Exploring the Role of Vanillic Acid in Liquid Crystal Applications: A Review

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Abstract*: *Vanillic acid, a naturally occurring phenolic acid found in various plant sources such as vanilla beans and certain fruits, has recently gained interest as a precursor for synthesizing liquid crystals. With its phenolic hydroxyl group and methoxy substitution on the aromatic ring, vanillic acid offers multiple functionalization opportunities that can lead to the formation of liquid crystalline structures. The ease of chemical modification and the environmentally friendly nature of vanillic acid make it a promising compound for creating novel LC materials. This review provides an overview of the advancements in vanillic acid-based liquid crystals. It explores the chemical strategies used to transform vanillic acid into mesogenic compounds, the resulting liquid crystalline phases, and their properties. Furthermore, we examine the thermal, optical, and mechanical behaviors of these materials and highlight their potential applications. Given the growing need for sustainable materials, vanillic acid-based liquid crystals offer an exciting new direction for academic research and practical applications.

Keywords: Liquid Crystal, Hydroxy Carboxylic Acid, LC Phases.

Abbreviations:
LCs: Liquid Crystals
XRD: X-ray Diffraction
PET: Poly Ethylene Terephthalate
FDCA: Furan Dicarboxylic Acid
AVA: Acetyl Vanillic Acid
DABP: Diacetoxybiphenyl
ABA: Acetoxy Benzoic Acid
WAXD: Wide-Angle X-ray Diffraction
PPDL: Poly ω-Pentadecalactone
LCP: Liquid Crystalline Polyester
POM: Polarized Optical Microscopy
PLA: Polyester and Polylactide
FE-SEM: Field Emission Scanning Electron Microscopy
EDX: Energy-Dispersive X-Ray Spectroscopy
Si: Silicon
Cl: Chlorine
Na: Sodium

I. INTRODUCTION

The Liquid crystals (LCs) represent a unique state of matter, exhibiting characteristics of both liquids and crystalline solids. This review focuses on the development and properties of liquid crystals derived from vanillic acid (4-hydroxy-3-methoxybenzoic acid), a naturally occurring phenolic acid with versatile chemical reactivity. Vanillic acid's structural components, such as the phenolic hydroxyl group and methoxy substituent, offer opportunities for functionalization, making it an attractive precursor for the synthesis of novel liquid crystalline materials. The methoxy group stabilizes nematic mesophases through electron-donating effects, aids in packing, and impacts thermal properties by reducing the melting temperature. The hydroxyl group provides strong intermolecular hydrogen bonding, increases molecular polarity, and improves mesophase stability and transition temperatures. The carboxylic acid group contributes to strong intermolecular interactions through hydrogen bonding and dipole-dipole interactions, influences the mesophase range, and increases the material's overall stability. By controlling the molecular packing, stability of mesophases, thermal properties, and intermolecular interactions, these groups help tailor the performance of vanillic acid-based liquid crystals for various technological applications.

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The review discusses the synthesis routes for vanillic acid-based liquid crystals, including esterification and alkylation, which allow for the design of mesogenic cores with varying molecular architectures. Emphasis is placed on the impact of molecular structure on mesophase behavior, thermal stability, and optical properties. Studies have shown that modifications of vanillic acid can lead to different liquid crystal phases, such as nematic, smectic, and cholesteric, depending on the nature and length of side chains attached to the core. This comprehensive review aims to provide a foundation for researchers interested in the intersection of natural products and liquid crystal technology, offering insights into the potential of vanillic acid as a sustainable resource for advanced functional materials.

Vanillic acid is of great interest in the medical field as it possesses numerous biological properties e.g. antioxidant [1], antimicrobial [2], anti-inflammatory [3], anticancer [4], antidiabetic [5], and antinociceptive activities [6] anticoagulant [7], antiulcer [8], etc. The roots of Angelica Sinensis [9] and Euterpe Oleracea [10] are rich sources of vanillic acid. Vanillic acid can also be synthesized from vanillin by silver oxide method [11]. Vanillic acid can be produced by oxidizing vanillin [12], which can be isolated from lignin [13]. Vanillic acid is also a building block in the various polymer syntheses [14]. The presence of the bulky side methoxy group possesses mesogenic properties and is suitable as a co-monomer for the synthesis of Thermotropic polyesters [15]. Vanillic acid can (a) improve the monomer sequence distribution, (b) increase the stability of the thermotropic melt (c) decrease the polymer melting temperature and (d) improve the spinnability of thermotropic polyesters [16].

II. RESULTS AND DISCUSSION

Li and co-workers synthesized thermotropic liquid-crystalline copolyesters through the polycondensation of vanillic acid (V), 4-hydroxybenzoic acid (B), and poly (ethylene terephthalate) (E) [17]. They observed that the sequence distribution of V/B/E copolyesters transitions from random to block-like as the content of 4-hydroxybenzoic acid (B) increases. This sequence distribution was also found to be sensitive to the catalyst concentration and the polycondensation time. Furthermore, the molecular weight distribution of the copolyesters narrows progressively as the vanillic acid content increases from 0% to 5 mol%.

Building on this earlier work, Li and co-workers synthesized a series of thermotropic liquid-crystalline copolymers by incorporating different diols, such as 2,7-, 1,3-, or 1,4-naphthalene diol (N), into the polymerization with terephthalic acid, 4-hydroxybenzoic acid, and poly(ethylene 2,6-naphthalene dicarboxylate) or vanillic acid (V) along with other variations of 4-hydroxybenzoic acid/poly(ethylene terephthalate)/comonomer copolymers [18]. The resulting copolymers were turbid and exhibited a thready texture when visually observed. Strong shear and stir opalescence were also observed in the copolymer melts, further indicating the presence of thermotropic liquid-crystalline properties. Polarized light micrographs of the copolymer melts revealed a marble or threaded schlieren texture, which is characteristic of the nematic mesophase. Polarizing microscopy of the copolymer films which were obtained by drawing the melts revealed that the films were highly oriented, fibrillated, and showed well-developed nematic liquid-crystalline order.

The study demonstrated that most copolymer melts, especially those derived from 4-hydroxybenzoic acid and either 2,7-, 1,3-, or 1,4-naphthalene diol, along with terephthalic acid or vanillic acid, exhibited strong shear and stir opalescence, indicating thermotropic liquid crystallinity. Notably, both 2,7-naphthalene diol and vanillic acid were more effective in imparting thermotropic liquid-crystalline properties and orientation ability to the copolymers compared to the other co-monomers in the study. Most of the copolymers displayed either a marble texture or a dense threaded texture, indicative of a nematic mesophase, over a wide temperature range from 183°C to 390°C. Interestingly, the copolymers did not exhibit an isotropic phase before decomposition, suggesting that the copolymers possess a large nematic temperature window of at least 100°C. This broad nematic phase window makes these copolymers suitable for a wide range of conventional melt-processing conditions. The nematic textures were further confirmed by X-ray diffraction (XRD) fiber diagrams of solid copolymer extrudates, which showed clear patterns indicative of oriented molecular structures in the solid state. Monomer ratios were identified as critical factors influencing both the melt texture and the melting temperature of the copolymers. In particular, the elliptical shape of the scattering pattern in the H-region of the sheared films of the three naphthalene diol unit-containing copolymers suggested that the films consisted of oriented rod-like aggregates. These rod aggregates are composed of well-aligned, rigid macromolecules, further confirming the liquid-crystalline nature of the materials.

This study and demonstrates the successful synthesis of thermotropic liquid-crystalline copolyesters and copolymers with a broad nematic phase window [17]. The orientation behavior, melt texture, and high thermal stability of these materials make them promising candidates for advanced applications in the polymer industry, especially for uses that require high-temperature stability and liquid-crystalline properties [18]. The results underscore the importance of monomer selection and composition in tuning the thermotropic behavior and structural characteristics of these copolymers.

Xin-Gui Li and Mei-Rong Huang [19], investigated the thermotropic liquid-crystalline terpolymers synthesized from acetoxy vanillic acid, p-acetoxy benzoic acid [20], and poly (ethylene terephthalate) (PET) in different molar ratios of these monomers. The study aimed to determine the thermal stability and kinetic parameters of the thermal decomposition of the copolymers derived from p-oxybenzoate (B), ethylene terephthalate (E), and vanillate (V). The researchers observed that thermal degradation of the copolymers began at 436°C in nitrogen and 424°C in air, with the degradation temperature increasing as the content of the B-unit increased while maintaining a fixed V-unit content of 5 mol%. The first maximum weight loss occurred above 444°C in nitrogen and 431°C in air. At 500°C and 800°C, the char yields in nitrogen and air showed considerable differences, indicating the influence of the atmospheric conditions on the degradation process. The thermal decomposition process was hypothesized to occur in multiple stages. The first major stage is likely associated with the removal of ester, ethylene, methoxyl groups, and hydrogen atoms from the terpolymer chain. Following this, intermolecular condensations may occur, leading to the formation of carbonaceous char at relatively high temperatures. Furthermore, the introduction of a methoxyl group in the benzene ring of the aromatic polyester chain was found to lower the overall thermal stability of the copolymer and accelerate the degradation rate under non-isothermal heating conditions.

The findings and suggest that the introduction of different monomers, particularly the methoxylated vanillic acid derivative, influences the thermal stability and degradation mechanisms of these terpolymers [19]. The study also provides insights into how the composition of the terpolymer impacts its thermal behavior, with increased B-unit content and the presence of methoxyl groups affecting both the thermal degradation onset and the char formation process. These insights are crucial for designing high-performance materials with tailored thermal properties for various industrial applications [20].

Kricheldorf and co-workers synthesized randomly branched copolyesters from β-(4-hydroxyphenyl) propionic acid, 4-hydroxybenzoic acid, and vanillic acid in a 1:1:1 molar ratio [21]. A binary copolyester was also obtained from trimethylsilyl- β- (4-acetoxyphenyl) propionate, trimethylsilyl -4- acetoxy benzoate, and tris acetyl gallic acid. In this process, difunctional monomers, such as vanillic acid, were used in their silylated forms. Additionally, biodegradable thermotropic copolyesters were synthesized through polycondensation of aromatic hydroxy acids (with acetylated phenolic OH groups and silylated carboxyl groups) in combination with tris acetyl gallic acid. The researchers found that the stability of the nematic phase increased as the branching density decreased. Interestingly, a partial liquid-crystalline (LC) character was observed even when the linear chain segments were relatively short. They also observed that lower branching density could improve the mechanical properties of the copolyesters. However, an increase in branching density, such as the inclusion of vanillic acid, gradually destabilized the LC phase, leading to a reduced thermotropic liquid-crystalline behavior.

This study demonstrates that the degree of branching significantly influences the thermal and mechanical properties of the copolyesters. While a lower branching density enhances the stability of the nematic phase and improves the mechanical properties, increasing the branching density, particularly with vanillic acid, destabilizes the liquid-crystalline phase. These findings underscore the importance of controlling the branching structure to optimize the performance of thermotropic copolyesters, especially for applications where both thermal stability and mechanical strength are critical [21].

Xin-Gui Li and co-workers synthesized a series of terpolymers from p-acetoxybenzoic acid (B), polyethylene terephthalate (E), and p-acetoxyvanillic acid (V) or 1,4-diacetoxybenzene/ terephthalic acid (P) through molten polycondensation. For structural characterization, films and ribbons were prepared from the polycondensation melts. IR spectra, 1H-NMR spectra, and wide-angle X-ray diffractograms for the as-drawn ribbons of different monomer unit ratios of B/E/P were recorded. The study revealed that the terpolymers exhibited almost identical FTIR spectral characteristics, indicating that these properties were independent of the monomer unit ratio. In contrast, in the 1H-NMR spectra, the chemical shifts of the protons on the B, E, and P units showed minimal variation with changes in the copolymer composition, suggesting that the molecular environment of the protons was largely unaffected by the monomer ratio. Additionally, the meridional maxima in the wide-angle X-ray diffraction patterns were periodic and exhibited only slight variations in d-spacing with changes in the copolymer composition, further supporting the idea that the structural organization of the terpolymers was relatively consistent across different compositions [22].

This study demonstrates that the incorporation of different monomer ratios (B/E/P or B/E/V) in the terpolymers does not significantly affect the overall molecular structure as observed through FTIR and 1H-NMR spectroscopy. The consistent structural features across varying compositions suggest that these terpolymers maintain a stable, well-defined structure regardless of the monomer ratio. Additionally, the slight variations in the X-ray diffraction patterns with composition indicate that while the terpolymers may have some degree of structural flexibility, their basic molecular organization remains relatively constant. These findings are important for understanding the structural stability and potential applications of these terpolymers in various fields, including materials science and polymer engineering [22].

Sanjay Rastogi and co-workers synthesized aromatic-aliphatic bio-based polyesters using 2,5-furan dicarboxylic acid, suberic acid, and acetylated vanillic acid. They found that the incorporation of the rigid, aromatic 2,5-furan dicarboxylic acid moiety led to the formation of block copolymers, while the vanillic acid moiety tended to decrease the extent of block formation. As the aromatic content increased, the mechanical performance of compression-molded articles improved. These bio-based polyesters exhibited low melting temperatures, stable liquid-crystalline (LC) behavior, and low crystallinity, all of which contributed to good mechanical performance for compression-molded samples. The presence of the 2,5-furan dicarboxylic acid ring and the vanillic acid moiety required higher thermal energy to rotate the aromatic ring, which was anticipated to enhance the dimensional stability and high-temperature performance of these polymers. These aromatic-aliphatic bio-based polyesters also exhibited a low-temperature transition from the crystalline to the nematic phase, with stable nematic phases observed up to 300°C and beyond. Mechanical analysis indicated that the polymer performance correlated with their crystallinity. Higher crystallinity resulted in ductile behavior, while lower crystallinity led to higher modulus, increased stress at break, and lower strain at break [23].

Building on this work, Sanjay Rastogi and co-workers synthesized thermotropic polyesters by copolymerization of 2,5-furan dicarboxylic acid (2,5-FDCA), O-acetyl vanillic acid (AVA), 4-acetoxy benzoic acid (ABA), 4-acetoxy-3-methoxybenzoic acid, and 4,4'-diacetoxybiphenyl (DABP) using various compositions [24]. The high melting temperatures of the 2,5-FDCA/DABP/ABA polymers hindered molecular weight buildup, leading to the use of O-acetyl vanillic acid (AVA) as a co-monomer during polymerization. The methoxy group in AVA was found to disrupt the crystal lattice of the 2,5-FDCA/DABP/ABA systems, lowering the melting temperature. To examine the impact of AVA on the melting temperature and morphological properties, they replaced ABA with AVA. Morphological changes were observed in the 2,5-FDCA/DABP/ABA/AVA 15/15/60/10 copolymer at 300°C. Similar experiments were conducted with other compositions, such as the 2,5-FDCA/DABP/ABA/AVA 15/15/50/20 system and the 15/15/70/0 system, with temperature-dependent morphological changes measured between 220°C and 380°C.

Further expanding on this research, Sanjay Rastogi and co-workers focused on the melt drawing, compression molding, and solvent casting of aromatic-aliphatic thermotropic polyesters based on vanillic acid [25]. To develop fully renewable thermotropic polyesters with high-temperature resistance, it was recommended to reduce or eliminate the aliphatic content in the polymer backbone. Decreasing the aliphatic content resulted in longer relaxation times during processing, likely leading to fibers with better mechanical performance. Additionally, reducing the aliphatic content allowed for the development of thermotropic polymers with higher melting temperatures, enabling a high-temperature heat treatment step that further enhanced their properties. Wide-angle X-ray diffraction (WAXD) analysis of the thermotropic polymers revealed that the orientation parameter increased with an increasing draw ratio of the fiber. The polymers, processed from their thermotropic melts, retained their orientation up to 120-130°C, after which they started to melt.

The studies conducted by Sanjay Rastogi and co-workers, and highlight the importance of polymer composition and structure in determining the thermal, mechanical [23], and liquid-crystalline properties of bio-based thermotropic polyesters [24]. Incorporating aromatic moieties, such as 2,5-furan dicarboxylic acid and O-acetyl vanillic acid, significantly enhances the thermal stability, dimensional stability, and mechanical performance of these materials [25]. The results indicate that controlling the monomer composition, particularly the aromatic content and the presence of methoxy groups plays a key role in tailoring the properties of these bio-based polyesters. Additionally, reducing the aliphatic content in the polymer backbone can improve the polymer's high-temperature performance, allowing for further processing and the development of fibers with improved mechanical properties. These findings contribute to the design of high-performance thermotropic polyesters for various applications, particularly in areas requiring high-temperature resistance and good mechanical properties.

Wilsens and co-workers studied the morphology and performance of melt-drawn poly(ω-pentadecalactone) (PPDL) fibers reinforced with a vanillic acid-based thermotropic liquid crystalline polyester (LCP) through in situ reinforcement. PPDL was synthesized using ω -pentadecalactone, triethylaluminum, and N, N´ -ethylene bis -(salicylimine). The vanillic acid-based LCP was prepared by melt-acidolysis copolymerization of acetylated p-hydroxy benzoic acid, vanillic acid, suberic acid, and hydroquinone. The morphological properties of the PPDL/LCP blend were examined using varying proportions of both components. The results showed that melt-drawn fibers containing up to 30 wt% LCP maintained their ductile behavior while exhibiting increased tensile modulus and tensile strength. As the LCP content and orientation increased, both the tensile modulus and tensile strength of the fibers were enhanced. The PPDL/LCP interface revealed that transcrystallization of PPDL occurred on the surface of the oriented LCP fibrils. This transcrystallization mechanism improved the interfacial interactions between the two components, leading to better mechanical properties. These improvements were attributed to the enhanced interfacial bonding, which allowed for better load transfer between the PPDL and LCP phases. The morphology of the blend was found to be strongly dependent on both the fiber morphology and the processing conditions. These factors affected the degree of LCP orientation and crystallization behavior, which, in turn, influenced the mechanical properties of the fibers [26].

The study by Wilsens and co-workers demonstrates that blending PPDL with vanillic acid-based LCP significantly improves the mechanical properties of PPDL fibers. The addition of LCP enhances the tensile modulus, yield strength, and toughness of the fibers without compromising their ductility, especially at LCP concentrations up to 30 wt%. The improved performance can be attributed to the enhanced interfacial interactions between the PPDL and LCP phases, facilitated by the transcrystallization of PPDL on the LCP fibrils. These findings suggest that LCP blending is a promising strategy for improving the mechanical performance of ductile aliphatic polyesters, offering a potential route for developing high-performance, and reinforced biodegradable fibers [26].

Dietmar Auhl and co-workers investigated the effect of shear rate on the orientation and relaxation behavior of vanillic acid-based liquid crystalline polymers (LCPs). To synthesize the monomer for these studies, they acetylated vanillic acid to produce 4-acetoxy-3-methoxybenzoic acid. This monomer was then reacted with p-acetoxybenzoic acid, suberic acid, and 1,4-diacetoxybenzene in the presence of $Zn(AcO)_2$. The resulting polymerization of this monomer yielded the vanillic acid-based aromatic-aliphatic thermotropic polyester polymer. The researchers observed that the vanillic acid-based LCPs exhibited rapid molecular relaxation during processing. To better understand the orientation and relaxation processes involved, they studied the rheological response of these materials using in situ wide-angle X-ray diffraction (WAXD) and polarized optical microscopy (POM). They identified a two-step process for the relaxation of shear stress. The first, faster step of relaxation was associated with the release of elastic energy stored in the stretched poly domain texture, while the second, slower process was linked to the coalescence of domains and the relaxation of inter-chain orientation. These findings provided a deeper understanding of the relationship between the mechanical properties of LCPs and their processing conditions. The researchers also found that processing at high shear rates accelerated the relaxation of inter-chain orientation, which could limit the mechanical performance of the LCPs after processing. This insight helps reconcile seemingly contradictory reports on the processing and mechanical properties of LCPs and their blends [27].

Dietmar Auhl and co-workers' study highlights the complex relationship between shear rate, molecular orientation, and relaxation in vanillic acid-based liquid crystalline polymers. The two-step shear stress relaxation process they observed—comprising an initial rapid release of elastic energy followed by a slower coalescence of domains—illustrates the intricate mechanisms underlying the mechanical properties of these materials during processing. Their findings emphasize that high shear rates can accelerate the relaxation of inter-chain orientation, potentially compromising the mechanical performance of the LCPs. This information is crucial for optimizing processing conditions and improving the mechanical properties of LCPs and their blends, especially in applications requiring precise control over molecular orientation and relaxation behavior [27].

Gijsbert Willem de Kort investigated the potential of liquid crystal polymer (LCP) reinforced thermoplastic composites, aiming to identify key parameters for the production of processable materials [28]. It focuses on the combination of thermotropic polyester and polylactide (PLA) and demonstrates that amorphous LCPs with low processing temperatures can be effectively used. A suitable LCP, with a viscosity slightly lower than the molten matrix, enables the formation of a fibrillar morphology under different processing conditions while minimizing the thermal degradation of the PLA matrix. Furthermore, the recycling of LCP-PLA composites without a loss in mechanical performance is shown, provided that the viscosity ratio stays below one. The study leads to the development of a system for producing amorphous LCPs with tunable viscosity, and the findings apply to other polymer-polymer systems as well.

Olga Ferreira and co-workers investigated the solubility of syringic acid, vanillic acid, and veratric acid in pure water as well as in various organic solvents, including methanol, ethanol, 1-propanol, 2-propanol, 2-butanone, ethyl acetate, acetonitrile, dimethylformamide, 1,2-propanediol, 1,3-propanediol, and 1,3-butanediol [29]. The solubility measurements were carried out at two different temperatures, 25.2°C and 40.2°C, to assess the effects of temperature on solubility. In addition to the solubility data, they also determined the enthalpies of solution for the solutes in the selected solvents. The solubility values were found to vary significantly depending on both the solute (syringic acid, vanillic acid, or veratric acid) and the solvent used. The organic solvents generally showed higher solubility for the acids compared to pure water. Among the organic solvents, alcohols like methanol and ethanol exhibited the highest solubility for all three acids, while solvents such as acetonitrile and dimethylformamide also showed relatively high solubility values. The temperature increase from 25.2°C to 40.2°C led to a general increase in the solubility of all acids in most solvents, with some exceptions. Enthalpy data indicated that the dissolution process of these acids was endothermic, meaning that heat was required for the dissolution process to occur. The magnitude of the enthalpy change varied between the different acids and solvents, suggesting that the interaction between solute and solvent molecules plays a key role in the solubility process.

Olga Ferreira and co-workers' study provides valuable insights into the solubility behavior of syringic acid, vanillic acid, and veratric acid in both water and various organic solvents. The results indicate that these acids are more soluble in organic solvents than in pure water, with alcohols being the most effective solvents for dissolution. The increase in solubility with temperature suggests that the dissolution process is endothermic, and the enthalpy data further supports the notion that solvent-solute interactions are crucial in determining solubility. These findings can be useful for applications involving the extraction and use of these acids in different solvent systems, particularly in pharmaceutical and chemical industries where solvent choice and temperature control are essential for optimizing solubility and dissolution rates [29].

Thiruvengadam and co-workers synthesized vanillic acid nanocomposites using chitosan and silver nanoparticles and conducted morphological studies using field emission scanning electron microscopy (FE-SEM). To prepare the nanocomposite, they first prepared a chitosan nanoparticle suspension. Vanillic acid silver nanoparticles were synthesized by mixing vanillic acid with silver nitrate solution, followed by reduction and nanoparticle formation. The nanocomposites were characterized by various techniques, including FE-SEM, which revealed the morphology and particle size distribution of the nanocomposite materials. The elemental composition of the vanillic acid nanocomposites was determined through energy-dispersive X-ray spectroscopy (EDX), which showed the presence of silver, calcium, carbon, oxygen, nitrogen, and trace amounts of silicon (Si), chlorine (Cl), and sodium (Na). The presence of silver nanoparticles is thought to contribute significantly to the biological activity of the nanocomposite. Additionally, the vanillic acid-based nanocomposites exhibited significant anticancer activity, which was likely attributed to the synergistic effects of the chitosan, silver nanoparticles, and vanillic acid. The biological evaluation showed promising results, indicating the potential of these nanocomposites for use in cancer therapy [30].

This study demonstrates the successful synthesis of vanillic acid nanocomposites incorporating chitosan and silver nanoparticles. The nanocomposites exhibited a unique elemental composition and morphology, as confirmed by EDX and FE-SEM analysis. The presence of silver nanoparticles, in combination with vanillic acid, appears to enhance the biological properties of the nanocomposites, particularly their anticancer activity. These findings suggest that the vanillic acid-based nanocomposites may hold promise as a novel therapeutic agent in cancer treatment, offering a biocompatible, multifunctional material with potential for targeted therapy. The incorporation of silver nanoparticles into chitosan-based systems could lead to the development of effective drug delivery platforms with enhanced biological efficacy [30].

Patel and co-workers synthesized a series of alkoxy derivatives of vanillic acid, which were combined with 4'-hydroxy-4-ethyl carboxylate azo benzene [31]. Steglich esterification was employed to synthesize the compounds, resulting in the formation of 4-(4'-n-alkoxy vanilloyloxy) phenyl azo 4''-ethyl benzoate [32]. The synthesized compounds were characterized as nematogenic, displaying a short-range liquid crystalline phase with the exhibition of a smectic phase [33]. The thermal stability of the compounds was evaluated, and the average thermal stability was found to be 208.5°C. The nematogenic mesophase of these compounds was observed to range from 5.0°C to 45.0°C, indicating that the materials exhibit liquid crystalline properties within this temperature range [34]. These results suggest that the compounds could be suitable for applications requiring materials with thermal stability and specific liquid crystalline properties.

This study demonstrates that the synthesized compounds exhibited a smectic phase, indicating their potential as nematogenic materials with short-range liquid crystallinity. The thermal stability of these compounds, with an average decomposition temperature of 208.5°C, and the nematogenic mesophase observed between 5.0°C and 45.0°C, demonstrate their promising potential for use in applications where liquid crystalline properties and thermal stability are required. These findings could contribute to the development of new liquid crystalline materials for a range of advanced technological applications, including displays and sensors.

III. CONCLUSION

Vanillic acid, with its unique molecular structure and functional groups, plays a significant role in the development of liquid crystalline materials. Through various studies, it has been demonstrated that vanillic acid can be effectively incorporated into polymeric systems to impart desirable liquid crystalline properties. These properties include nematic and smectic mesophases, which are critical for a wide range of technological applications, including displays, sensors, and optical devices. The introduction of vanillic acid into copolymers and composites has been shown to enhance thermal stability, orientational behavior, and mechanical performance, making it a valuable building block for the synthesis of advanced liquid crystalline materials. As research continues, the role of vanillic acid in tailoring the thermal, mechanical, and optical properties of liquid crystalline systems remains promising. The ability to modify the molecular structure of vanillic acid derivatives and their integration into complex polymer matrices opens up new possibilities for the development of high-performance materials. The continued exploration of vanillic acid-based liquid crystals offers exciting prospects for innovations in material science, especially in the fields of flexible electronics, smart materials, and sustainable technologies.

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DECLARATION STATEMENT

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