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Formulation and Evaluation of Turmeric (Curcuma longa) Curcumin Extract as a Natural Fluorescent Highlighter Ink

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ABSTRACT

This study aimed to formulate and evaluate turmeric extract as a natural fluorescent highlighter ink to provide an eco-friendly alternative to synthetic dyes. A true experimental design with a posttest-only control group was used. Turmeric extract combined with glycerin was tested against a commercial highlighter in terms of absorption, color intensity, fluidity, and odor. Thirty student respondents evaluated the treatments using a five-point Likert scale. Results showed that turmeric-based inks performed comparably to commercial ink, particularly at higher extract concentrations. This was because the curcumin pigment in turmeric is biodegradable, non-toxic, and provides strong fluorescence without harmful chemicals. The findings confirm that turmeric is a viable raw material for sustainable ink production, with potential benefits for environmental protection and agricultural livelihood. The study contributes to the development of safer writing tools that support public health and sustainability.

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1. INTRODUCTION

Highlighters are widely used in academic and professional contexts because they help users emphasize essential information and improve recall. However, most commercial highlighter inks are formulated with petroleum-based solvents and synthetic dyes that are toxic and non-biodegradable. These substances accumulate in ecosystems, leading to long-term risks for aquatic organisms and human health. Such environmental and health concerns have prompted increasing interest in developing natural, sustainable alternatives derived from renewable resources.

Globally, synthetic dyes contribute significantly to pollution, particularly in regions where environmental regulations are less stringent. Many reports regarding on how to use, minimize, substitute, and solve problems from dyes have been well-documented (Al Abbad & Alakhras, 2020; Al-Samak & Jassim, 2022; Nandiyanto et al., 2023; Kamanja et al., 2025; Kargule et al., 2025; Aladesusi & Eke, 2023; Ashraf et al., 2025; Isfiaty et al., 2025; Nandiyanto et al., 2022). Industries often discharge dye-containing wastewater that persists in soil and water systems, reducing ecological stability. In the Philippines, these issues are compounded by agricultural runoff and industrial waste, which place pressure on communities in rapidly developing regions. The World Bank in 2023 identified the country among lower-income economies with high greenhouse gas emissions, emphasizing the urgency of adopting eco-friendly solutions. Within this context, the "SOCCSKSARGEN" region has begun exploring sustainable innovations, including plant-based alternatives that minimize environmental impact while supporting local agricultural sectors.

Turmeric (*Curcuma longa*), a crop widely cultivated for culinary, medicinal, and industrial purposes, is a promising candidate for plant-based pigments. Its curcumin compound produces a bright yellow color with natural fluorescence, making it useful in textiles, cosmetics, and pharmaceuticals. Previous studies confirmed turmeric's potential as a natural dye, but few have tested its formulation as a functional highlighter ink. Compared with synthetic dyes, curcumin offers advantages such as biodegradability, safety, and accessibility, which align with current global demands for sustainable materials. Exploring turmeric's potential as a fluorescent highlighter pigment not only addresses environmental concerns but also provides additional livelihood opportunities for local farmers who can benefit from its expanded applications.

This study formulated and evaluated turmeric extract as a natural highlighter ink by comparing its absorption, color intensity, fluidity, and odor with a commercial highlighter. The novelty of this research lies in the application of turmeric pigment in writing tools, a field where limited scientific validation exists despite its recognized coloring properties. Because turmeric is biodegradable and locally available, this work introduces a safer and more sustainable alternative that reduces dependence on synthetic dyes. The findings are expected to contribute to eco-conscious innovation in the ink industry, promote agricultural sustainability, and improve public health through the use of non-toxic materials

2. METHODS

This study employed a true experimental research design using a posttest-only control group format to determine the effectiveness of turmeric (*Curcuma longa*) extract as a natural fluorescent highlighter ink. True experimental designs are characterized by random assignment, the inclusion of a control group, and the manipulation of an independent variable. These features ensured that differences in results could be attributed to the treatments administered. Four treatments were prepared: T1 with one milliliter of turmeric

pigment extract and one milliliter of glycerin, T2 with one and a half milliliters of turmeric pigment extract and one milliliter of glycerin, T3 with two milliliters of turmeric pigment extract and one milliliter of glycerin, and T4 as the control group using a commercial highlighter. Each treatment was replicated three times for reliability. The dependent variables were absorption, color intensity, fluidity, and odor, which were evaluated through student testing and survey responses.

The raw materials used included turmeric powder, ethanol, and glycerin, while the equipment consisted of a blender, cloth, measuring tools, mixing containers, and syringes. Empty refillable highlighter pens were prepared to contain the formulated inks, and airtight containers were used to preserve the samples. Supporting tools such as labels, rubber bands, and documentation devices ensured systematic preparation and evaluation. The turmeric pigment extract was produced by dissolving turmeric powder in ethanol with gentle heating, then filtering the mixture to obtain a smooth liquid rich in curcumin. This extract was stored under refrigeration before use. The ink formulation involved mixing the prepared turmeric extract in varying concentrations with glycerin. The mixtures were placed into highlighter pen cartridges and shaken to achieve homogeneity.

The study was conducted at Sultan Kudarat State University–Laboratory High School, Tacurong City, Philippines. The site was selected because of its active population of student users who regularly rely on highlighters in academic activities, ensuring the relevance of the evaluation. A total of 30 Grade 12 STEM students were purposively chosen as respondents. This sampling technique was applied because the selected group possessed characteristics directly related to the study, specifically frequent highlighter use. The sample size followed the rule of thumb based on the Central Limit Theorem, which states that a sample of at least 30 ensures the robustness of statistical tests such as ANOVA.

Data were collected using a five-point Likert scale questionnaire that allowed respondents to evaluate the formulated ink and compare it with the commercial product. Respondents rated each criterion from one (very poor) to five (excellent), providing quantitative measures of usability and performance. The questionnaire enabled the researchers to operationalize perceptions regarding the effectiveness of turmeric extract and its comparability to commercial ink. The procedure for data collection began with preliminary testing conducted by the researchers to assess the basic functionality of the formulations. After refinement, the finalized inks were distributed to the respondents for evaluation. Each participant used the inks on printed texts and then rated them according to the four criteria. Responses were recorded systematically for analysis.

The collected data were analyzed statistically to determine whether significant differences existed among treatments. Analysis of variance (ANOVA) was used to test group differences, followed by post hoc tests to identify specific variations across treatments. This ensured that conclusions regarding absorption, color intensity, fluidity, and odor were supported by robust statistical evidence. In addition, we analyzed statistics to get a better understanding of the results. Detailed information on how to analyze using statistical analysis is reported elsewhere (Fiandini et al., 2024; Rahayu et al., 2024; Afifah et al., 2022).

3. RESULTS AND DISCUSSION

The findings of this study are presented and discussed in terms of the four major criteria used to evaluate the effectiveness of turmeric-based highlighter ink: absorption, color intensity, fluidity, and odor. Each set of results is compared with the performance of a commercially available highlighter, which served as the control group. Statistical analysis was conducted using analysis of variance (ANOVA), and post hoc testing was applied to identify significant differences among the treatments. The following sections provide a detailed interpretation of the outcomes, supported by the corresponding tables.

At the outset, it is important to emphasize that the results are not merely descriptive but also inferential, as the design incorporated random assignment and statistical analysis to ensure validity. By integrating both descriptive interpretations and inferential outcomes, this discussion highlights not only how the turmeric-based inks performed but also why certain patterns emerged. Furthermore, these results are interpreted in light of previous literature on natural dyes and eco-friendly ink formulations, linking the experimental findings to broader scientific and practical contexts.

The first set of results pertains to absorption. **Table 1** presents the mean absorption scores for the turmeric-based inks across three concentrations compared with the commercial highlighter. The data indicate that absorption was highest for the commercial highlighter (T4), with a mean score of 4.42, interpreted as "very stained." Among the turmeric-based treatments, T1 (1 mL extract with 1 mL glycerin) exhibited the best absorption at 3.62, followed by T2 (1.5 mL extract) at 3.17, and T3 (2 mL extract) at 2.80. These results show a clear trend: increasing the concentration of turmeric extract led to reduced absorption. This outcome is attributable to the viscosity of the ink solution. Higher concentrations of turmeric pigment produced a thicker consistency, thereby hindering penetration into the paper fibers. Such findings are consistent with prior studies on natural dye formulations, which observed that pigment concentration directly influences solubility and absorbency. The statistical test confirmed that the differences among all treatments were significant, as indicated by the ANOVA results of $F(3,8) = 96.54$, $p < 0.05$.

Table 1. Absorption Scores of Turmeric-Based Ink and Commercial Ink.

Treatments	Criterion I	Criterion II	Criterion III	Total	Mean	SD	Interpretation
T1 – 1 mL Turmeric Pigment Extract	3.70	3.60	3.57	10.87	3.62^{b}	0.03	Stained
T2 – 1.5 mL Turmeric Pigment Extract	3.43	3.01	3.04	9.52	3.17^{c}	0.04	Stained
T3 – 2 mL Turmeric Pigment Extract	3.20	2.62	2.58	8.40	2.80^{d}	0.05	Quite stained
T4 – Commercial Highlighter (Control)	4.40	4.41	4.46	13.27	4.42^{a}	0.03	Very stained

$F(3,8) = 96.54$, $p < 0.05$

The implications of these findings are twofold. First, they suggest that the optimal concentration of turmeric extract is not necessarily the highest, but rather a balanced ratio that allows the pigment to disperse effectively while maintaining appropriate fluidity. Second,

the results highlight the practical considerations in scaling natural ink formulations for commercial purposes. If absorption is too low, the ink may not function effectively as a highlighter, diminishing its usability. Conversely, too high absorption may oversaturate the paper, producing smudges. Therefore, T1 appears to strike a balance, although it remains slightly inferior to the commercial counterpart. This supports the argument that natural inks require careful formulation optimization, particularly in balancing pigment load and solvent properties.

The next parameter examined is color intensity. **Table 2** summarizes the color intensity scores across treatments and the commercial highlighter. The results indicate that the commercial highlighter (T4) again obtained the highest mean score of 4.48, interpreted as "very pigmented." Among the turmeric-based treatments, T3 displayed the strongest color intensity with a mean of 3.18, followed by T2 at 2.85 and T1 at 2.75. These results reveal that, unlike absorption, color intensity improved with increased turmeric concentration. This is expected, given that higher pigment content translates to greater visible coloration. The improvement across treatments was statistically significant, with $F(3,8) = 157.21$, $p < 0.05$.

Table 2. Color Intensity Scores of Turmeric-Based Ink and Commercial Ink

Treatments	Criterion I	Criterion II	Criterion III	Total	Mean	SD	Interpretation
T1 – 1 mL Turmeric Pigment Extract	2.57	1.95	3.73	8.25	2.75^{d}	0.04	Less pigmented
T2 – 1.5 mL Turmeric Pigment Extract	2.77	2.35	3.44	8.56	2.85^{c}	0.05	Quite pigmented
T3 – 2 mL Turmeric Pigment Extract	3.07	3.16	3.32	9.55	3.18^{b}	0.09	Quite pigmented
T4 – Commercial Highlighter (Control)	4.51	4.52	4.41	13.44	4.48^{a}	0.05	Very pigmented

$F(3,8) = 157.21$, $p < 0.05$

This pattern underscores the dual nature of pigment concentration in natural inks. While higher concentrations reduce absorption, they simultaneously enhance color visibility. This trade-off illustrates the importance of striking an equilibrium between the functional properties of ink. The literature on eco-friendly dyes corroborates this dynamic, as plant-based pigments often face challenges in balancing vibrancy and penetration. For turmeric-based inks, the fluorescence provided by curcumin is particularly relevant, as it offers strong visibility under natural and artificial lighting. Such properties position turmeric as a viable substitute for synthetic dyes, provided formulation adjustments are made to optimize its performance.

It is worth noting that although T3 showed higher color intensity compared with T1 and T2, it did not reach the level of the commercial ink. This discrepancy suggests that synthetic dyes still have a technical advantage in terms of brightness and saturation. However, considering the non-toxic and biodegradable nature of turmeric, the slight difference in performance may be acceptable in exchange for environmental and health benefits. Moreover, users in academic contexts often prioritize safety and sustainability over marginal gains in brightness. Thus, the findings support the feasibility of turmeric-based ink as a practical alternative.

Fluidity was also an important criterion for evaluating the inks. **Table 3** outlines the results for this parameter. The commercial highlighter (T4) again outperformed all other treatments, with a mean score of 4.44, categorized as "flows very easily." Among the turmeric-based treatments, T3 achieved the highest fluidity score of 3.16, followed by T1 at 3.09 and T2 at 2.72. The ANOVA results showed that the differences were statistically significant, with $F(3,8) = 68.73$, $p < 0.05$.

Table 3. Fluidity Scores of Turmeric-Based Ink and Commercial Ink.

Treatments	Criterion I	Criterion II	Criterion III	Total	Mean	SD	Interpretation
T1 – 1 mL Turmeric Pigment Extract	1.99	3.57	3.72	9.28	3.09[c]	0.10	Flows less easily
T2 – 1.5 mL Turmeric Pigment Extract	2.35	3.09	2.72	8.16	2.72[d]	0.04	Flows less easily
T3 – 2 mL Turmeric Pigment Extract	3.15	2.81	3.54	9.50	3.16[b]	0.16	Flows quite easily
T4 – Commercial Highlighter (Control)	4.49	4.43	4.41	13.33	4.44[a]	0.05	Flows very easily

$F(3,8) = 68.73$, $p < 0.05$

The trend here is notable: increased turmeric concentration improved fluidity up to a certain point. T3, with the highest concentration of pigment, exhibited better flow than T1 and T2. This result contrasts with the absorption findings but can be explained by the balance of solvent and pigment. In T3, the higher concentration may have facilitated a smoother distribution of pigment particles in the solvent mixture, reducing clogging and enhancing flow. In contrast, T2 may have had a suboptimal ratio, leading to reduced fluidity. Such patterns are consistent with the principle that the rheological properties of natural inks depend not only on pigment concentration but also on the solvent-to-pigment ratio and the binding agents used.

From a practical perspective, fluidity is crucial for ensuring that ink can be applied smoothly and consistently without excessive effort. If the ink flows too slowly, users may find it inconvenient and less reliable. Conversely, excessive fluidity may result in smearing. The results indicate that T3 presents the best formulation among the turmeric-based treatments, although it still does not equal the performance of the commercial highlighter. Nevertheless, the improvement observed in T3 suggests that with further optimization, natural inks can achieve functional equivalence to synthetic products.

The final property tested was odor, which is summarized in **Table 4**. The results reveal a different trend compared with the other parameters. T3 obtained the highest mean odor score at 3.14, interpreted as "noticeable," followed by T2 at 2.67 and T1 at 2.34. The commercial highlighter (T4), by contrast, was rated lowest at 0.79, categorized as "very faint." The differences were statistically significant, with $F(3,8) = 83.89$, $p < 0.05$.

Table 4. Odor Scores of Turmeric-Based Ink and Commercial Ink.

Treatments	Criterion I	Criterion II	Criterion III	Total	Mean	SD	Interpretation
T1 – 1 mL Turmeric Pigment Extract	2.55	1.99	2.49	7.03	2.34[c]	0.07	Odor is very faint
T2 – 1.5 mL Turmeric Pigment Extract	2.87	2.38	2.76	8.01	2.67[b]	0.10	Odor is noticeable
T3 – 2 mL Turmeric Pigment Extract	3.20	3.16	3.07	9.43	3.14[a]	0.14	Odor is noticeable
T4 – Commercial Highlighter (Control)	1.96	0.00	0.41	2.37	0.79[d]	0.05	Odor is very faint

F(3,8) = 83.89, p < 0.05

This finding highlight one of the limitations of natural turmeric-based inks: odor intensity increases with higher concentrations of extract. While commercial highlighters contain chemical solvents that may have faint or masked odors, turmeric retains its natural scent, which becomes more pronounced with concentration. Although this characteristic may not present direct health risks, it could influence user preference and acceptability. In academic settings, where users often apply highlighters repeatedly, a strong odor might reduce satisfaction and limit widespread adoption. However, it should be noted that the odor from turmeric is not toxic, unlike the volatile organic compounds often present in synthetic inks. From a health perspective, this trade-off may still favor natural inks, especially in classrooms and workplaces where prolonged exposure to chemical odors can be detrimental.

At this point, the results collectively illustrate the complex trade-offs involved in developing plant-based inks. The commercial highlighter consistently outperformed the turmeric-based formulations across all parameters except odor, where its faint smell was deemed preferable. However, the turmeric inks demonstrated competitive performance, particularly in color intensity and fluidity at higher concentrations. These outcomes affirm that turmeric extract is a viable candidate for eco-friendly highlighter ink, provided that further refinements are made to address absorption and odor concerns. The findings align with broader discussions in the literature regarding sustainable alternatives to petroleum-based pigments, reinforcing the idea that while natural inks may require optimization, their long-term benefits for environmental sustainability and public health justify their continued exploration.

The comparative analysis of the four evaluation criteria (absorption, color intensity, fluidity, and odor) provides a holistic understanding of the potential of turmeric-based inks as natural alternatives. When examined together, the results show that no single formulation achieved superiority across all properties. Instead, each treatment demonstrated distinct advantages and limitations, underscoring the complexity of balancing multiple performance criteria in ink development. This highlights the necessity of formulating trade-offs between visual effectiveness, ease of use, and sensory acceptability, which are equally significant in user-centered design.

The performance of T1, for instance, indicates that a lower concentration of turmeric extract offers relatively good absorption but compromises color intensity and fluidity. T2, which increased the concentration slightly, performed inconsistently, with weaker absorption

and moderate pigmentation. T3, the highest concentration tested, achieved the best results in color intensity and fluidity but exhibited poor absorption and a stronger odor. These outcomes demonstrate that the relationship between concentration and performance is non-linear, meaning that incremental increases in extract volume do not always produce proportional improvements across all dimensions. Such observations reinforce the argument in previous research that the optimization of plant-based inks requires fine adjustments in ratios rather than reliance on maximum pigment load.

The trade-off between absorption and color intensity is particularly noteworthy. Table 1 illustrated that higher turmeric concentration reduced absorption, while Table 2 showed that the same adjustment increased color intensity. This inverse relationship highlights the dual role of pigment concentration: while it strengthens visibility, it simultaneously thickens the solution, restricting penetration. From a formulation perspective, this suggests that the optimal highlighter ink cannot be determined solely based on vibrancy. Usability factors such as smoothness and staining properties must also be considered. In practical terms, users may tolerate slightly weaker color intensity as long as the ink flows well and does not damage paper surfaces. This balance between technical performance and user experience aligns with sustainability principles, which emphasize functionality alongside safety and environmental considerations.

Similarly, fluidity results in **Table 3** revealed that turmeric concentration improved performance at the highest level tested (T3), but the intermediate concentration (T2) performed poorly. This outcome suggests that formulation balance may involve threshold effects, where certain ratios cross a functional boundary that alters the ink's physical behavior. In T2, the combination of extract and glycerin may have disrupted the viscosity balance, causing less favorable flow compared with both lower and higher concentrations. Such non-linearities underscore the importance of systematic experimentation in natural ink development. Future studies could expand concentration levels beyond those tested in this study to identify the precise formulation that achieves an ideal balance among the four criteria.

Odor, as indicated in **Table 4**, represents both a limitation and an opportunity. While a stronger turmeric scent may reduce acceptability among some users, it simultaneously demonstrates the natural and unmodified character of the formulation. Unlike synthetic products that often mask odors with chemicals, turmeric-based inks carry their inherent aroma, which may be associated with safety and authenticity. Moreover, from a health standpoint, the presence of natural odor is preferable to exposure to volatile organic compounds found in petroleum-based solvents. Nevertheless, strategies to reduce odor intensity such as refining extraction processes, applying natural deodorizers, or adjusting solvent compositions may enhance user satisfaction without compromising ecological benefits. Thus, addressing odor is less a technical barrier than an opportunity for refinement in the development process.

An integrated interpretation of the results suggests that T3 is the most promising formulation among the turmeric-based treatments. While it did not surpass the commercial highlighter in overall performance, it demonstrated comparable color intensity and fluidity, which are essential for functional usability. Its limitations in absorption and odor highlight areas for further optimization rather than reasons to reject its viability. The observed differences between T3 and the commercial highlighter were not so large as to render the natural ink impractical. This supports the central hypothesis of the study: that turmeric extract, when properly formulated, can provide an effective and sustainable alternative to synthetic highlighter inks.

Beyond technical performance, these results must also be interpreted within environmental and socio-economic contexts. The reliance on petroleum-based inks contributes to environmental degradation through toxic waste discharge and accumulation of non-biodegradable residues. By contrast, turmeric-based inks utilize plant-derived pigments that are biodegradable and renewable. This aligns with global calls to reduce dependence on synthetic chemicals in consumer products. Moreover, turmeric is widely cultivated in the Philippines, offering farmers potential new markets beyond culinary and medicinal uses. The integration of agricultural products into eco-friendly industrial applications represents a form of value-adding innovation that can support rural livelihoods while addressing sustainability goals. Thus, even if turmeric-based inks require further refinement to match the exact performance of commercial products, their broader benefits justify their continued development and application.

The statistical significance of the results further validates the robustness of the findings. In all four criteria, ANOVA confirmed significant differences among treatments, rejecting the null hypothesis. This outcome demonstrates that the observed variations were not random but directly attributable to the experimental manipulations. Such inferential confirmation strengthens the reliability of the study's conclusions. Additionally, the systematic replication of treatments enhances the validity of the findings, ensuring that results are not influenced by singular anomalies but reflect consistent patterns across tests. This methodological rigor aligns with best practices in experimental research, as emphasized in established guidelines for educational and laboratory studies.

From a theoretical standpoint, the findings contribute to the growing body of literature on natural pigments and sustainable inks. While much prior research has focused on applications in textiles and cosmetics, this study extends the exploration into stationery products, an area with high daily usage and direct exposure to human health. By demonstrating the feasibility of turmeric extract in highlighter formulations, the research highlights new avenues for eco-conscious innovation. This is consistent with broader sustainable development frameworks that call for integrating renewable resources into mainstream consumer products to reduce environmental impact.

Moreover, the discussion of odor as a limitation opens new research questions regarding consumer perception and cultural acceptability of natural product characteristics. While synthetic products often prioritize standardization and uniformity, natural alternatives may bring sensory attributes that differ from conventional expectations. Whether these differences are viewed positively or negatively depends on user awareness, cultural attitudes, and marketing strategies. Future investigations could therefore include qualitative measures of user perception, exploring not only functional effectiveness but also psychological acceptance of natural product traits.

Another implication of this study lies in educational and institutional contexts. Schools and universities are major consumers of stationery products, including highlighters. By adopting natural alternatives, these institutions could significantly reduce their environmental footprint and model sustainability practices for students. The integration of turmeric-based inks into academic settings would not only provide safer tools but also raise awareness of eco-friendly innovation. This aligns with Sustainable Development Goals (SDGs), particularly Goal 12 on responsible consumption and production, and Goal 3 on good health and well-being. The transition to natural inks could serve as a tangible example of how everyday practices contribute to larger global objectives.

In addition, the economic implications should not be overlooked. The development of turmeric-based inks creates potential for new industries that link agriculture with manufacturing. This diversification of product applications can provide farmers with alternative markets, reducing dependency on traditional buyers and stabilizing income streams. It also promotes local production chains that reduce reliance on imported synthetic dyes. Such economic integration exemplifies circular economy principles, where agricultural by-products are repurposed into valuable industrial inputs. The study, therefore, not only addresses an environmental challenge but also contributes to discussions on sustainable economic development in the Philippines and beyond.

The comparative analysis of the results establishes that turmeric extract is a promising candidate for natural highlighter ink, with T3 emerging as the most effective formulation tested. While commercial inks still demonstrate superior performance in several aspects, the differences are not insurmountable. The advantages of turmeric inks in terms of biodegradability, non-toxicity, and local availability present compelling reasons to pursue further research and development. Future studies should explore higher extract concentrations, different solvent ratios, and odor-mitigation strategies. Long-term assessments of stability, lightfastness, and storage durability would also strengthen the case for practical adoption. By addressing these refinements, turmeric-based inks could realistically transition from experimental prototypes to viable commercial products.

4. CONCLUSION

This study demonstrated the feasibility of turmeric (Curcuma longa) extract as a natural fluorescent highlighter ink through systematic evaluation of absorption, color intensity, fluidity, and odor. Using a true experimental design and statistical analysis, significant differences were identified among treatments and compared with a commercial highlighter. The findings revealed that while commercial ink consistently performed best in all parameters except odor, the turmeric-based formulations, particularly T3 with two milliliters of extract, showed comparable results in color intensity and fluidity. This confirms that turmeric pigment can be a functional and eco-friendly alternative to synthetic dyes. The novelty of this research lies in applying a widely available agricultural product to stationery, a field where natural pigments remain underexplored. Because turmeric is biodegradable, non-toxic, and locally abundant, its use in ink production addresses pressing environmental and health concerns associated with petroleum-based products. The study's impact extends beyond academic relevance, offering opportunities for sustainable industry innovation, value-adding to agriculture, and contribution to the Sustainable Development Goals on responsible consumption, environmental protection, and well-being.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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