 3, no. 1, pp. 40–48, 2023.
[41] Flores Cuautle, J.J.A. Thermal properties of vegetable oils used in lubricants. Discov Chem Eng 5, 17 (2025). https://doi.org/10.1007/s43938-025-00093-w.
[42] Thermtest, “Heat Conductivity of Water,” Thermtest Thermal Conductivity Blog, Nov. 29, 2021. [Online]. Available: https://thermtest.com/heat-conductivity-of-water.
[43] F. Soltani, D. Toghraie, and A. Karimipour, “Experimental measurements of thermal conductivity of engine oil-based hybrid and mono nanofluids with tungsten oxide (WO_3) and MWCNTs inclusions,” Powder Technology, vol. 374, pp. 228–239, 2020, doi: 10.1016/j.powtec.2020.05.059.
[44] K. Achille, M. M. Ghislain, L. Monkam, dan I. I. Adolphe, “Determination at Variable Temperatures and Analysis of the Physico-Thermal Properties of Palm Kernel and Castor Oil Methyl Esters as Dielectrics for Power Transformers,” International Journal of Heat and Technology, vol. 41, no. 1, hlm. 63–71, Feb 2023. DOI: 10.18280/ijht.410107.
[45] A. J. Asalekar dan D. V. A. Rama Sastry, “Comparative Analysis of Thermal Conductivity of the Hybrid Nanoparticles Based Sunflower and Jatropha Vegetable Oil,” Journal of Polymer and Composites, vol. 11, Special Issue 08, hlm. 164–171, 2023. → mengukur thermal conductivity nanofluid minyak nabati.
[46] Matijevic, B., Liščić, B., Totten, G., & Canale, L. C. F. (2017). Comparative measurement and evaluation of the quenching intensity of palm oil, canola oil and a conventional petroleum oil quenchant based on temperature gradient measurements. Materials Performance and Characterization, 6(1), 20170041. https://doi.org/10.1520/MPC20170041).
[47] S. Onukwuli, C. U. Iloamaeke, and G. E. Okoye, “A comprehensive study on physicochemical properties of fatty acid esters derived from different vegetable oils,” Energies, vol. 17, no. 24, pp. 1–18, 2024.
[48] Kolawole, M. Y., Aliyu, S. A., Bello, S. A., Oladosu, K. O., & Owoeye, I. J. (2023). Effect of bio-mineral oil blend quenchant on the mechanical properties of carburized mild steel. *Journal of Engineering and Applied Science*, Article 263. https://doi.org/10.1186/s44147-023-00263-z.
[49] E. A. Pérez R., S. Frye R., J. F. Llano M., and D. A. Zuleta D., “Performance of vegetable oils on the hardness and microstructure of AISI 1045 steel quenched,” International Journal of Mechanical Engineering and Technology (IJMET), vol. 10, no. 1, pp. 1120–1127, Jan. 2019. Available: http://iaeme.com/Home/issue/IJMET?Volume=10&Issue=1
[50] I. B. Rahardja, D. Prumanto, Muchayar, and A. I. R. S. C. W. Edukasi, "Hardening of Iron ST 37 with Various Heat Treatments Using Cooling Crude Palm Oil (CPO), "International Journal of Scientific & Technology Research, vol. 8, no. 9, pp. 1275–1280, 2019.
[51] Civera, C., Rivolta, B., Simencio-Otero, R. L., Lu'cio, J. G., Totten, G. E., and Canale, L. C. F., “Vegetable Oils as Quenchants for Steels: Residual Stresses and Dimensional Changes,” Materials Performance and Characterization, Vol. 3, No. 4, 2014, pp. 1–20, doi:10.1520/MPC20140039. ISSN 2165-3992.
[52] O. T. Johnson, E. N. Ogunmuyiwa, A. U. Ude, N. Gwangwava, and R. Addo-Tenkorang, “Mechanical Properties of Heat-treated Medium Carbon Steel in Renewable and Biodegradable Oil,” Procedia Manufacturing, vol. 35, pp. 229–235, 2019, 2nd Int. Conf. on Sustainable Materials Processing and Manufacturing (SMPM 2019).
[53] K. J. Franklin, S. Joshy, M. R., and N. A. Nikhil, “Microstructural study of quenched EN 31 steel in biodegradable oils,” International Journal of Research in Technology and Innovation (IJRTI), vol. 4, no. 1, pp. –, 2019, ISSN: 2456-3315.
[54] S. V. Sreeja, P. Dinesh, and S. B. Patil, "Study of Mechanical Properties of Steel Quenched in a Blend of Biodegradable Oils with Quench Accelerators," *IJLTEMAS*, vol. V, no. V, May 2016, ISSN 2278–2540.
[55] Joel Passanha, Sathyashankara Sharma, Ananda Hegde, Bhagya Lakshmi, Gowri Shankar & Guru Murthy (2022) Experimental and statistical analysis of vegetable oil brine egg yolk emulsion quench on the properties of AISI 4140 steel, Cogent Engineering, 9:1, 2146626, DOI: 10.1080/23311916.2022.2146626.

[56] I. Y. Suleiman, T. A. Mohammed, and L. Shuaibu, “Assessment of Coconut and Ghee Oils as Quenchants in Hardening of Plain Carbon Steel Process,” Journal of Advancement in Engineering and Technology, vol. 6, no. 4, pp. 1–6, Aug. 2018.

[57] E. C. de Souza, M. R. Fernandes, S. C. M. Augustinho, L. C. F. Canale, and G. E. Totten, “Comparison of Structure and Quenching Performance of Vegetable Oils,” *Journal of ASTM International*, vol. 6, no. 9, Paper ID JAI102188, pp. 1–15, Sep. 2009.