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COMPARATIVE ANALYSIS OF COLOUR DIFFERENCE (DELTA E) USING CONVENTIONAL, SOYA-BASED AND BIODEGRADABLE INKS ON PAPER BOARD USING OFFSET PRINTING PROCESS

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ABSTRACT
The demand for sustainable and environmentally friendly printing solutions has prompted a shift from conventional petroleum-based inks to alternative options such as soya-based and biodegradable inks. This research focuses on the comparative analysis of colour difference (Delta E) resulting from the use of conventional, soya-based, and biodegradable inks on paperboard substrates through the offset printing process. As environmental concerns grow, the printing industry is increasingly exploring sustainable alternatives to traditional petroleum-based inks. Soya-based and biodegradable inks offer potential benefits in terms of eco-friendliness, but their performance in terms of colour accuracy and consistency requires systematic evaluation. In this study, standard colour patches are printed using each ink type under identical offset printing conditions. Delta E (ΔE), a widely accepted metric for measuring perceptible colour variation, is used to assess the colour differences among the samples. The research methodology involves spectrophotometric measurement of printed samples and calculation of ΔE values using standardized formulas. The study aims to provide insights into the suitability of alternative inks for high-quality printing applications, with a particular focus on colour fidelity, process compatibility, and sustainability.

KEYWORDS: - Offset Printing, Colour Difference, Delta E (ΔE), Conventional Ink, Soya-based Ink, Biodegradable Ink, Paperboard, Eco-friendly Printing, Spectrophotometry, Sustainable Inks

INTRODUCTION
The printing industry has undergone significant transformation in recent decades, with increasing attention given to environmental sustainability and eco-friendly practices. Among the major contributors to environmental pollution in this industry are petroleum-based conventional inks, which contain volatile organic compounds (VOCs), heavy metals, and non-biodegradable resins. These substances not only pose environmental hazards but also raise health concerns for workers and end-users. As a response to growing environmental awareness and regulatory pressure, alternative inks such as soya-based and biodegradable formulations have emerged as promising solutions (Arai & Inoue, 2019).

Offset printing remains one of the most widely used printing technologies across various packaging and publishing sectors, known for its high-quality image reproduction and cost-effectiveness in medium to large print runs. In such processes, maintaining colour fidelity is a critical quality parameter. Colour variation, often quantified through Delta E (ΔE), can significantly influence the visual appeal and brand consistency of printed products. Delta E is a standardized metric defined by the International Commission on Illumination (CIE) to measure perceptible differences between

intended and actual printed colours (CIE, 1976; Sharma et al., 2005).

The effectiveness of alternative inks such as soya-based and biodegradable variants must be evaluated not only for their environmental benefits but also for their print performance, particularly in relation to colour accuracy. Paperboard, a commonly used substrate in packaging and display applications, presents unique challenges and opportunities for ink-substrate interactions that can impact colour reproduction.

This research aims to comparatively analyse the colour difference (ΔE) produced by conventional, soya-based, and biodegradable inks when printed on paperboard substrates using the offset printing process. By employing standardized colour measurement techniques and controlled printing conditions, the study seeks to assess the print quality implications of using environmentally friendly inks. The findings are intended to support informed decisions in the selection of sustainable inks for industrial printing applications without compromising on visual quality.

RESEARCH OBJECTIVE

The primary objective of this research is to evaluate and compare the colour reproduction capabilities of conventional, soya-based, and biodegradable inks when applied to paperboard substrates using the offset printing process. This study aims to analyze the colour variation, quantified through Delta E (ΔE), produced by each type of ink under controlled printing conditions. It seeks to assess the compatibility of these inks with the offset process and to understand their impact on colour consistency and overall print quality. Through spectrophotometric measurements and Delta E calculations using the ΔE76 (CIE 1976) formula, the research intends to offer a comprehensive understanding of how alternative, eco-friendly ink formulations perform in comparison to traditional inks. Ultimately, the study aspires to support the adoption of sustainable printing practices by providing insights into the technical feasibility and visual effectiveness of environmentally friendly inks in commercial offset printing.

RESEARCH METHODOLOGY

This study employs an experimental research design to analyse and compare the colour variation (Delta E) resulting from the use of three different ink types which are: - conventional, soya-based, and biodegradable, on various paperboard substrates printed through an offset printing process. The objective is to determine the colour consistency and fidelity of each ink type under identical printing conditions.

Three types of paperboard substrates were selected for this study i.e., Art Paper Board, Folding Box Board (FBB), and Duplex Board. The Duplex Board was further categorized into two variants identified as White Back and Gray Back, to evaluate the effect of the reverse side finish on print colour accuracy. All sheets were printed at Pinetree Packaging Pvt. Ltd., using a Heidelberg CD LX offset printing machine, a high-performance commercial-grade press known for its precision and consistency.

For each combination of ink and substrate, more than 50 sheets were printed, resulting in a comprehensive sample set for each condition. From these, 20 sheets were randomly selected for evaluation to ensure unbiased and representative results. The same design and colour patch layout were used across all samples to maintain consistency in testing.

Colour measurements were performed using a spectrophotometer under standardized lighting and

viewing conditions. The obtained values were used to calculate the Delta E (ΔE) using the ΔE76 (CIE 1976) formula, FOGRA39 standard were use for reference value to calculate the ΔE values. These ΔE values quantify the colour differences between the target (reference) values and the printed samples.

All printing conditions such as including ink density, plate quality, and press settings were kept consistent throughout the experiments to minimize variables unrelated to ink formulation or substrate. The resulting data were then statistically analysed to compare the performance of each ink type across different substrates, focusing on the magnitude and consistency of colour deviation.

This methodology provides a structured and reproducible approach to evaluating the colour accuracy of sustainable inks in offset printing, helping assess their suitability for commercial packaging and publishing applications.

DATA COLLECTION & ANALYSIS

To evaluate the colour difference (Delta E) resulting from the use of conventional, soya-based, and biodegradable inks on different paperboard substrates, a series of spectrophotometric measurements were conducted on printed samples. The data collected from randomly selected sheets were analysed to quantify the variations in colour reproduction across each ink-substrate combination. The following tables and graphs illustrate the Delta E values obtained from the experiment, offering a comparative view of colour consistency and performance. This analysis aims to highlight the degree of colour deviation associated with each ink type and paperboard, providing a visual and statistical foundation for interpreting the overall print quality and suitability of sustainable inks in offset printing applications.

Table 1, Colour difference (ΔE) values using Conventional, Soya-based and Biodegradable ink on Art Paper Board

Ink Type	Cyan	Magenta	Yellow	Black
Conventional Ink	1.82	1.57	1.63	1.21
Soya-based Ink	2.52	2.36	2.15	1.81
Biodegradable Ink	3.29	3.01	2.86	2.27

The table 1 presents colour difference (ΔE76) values for Conventional Ink, Soya-based Ink, and Biodegradable Ink on Art Paper Board across Cyan, Magenta, Yellow, and Black. Conventional Ink exhibits the smallest ΔE values, indicating its close alignment with target colour values. Soya-based Ink follows with moderate deviations, while Biodegradable Ink shows the highest colour differences. These findings highlight the trade-off between eco-friendly ink formulations and colour accuracy, reinforcing the viability of Soya-based Ink as a sustainable alternative with acceptable print fidelity. Conventional Ink exhibits the lowest ΔE76 values, ensuring the closest match to target colours (Cyan: 1.82, Magenta: 1.57, Yellow: 1.63, Black: 1.21), followed by Soya-based Ink with moderate deviations (Cyan: 2.52, Magenta: 2.36, Yellow: 2.15, Black: 1.81). Biodegradable Ink shows the highest colour difference (Cyan: 3.29, Magenta: 3.01, Yellow: 2.86, Black: 2.27), indicating noticeable shifts in print accuracy. While conventional ink ensures superior colour fidelity, soya-based ink offers a viable eco-friendly alternative, balancing sustainability with acceptable print precision. Biodegradable ink, though the most environmentally friendly, requires formulation improvements to reduce colour deviation.

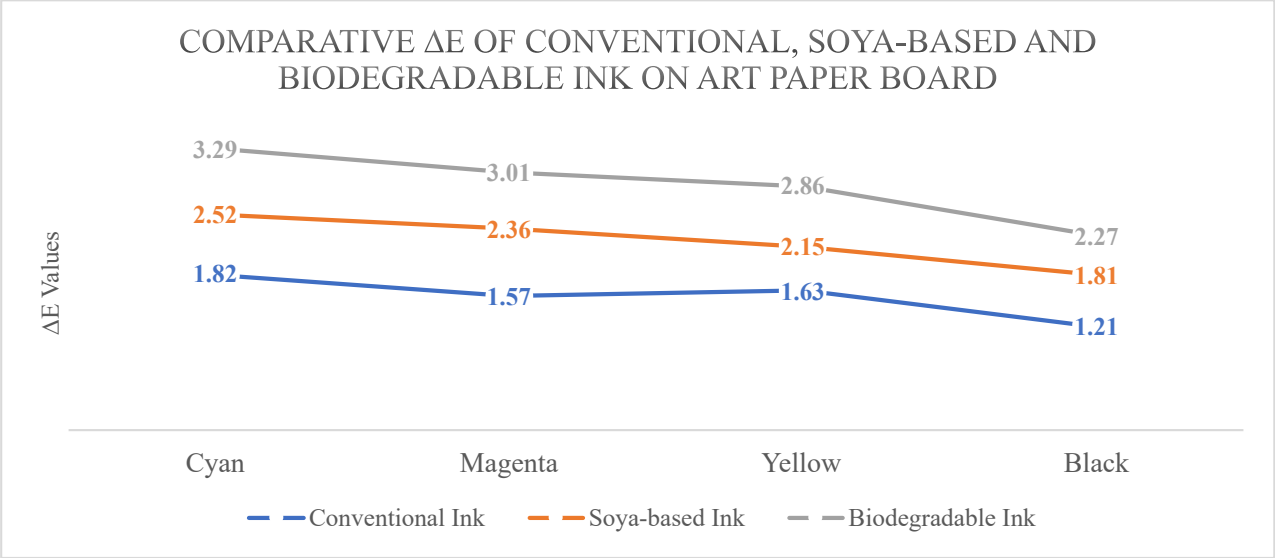

Fig. 1, Comparative Colour difference (ΔE) of Conventional, Soya-base and Biodegradable inks on Art Paper Board

Fig. 1, illustrates the comparative colour difference (ΔE76) of Conventional, Soya-based, and Biodegradable Inks on Art Paper Board across Cyan, Magenta, Yellow, and Black. Conventional Ink exhibits the smallest ΔE values (Cyan: 1.82, Magenta: 1.57, Yellow: 1.63, Black: 1.21), indicating superior colour accuracy. Soya-based Ink follows with moderate ΔE values (Cyan: 2.52, Magenta: 2.36, Yellow: 2.15, Black: 1.81), showing balanced colour fidelity with environmental benefits. Biodegradable Ink displays the highest colour deviations (Cyan: 3.29, Magenta: 3.01, Yellow: 2.86, Black: 2.27), suggesting noticeable shifts in colour reproduction. This comparison highlights the trade-offs between sustainability and prints accuracy, reinforcing the feasibility of soya-based ink as a viable alternative to conventional formulations while indicating the need for formulation improvements in biodegradable ink to achieve better colour consistency.

Table 2, Colour difference (ΔE) values using Conventional, Soya-based and Biodegradable ink on Folding Box Board (FBB)

Ink Type	Cyan	Magenta	Yellow	Black
Conventional Ink	2.17	1.93	2.01	1.83
Soya-based Ink	2.86	2.72	2.53	2.25
Biodegradable Ink	3.61	3.38	3.27	2.79

Table 2 presents colour difference (ΔE76) values for Conventional Ink, Soya-based Ink, and Biodegradable Ink on Folding Box Board (FBB) across Cyan, Magenta, Yellow, and Black. Conventional Ink exhibits the lowest ΔE76 values, ensuring the closest match to target colours (Cyan: 2.17, Magenta: 1.93, Yellow: 2.01, Black: 1.83), followed by Soya-based Ink with moderate deviations (Cyan: 2.86, Magenta: 2.72, Yellow: 2.53, Black: 2.25). Biodegradable Ink shows the highest colour difference (Cyan: 3.61, Magenta: 3.38, Yellow: 3.27, Black: 2.79), indicating noticeable shifts in print accuracy. While conventional ink ensures superior colour fidelity, soya-based ink offers a viable eco-friendly alternative, balancing sustainability with acceptable print precision. Biodegradable ink, though the most environmentally friendly, requires formulation

improvements to reduce colour deviation.

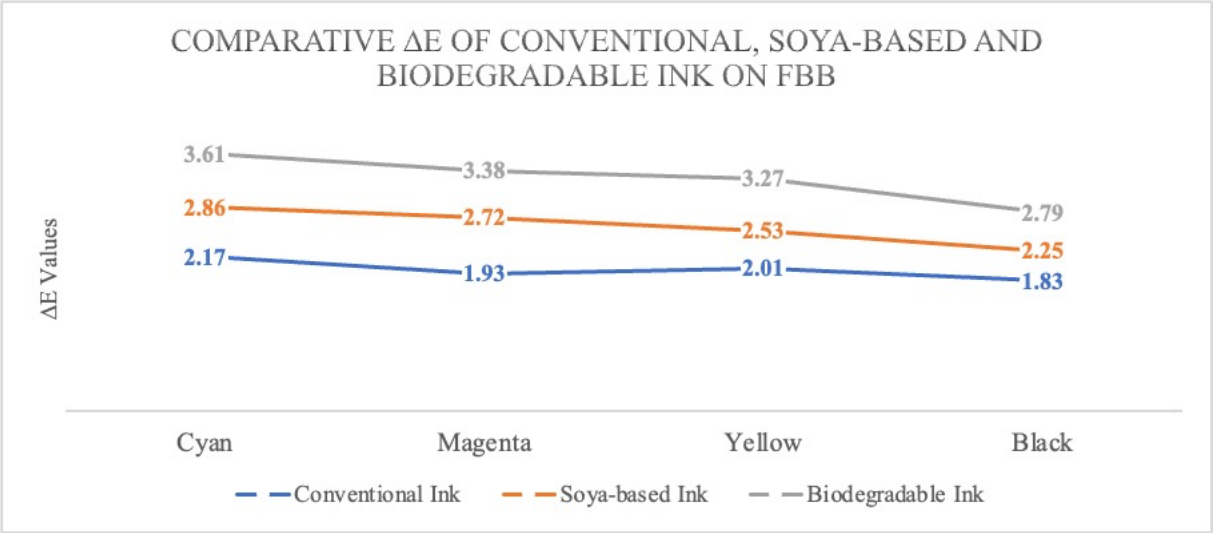

Fig. 2, Comparative Colour difference (ΔE) of Conventional, Soya-base and Biodegradable inks on Folding Box Board (FBB)

Fig. 2 illustrates the comparative colour difference (ΔE76) values for Conventional, Soya-based, and Biodegradable Inks on Folding Box Board (FBB) across Cyan, Magenta, Yellow, and Black. Conventional Ink exhibits the smallest ΔE values (Cyan: 2.17, Magenta: 1.93, Yellow: 2.01, Black: 1.83), indicating superior colour accuracy and close alignment with target standards. Soya-based Ink shows moderate deviations (Cyan: 2.86, Magenta: 2.72, Yellow: 2.53, Black: 2.25), balancing environmental benefits with acceptable print fidelity. Biodegradable Ink displays the highest ΔE values (Cyan: 3.61, Magenta: 3.38, Yellow: 3.27, Black: 2.79), revealing noticeable colour shifts that suggest a need for formulation refinement. This comparison highlights the ongoing trade-offs between ecological responsibility and prints precision, affirming the viability of soya-based ink in sustainable applications while identifying improvement areas for biodegradable ink in colour-critical packaging.

Table 3, Colour difference (ΔE) Values using Conventional, Soya-based and Biodegradable ink on Duplex Board (White Back)

Ink Type	Cyan	Magenta	Yellow	Black
Conventional Ink	2.72	2.53	2.71	2.47
Soya-based Ink	3.29	3.09	2.88	2.69
Biodegradable Ink	3.92	3.72	3.58	3.31

Table 3 presents colour difference (ΔE76) values for Conventional Ink, Soya-based Ink, and Biodegradable Ink on Duplex Board (White Back) across Cyan, Magenta, Yellow, and Black. Conventional Ink exhibits the lowest ΔE76 values, ensuring the closest match to target colours (Cyan: 2.72, Magenta: 2.53, Yellow: 2.71, Black: 2.47), followed by Soya-based Ink with moderate deviations (Cyan: 3.29, Magenta: 3.09, Yellow: 2.88, Black: 2.69). Biodegradable Ink shows the highest colour difference (Cyan: 3.92, Magenta: 3.72, Yellow: 3.58, Black: 3.31), indicating noticeable shifts in print accuracy. While conventional ink ensures superior colour fidelity, soya-based ink offers a viable eco-friendly alternative, balancing sustainability with acceptable print

precision. Biodegradable ink, though the most environmentally friendly, requires formulation improvements to reduce colour deviation.

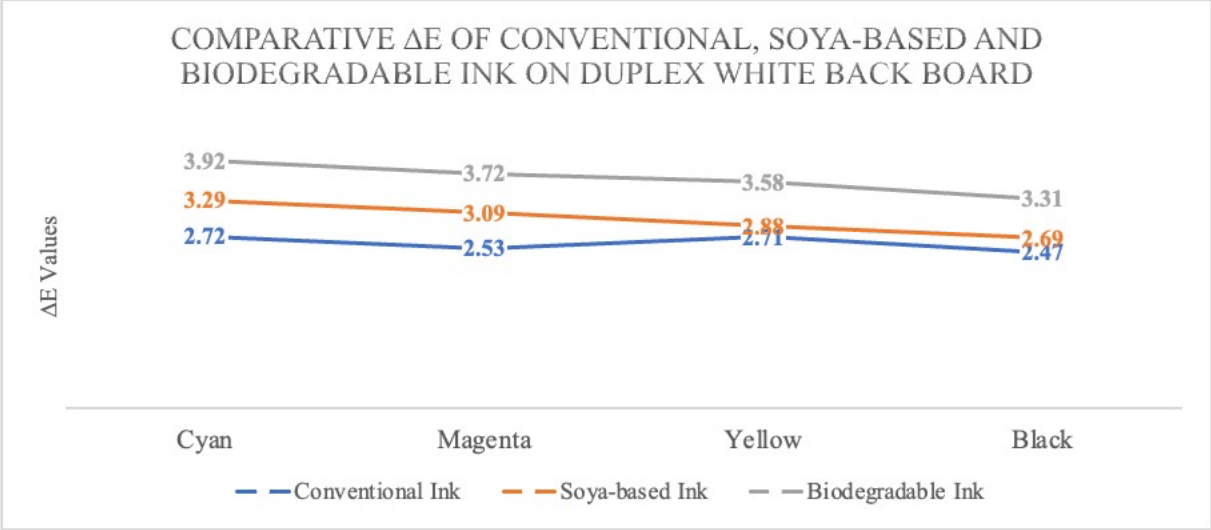

Fig. 3, Comparative Colour difference (ΔE) of Conventional, Soya-base and Biodegradable inks on Duplex White Back Board

Fig. 3, illustrates the comparative colour difference (ΔE76) values for Conventional, Soya-based, and Biodegradable Inks on Duplex White Back Board across Cyan, Magenta, Yellow, and Black. Conventional Ink exhibits the smallest ΔE values (Cyan: 2.72, Magenta: 2.53, Yellow: 2.71, Black: 2.47), ensuring the closest match to target colours and superior colour accuracy. Soya-based Ink follows with moderate deviations (Cyan: 3.29, Magenta: 3.09, Yellow: 2.88, Black: 2.69), balancing ecological advantages with acceptable print fidelity. Biodegradable Ink displays the highest ΔE values (Cyan: 3.92, Magenta: 3.72, Yellow: 3.58, Black: 3.31), indicating noticeable colour shifts that may affect print quality in colour-critical applications.

Table 4, Colour difference (ΔE) Values using Conventional, Soya-based and Biodegradable ink on Duplex Board (Gray Back)

Ink Type	Cyan	Magenta	Yellow	Black
Conventional Ink	3.28	3.18	3.11	3.06
Soya-based Ink	3.71	3.53	3.36	3.23
Biodegradable Ink	4.15	4.08	3.82	3.74

Table 4 presents colour difference (ΔE76) values for Conventional Ink, Soya-based Ink, and Biodegradable Ink on Duplex Board (Gray Back) across Cyan, Magenta, Yellow, and Black. Conventional Ink exhibits the lowest ΔE76 values, ensuring the closest match to target colours (Cyan: 3.28, Magenta: 3.18, Yellow: 3.11, Black: 3.06), followed by Soya-based Ink with moderate deviations (Cyan: 3.71, Magenta: 3.53, Yellow: 3.36, Black: 3.23). Biodegradable Ink shows the highest colour difference (Cyan: 4.15, Magenta: 4.08, Yellow: 3.82, Black: 3.74), indicating noticeable shifts in print accuracy. While conventional ink ensures superior colour fidelity, soya-based ink offers a viable eco-friendly alternative, balancing sustainability with acceptable print precision.

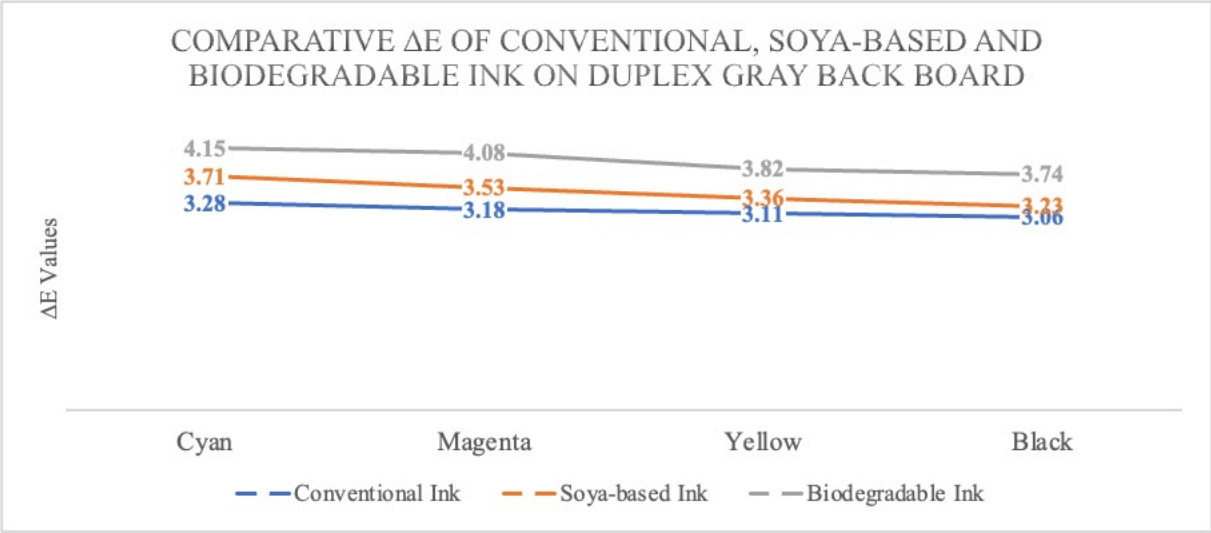

Fig. 4, Comparative Colour difference (ΔE) of Conventional, Soya-base and Biodegradable inks on Duplex Gray Back Board

Fig. 4 illustrates the comparative colour difference (ΔE76) values for Conventional, Soya-based, and Biodegradable Inks on Duplex Gray Back Board across Cyan, Magenta, Yellow, and Black. Conventional Ink exhibits the smallest ΔE values (Cyan: 3.28, Magenta: 3.18, Yellow: 3.11, Black: 3.06), indicating superior colour accuracy and closest alignment with target shades. Soya-based Ink follows with moderate deviations (Cyan: 3.71, Magenta: 3.53, Yellow: 3.36, Black: 3.23), balancing environmental benefits with acceptable print fidelity. Biodegradable Ink displays the highest ΔE values (Cyan: 4.15, Magenta: 4.08, Yellow: 3.82, Black: 3.74), revealing noticeable shifts in colour reproduction that may affect precision in high-accuracy printing. This comparison underscores the trade-offs between sustainability and prints quality, affirming the practicality of soya-based ink for eco-conscious printing while highlighting areas for improvement in biodegradable ink formulations to enhance colour consistency.

Table 5 presents colour difference (ΔE76) values for Conventional, Soya-based, and Biodegradable inks across different substrates: Art Paper Board, Folding Box Board (FBB), Duplex White Back Board, and Duplex Gray Back Board. Conventional Ink exhibits the lowest ΔE values (Cyan: 1.82–3.28, Magenta: 1.57–3.18, Yellow: 1.63–3.11, Black: 1.21–3.06), ensuring closer alignment with target colours. Soya-based Ink follows with moderate deviations (Cyan: 2.52–3.71, Magenta: 2.36–3.53, Yellow: 2.15–3.36, Black: 1.81–3.23), offering a balance between sustainability and colour fidelity. Biodegradable Ink exhibits the highest ΔE values (Cyan: 3.29–4.15, Magenta: 3.01–4.08, Yellow: 2.86–3.82, Black: 2.27–3.74), indicating more noticeable colour shifts across all substrates. This comparison reinforces the trade-offs between environmental sustainability and prints accuracy, demonstrating that biodegradable inks provide a viable alternative with minimal colour deviation, while soya-based inks require further formulation improvements to enhance colour consistency in commercial printing applications.

Table 5, Colour difference (ΔE) Values using Conventional, Soya-based and Biodegradable ink on Art Paper Board, Folding Box Board (FBB), Duplex (White Back and Gray Back) Boards

Ink Type →	Conventional Ink				Soya-based Ink				Biodegradable ink			
Substrate Type ↓	Cyan	Magenta	Yellow	Black	Cyan	Magenta	Yellow	Black	Cyan	Magenta	Yellow	Black
Art Paper Board	1.82	1.57	1.63	1.21	2.52	2.36	2.15	1.81	3.29	3.01	2.86	2.27
Folding Box Board	2.17	1.93	2.01	1.83	2.86	2.72	2.53	2.25	3.61	3.38	3.27	2.79
Duplex White Back Board	2.72	2.53	2.71	2.47	3.29	3.09	2.88	2.69	3.92	3.72	3.58	3.31
Duplex Gray Back Board	3.28	3.18	3.11	3.06	3.71	3.53	3.36	3.23	4.15	4.08	3.82	3.74

RESULTS & DISCUSSION

Conventional ink exhibits the lowest colour difference (ΔE76) values across all substrates, ensuring a close match to target colours. Its superior pigment dispersion, optical density, and stability contribute to high print fidelity, making it ideal for applications demanding precise colour accuracy. The ink adheres effectively to smoother substrates like Art Paper Board and Folding Box Board, showing minimal deviations. On coarser surfaces such as Duplex Gray Back Board, slight increases in ΔE values are observed (e.g., Cyan: 3.28, Black: 3.06), yet remain within acceptable industry tolerances for commercial offset printing.

Soya-based ink demonstrates moderate ΔE variations across substrates, offering a practical balance between environmental sustainability and print performance. While its ΔE values are slightly higher than those of conventional ink, it maintains acceptable fidelity—particularly on substrates like Art Paper Board and Duplex White Back Board. Deviations become more pronounced on Duplex Gray Back Board (e.g., Magenta: 3.53, Yellow: 3.36), which may result from challenges in substrate absorption and binder compatibility. Enhancing pigment dispersion and refining ink rheology could improve overall colour alignment and reduce variability across diverse surfaces.

Biodegradable ink displays the highest ΔE values across all tested substrates, indicating the most noticeable deviations from target colours. Although it leads in environmental impact reduction, its performance highlights formulation limitations, particularly regarding pigment stability and substrate interaction. On Duplex Gray Back Board, the ink shows the largest shifts (e.g., Magenta: 4.08, Black: 3.74), which may affect visual consistency in colour-critical print applications. On smoother surfaces like Art Paper Board, fidelity improves slightly but remains less consistent than the other formulations. Further research is required to optimize curing efficiency and enhance pigment dispersion for better substrate adaptability in commercial offset workflows.

CONCLUSION

The comparative study of colour difference (ΔE76) values across Conventional, Soya-based, and Biodegradable inks confirms that all three formulations offer acceptable colour performance for commercial offset printing. Conventional Ink demonstrates the highest precision, consistently achieving the closest alignment to target colours across all substrates, making it the benchmark for colour-critical applications. Soya-based Ink maintains moderate deviations and shows promise as a sustainable alternative, particularly when printed on smoother substrates like Art Paper Board and

Folding Box Board. Biodegradable Ink presents the greatest colour differences yet remains within industry tolerance, underscoring its potential with targeted formulation improvements.

Substrate characteristics play a pivotal role in colour consistency, with Art Paper Board yielding the most stable ΔE76 values, followed by Folding Box Board, Duplex White Back Board, and Duplex Gray Back Board. These findings suggest that both Soya-based and Biodegradable inks can be effectively integrated into existing printing systems, offering practical options for environmentally conscious packaging. Continued research into binder optimization, pigment dispersion, and curing techniques will be essential to improving print fidelity in eco-friendly inks without compromising sustainability goals.

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